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VOL. VI.

LEAD AND ZINC
AND
ARTESIAN WELLS
1897

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GEOLOGICAL SURVEY

VOLUME VI.

REPORT ON LEAD, ZINC, ARTESIAN WELLS, ETC.

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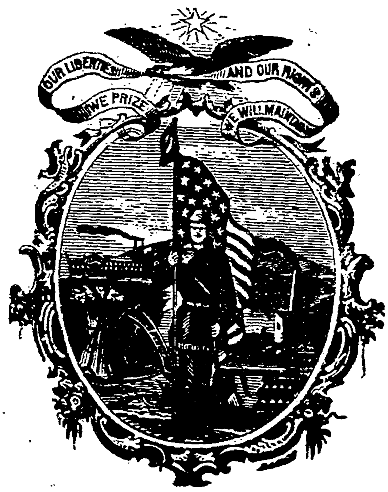

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CONTENTS.

LIST OF ILLUSTRATIONS.

FIGURES.

LETTER OF TRANSMITTAL

IOWA GEOLOGICAL SURVEY,
DES MOINES, Iowa, December 31, 1897.

To Governor Drake and Members of the Geological Board:

GENTLEMEN—I have the honor herewith to transmit the last of the manuscript for volume VI of the Iowa Geological Reports. In this volume are gathered a number of separate papers of general economic interest. Its publication was authorized early in 1896, in order that the memoir of Prof. A. G. Leonard, on the "Lead and Zinc Deposits of Iowa," and that of Dr. S. W. Beyer, on the "Sioux Quartzite and Certain Associated Rocks," might be placed in the hands of persons to whom they would be of service at as early a date as possible. Accordingly these memoirs were printed, and a sufficient number of copies were distributed to meet the most pressing demands. Professor Norton's memoir, on the "Artesian Wells of Iowa," which, it was believed would soon be ready for publication, has been purposely delayed, owing to the desire to incorporate data from certain important borings which have only recently been finished. The delay has made it possible to add to the completeness and value of the memoir in other important respects. It is now presented as a very complete statement of the accessible facts relating to the subjects of which it treats, to present date, and it is confidently believed that it will be welcomed by the public as a worthy contribution to the economic geology of the state.

The paper of Mr. H. F. Bain, on "The Relations of the Wisconsin and Kansan Drifts in Central Iowa," is a summary of some of the most recent work of the Survey in a very interesting field. The importance of these results seem to warrant their publication in a more general form than the limits of a county report will allow.

The first two papers of this volume were published under the supervision of Mr. H. F. Bain, as assistant state geologist, but Mr. Bain being now absent on leave for one year, the publication of the remaining portions of the volume will be supervised by Prof. A. G. Leonard, who is acting during Mr. Bain's absence. I have the honor to remain, gentlemen,

Yours very respectfully,

SAMUEL CALVIN,
State Geologist.

LEAD AND ZINC DEPOSITS OF IOWA.

BY

A. G. LEONARD.

LEAD AND ZINC DEPOSITS OF IOWA.

BY A. G. LEONARD.

CHIEF SOURCES OF THE WORLD'S SUPPLY OF LEAD AND ZINC.

Lead and zinc are widely distributed over the globe, nearly every inhabited country producing both in greater or less quantity. A complete list of all the countries where these are found would, therefore, be a long one. In the following summary the attempt has been made to mention only the more productive regions; those containing extensive deposits of lead and zinc. The facts have been recently collected by Winslow in his late report on the Missouri deposits.*

German Empire.—The zinc ore production of Germany during the past ten years has varied from one-half to three-fourths of the production of all Europe, averaging 800,000 tons annually. The lead output has not been so large. The great zinc producing region of Germany is Upper Silesia, which has yielded nearly three-fourths of the total amount. Next in order of importance are the Rhine provinces, Westphalia and Nassau. In lead production the Rhine provinces rank first, and then come Harz, Silesia, Saxony and Nassau.

Spain.—This country ranks far ahead of any other in Europe in the production of lead, and is third during recent years in the output of zinc. The principal lead ore deposits are at Linares and Cartagena; the zinc ores are chiefly from Santander. With the possible exception of the Broken Hill mine in New South Wales, the Linares mines rank first in the world as lead producers. In 1892 they yielded 128,000 tons.

Austria.—Both lead and zinc are here mined in large quantities.

Belgium.—The principal deposits are the Bleiberg lead mines and the Vieille Montagne zinc mines.

Great Britain.—The most important deposits are in the north of England lead district, which includes the counties of Durham, Northumberland, Cumberland, Westmoreland and Yorkshire.

Greece.—The chief mines are those of Laurium.

*Missouri Geol. Surv., vols. VI and VII. Jefferson City, 1894.

Italy.—This country is an important zinc producer, and the yield of lead is large. The great bulk of the ore comes from Sardinia.

Russia, France and Sweden should also be mentioned as producing considerable quantities of lead and zinc.

New South Wales.—The Broken Hill mines are at present the largest producers of lead in the world. They were discovered in 1883, and in 1890 yielded 222,000 tons of ore.

United States.—The ores of lead and zinc occur to a greater or less extent in nearly every state; but in only a dozen or fifteen is lead produced in large amounts, and not more than eight rank as zinc producers. A large proportion of the lead comes from the Rocky Mountain and Great Basin regions. During the last twenty years over three-fourths of the total lead production of the country has been supplied from the western states and territories. These ores are argentiferous, and are mined not so much for their lead as for the gold and silver they contain. The following is a list of states that rank as lead producers: Colorado, Missouri, New Mexico, Utah, Nevada, Arizona, California, Idaho, Montana, Wisconsin and Kansas. Colorado leads in the output of lead, and is closely followed by Missouri. Illinois and Iowa produce small quantities.

The zinc producing states are Missouri, New Jersey, Wisconsin, Kansas, Illinois and Iowa. Missouri stands far ahead of any of the rest, showing a product of 108,000 tons for 1893. Iowa's production of zinc has rapidly increased of late years while its lead output has decreased. In bulletin 80 of the eleventh census, Iowa is credited with the production of 450 tons of zinc during 1889 whereas in the previous report no mention of the zinc output was made.

HISTORY OF LEAD AND ZINC MINING IN IOWA.

It is now nearly two hundred years since the white man discovered lead in the Upper Mississippi region. In 1700 the French explorer Le Sueur made an expedition up the great river from New Orleans in search of ores. He ascended as far as the Saint Peters river, now the Minnesota, and it is generally supposed, observed lead at several points along the "Father of Waters." It is interesting to note that as long ago as 1752 the lead region of the Upper Mississippi was located on a map published during that year by Philippe Bauche.* The mines are also mentioned briefly in an article by M. Guettard in the same volume, pp. 189-220, where they are described as being very rich.

In 1788 the first mining was done within the territory of what is now the state of Iowa. In that year Julien Dubuque, a native of Canada, obtained from the Sacs and Foxes a grant or lease of land for mining purposes. His claim included seven leagues on the west bank of the Mississippi, from the mouth of the Little Maquoketa to the Tete des Morts and three leagues deep. The area includes most of the productive crevices of Dubuque county. Lead is reported to have been discovered here seven years previously by the wife of Peosa Fox. Dubuque at once took possession of his claim and began mining operations. The place became known as "Spanish Mines" or more commonly as Dubuque's Lead mines. In 1796 he petitioned Carondelet, the Spanish governor of Louisiana, that the tract be granted him by patent from the Spanish government. His request was allowed and was subsequently confirmed by the board of land commissioners of Louisiana. Dubuque continued to develop his prospects until his death in 1810.

It was twenty years later however, before the mines of the state began to be actively developed. During 1830 several miners from Galena, influenced by the reports they had heard of the Dubuque region, crossed the river and obtaining the consent of the Indians commenced work where the city now stands. One of the first to be opened was the Langworthy crevice on Eagle Point avenue.

But the land on the west of the Mississippi, though it had come under the control of the United States by the Louisiana

*Histoire le L' Academie Royale des Sciences. 1752.

purchase still belonged to the Indians, and the government, to keep the treaty with them soon ordered the miners to leave and subsequently sent troops from Prairie du Chien to enforce the order.

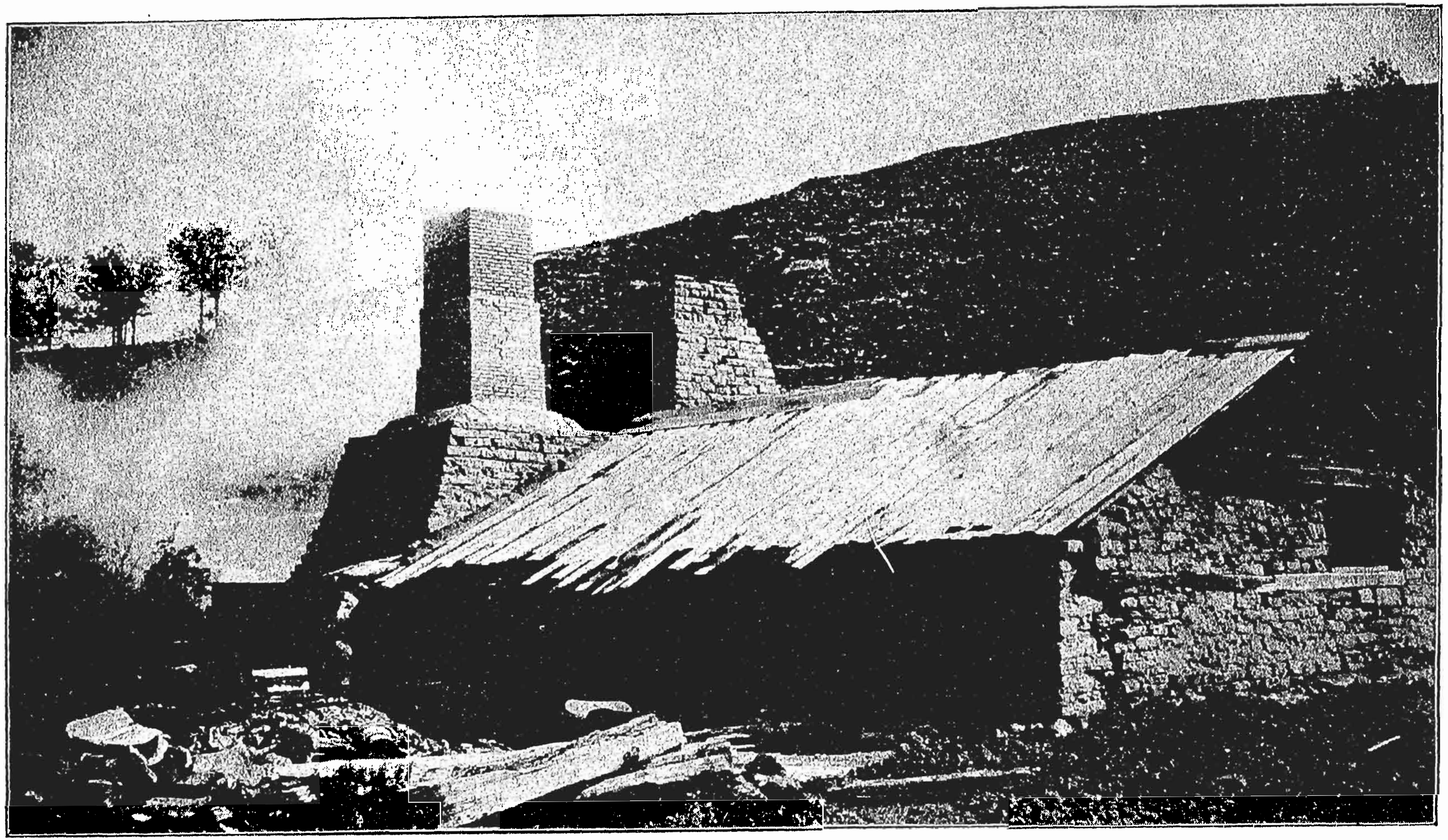
Two years later, at the close of the Black Hawk war, the large tract known as the Black Hawk purchase, including one-third of the present area of Iowa, was ceded to the United States by the Sacs and Foxes. After the completion of the treaty negotiations the miners again crossed over into the much coveted region where they built cabins and commenced to take out much ore. But a second time they were forced to leave because the treaty had not been ratified. In June, 1833, the treaty went into effect and the way was at length clear for settlers to take possession of the land. During the next few years large numbers flocked in, prospecting was actively carried on and many mines were soon in operation.

A superintendent of mines was appointed by the government and a system of permits to miners and smelters was adopted. For some years the smelters were required to pay 6 per cent of all the lead produced. This tax was the cause of much dissatisfaction and was abolished at the end of ten years.

The first "legislation" in Iowa dates from 1830. In June of that year a number of miners met on the banks of the Mississippi and enacted regulations to govern them in their relations to each other. One of the articles was that "every man shall hold 200 yards square of ground by working said ground one day in six." The most productive period of the Dubuque mines was probably during the years 1835 to 1849. No record was kept of the amount produced nor can this now be accurately ascertained. Owen* gives the output for 1839 as over 3,000,000 pounds. In 1854 8,770,000 pounds of lead were exported from Dubuque.

Furnaces were early established for smelting purposes. The first contrivance employed was the primitive one of the

*Ex. Doc., 1st Sess., 26 Cong., vol VI, 39-40.



WATER'S LEAD FURNACE, NEAR DUBUQUE.

Indians, though on a larger scale. A foundation or platform of rock was built about fifteen feet square, the cracks between the stones being carefully filled, and the platform made to slope towards the center. A layer of logs was placed on the rude hearth thus constructed, then a layer of ore and so on alternately until there was enough for the blast. The wood was then fired and the pile allowed to burn down. The metal as it melted sought the lower part of the platform, where it was drawn off from time to time. This process was very wasteful, as besides consuming great quantities of timber it secured less than 50 per cent of the lead. The rich slag thus left behind was eagerly sought in later years.

The next method of smelting employed was what is known as the cupola furnace, a great improvement over the former system, since by its use 65 to 70 per cent of the lead was obtained. In 1834 Peter Lorimier built one of these furnaces at the mouth of Catfish creek, this being the first of the kind in the state. The next year two others were constructed, one on the Little Maquoketa and another in the city of Dubuque. But it still remained true that quite a large per cent of mineral was not extracted and this loss brought about the adoption of the hearth furnace. The first one of these erected in America for smelting lead ore was built in Wisconsin in 1835 about midway between Dubuque and Mineral Point. The second in the country, and the first in Iowa, was located on Catfish creek just above Rockdale in Dubuque county. This furnace, which has played an important part in the mining industry of the state, has been in operation more or less since its establishment and it is still running. [See plate i.]

With the hearth furnace practically all of the lead is extracted from the ore and hence it is so much superior to the earlier processes employed that it soon replaced them. There were several of these furnaces in the vicinity of Dubuque. Besides the one already mentioned, may be named Mr. Brunskill's, on Catfish creek near Center Grove, and Nathan Simpson's, not far northeast of Dubuque.

It was not until 1860 that zinc came into the market and since then the production of this kindred metal has rapidly increased. During the ten years previous to 1882 the output of zinc more than doubled that of lead, while in 1889, according to the last federal census, the production was 13 to 1 for the entire region.

The principal ore of zinc now shipped from the Iowa mines is the carbonate, or "dry bone" of the miners. Until some thirteen years ago this material was regarded as worthless and was thrown away on the dump piles, or the workings were abandoned when it appeared.

In the fall of 1880 two wagon loads were taken to Benton, Wisconsin, and sold for $16 a ton. So far as known, this was the first zinc ore marketed from the mines of the state, and from this time on the carbonate has been removed in rapidly increasing amounts. The first mine to be worked for zinc was the McNulty (often called the Avenue Top) at the head of Julien avenue, Dubuque. This had previously been operated for lead and $25,000 worth is said to have been taken from it. The galena gave out in the crevices and a short distance beyond the zinc carbonate began to appear. It is estimated that this mine has yielded not less than $50,000 worth of zinc. After the sale of the first dry bone many began at once to search for it, and numerous mines were soon being operated. Old lead diggings that had been abandoned when the associated metal began to appear, were again opened up and worked.

UPPER MISSISSIPPI LEAD AND ZINC REGION.

The lead and zinc region of the Upper Mississippi includes an area having a length east and west of ninety-six miles and a width north and south of fifty miles. It embraces the southwest portion of Wisconsin, the northwest corner of Illinois and the adjoining portion of Iowa, comprising within its limits some 3,000 square miles, an area nearly equal to that of Connecticut. The entire region is included in what is known as the driftless area. On all sides are found the deposits of clay, sand, pebbles and boulders left by the ancient ice sheet, but the district under consideration is free from glacial deposits of any kind; its topography forms, therefore, a sharp contrast with that of the drift-covered area on every side.

The soils are made up of the residue left from the decay and solution of the surface rocks with a thin covering of loess over a considerable portion of the area. Over most of the region the Galena limestone forms the country rock, and in it most of the ore deposits occur. Overlying the limestone are the soft and easily decomposed Maquoketa shales, which have been largely removed by erosion. Perhaps the most conspicuous features in the topography of the district are the so-called "mounds," isolated, more or less conical and flat-topped hills rising from several hundred feet to 500 feet above the surrounding country. These elevations are commonly capped by Niagara limestone and are the outliers of the formation that have been left by the wearing away of the other portions. They furnish an index of the work accomplished by the denuding agencies that have been acting since the elevation of the land surface above the sea. Several of these marked objects in the landscape are found in Dubuque county, among which Sherrill Mound and Table Mound are well known examples. The former rises 600 and the latter 472 feet above the Mississippi. Sinsinawa Mound in Wisconsin is another conspicuous example.

Before beginning the description of the ore deposits a brief account of the formations occurring in the district may be given.

The strata all have a gentle dip to the southwest so that in ascending the Mississippi the lower members of the series are successively met with. For example, at Dubuque the Trenton limestone is only a few feet above the level of the river but followed northward it is seen gradually to raise until a few miles above Guttenberg the underlying Saint Peter sandstone makes its appearance above water level.

Saint Croix or Cambrian Sandstone.—This sandstone is the lowest of the formations which appear in the lead and zinc region. It is found along the streams in the northeastern corner of the state, where it is exposed in the bluffs of the Mississippi, the Oneota and their tributaries. The rock is for the most part a very pure sandstone, made up of rather coarse, rounded and transparant grains of silica. In some portions these are loosely held together by a calcareous or ferruginous cement and the rock is more or less indurated; in other portions the formation is merely an unconsolidated sand bed. The ledges often present a hard exterior but on removing the outer crust the material crumbles at the slightest touch. Occasional bands of calcareous and argillaceous material appear at certain horizons, especially in the upper 200 feet. At Lansing fully 300 feet of Saint Croix are exposed in the bluffs; and this is capped by 100 feet of the Oneota limestone. This sandstone was formerly quarried at the above mentioned locality, but it furnishes an inferior quality of building stone. Where exposed in the old quarry the rock is a thin-bedded arenaceous limestone with shaly bands in the lower portion.

Oneota Limestone.—The Saint Croix passes above into the Oneota limestone. There are twenty-five to thirty feet of alternating beds of limestone and sandstone at the contact of the two formations, the one rock thus passing gradually into the other without any sharp line of demarcation. The limestone is mostly a coarsely granular magnesian rock containing numerous small cavities. Some portions contain an abundance of siliceous matter in the form of chert. Large beds of this material occur where the limestone has been dissolved leaving behind the hard and insoluble quartz. The rock ranges in color from a very light buff to gray. A good section of the Oneota is exhibited in a quarry one mile north of Lansing where nearly 100 feet of the lower beds are exposed. The stone here is fine-grained and of a light cream, almost white, color. The beds are from two to five feet thick, with some well-bedded layers six to eight inches thick.

Lead appears to occur scattered through this rock in considerable quantities, judging from the large amount of "float" that is found throughout Allamakee county. In some instances, as in the case of the Lansing lead mine, the ore occurs in fissures of considerable extent. The above mentioned occurrence of lead in the Oneota is of much interest both on account of the extent of the ore body and also because it is probably the first extensive lead mine ever worked in this formation. It will be fully described in another portion of this report. In thickness the Oneota varies from 200 to 300 feet.

Saint Peter Sandstone.—This rock, like the Saint Croix sandstone is of very pure siliceous sand, composed of rounded and transparent grains of quartz. In some portions the beds are soft and friable, while in others the sand grains are loosely cemented together, and a more or less indurated rock is formed. The formation has a thickness of not over 100 feet. At McGregor where the beds are finely exposed in the bluffs, they furnish an excellent quality of glass sand. As a rule this rock is notably free from any argillaceous or calcareous layers.

These strata have a wide range of color, including white, green, brown, red, buff, yellow, and salmon, all of common occurrence. Where the white and green have been interlaminated by false bedding the contrast between the colors is striking. It is the Saint Peter sandstone that forms the "Pictured Rocks" of the upper Mississippi. An analysis of some of the sand from Clayton showed 98.85 per cent of silica. Very little if any lead is found in this formation.

Trenton Limestone.—The Trenton differs from the three other limestone formations of the region in being a pure lime rock free from magnesia. It is a very compact blue stone characterized by an abundance of organic remains, differing thus from the Galena and Oneota, but in the matter of organic remains resembling the Niagara, which is also very fossiliferous. In some portions it is thin and very unevenly bedded, while at other horizons, especially in the lower buff beds near the base of the formation, it is well-bedded, with layers three to four feet thick. Where exposed to the weather the rock changes color as is shown in the quarry blocks which are blue on the interior and gray on the outside next to the joints. This limestone is exposed at various points in Dubuque county, above Eagle Point, along the Little Maquoketa and below Spechts Ferry, for example. In the counties farther to the north it is quite extensively quarried for building purposes. In Wisconsin the Trenton rock carries a large part of the zinc ores, but in Iowa little lead and zinc have been found in it.

Galena Limestone.—This formation is of special interest and importance as containing the lead and zinc deposits of the state. The rock is a heavily bedded and nearly pure dolomitic limestone, coarsely granular and filled with numerous small cavities. Its color is a buff or light brown, weathering on the surface to a dull gray. Many of the beds have a thickness of seven feet and more, ranging from this to thin evenly bedded layers, near the top. It is in these upper strata that the large quarries in Dubuque, such as those on Dodge street, are situated. The formation contains more or less of argillaceous matter confined mostly to the partings between the beds. Numerous chert nodules also occur at certain horizons. This limestone varies greatly in compactness, being filled with soft patches which are readily affected by atmospheric agencies and soon give rise to the cavities so characteristic of the rock. A weathered surface of Galena limestone always presents a very rough and pitted appearance. Large masses that have fallen from the cliffs look not unlike fragments of scoria from some volcano. Bluffs of this limestone give rise to strange and fantastic forms resembling ancient castles or venerable towers. Wherever cut by streams the Galena limestone forms escarpments with projecting spurs and isolated turrets. The Galena rock is everywhere cleft by fissures, or crevices, often miles in extent. In these fissures, and in the "openings" formed by their widening out, the lead and zinc have accumulated. The crevices serve as channels for underground drainage and have thus been greatly enlarged until some are the size of a railroad tunnel.

The formation has a thickness of 250 feet when fully developed. Fossils are not very abundant, most of those found being casts. *Lingula quadrata* is, however, quite common, as is also a species of Receptculites, the *R. oweni* Hall, which is often called the "lead fossil." The upper beds of this limestone are quite extensively quarried about Dubuque and used for curbing, foundations and other rough masonry. It also affords a very good quality of lime.

Maquoketa Shales.—The Galena limestone is commonly covered by the soft and easily decomposed Maquoketa shales. In the lead and zinc region these seldom have a thickness of more than thirty feet, though when fully developed they attain a depth of 100 feet and more. In some cases the ore deposits extend upward nearly or quite to the shale. Two small sheets of lead are reported as occurring in the shales themselves, and occasionally good sized pieces of ore are found in the same rock. Most of the shafts in Dubuque county have been sunk through a varying thickness of these shales before reaching the ore deposits.

Niagara Limestone.—Overlying the Maquoketa beds is the Niagara limestone, which forms a line of bluffs rising abruptly six or seven miles west of Dubuque and gradually approaching the Mississippi south of the city.

MODE OF OCCURRENCE OF LEAD AND ZINC.

It may be stated as a general law that the ore deposits of the world, including those of lead and zinc, are located within areas of disturbance in the earth's crust. The strata have been more or less tilted from their original horizontal position;

they have been fractured and faulted, and in numerous instances masses of igneous rock have been intruded into them.

The ore deposits of the Upper Mississippi form a notable exception to the above rule. They occur in practically undisturbed strata, which show no evidence of having been subjected to powerful dynamic forces nor of having been affected by igneous intrusions. It is true, as will be noted later, that slight anticlinal folds exist in the region, but these are of minor importance and have not given rise to profound fissures or faults.

While some beds of lead and zinc occur in massive or crystalline rocks, the great majority of the world's deposits, including those which are most productive, are found in limestone or are closely associated with that rock. This fact is one of much significance since it does not hold true for deposits of the other metalliferous ores. As illustrations of lead deposits in limestone may be mentioned those of Colorado, Montana, Idaho and Nevada; those of the Mississippi valley, and in Europe the large mines of Upper Silesia, Laurium, Cartagena, Santander, Bleiberg, North of England, Sardinia and numerous others.

In their geological distribution these ores are not confined to any one horizon or group of strata, but are scattered through rocks of all periods from Archæan to Tertiary. The rocks, however, which contain the largest and most important deposits are those of the Silurian, Lower Carboniferous and Triassic. The Iowa mines are confined to the Lower Silurian.

A brief comparison of the Upper Mississippi mines with those of Missouri will be in place here. The Missouri mines are grouped about certain centers and are included in three districts, the southwestern, southeastern and central. In the southwest almost all the deposits are in the Lower Carboniferous limestones and cherts. In the southeast and central districts they are in the Lower Silurian limestones.

The massive form of ore deposits prevails in the southwest; the ore bodies are extensive accumulations of breccia, the fragments being principally chert derived from the country rocks. In the southeast the Galena is disseminated through the country rock, large masses of magnesian limestone being impregnated with the mineral.

The Missouri deposits are thus of three kinds:

(1) Filling crevices, chambers or caverns, such as occur in all three districts.

(2) Brecciated deposits of the southwestern and central districts.

(3) Deposits impregnating the country rock of the southeastern district.

The Missouri deposits resemble those of Iowa in the absence throughout most of the region of great fissures and faults, and also in being confined to beds near the surface.

THE LEAD AND ZINC ORES AND ASSOCIATED MINERALS.

The only ore of lead that is found to any extent in the Iowa mines is the sulphide, Galena (Pb S). The carbonate, Cerussite (Pb CO_3), is of rare occurrence, and is derived by alteration from the more common sulphide.

Galena.—This mineral occurs as a rule in well defined cubes, which are joined together in masses of greater or less size, forming groups or aggregates of crystals. The corners of the cube are sometimes replaced by the faces of the octahedron, and this form may predominate until, in rare cases, the cubic faces have disappeared altogether. All the specimens observed from the mines directly about Dubuque were clusters of cubes unmodified, but the Galena from a section lying south of the city, as well as that from the Guttenberg mines, is crystallized in forms showing the combination of the cube and octahedron. From the last mentioned locality a few unmodified octahedrons were obtained.

The crystals seldom present bright metallic surfaces, the faces being dull and more or less corroded or coated over with some foreign substance. The miners have different names for the various kinds of lead ore. Thus the term "cog mineral" is applied to groups of good sized cubic crystals. When these are small the ore is called "dice mineral." When the sulphide occurs filling a narrow fissure, it is rarely well crystallized, and is then known as "sheet mineral," and when occurring in irregular masses it is called "chunk mineral."

The lead from the Iowa mines, like that from the other regions of the Mississippi valley, contains only a trace of silver, and is known as soft lead in contrast with the argentiferous ore of the western mines. More or less of silver is almost invariably present in lead ore, especially when the latter is found occurring in the neighborhood of metamorphic or igneous rocks. But the deposits found in undisturbed sedimentary strata commonly contain no silver except in very small amounts.

It requires at least six ounces of silver to the ton to pay the cost of extracting, and the Iowa ores carry a percentage less than this. The Galena is very free from impurities of any kind and furnishes a product of excellent quality.

Cerussite.—This mineral occurs as a coating upon the sulphide and also at the Lansing mine in crystals lining small cavities in the Galena. The ore from this mine is also frequently covered by a thin layer made up of numerous, small, twin crystals of Cerussite. Wherever the Galena has been long exposed to the weather, as in the case of the float lead found in the soil, the carbonate supplies it with a white coating. In the formation of the Cerussite, which is evidently a secondary mineral formed by the alteration of Galena, the sulphide is first converted into the sulphate ($Pb\,SO_4$) and the latter, through the agency of water holding bicarbonate of lime in solution, is transformed into the lead carbonate.

Smithsonite.—The zinc ores found in Iowa are the carbonate, Smithsonite ($Zn\,CO_3$) and the sulphide, Sphalerite or Blende ($Zn\,S$).

The carbonate, or "dry bone" as it is commonly called, is by far the most common in the Dubuque mines. It occurs in a variety of forms which may be described respectively as cellular masses, botryoidal coatings, earthy masses and small bodies impregnating the rock. It often bears a close resemblance to the calcareous tufa found about so many springs in limestone regions. Sometimes it supplies a coating for galena crystals, or it entirely replaces them and forms pseudomorphs. Several interesting specimens were seen in which fossils had been entirely replaced by the carbonate. One of these was a slab of Smithsonite on which were several large gastropods, their substance wholly gone and the place filled by zinc ore, the outline being perfectly preserved. The carbonate contains, on an average, from 30 to 40 per cent of zinc, though some specimens run as high as 49 per cent.

Sphalerite.—The sulphide, the "black jack" of the miners, is much less abundant in the Iowa mines than the Smithsonite. This is doubtless due to the transformation that has taken place, by which the former was changed over into the carbonate as will be explained later. The blend commonly occurs in compact layers or masses, and does not exhibit any crystal form. But crystals are by no means rare, being found in cavities in the limestones or in geodes. The sulphide contains considerable iron which imparts a very dark, almost black, color and renders the mineral opaque.

The zinc silicate, or Calamine, was not observed in any of the mines, though it probably exists in small quantities along with the Smithsonite.

The change of the sulphide to the carbonate seems to have been very extensive, and the latter is probably all of secondary origin and derived from the blende. Several facts indicate that the latter has been the source of the carbonate.

(1) Specimens are very common in which the outside is dry bone, while the unaltered interior is composed of the sulphide. (2) In the lower levels and where water abounds the ore is the Sphalerite. This is the universal rule and would

seem to be owing to the fact that the lower deposits are not subjected to the atmospheric agencies at work nearer the surface. The chemical changes that have taken place in the zinc blende are probably as follows: The sulphide ($Zn S$) in the first place became by oxidation the sulphate ($Zn SO_4$) which is a very soluble compound; then through the agency of the alkaline and earthy carbonates in solution in the circulating waters, the zinc sulphate would be changed into the carbonate and redeposited in the crevices. Where the blende is under water it is little affected by oxidation and hence remains unaltered.

ASSOCIATED MINERALS.

A variety of different minerals occur in the same crevices along with the lead and zinc, and these deserve more than a passing notice since they serve to throw light upon the origin of the two associated metals.

Pyrite and Marcasite.—These are very common in the workings and are the "sulphur" of the miners. They have the same composition with a ratio of 46.7 of iron and 53.3 of sulphur, but crystallize in different systems, Pyrite being isometric, and Marcasite orthorhombic. The latter is commonly whiter than Pyrite. They do not occur in well defined crystals so much as in crystalline aggregates of irregular form.

At the mine of the Dubuque Lead Mining company, however, the Pyrite is found well crystallized. The limestone has here been much affected by dissolving agencies and is so filled with cavities that the rock has somewhat the appearance of a breccia cemented together by iron pyrites. Instead of the more common cube the mineral here occurs in perfect octahedrons sometimes modified by the faces of the cube. Penetration twins are also of frequent occurrence. The crystals vary in size from one-fourth to three-fourths of an inch. When exposed to the air these sulphides readily oxidize and change over into Limonite. This alteration is finely illustrated in a specimen from the Lansing lead mine. The interior is made up of Marcasite while on the outside this has undergone a chemical change and a coating of Limonite one-fourth of an inch thick has been been formed. The same specimen is covered on one side by Galena and on the surface thus protected the Marcasite has suffered but slight alteration, showing that the changes took place after the deposition of the Galena on the iron sulphide. Otherwise there would seem to be no reason why the Limonite should not be of the same thickness on all sides.

Limonite. (Ocher. Rust.)—This is a hydrated oxide of iron and is found in large quantities in the ore-bearing crevices where it was formed by the oxidation of the Pyrite and Marcasite. This alteration process has gone on so extensively that a large part of the original minerals has been changed into the iron oxide. It is usually impure and earthy, imparting to the clay and other crevice material a brown color.

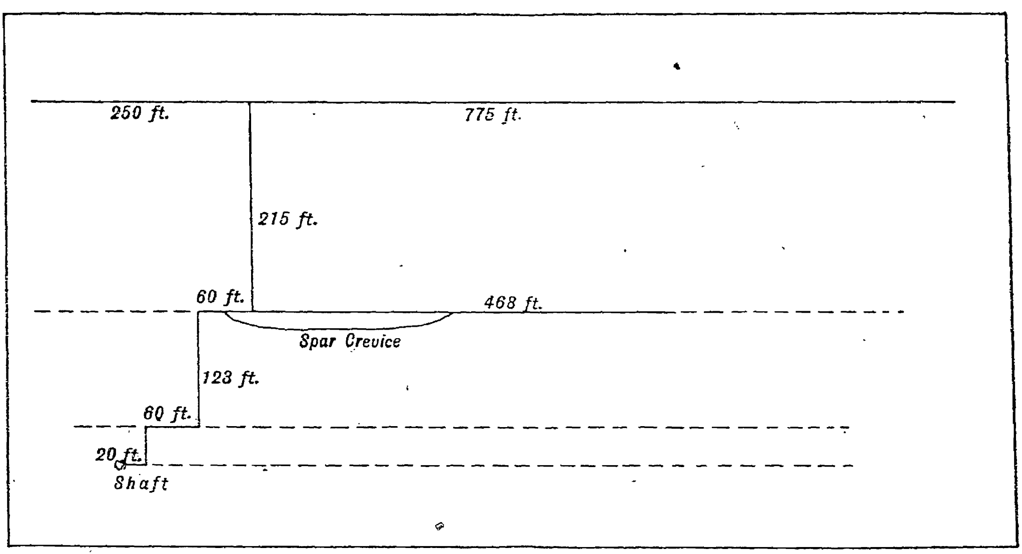


FIG. 1. Crevices followed in prospecting for lead south of Dubuque. These crevices contain satin spar and stalactites.

Calcite and Aragonite.—These are the most common of the associated minerals, occurring abundantly throughout the region. The following varieties were observed:

1. Well crystallized calcite; the "tiff" of the miners.
2. Fibrous variety or satin spar.
3. Lamellar, pearly white variety or argentine.

The two latter are closely associated and are found together in the same stalactites.

The crystallized calcite forms fine crystals and groups of crystals often of much beauty. A very common occurrence is the combination of the scalenohdron (R 3) with the rhombehedron (R) and the prism of the first order (∞P). But more complex combinations are found. Thus one specimen showed the prism of the first order and three scalenodrons, two positive (R 3 and $\frac{1}{4}$ R 3) and one negative, the latter beveling the acute angles of R 3.

Satin spar and argentine are associated in some crevices about five miles south of Dubuque (Tp. 88 N., R. III E., Secs. 16 and 17).

Some of these "spar caves" have been productive crevices from which large quantities of ore have been taken, while others are barren and filled to a greater or less extent with clay. The Galena limestone in this locality is cleft by a complex system of extensive fissures which form a labyrinth of underground passages, and in certain portions contain large deposits of calc spar lining the top, sides and bottom. The deposition of lime carbonate does not go on extensively where there is more than forty feet of limestone above the cap rock. One remarkable feature of these "caves" deserves more than a passing notice. The floor, which is formed of a layer of calcium carbonate 6-10 inches thick, is suspended in the top

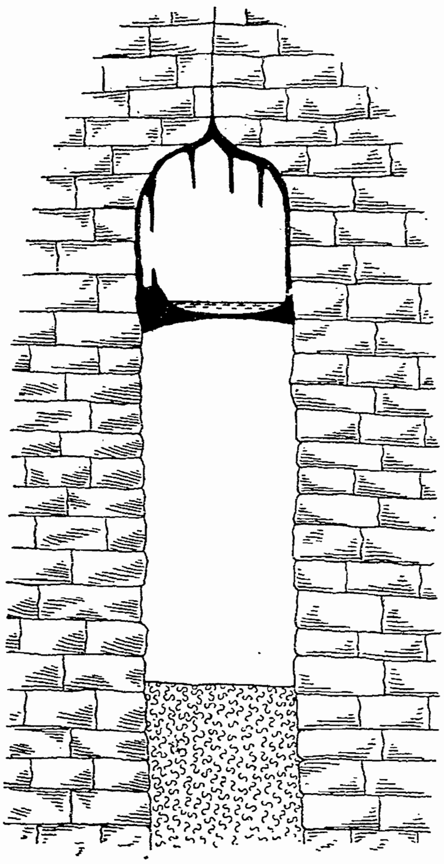


FIG. 2. Section through Kemling's spar cave showing floor suspended in top of crevice, stalactites and miniature lake.

of the crevice. This is well shown in the accompanying figure (Fig. 2). The floor was evidently formed when the clay was at that height in the fissure and was deposited on top of this impervious material. Later the clay has settled, leaving the crevice open beneath the lime deposit; sometimes this settling amounts to as much as thirty or forty feet. The floor of the cave thus forms a horizontal partition across the top of the crevice. It may be connected with the roof by several columns formed by the growing together of stalactites and sta-

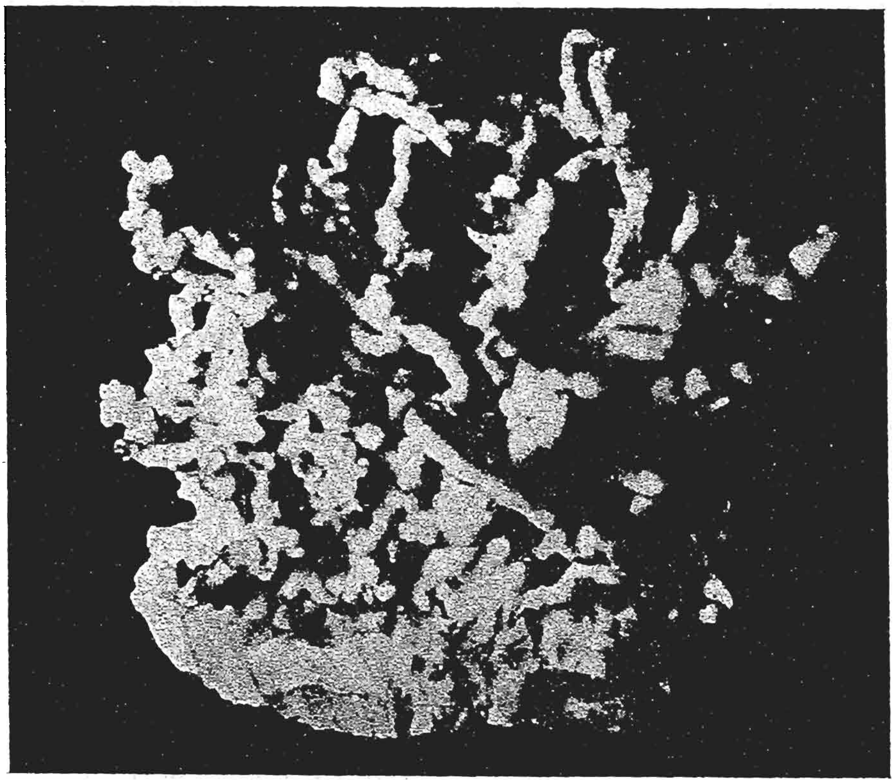


FIG. 3. Satin spar showing twisted stem-like forms. Linden's cave, south of Dubuque.

lagmites. On this floor is sometimes found a clear pool of water.

The Satin spar has a fibrous structure, silky luster and is colorless or white. It is made up of delicate acicular crystals of Aragonite.

The Argentine (Schieferspath) has a pearly luster and is composed of more or less undulating lamellae of pure white color.

The specimens found here agree well with the descriptions given by Dana and Tschermak. Several different forms of stalactites occur: (1) Those specimens which are pearly white on surface of fracture, with a silky luster due to the radiating fibers that form a velvety surface of great beauty. This variety occurs in bunches or clusters of twisted and gnarled stem-like forms. (2) Stalactites proper; formed of radiating fibers. In cross section these have a vitreous

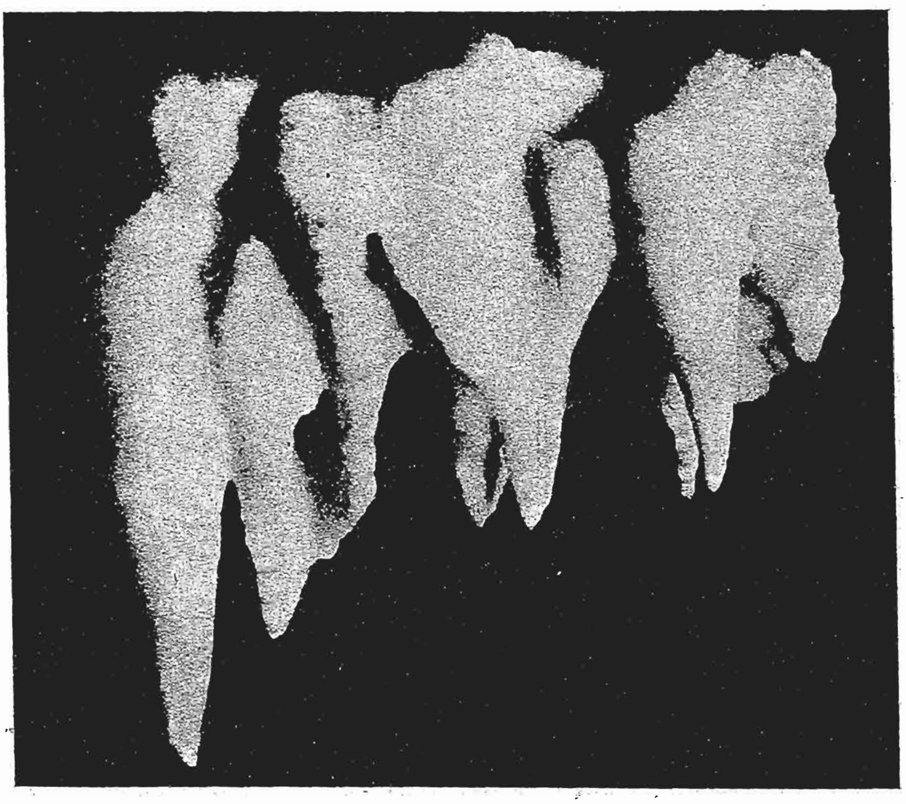


FIG. 4. Group of Stalactites from Kemling's cave, south of Dubuque.

luster, and on the surface are (a) either covered with a fine white powder, and show no luster or (b) the outer surface is formed of little rhombohedrons and has a silky luster. They are white or colorless; opaque or translucent.

Other stalactites have a concentric banded structure and possess several points of unusual interest. Beginning at the center they show (1) a crystalline or granular core, often displaying bright rhombohedral faces; (2) a thin band of clay, apparently wanting in some cases; (3) pearly white lamellar Calcite (Argentine); (4) a band of clay; (5) a fibrous Aragonite; (6) an outer surface composed of little rhombodedrons.

Several features in the structure of these stalactites deserve special notice. There is every indication that the crystalline core was once fibrous, but this structure has mostly disappeared, especially in the larger specimens, and is replaced by the rhombohedral cleavage. In the smaller forms the transition from the radiating fibrous variety to the crystalline aggregate of rhombohedrons can be traced. The long acicular crystals become less and less distinct, though traces remain visible after the rhombohedral form makes its appearance. Recrystallization has taken place and the molecules have rearranged themselves to conform to the interior structure of the rhombohedron; or in other words, they are identical with the latter crystal form in all but external outline and this has been prevented from developing, showing itself only on cleavage faces. Another strong indication that this granular core was once fibrous is found in the fact that this latter structure is the common one in all these caves. The small forms all show the radiating fibers but as they increase in size alteration has taken place.

Another point of interest relates to the band of pearly lamellar Calcite occurring between the granular, crystalline core and the fibrous external layer. These white lamellæ form concentric rings in marked contrast to the radiating fibers associated with them. Occurring on both sides of the Argentine in most cases if not in all, there is a thin band of clay. It is this that doubtless marks the suspension of deposition for a time, and when redeposition commenced the conditions were so changed that a different variety was formed.

The rhombohedrons forming the surface while the interior is fibrous, also deserve notice. They occur on the larger stalactites but not on the delicate branch-like forms. The exterior of the latter owes its silky luster to the innumerable fibers of which it is composed. They frequently form delicate cotton-like masses covering the outside of the satin spar.

On the majority of stalactites, however, the crystal aggregate of rhombohedrons occurs. They may have been deposited after the radiated interior was formed, but they seem to be due rather to the alteration or recrystallization of the fibrous mass, as in the case of the granular core. The conditions under which the fibers were formed have changed, and there has been a corresponding change in the crystalline condition of the calcium carbonate.

The satin spar occurring in the large branch-like clusters is notable on account of its great beauty and rarity. As it

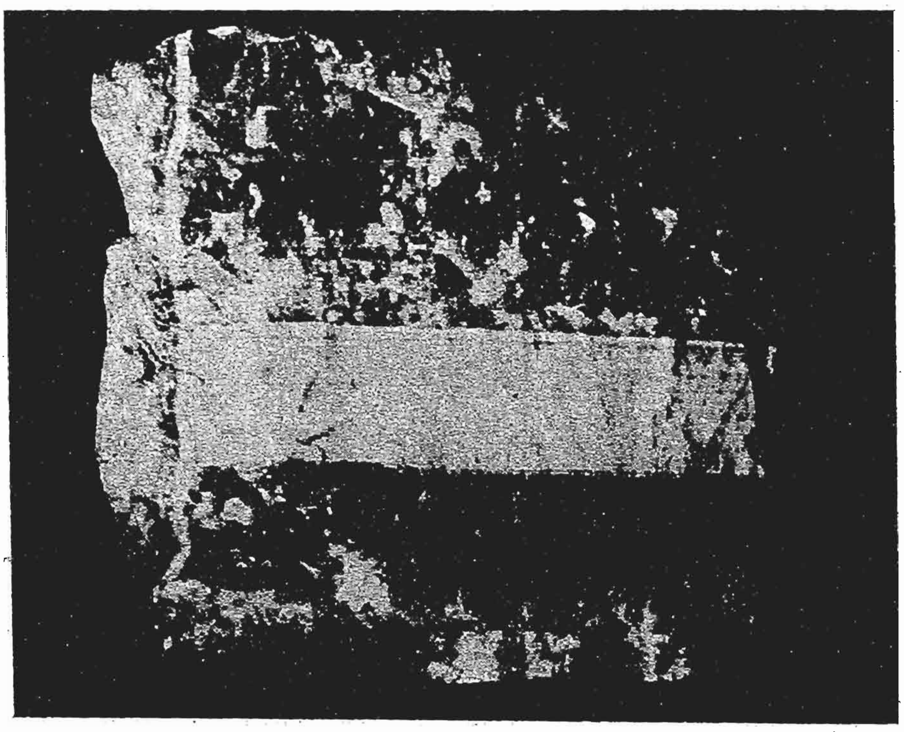


FIG. 5. Specimen showing band of pearly Argentine in transparent calcite from floor of Kemling's cave, south of Dubuque.

hangs suspended from the roofs of the caverns it resembles at a distance branching coral, but near at hand the twisted and gnarled stems with their beautiful silky luster bear no likeness to the polyp structures.

There are several ways of accounting for these irregular forms. They are perhaps due in some cases to the air currents which move through these underground passages. The wind, coming now from one direction, now from another, causes the drops holding the lime in solution to be blown to one side and another of the slowly growing stem, the drops being held by the surface tension of the solution. The water does not trickle down undisturbed as when forming the long straight stalactites, depositing the carbonate evenly on the ends and sides, but is deposited for a time on one side of the branch and then on another.

In a recent paper* on the formation of stalactites Merrill describes some irregular forms from Wyandotte cave, Indiana, and ascribes their peculiar shapes to capillarity. He says: "An examination of the medusa-like forms of Wyandotte reveals the fact that they occur not as dependents from the naked limestone of the roof, but are offshoots from a stalactitic crust which forms first and which varies from a mere film to several inches in thickness. They occur sometimes singly but more commonly in groups or clusters of several, ranging in size from three to ten mm. in diameter. Closer inspection reveals the fact that while in most cases tubular, the tube itself is of almost microscopic proportions, being as a rule less than half a millimeter in diameter. So small is it in fact, that capillarity, not gravity, is the controlling principle in giving direction to the lime-carrying solution. A small spicule of calcite crystallizing on the extremity is as likely to point any other direction as downward; the direction of the next drop is controlled in part by the first, when the same process is repeated. On the assumption that the stalactite increases in length by constant addition to the tube on all sides, it is easy to imagine that the deposit takes place for a time more rapidly on one side than another, perhaps partially closing the orifice or giving it a different direction. The essential fact is, however, that it is to capillarity and not to gravity, that is due the peculiar vermicular forms."

*Proc. U. S. Nat. Mus., Vol. XVII., pp. 77-81.

It is not unlikely that some at least of the Dubuque stalactites, and possibly all, have originated in the manner just described.

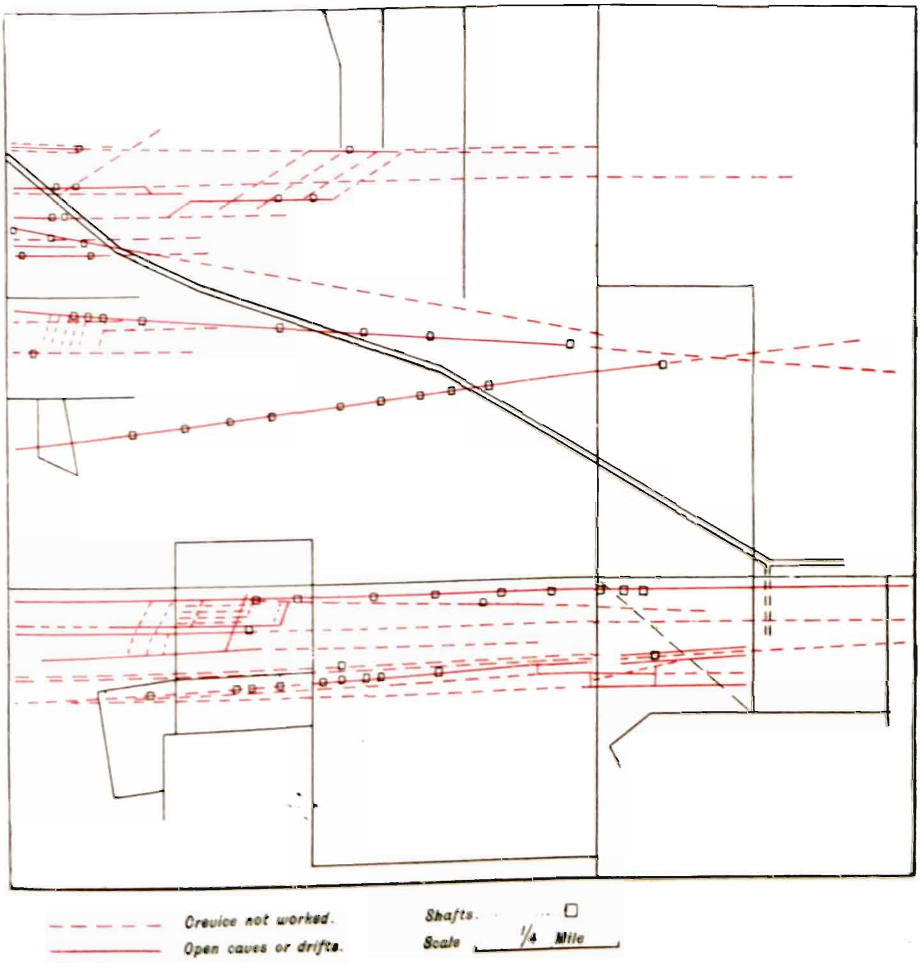
Gypsum.—This mineral is not of common occurrence in the region under view. It is, however, occasionally found in the crevices along with the ores. There is a very unusual occurrence of crystallized Gypsum, or Selenite, in the "spar caves." The specimens are found on the top of the clay forming the floor. The Selenite occurs in very long acicular crystals. These needle-like forms are composed of two individuals, whose twinning plane is the orthopinacoid ($\infty P \bar{\infty}$), and are greatly elongated in the direction of the vertical axis. The faces which appear are those of the clinopinacoid ($\infty P \breve{\infty}$) and unit prism (∞P).

Two cleavages are well shown: (1) The most perfect is parallel to the clinopinacoid; (2) there is a second good cleavage parallel to the negative pyramid ($-m P$). The extent to which these twin crystals have been elongated is remarkable. One specimen had a length of 6½ inches, with a width of less than ¼ of one inch. Another was 5¼ inches long and extremely slender, being less than $\frac{1}{16}$ of an inch wide and perfectly transparent.

Dolomite.—Crystallized dolomite is not common, and when found usually lines the sides of small cavities in the limestone. Since the latter is highly magnesian, it might be expected that dolomite would more frequently occur, but its rarity is doubtless due to the greater solubility of the magnesian carbonate. On this account it would remain in solution while the lime carbonate was deposited.

MODE OF OCCURRENCE OF THE IOWA ORES.

The lead and zinc deposits of the state are found in crevices in the Galena limestone. The strata of the region are cut by fissures of greater or less extent, and in the expansion or "openings" of these the ores occur. There is a very noticeable uniformity in the general direction of the crevices,



TYPICAL CREVICE AREA NEAR DUBUQUE.

a great majority, and all of those which carry the large ore bodies, have an approximate east and west course. A less important set bear north and south; these are narrow without any true opening, and in them the ore occurs without exception in sheets. Cutting these two sets of fissures there are others known as "quarterings" that cross the former at varying angles. These seldom form open crevices and rarely carry ore; but where they cut the main crevice large ore bodies are apt to occur, and these secondary clefts are called by the miners "feeders."

The system of east and west fissures deserves special notice. They have yielded most of the lead and zinc and are by far the most extensive. While their general direction is nearly east and west they vary more or less from such a course. This variation will not, however, exceed ten degrees, and most of the crevices of the Dubuque district are found to bear a few degrees, from one to ten, south of west. Excepting where several are associated together forming a range, the crevices are not parallel and no two have exactly the same direction. Thus it happens that they approach or recede from one another and in some cases even intersect.

The great extent of many of these crevices is another remarkable feature. They extend for miles across the country, and, excepting slight local deviations, their course is nearly a straight line. Thus in some instances, when the true direction was found and a shaft sunk on this line, it struck the opening, or perhaps missed it by only a few inches. The Timber range, a few miles north of Dubuque in Peru and Jefferson townships, affords a good example of the length of some of these fissures. The range is composed of three main crevices which are parallel, with several minor ones, and has a width of 100 feet. It has been worked for a distance of five miles or more, in some portions yielding lead and in others zinc.

The crevices composing a range are quite closely related. They are parallel, only a few feet apart, and are connected by cross fissures. The ore may give out in one, but will be found again in the next neighbor to the north or south. It is thus not uncommon to have the ore pass from one crevice to another in the same range.

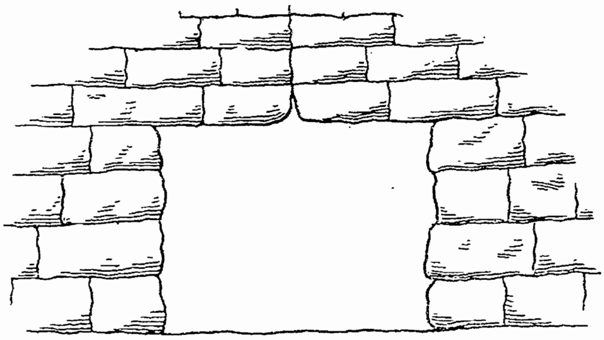


FIG. 6. Crevice opening in Spring Street mine of Dubuque Zinc and Lead Mining Co.

The characteristic features of the crevices are the "openings." These are formed by a widening process due to the decomposition and solution of the limestone in these particular layers. They serve as channels for underground drainage and have thus in many instances been greatly enlarged. These cave-like expansions usually include several strata, the rough edges of which form an irregular wall on either side. At the surface the fissure commonly appears as a mere seam or crack in the rock, which, followed down, probably contains little or no mineral until it suddenly widens out into the space where the ore, if anywhere, will be found. The openings vary greatly in dimension; in height they are all the way from a few feet to forty, and in width from several inches up to twenty feet, and in rare cases even forty feet. They are usually limited above by the "cap rock," a hard and persistent layer of limestone four feet in thickness. This is almost invariably cut through by a seam which may be so small as scarcely to be distinguished, or by

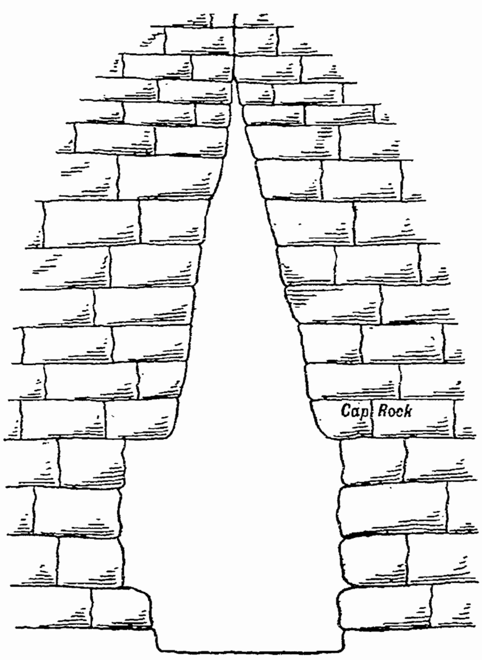


FIG. 7. Section showing open crevice extending up through cap rock, mine of Dubuque Zinc and Lead Co.

an open fissure of varying width that often carries ore. A section of the Galena limestone above the "cap rock" is given below. It is seen in no one locality, but is made up from records of shafts and from quarries.

		FEET.	INCHES.
1.	Maquoketa shales		
2.	Bright red to yellow, cavernous limestone	4	5
3.	Compact blue limestone, difficult to penetrate (the "blue rock" of miners)	20	
4.	Regularly bedded limestone, layers 4 -12 inches thick ("quarry rock")	20	
5.	Heavily bedded limestone	10	

The "cap rock" composes the lower portion of No. 5, is 3 to 4 feet thick and is more compact and hard than the beds below. It is quite easily recognized in sinking a shaft, and among the quarrymen is known as the "four-foot" layer. The lower portion of the above section is well shown in several extensive quarries on Dodge street, below Grandview avenue, Dubuque. These have reached a depth of twenty to forty feet below the surface. Nos. 4 and 5 are well exposed. The layers of the upper portion of No. 4 are uniform in thickness and separated by clayey matter.

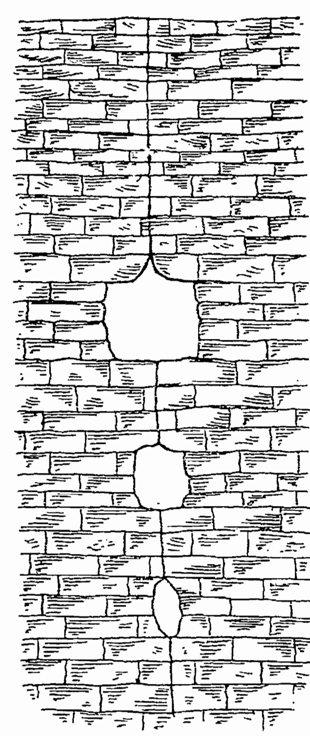


FIG. 8. Crevice with three openings.

The "four-foot" layer is well shown in the quarry north of the road. It is here broken through by several crevices and in one place a large east and west open fissure extends up into the "cap."

A crevice does not widen out into a single opening only, but into several, one below another. The upper is commonly called the "first" opening, the next underneath the "second," while still farther down are a third and fourth. (See figure 8.)

About Dubuque only the first openings have been extensively worked, though considerable ore has been removed from the second. But water hinders progress at the lower levels, and it is only by resorting to costly pumping machinery that these can be reached. The upper opening is usually the main one and also the most productive, while the lower ones are smaller and contain less clay; the ore in these being therefore clean and bright. The first opening is found to occur forty-five to fifty feet below the Maquoketa shale, that is to say the opening proper is at that depth below the shale, and yet it frequently extends upward through the cap rock as an open crevice scarcely to be distinguished from the opening itself, though the miners always make the distinction. As a rule it is not so wide as the portion below the cap rock, just beneath which the marked enlargement occurs. (Figure 7.) This open crevice often extends to within a few feet of the shale or even quite up to it.

A peculiar feature of many openings is found in the chimneys that continue above the general level of the roof, as large cone-shaped or irregular cavities commonly also carrying ore. (See figure 9.) On the other hand the opening may widen out into spacious rooms or caves. Again, the crevice may be divided or almost blocked up by alarge mass of limestone known as a "key rock." It is doubtless on account of its greater compactness that this obstruction has been able to resist the destructive forces which have removed the surrounding rock. The opening is not necessarily an empty cavity, but may be partially or entirely filled with ore or crevice material, such as clay and rock fragments. On the other hand the openings are often empty and can be traversed for hundreds and even thousands of feet.

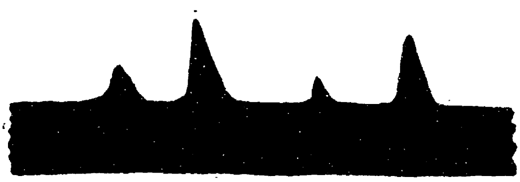


FIG. 9. Crevice opening with chimneys.

The simplest mode of occurrence for lead and zinc is in that of the verticle sheet. (See figure 10.) In this case the ore is found filling a narrow fissure, the walls of which are parallel, and the entire space between them is filled with galena or blende; or the rock may have decomposed more or less, and some clay will then be present enclosing the sheet. The thickness of the latter is variable but will seldom exceed three inches, diminishing to a quarter of an inch and less. The longitudinal extent is usually not great.

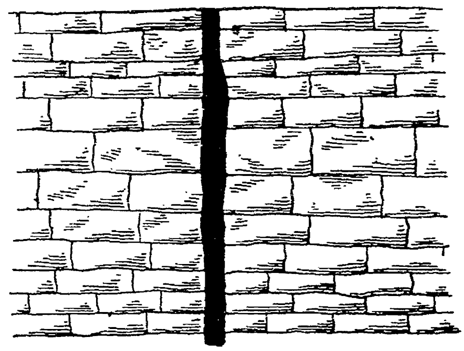


FIG. 10. Occurrence of lead as vertical sheet.

A fine example of such a sheet is furnished by the Lansing lead mine in Allamakee county. This, like all such, lies in a north and south fissure, has a thickness of three inches, and a vertical extent of at least thirty feet. Though followed for 1,000 feet, its northern and southern limits have not yet been reached. This mine will be more fully described later.

The above occurrence, however, is exceptional in the Iowa mines. Most of the ore occurs in the openings above described, where it is either pure or mixed with more or less of clay and fragments of rock. It is commonly found attached to the top and sides of the cavities, or has fallen to the floor where it lies partially buried in clay. The lead, especially, bears evidence of having been formed in the "cap." It is frequently seen suspended in large masses from the roof and extending up into the crevice in the "cap rock." After it has fallen, a second sheet may form in its place, and thus several separate masses may be formed successively. Lead is also found filling the chimneys and continuing upward above the opening. The zinc ore, besides lining the crevice, is also found in large, loose masses, nearly filling the opening and coating the loose rock fragments. Oftentimes it is quite pure, with only a slight admixture of clay or limestone. Sometimes it fills great cavities, and in one of these it was so loosely deposited that a blow of the pick caused tons to come tumbling down.

A very noticeable feature of the Iowa deposits is seen in the way the lead and zinc occur concentrated at certain points forming "ore bodies." The crevices are not productive throughout their entire length, but only here and there, where, for some reason, the conditions have been exceptionally favorable for the concentration of the minerals. It may be that a quartering crevice or a north and south fissure intersects the main one just here, and has brought in the waters from which the ore was deposited. At any rate, these ore bodies frequently occur where several crevices cross. In a great many cases also they appear to accumulate and "make back" as the miners say, from some obstruction in the crevice, as a "key rock." These concentrated masses of mineral do not usually extend more than 300 or 400 feet, though they may reach 800 or 1,000 feet. The opening, on the other hand, may be several miles in length. The ore bodies are thus commonly quite limited. They do not usually give out suddenly, but the valuable contents diminish in quantity and finally disappear.

The lead and zinc deposits of Iowa are confined mostly to the upper part of the Galena limestone. This is true for all the mines of Dubuque county. Farther north at Guttenberg, where formerly considerable lead was found, the mines are in the lower portion of this formation, and at Lansing some ore is even found in the Oneota limestone; but with few exceptions the deposits are near the top of the Galena. The Iowa mines appear to form an exception to the rule that holds good for the rest of the region. Chamberlain* makes the following statement concerning the occurrence of the metals in the field as a whole. "It is a law to which no noteworthy exceptions have yet been authentically reported, that lead predominates in the upper beds, but relatively decreases in the lower, while the zinc ores are very scant in the upper horizons but relatively increase and often predominate below." If reference is made only to the zinc blende, then the above

*Geology of Wisconsin, Vol. IV, 1873, p. 488. 1879.

statement would be true for Iowa as well, for the sulphide is always found at the lower horizons and usually below the Galena. But if it is made to include the zinc carbonate or dry bone, the Iowa deposits are an exception.

In the Dubuque region the zinc commonly occurs on the same level as lead, and in some cases above it, as will be shown later. Most of the great ore bodies have been in the upper fifty or sixty feet of the Galena limestone, and it is doubtless true that the bulk of both minerals so far marketed from these mines has been taken from the upper one-fourth of that formation. Very little ore has been removed from a greater depth than 100 feet below the Maquoketa shale. In Wisconsin the zinc is confined mostly to the underlying Trenton rock, but only in rare instances have the diggings reached that depth upon the west bank of the Mississippi.

Both lead and zinc frequently occur in the same opening, though they are not usually intermingled. The lead gives out in the crevice and a short distance beyond the zinc appears. Thus many crevices have been worked in one section for the former and in another for the latter. The carbonate is found in immense quantities above the openings carrying the lead. The two ores rarely occur mixed together in the Iowa mines, and even in such cases it is only in small amounts. In other portions of the same region, in Wisconsin and Illinois, the two are more closely associated and are often found in alternate layers.

SPECIAL DESCRIPTION OF THE MINES.

The lead and zinc deposits of Iowa extend along the Mississippi for nearly eighty miles in the counties of Dubuque, Clayton and Allamakee.

The Dubuque area is by far the most extensive and important and has yielded a large proportion of the entire product of the state. Beginning at the valley of the Tete des Morts the metalliferous tract extends northwest to the Little Maquoketa. The diggings in the neighborhood of the former stream, however, were never very productive and have long since been abandoned. The Dubuque area proper is included between Catfish creek and the Little Maquoketa forming a belt from three to four miles wide and six miles long, with an area of some twenty square miles. The Galena limestone of this section has been deeply cut by the streams and is overlain in all its higher portions by the Maquoketa shales. Most of the shafts penetrate these shales for a greater or less distance before reaching the limestone sought. The number

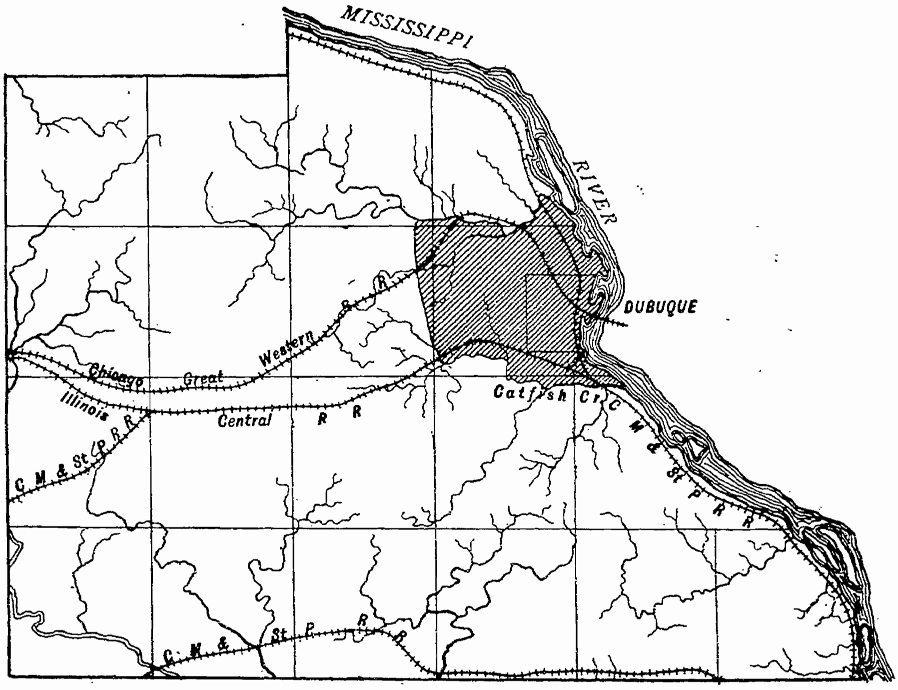


FIG. 11. Lead and zinc region of Dubuque county. The shaded area represents the productive region.

and size of the productive crevices included within this comparatively small area is very remarkable and it is probable that no other district of equal extent in the Mississippi valley has yielded so large an amount of ore.

Most of the mines are now being worked for zinc carbonate, or dry bone, and only a few are producing lead in any amount.

A special description of some of the more important and characteristic mines will serve to illustrate the mode of occurrence of the deposits and bring out more clearly their appearance. It is not claimed that the list is complete. Some of the most interesting mines were closed at the time the field work was done, and hence could not be visited. Other famous diggings have been worked out, or abandoned on account of the water, and are now inaccessible. For such reasons those which could be examined were comparatively few.

The first one selected for notice illustrates the occurrence of the zinc above the lead.

The Timber Range, or old "Ewing Diggings" at Durango, five miles northwest of Dubuque (Tp. 90 N., R. I E., Sec. 36, Se. qr.) was once famous for its Galena. The range has a width of 100 feet and is formed by three main crevices with

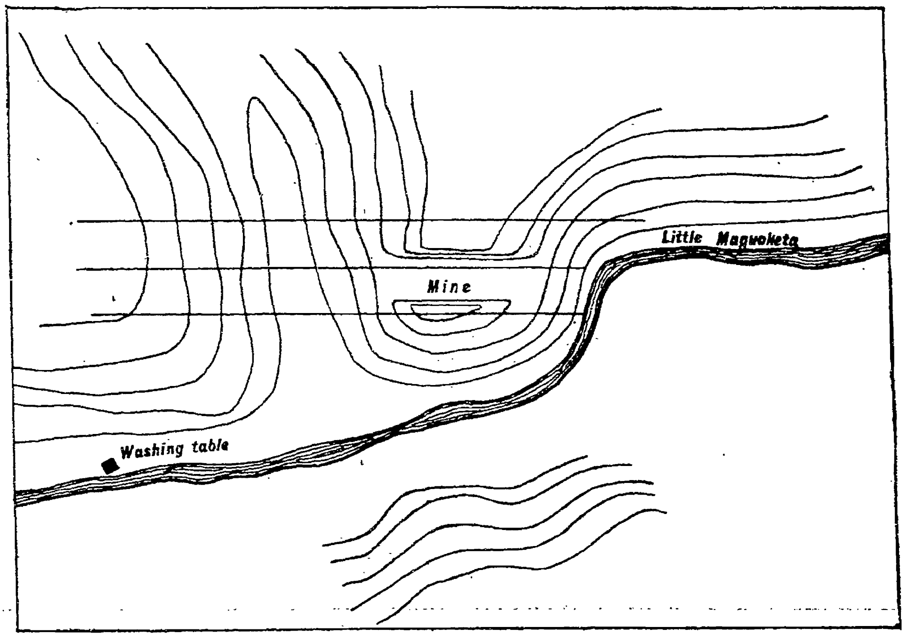


FIG. 12. Sketch showing location of Durango zinc mine in hill above the Little Maquoketa. Three crevices represented.

a general direction S. 80° E. The openings occur ninety feet below the crown of the hill, and where they are enlarged the three fissures unite in caverns of immense size.

In these openings the lead occurred, and above them, extending to the surface, the hill is filled with zinc carbonate The zinc is known to extend also below the level of the lead. The mine is worked by means of an open cut extending through the hill with a width of forty feet and a depth of about eighty feet. The crevices are more or less open up to the surface. Several can be seen in the face of the cut, and in them the ore is most abundant, though this is also found mixed all through the fractured limestone. The strata have been subjected to more or less strain, possibly owing to the large caves below, and are broken into fragments. The carbonate is found coating these pieces and filling the spaces between, occurring also, as stated, in the open crevices. The

FIG. 13. Open cut at Durango zinc mine.

latter where they appear in the cut, have a width of from one to two feet. In working the mine the larger masses are blasted, and the smaller ones loosened with the pick. The ore is removed from the rock, the latter is carted off to the dump, and the dry bone, mixed with more or less waste material, is carried to a neighboring stream. Here it is washed by an ingenious contrivance which thoroughly frees the ore from all sand and dirt. The method was invented by Mr. Goldthorp, superintendent of the mine, and is quite extensively used about Dubuque. An Archimedes screw, turned by horse power, revolves in a trough through which a stream of water is kept flowing. As the screw revolves it gradually works the ore up the gentle incline while the water runs down and carries with it all sand and dirt. Afterwards the dry bone is picked over by hand and the rock fragments thus separated. During the past season eighteen men were

FIG. 14. Cleaning the ore from the Durango zinc mine.

employed at the mine and the daily output was from fifteen to eighteen tons of ore. This would mean a yield of over 2,500 tons for six months and is probably about the annual production of the mine for the last few years. The only zinc ore occurring in any amount at the Durango mine is the carbonate. Lead occurs in small amounts mixed with the zinc, this being one of the two instances noted in which this phenomena appeared.

Dubuque Lead Mining Company.—The mine of this company is located one mile west of Dubuque and has been worked for about one year and a half. It is on the west end of the old Level Range, which has been followed for nearly three miles and has yielded considerable ore from various points along its length. At present (November, 1895) there are seventy-five men employed at the mine. The three shafts are 210 feet deep, with a steam hoist on one, and gins on the other two. The company have just erected a concentrator at the mine for the purpose of crushing and cleaning the ore. This was made necessary by the fact that in this mine much of the Galena occurs scattered through the rock, sometimes in particles of considerable size. The limestone is crushed and the lead then separated from it. The ore-bearing dolomite forms a zone from two to four feet wide and contains an abundance of iron pyrites. This latter mineral is often found here crystallized in beautiful octahedrons with a length of from one-fourth to three-fourths inches. Besides being disseminated through the rock the Galena occurs in large masses in what is probably the fourth opening, and it likewise fills the crevice above for some distance. The ore body is apparently an extensive one; 700,000 pounds of lead have already been raised. Work in this mine is made possible only by the constant operation of a steam pump which keeps the water below the opening where the ore occurs, and thus allows the miners to reach the deposit.

The McGowen Crevice—Direction N. 86° W. This crevice is located just west of Dubuque and was formerly operated for lead, but for the past eight years it has produced zinc ore. The shaft is 112 feet deep. Only the first of the openings present have been explored. The greater portion is above the cap rock and is called by the miners a "cap rock" opening. The expanded crevice is a large one, the average height being forty to fifty feet, and the width four to ten feet. In some portions it opens into caves with twice the above width, and these are filled with zinc ore mixed with clay and more or less rock, much as in the Durango mine. Some twelve feet west of the shaft the lead gave out and a few yards beyond zinc carbonate began to appear and soon occupied the entire opening. At one point almost the whole cavity is filled by the "keyrock," leaving only a narrow space on either side for the ore.

Wharton Crevice.—This mine has been operated for zinc twelve years. The shaft opens out into a large "cave" from which much lead was formerly taken. From this point the Galena pitched down toward the west and was followed in the first opening for 150 feet. It then descended again to the second opening where it was followed 150 to 200 feet. Work was stopped at this point by water. The zinc is found in the upper opening above the section where much of the lead occurred, thus furnishing another example of the former ore occurring above the latter.

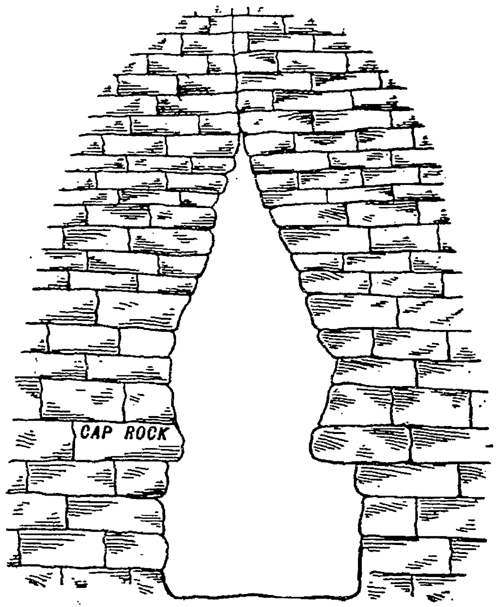


FIG. 15. McGowen crevice showing cap rock opening.

This crevice, like many in the Dubuque region, is extensive, being forty to fifty feet high by four to ten feet wide. In it, as in the McGowen crevice, occur many large caves which extend up into the "quarry rock." The crevice has been followed for over a mile west from the shaft.

Trueb, Southwell & Co.—The mine belonging to this company is located in the city of Dubuque and has been in operation about nine years. It has yielded large quantities of zinc. It is worked by means of four or five shafts, one of which has reached a depth of 210 feet, being one of the deepest in the region. The mine has been closed for some time and cannot now be examined, but divers facts of interest were obtained from the owners and others.

It is apparently an exception to the rule that the first opening is the largest, for here the second holds the place of honor, having a height and a width of forty feet. In it abound both the sulphide and carbonate of zinc, and the alteration of the blende into the Smithsonite can be traced in specimens collected here. In the first opening some Galena occurs with the zinc, this and the Durango mine being the only ones in the state where the two ores exist together in this fashion. Between the shaft on Alpine street and the first one to the west, there is a bar that holds the water back. This extends in a general northeast and southwest direction and during part of its course is about under Nevada street. The water level west of this barrier is much higher than upon the other side. Thus in the Alpine shaft a depth has been reached seventy feet below the water level west of the obstruction.

Howe, Alexander & Seller's Co.—This mine, which is located at the corner of Eleventh and Spruce streets, Dubuque, is a comparatively new one, having been operated only since March, 1892. The shaft reaches the first opening at a depth of eighty-five feet, and from this level alone has ore been removed. Drifts have been run east and west from the shaft, and only enough of the ore removed to give the miners room to work to advantage. The opening, while its dimensions have not been accurately determined, is known to be a large one and immense quantities of ore are in sight. Although, when visited, the mine had been worked only a little more than a year the drift had reached a length of about 800 feet, and 1,000 tons of zinc ore had been removed.

Kerrick Mine.—This mine, one of the largest and most productive in the district, is still being worked for lead. The crevice is almost an east and west one, having a direction N. 89° W. A pump has recently been introduced, and by means of it the water was so lowered that a body of ore in the second opening could be reached. Thus in fifteen days 317,000 pounds of Galena were raised, and in all, the mine is said to have yielded 20,000,000 pounds.

Passing north from the Dubuque area we find a few diggings about Sherrill Mound, three miles from Durango. They are the last met with in Dubuque county in this direction.

CLAYTON COUNTY MINES.

Lead has been mined in considerable quantities at two points in Clayton county—Buena Vista and Guttenberg. At Buena Vista a beginning was made in 1851 in Tp. 91 N., R. I W., Sec. 28, Ne. qr. Two nearly east and west ranges have been worked, and both are formed by three main parallel crevices with several minor ones. The ore in the south range occurred in a large body at the surface. The mine is on a side hill where the overlying strata have been eroded, leaving the deposit exposed. It was worked by an open cut and yielded lead in a generous measure. The crevice was followed 700 feet west of the ore body, but without further discoveries. The fissure is open up to the very surface, where it is from one to three feet wide, and is filled with clay and soil. One crevice in the north range has been worked by a level run into the hillside. Mining has been carried on here at intervals for over thirty years, and, although no record has been kept, the mine is known to have produced large quantities of Galena. Some zinc carbonate occurs in this same locality, but not in paying amounts. Several specimens of lead carbonate, Cerussite, were obtained here, and one of them analyzed by Prof. G. E.

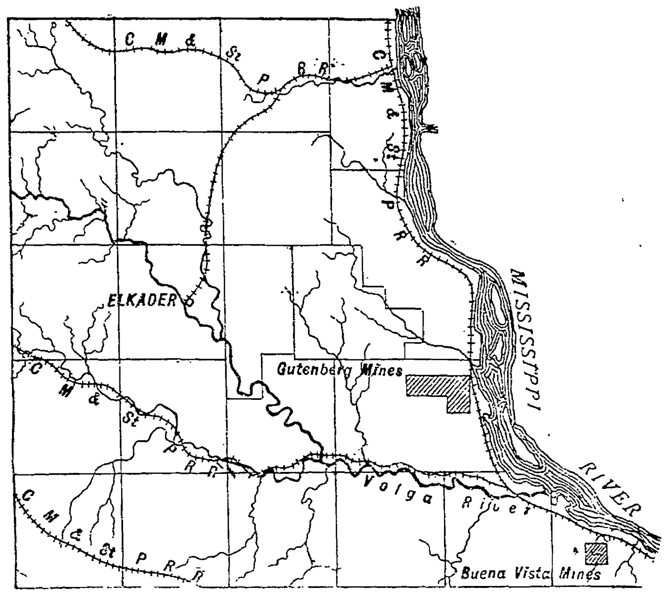


FIG. 16. Lead and zinc mines of Clayton county.

Patrick yielded 69.67 per cent of lead. It occurs only in small quantities and has been derived by alteration from the Galena. For many years little has been done in these mines, although some prospecting has been carried on from time to time. The deposits are met with lower in the Galena limestone than at Dubuque, but not at the base of the formation as at Guttenberg.

The Guttenberg mines are several miles northwest of the village of that name on Miner's creek, a small stream flowing into the Mississippi just below the town. The larger diggings were in Tp. 92 N., R. II W., Sec. 7, but there were others in section 18 of the same township and range, and still others in sections 11 and 12, Tp. 92 N., R. III W. Both the Galena and Trenton limestones are here well exposed, the latter rising from 125 to 150 feet above the river. The higher hills are capped with 100 feet of Galena limestone. Miner's creek and its tributaries have cut deeply into both those formations, and the mines are located on the sides of the valleys which have in places cut across the east and west crevices. Work has been carried on almost entirely by means of tunnels or levels run into the hillside. The deposits here occur at the base of the Galena, at its junction with the Trenton. The ore is found in flat, comparatively wide openings, and is scattered through the crevice clay.

The Holmes mine is the largest in this district. The opening, which is in places fifty feet wide, was followed 2,000 feet. The cap rock forms a flat roof without fissure. The lead ore lay loose in the crevice material occupying the cavity, and was easily removed without blasting. Crossing the Holmes range was a "quartering," northeast and southwest, which was rich in ore. A north and south fissure close by also carried considerable amounts. The mineral in the Holmes, as not unfrequently occurs in the mines, "jumped" from one east and west to another parallel crevice of the same range. In this case the opening in the crevice followed became narrow and the Galena gradually disappeared, but only to reappear in the other crevice. In all the specimens seen from the Guttenberg district the lead crystallized not in simple cubes, but in combination forms of the cube and octahedron, the latter form often predominating or occurring alone. This locality formerly produced considerable lead, and two smelters were at one time in operation on Miner's creek. After a few years' working the deposits gave out in the majority of the diggings, and they are now practically abandoned.

Very little careful prospecting by experienced miners has been done in this region, the mineral having been hit upon almost by chance. Probably by careful and systematic search other ore-bearing crevices might be discovered.

ALLAMAKEE COUNTY MINES.

The only mine now being worked in this county is that of the Lansing Mining and Smelting Co., located five miles

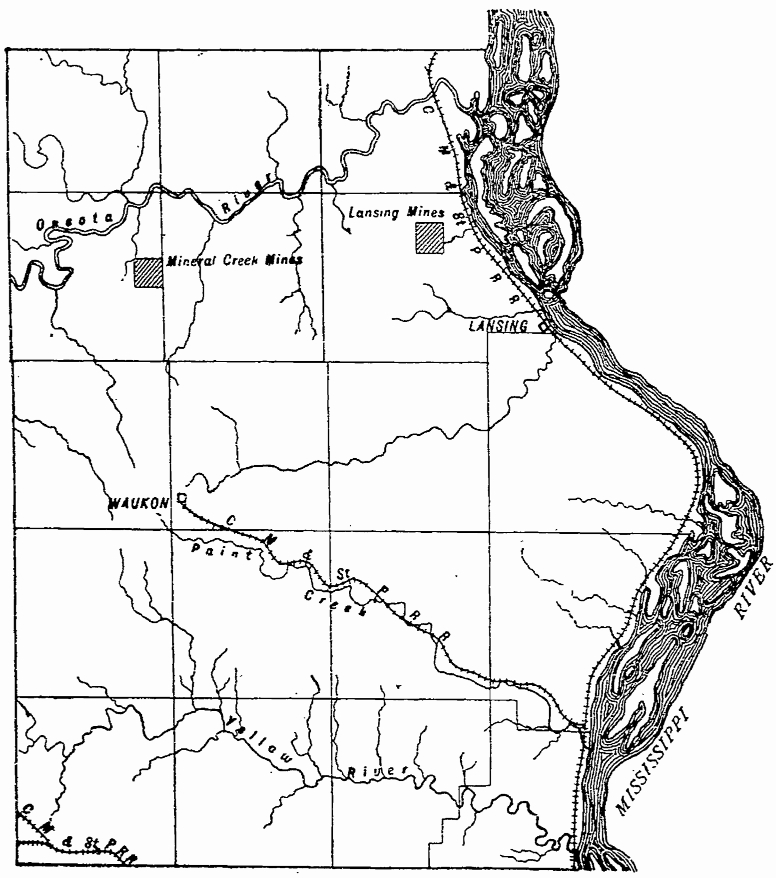


FIG. 17. Lead and zinc mines of Allamakee county.

northwest of Lansing in Tp. 99 N., R. IV W., Sec. 10, Nw. qr. This is of unusual interest on account of being in the Oneota limestone, in which ore had not previously been discovered except in small quantities. It was, indeed, considered practically useless to look for lead in this formation. Another remarkable fact in connection with this deposit is that it occurs as a vertical sheet in a north and south fissure. While these north and south crevices are not uncommon in the state, they are usually of limited extent and do not contain large bodies of ore. But here the sheet is an extensive one, and does not as yet show any signs of giving out. The mine was discovered in January, 1891, by Captain Turner, who had reached the conclusion that lead occurred in the Oneota, and had done considerable prospecting at various points.

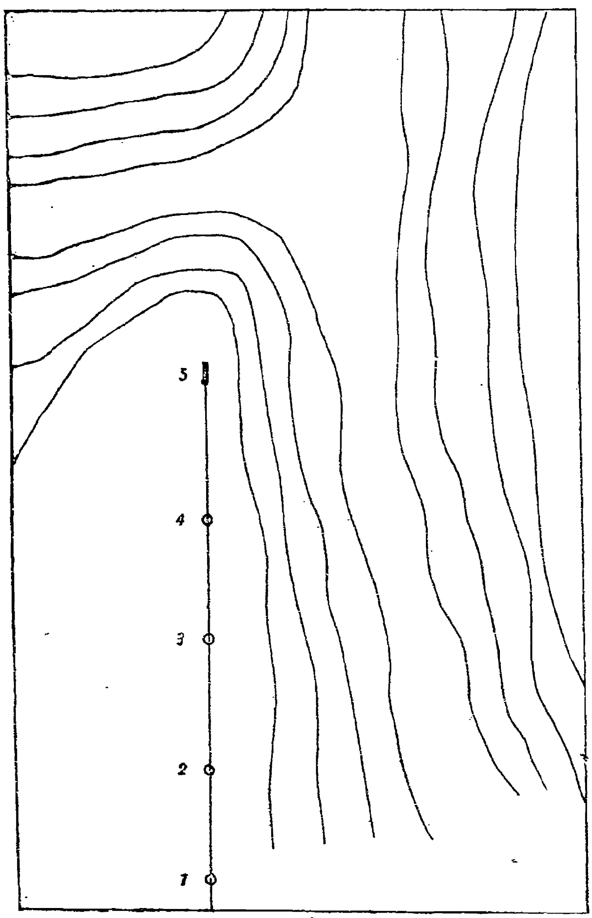


FIG. 18. Crevice and shafts at the Lansing lead mine.

The location is on a hillside that slopes to the north and east. While the general direction of the crevice is nearly north and south (S 10° E.), its course is not straight but zigzags back and forth within certain limits, so that a shaft sunk on the general line of the fissure may be several feet out of the way.

The sheet has been followed 1,000 feet and its limits have not been reached either to the north or south. At the north end of the present workings the fissure is interrupted by a ravine and the sheet thus outcrops. There is reason for supposing that it will be found again upon the other side. The main body of the sheet has a vertical extent of from twenty-five to thirty feet, and a width of from three to four inches. A shaft was sunk 113 feet to the Saint Croix or Potsdam sandstone, and Galena was found in small quantities downward to within four or five feet of the latter. The bulk of the ore is, however, about fifty feet above the sandstone.

The sheet of lead is either interbedded in the crevice clay or fills the entire space between the rock walls. Where it extends south under the hill and has been little exposed to weathering agencies, the sides of the fissure have not undergone decomposition and the sheet is in contact with the rock. In other places where examined an inch or so of clay was found between it and the limestone, the crevice in this case being from six to eight inches wide. Again, the fissure may open out until it has a width of three or four feet, and then be filled with clay with the sheet of ore against the wall. In such a case the ore commonly lies against the east wall, or toward the lower side of the hill. The sheet does not extend vertically to the surface, but in the upper eight or ten feet curves over toward the east or down the slope. Evidently there has been a slipping of the hillside which has carried with it the top of the sheet, this bending being a result.

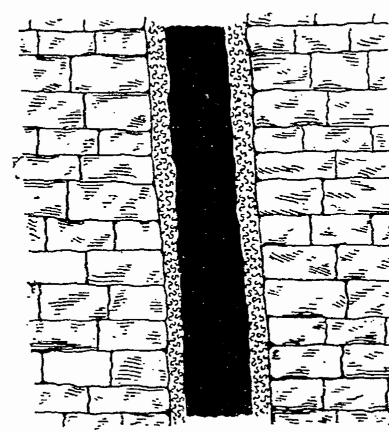


FIG. 19. Lead in vertical crevice between sheets of clay, Lansing lead mine.

The mine has been worked by means of three or four shafts from thirty to sixty feet deep. From these, drifts are run in each direction at various levels, and thus the ore is removed.

At the north end of the present workings a tunnel has also been cut along the side of the sheet.

Most of the ore is taken out in pieces of considerable size. The Galena is filled with many cavities, often lined with crystals of lead carbonate or Cerussite, formed by the alteration of the sulphide. One sample showed 80.55 per cent of lead. The ore contains nearly four ounces of silver to the ton. At the present time (November, 1895) the production has reached 500,000 pounds with excellent prospects for the future.

The following reference to the occurrence of lead in the Saint Croix is found in Professor Calvin's report on Allamakee county.*

"While the Oneota limestone is the lead-producing, and in general the lead-bearing rock of Allamakee county, some ore bodies are occasionally found in the underlying Saint Croix sandstone. The Saint Croix lead ore was doubtless deposited by descending waters that became charged with salts of lead while passing through the Oneota limestone and reached the Saint Croix before the sulphide was precipitated. Concerning one of these deposits very recently worked on the Lansing company's property Mr. Trewin writes: 'We took several thousand pounds from the Potsdam (Saint Croix) sandstone, but there does not seem to be much yield in that formation.' The ore body of the Saint Croix referred to by Mr. Trewin lay in a fissure in the sandstone immediately beneath the lead-bearing crevice of the Oneota from which the Lansing Mining and Smelting Co. have taken practically all of the ore thus far produced. It occurred at the north end of the mine, where a ravine cuts transversely to the crevice, and all the ore contained in the sandstone was found within a hundred feet of the face of the bluff."

Lead was formerly mined at one other locality in Allamakee county, on Mineral creek (Tp. 99, R. VI W., Sec. 13), about two and one-half miles south of where it empties into the Oneota. Near the confluence of the two streams, a small

*Iowa Geol. Survey, Vol. IV, p. 107.

town, New Galena, sprang up, and during the years 1856-57 prospecting and mining were actively carried on. The mines were in the upper part of the Oneota limestone, not far from its juncture with the Saint Peter sandstone. Mineral creek has cut its valley through this sandstone and well down into the underlying limestone which here has an exposed thickness of more than 100 feet. This latter rock shows evidence of considerable disturbance, being more or less brecciated, and has been recemented by siliceous material. It is full of cherty or flinty matter and is very impure.

The mines were on a hillside and were worked by means of short drifts. Instead of being in crevices the ore occurred scattered through the limestone, necessitating considerable blasting. None of the drifts extended more than forty to fifty feet from the surface as the mineral-bearing rock did not reach a greater depth. To separate the mineral great heaps were constructed with wood intermingled with the rock. These were fired, and after the fire had done its work, the heat was found to have been insufficient to melt the Galena. It had only broken the rock into small pieces. Then this was washed and the mineral was separated. The latter was smelted in a furnace located at the mouth of Mineral creek. During the two years that the mines were in operation sixty-three pigs were turned out and this trifling return represents almost the entire product of this district. When the locality was visited early in 1894 some prospecting was in progress, but with little chance of success. Float lead is found quite abundantly in the county, and the Oneota probably contains more or less of this mineral. But it is doubtful whether, as a rule, the ore occurs in well defined crevices and in amounts sufficient to make the mining profitable.

ORIGIN OF THE ORE DEPOSITS.

The question of the origin of the lead and zinc deposits is one of much practical importance as well as great scientific interest. The subject has recently come into renewed prominence and has been ably discussed by Winslow, Jenney, Blake and others, all of whom are well acquainted with the Mississippi valley deposits.

In treating of the genesis of these deposits it will be well to consider in the first place the original source of the lead and zinc and the manner in which the ores came to be confined to certain districts, and then to discuss the formation of the crevices and the deposition of the ore in these receptacles.

Original Source of the Lead and Zinc.—For the source whence the materials were originally derived we must doubtless look to the primitive Archean rocks forming the land mass to the north. As this was washed away and its materials carried into the Silurian sea, the waters became charged with metallic salts which were deposited along with the limestones. The chief agent in the precipitation of the metals appears to have been the organic life so abundant during this period. The death and decay of the vast multitudes of brachiopods, mollusks, and other forms gave rise to sulphureted gases. These gases were doubtless very effective in precipitating the metallic sulphides which were thus deposited along with the sediments.

Localization of the Deposits.—One fact in connection with these deposits is difficult of explanation on the theory of oceanic deposition; namely, the localization of the ore bodies. These bodies are confined to certain districts, outside of which the ground is nearly or quite barren, although as far as can be seen the conditions are quite as favorable. For example, the Dubuque mines are confined to an area of some twenty square miles, while to the north and south the Galena limestone carries no ore though everywhere cut by numerous crevices favorable for its reception. The same is true of the many mining districts of Wisconsin and Missouri. The mines are noticeably grouped about certain centers, while the surrounding country is unproductive. The natural supposition would be that the minerals were everywhere equally disseminated through the rock and that they have been leached out and deposited in the fissures only in certain favorable localities. But this is hardly probable in view of the fact that the conditions are apparently just as favorable for the formation of ore bodies in the barren districts as in the productive ones. How then can the localization of the deposits be accounted for on the generally accepted theory that the lead and zinc were contained in the oceanic waters and were distributed through the rocks at the time of their formation?

Prof. J. D. Whitney,* over thirty years ago, published an elaborate report on the lead region and discussed at considerable length the origin of the deposits. His views differed quite radically from those of Messrs. Owen and Percival, who had maintained that the metals were derived from great depths. Professor Whitney was the first to advance the theory that the metallic salts were held in solution in the waters of the ancient sea, and were thrown down by organic matter or the sulphureted hydrogen arising from its decay. But no satisfactory explanation was given for the localization of the lead and zinc.

Professor Chamberlain† attributes the original concentration of the deposits to the currents of the old Silurian sea. The oceanic waters impregnated with metallic salts derived from the leaching of the adjacent lands were borne by currents to areas where there was an abundance of organic life, and here the metals would be extracted and thrown down along with the sediments.

Mr. Arthur Winslow‡ has recently advanced a somewhat different hypothesis concerning the origin of the Missouri ore bodies. He holds that the concentration is due to the surface decomposition of the rocks. "According to our theory the concentration is entirely secondary. It is primarily a result of great and long-continued surface decay of the rocks; and secondarily the result of the presence of local

*Geology of Wisconsin, 1862.
†Geol. Wisconsin, Vol. IV, p. 529, 1882.
‡Missouri Geol. Surv., Vol. VII, p. 477. Jefferson City, 1894.

favorable physical and chemical conditions." The hypothesis starts with the proposition that the minerals existed in the Archean rocks, and with the decay of these became diffused through the later formed sediments. It will be noticed that this theory agrees with that of Chamberlain in recognizing the presence of the minerals in the country rocks and the derivation of the deposits from them; but it differs in maintaining a condition of general diffusion, rather than one of concentration over certain favored areas.

The evidence is abundant that very extensive sub-aerial decay has befallen the rocks in the Missouri region, and during successive geological periods many hundreds of feet have been removed. Mr. Winslow believes that in the Wisconsin-Iowa area the same processes were long operating to concentrate the ores. It has already been stated that the district is unglaciated, and thus has long been exposed to atmospheric agencies by which the rocks were extensively decomposed.

Mr. W. P. Blake,* who is familiar with the Wisconsin deposits, seems to hold something of the same view as Winslow, if we may judge from the following words: "The evidence is strongly in favor of the view of the long-continued decomposition, downward flow and recomposition of not only the ores of zinc but of lead and of the pyrite from the upper formations to the lower, as the general water-level of the region subsided and as the upper formations by long continued exposure through geologic ages were gradually decomposed in place. By such a process the present zinc deposits would seem to have accumulated and to represent the originally diffused ores in many formations, possibly as high in the geologic scale as those of Missouri, or the Lower Carboniferous. This is, however, improbable owing to the dense and impervious nature of the intervening Hudson river (Maquoketa) shales." It would seem that this impervious character of the shales constitutes a serious objection to Winslow's theory as applied to the Iowa deposits. The ore-

*Trans. Am. Inst. Ming. Eng., Vol. XXII, p. 621. New York, 1894.

bearing beds are commonly overlain by these shales and ore occurs mostly near the top of the Galena limestone. Granting that the overlying Niagara and Maquoketa formations were impregnated with lead and zinc, it would hardly have been possible for these to make their way in solution through the impervious shales. In other words there could not have been in this area a very extensive downward flow and re-composition of the ores. The process has doubtless been going on within the Galena formation itself and may have caused some local concentration, but the limestone has not undergone very extensive decomposition in situ, and the ore is found largely in the upper beds.

For these reasons, while Chamberlain's theory of ocean currents may appear somewhat too hypothetical, it furnishes on the whole the most plausible explanation yet offered for the localization of the Upper Mississippi deposits.

Formation of the Crevices.—Cavities and crevices in the rocks are formed in several different ways. They may result from contraction due to solidification, drying or cooling. A familiar example of this process is seen in the cracks found in basalt. It is probable that some of the joints of sedimentary rocks have had the same origin.

But the most important cause of fracture is found in the movements of the earth's crust, producing a folding and crumpling of the strata. When such anticlinals and synclinals are formed, the rocks are fissured by the strain to which they are subjected. Should the walls of the fissure slip over each other, one side being raised or lowered, a fault would result. The fractures, when once formed, become the channels for subterranean drainage, and thus are enlarged and modified by the dissolving power of water.

The crevices of the Upper Mississippi region are apparently due to the second cause. Extending east and west through the lead district are numerous undulations of the strata. These flexures were doubtless the chief agent in the production of the crevices. As the strata were slowly elevated the heavily bedded limestones were fissured in a direction parallel to the axis of elevation, and crevices more or less open were formed. In a direction at right angles little force was exerted, and the beds were simply fractured, producing the narrow north and south fissures. It is also possible that the latter may be due to the contraction of the rock as it solidified.

It is to be noted that the ore deposits of this region do not occur as fissure veins of indefinite extent in depth, but are what are known as "gash veins" of limited extent and confined to one rock series.

Filling of the Crevices.—Two opposite views are at present held concerning the source from which veins have derived their metalliferous contents. (1) It is claimed on the one hand that the minerals have been deposited from hot solutions rising through fissures from profound depths. The solvent power of such waters would be great on account of the temperature and pressure, and they would thus be rich in mineral materials which would be deposited on cooling, or on relief from pressure. This is the view so ably advocated by Professor Posepny in his recent paper on the "Genesis of Ore Deposits,"* and it has among its supporters many eminent geologists and mining engineers. (2) Opposed to this ascension theory is that of lateral secretion, according to which the contents of the vein are derived from the wall rock itself, instead of from unknown depths. A broad interpretation of this theory does not necessitate the derivation of the minerals from the rock directly bounding the vein, but admits that they may have been leached out from a considerable distance on all sides. It supposes that there is a free circulation of surface water through crevices and porous strata, and consequently a ready transfer of solution would result. These waters may traverse the rocks in any direction, and may thus in some cases rise and be said to come from below. Or again, they may flow into the crevice either

*Trans. Am. Inst. Ming. Eng., XXIII, p. 197. New York, 1894.

from the sides or from above. This broad conception of the lateral secretion theory has much in common with the one first named. But it differs from that, however, since it does not necessitate the presence of profound fissures or faults, nor the rising of the heated waters through these from great depths.

A third view as to the origin of ore deposits is mentioned by Professor Kemp.* It is held by a number of careful observers and was brought into prominence by Emmons† in his report on the Leadville region. According to the replacement theory, as it is called, no large cavity is supposed to have previously existed. There is a circulation of ore-bearing solutions which interchange their metallic contents, molecule by molecule, for the substance of the rock. The ore body in this case has no well defined limits but shades off gradually into the barren country rock.

We are now ready to inquire which one of the above theories explains in the most satisfactory way the source of the Iowa deposits. There seems to be little doubt that to the process of lateral secretion is due the deposition of the ores in the crevices and that they have thus been derived from the limestone whence they have been leached by surface waters.

The view that the metal-bearing solutions came from below is strongly advocated by Professor Jenney‡ who holds that the Mississippi valley ores have been deposited by hot waters rising through fissures.

But there are numerous objections to this theory as applied to the region under consideration and among them may be mentioned the following: (1) No true fissures extending to great depths have been discovered. (2) Faults are of rare occurrence, and where they are occasionally found have no apparent connection with the deposits. (3) The ores exist only in comparatively small amounts in the underlying Saint

*Ore Deposits of the United States. New York, 1895.

†The Geology and Mining Industry of Leadville, with atlas, Monograph XII, U. S. Geol. Surv., Washington, 1886.

‡The Lead and Zinc Deposits of the Mississippi Valley; Trans. Am. Inst. Ming. Eng., Vol. XXII, p. 171. New York, 1894.

Peter sandstone and Oneota limestone, and are almost altogether absent from the Saint Croix or Potsdam formation.

On the other hand there are many facts connected with the mode of occurrence of the ores which go to prove that the waters came from above. Masses of Galena are frequently found suspended from the roof of the openings. These could only have been formed by waters that reached the crevices from the upper strata. A few miles south of Dubuque crevices are met with identical in every respect with the ore-bearing fissures farther north, but instead of carrying lead and zinc, except in small amounts, they are decorated with great numbers of stalactites and stalagmites. The ore deposits of the region have evidently had the same origin as these lime formations, and no one questions the fact that the latter are due to moisture trickling down from above.

In order that the theory of lateral secretion may be well established it must be shown that the metals are diffused through the country rock. The necessary analyses have not been made for the Iowa region, but Winslow in his lead and zinc report* shows that the limestones and crystalline rocks of Missouri do contain small quantities of these minerals.

"The amounts of metallic lead vary from about .0004 to .007 per cent, of metallic zinc from about .0002 to .018 per cent, and of copper, magnese and barite there are correspondingly small amounts. It thus appears on this hypothesis, which does not require that the ores should come from the immediately adjacent wall rocks, that the metalliferous contents of the country rocks are ample to supply the ore deposits."

There is every reason to believe that the Galena limestone of Iowa also contains small quantities of lead and zinc, and that these have been leached out by percolating waters and deposited in the crevices.

It is not uncommon to find small particles of Galena or sphalerite in the different limestone formations of the state.

*Missouri Geol. Surv., Vol. VII, p. 478. Jefferson City, 1894.

In the Oneota small pockets of lead are very common and denote the presence of this mineral in considerable abundance.

GENERAL METHODS OF WORKING THE MINES.

In working the mines the very simplest methods are used. Expensive machinery has never been employed in the Iowa region. Only a few of the shafts have reached a depth greater than 200 feet, and the majority are less than this. The most common method of hoisting the ore is by means of the windlass. In the larger mines, however, it is customary to use a gin. The latter consists of a large wooden drum, six to eight feet in diameter, which revolves in a horizontal plane and is turned by horse power. The only steam hoist in the Dubuque district is the one recently put in by the Dubuque Lead Mining Co. The same company has a steam pump in operation in their mines, by means of which the water has been lowered so that ore is being taken from one of the deeper openings. As already stated the Durango zinc mine is worked by an open cut. The ore is loaded directly into the wagons as it is removed and is taken down to the neighboring stream and washed as described above. Some of the mines, such as those at Guttenberg, have been worked by means of drifts run into the hillside but in the great majority of cases the openings are reached by shafts.

STATISTICS.

The following is a list of the principal lead and zinc mining companies of the state:

Dubuque Lead Mining Co., A. W. Hosford, president; E. T. Goldthorp, superintendent.

Lansing Mining & Smelting Co., J. H. Trewin, president.

Dubuque Zinc & Lead Mining Co., E. T. Goldthorp, superintendent.

The four companies which follow, own and operate zinc mines in the city of Dubuque:

Trueb, Southwell & Co.; James Hird & Son; Howe, Alexander & Sellers Mining Co.; Dexter & Hird.

Royce & Co., and the Key City Co., are operating mines near Dubuque.

Most of the zinc mines have been closed for nearly two years on account of the low price paid for carbonate, the average being only $5 to $6 per ton the past year. About 800 tons were, however, sold at these figures. There are very large quanties of ore in sight in these mines as even a brief inspection clearly shows, and they are capable of yielding thousands of tons for some years to come.

All the zinc carbonate from the Iowa mines is bought by Mineral Point, Wisconsin, smelters, where it is used in the manufacture of paint. The price of the ore has advanced somewhat within a few months with prospects of a still further rise. Until the past year or two the dry bone has brought from $12 to $18 per ton, according to the quality.

Most of the lead from the Dubuque district is sold to W. G. Waters, who has a smelter a short distance south of the city. The lead from the Lansing mine is sent to Chicago to be smelted. The price of lead is also low at present, mineral which formerly sold at $20 to $22 now bringing only $17 per thousand pounds.

The output of the Iowa mines for the past year (1895) can be given only approximately. They have produced about 750,000 pounds of lead ore and from 3,000 to 3,500 tons of zinc. But it must be remembered that most of the zinc mines have been closed during the past two seasons. They are easily capable of yielding from 8,000 to 10,000 tons of ore annually.

THE SIOUX QUARTZITE

AND CERTAIN ASSOCIATED ROCKS

BY

SAMUEL WALKER BEYER.

SIOUX QUARTZITE AND CERTAIN ASSOCIATED ROCKS.

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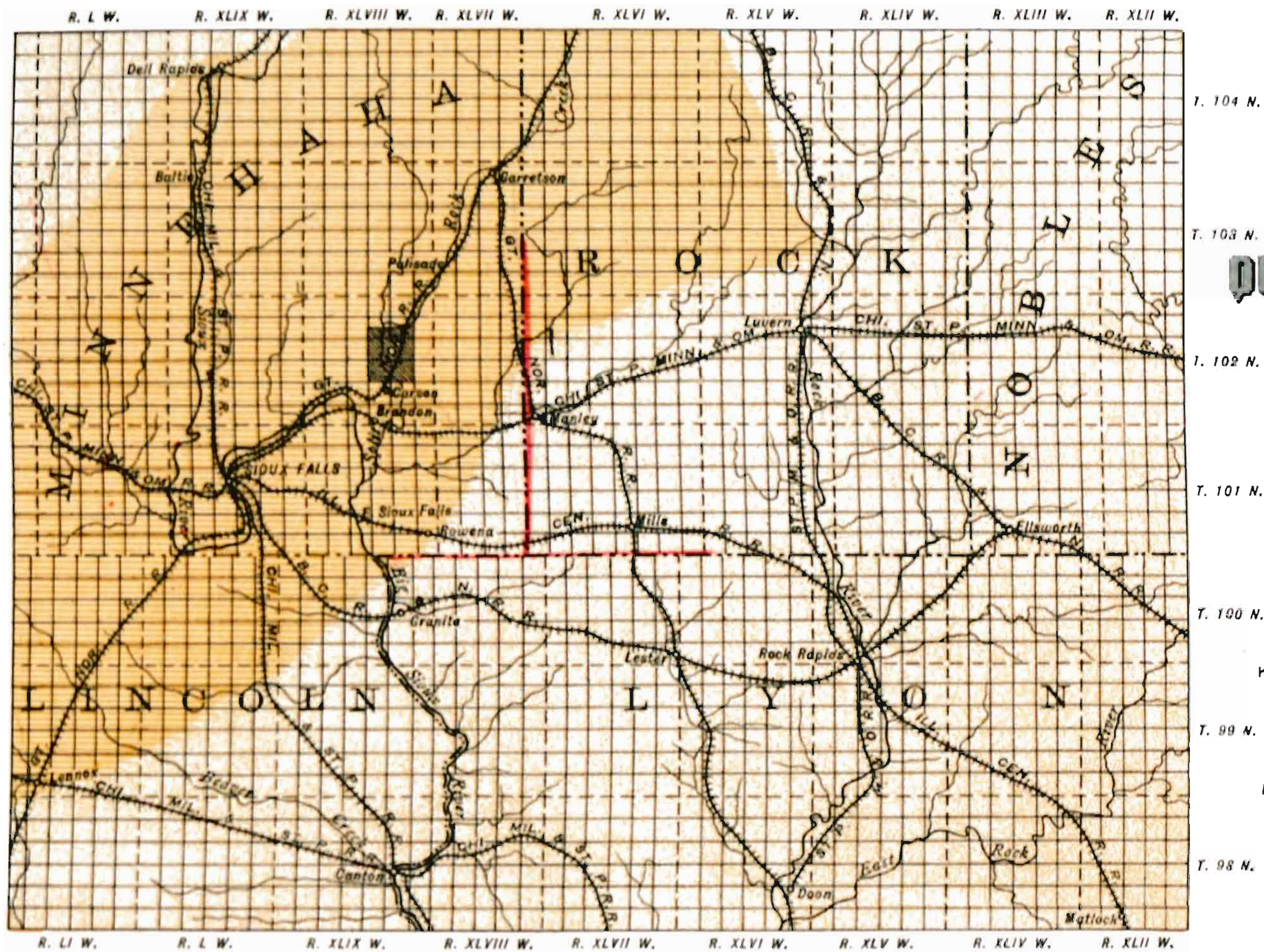
CONTENTS.



SKETCH MAP

OF THE

QUARTZITE REGION

BY

S. W. BEYER

1896.

KNOWN QUARTZITE.

PLEISTOCENE.

IOWA PRINTING CO. LITH. DES MOINES, IA.

DRAWN BY F. C. TATE

INTRODUCTION.

AREA.

The Sioux quartzite is a southwestward prolongation of "Minnesota Point."* It extends across the northwestern corner of Iowa and underlies about equal areas in South Dakota and Minnesota. Its extreme eastern limit of outcrop is marked approximately by Redstone, at the junction of the Cottonwood and Minnesota rivers, while its most westerly exposure is near Mitchell on the James river. It has a maximum width of sixty miles extending from Flandreau, its

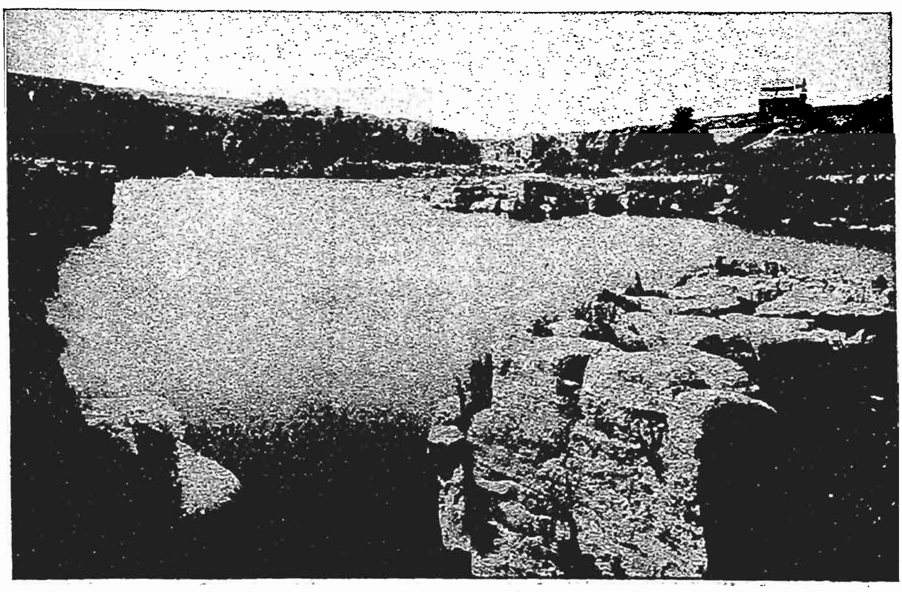


FIG. 20. Canyon on Split Rock creek at the Palisades.

northern limit, to Canton, just within its southern boundary. The formation, although generally concealed by glacial debris and by scattered patches of Cretaceous, probably extends over an area of more than 6,000 square miles.†

*Geology of Wisconsin, Vol. IV, p. 533. 1873-1879.

† For a historical resume of the literature on the Sioux quartzite, see Geol. and Nat. Hist. Sur. Minn., Vol. I, pp. 537-543. Also Iowa Academy of Sciences, Vol., II, pp 218-222.

TOPOGRAPHY.

A southwestward extension of the "Couteau des Prairies" traverses the quartzite area at right angles, a short distance east of its middle, forming a watershed for the tributaries of the Mississippi and Missouri drainage systems. The crest of the Coteau, at its middle point in the quartzite area, has an elevation of nearly 2,000 feet above sea level. There is a gentle slope westward to the James river, which, in the vicinity of Mitchell, has an altitude of about 1,200 feet. The eastward slope inclines rather more rapidly toward the Minnesota river, where, near the mouth of the Cottonwood, the elevation is considerably less than 1,000 feet. The divide which separates the Red river valley from the valley of the

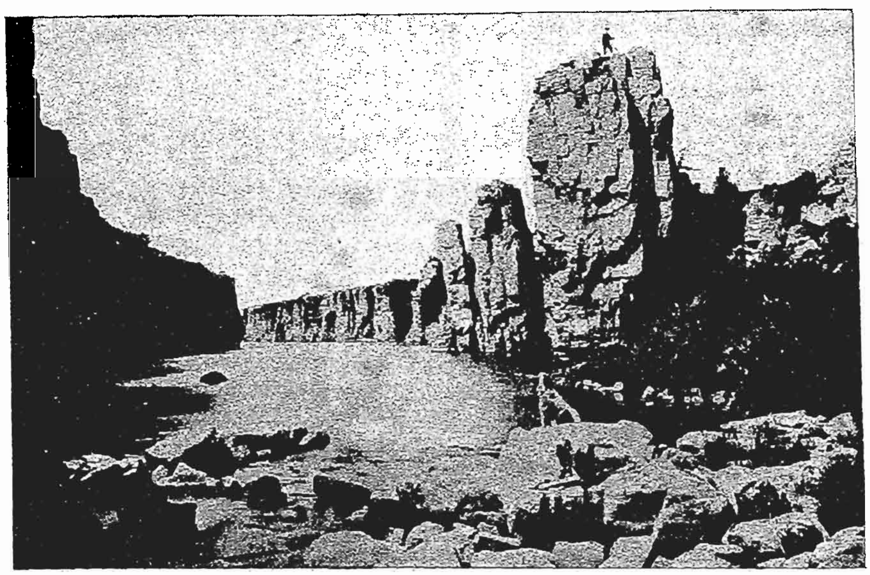


FIG. 21. Vertical cliffs of quartzite at the Palisades.

Big Sioux lies some distance to the north of the quartzite belt, so that the surface of the formation as a whole pitches southward at a low angle. The Big Sioux river, with its tributaries, drains the major portion of the area covered by the quartzite in Dakota.

The streams have high gradients, and have deeply incised the region. Rapids and falls are not uncommon. The flood plains are narrow, and in some instances, as along Split Rock creek at the "palisades" and the Big Sioux at Dell Rapids, there are canyons whose vertical walls range from fifty to seventy feet in height. In both of the above cases, canyon cutting is not confined to the main stream, but is being performed by the side branches as well. As an illustration of the sculpturing done by the short lateral branches, may be mentioned a case which occurs about one mile north of the Palisades. At this point a gulch makes off at right angles from the main stream and extends eastward more than a mile.

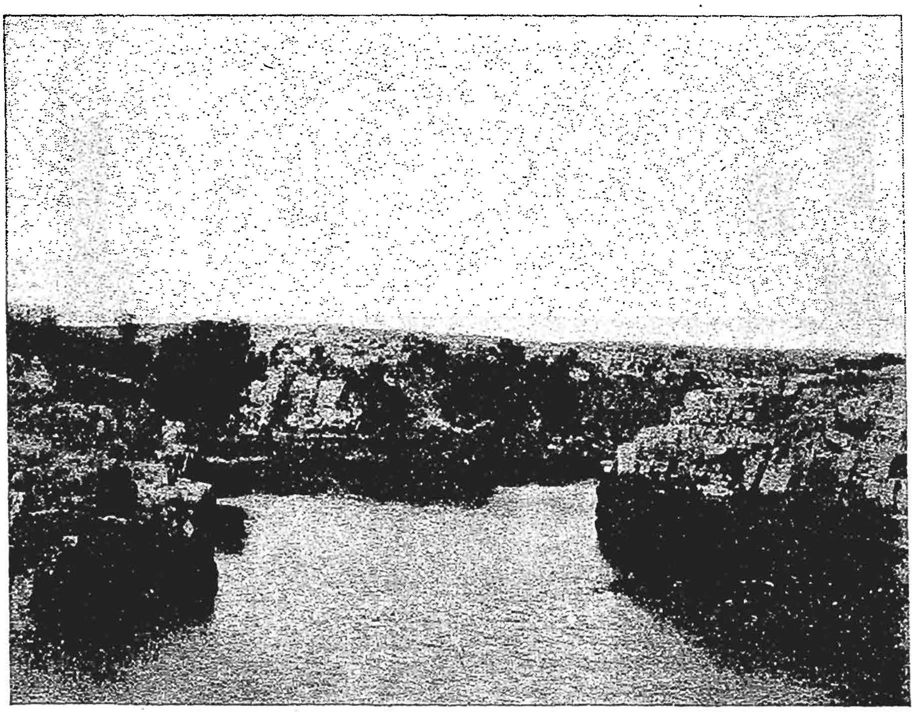


FIG. 22. Jasper pool, near the northwestern corner of Lyon county, Iowa.

It is a narrow gorge which, in places, has reached a depth of from seventy-five to nearly 100 feet. This appears the more striking in that the surface features of the prairie give no indication of the presence of the gorge until one is in close proximity to its edge. The erosion forms developed in the quartzite area are well shown at Jasper pool in Lyon county, Iowa.

SPECIAL AREA CONSIDERED.

In the following paper is given an account of the structural relations existing between the Sioux quartzite and associated rocks as found exposed in sections 10, 11, 14, 15, 22 and 23, Tp. 102 N., R. XLVIII W., Minnehaha county, South Dakota. Detailed petrographical descriptions of the rocks outcropping in the region are also given. From the description of this area, which may be considered typical for the whole formation, it is hoped that there may be established a more substantial basis for the correlation of the beds occurring within the district with formations of other areas of known age.

The special area in question is located about twelve miles northeast of Sioux Falls. Corson station, on the Great Northern Railway, is just within the southern limit of the area and is a central point in the greater quartzite region. Split Rock creek, a tributary of the Big Sioux, meanders through the area from north to south and is flanked on either side by a chain of hills, the summits of which rise to a height of nearly 100 feet above the channel of the stream. The valley of this stream, measured from crest to crest, is about one mile in width. Near the northeast corner of the northeast quarter of section 15, an isolated hill, Keyes knob, rises within the valley and is the most prominent topographic feature in the vicinity.

GEOLOGICAL FORMATIONS.

NIOBRARA.

Originally, the Niobrara probably formed a continuous mantle over the older formations in the region; but, on account of the readiness with which it succumbs to weathering and erosive agencies it has been removed largely or so thoroughly worked over and incorporated into the drift that only a few, small, isolated areas have maintained their identity. Exposures of the chalk beds of this terrain occur at certain points where the creek impinges on one side or the other of its flood plain. The maximum elevation of the chalk is not more than twenty feet above the stream channel. The remnants probably mark out the position occupied by the river valley during pre-Cretaceous times.

The "chalk rock" is, when fresh, a dirty gray color, but soon whitens upon exposure. It is of a porous nature and percolating waters easily circulate through it. The rock often becomes cavernous as a result of the removal of the calcium carbonate, and cherty concretions, present in all the rock, become then a more prominent feature. The chalk is thinly bedded. The weathering agencies have in many instances almost obliterated bedding planes, so that it is impossible to determine dip and strike with any degree of certainty; but in all probability, the planes of stratification do not depart far from the horizontal.

At the point marked Bx on the map the chalk is exposed horizontally a distance of about 200 yards on the east side of Split Rock creek, and presents a maximum vertical exposure of about sixteen feet. The overlying drift contains fragments of spotted slate.

QUARTZITE.

The quartzite, as already mentioned, forms a base upon which the later sediments have been deposited and through which the diabase (to be described later) must have broken. There is an almost continuous exposure from a central point on the north boundary of section 26 to the center of section 11. No quartzite was found *in situ* on the west bank of Split Rock creek, nor west of the line AB. (See plate iv.) This line marks a ravine which almost connects the two limbs of the large bend in the creek. The dip of the rock varies from 3 to 7 degrees, in a southwesterly direction. At the points A and F are vertical scarps rising about twelve feet above the water in the creek. The quartzite at A is capped with "chalk." At H on the map, the quartzite outcrops in the open prairie and is exposed over a superficial area of some twenty acres. It also forms a low escarpment along the ravine previously mentioned. Along this ravine the quartzite breaks into large cuboidal or trapezoidal blocks, as a result of the presence of two systems of vertical cracks which are nearly at right angles to each other and conform closely to the cardinal points of the compass. These two sets of joints are common throughout the formation and to them are due the vertical-walled canyons and square-faced escarpments which form such characteristic features in the Sioux quartzite topography. The exposed surface of the rock is often beautifully wind polished* not unlike the mirror-like surfaces presented by the Mountain sandstone which caps many of the summits of the Blue Ridge mountains.

Catlin* in describing the quartzite at Pipestone, Minnesota, wrote as follows: "The quartz is of a close grain and exceed-

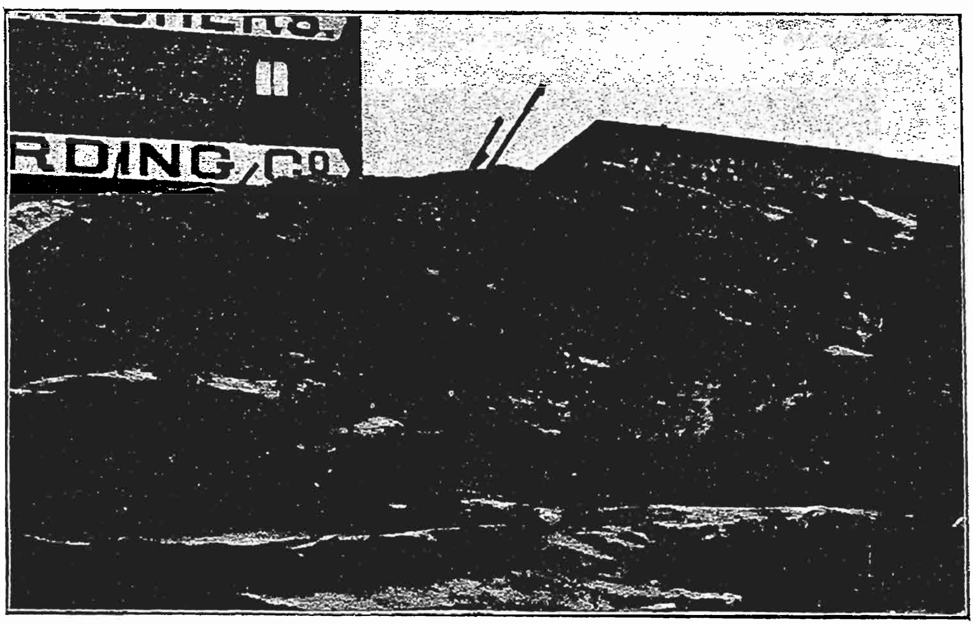


FIG. 23. Cross-bedding in the quartzite at Sioux Falls. An exposure near the Chicago, Milwaukee & Saint Paul railway station.

ingly hard, eliciting the most brilliant sparks from steel, and in most places where it is exposed to the sun and air its surface has a high polish entirely beyond any result which could

* For a full discussion of wind polishing, see G. K. Gilbert, Proc. Am. As. Adv. Sci., Vol. XXIII, Hartford Meeting. 1875. Von Walther, Einleitung in die Geologie, S. 589 et seq. 1893 and 1894.

* Am. Jour. Sci., (1), Vol. XXXVIII, p. 1840.

have been produced by diluvial action, being perfectly glazed as if by ignition."

Beach phenomena are not uncommon in the quartzite, being expressed in ripple marks and false bedding. The best example of false bedding observed is at Sioux Falls near the Chicago, Milwaukee & St. Paul railway bridge across the Big Sioux. Here the normal strata are nearly horizontal or inclined slightly toward the south, while the overlying false beds are tilted at an angle of about 30° to the north. (See figure 23.) At Fort James this same phenomenon occurs on a small scale and is rendered beautifully apparent by alternations of red and pink layers.

SLATES.

About 200 yards north of the exposure of chalk marked Bx on the map, a purplish black slate outcrops on the edge of a low ridge which marks the eastern limit of the flood plain of Split Rock creek. At this point a prospect hole put down in the hope of finding coal, revealed a thickness of about ten feet of slate, which was immediately underlain by weathered diabase. The diabase, which offered little resistance to removal, was penetrated nearly ten feet, when further prospecting was discontinued.

The slate also outcrops along the north bank of Split Rock creek in the Se. ¼ of section 10, and Sw. ¼ of section 11, near the wagon road. The outcrop along the creek continues eastward to within 300 yards of the quartzite escarpment at F, but presents a maximum vertical exposure at E of about ten feet. In all of the outcrops of slate observed true slaty cleavage is absent, but partings along the bedding planes in conjunction with vertical joints making various angles with each other, facilitate the ready removal of the rock in tabular blocks from two or three to six inches in thickness. The rock, wherever exposed, presents a curiously mottled aspect due to the irregular distribution of light colored spots throughout its mass. These spots appear to be wholly independent of the structural features of the rock, and their color is not unlike that presented by weathered surfaces along joints.

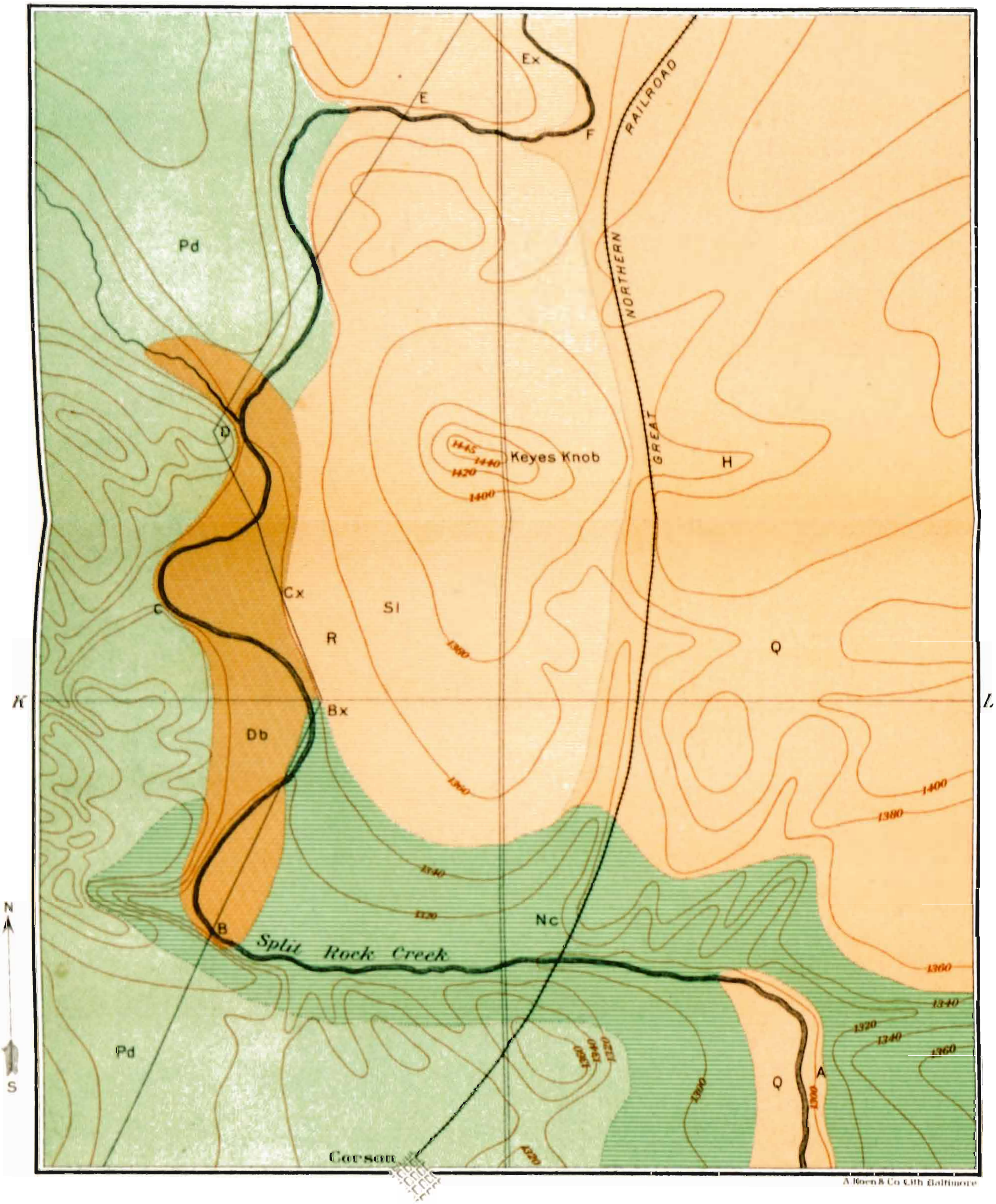
RELATION OF SLATE TO QUARTZITE.

As the slate and quartzite are not represented together in any exposure within this area, it is necessary to go beyond its border for positive evidence regarding their relationship. At the Palisades, about four miles to the northeast, slate is exposed in perfect conformity with the quartzite, often interbedded with the upper quartzitic layers, and sometimes grading into them. The spots, which were always present in exposures further south, are typically developed at the Palisades, while the texture and composition of the slates at the two localities are very similar, so that their correlation seems to be perfectly justifiable. Moreover, a legitimate inference would be that the slates are an upward extension of the quartzite formation, and that they have been removed in large part, owing to the greater readiness with which they would yield to erosive agents.

THICKNESS OF THE QUARTZITE FORMATION.

Irving* in his preliminary report upon the Archean formations of the northwestern states, estimated the thickness of the Sioux quartzite to be from 3,000 to 4,000 feet. This estimate was based upon the section along Split Rock creek from the Palisades to Corson, and the assumption that the average dip was about seven degrees. The shortest distance between the two areas measured perpendicular to the strike (which is nearly north and south) is about two miles, and the change in altitude is 140 feet. The slates have been shown to be practically identical at the two points and therefore the assumed dip value is far too great. The average inclination of the strata between the outcrops cannot be more than one degree. It is evident that the dip is far from constant, and that the relatively high dips at the termini of the above section must be counterbalanced by dips at very low, or even

*Fifth Ann. Rept. of the U. S. Geol. Surv., p. 201. 1885.

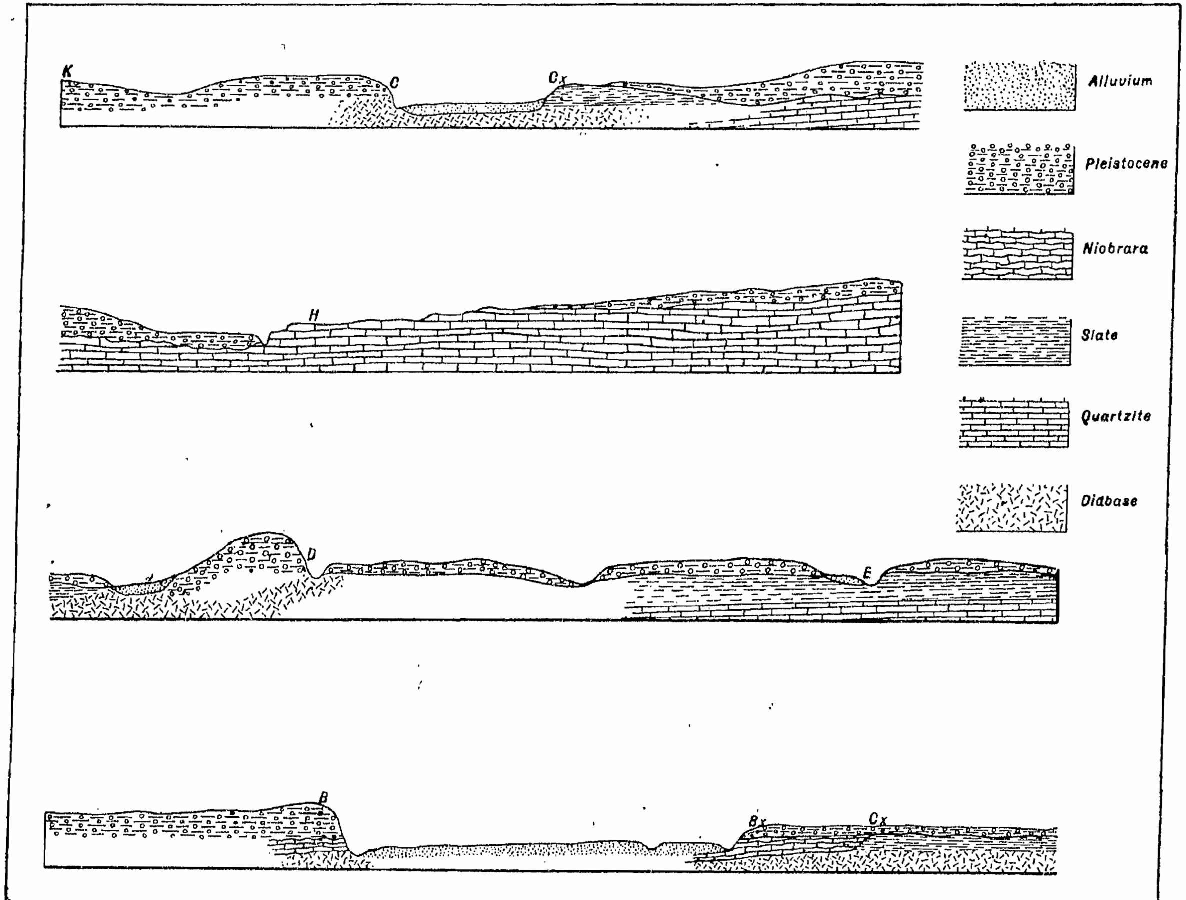


MAP OF THE DIABASE AREA NEAR CORSON, S.D.

BY S.W. BEYER.

SCALE 3 INCHES = 1 MILE. CONTOURS 20 FEET.

PLEISTOCENE	NIOBRARA	SLATE	QUARTZITE	DIABASE
Pd	Nc	Sl	Q	Db



CROSS-SECTIONS THROUGH DIABASE AREA.

reversed angles. That the dip is not constant, is evident from the field relations of the strata a few hundred yards to the north of the Palisades, where the beds are inclined in the opposite direction. It would appear that any estimate of the thickness of the formation must of necessity be little more than a guess, and Todd's* estimate of 1,500 feet would seem to be, in the opinion of the writer, a very liberal one.

DIABASE.

Diabase extends from a point near the center of section 22, almost due north, a distance of about one mile and a quarter and exposures are afforded wherever the creek impinges upon its western bank. The maximum vertical exposure is about twenty feet at D (see plates iv and v). At this point the diabase appears to be composed of completely weathered material. Fresh diabase in place occurs only as a low ridge extending across the creek at the point mentioned. It forms a slight fall in the creek and the outcrop continues southward along the east bank a distance of some 250 yards to the point Dx, but the rock never rises more than two feet above low water level. There are continuous rapids between the two points D and Dx. The exposure at C is in large part a duplication of the one just described; but since the structural features are here better expressed, it will be treated as the typical exposure. The diabase, although so completely weathered that a pick can be driven into it without difficulty, maintains a vertical wall some fifteen feet in height on the west bank of the creek, and the characteristic ophitic texture is perfectly preserved. The jointed structure, which is characteristic of massive rocks in general, is especially prominent owing to the filling in along the joint planes by vein material which offers greater resistance to disintegrating forces than the wall rock. Three systems of joints may be readily distinguished, of which the first is horizontal, while the second and third are vertical and approximately at right angles to each other. In certain places a fourth series of joints may be observed which

*South Dakota Geol. Surv., Bul. No. 1, p. 35. 1895.

is inclined at an angle of 45° to the horizon. Many of the blocks which are found in the stream channel and on the flood plain faithfully represent the above jointing in their rectangular, trapezoidal and wedge-shaped forms. The prismatic or columnar structure, which so often characterizes the basic igneous rocks that have solidified near the surface, is entirely wanting; and the amygdaloidal structure, which more strongly

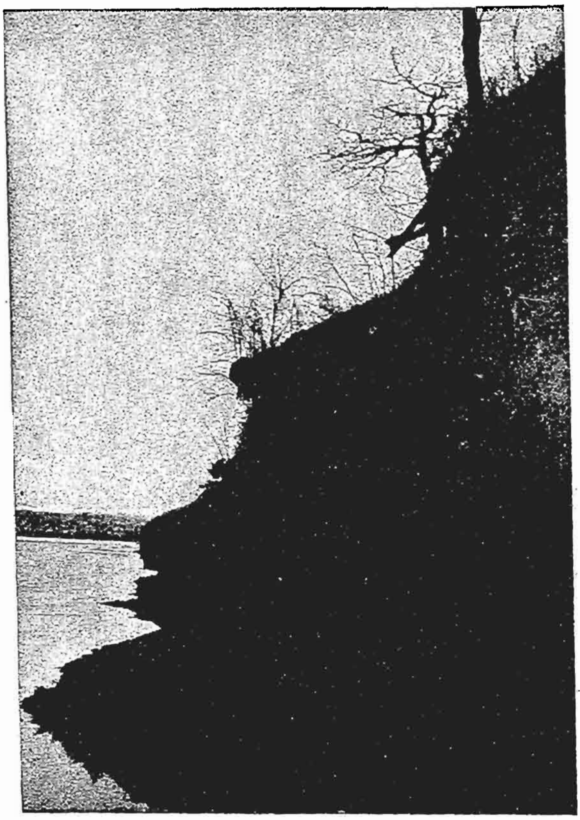


FIG. 24. Diabase ledge at Risty's.

bespeaks surface conditions of cooling, is not represented. The rock is thoroughly holocrystalline and its coarse texture, considered in connection with the absence of glass, may be taken as evidence of its slow rate of cooling.

The vein material effervesces freely when treated with hydrochloric acid, and seems to be in large part a calcareous substance much stained by iron oxide. It is probably of secondary origin, having been deposited by percolating waters which derived their load from some extraneous source, or from the decomposing diabase itself.

The extreme width of the diabase outcrop is best shown by the map, plate iv. The diabase at B is capped with chalk, a layer of residual clay two or three inches in thickness separating the two. There is no evidence here of contact metamorphism, either of an exogeneous or endogeneous nature. At C and D the diabase is immediately overlain by drift. At the latter place a layer of sand and gravel, which forms the contact zone, has been cemented in many places into a pudding stone. At Cx, as has been mentioned, slate conceals the igneous rock; and, as the contact zone cannot be observed, it is impossible to say definitely whether or not there has been any contact action. Here as in other exposures, the diabase is greatly weathered, and the structure is perfectly preserved and normal. Judging from the material excavated it gives no evidence of endomorphic action.

Perhaps as Culver* has pointed out, "the most prominent field characteristic of this rock is the profound decomposition it has suffered. How much of it has been removed by erosion it is impossible to say, but the whole exposure, from its upper surface down to the bed of the stream, a distance of twenty-five feet seems to be thoroughly disintegrated. It apparently maintains its vertical position now only by the support of a network of thin quartz veins which ramify through it in all directions." (This last statement has not been verified during the present investigation.)

In regard to the amount of pre-Cretaceous weathering† we have no measure; but that conditions have been favorable to rapid weathering during post-Cretaceous time appears evident; the rate being determined by the geological structure of the region and the texture of the rock. The dike coincides with a well-marked depression, probably constructional, which

* Wis. Acad. Sci., Arts and Letters, p. 207. 1891.

† It has been suggested by Prof. C. R. Van Hise, that in order to account for the great amount of weathered material it is not necessary to assume that all of the weathering has been done during post-Cretaceous times, much less since the glacial epoch. That in both cases, the deposits were laid down gently and would not necessarily have disturbed even a badly weathered surface.

has been sought out by Split Rock creek; moreover its contacts with the porous chalk and the sandy gravel layer of the drift would form natural water courses. Its relation to the slate cannot be definitely stated, but it appears quite probable that the diabase is intruded between the bedding planes of the slate, and even here the conditions may be favorable to the active circulation of the universal solvent. Weathering is facilitated also by the coarse texture of the rock and its complicated systems of jointing.

PETROGRAPHIC DESCRIPTION OF THE ERUPTIVE ROCKS.

OLIVINE DIABASE.*

MINERALOGICAL COMPOSITION.

The eruptive rocks of this area are confined, so far as known, to a single type, which is composed essentially of a lime soda feldspar, a monoclinic pyroxene and olivine. This rock is very similar in general appearance to the olivine-gabbro forming the axis of Pigeon Point as described by Bayley.† It also bears a very close resemblance to Törnebohm's "Åsby-type."‡ It is a coarse-grained rock and exposed surfaces present a peculiarly pitted aspect due to the relatively greater readiness with which the ferro-magnesian constituents, as compared with the feldspar, succumb to atmospheric agencies. The perfectly fresh diabase is black, with a greenish-yellow tinge, and an oily lustre which depends on the amount of olivine present. In the unaltered rock the feldspar is extremely fresh and glassy, and on account of its transparency, almost escapes notice. One of the most marked effects of weathering, even in its incipiency, is to bring the feldspar into prominence. As weathering proceeds the oily lustre of the olivine is lost, and the surface soon becomes rough. When the weathered portion is protected

* G. E. Culver has given a brief account of this occurrence accompanied by a petrographic description of two thin sections of the rock by Prof. W. H. Hobbs. (Trans. Wis. Acad. Sci., Vol. VIII, p. 206. 1892)

† Bul. 109. U. S. G. S., p. 32, et seq. Washington, 1893.

‡ Über die wichtigeren Diabase u. Gabbro-Gesteine Schwedens. N. J. B., p. 268. 1877.

from removal, the rock passes into a rusty-gray residuum in which its characteristic structure is preserved, even when the resultant product can be reduced to a powder between the fingers. This lustreless mass finally breaks down into a yellowish-red soil. The work of the atmospheric agencies is facilitated by the triple system of joints which separate the rock into more or less rectangular blocks, so that nearly all of the rock accessible is much altered, save the dislocated blocks lying upon the flood plain of the creek.

The feldspar is the most prominent constituent, occurring in large divergent laths, some of which are nearly an inch in length and having twin lamellæ easily seen with the unaided eye. The pyroxenes are less clearly defined and sometimes tend toward porphyritic development, measuring an inch or more in length, with feldspar laths as inclusions or forming embayments. At other times the rock becomes more or less granular through contemporaneous development of feldspar and pyroxene.

Feldspar.—Microscopically the feldspar occurs as laths parallel to crystallographic a or assumes the tabular form parallel to the clinopinacoid. In either case it is idiomorphic with respect to the augite, though generally influenced by the olivine. Sometimes the feldspar develops equally in all directions and then is allotriomorphic with respect to the augite; when such is the case, the rock assumes a granular structure.

When fresh the feldspar is colorless or water-colored, often perfectly transparent, seeming to similate the microtine habit, but when even slightly altered it rapidly loses its transparency and becomes white or grayish, and, as alteration progresses, may assume a green, yellow, reddish or brown hue.

The cleavage is not so pronounced as in orthoclase, but in sections cut favorably, two cleavages can be recognized readily according to P and M. The basal pinacoidal cleavage is usually the more perfect.

The laths are generally albite twins, composed of but few lamellæ, seldom more than four, and often only two. Twinning according to the Pericline law is also quite common and manifests itself in its characteristic cross-hachuring; which, when observed between crossed nicols, appears as fine striæ nearly normal to c. One or both of the above laws occasionally appear in conjunction with the Carlsbad law.

The extinction angle when measured against the composition face in the zone P-M, according to Pumpelly's* modification of the Des Cloizeaux' method was found to reach a maximum of 30° at which point the laminæ extinguished symmetrically. It was also found that certain individuals under similar circumstances presented an extinction angle of only 16 or 17°. On submitting the feldspar powder to Thoulet's solution it was found that a portion dropped when the solution was reduced to a specific gravity of 2.702, and another portion when the solution was still further reduced to about 2.65. This would indicate the presence of at least two feldspars; one a labradorite and the other an oligoclase. The first, according to Max Schuster,† would correspond to the $ab_3\ an_4$ molecule with a theoretical sp. gr. of 2.703 and the second to $ab_4\ an_1$ molecule whose theoretical sp. gr. he determined to be 2.652. The above results accord very well with the observed optical angles. Senfter‡ states as a result of his work on the diabase of Nassau, that an alkali feldspar, oligoclase, is regularly present; it being usually accompanied by a calcium feldspar, apparently labradorite. G. W. Hawes§ in his study of some Jersey City diabase, proved the presence of at least two feldspars. By means of Thoulet's solution he separated the feldspar constituent into two parts; the first having a specific gravity above 2.69 and containing 52.84 per cent of $Si\ O_2$ and the second with a sp. gr. less than 2.69 was found

*Geol. Wisconsin, Vol. III, p. 30. 1873-9.

†Ueber die Optische Orienterung der Plagioklase. T. M. P. M., Vol. III, p. 153. 1880.

‡Zur. Kenntniss des Diabases. N. J. B., p. 698. 1872.

§On the Mineralogical Composition of the Normal Mesozoic Diabase upon the Atlantic Border. Proc. U. S. Nat. Mus., p. 131. 1881.

to contain 60.54 per cent Si O_2. Dathe records a similar occurrence in the diabase dike at Ebersdorf.* Barrois † mentions labradorite and oligoclase as essential constituents of the olivine free diabase of the Menez-Hom.

The relation of the two feldspars in the South Dakota diabase seems to be normal. They occur in zonal growths, the central zone being the more basic and increasing in acidity peripherally. They also occur as distinct individuals.

The feldspars often show pressure phenomena, and at times evidence of mechanical deformation; attested to by undulatory extinction, bent laminae and broken crystals. These results cannot be ascribed wholly to protoclastic influences, for the other constituents have been effected in a similar manner though in less degree, and a legitimate interpretation would seem to be, that deformation took place subsequent to the consolidation of the magma.

Undulatory extinction may be due in many cases to zonal growths; but there are numerous instances in which the

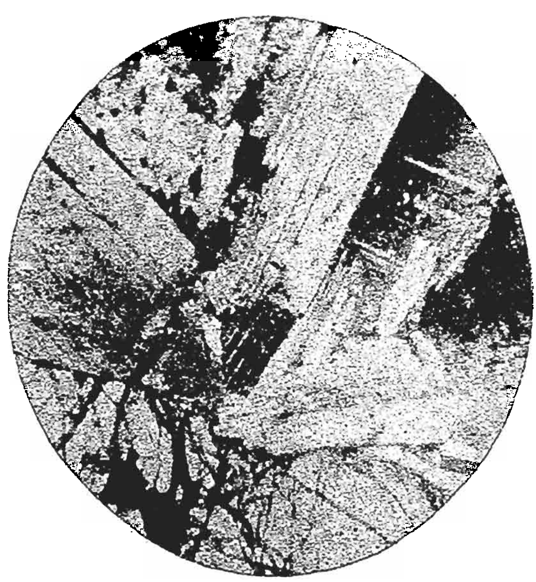


FIG. 25. Secondary twinning in feldspar due to mechanical deformation. Micro-photograph taken in polarized light.

cleavage lines are distinctly bent and these suggest the true cause to be mechanical and external rather than molecular

* Diabasgang im Culm bei Ebersdorf; Jahrb. pr. Geol. Landst Anst. für 1881. p. 307.

† Memoire sur les Eruptions Diabasiques Siluriennes du Menez-Hom, Finistere. Bul. d. Serv. d. l' Carte géol d. l' France, No. 7, p. 11, 1890. Paris.

and internal. Where distortion has exceeded the limit of cohesion of the crystals, rupture occurs, and one or both of the broken ends show the development of extremely fine secondary twin lamellæ which seldom persist the entire length of the individual. In such cases, when rupture has relieved the strain in the crystal, undulatory extinction is not noticeable.

Von Werweke,* in his study of the Olivine norites of Pauls Island on the coast of Labrador, and also in the case of the feldspar of the olivine gabbro from Store Bekkafjord, Norway, was the first to call attention to this phenomenon. He believes deformation and the consequent twinning to be of a secondary nature and the result of pressure.

A review of the literature of the subject shows a considerable number of observations, which tend to confirm Von Werweke's work. Lehman† proves that dynamic agencies have been efficient in producing secondary twinning in the plagioclase of the gabbro from the Saxon Granulitgebirge. Teall‡ in his study of the metamorphosis of dolerite into hornblende-schist says: "Optical anomalies due to strain are frequently recognizable. The extinction shadows sweep over the sections as the stage is rotated under crossed nicols. The lines separating adjacent twin lamellae are frequently curved, and sometimes, where the limit of elasticity has been exceeded, a crystal is seen to have been fractured. The twin lamellae often show a great want of persistence in one and the same crystal and sometimes they appear to be related to the fractures in such a way as to suggest that they may be in part of secondary origin."

Judd,§ in his study of the plagioclases of the "Older Basic Rocks of Scotland," shows that twin lamellae are not essentially a primary character, but are dependent in large part on conditions of cooling; or may be superinduced by mechan-

* Eigenthümliche Zwillingsbildung in Feldspath und Diallage. N. J. B., II, pp. 97-101. 1883.

† Untersuchungen ueber die Entstehung der Altkrystallinischen Schiefergesteine, etc., p. 196, Bonn. 1894.

‡ On the Metamorphosis of Dolerite into Hornblende-Schist. Quar. Jour. Geol. Soc., Vol. XLI, p. 136. 1885.

§ On the Tertiary and Older Peridotites of Scotland. Quar. Jour. Geol. Soc., Vol. XLI, p. 365. 1885.

ical means. Similar observations have been recorded by Stecher,[1] Bergt,[2] Doss,[3] Williams[4] and Adams.[5] Rosenbusch[6] considers undulatory extinction, mechanical deformation and the development of secondary twin lamellæ as the results of dynamo-metamorphism. From an experimental standpoint Fouque and Lévy* have demonstrated by their synthetic experiments with the plagioclase feldspar that twin lamellæ are not necessarily a primary characteristic but may be developed artificially. Foerstner† also proved the same thing to hold true in nature, by developing artificially, twin striæ on the untwinned crystals of feldspar from Pantellaria.

Aside from the earliest secretions of the magma, such as magnetite, olivine and some apatite, the feldspars contain relatively few primary inclusions. Gas inclusions are not uncommon, but generally seem to be of a secondary nature. Chloritic aggregates which probably represent devitrified magmatic glass inclusions, were noted. A few crystals seemed to be charged with reddish-brown dust particles which gave a brownish tone under low power. In such instances the adjoining pyroxenes often showed a similar effect.

ALTERATION OF THE FELDSPAR.

The first evidence of the alteration of the feldspar is commonly seen in the presence thoughout its mass of nearly colorless scales of a micaceous mineral giving high interference colors between crossed nicols. The mineral is probably sericite or kaolin. Incipient alteration begins along the

[1]Contacterscheinungen an schottischen Olivindiabasen. T. M. P. M., Vol. IX, p. 155, et seq. 1888.

[2]Beitrag zur Petrographie der Sierra de Santo Monta. etc. T. M. P. M., Vol. X, pp. 342, 333. 1889.

[3]Die Lamprophyre und Malaphyre des Plauen' schen Grundes bei Dresden, Vol. XI, p. 31. 1890.

[4]The Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan. Bul. 62, U. S. G. S., p. 205. 1890.

[5]Ueber das Norian oder Ober-Laurentian von Canada. N. J. B., B. B., VIII, p. 433. 1893.

[6]Mik. Phys. d. Mas. Ges., Zwelte Auf., Bd. II, p. 155. 1887.

*Reproduction des Feldspaths par Fusion et par maintien prolongé a une température voisine à celle de la fusion. Comp. Rend., LXXXVII, No. 191. Nov, 1878, p. 700. Ref. N. J. B, p. 412. 1879.

†Ueber Künstliche physikalische Veränderungen der Feldspäthe von Pantellaria. G. Z. f. K., Bd. IX, pp. 333 et seq. 1884.

cracks which traverse the crystals in every direction and sometimes, as remarked by Dathe,* proceeds most rapidly parallel to the principal cleavages and the composition face. Series of lozenge-shaped cavities, which may or may not contain liquid inclusions, arranged with their major axes parallel to each other, anticipate the appearance of the micaceous mineral. The first effect of alteration is the gradual obliteration of the twin lamellae; and the whole individual becoming more or less opaque and showing aggregate polarization. The process is accompanied by the separation of calcite and free silica. A second alteration of the feldspar leads to patches filled with rounded granules which, from their high index of refraction and moderate double refraction, are probably zoisite; but in this rock this is not a prominent feature in its alteration. The aggregate thus formed would correspond to Cathrein's† definition of "saussurite." A third alteration takes place when the feldspar comes in contact with olivine. Here tufts of a greenish, slightly pleochroic mineral, project into the feldspar and seem to be the result of an interaction between the two minerals. This mineral was identified as chlorite. In many cases the outer zone of a feldspar has been completely changed, while there still remains a central core of perfectly fresh material.

Augite.—The augite is almost always allotriomorphic and occurs filling large wedge-shaped areas between the feldspars or sometimes as large porphyritic crystals‡ more than an inch in length, in which numerous feldspars are imbedded. When the feldspars are more or less isomerous, and the rock tends toward a granular structure, the augite individuals often appear as idiomorphic crystals, and present their characteristic eight-sided cross-section, bounded by the prism and the two vertical pinacoids. Prismatic cleavage is clearly defined in sections cut perpendicular to c, but in inclined sections is not

*Mikroskopische Untersuchungen ueber Diabase, Z. d. D. G., Vol. XXVI, p. 5.

†Zeitschrift für Krystallographie, Vol. VII, p. 234. 1883.

‡Such an augite would correspond to the "ophitic plate" of Teall. British Petrography p 58. London, 1888.

pronounced. Sections favorably cut often show traces of a clino-pinacoidal cleavage, which manifests itself as a series of cracks which tend to wedge. The extinction c to c is about 41°. Twins, with the ortho-pinacoid ($\infty P \bar{\infty}$) as twinning plane are not uncommon.

In one instance, the polysynthetically twinned individual was observed in a section showing but a single system of

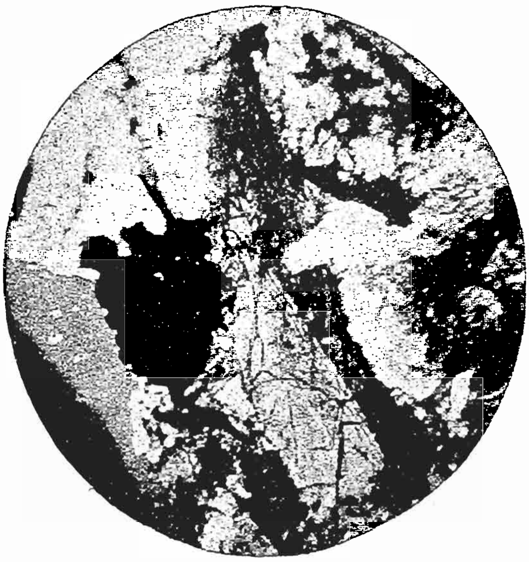


FIG. 26. Augite twin according to $\infty P \bar{\infty}$. Microphotograph taken in polarized light.

cleavage cracks with the twin striae inclined to them at an angle of 26°. This might at first glance be thought to indicate a new twinning law, as was actually suggested by Cohen,* who described a strikingly similar occurrence. Klein, from data furnished by Cohen, calculated the new twinning plane to be ∞P_2. Becker† in his study of the Washoe District observed the same phenomenon but thought it an example of twinning according to the common law, where $\infty P \bar{\infty}$ is the twinning plane. He "considers it to be a section making a considerable angle to the principal axis; and cutting a prismatic face nearly parallel to the edge OP, ∞P. The second system of cleavage does not appear in this instance, because it cuts the section at a very low angle."

*Geognostische Beschreiubung der Umgegand von Heidelburg, p. 69, 1881, und Sammlung-M ik. Pho., T. XXVIII, Fig. 4, 1889.

†Monograph III, U. S. G. S., p. 113, pl. iv, Fig. 28. Washington, 1882.

F. Becke* re-examined Cohen's original preparation and through an elaborate mathematical demonstration proved conclusively that no new law was necessary; reaching thus practically the same result as that previously attained by Becker. Rosenbusch†, in the third edition of his Mikroskopische Physiographie, accepts Becke's results. Becke's solution, with respect to the proper reference of the twinning-plane seems to apply perfectly in the case under consideration. The reason for the non-appearance of the second cleavage may merit a brief explanation. It is a well known fact that cleavage depends upon an inherent property of the crystal. In general, crystalline substances tend to break more readily in one direction than in another; i. e. they possess directions of cohesions maxima and minima; and the so called cleavage planes are normal to cohesions minima, and are only made manifest when the crystals have been subjected to sufficient external force to overcome said cohesions minima. This efficient force may be any of those natural forces which have to do with the deformation of rock masses, or in case of thin sections, may be the power used in cutting the sections. That the process of manufacturing thin sections is efficient in developing cleavage cracks is evidenced by the fact that thin sections show cleavage lines much better than thick ones. In minerals where the difference between cohesions maxima and minima is not great, as in the pyroxenes, it is clear that if the plane normal to cohesions minima makes a very low angle with the plane of the section, as in the case of the "second cleavage" alluded to above, the conditions would be unfavorable for the manifestation of the cleavage lines; because the resistance to development would be represented by the hypothenuse of a right-triangle the base of which would be the plane of the section and the altitude its thickness. Moreover, the applied force would act practically parallel to the plane of the section, and according to the

*Ueber Zwilling's verwachsungen gesteinbildener Pyroxenes und Amphibole. T. M. P. M., Vol. VII, pp. 93-107. Wien, 1886.

†Mik. Phys. d-Min. und. Ges., Dritte Auf., Vol. I, p. 251. Stuttgart, 1892.

parellelogram of forces, the component tending to develop the "second cleavage" would be insignificant as compared with the component which would tend to produce fractures perpendicular to the plane of the section and to accentuate the "first cleavage." A glance at figure 25 will show the development of fractures nearly normal to cleavage lines.

The color of the augite in incident light is black or greenish-black; in transmitted light it is a light purplish-brown. Pleochorism is pronounced in all save clinopinacoidal sections; the ray vibrating parallel to $\mathfrak{a}$ is an olive brown; parallel to $\mathfrak{b}$ a reddish-brown; and parallel to $\mathfrak{c}$ is a light olive brown. The depth of the color depends, in a measure, upon the thickness of the section.

Zonal structure is not uncommon, and in general the outer zone is the darker, although this arrangement is at times reversed. As augite is the youngest of the essential constituents, inclusions of the earlier secretions of the magma are extremely abundant, especially apatite. Gas and fluid inclusions are not numerous and when present seem to be of secondary origin, as they are confined to areas which show incipient alteration.

ALTERATION OF THE AUGITE.

Augite and hornblende are so closely associated that it is often difficult to determine whether they are true intergrowths or whether the hornblende is an alteration product of the augite. The hornblende not only occurs as a rim around the augite, but also in scattered areas through the pyroxene individual. There seems to be a sharp gradation from one to the other, and in those augites which are more or less idiomorphic the characteristic pyroxene cross-section is preserved. Such occurrences appear to indicate a secondary origin for the amphibole.*

The hornblende is readily identified by its strong absorption, characteristic prismatic cleavage making an angle of

*In regard to the primary or secondary nature of hornblende intergrowths with pyroxene See Bul. 62, U. S. G. S., pp. 53 et seq. 1890.

about 125° to each other in cross-section and low extinction angle. Its orientation* is such that b and ċ are common for the two minerals.

In some instances the compact brown hornblende is further altered into the fibrous hornblende† (Uralite‡); the fibers are prisms with small cross-sections and are elongated parallel to crystallographic ċ. The compact hornblende is subject to a change in color; often assuming a bluish-green color peripherally and accompanied by gradual loss of pleochorism probably due to the reduction and hydration of the iron. This change may be considered the incipient stage of chloritization.

Augite also changes to biotite.§ Scales of biotite occur scattered through the augite area, as well as in what appear to be parallel growths. These are very similar in distribution to and very intimately associated with the hornblende; though readily distinguished from that mineral by its characteristic "birch-bark" sheen just before extinction. The cleavage cracks of the biotite are approximately parallel to those of the augite in the prismatic zone. This alteration is generally accompanied by the separation of magnetite.

A third alteration of augite is to a chloritic aggregate, which often assumes the form of a rosette or spherulite. The spherulites show a black cross when observed in parallel light between crossed nicols. The individual scales or fibers exhibit a low index of refraction and low interference colors. They are of a light greenish color in transmitted light and are decidedly pleochroic. The ray vibrating parallel to the fibers is green, while the ray vibrating at right angles is a straw yellow. These chlorite aggregates seem oftentimes

*G. H. Williams; Paramorphism of Augite and Hornblende, Am. Jour. Sci. (3), Vol. XXVIII, p. 259. 1885.

†Bergt, in his study of the rocks from Columbia, South America, says that pyroxene, in passing to fibrous hornblende passes through the compact brown hornblende stage. T. M. P. M., Vol. X. p. 288, 1889. Williams (G. H.). in his work on the Greenstone Schists of Michigan, considers the compact brown hornblende to be. in many cases, an intermediate stage between the pyroxene and fibrous hornblende. Bul. 62, pp. 72, 211. Doss records the same cycle of changes in the pyroxene of the lamprophyres and melaphyres of the Plauen'schen Grundes bei Dresden. T. M. P. M., Vol. XI, p. 47. 1890.

‡Bul. 62., op. cit. pp. 52 et seq.

§For full discussion and literature references, see Bul. 109, U. S. G. S., p. 42.

to be imbedded in a matrix of calcite. A fourth product which probably owes its origin to the pyroxene, is that occurring in triangular areas, in the form of radiating, unterminated, light green prisms which generally diverge from a fragment of augite or magnetite. Numerous quadratic grains of magnetite are scattered among the prisms and the whole is imbedded in a matrix of calcite. The crystals show high relief and also high interference colors, and have an extinction angle of about 17° to the prismatic face. Poussin and Renard* in their study of the gabbro of the Hozémont have described and figured a similar occurrence and determined the mineral to be actinolite. It is probable that the mineral in the present case is the same.

Olivine.—This mineral is the oldest secretion and hence seldom contains the other constitutents as inclusions. When seen under the microscope it tends towards six-sided cross-sections which are often more or less rounded, the latter being due to magmatic corrosion. In such cases the mineral is surrounded by a black rim. Olivine also occurs in irregular grains without characteristic outlines. In relatively rare instances individual olivines are allotriomorphic toward the feldspar. In some cases idiomorphic feldspars project into, or, at times are entirely included within the olivine. This would indicate that the feldspar commenced to separate out from the magma before the close of the olivine period of crystallization. As an essential constitutent olivine seems to play a reciprocal role with the augite. In those sections showing most pyroxene, olivine is least abundant; the converse is also true. A similar relationship is noted by Zirkel† in the case of olivine and an orthorhombic pyroxene.

The cleavage is usually poor, but traces of that parallel to the clinopinacoid may sometimes be observed. In sections these striæ divide the crystal into a number of wedge-shaped areas, which are broken by irregular cross-fracturing. The

*Mém. Sur. les Caracteres Mineralogiques et Stratigraphiques des Roches Dites Plutiniennes d. la Belgique et d. l' Ardenne, Francaise. p. 74. Brussels, 1876.

†Lehrbuch der Petrographie, Zweite Auf., Vol. II, p. 633. 1894.

color is a pale yellow and the mineral is sometimes faintly pleochroic in tones of that color. Both index and double refraction are high, showing the characteristic shagreen surface in ordinary light and colors of the second and third orders between crossed nicols.

Inclusions in olivine are not uncommon; the most prominent being inclusions of magmatic glass, now represented by chloritic aggregates containing grains of magnetite and in some cases scales of biotite, derived through devitrification. These inclusions are characterized by black rims similar to those which surround the olivine crystals; and are probably of the same origin. Other inclusions are unimportant.

ALTERATION PRODUCTS.

Olivine is the least resistant to weathering agencies of all the essential constitutents of the diabase. The numerous cracks which traverse the crystals in all directions afford easy access for the circulating water and it is along these that alteration begins. The cracks become accentuated by trails of magnetite grains set in a matrix of a greenish chloritic or serpentinous, felty material which oftentimes contains needles of hornblende. (Pilite according to Becke.*) Serpentine seems to be rare as an alteration product in the Dakota diabase, but probably occurs in limited amounts, when it is likely to be confused with chlorite. Williams† in his study of the greenstone schist areas of the Menominee and Marquette regions of Michigan, was able to distinguish two classes of such secondary products, and suggested the following criteria for their separation: "First, such as are more or less fibrous in structure, without pleochroism, and have a decided action upon polarized light; and second, such as are scaly in structure, with pleochroism and so weakly polarizing as to appear isotropic." The first class embraces substances allied to serpentines; the second, those which more or less closely resembly chlorite. According to

*T. M. P. M., Vol. III, pp. 330-350 and 450. 1882.

†Bul. 62, U. S. G. S., p. 55, 1890. Here will be found an elaborate discussion of Chloritization with full literature references.

the above criteria, chloritization is much more common than serpentinization in the case under consideration; the necessary alumina being furnished by the plagioclase. This kind of alteration may present complete pseudomorphs of the olivine, which oftentimes, are stained a deep yellowish-brown, are non-pleochroic, and have but little effect upon polarized light. Biotite* is rather common as an alteration product of the olivine in this rock. Flakes of biotite which are readily recognized by their intense absorption, are scattered through the slightly weathered portion of the mineral, along fractures, forming irregular areas. According to Julien,† both biotite and hornblende are supposed to be due to the action upon the olivine of alkaline waters emanating from the plagioclase.

Biotite.—Biotite, aside from being an alteration product of augite and olivine, also seems to occur as an original constituent. Rosenbusch‡ says: "All olivine diabase contains brown biotite and hornblende as original constituents." Ch. Barrois,§ in his memoir on the diabases of Menez-Hom, remarks that the mica is original when olivine is present. Wadsworth,‖ in discussing the origin of biotite in the gabbro of Minnesota says: "This biotite is evidently formed from the magnetite with associated feldspathic material during the process of alteration." Again in describing Figure 1, plate vi, he continues: "The biotite is supposed by the writer to be the result of alteration and a reaction between the magnetite and the feldspar. The clear, feebly polarizing, greenish substance of an unknown character is probably an early stage in the formation of biotite." Zirkel¶ mentions magnesian mica as the constant companion of hornblende in the coarser grained diabase.

Biotite occurs in allotriomorphic flakes, commonly in close connection with magnetite, as inclusions in skeleton crystals,

*See Bul. 109, U. S. G. S., p. 39, 1893, for full literature references (2) Geology of Wisconsin, Vol. III, p. 235.

†Geology of Wisconsin, Vol. III, p. 235.

‡Der Massige Gesteine, Zweite Auf., p. 217. 1887.

§Bul. d. Services d. l' Carte géol. d. l' France, p. 4. 1890.

‖Minn. Geol. and Nat. Hist. Surv., Bul. 2, p. 87. 1887.

¶Lehrbuch der Petrographie, Zweite Auf., Vol. II, p. 631.

and filling the hackley indentations of the same, or surrounding magnetite grains. It is usually of a deep reddish-brown color but sometimes fades into a light green, or may become almost colorless as a result of hydration and leaching of the iron. The absorption is very strong, even in the lighter varieties, and is expressed in the absorption formula $\mathfrak{b} \geqq \mathfrak{c} > > \mathfrak{a}$ determined by a study of fresh material. The pleochroism is not marked except in shades of brown and yellow. The optic angle is small; as the hyperboles scarcely separate on revolution of the stage. The bisectrix $\mathfrak{a}$ is very slightly inclined to OP; foron a cleavage flake, the interference cross remains almost absolutely in the center of the field on revolving the stage.

The alteration of biotite to chlorite takes place readily; so that what Wadsworth denominates the first stage of biotitization would seem to be the first stage of the alteration to chlorite in the present case.

Hornblende.—Though hornblende, like biotite, appears to occur as an alteration product of the augite and olivine, it deserves notice as a primary constituent. As an original mineral, hornblende shows characteristic six-sided sections bounded by the prism and clinopinacoid. Prismatic cleavage is perfect, the prismatic angle being about 125°. The extinction angle is about 15°. The color is brown, with the periphery, in many cases a blue-green, as previously mentioned for the secondary hornblende. Absorption is strong for brown hornblende but less marked in case of the green, according to the formula $\mathfrak{c} > \mathfrak{b} > > \mathfrak{a}$. The hornblende in turn, alters to chlorite.

Apatite.—Apatite is very abundant in certain portions of the rock and is especially prominent in weathered areas. The latter fact might lead one to infer that it is of secondary origin, as has Wadsworth* in his study of the "Gabbros and Diabases of Minnesota," where he says: "This mode of occurrence, with the increasing abundance in proportion to

*Bul. No. 2, Geol. and Nat. Hist. Surv., p. 68. 1887.

the alteration of the rock, and its being found in known secondary minerals like quartz, indicates that in the majority of its occurrences, if not in all, it is a product of alteration in the rock and is due to the aggregation of the phosphate of lime in the rock during the general process of rock alterations." The apatite in the Dakota diabase, although most abundant in weathered areas, does not lend confirmation to the above view, but rather emphasizes its primary nature. Its presence in any mineral seems to give easy access to the weathering agents, for apatites are often surrounded by rims of much altered material, and the outer portion of a feldspar crystal filled with apatite is oftentimes completely altered, while a central core remains perfectly fresh. It occurs in extremely long hexagonal prisms, showing here and there the characteristic cross-jointing. As evidence of its primary character it may be mentioned that it occurs in abundance in unaltered augite and in the outer portion of feldspar crystals; but even in extremely altered areas, one end of a prism generally extends into the unaltered feldspar or augite. Sometimes single crystals of apatite penetrate two or more crystals of the other minerals. In section 11 an apatite passes through an augite and projects into a feldspar at either end. Inclusions in the apatite crystals are numerous and are often so arranged as to give the prisms a reed-like appearance. It is difficult to determine the nature of the inclusions. In some instances the cavities seem to be empty, in others they contain magmatic glass which has since devitrified into a chloritic aggregate, and sometimes scales of biotite are present. Skeleton crystals similar to those figured and described by Bayley* in his study of the diabase of Pigeon Point are common.

Magnetite.—Magnetite is extremely abundant, and as in the case of apatite its abundance seems to vary directly with the alteration of the rock. As a primary constituent it is one of the earliest to crystallize and occurs in idiomorphic crystals—

*Bul. 109, U. S. G. S., p. 47. 1893.

octohedra, presenting quadratic cross-sections. It also occurs as irregular grains and finely divided particles in the form of inclusions in all of the other constituents. Magnetite also originates as a secondary product from the decomposition of the ferro-magnesian constituents, and in such instances may occur as small crystals or grains widely scattered throughout the altered areas, or in large idiomorphic skeleton forms, some of which are more than one-fourth square inch in area. Tests for titanium failed to disclose the presence of that element. Barrois* states that the olivine disease of Menez-Hom contains pure magnetite while the non-olivine-bearing rocks contain titanium magnetite, ilmenite, and its decomposition product, leucoxene, are rare. Section No. 7 shows rhombic plates of a light gray color, more or less opaque, which may be altered ilmenite. Magnetite gives rise to the other oxides and hydrates of iron, through oxidation and hydration. In numerous instances pyrite was noted in close relationship to the magnetite.

In section 7 diamond-shaped crystals of sphene were observed. The obtuse angle was about 135° and in some instances the margins of the crystals were darkened through magmatic corrosion, testifying to their primary character. Pleochorism is pronounced. The ray vibrating parallel to the long dimension is a pale yellow, while the ray vibrating at right angles to this is a reddish-brown.

GENERAL ALTERATION OF THE ROCK.

All of the principal constituents tend to alter, directly or indirectly to a chloritic aggregate, "viridite" and kaolin. The most prominent by-products in this general process of chemical adjustment, are the iron ores, calcite, and free silica. In the breaking down of the feldspars to micaceous or chloritic minerals $Ca\,O$ and $Si\,O_2$ are constantly in excess; the former becomes fixed as calcite, the percolating waters furnishing the necessary carbon dioxide, while the latter crystallizes out as quartz.

*Bul. d. Services d. l' Carte géol. d. l' France, p, 179. 1890.

In all of the changes to which the ferro-magnesian minerals are subject, iron seems to be in excess and makes its appearance in the form of magnetite crystals and grains, hematite scales, ochreous stains, and earthy material. These products often wander out into the feldspar areas.

The secondary quartz sometimes occurs in large irregular areas, which, when viewed between crossed nicols, break up into sectors composed of convergent fibres. The fibres are positive in character (developed parallel to c) and corresponding closely to Miche-Lévy* and Munier-Chalmas' "quartzine."

The final alteration is accomplished by the leaching out of the soluble constituents and the reduction of the rock to a yellowish-gray residual clay.

CHEMICAL COMPOSITION.

A chemical investigation of the South Dakota diabase tends to confirm the work of the microscope. In order to obtain a representative analysis, samples were taken from a number of boulders and from the fresh diabase ledge and, after being powdered, were thoroughly mixed. A portion of the composit product was analyzed with the following results.

$Si\,O_2$	42.85
$Ti\,O_2$	Trace
$Fe_2\,O_3$ / $Fe\,O$	13.66
$Al_2\,O_3$	20.23
$Ca\,O$	6.85
$Mg\,O$	3.42
$K_2\,O$	1.90
$Na_2\,O$	5.78
$H_2\,O$	0.88
$P_2\,O_5$	Trace
Total	100.57

But few comments on the above analysis are necessary. The low percentages of silica, lime and magnesia, and the relatively large amounts of iron, alumina, potash and soda are interesting facts, highly confirmatory of the microscopical

*Comp. Rend., March 24, 1890.

determinations of the mineralogical constitution of the rock. The specific gravity is high, the average being about 3.1.

STRUCTURE.

Structurally the diabase is holocrystalline, hypidiomorphic; varying from a true ophitic* to a more or less granular structure. The expression of these structures is the direct result of the relative ages of the feldspar and pyroxene. In the first case, the feldspar is always idiomorphic with respect to the pyroxene and hence the earlier to crystallize. The habit of the feldspar in this instance is prismatic according to a, or tabular after the clinopinacoid. In the second case where there is a tendency toward the granular structure, both constituents approach isomerism (become equi-dimensional) in development. Sometimes the feldspar is idiomorphic with respect to the augite, and sometimes the augite is idiomorphic toward the feldspar; which means in terms of age, that in the one case the feldspar is the older, and the augite in the other. As both cases may be observed in a single section, a legitimate inference would be, that both minerals were crystallizing simultaneously in slightly separated areas.

When we compare the above structures with the purely granular structure in the plagioclase-pyroxene rocks, a third relationship between the plagioclase and pyroxene is observed. In those rocks possessing a strictly granular structure, the feldspar is never idiomorphic with respect to the pyroxene, while in numerous instances when the two minerals are in juxtaposition, the pyroxene shows more or less idiomorphism, proving that it was the first to crystallize. In this case the two constituents are equi-dimensional. In the study of the holocrystalline plagioclase pyroxene rocks, no exceptions have been observed, and, so far as the writer is aware, no observations have been recorded which are not in accord with the above statements. Hence, it seems clear that we

*Structure ophitique of Fouque and Lévy, diabassischkörnig, of Rosenbusch or divergent-strahlig-körnig of Lossen.

have a series of structures which are the direct expression of the relative ages of the two principal constituents. To summarize, we have, in terms of feldspar relations to pyroxene:

Feldspar, idiomorphic, older than the pyroxene; habit columnar or tabular ....Ophitic Structure.

Feldspar, idiomorphic or allotriomorphic; contemporaneous with the pyroxene and approaching isomerism......
..............................Intermediate Structure.*

Feldspar, allotriomorphic, younger than the pyroxene; equidimensional.............................Granitic Structure.

PETROGRAPHIC DESCRIPTION OF THE QUARTZITE AND SLATE.

QUARTZITE.

Macroscopically the quartzite varies in color from the various shades of gray in the leached upper layers, to pink and red, or dark purplish-brown in the lower beds. Some of the slightly argillaceous portions assume a deep, brick-red color, and are usually thin-bedded. In general the massiveness as well as the color increases with the depth, but certain exposures show remarkable variations in texture and compactness, both horizontally and vertically. These changes are often extremely abrupt; a layer of perfectly compact, vitreous quartzite, with conchoidal fracture, and responding with an almost metallic ring when struck with the hammer, may be followed by a layer of incoherent sand, and this, in turn, by firmer rock. The sand layers are commonly of but slight thickness; rarely exceeding a few inches in the section observed in the area about Sioux Falls, though Merriam has recorded observations made about twenty miles to the west, in which the sandy layers often reach a thickness of several feet. Where the rock is not thoroughly quartzitic, it breaks around the integral grains instead of through them; so that freshly broken surfaces glisten in the sunlight, by virtue of

*Prof. W. C. Brogger in his work "On the Basic Eruptive Rocks of Gran" recognizes this transitional structure in the name "Olivine-Gabbro-Diabase," which he gives to one of his rock types. Quar. Jour. Geol. Soc., Vol. I, p. 18. February 1, 1894.

the numerous crystal-faced quartz grains. Such surfaces present a sugary appearance.

The size of the grain is an extremely constant factor over nearly the whole area. At the Palisades a large boulder of quartzite conglomerate was observed, but the parent ledge could not be found. In this boulder the conglomeratic pebbles varied in size from that of a pea up to that of a walnut. They consisted of vein quartz and were imbedded in a quartzitic matrix. Similar occurrences have been noted by the Minnesota geologists* in their study of the northeastern continuation of this same formation.

A thin section of the quartzite, when viewed under the microscope in ordinary light, is seen to be composed essentially of rounded quartz grains, the outlines of which are delicately traced by circlets of iron oxide, imbedded in an almost transparent matrix of interstitial quartz. In some of the most ferruginous varieties the interstitial cement takes on a jaspery appearance and becomes opaque.

The completely vitreous quartzite, when observed between crossed nicols, breaks up into numerous irregularly bounded areas which are oftentimes dove-tailed together in a very intricate manner, often forming a quartz mosaic. The interstitial quartz is found to be, in large part, in perfect optical accord with the original quartz grains.† In the Sioux quartzite the quartz grains often show the action of pressure as manifested in undulatory extinction and fractured grains. The cracked grains are readily detected by the slight displacement of some of the parts and their failure to extinguish as a unit. Several instances were noted in which the parts were slightly faulted and in one instance the fault-fissure was filled with sericite. Faulting was especially noticeable where a quartz grain contained so-called "quartz needles," the discontinuity of the needles emphasizing the displace-

*Final Report of the Geol. and Nat. Hist. Surv., of Minn., Vol. I, p. 541. 1894.

†Vid. Irving and Van Hise "On Secondary Enlargements of Mineral Fragments in Certain Rocks." Bul. No. 8, U. S. G. S. 1884.

ment. The movement of one grain upon another was in a few instances accompanied by a slight peripheral granulation.

Inclusions are extremely common, especially small, dark-colored dust particles and irregular gas cavities. Liquid inclusions are abundant in certain specimens and often contain movable bubbles. Fluid inclusions are, at times, arranged in more or less parallel lines and these lines extend across more than one individual and hence are of secondary origin.

Of the individualized inclusions, zircon and "quartz needles" (rutile) are most abundant. The zircons are often doubly terminated and show beautiful zonal growths (No. 6916). The ratio of length to breadth is generally about 1:3. The zircons* themselves, commonly contain inclusions arranged parallel to c and centrally located. In some instances the zircons are slightly iron-stained and their crystal angles are occasionally rounded. Aside from occurring as inclusions in the quartz grains, they are not infrequently located in the interstices.

The most interesting of all the inclusions are the so-called "quartz needles" of Hawes (Lithology of New Hampshire), which are very abundant.

It is comparatively easy to trace the stages from the indeterminate hair-like forms to bodies whose optical characters, so far as can be observed, are identical with those of rutile. Section 4863 shows all gradations. Certain of the quartz grains containing "quartz needles" are slightly altered and the needles are much jointed; considerable space intervening between consecutive segments. The segments are larger than the ordinary fibers; many of them so large that a distinct, pale yellow color could be distinguished, and they show strong relief and high double refraction; which is considered presumptive evidence of their identity as rutiles. The linear arrangement of the fragments suggest that they

* Von Crustschoff considers zircons which generally have a rounded form, with more or less characteristic crystal form and a central, very dark brown opaque single inclusion, or at times a group of inclusions, to be characteristic in a high degree for gneisses and related Archæan rocks. T. M. P. M., Vol. VII, p. 410. 1886.

were once integral portions of a continuous needle. Romberg,* in his study of the "Argentine Granites" proves the so-called "quartz needles" to be optically positive. In another instance a well developed rutile crystal in the interstitial area immediately adjoining the quartz grains was accompanied by another individual of pyramidal habit, probably anatase. Both crystals are of secondary origin and were derived perhaps from the rutilated quartz. No. 4849 shows comparatively large rutiles, as single individuals and as geniculate and polysynthetic twins similar to those described by Sauer† as occurring in the Adorf phyllites. All of these crystals are located in interstitial areas and hence are secondary. Other occurrences of anatase‡ were noted. As to the source of the titanium it must be said that one is hardly warranted in supposing that the "quartz needles" would be an all sufficient source, but it is a fact worthy of mention that in nearly every case, the individualized interstitial rutiles are in close proximity to the rutillated quartzes and strongly suggest as their source, the "quartz needles." It is quite probable that some titanium has been furnished by the biotite, which was undoubtedly present in small amounts, but which has given place to muscovite or to epidote (4859). Sagenite webs have often been recognized in biotite from other localities, while Thürach proved the presence of titanium in biotite, even when it did not manifest itself as individualized rutile. Hexagonal plates of hematite often accompany the rutile needles. Apatite was rarely noted as an inclusion in quartz and when present, the cross-gashing is never prominent.

Besides quartz, traces of orthoclase remain. Certain quadratic areas which have given place completely to sericite were probably of orthoclastic origin. In some instances the

*N. J. B., B. B. VIII, p 250. 1892.

*A. Sauer, Rutile als microscopische Gemengtheil in der Gneiss und Glimmer-schiefer formation, sowie als Thonschiefernädelchen in der Phyllit-formation, N. J. B., Vol I, p. 273. 1881.

*Vid. Thürach on the distribution of Anatase in Clastic Rocks. Verhand. der phys-medic. Gessell zu Würzberg, Bd XVIII.

sericite takes the form of rosettes, assuming a more or less radial arrangement.

Section 4867, from the James river, contains a considerable amount of plagioclase which shows the characteristic twin lamellæ and is remarkably fresh. Some of the individuals present very irregular outlines and show dynamic effects, as evidenced in bent laminæ and the development of fine twin striations. The same section shows certain light green, pleochroic, scaly particles, of slight relief and low double refraction, which were identified as chlorite. The plates occur bent around the quartz grains, and probably have resulted from the alteration of biotite or the interaction of the feldspar and the iron ores.

Section 6920 contains epidote in large amount, which probably originated from plagioclase.

SLATES.

The slates vary in color from a brick-red to a purplish-black, and weather to a light-gray or pinkish-gray. True slaty cleavage is absent, but parting may be readily effected along the bedding plane. These are not true slates in the common acceptance of the term, but correspond very closely to the quartz-slate of Irving and Van Hise.* Their specific gravity varies from an average of 2.65 in the slightly carbonaceous, purplish-black slates near Corson, to 2.83 for the deep-red, ferruginous slates of the Palisades. They vary in texture from the extremely fine-grained homogeneous "pipestone" to arenaceous slates or argillaceous quartzites. At the Palisades, as has been previously mentioned, the slates are interbedded with the quartzite, and there are insensible transitions from the pipestone to a vitreous quartzite.

Microscopically considered, the slates are composed essentially of quartz, a micaceous mineral, the iron ores and more or less carbonaceous material. They differ from the quartzite, in that the quartz grains are smaller and more angular,

*The Penokee Iron-Bearing Series; Tenth Annual U. S. G. S., p. 370 et seq. 1890.

and in the presence of a large amount of argillaceous material, which has crystallized as sericite or kaolin, or in some instances, chlorite; and in the increased percentage of iron. The angularity of the quartz grains seem to vary inversely as their size. Hence, in general, the smaller the grains, the sharper are their angles. When the amount of interstitial material is relatively great, the quartz grains seldom have definite boundaries, but seem to fade out at the edges, and often the peripheral portions of the grains are charged with very finely divided particles of iron and carbonaceous material. This rim is undoubtedly of "secondary growth." When observed between crossed nicols, siliceous matrix is seen to be in optical continuity with the original grain, as in the quartzite, although the result is more obscure.

Inclusions in the original grains are the same as in the quartzite.

In the finer grained varieties the micaceous scales are often bent or disturbed in various ways, being forced to adapt themselves to the quartz grains. In many instances

FIG. 27. Crushed quartz grain in slate from the Palisades.

the scales become more or less fibrous and are radially arranged. In the slates at the Palisades large flakes of mica are arranged parallel to the bedding and noticeably increase the fissility of the rock. The quartz grains and mica scales testify to horizontal movement in the rock,—shearing on a miscroscopic scale.

The iron oxide is abundant in the unaltered rock and occurs as indefinite grains in the interstices and also as inclusions in the peripheral portion of quartz grains and to some extent in the mica. It generally appears black or brownish-black and lustreless, but in the more ferruginous varieties some shade of red is the prevailing color. Van Hise ascribes the source of the iron in the graywackes of the Penokee-Gogebic iron-bearing series, to pyrite, marcasite and ferrite. This is probably true of the rock under consideration, so evidenced by the blackened areas, which are not unlikely the remnants of iron pyrites.

THE SPOTTED SLATES.

The slates over the whole district present peculiar markings in the form of circular spots which, seen in three dimensions, are spheroidal, with the major axis parallel to the

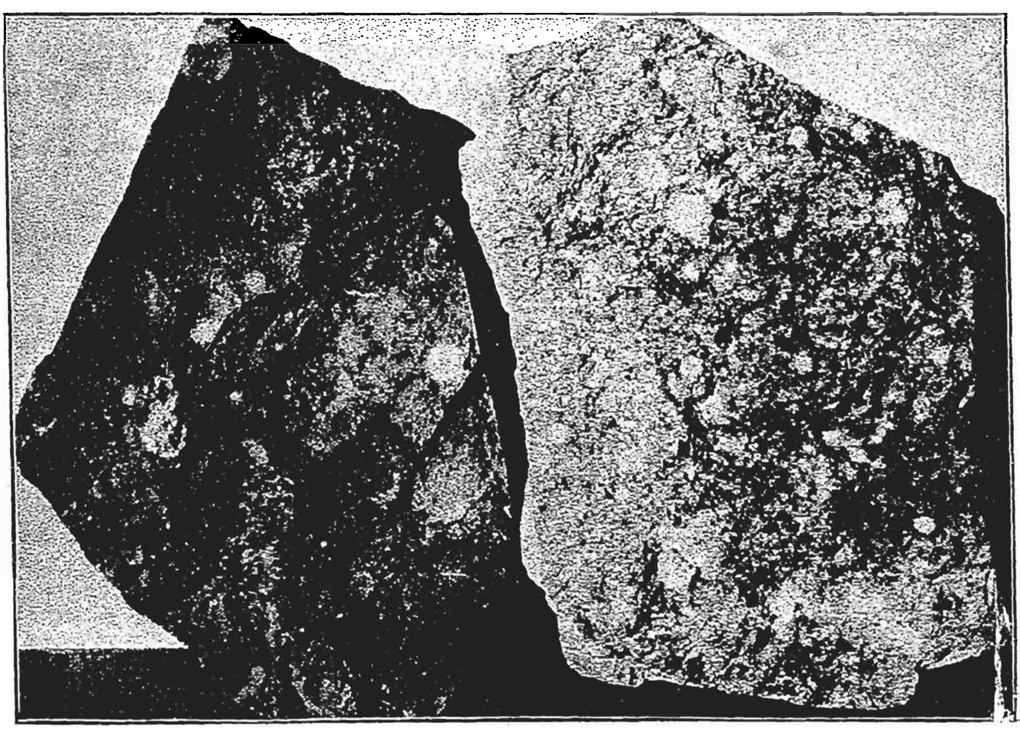


FIG. 28. Spotted slates near Corson, S. D.

bedding plane and present extremely sharp contours. These spots vary in size from a centimeter in diameter down to mere specks. They are always of lighter color than their matrix and commonly show a concentric arrangement of color in alternating yellowish-gray and pink shells. This alternation is rarely repeated more than three times; the series from the outside in generally being gray, pink, and gray center. In the smaller spots there may be but a single alternation. The matrix, in immediate contact with the spot, is usually of deeper color than the mass of the rock and thus tends to heighten the contrast. As to disposition of the spots, there seems to be no law controlling their arrangement. They sometimes occur along joint and bedding planes, but are quite as numerous in other positions.

Microscopically, the spots are essentially the same as their matrix, save that they contain less of the iron constituent and seemingly more of the micaceous mineral, which probably owes its increased prominence to the increase in transparency due to loss in iron. That the difference in color does not arise from the change in the state of combination, but from the withdrawal of the iron constituent, has been proved by numerous chemical analyses of related occurrences. Maw,* in his studies "On the Disposition of Iron in Varigated Strata," carefully separated the material composing the light colored spots from their deeply colored matrices, in sandstones, shales and slates, and demonstrated by an elaborate series of chemical analyses, that the bleaching is due to the removal of the iron.

The general appearance of the spots both microscopically and macroscopically, is almost if not wholly identical with the decolorized areas along joints and exposed surfaces where the present state can be definitely referred to the action of weathering agencies. In both cases the resultant product owes its origin to the removal of its iron constituent; but the anomalous arrangement of the spots and their entire independence of joints, fractures and bedding planes, precludes their reference to any external agency. The active principle in the leaching process must have originated within

*Quar. Jour. Geol. Soc., Vol XXIV, pp. 351-400. 1868.

themselves. Iron as a coloring agent in rocks is generally in the form of the insoluble ferric oxide (Sesquioxide) and according to Dawson* the leaching process is inaugurated by the reduction of the sesquioxide, through the action of organic matter, to the soluble protoxide, which is then readily removed by the percolating waters. The verity of this process has been confirmed by many observers, and has come to be widely recognized in the theory of the bog-iron ore accumulation. Diligent search was made for any trace of organic remains in the spots under consideration but without success; yet no other explanation of their origin appears tenable.

ORIGIN OF THE QUARTZITE AND SLATES.

Sorby,† in his second presidential address before the Geological Society of London, considers it probable that "the cohesion of the grains in hard and compact quartzites" was due to the deposition of interstitial quartz, but it was left to Irving and Van Hise‡ to transform a probability into a demonstrated reality and to make manifest the true geological significance of the process.§

Irving,‖ in his summary of general conclusions regarding the genesis of the Huronian quartzites, says: "All the true quartzites of the Huronian are merely sandstones which have received various degrees of induration by the interstitial deposition of siliceous cement, which has generally taken the form of enlargements of the original quartz particles, less commonly of chalcedonic or amorphous silica, two or even all of the three forms occurring at times in the same

*Quar Jour. Geol. Soc., Vol. V, p. 25. 1848.

†Quar. Jour. Geol. Soc., p. 62. 1880.

‡Bul. No. 8, U. S. G. S. 1884.

§The relation of the interstitial silica to the original quartz grains was correctly interpreted by A. Knop (Ueber Kieselsaure-Abscheidungen ünd Oölithbildung, N. J. B., p. 281, 1884) After giving a careful description, he says: "Jedes dieser Quarzkryställchen ist nichts Anderes, als das Product des Fortwachsens obgerundeter und individualister Quartzkörperchen in einer Kieselsaurelosung und Art ihrer Aggregation, das gegenseitige Abstossen der Krystalle mit Contactflachen, sowie der Mangel solcher Contactflachen an den rundlichen Kornern selbst beweisen, dass die Regeneration dieser zu Krystallen. nach der bereits erfolgten Ablagergung der Sandkorner auf eine noch fur uns rathselhafte Weise vor sich ging, denn keinerlei Einwirkung hoherer Temperatur, weder at den Gesteinselementen, noch an dem Bindemittel lasst sich mit Sicherheit constatiren." Inostranzeff fully explains the origin of quartzite by metasomatic growth. Studien uber metamorphis'rte Gesteine im government Olonez. Die Entstehung der Conglomerate und Quartzite u. s. w. Leipsig, 1879.

‖Bul. No. 48, U. S. G. S. 1894.

rock. There may have been, in some cases, some solution and redeposition of the original quartz material, but in the main these rocks are still made up of the fragmental constituents that composed them before induration, the fragments retaining for the most part their original contours."

"It also appears that besides the true quartzites, ... other rocks of the Huronian, e. g., the graywackes, in which quartz is merely subordinate, or at least not the principal ingredient, have been affected by the same sort of siliceous induration, the indurating silica occurring both as enlargements of the quartz fragments and independently of them. Accompanying this induration there has been at times replacement of feldspathic material by quartz, and the alteration of feldspar to chlorite occurring both as a pseudomorphic substance for the feldspars and independently crystallized in the interstices. * * * By one or more of these processes, rocks have been changed so as to present macroscopically and microscopically the appearance of more or less complete original crystallization, and yet they are made up almost entirely of the original fragmental material, the alteration which they have undergone having been merely metasomatic, and not 'metamorphic' as the term is generally understood."

The facts observed in the study of the Sioux quartzite and slates are in complete accord with the above conclusions. That the original sand grains served as nuclei, around which the interstitial silica was deposited is a matter of simple observation. The source of the silica, however, is not so self-evident. An arkose or feldspathic sandstone, undergoing alteration, would give up a considerable amount of free silica when the feldspar changed to mica or chlorite and this might in some instances be sufficient to cement the rock. But the Sioux quartzite bears evidence of but little original feldspar and hence it becomes necessary to seek another source for the added silica. Irving (Ibid. p. 49) speaks of the percolating silica-bearing waters, but does not specify the origin of their load. Newton* in discussing the probable origin of the interbedded quartzites of the Black Hills, ascribes the source of the silica to diatoms, sponge spicules, etc., which were original constituents of the formation. This view has been elaborated by Crosby† in his study of "Quartzites and Siliceous Concretions.". As no evidence of organic life could be found in the Sioux formation, and it is improbable that the rock has been able to furnish sufficient silica to cement itself, the natural inference is that the percolating waters received their silica burden from some extraneous source. The exact source can only be conjectured with the data at hand, but it is not impossible that the quartzite has been covered by a highly feldspathic deposit which has long since been removed.

AGE OF THE QUARTZITE FORMATION.‡

The Sioux quartzite has been referred to the Huronian by Hall, White, Kloos, Irving and Van Hise in their respective writings upon the subject. Hayden approached the area from the southwest and believed the formation to be possibly Cretaceous, while the Minnesota geologists assert with equal positiveness its equivalency with the Potsdam of New York. Todd, in a preliminary report on the geology of South Dakota, follows Hall in his treatment of the quartzite formation.

The present investigation leads to the reference of the formation to the pre-Cretaceous times for the following reasons:

I. Character of its inclusions.

a The coarse, holocrystalline diabase and the absence of pyroclastics argues strongly in favor of intrusion under high temperature and pressure. In other words the diabase is of deep-seated origin.

b The Mesozoic diabases of the Atlantic slope are close textured and in nearly all instances carry more or less glass.

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*Geology and Resources of the Black Hills of Dakota, pp. 92 and 93. 1880.

†Technology Quarterly, pp 397, 407. May, 1888.

‡See Geol. and Nat. Hist. Surv. of Minn., Vol. VII, pp. 533-561; also Iowa Acad. Sci., Vol. II, pp. 218-222.

II. Lithological character of the formation. Much of the slate and quartzite is thoroughly indurated. The induration is due in large part, to metasomatic infiltration. So far as the writer is aware, no instances have been recorded of Mesozoic arenaceous deposits in undisturbed areas becoming completely indurated according to the above process.

III. Geological structural relationships. The Niobrara overlies the quartzite formation unconformably. According to Irving* there is reason to believe that the Sioux quartzite underlies unconformably the Saint Croix as exemplified by the exposures in the vicinity of Mankato and New Ulm. The Minnesota geologists concur in this view.

The following facts may be adduced in support to Hall's reference to Huronian.

1. As has been emphasized by Irving, the lithological characters of the quartzite are almost identical with those of the Baraboo quartzite in Wisconsin. The latter formation has been referred with some degree of confidence to the Huronian by both Irving and Van Hise.

2. The diabase near Corson in South Dakota and the quartz-porphyry† discovered at Hull in Iowa are strikingly similar to the intrusives which are peculiar to the Huronian in the Lake Superior region.

ACKNOWLEDGMENTS.

Prof. C. R. Van Hise kindly placed at the writer's disposal the note books of R. D. Irving and W. N. Merriam on the Sioux quartzite area. The note books were illustrated by forty-four thin sections of quartzite and related rocks made from specimens collected by the above investigators.

The laboratory work was carried on under the personal supervision of Dr. E. B. Mathews, and to him the writer desires to express his hearty appreciation for many valuable suggestions.

Above all the writer takes this opportunity to acknowledge his great indebtedness to the late Prof. G. H. Williams, to whose influence and teaching is due anything that may be found of merit in the paper.

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* Fifth Ann. Rept. U. S. G. S., p. 202.

† Iowa Geol. Surv., Vol. I, p. 165. 1892.

ARTESIAN WELLS OF IOWA.

BY

WILLIAM HARMON NORTON.

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CONTENTS.

INTRODUCTION.

So intimately is geology concerned with water and its work that the investigation of the deep waters of the state lies clearly within the field of the State Geological Survey. Geological structure is largely the product of aqueous agencies. Geological dynamics deal with the work of rain and ice, of wave and river, with sedimentation and solution. Economic geology finds in water the most precious of all mineral resources. For water is as much a mineral as is petroleum, and, like petroleum, its distribution beneath the surface depends upon stratigraphy and structure. From other minerals it is separated by its abundance and its relations to life; and these are so essential that it becomes of greater value than all the possible wealth of mines and quarries.

The province of Artesia, however, has not as yet come under the direct and complete control of any single science. Like some region in a new found continent, it has passed from one domain to another. Different sciences, in number as many as the great colonizing powers of Europe, have sustained their independent rights of discovery in different parts of the field. If the landfall, so to say, belongs to engineering, physics and geology very early made valuable contributions to our knowledge of the terra incognita. Later explorations have been conducted by chemistry, medicine and hygiene; and perhaps all claims ultimately may be vested in the new and composite science of hydrology. Claimed by all these sciences the field has been thoroughly exploited by none. If geology has suffered it to lie in part neglected, it is only because so many other fields of research, wholly and unquestionably her own, demanded immediate attention. Nevertheless much has been done. In Europe many eminent geologists have given serious attention to hydro-geologic problems. In America the geological surveys of several states have considered the general relations of the problems involved in artesian waters and have set forth the local conditions obtaining in their respective areas. Geological sections of deep wells, indeed, are always noted in such reports, but in several instances invesgation has been carried over into purely hydrologic subjects. Mineral waters have been analyzed and their therapeutic qualities considered. Rainfall has been calculated, streams gauged, and water power measured. Indeed all the various problems of water supply, including rainfall, storm-water, evaporation, percolation, ground storage, and the pollution of wells and rivers, have received the attention of state geological surveys.

The field of the United States Geological Survey has been made still more comprehensive. The monograph on the Requisite and Qualifying Conditions of Artesian Wells by Prof. T. C. Chamberlin* remains the best treatise extant on this subject. In later reports of the Survey statistics of depth and flows of artesian wells in many states and territories are published in detail, the relation of artesian wells to irrigation is fully discussed, and the entire subject of water supply, including potable and mineral waters and irrigation, even in its mechanical and engineering phases, is fully canvassed.

The economic importance of the subject also justifies its presentation by the Survey. The cities and towns of Iowa are now passing through the stage in their history in which the question of water supply is of special interest. At the time of the earlier geological surveys of the state little or nothing had been done in communal supply. Not a single system of water works was in operation, or even begun, in 1870, the date of publication of the report of the State Survey under the directorship of Dr. C. A. White. In that report less than three pages are assigned to artesian waters, and three artesian wells only are mentioned. Before the end of 1880, sixteen systems of water works were in operation in Iowa. By the end of 1885 the number had increased to forty. Soon after the end of another semi-decade the number had again more than doubled, some eight-five towns being listed in the Manual of American Water Works for 1890 and 1891.

*Fifth Ann. Rep U. S. Geol. Surv., pp. 125-173. 1885.

Eight of these towns used their works for fire protection only. The remaining seventy-seven towns represented a population of 438,982. Their works embodied 510 miles of mains, and the estimated cost of the works was over $7,000,000.*

At this stage in the municipal history of Iowa when a larger number of water works are being built than ever before, and a larger number of towns are considering the question of their installation, when many cities also have under advisement a change in supply or additional sources of supply, certainly there is need of specific and authoritative information as to the aqueous treasures of the rocks. Can potable artesian water be found at an accessible depth; will it be copious or scanty in quantity; in quality will it be adapted to all urban uses; at what depth can it be found, through what formations will the drill proceed, and at what cost can the supply be obtained; how will such supply compare with other possible sources of supply in expense, in purity, and in utility, —all these are questions which each community in the state has a right to ask of the State Survey. It has a right to an answer as definite as can be made by the most skillful deduction from the entire obtainable body of facts bearing upon the subject.

That these questions are sometimes unasked, that towns proceed sometimes in these matters entirely without expert advice, is due to several causes. In no science, political, economical or physical, is the disinterested judgment of the specialist sought with the eagerness which he himself might expect. Hundreds of thousands of dollars have been wasted in the United States in the fruitless search for coal, oil and gas, and the precious metals, as well as for artesian waters—a search fruitless, that is, except to the science to the neglect of which these ill-advised undertakings were due. The chief reason, however, that the services of the Survey have not been used as widely as was possible is that its functions and resources are not generally known on account of the recency

*Manual of American Water Works, for 1890-1891, p. 6. New York, 1892.

of its establishment. With the continuance of the Survey as a permanent institution of the state it can reach its highest efficiency. The present policy of the state is an eminently wise one, and is especially helpful to scientific investigation in the field of deep wells and water supply. The discontinuance of a state geological survey whose work is unfinished in any field entails a direct economic loss. Material resources remain undiscovered or without due advertisement. Money is squandered in useless exploitations. The youth of the state remain in ignorance of the geological structure of their own domain, and thus fail to possess a scientific heritage which should be theirs together with their economic heritage of the lands of the commonwealth. The material, however, with which investigation deals is still available for the most part. When after a lapse of years work may be resumed, mines, quarries, natural sections, the topographic features of the country, await in patience the return of the geologist and will yield their hidden secrets as before. But in the artesian field the suspension of work involves a loss less remediable, a loss of the facts themselves in which the entire body of knowledge of the subject consists. The strata penetrated, the depth of water horizons, almost all the facts of use in artesian investigations must be gathered while the boring of any well is in progress, or not at all.

The preparation of this report in two seasons has limited the data on which it is based to the records of wells drilled during 1895 and 1896 and of wells previously drilled where the facts were at the time carefully noted and preserved by intelligent citizens. Unfortunately these wells constitute less than one-half of the deep borings in the state. In the case of many of the deep wells of Iowa nothing will ever be known of the thickness and character of the various geological formations penetrated by the drill, nor of the number, the depth, or the nature of the water-bearing strata, nor of the quantity and quality of the water from each of these strata, nor of the quality and quantity and pressure of the flow at the completion of the well compared with the same at later times. In many wells some of these facts are known, but others of equal importance escaped observation or record and cannot be rediscovered. These limits in fundamental facts obviously impose strict limits on the deductions and conclusions of the report. Addition to these data and their verification or correction are impossible by any further research. In this respect this work differs from other geological studies in which the field lies open at all times, and patient and continued investigation may at any time win the secrets concealed from the casual observer. But if no new facts in the way of corroboration or amendment can be looked for from the past, the future offers such in abundance. New borings will doubtless be made within the limits of the state each year. During the continuation of the Survey the supervision of these will be as careful as is possible, and the new facts gained will no doubt illuminate portions of the field now in darkness or in shadow.

Another limit to the investigation is imposed by the nature of the subject. Little in this report can be the result of personal observation except the lithological determinations of the well drillings; even here the thickness and location of the strata which the drillings represent rest on other authority than that of the author. The report deals thus with thousands of statements and observations of very many individuals, and mistakes in judgment may easily occur in accepting or rejecting any of these data at second hand, which cannot be verified by personal examination.

A word may be added as to the scope of the work. It has seemed good to the Director of the Survey—and his judgment has been cheerfully followed by the writer—that the interests of the citizen should be set above the interests of the specialist. While, therefore, something may be found in the discussion of the Iowa artesian basin which will prove new and interesting to the geologist, much is added in restatement of facts already familiar to special students, but which may be less a matter of common knowledge. Yet it is hoped that nothing has found place which is without at least an educational value, nothing that fails in some manner to elucidate or complete the main theme, nothing that is not of practical application.

It affords a distinct pleasure to here return hearty thanks to the very many who have aided in the prosecution of the work. In all parts of the state public spirited citizens have secured the facts here put on permanent record. Without their earnest co-operation, without their diligence and large outlay of time and effort in gathering data the scientific value of which few appreciate, this report not merely would have been incomplete; it would have been made quite impracticable.

Our indebtedness to some is so large that we cannot refrain from personal mention. The chemists of several railways, in especial of the Chicago, Milwaukee & St. Paul, the Chicago & Northwestern, and the Chicago, Burlington & Quincy, placed at our disposal all their many and valuable analyses of Iowa waters. The generosity of Prof. J. B. Weems, Ph. D., of the Iowa Agricultural College, supplied the most complete series of analyses of Iowa artesian waters yet collated and published. The leading well drilling firms have supplied many facts of great value in the investigation. To our colleagues of the survey, to Messrs. Bain and Beyer, and to the Director, Dr. Samuel Calvin, we acknowledge with hearty pleasure an unfailing helpfulness which has far outrun the metes of official duties.

THE DEFINITION AND THEORY OF ARTESIAN WELLS.

DEFINITION.

In its etymology the term artesian carries no definition. It is derived from *Artesium*, the Latin equivalent of Artois, the name of the ancient province of France which, with Picardy on the west and French Flanders on the east, held the northern salient of the national territory. In this province, now included in the department of Pas de Calais, it was discovered very early in the history of the civilization of western Europe that artificial springs could be obtained by boring deeply into the earth. Within the walls of an old Carthusian convent at Lillers, there has steadily flowed since the year 1126 the most ancient, perhaps, of these wells of Artois. Not that it is in fact the first of all flowing wells. Traces of such wells are found in the territories of almost all of the great monarchies of the ancient world, in Egypt, in China, in Persia, in Asia Minor and in Italy. These, however, do not seem to be in direct historic continuity with the artesian wells of modern times, and may, therefore, be omitted from consideration.

The flowing wells of Modena in northern Italy are, perhaps, of nearly equal antiquity with those of Artois. In such repute were they held that two well borers' augers were made the coat of arms of the town. In 1691 Bernadini Ramazzini, a professor of medicine at Modena, published a little work upon these wells, which is said to contain the first certain statements in literature on the employment of the miner's drill in sinking wells.* In this he discusses not only the methods employed in well drilling, but also the origin of spouting waters, their nature, and their excellent quality. Nearly a century later the wells of Modena were again described and were brought to public notice in France, by J. D. Cassini, who was called from Italy to France by Louis XIV and made a member of the French Academy of Science. Indeed Modena, the old Roman town of Mutina, might well have disputed the claims of Artois to give name to flowing wells, and it may be little more than an accident that we do not call such wells to-day mutinian rather than artesian.

The discovery of artesian waters at these early dates is to be attributed to happy chances. The modern history of flowing wells could not commence until geology was ready to point out the necessary dispositions of the strata, until the dynamical theory was understood, and the art of the drill was mastered. Unquestionably the renaissance in the art of flowing

*De fontium mutiniensium admiranda Scaturigine tractatus physico-hydrostaticus, Barnadini Ramazzini Mutinæ. 1691.

wells was well begun with the present century. During its first three or four decades a large number of memoirs, descriptions and manuals upon this subject were published by various authors, of whom we may name Lamarck,* Garnier,† Hericart de Thury,‡ Baillet,§ Here,‖ Bruckmann,¶ and Arago.** Improved machinery for drilling was invented, and much attention was devoted to the subject. Nothing will better illustrate the popular interest than the fact that for a number of years the Royal and Central Society of Agriculture of France each year distributed medals and prizes—the highest was 3,000 francs—to workers in the field, to authors, inventors, well drillers, and to those who introduced these wells where not before known. The center of this new interest was in France. In other countries, as in England for example, many flowing wells were drilled during this period, but the chief honors belong without question to French savants and mechanicians. It is not strange or unreasonable, therefore, that a province in France gave its name to this class of wells as its final designation, a name that was thus applied in scientific literature at least as early as 1805.††

The term artesian wells, or wells of Artois, at first could include in its meaning little or nothing more than the superficial phenomena of the flow of water. But as the physical and geological conditions of these wells were investigated the emphasis of the definition naturally shifted from the mere fact of the artificial fountain to the structural and dynamical relations which conditioned it. The older use of the term is still retained, however, by some eminent authorities, and is restricted by them to fountain wells.‡‡ Commonly, however,

* Hydrogéologie. Paris. 1802.

† Manuel du fontenièr-sondeur. 1822.

‡ Considerations sur les puits fores. Paris. 1829.

§ Rapports sur divers sondages et puits artésiens. 1822.

‖ Memoirs sur les puits artésiens. St. Quentin. 1828.

¶ Ueber Artesische Brunne. Heilb. 1833.

** Bureau des Longitudes, Annuaire. Paris. 1835.

†† Lionnais, Historie de la ville de Nancy, Description de la fontaine artésienne de Jarville. Nancy. 1805.

‡‡ Chamberlin: Requisite and Qualifying Conditions of Artesian Wells. Fifth Ann. Rept. U. S. Geol. Surv., p. 132. 1885.

both in Europe and America, the mere fact of overflow is considered unessential. An artesian well may, therefore, be briefly defined as a vertical well in which water rises near to or above the surface by natural hydrostatic pressure consequent upon certain structural conditions. Usually these wells are of small diameter varying from two to twelve inches, any bores above the latter dimension being exceptional. While artesian wells include most of the deep borings of the world, depth is not included in the definition, many shallow wells being as purely artesian in structure and character as are wells whose waters rise from strata lying thousands of feet beneath the surface.

It is unfortunate that men of science are not agreed in the use of the term artesian, and that the introduction of an acceptable and unequivocal nomenclature seems now quite impracticable. Bored wells, deep wells, artesian wells, artesian fountains, and even "bubbling" wells, all these phrases have been applied to the same phenomena. As wide a range of epithets is found in French scientific literature:—puits forés, puits artésiens, fountaines artésiennes, fountaines artificielles, fountaines jaillissantes des puits forés. In its early use the term "bored wells," puits forés, was practically equivalent to artesian wells, since these alone were bored or drilled, while common wells were dug; but the term can not now be so restricted, since many wells are drilled at the present time whose waters are not artesian.

Using the term artesian according to our definition for both classes of wells, for those whose waters overflow and for those whose waters under similar conditions fall short of reaching the surface, we fail to distinguish these two classes except by further qualification in some such way as by using the term artesian fountains or flowing artesians for the one, and sub-artesians, negative or non-flowing artesians for the other. But if we speak of flowing wells only as artesian, we are still left without a suitable term for the second class. To designate them deep bores, deep borings, or deep wells, as is frequently done is to use terms that are vague and inexact, that apply to other things also, and that omit the essential characteristics of these wells, the fact that the water ascends within the tube to near the surface under hydrostatic pressure.

But the separation of these two classes is so slight and unessential, that it is far more important that we have a common name for both than a separate name for each. To restrict artesian to flowing wells has its practical inconvenience. In the same town, for example, are two deep wells, one situated on ground slightly lower than the other. The waters of the first overflow, and the well is, therefore, an artesian. The waters of the other, derived from the same source, of the same quality, rising through the same strata, under the same pressure, to the same height, fail by a few feet of the surface, and the well can not, therefore, be termed an artesian. An artesian well may at any time cease to be such by an accident to its tubing, and be reinstated in the category by the necessary repairs. On account of an overdraft on the local supply the artesian wells of a district become something else, deep wells or deep borings, by the sinking of their waters a few feet. It is quite conceivable that under some such fluctuations in level as have been reported in other countries the same well frequently might oscillate between an artesian condition and the reverse. This restriction of the word artesian would make it merely the synonym of "flowing," and its demission from the language of science would then be a distinct gain in clearness, purity and precision.

In this report artesian wells will embrace both classes, both flowing artesians and sub-artesians. In our tables the relative heights of the head of water and the curb of the well show to which class each well belongs.

HISTORICAL RESUME.

The theory of artesian wells is known to every school boy, not the omniscient familiar spirit of Macauley, but the common school boy of the Iowa grammar schools. It has reached the stage of universal acceptance among men of science, and nothing new can be added either in fact or illustration. Little indeed has been added to the theory since the early years of the century, and probably the freshest presentation of the subject now possible would be by literal quotation from the masters who first enunciated it.

In the early decades of the century the theory was fully stated and ably defended, but had not yet advanced beyond the stage of discussion. Rival hypotheses were yet in the field to be answered. Thus Arago felt it incumbent upon him elaborately to refute the older notions, still extant in his time, which denied the competency of atmospheric waters to supply ordinary springs, rivers and artesian reservoirs. On the other side may be mentioned one Azais,* who bravely stood for the universal principle of expansion as the cause of artesian flow, which flow, he said, seemed contrary to all common laws. The interior of the earth, said Azais, is a centre of expansion in a state of continuous pressure—*ressort*—against its envelopes, and this produces a transpiration of caloric, electricity, and atmospheric gases, and a transudation or sweating of natural waters. On account of this pressure from the principle of interior expansion, artesian waters spring from the earth under the drill, like blood from the body at the stroke of the lancet.

An American contributor to this controversy* postulated a similar centrifugal force, driving to the surface waters from the earth's interior, whither they had descended into vast caverns from the sea, an echo this of the hydrologic theory of the great Descartes propounded early in the seventeenth century. Our American author, whose account of American artesian wells was currently held to have considerable merit, showed that under this theory artesian water can be obtained anywhere if one only goes deep enough—a comfortable opinion not yet

*Azais: Memoire sur les puits artésiens. 1825.

*Dickson: An Essay on the Art of Boring the Earth for the obtainment of a Spontaneous Flow of Water, etc. New Brunswick. 1826.

quite extinct. These fancies were seriously debated within the lifetime of men now living. And yet as early as the sixteenth century, Bernard Palissy had overthrown the ancient theories of springs made sacred by the names of Aristotle and Seneca, and had shown that they are fed, not by ascending vapors from beneath, but by the waters of rain and melted snow descending from the earth's surface.*

In 1671 Cassini suggested that the waters of the artesian wells of Modena and Bologna might come through subterranean channels from the top of the Apennine mountains, which are only ten miles distant from this territory. In 1729 Bellidor in his Science of Engineering left little of the modern view to be more explicitly stated. "It would be desirable," says he, "to make such wells in all sorts of places, which appears impossible, since conditions of the terrane are requisite that are not everywhere found. For, as these wells are caused by waters, which, proceeding from neighboring mountains, make a subterranean channel to a certain point where they are retained by beds of clay or rock which prevent their escape, it is necessary that these beds should be pierced with drills, and that the water which is beneath should be capable of ascending in a vertical tube to the surface of the earth."†

THE REQUISITE CONDITIONS.

The theory of artesian wells includes certain requisite conditions which may be considered under:

A. Conditions of Supply.
B. Conditions of Transmission.

The former comprise the outcrop of a stratum of such texture that it can absorb water freely, and sufficient rainfall and facilities for percolation to insure its supply. The region of the outcrop is termed the gathering ground, the area of intake

*Discours admirable de la nature des eaux et fountaines tant naturelles qu' artificielles, etc. Paris. 1586.

†Considerations sur la Theorie des Puits Forés. Hericart de Thury. Paris. 1829, pages 23, 24.

or supply, or an equivalent term, and the water-bearing layer in this region is called the reservoir.

The conditions of transmission embrace a lateral and a vertical element. The lateral element consists of conditions of attitude, continuity, and texture in the water-bearing layer which permit the transmission of water from the reservoir to

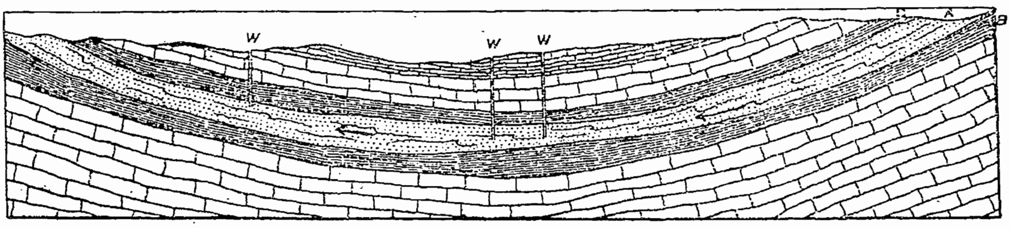


FIG. 29. Synclinal artesian basin. Illustrating also the prevention by upward flexure of terminal escape. *a* Outcrop of aquifer, the area of supply. *b* Lower confining stratum. *c* Upper confining stratum. *w* Artesian wells.

the region of the wells. The vertical component includes the conditions which insure the rise of the water by hydrostatic pressure from the water-bearing bed to or toward the surface, to-wit:

First.—The greater altitude of the gathering ground, and the dip of the water-bearing stratum from it to the region of the wells.

Second.—The confinement of the water of the water-bearing layer within it. Escape above and below is best prevented when the water-bearing layer lies between impervious layers, such as layers of clay or shale. Terminal escape beyond the

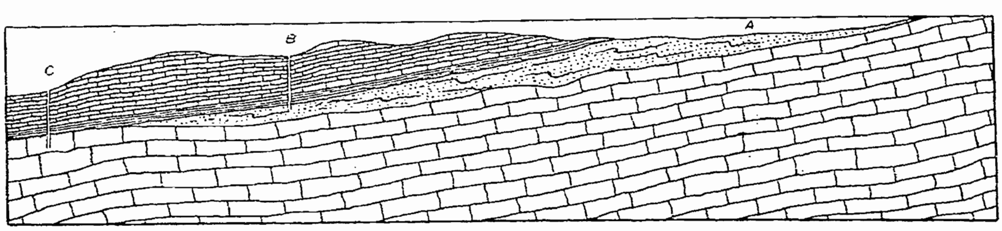


FIG. 30. Prevention of terminal escape by thinning out of aquifer *a*. *b* A successful and *c* an unsuccessful artesian well.

location of the wells is precluded when the water-bearing stratum runs out, is flexed upward, or becomes impervious from change of texture.

A simple illustration of the conditions of structure may be made by setting one basin within another of slightly greater width and depth, the space between them being filled with coarse sand. The sand represents the permeable water-bearing layer, the *aquifer*, to revive a term of Arago's, and its

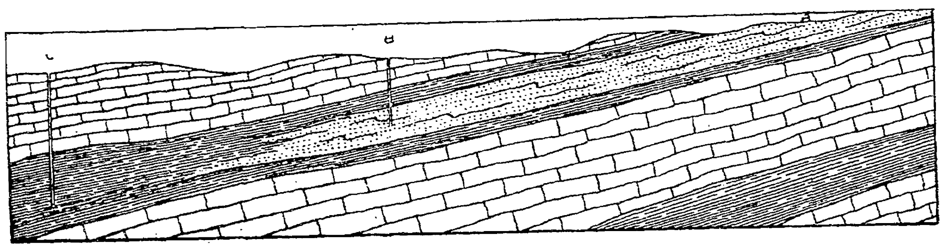


FIG. 31. Progressive change in texture of aquifer, *a*, from an open water-bearing sandstone at outcrop and at *b* a successful artesian well, to a dry sandy shale at *c*, an unsuccessful boring.

outcrop between the basin rims the area of supply. The two basins represent the two impermeable layers which confine the water within the aquifer. If now water is poured upon the rim of sand, it flows onward and downward until the sand is completely saturated. Let now a hole be made in the bottom of the upper basin, and water will be forced upward through it precisely as water rises in an artesian well, *i. e.*, by the pressure of the water held at a higher level.

An illustration of the dynamical element is readily made by taking a tube bent in the shape of the letter U. Water poured into one arm rises in the other, finds its level, and stands at equilibrium at the same height in both. If now one arm is cut off near its base, the weight of the water in the other produces an overflow, which may easily be converted into a jet whose height is proportional to the height of the water in the other arm. This sets forth the fundamental conception of the artesian well; the long arm represents the water-bearing layer; the short, the well; and the jet, the artesian fountain. Simple as the conception is, it may be found somewhat difficult to realize, when one stands by the side of some beautiful artesian fountain in Iowa and watches the constant spring of its sparkling jet high in air. There is apt to recur then something of the ancient sense of mystery and wonder which led men of olden times to think of the fountain as a dwelling place of divinity. Yet the simplicity of the means by which the display is effected really heightens its beauty and charm. The rise of the water from a thousand feet beneath the ground, its upward play for a score of feet in air, is only its return toward the level of its source a hundred miles and more away in the hills of Wisconsin and Minnesota.

A useful variation of the illustration just described is obtained by using, instead of a bent tube as apparatus, a straight tube closed at one end and filled with water. If this tube is tilted at an angle and a hole is bored near the lower end, the water will jet to a height depending upon the difference in height of the orifice and the water level, as is seen by the varying height of the jet as the water sinks in the tube, or as the tube is tilted at different angles. By filling the tube with sand and repeating the experiment, the diminished height of the jet shows the effect of the increased friction. Another hole bored beyond and below the first draws down the original jet and illustrates the effect of terminal escape.

An apparatus ready to hand is supplied by the water works of a town using the gravity system. Here water flows down from reservoir or standpipe through the mains and rises in the delivery pipes under a pressure proportional to the relative height of the reservoir. It is perhaps unnecessary to add that the capacity of the stand pipe has no influence upon the pressure of the water and the height to which it will rise. A standpipe one foot in diameter is as effective in this respect as one of sixty feet, the one exerting the same pressure—friction aside—as the other, under the well known law that hydrostatic pressures depend on depths and densities but are independent of quantities of liquids or shape of containing vessels. The reservoir of the water works is an unfortunate addition to the illustration, since it has no especial counterpart in the artesian system, the water-bearing stratum being itself both reservoir and conduit. The pumps which supply the reservoir may serve to illustrate the energy of the sun, which is continually lifting water from the seas and carrying it far away to the gathering grounds of artesian waters.

A rival theory to the hydrostatic theory which has just been illustrated at such length was that of "rock pressure," which assumed that the water of artesian wells is squeezed out of the aquifer by the enormous pressure of the superincumbent rocks. This was answered by Arago early in the century, but lingering in the popular mind, and again put forward of late years as an explanation of the flows of petroleum and natural gas, it has once more been laid by Lesley* and by Orton.†

Recently it has been revived, as at least a subordinate and occasional factor in artesian flows by Prof. Robt. Hay.‡ Assuming a specific gravity of three times that of water for the strata of a region to the depth of 600 feet, he states that at that depth the pressure of the superincumbent rocks amounts to fifty-two atmospheres, and that if a water-bearing stratum at that depth be pierced by the drill "we should then have the rock pressure of fifty-two atmospheres squeezing the water out of the rock pores, and granting sufficient plasticity in the rock and a sufficient quantity of water, it must rise in the tube which has only the pressure of one atmosphere upon it. A large bore to the well and a small supply of water would be against its reaching the surface. On the other hand, a bed-rock with mobile molecules at or near saturation under this enormous pressure must cause in a narrow tube a flowing well."

No objection need be offered to the supposition that circumstances might occur in which for a short time rock pressure might produce a flow of water under certain assumed conditions. But such occurences must be local and temporary,

*Annual Rept. Penna. Geol. Surv. 1885.

†Geol. Surv. Ohio, Econ, Vol. 6.

‡Final Geol. Rept. of Artesian and Underflow Invest., Sen. Ex. Doc No. 41, 52d Congress, 1st Sess., p. 38, Washington. 1893.

as is the flow from wells sometimes produced by earthquake shocks.

Flow from rock pressure demands as its first condition that the rock of the water-bearing stratum has lost its cohesion. It must be plastic and mobile, crushed and comminuted; otherwise it exerts no more pressure on the water in its interstices than do the iron walls of a water main on the water flowing within them. The walls of a high building exert great pressure on their foundations, but it would hardly be suggested that this "rock pressure," exerted upon the water pipes passing through or beneath these foundations, is the cause of the rise of water from them to the upper stories of the building. And not only must the rock of the water-bearing stratum be crushed and incoherent in order to transmit rock pressure to the water which it contains; that water must also have entered the stratum before the pressure was exerted upon the rock, or before the rock was in a condition of mobility so that it could transmit the pressure to the water. For a pressure sufficient to squeeze water out of a stratum is sufficient to prevent the entrance of water into that stratum. A flow from rock pressure is limited, therefore, to the amount of water which the water-bearing stratum will hold without replenishing.

With the theory of rock pressure as a general cause of artesian flow Arago's summary dealing is still sufficient.* He showed that there are three cases of rock pressure which may be considered. The rocks above and including the upper impermeable stratum either continue to yield until they come in contact with the lower impermeable stratum, or they stop in a position of equilibrium before that contact, or they experience an oscillatory movement. In the latter case the flow will be intermittent, and in the first two cases it will stop entirely, and thus in any case the theory is incompetent to account for the steady flow of artesian wells.

*Sur les Puits Forés, Annuaire par de Bureau des Longitudes, pp. 228-229. Paris. 1835.

In no instance in Iowa is it supposed that artesian flows are caused in any part by rock pressure.

Only one artesian well in the state, a well in glacial drift in Wheatland township, Carroll county, demands any other cause than hydrostatic pressure. Its paroxysmal flow was caused by gas.

ILLUSTRATIONS OF ARTESIAN AREAS.

Districts in which all the conditions of artesian wells that have been named are alike fully met may yet differ from one another in geological structure and in origin. The varieties of artesian areas may be briefly touched upon, before we proceed to the Iowa field.

Many artesian areas form true basins. They are constituted of nested alternating permeable and impervious layers, which sag in the center from uplifted rims upon the margin of the area. To this class belong several desiccated basins of ancient lakes. Sands laid down on the concave floor

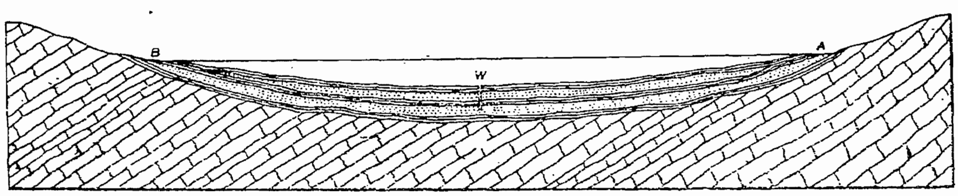


FIG. 32. Artesian basin of lacustrine formation. *a-b*, Line of level of outcrops of aquifer. *w* Artesian well.

of the lake were covered with an impervious layer of fine silts as the lake gradually died away, or by playa wash after its removal. These sands are now easily reached by driven wells, and freely yield the waters which they receive on their exposed margins. Or the strata in which the lake basin was originally excavated may be permeable in texture, and, being overlain by water-tight lacustrine clays, may yield artesian waters at comparatively little depth. Examples of lacustrine artesian basins are those of the Salt Lake valley of Utah, and the San Luis valley of Colorado, the latter of which supplies some 3,700 artesian wells.

In other instances the central depression is due to an ancient river valley toward whose median line sands of various derivations and covering, often Pleistocene in age, slope from the margins. The artesian basin of the Red River valley seems to be of this class.

The basin form may also be displayed in transverse sections of estuaries eroded and filled in past geological epochs. One of the best known of these is the famous London basin. Here interbedded sands and clays were laid down in a shallow depression cut in the chalk, the estuary of a Tertiary river, and afterwards sealed by several hundred feet of river silt called the London clay. In this clay the present valley of the Thames is eroded. As London occupies the central portion of the basin, borings there made through the London clay tap water in the sands beneath and in the chalk, under sufficient hydrostatic pressure to produce artesian flows, and during the early part of the century these constituted to a large extent the water supply of the city.

To this class belong also synclinal basins formed by folding of strata originally horizontal. Such basins are illustrated in figure 30, p. 129.

The basin or synclinal structure, however, is not an essential artesian condition. More often the attitude of the retaining and water-bearing beds is monoclinal. They slope in one direction from the higher ground of the receiving area toward plain or sea, often with a gradient so slight as to be almost imperceptible. The largest artesian fields of the

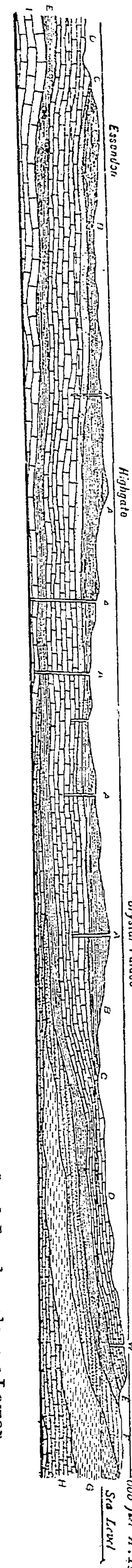


FIG. 33. Estuarian artesian basin. Section across the Thames basin—36 miles. After Prestwick. *a* Bugshot sands; *b* London clay; *c* Lower Tertiary strata: *d* Chalk; *e* Gault; *f* Lower Greensand; *g* Wealden; *h* Jurassic; *i* Paleozoic; A artesian well.

world belong to this class; the Australian field, the Atlantic and Gulf fields of the United States, the Texas field, the Dakota field, and the field of the Upper Mississippi valley, in which the Iowa field is included. This is due to the fact that their terranes are geological formations, sea laid, of vast extent and often of great thickness. They preserve to some degree the slant of the ocean floor as it sloped downward from the margin of an old continent, though this dip is often accentuated and altered by the epeirogenic movements that

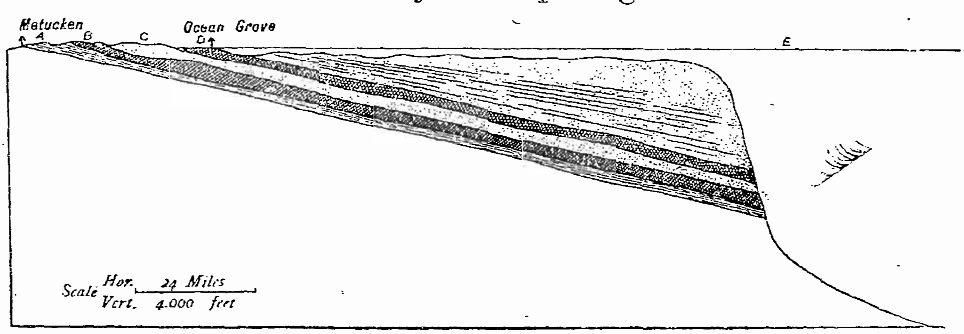


FIG. 34. Monoclinal artesian area of southwestern New Jersey.* *a* Raritan clays; *b* Clay Marls; *c* Greensand Marl beds; *d* Upper Marl bed; *e* Atlantic ocean.

lifted them above the sea, and less frequently by orogenic, or mountain making, movements also. See figure 33, and also figure 35, on p. 137.

The Iowa Field and its Artesian Conditions.

The artesian field of Iowa is but a part of an extensive basin, which may be termed the artesian area of the upper Mississippi valley. It includes a portion of Missouri, a large part of Illinois, and southern Wisconsin and southern Minnesota. In the two states last mentioned lies the area of intake for the entire field, and from this higher gathering ground there slopes southward a complex of strata which furnishes the various other requisite conditions for artesian wells.

Attention must be given for a little space to this assemblage of geological formations. For the conditions of the accumulation and transmission of water beneath the surface are almost wholly geological. A complete geological section across any

* From Ann. Rept. New Jersey Geol. Survey. 1884

state or region in a humid climate supplies of itself data from which may be calculated for any point along the line of the traverse, the depth at which artesian water can be found, or whether it can be found at all, the height to which it will rise, and its probable quantity and quality. For such a section shows what strata are by their texture, continuity and outcrop made the aqueducts of subterranean waters. Their thickness, uniformity of thickness, and the dimensions of their outcrops, together with the nature of the overlying and underlying beds, afford measures of the quantity of water available, and their dip and the profile of the section afford data by which the heights to which water will rise in wells can be estimated. The lithological nature of the beds indi-

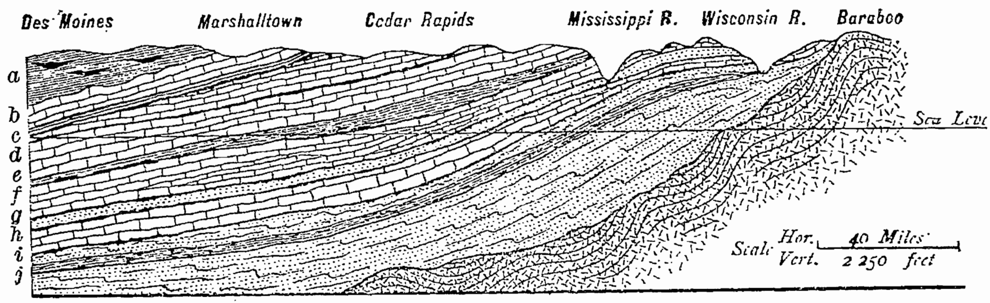


FIG. 35. Geological section from Baraboo, Wisconsin, to Des Moines, Iowa, showing the general stratigraphy of the Iowa artesian area and of the Wisconsin gathering ground. The chief aquifers are he Saint Peter, the Jordan and the Basal sandstone. The line of juncture of the Basal sandstone and the Algonkian is hypothetical. *a* Des Moines; *b* Mississippian; *c* Kinderhook; *d* Devonian; *e* Silurian; *f* Hudson River; *g* Galena-Trenton; *i* Oneota; *j* St. Croix, including the Jordan, St. Lawrence and Basal sandstone.

cates the kind and degree of the mineralization of the water. Some understanding of the general geology of Iowa is therefore pre-requisite to the consideration of the local artesian problem.

Geological Structure.

The rocks of the great sedimentary series in Iowa include nearly all of the formations of the Paleozoic system and contain representatives of the Mesozoic also. Above the foundation crystallines and quartzites of the Algonkian, they consist of sandstones, shales, and limestones, many times repeated and in varying order. These great sheets of rock lie with a gentle southward inclination. In the northern portion of Iowa they also sag from the eastern and western boundaries of the state toward a median line, forming a shallow trough whose axis extends north and south in about the longitude of the Upper Des Moines river. In southern Iowa the western limb of this syncline is depressed, and over the southwestern counties the strata lie more nearly level. In southeastern Iowa the lower terranes of the Paleozoic rise in a dome now covered and concealed by the later formations of the same series.

The attitude of the strata as we have just described it may be roughly illustrated, if the reader will lay a sheet of paper on the table before him, and then lift it for an inch or so by the upper right hand and upper left hand corners—the former a little higher than the latter—at the same time slightly raising the lower right hand corner, as with a pencil laid underneath it.

While this illustration represents the lie of the sedimentary series as a whole, it fails to bring to mind the disposition of the outcrops of the different formations of which the series is composed. On consulting the map, plate V, it will be seen that east of the Des Moines river these outcrops lie in approximately parallel and concentric belts, surrounding the elevation of the northeastern corner of the state, and stretching from the Minnesota line across the state to the Mississippi river in northwest southeast direction, at right angles to the dip of the strata. West of the Des Moines river the disposition of the surface strata is under the control of two great unconformities—excluding that of the drift—the unconformity of the coal measures, and that of the Cretaceous, with the underlying terranes. The Cretaceous, in especial, is conceived to cover the upturned and beveled edges of the older formations, which otherwise would appear surrounding the elevation of the northwestern corner of the state in concentric belts narrower but similar to those which girdle the northeastern elevation.

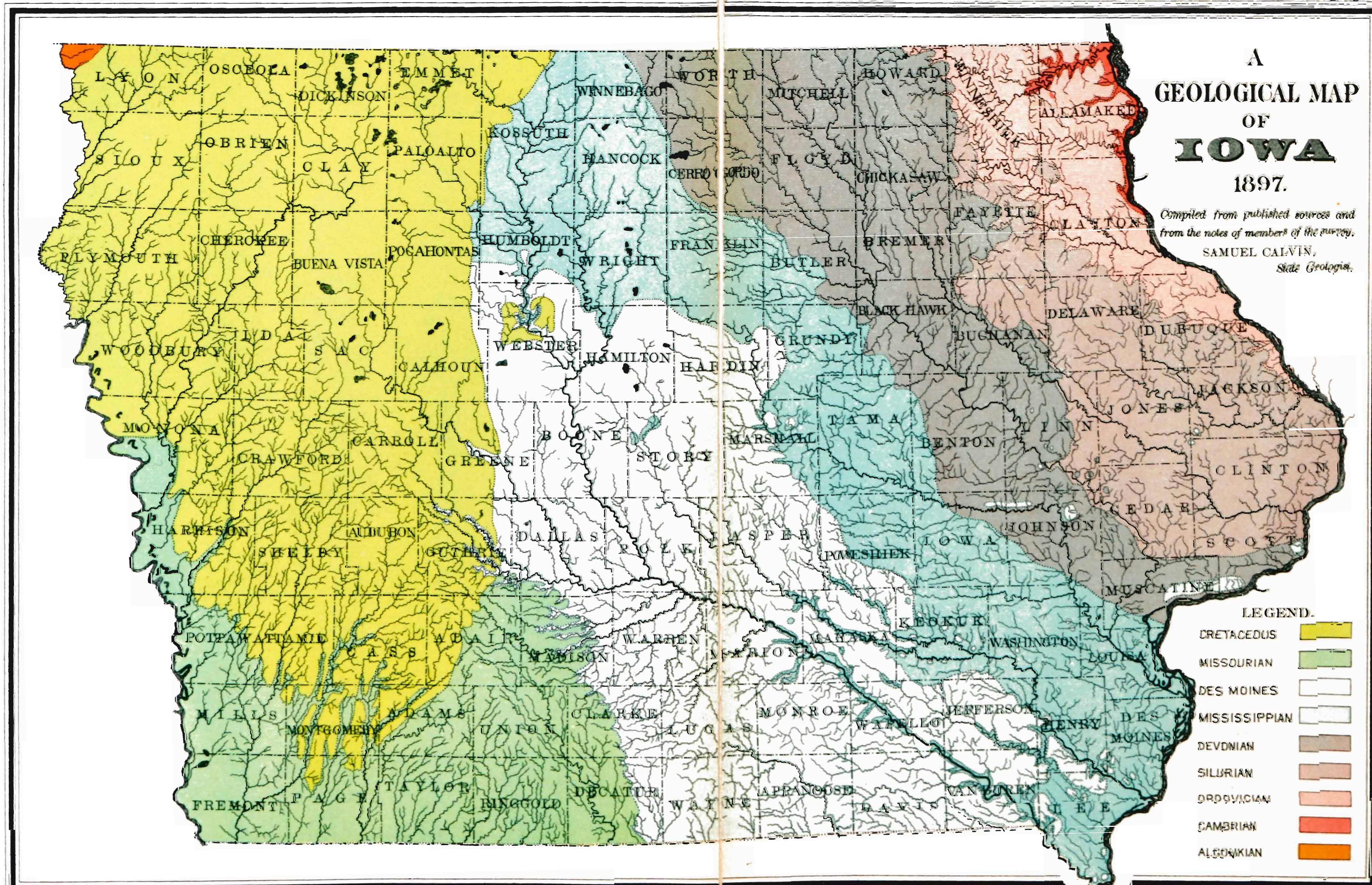
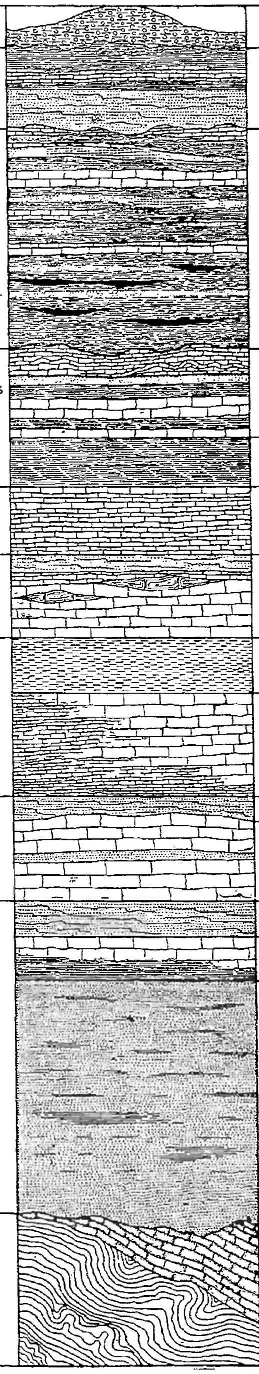


Photo-Lith. by A. Hoen & Co., Balto. Md.



GROUP	SYSTEM	SERIES	Thickness	STAGE	SUB-STAGE
CENOZOIC	PLEISTOCENE		200		SUBSTAGES NOT DISCRIMINATED IN DEEP-WELL SECTION
MESOZOIC	CRETACEOUS	Upper	400	*Montana* *Colorado* *Dakota*	
PALEOZOIC	CARBONIFEROUS	Upper Carboniferous or Coal Measures	1060	*Missouri* *Des Moines*	
		Lower Carboniferous or Mississippian	420	*Saint Louis* *Augusta*	
			250	*Kinderhook*	
	DEVONIAN	Upper Devonian Middle Devonian	300	*State Quarry* *Lime Creek* *Cedar Valley* *Wapsipinicon*	
	SILURIAN	Oriskany ? Salina ? Niagara	415	*Niagara—Clinton*	
	ORDOVICIAN		275	*Hudson River*	MAQUOKETA
		Trenton	500	*Trenton*	GALENA – TRENTON
			100	*Saint Peter*	
		Canadian ?	600	*Oneota*	UPPER ONEOTA NEW RICHMOND LOWER ONEOTA
	CAMBRIAN	Potsdam	160		JORDAN
			230		SAINT LAWRENCE
			1110	*Saint Croix*	BASAL SANDSTONE
PROTEROZOIC	ALGONKIAN	Huronian	750	*Sioux Quartzite* *Undetermined* *Gneiss and Schist*	

Scale: 1 c m=200 feet.

GENERAL GEOLOGICAL SECTION OF IOWA.

Exhibiting the maximum thickness of each formation as shown in deep well sections.

By W. H. Norton.

It will often be necessary to refer to the various geological formations which are pierced by the drill in different parts of the state, and if the reader is somewhat unfamiliar with them, or with their recent nomenclature, the chart may be consulted—plate VI—which presents graphically their place and nature and greatest thickness. Let it be remembered that the table does not represent the thickness of the entire sedimentary series as it will be found at any one locality. Where one formation is thickest, another may be thin or absent. The table states the maximum thickness of each formation as disclosed in the present investigation, and it may be compared with the general geological section of Keyes,* which gives the thickness of the formations as estimated at that time from their outcrops. The sum of the thicknesses of the geological formations above the Sioux quartzite as given by Keyes amounts to 4,700 feet. In our computation the sum of the maxima of the same formations reaches 6,020 feet, and that, too, although the thickness of the coal measures is reduced over 500 feet.

The formations of Iowa have been frequently described in geological literature, and no detailed account of them need here be given. The changes which obtain as they pass beneath the surface beyond their outcrops were stated, so far as then known, by the author in a previous paper.* The present investigation has added a number of interesting facts to those already known, and a brief summary may here be useful, although the full account of the geology of the deeper strata will be found in the following section under the discussion of the geology of each of the sections along which the wells of the state are ranged.

ALGONKIAN.

The lowest, the oldest, and the only metamorphic or crystalline rocks of Iowa belong to this age, so inconceivably remote that none but the humblest forms of living creatures

*Plate ii, vol. I, Iowa Geological Survey. 1893.

*Thickness of Paleozoic Strata Northeastern Iowa. Iowa Geol. Surv., vol. III, pp. 174-186.

then tenanted the earth. The Algonkian outcrops in the northwestern corner of Iowa, where it is known as the Sioux quartzite, a familiar building stone in the larger towns of the state. It sinks rapidly to the south and east, and is discovered near the region of its outcrop only by the deep wells at Sioux City, Hull and Le Mars. A similar outcrop occurs to the northeast beyond the limits of the state at Baraboo, Wisconsin. From this latter outcrop the Algonkian sinks more gently to the southwest and is reached by the drill at Lansing.

In east central Iowa there seems to occur another elevation of the Algonkian floor. This is comparatively a slight one, and is disclosed by the artesian well at Cedar Rapids. At no other station in Iowa has the drill gone deep enough to pierce the entire thickness of the Paleozoic rocks.

SAINT CROIX.

BASAL SANDSTONE.

The Algonkian floor is probably one of great diversity of relief. Upon its buried hills and valleys rests unconformably a massive sandstone. In places this contains layers of a conglomerate of water-worn pebbles, but more frequently it passes in part into arenaceous shales and marls. The Basal sandstone is laid down with an enormous thickness befitting the foundation terrane of the Paleozoic series. In the northeastern corner of the state it is 800 feet thick. As far south as Aledo, Ill., it still maintains a thickness of at least nearly 1,000 feet. At Dubuque it is over 1,100 feet thick, the bottom of it not being reached. Toward the west the Basal sandstone diminishes in thickness, and it seems to attenuate rapidly as it rises on the western side of the central Iowa syncline. The divisions of the Basal sandstone adopted by the Minnesota Geological Survey have not been clearly made out in Iowa, and it does not seem well to designate it by any of the local terms that have been used for this purpose in other states. It is the equivalent of the "Potsdam," as this term is employed by Hall and Sardeson, but its identity with the typical "Potsdam" of New York remains to be proven. As used by Hall in the first geological survey of Iowa and by the Wisconsin geologists, the Potsdam includes not only the Basal sandstone, but the Jordan and Saint Lawrence also. As used by the state geologists of Minnesota, the Potsdam is restricted to the quartzites which in Iowa have been alloted to the Algonkian. Avoiding, then, the use of a term so ambiguous, which has at least three distinctly different meanings in the geological literature of the upper Mississippi valley, we designate provisionally as the Basal sandstone the strata included between the summit of the Algonkian and the base of the Saint Lawrence, which is the first formation of dolomites and shales below the Jordan. It thus embraces the equivalents of the Dresbach sandrock with the unnamed shale beneath it, and of the Hinckley sandrock with the unnamed red shales and red sandrock beneath it.

With our present knowledge, the Basal sandstone may be ranked as the lowest member of the Saint Croix. In the earlier stages of the investigation it was designated simply as a sandstone lying below the formation then termed the Lower Saint Croix.* In this preliminary paper a dual division of the Saint Croix in Iowa was proposed, the upper member being termed the Upper Saint Croix, consisting of sandstones; and the lower member the Lower Saint Croix, composed of dolomites and shales. Ranking now the Basal sandstone with the Saint Croix, these terms lose their appropriateness; and the progress of the investigation so fully confirms the earlier differentiation that we need hesitate no longer to apply to the strata of the Saint Croix lying above the Basal sandstone, the terms already in use in Minnesota, viz., the Jordan sandstone and the Saint Lawrence dolomites and shales.

SAINT LAWRENCE AND JORDAN.

The Saint Lawrence dolomites and shales rest directly upon the Basal sandstone. In eastern Iowa they constitute a well

*Thickness of Paleozoic strata of Northeastern Iowa, Iowa Geol. Surv., vol. III, pp. 185-186.

defined terrane of moderate thickness, but to the west they are not well defined with the scanty data at hand. They are usually glauconiferous and arenaceous. The Jordan sandstone succeeds the Saint Lawrence. It is a saccharoidal sandstone of light color. Its usual thickness is from one hundred to two hundred feet. The combined thickness of the two upper divisions of the Saint Croix is singularly uniform and averages about three hundred feet. Both the Jordan and Saint Lawrence outcrop in the extreme northeastern part of the state, where they were first recognized in the field in Iowa by Calvin* as distinct formations.

UPPER ONEOTA, NEW RICHMOND, AND LOWER ONEOTA.

Upon the Jordan sandstone rests a massive dolomite, designated by Hall and by White in the earlier geological surveys of the state as the Lower Magnesian. By the present Survey this is called the Oneota, a term proposed by McGee. In the author's previous investigation of the deep wells of eastern Iowa, this dolomite was found to be divided by a medial sandstone, the equivalent of the New Richmond of the Wisconsin and Minnesota geologists. Arenaceous strata corresponding to the New Richmond were also found in the field by Calvin in the outcrops of the Oneota in Allamakee county. As the New Richmond occasionally fails to appear in deep well sections it is found convenient to retain the Oneota as a term including the entire body of dolomite between the Jordan and the Saint Peter. McGee, however, limited the original definition to the lower division here called the Lower Oneota, termed by the Minnesota survey the "Main body of limestone." The Upper Oneota of this paper, the equivalent of the Shakopee of Minnesota, McGee included, together with the New Richmond, in the Saint Peter. But the evidence here presented proves the Upper Oneota so thick and so persistent that no reason remains for

*Geology of Allamakee county, Iowa Geol. Surv., vol. IV. 1894.

including it in a formation so distinctively a sandstone as is the Saint Peter. Its alliance is clearly with the Oneota.*

The evidence from deep wells proves also what before was a matter of conjucture only, that the Oneota passes south and west of the narrow area of its outcrop in Allamakee and Clayton counties and underlies nearly the whole of the state. Throughout this great extent it preserves unchanged the characteristics of its outcrop, its complete and perfect dolomitization and its greater or less admixture with arenaceous material. The thickness has not been found less than that of its outcrop, which has been estimated at 300 feet. Over northeastern Iowa it ranges from 300 to 400 feet. At Boone it may reach 500 feet, at Ames about 600 feet and in southeastern Iowa it seems to be still thicker. The Upper Oneota alone is usually about 100 feet thick.

Thus below the Saint Peter the drill enters three great masses of dolomite, the Upper Oneota, the Lower Oneota and the Saint Lawrence. These three formations with the intervening sandstones have been classed together by Hall and Sardeson as the Magnesian series. This term is particularly welcome to students of artesian records, since the upper and lower limits of the series are so well marked that drillers usually recognize them even when they may fail to put on record the different members of it. The entire thickness of the series ranges from between 500 and 600 feet in northeastern Iowa to 700 feet in central Iowa, and to 800 feet and over in the southeastern portion of the state. The aggregate of the maxima of the five different formations which constitute the series, as given by Hall and Sardeson,* amounts to 673 feet in Minnesota.

The following table exhibits some of the various designations which have been used in the classification of the

*This classification of the Oneota is clearly stated in the author's previous paper on the deep wells of Iowa; Iowa Geol Surv., vol. III, pp. 180-184, and it is difficult to conceive how we could have been misunderstood and misquoted by Sardeson as including the Upper Oneota and the New Richmond with the Saint Peter, as stated in his paper on the Saint Peter sandstone. (Bull. Minn. Acad. of Nat. Sci., vol. IV, No. 1, Pt. 1, pp. 65-80.)

*The Magnesian series of the northwestern states. Bul. G. S. A., vol. VI, p. 170.

Cambrian of the Upper Mississippi valley. The Saint Peter is added for the sake of clearness.

IOWA.	IOWA. M'GEE.	MINNESOTA. N. H. WINCHELL.	MINNESOTA. HALL AND SARDESON.	WISCONSIN.
Ordovician.	*Lower Silurian.*	*Cambrian.*	*Lower Silurian.*	*Lower Silurian.*
Saint Peter.	Saint Peter. (Saint Peter, Upper Oneota, New Richmond)	Saint Peter.	Saint Peter.	Saint Peter.
Upper Oneota.			*Cambrian.*	*Cambrian.*
New Richmond.		Shakopee.	Shakopee.	Willow River.
Lower Oneota.	Oneota.	New Richmond.	NewRichmond	New Richmond.
		Main Body of Limestone.	Oneota.	Main Body of Limestone.
Cambrian.	*Cambrian.*			
St. Croix: Jordan.	Potsdam. (Jordan, St. Lawrence, Basal Sandstone)	St. Croix: Jordan.	Jordan.	Potsdam: Madison.
St. Croix: St. Lawrence.		St. Croix: St. Lawrence	St. Lawrence.	Potsdam: Mendota.
St. Croix: Basal Sandstone.		St. Croix: Shales.	Potsdam. (Shales, Dresbach, Shales, Hinckley)	Potsdam: Calc. Sandstone.
		St. Croix: Dresbach.		Potsdam: Sandstone.
		Shales.		
		Hinckley.		

SAINT PETER.

This bed of white incoherent sand is also a remarkably persistent formation. In no well in the state deep enough to reach its assumed horizon does it fail to appear, if the record and other data are complete. The normal thickness seems to be about 100 feet. It never much exceeds this limit; and it occasionally pinches to thirty or even to fifteen or twenty feet, either from inequalities in the surface of the Upper Oneota, or from erosion suffered before the Trenton was laid down upon it.

At a few points the Saint Peter includes intercalary beds of shale, as at Boone and Sabula, and of limestone as at Dubuque and possibly at Postville. More frequently passage beds of shale occur in the Upper Oneota to the Saint Peter. These are specially heavy at Anamosa. Commonly the Saint Peter is overlain by Trenton shales which sometimes are arenaceous, as at Washington.

In the midst of the oscillations of the Ordovician sea bottom and the shifting of its shore line, which permitted now the laying down of the limestones and shales of the Upper Oneota and now the shales and limestones of the Trenton, there occurred the conditions which now can scarcely be imagined on which depended the deposition of the Saint Peter sandstone. The succession from the Saint Peter upward may be explained by a depression of a base-leveled Oneota land allowing the sea to transgress the whole width of Iowa and far into Wisconsin and Minnesota. As the land gradually subsided the long line of its sea beaches advanced little by little toward the north and east, leaving spread out behind it a broad sheet of beach sands, just as the prairie fire leaves in its track a continuous area of burned and blackened vegetation. In coast marshes these sands would, by organic acids which would dissolve their ferruginous stains, be bleached white as we see them to-day. With continued subsidence they would be covered with finer sediments, with clays and marls washed from the shore, and at last with the limestones of the deeper Trenton sea. In some such way, perhaps, was this one of the channels for the future artesian waters of the state made ready. But a difficulty lies in the nature of the grains of this white sand. They are rounded and worn and polished as are no beach sands on any sea coast to-day. Possibly their forms may have been given them by the wind, and they were long blown about in some ancient desert before they were sea laid. However this may be, these rounded, incoherent grains make an excellent water-way, and they are so distinct from any sandstone above them that the experienced driller may always be expected to recognize the Saint Peter when he comes to it.

GALENA-TRENTON.

As used in this report, the Galena-Trenton includes both the lower non-magnesian limestone and shales to which the term Trenton is popularly restricted and also the upper dolomite beds which are known as the Galena, the lead-bearing rock of

Dubuque county and adjacent areas in Wisconsin and Illinois. The difference between the Galena and the Lower Trenton is considered merely lithological and not formational. That the two constitute but one formation whose strata have been differently affected in different places by the process of dolomitization is well nigh proven by the results of investigation of deep wells of the state. To demonstrate their formational identity it will be necessary to trace through both the same life zones and this may be left in confidence to future work in the field. It was indeed from paleontological evidence gathered in Minnesota that the suggestion was first made by N. H. Winchell* that the "Galena limestone is only a phase of the Trenton, intensified in the typical region, but fading out in all directions. It is a convenient designation in Iowa and some parts of Wisconsin and Illinois, but in Minnesota its convenience hardly warrants its continued use."

The same conclusion was reached by Calvin† from his examination of the samples of the Postville well, and it is fully corroborated by a large amount of still stronger evidence from other borings. In the western part of the state the limestones of the group appear wholly magnesian. In eastern Iowa the upper portion only is dolomitic, yet occasionally even here the entire body of strata has been dolomitized, as at Sabula. Occasionally the whole formation escaped dolomitization, as at Manchester and Postville.

The lower beds of the Trenton are often shaly. Bituminous shales, occurring at Washington, Cedar Rapids, and Anamosa, still encourage the hope that possibly in Iowa the drill may sometime strike beneath the saddle of an anticline some store of gas or oil, such as in other states are derived from similar beds at the same horizon.

The thickness of the Galena-Trenton usually lies between 300 and 400 feet. At Calmar we have provisionally assigned 538 feet to it, and at Des Moines nearly as much. In extreme

*The Age of the Galena Limestone. Am. Geol., vol. XV. p. 33 1895.

†Am. Geol., vol. XVII, pp. 195-203. 1896.

southeastern Iowa it attenuates over the dome of the Lower Ordovician strata and is only 140 feet thick.

MAQUOKETA SHALE.

This is a heavy bed of bluish or greenish shale, usually somewhat calcareo-magnesian, outcropping in a narrow belt in northeastern Iowa from Clinton to the Minnesota line. Its greatest estimated thickness of outcrop has been 100 feet.* But in this investigation it has been found to underlie the larger portion of state, and to reach an unsuspected maximum thickness of about 275 feet in east central Iowa in the valley of the Cedar. It is often parted by a bed of dolomitic limestone, and it is not impossible that, were fossils obtainable, the lower shale would be found to belong to the Galena, which in part passes into shale in Minnesota.

SILURIAN.

The Maquoketa is the highest member of the Ordovician, or Lower Silurian. The Upper Silurian, or the Silurian as it is better termed, comprises in eastern Iowa several divisions which are all included, so far as our present knowledge goes, in the Niagara. These divisions do not concern us in this investigation, since they can not be discriminated in the powdered rock of well drillings. Passing westward and southward from the outcrop, the dolomites of the Silurian are affected with lithological changes which indicate the presence of other formations than the Niagara. At Marshalltown the Silurian contains gypsum, and at Des Moines, Pella, Oskaloosa and Glenwood, gypsum and gypseous marls are so pronounced a feature that the Onondaga salt group may be held to be present with a fair degree of probability. Again, to the south the Silurian becomes arenaceous, as was first noted by Calvin in the deep well at Washington. These Silurian sandstones extend widely over southeastern Iowa, and would naturally fall in with the Oriskany. The greatest certain measurements of the Silurian are obtained at Davenport,

*Keyes, Iowa Geol. Surv., vol. I, Plate ii.

344 feet, and at Cedar Rapids, 415 feet. At Des Moines we have assigned it a thickness of 507 feet. If our interpretation of the data is correct, it persists as far to the southwest as Glenwood, retaining there a thickness of 400 feet. The Niagara feathers out in the extreme northern part of the state. In northwest Iowa it is probably wanting, and over the dome in southeastern Iowa it attenuates to 120 feet at Keokuk.

DEVONIAN.

The following classification of the Devonian represents the results of recent investigations in the field.

SYSTEM.	SERIES.	STAGE.	SUB-STAGE.
Devonian.	Upper Devonian.	State Quarry.	
	Middle Devonian	Lime Creek.	Owen. Hackberry.
		Cedar Valley	Mason City. Solon.
		Wapsipinicon.	Upper Davenport. Lower Davenport. Independence. Otis.

These divisions have not been clearly made out in the records of the deep wells. The limestones are indistinguishable one from another in the rock-meal and powder of the drillings. The Independence shale is probably not persistent over wide areas, and the Lime Creek shale cannot be separated in well sections from the similar shale, called the Kinderhook, which directly overlies it. In the northern part of the state, where the Devonian is dolomitized, it becomes difficult or impossible to draw the line of demarkation between it and the underlying dolomites of the Silurian. For these reasons the thickness of the Devonian cannot be stated with confidence. It probably somewhat exceeds 300 feet immediately west of its outcrop in central Iowa.

KINDERHOOK SHALES.

This heavy bed of shale outcrops at many points from Burlington northwestward along the western portion of the Devonian outcrop and the eastern limit of the Mississippian. Heretofore it has been classed with the latter formation, but the evidence at hand now seems to indicate an alliance rather with the Devonian, Since the question is still unsettled, the Kinderhook shale is as far as possible separated from both formations in our sections. In consulting these sections it must be remembered that it may include any upper shales of the Devonian and may indeed belong wholly to that age.

At Marshalltown the Kinderhook shale is 175 feet thick. In southeastern Iowa it reaches a maximum thickness of from about 200 to 250 feet. Any limestones of the Kinderhook must here be classed with the undifferentiated Mississippian.

MISSISSIPPIAN.

As this term is often here used, it does not include the Kinderhook shale, but consists of the various stages of the Lower Carboniferous, which lie above that formation. These stages have been skillfully made out in southeastern Iowa by Bain, Keyes, and Gordon. At a distance from the outcrop they usually cannot be distinguished. Specially characteristic of the Mississippian are the cherty beds which it carries. These are particularly noticeable at Glenwood and Atlantic, and their significance in indicating the horizon of the floor of the Upper Carboniferous in that region is discussed under the geology of southwestern Iowa in another part of this report.

At Atlantic and at Boone the Mississippian, exclusive of the Kinderhook shale, seems to be about 400 feet thick. At Oskaloosa it may be 455 feet thick, but our data there are not reliable. The Mississippian may be assumed to underlie the entire Carboniferous area of the state, and it probably extends widely into northwest Iowa beneath a cover of Cretaceous sediments and drift.

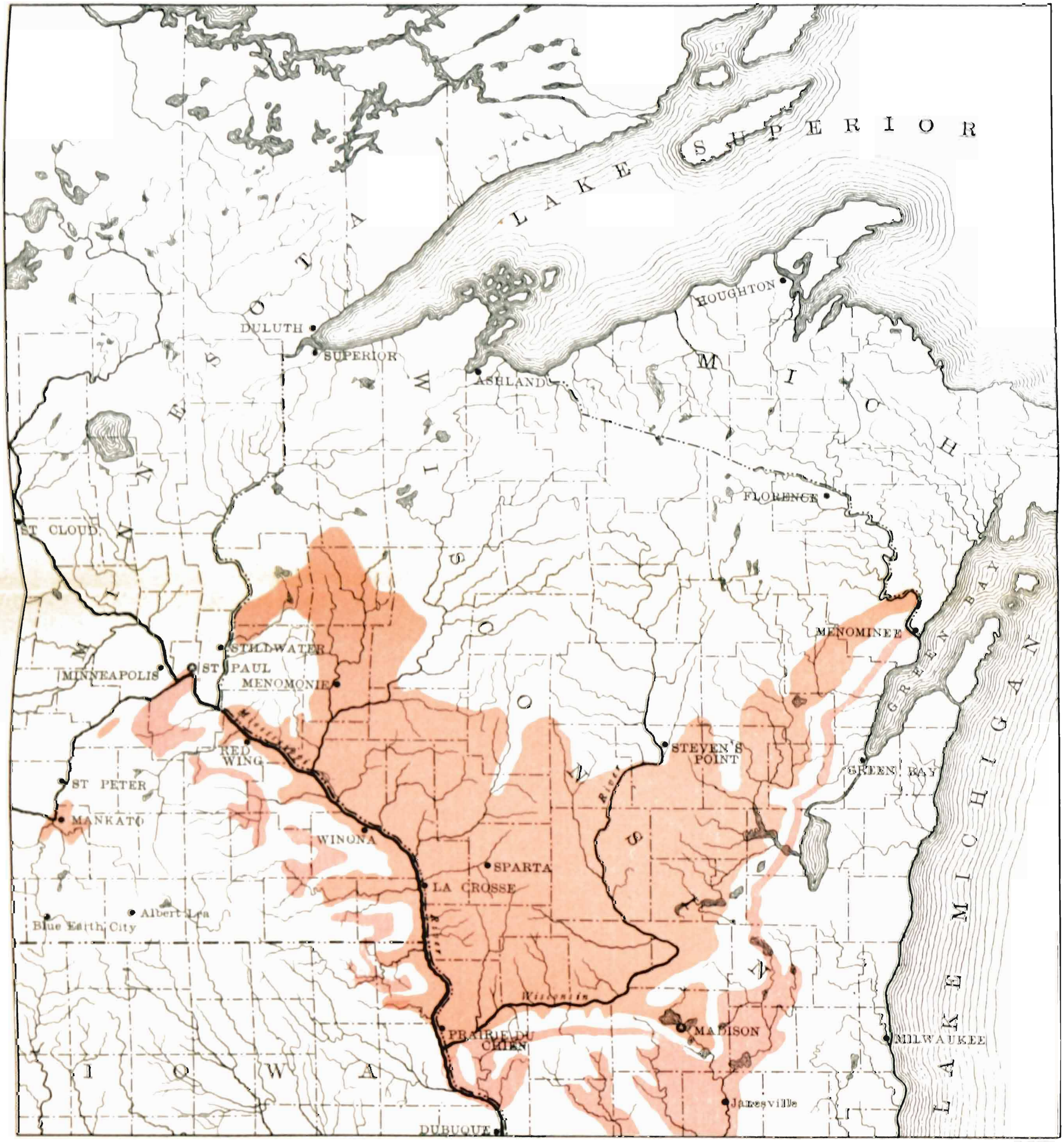
UPPER CARBONIFEROUS.

There are but one or two wells in the state with complete records so situated that they could be expected to show the division of the Upper Carboniferous into its two stages, the Missouri, or Upper Coal Measures, and the Des Moines, or Lower Coal Measures. At Glenwood this division is clearly drawn, the Missouri being 670 feet thick and the Des Moines 390 feet thick. The total, 1,060 feet, is the maximum observed thickness of the Coal Measures in Iowa. Possibly they may be somewhat thicker to the east and south, but the enormous estimates of nearly double this thickness that have been freely made are without foundation in fact. Singularly enough the first estimate of the thickness of the Iowa Coal Measures, made by Hall nearly forty years ago, coincides with that given by this investigation. At Centerville the Des Moines is probably about 600 feet thick, so that the sum of the maxima of the Des Moines and Missouri is nearly 1,300 feet.

From southwestern Iowa the Coal Measures attenuate to the north and east. At Des Moines they are still nearly 400 feet thick, and they spread uncomformably in outliers over all the outcrops of lower formations as far as the Ordovician. The few artesian well borings over the coal area have discovered no seams of coal suitable for profitable working, and so far they confirm the conclusion of the essentially local character of the coal seams of the Iowa field.

THE CRETACEOUS.

By the end of the Carboniferous the entire surface of Iowa had emerged from the sea, and it remained a land surface until, at the end of the Lower Cretaceous, the western portion at least of the state subsided sufficiently to allow an invasion from the west of the Cretaceous sea which then covered the Great Plains. The first sediments laid down consisted of a body of strata known as the Dakota. This is composed largely of sandstone, and to the northwest constitutes the



PRINCIPAL COLLECTING AREA OF THE ST CROIX AND ST PETER SANDSTONES.

artesian reservoir and aquifer of the Dakota artesian area. From this area Iowa is unfortunately separated by the outcrops of earlier formations and the valleys of intervening rivers. The Dakota, however, constitutes a well defined water horizon in northwestern Iowa, extending nearly or quite to the valley of the Des Moines river. So gentle is the inclination of the Dakota that its waters have low head, and they are usually unfit for public supply from the large amount of mineral salts which they have taken up from the marls with which the water-bearing sandstones are interbedded. Above the Dakota lie various members of the Cretaceous, which sometimes have been pierced by the drill, but of which nothing new has been thus learned. The Cretaceous frequently contains beds of lignite, and these and the buried vegetal accumulations of the drift sometimes evolve large quantities of gas—chiefly carbon dioxide, or choke damp—which, when set free by the drill, produces the curious phenomena of the "blowing wells" of northwestern Iowa.

Area of Supply.

The chief artesian supply of Iowa is derived from the outcrops of Ordovician and Cambrian sandstones in Minnesota and Wisconsin. The size of this area, which forms the main gathering ground of Iowa artesian waters, may be roughly estimated at about 14,500 square miles. Its irregular form and topographic relations are exhibited on the accompanying map, Plate VII.

The outcrop of the Saint Peter occupies a U-shaped area extending from St. Paul, Minn., to the mouth of the Turkey river, in Iowa, thence across southern Wisconsin along the valleys of the Wisconsin and Rock rivers, and thence northeast parallel with the shore of Lake Michigan, to at least the southern boundary of the Upper Peninsula. Over much of this region the Saint Peter forms a narrow sinuous band, following the streamways and branching and rebranching with their tributaries, until in any river basin the form of the area resembles the outline of a compound pinnatified leaf. Occasionally it widens and overspreads broad areas, especially where the cover of the Trenton limestone has been removed by erosion. In profile it varies from long and gentle slopes and undulating surfaces, the result of degradation, to vertical precipices caused by corrosion and sapping. The total area in Wisconsin and Minnesota, as estimated from the maps of the geological surveys of the two states, is about 2,000 square miles. This estimate may well be excessive, as the width of the band representing the outcrop of the sandstone is probably exaggerated in many places for the sake of distinctness. On the other hand, the artesian gathering ground really includes large unestimated areas in both states, where the Saint Peter is concealed by drift, where the Trenton limestone above it is pervious and forms the country rock, and where the lie of land directs to the outcrops of the Saint Peter the drainage of superior terranes.

The Cambrian sandstones, termed the Potsdam or Saint Croix, divided in this report into the Jordan and the Basal sandstone, outcrop with their included dolomites in a crescentic area whose eastern horn touches Mackinac, and whose western horn extends nearly to Duluth. Lying within and to the north of the Saint Peter area of outcrop, it is separated from it by a belt of the Oneota, or Lower Magnesian limestone. It resembles the Saint Peter in the form of its outcrop along the tributaries of the Minnesota and the lower Wisconsin rivers, but in central Wisconsin it occupies a broad and continuous field of several thousand square miles. The total area in Wisconsin is estimated by Irving at about 12,000 square miles. In Minnesota probably about 500 square miles are occupied by Cambrian sandstones.

CONDITIONS OF SUPPLY.

It is a matter of common knowledge that in its source artesian water is the same as the water of stream and rain and cloud. The mystery which once enveloped the spring has been dispelled for centuries. No longer is it believed to be the home of naiad, or to have been struck into existence by the hoof of Pegasus. The view of Aristotle, that springs flow from hidden caverns on whose cool sides air has changed into water by condensation, the view of Des Cartes, who assumed similar condensing chambers as parts of vast subterranean distilleries in which water, drawn through fissures from the ocean, is vaporized by the interior heat of the earth —all such ingenious hypotheses of philosophy have yielded to the simple conceptions of experimental science. Yet these early views are not yet quite extinct. They linger in the minds of some citizens of even more than average intelligence, as the writer has discovered with a pleasure akin to that with which he might come upon a living trilobite or a colony of the life forms of a previous geological epoch.

Over nearly the entire surface of the earth, water passes unobserved into the atmosphere. It is imbibed as vapor from sea, lake, and river; from forest, meadow and sown land; from snow and ice field; from all humid surfaces everywhere. While it remains in the air as invisible vapor, or as fog, cloud, rain or snow, it is known as *meteoric water*. Reaching the surface of the earth as rain it is termed *storm water*, and it is designated *stream water* as it returns through its natural subaerial channels to the sea.

Part of storm water sinks directly into the earth, the relative amount depending upon several factors. The plowed field, for example, absorbs more than the sod, sand more than clay, creviced limestone more than compact granite, level lands more than steep hillsides, and dry earth more than earth saturated by long rains. While it lingers near the surface, brought by capillary attraction within reach of roots, exuding in swales and feeding shallow wells, it is known as *ground water*. Under the action of gravity ground water passes continually downward. The level of its upper surface can be maintained only by fresh supplies of storm water. Much of ground water is evaporated, much escapes by springs. Some, however, passes below a lower limit hardly to be defined with any precision, and is known by the name of *phreatic water*.

Fed from the couche, or layer of ground water, phreatic water slowly moves downward through all permeable layers of the earth's crust. Where such are trenched by deep valleys it emerges in springs, and where confined by impermeable strata and under sufficient head from the pressure of its own weight, it may rise to the surface in fissure springs and artesian wells even from depths far greater than the level of the sea. Phreatic water under such conditions is termed *artesian water*. In the absence of these avenues of escape, much of the water whose descent we are tracing may find its way to such profound depths that it is vaporized by molten rocks and occluded in them as steam, there to work various chemical and lithological changes which do not here concern us. As it may again find issue to the light of day through the ducts of volcanoes, such water is known as *volcanic water*.

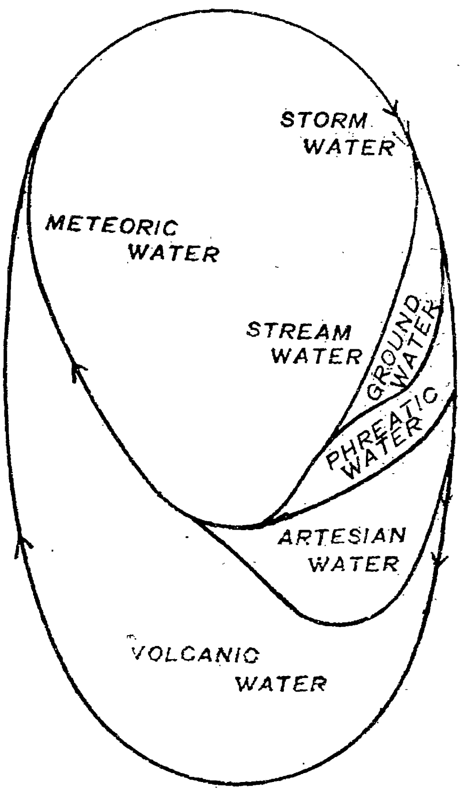


FIG. 36 The circulation of water.

These stages in the circulation of water may be graphically illustrated in the following diagram. The outer cycle represents the longer path descending deep into the earth's interior, the inner cycles, the shorter paths returning to the air by the stream and the sea.

Since artesian water is a certain stage in the cycle of the descent and return of meteoric water, the first condition of artesian supply is an adequate rainfall over the gathering ground. When the remaining conditions are present, this prerequisite is seldom lacking. For the gathering ground is situated on the elevated rim of the assemblage of tilted pervious and impervious strata, and this elevation will usually be sufficient to insure the abundant precipitation of moisture, even where the lower regions of the wells may be arid or semi-arid. Illustrations of this rule—to mention but two—may be found in the Dakota basin and the Australian basin, whose areas of supply are uplifted respectively upon the flanks of the Black Hills and the ranges fronting the eastern coast of Australia.

The entire Iowa field, together with the area of intake, lies in a region of abundant rains. The mean annual rainfall of the area of supply cannot be less than 32 or 33 inches, as is shown by the accompanying table selected from tables calculated by Greenleaf* in 1881 from tables published by the Smithsonian Institution.

TABLE I.

RAINFALL IN THE RIVER VALLEYS IN THE AREA OF SUPPLY OF THE IOWA ARTESIAN FIELD.

RIVERS.	Length in miles.	Area of basin in square miles.	Average annual precipitation in inches	Ratio of discharge to precipitation.
Chippewa	165	9,573	34	37%
Black	166	2,272	34	35%
Wisconsin	757	12,280	35	36%
Saint Croix	168	7,576	30	37%
Root	95	1,609	30	26%
Trempaleau	73	723	33	26%
Buffalo	50	468	33	26%
Zumbro	80	1,346	29	26%

According to De Rance† one inch of rainfall per year equals 14,555,280 imperial gallons to the square mile, a daily average of 40,000 gallons to the square mile. The total annual rainfall of the collecting area of the Iowa artesian field may

*Report on Water Power of the Mississippi River, etc., page 20, volume XVII, Tenth Census. U. S.

†Water Supply of England and Wales, page 20. London. 1882.

therefore be estimated at about 475,000,000 gallons to the square mile, a daily average of 1,280,000 gallons or a total annual precipitation for the entire collecting area of 6,887,-500,000,000 gallons.

From this enormous amount of storm water certain deductions may be made in order to reach an estimate of what remains for artesian supply. A large part of storm water finds its way into streams, either directly, or after a more or less prolonged storage in the ground; part is evaporated from the surface; part is consumed by growing vegetation.

Among the most accurate determinations of the ratio of stream flow to rainfall are those which measure the amount received by reservoirs whose catchment basin covers a considerable area. At Manchester, England, out of a rainfall of 45¾ inches no less than 38 inches, or 83.6 per cent, reached the reservoirs, leaving but 7¾ inches for losses. In this instance the springs are all within the catchment area, and the heavy rainfall, by heightening the plane of saturation of ground water, increases the amount which runs off directly into the streams. The slopes of the basin are steep and its fields uncultivated, but on the other hand most of the district is underlain by porous sandstones, ranking high in capacity for absorption.

In the United States the records of the rainfall and run off on the Croton watershed, N. Y., are among the most reliable. Out of an average rainfall for fourteen years (from 1868 to 1881 inclusive) of 45.29 inches, 22.25 inches, or 49.12 per cent found way to Croton dam.* The high per cent is due to the hilly country of the watershed, the large rainfall, the gneissic country rocks, as well as to other less important factors.

From much less reliable data the ratio of discharge to rainfall in the case of the rivers in the collecting area of the Iowa artesian field is estimated by Greenfield at from 26 per cent, in the case of the smaller rivers, as the Zumbro, to 36 per cent

* Compiled from Commissioner's Report, Department Public Works, New York City, Feb., 1882; quoted in Geological Survey of New Jersey, vol. III. 1894.

and 37 per cent in the case of the larger, the Wisconsin, the Chippewa, and the Saint Croix.

The proportion of rainfall evaporated in any district depends on many circumstances; upon elevation, temperature, rainfall, humidity, and the velocity of the winds; upon the physical condition of the soil and the character of the vegetation, and upon the proportion of land and water areas, the relief, and the geological structure. Many experiments are on record of the ratio of evaporation to rainfall; but as these were made under special and local conditions, they cannot be applied to the determination of a ratio for so large and complex an area as the region of supply of the Iowa field. For the same reason none of the experiments which have been made as to the amount of water consumed by growing crops and by forests need here be quoted. In the face of these experiments, some of which indicate that various crops consume each more water than falls upon them as rain, it is reassuring to remember that, although the fields of southern Wisconsin and Minnesota are each summer green with growing crops, although evaporation is there unstayed, yet the springs and streams of the region are not dried away, and the phreatic and artesian supplies have not failed.

No attempt, therefore, will be made to estimate the proportion of the rainfall of the area which goes to meet the different demands. Let it suffice to remember the fact that it must be divided among these claimants. Indeed, it is likely that the demands of the artesian reservoir are of the nature of preferred claims. Under an abundant rainfall the artesian reservoir is kept full. Thus supported, ground water reaches a high level and moisture readily rises to the surface, there to evaporate and to transpire in growing vegetation. As the soil is soon saturated a large part of the rainfall runs off to the streams. On the other hand, under a diminished rainfall the artesian reservoir may still remain full and adequate to all drafts made upon it, but the rainfall may be insufficient to supply also the demands of growing crops and the usual discharge of streams. With a further diminution of the rainfall the water of the artesian reservoir may sink away. The level of ground water must then be drawn down, soils and subsoils can furnish little water for evaporation and the uses of vegetation, and a large part of storm water will be absorbed by the thirsty earth before it can find way to the streams. Before the disposition of the rainfall can be resumed in its normal proportions, the artesian reservoir must be refilled. Any inadequacy of the rainfall to meet artesian demands will therefore be registered, first, in a general lowering of the ground water in the receiving area and the diminished flow of its springs and streams, and, secondly, in the general lowering of the head of water in the artesian reservoir, making itself felt in a general loss of pressure and diminution of flow of the wells of the field.

Applying these tests we have every reason to believe that the first condition of artesian wells is fully met in the Iowa field; the rainfall over the collecting area is more than sufficient to meet all demands made upon it by the Iowa wells.

For the total output for all the wells in Iowa can hardly exceed, at the most, 36,000,000 U. S. gallons per day, an amount about one-half of the ordinary discharge of the Turkey or the Maquoketa rivers. This would be supplied by the total rainfall of less than twenty-five square miles of the collecting area, or by less than 1-6 of 1 per cent of the total storm water of the area of supply.

Less than 2 per cent of the rainfall of the area—and certainly this amount could be spared after meeting all other demands—would feed 1,000 artesian wells, each discharging 300 gallons per minute, and each capable of supplying a town of between 6,000 and 7,000 inhabitants with seventy-five gallons for each inhabitant daily.

RESERVOIR.

We have seen that the gathering ground of artesian waters consists of the area of outcrop of the water-bearing stratum. The water which this stratum here receives and which it holds above the highest level of flow from the wells constitutes the artesian reservoir. Let this simple conception supplant all popular misconceptions. Not uncommonly the reservoir of an artesian well is looked for in some lake. The famous flowing well at Belle Plaine, which so long resisted control, was thought to draw its enormous volume of water from some of the larger lakes of Iowa, Storm Lake particularly being so honored.

Companies selling Iowa artesian water have advertised the merit of their wares by attempted demonstration of its source in Lake Superior, and this in the face of the fact that the water of the wells rose above the lake's level. But the life history of a lake, the conditions of its existence, show that it can not be the reservoir of artesian water. If the depression

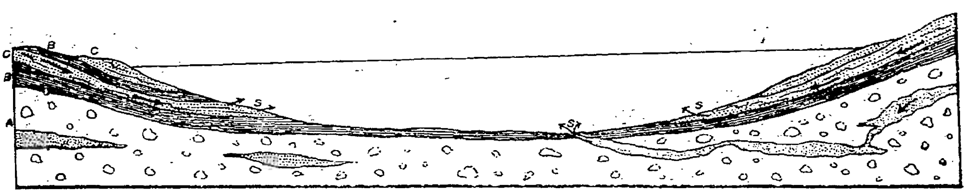


FIG. 37. Lake fed by sublacustrine springs, illustrating normal movements of ground waters to lakes and rivers. A Glacial till; B and C, stratified clays and sands; S, sublacustrine spring.

which the lake occupies is due to secular rock decay, residuary clays, the product of such decay, may cover the bottom with an impervious mantle. Though the depression may be due to other causes, it becomes an area of sedimentation on account of its relatively low relief. The floor is built up of layers which include, if they do not consist of, water tight clays. Nor do lake beaches of sand, or sandy bottoms, afford subterranean outlet. Even if clayey layers do not occur immediately beneath, yet the pressure of ground water from the higher levels of the surrounding land will usually prevent leakage. Such sandy layers thus become the conduits of sublacustrine springs and replenish instead of depleting the waters of the lake.

For reasons much the same it is not to be supposed that rivers contribute to artesian supply, except under special circumstances. Where the river aggrades, the bed may be built up of impervious silts. Where these sediments are pervious, and where the river corrodes its channel, it usually flows over a floor of ground water. Filter galleries built along the bank, beneath the bed, or on islands in the midst of the stream, are fed not by leakage from the river, but by ground water differing from that of the stream in hardness and in temperature. In arid climates, however, the level of saturation may lie below the river bed, and the river thus unsupported by the upward pressure of ground water, sinks into the sand, and there results what is known as "the under flow."

Another erroneous conception of the artesian reservoir is that of a subterranean lake or ocean. The reservoir of the artesian basin of the Dakotas has thus been spoken of in a committee of Congress as "an underlying sea of water reaching from the British possessions to Texas." It need not be said that such lakes and seas lying in vast caverns deep within the earth are products of the imagination only. The drill never pierces their roofs of rock and plunges through their waters to the bottom. Even if they existed, water from them could not rise to the surface except under forces, such as that of gases under pressure, which are known to be absent in artesian fountains.

In what way, then, is the reservoir of artesian water stored? Simply in the interstices and crevices of the rock of the water-bearing stratum. All rocks are more or less porous, and will therefore absorb water in greater or less quantity. The water which a rock will thus absorb,—the water necessary to completely saturate it, is called the *water of saturation*. This amount varies greatly in different rocks, something of the range being indicated in the following table.

TABLE II.

TABLE SHOWING AMOUNT OF WATER OF SATURATION ABSORBED BY VARIOUS ROCKS.

KIND OF ROCK.	LOCALITY.	Proportion of water by volume absorbed by 100 parts of rock.	AUTHORITY.
Sand and gravel		33-40	†R. J. Hinton.
Sandstone. Lower Tertiary		29	*Delesse.
Sandstone. Devonian, fine grey		20.62	††T. S. Hunt.
Sandstone	Jordan, Minn.	12.05	†G. P. Merrill.
Sandstone	Berea, O.	6.6	†D. W Mead.
Dry Clay		12	†R J. Hinton.
Shale. Hudson River		7.94	*T S. Hunt.
Dark Coal shale		2.85	*Delesse.
Oolitic limestone	Bath, Eng.	31.20	*Prestwich.
Upper Chalk	Issy, France	24.10	*Delesse
Limestone. Tertiary	Caen, France	29.54	††T. S. Hunt.
Limestone. Niagara	Lemont, Ill	1.12	†G. P. Merrill.
Limestone. Galena	Rockford, Ill.	4.2	†D W. Mead.
Granite, fine grained	Brittany	0.12	*Delesse.
Basalt	Haute-Loire	0.33	*Delesse.

If a block of stone of somewhat loose texture be immersed in water until fully saturated, and then be lifted out, a certain portion of the water of saturation will drain away under the action of gravity. This part may be termed the *water of percolation*. Another part will be held within the pores of the stone and can be disengaged only by evaporation and heat. This part is called *water of imbibition*, or quarry water. Rocks differ widely in the proportion of these two waters which they absorb. In some, as in flints, the water of saturation is wholly quarry water. Dry clay absorbs freely but transmits none. Sandstones like the Saint Peter absorb and transmit in large quantities. Chalk ranks with sandstone in its capacity to absorb, but it transmits but little and that slowly. The value of any rock as a water-bearing layer depends evidently upon its capacity for percolation rather than upon its capacity for imbibition. The best reservoir

†Mead: Hydrogeology of Upper Mississippi valley. Journal A. E. S. vol. XIII. July, 1894.
*Prestwich: Geology, vol. 1. Oxford. 1886. Chap. X.
††Chemical and Geological Essays. Salem, 1878. p. 166.

rocks, therefore, are the loose, pure quartzose sandstones. A slight admixture of clay or lime, while it may but slightly lessen the water of saturation, will distinctly impair the power of the rock to transmit, as the following table of experiments by Prestwich* clearly shows.

TABLE III.

	WATER OF SATURATION PER CUBIC FOOT GALLON.	PERCOLATION PER HOUR—CUBIC INCHES
Thanet sands, fine and slightly argillaceous	2.80	1.5
Woolwich sands, fine grained, quartzose	2.60	5.1
Upper Greensand, slightly argillaceous, quartzose	3.00	3.6
Lower Greensand, very coarse	2.18	8.4

The capacity of porous rocks as reservoirs of water is increased by the fact that they do not lie in an undivided massif. Planes of stratification, nearly horizontal in the Upper Mississippi valley, part them at frequent intervals. Intersecting joints divide the strata into cubic or rhombic blocks, which again are often broken up, especially near the surface, by fissures and cracks innumerable. Water readily percolates through these, and below the plane of saturation of ground water collects in them in large quantities. The capacity of these natural waterways hardly admits of estimate, yet without taking their fissures into consideration, the capacity of porous rocks is evidently enormous. For example, the reservoir sandstones underlying our artesian gathering ground certainly can absorb water on the average to at least 5 per cent of their volume. A sample of these sandstones from Jordan, Minnesota, was found to have an absorption capacity of over 12 per cent of its volume, and this sample was taken from building stone layers, and therefore was of exceptional closeness of texture. Many layers of these sandstones can absorb at least 20 per cent of their volume. The estimate made of 5 per cent surely does not err on the side of excess.

*Treatise on the Water-bearing Strata of London, p 114.

The thickness of the reservoir sandstones varies widely in different portions of the area of supply, but an approximation to their average thickness in Wisconsin and Minnesota can be obtained from the computations of the geologists of these states.

TABLE IV.

THICKNESS OF THE RESERVOIR SANDSTONES IN MINNESOTA.

FORMATION.	MAXIMUM.*	MINIMUM.*	AVERAGE.
Saint Peter	164	75	119
New Richmond	20	0	10
Jordan	200	75	137
Potsdam	1300	0	650
Totals	1684	150	917

The average thickness of 917 feet found to obtain in Minnesota is nearly equalled in Wisconsin. The Saint Peter averages about eighty feet in thickness in that state.†

In eastern Wisconsin the thickness of the Cambrian sandstones is estimated at 630 feet,‡ and, in central Wisconsin their combined thickness is considerably greater.§

The estimate is therefore a moderate one, if we set the average thickness of the water-bearing sandstones which contain the fountain head of our artesian wells at 500 feet over the area of supply. As this equals 14,500 square miles, and as we have estimated the porosity of the sandstone at 5 per cent, the reservoir sandstones thus contain an amount of water equivalent to a lake of the area of Lake Ontario and fifty feet deep. To fill this reservoir, if one-tenth of the rainfall of the region were devoted to this purpose, would require nearly 100 years. To exhaust it by the discharge of the artesian wells of Iowa, estimating their output at 36,000,000 gallons daily, would demand over 5,000 years. In these estimates we have not included the Oneota or Lower Magnesian

*Hall and Sardeson. Paleozoic formations of Southern Minnesota. Bul. G. S. A. vol. III, p. 308.

†Geology of Wisconsin, vol. II, pp. 146-557.

‡Ibid, p. 259.

§Ibid, p. 527.

limestones, which draw a large amount of water from the area of supply and deliver it to the Iowa wells in the northeastern part of the state.

Limiting our calculations to the outcrop of the reservoir sandstones, we have omitted also the scores of thousands of square miles in the Upper Mississippi valley, in which these strata are buried more or less deeply beneath the surface, their pervious layers everywhere being water-logged. The entire storage of artesian water in this field thus becomes so enormous that it passes beyond any ready computation. It represents the accumulation of centuries. The water that rises in our wells may have fallen upon the ground as rain before the discovery of America. In some of the deeper strata where the underground water is static, it may have been imprisoned in the earth during the whole of human history and even since remote geological ages.

The extent of the area of supply depends upon the dip of the reservoir rocks. The steeper the inclination the narrower must be the outcrop, as is graphically illustrated in the diagram below, in which A, B and C represent the relative with of the outcrops of three strata equal in thickness, but differently inclined, A at 3°, B at 10°, and C at 20° from the horizontal plane.

It must be reckoned as a piece of good fortune that the southward slope of the strata of the Upper Mississippi valley

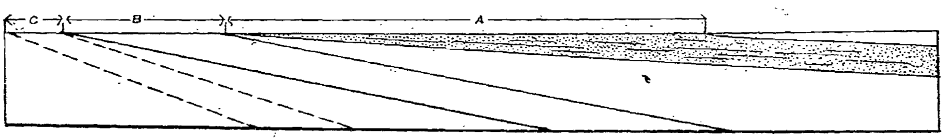


FIG. 38.

is so gentle. To this fact is due the great width of the collecting area, which, with other circumstances, forbids any anxiety as to the exhaustion of the artesian reservoir. Had the receiving strata been tilted at any considerable angle, their width of outcrop would necessarily have been measured in rods rather than in miles, and their intake would have been correspondingly less. The width of the gathering ground of the Dakota basin, for example, where the strata have been uplifted upon the flanks of the Black Hills, has been estimated at less than a mile in width, and its intake can be but a fraction of that of the reservoir of the Iowa field.

Conditions of Transmission.

THE PERMEABLE STRATUM.

We have seen that the reservoir of an artesian basin consists of the water held in the interstices and crevices of pervious strata over the region of their outcrop. As these strata are carried by their dip beneath impervious layers, water percolates through them downward under the action of gravity as far as they continue porous. For the transmission of water the same conditions of texture, and only the same, are required, as are necessary for its reception. The idea of vast tubular channels, or caverns, in which artesian water flows like a river, must be laid aside. If artesian water were transmitted through conduits of this nature, its head would be far greater than it is found to be, and pressures would correspond directly to flows. In all cases, however, allowance must be made for a friction far greater than that of the interior of a pipe, a friction commensurate with that obtaining in the case of water percolating through the interstices of rocks, or through many minute fissures.

The flow, however, is doubtless much more rapid through porous sandstones than appears in laboratory experiments at ordinary pressures. Rocks which transmit but feebly at the surface yield water in far greater ratios under the strong pressures of artesian head. Since one pound of pressure to the square inch is required to support each 2.31 feet of water, in a flowing artesian 1,155 feet deep in which the water rises to the surface from the bottom of the well, the water must exert at the base of the boring a pressure of 500 pounds to the square inch. The effect of such pressures, which are not uncommon in the Iowa field, must be to augment greatly the horizontal transmission of water. The effect of even a moderate increase of pressure is seen in mechanical filters, and the rapid rise in percolation accompanying the use of such pressures is set forth in certain experiments made by Isaac Roberts*. The stone through whose pores water was forced, is stated to have been ten and one-half inches thick and "of average coarseness."

PRESSURES.	PERCOLATION.
10 pounds to square inch	4½ Imperial gallons.
20 pounds to square inch	7½ Imperial gallons.
46 pounds to square inch	19 Imperial gallons.

Wherever the "aquifer," or water-bearing stratum, is cut and cross-cut by crevices, a more rapid collection is secured from the blocks into which the rock is divided, and a swifter transmission of water onward. But in deep seated aquifers we cannot expect to find the many cracks, crevices and fissures which obtain in the surface rocks. The latter are affected by frost, unequal expansion and contraction under heat and cold, the various influences of weathering, and the surface shocks of earthquakes,—agencies absent or comparatively inoperative in the deeper strata. Both surface rocks and those lying at some depth may be cracked and fissured by other dynamical agencies, such as crustal movements and contraction owing to lithification and cooling, but in the deeper rocks any fissures, when formed, will usually soon be closed by the creep of the rocks under the immense pressure of the superincumbent strata. Percolating waters also tend to heal such fissures with deposits from solution, as all mineral veins and veins of infiltration testify. For these theoretical reasons, amply confirmed by the experience of drillers, one must conceive of the transmission of the artesian waters of Iowa chiefly through the pores and interstitial spaces of saccharoidal sandstones.

*De Rance, Water Supply of England and Wales, p. 19.

But crevice-flow undoubtedly occurs also. This is more often the case in limestones like the Oneota, in which percolating waters but slightly mineralized have dissolved the rock little by little and thus made or enlarged their waterways. Inquiries of drillers in charge of wells, several of whom had had long and wide experience in their art, have brought to hand only two or three instances in which open crevices were discovered of sufficient size to be noted by the sudden sinking of the drill. At Sigourney the drill suddenly dropped two feet in the Saint Peter sandstone.* At Des Moines the drill dropped ten inches between 2,325 feet and 2,330 feet from the surface, in the Lower Oneota, followed by a lowering of water in the tube. These are the only instances that can be adduced from the state. We have been told by drillers that water-bearing crevices fifteen or sixteen inches deep occur at Chicago at a depth of from 1,000 to 1,300 feet from the surface, apparently in either the Saint Peter or the Oneota, and that at 1,200 feet from the surface in limestone, at Armour's glue works, a water-bearing crevice was encountered four feet in thickness.

In the literature of artesian wells several examples are cited of subterranean crevices through which waters flow rather than trickle. In boring the celebrated artesian at Grenelle near Paris, the drill suddenly dropped fourteen feet at a depth of 1,797 feet and this was followed by an outgush of water. Geikie adduces the occasional rise of twigs and leaves in the shafts of artesian wells. Where this has occurred in shallow artesians in recent deposits, it may be akin to the throwing out of long buried twigs and limbs by drift wells in Iowa. Instances are on record of the appearance in the outflow of artesian waters of living creatures, which certainly could not have percolated through the interstices of sandstone. The rise of crustaceans has recently been noted from an artesian in Texas, and the Dakota geologists have been confronted with affidavits that there have been collected from

* Bain: Sigourney Deep Well. Proc. Iowa Acad. Sci., vol. I, pt IV., p 38.

the discharge pipes of wells at Aberdeen, small live fish, which must have risen from nearly a thousand feet below the surface, where they endured without any special injury or apparent discomfort a pressure of 530 pounds to the square inch.* Fortunately no such accounts are brought forward from the deep wells in Iowa.†

Mr. R. E. Call in his paper on Iowa Artesian Wells makes the following statement with regard to fissure flow in Iowa: "There clearly is not, at least so far as the older rocks of the state are concerned, any well defined hydrographic basin. The flow of waters in the Iowa rocks must therefore occur through cracks and fissures which result from movements properly classed as orographic." Mr. Call connects the formations of these supposed fissures directly with the great Rocky mountain uplift, and says that "it is believed that Iowa is so far within the limits of this disturbance of the earth's crust that natural cracks and fissures have been formed and sometimes no doubt of very great extent. It will be difficult otherwise to account for the immense underground flows of water which have been tapped by the deeper artesian wells in the eastern part of the state, particularly those at Keokuk, Fort Madison, Davenport, Clinton and McGregor." He goes on to state that by solution "extensive underground channels probably have been in the course of time produced and through these channels large volumes of water are flowing. Occasionally some town or city is fortunate in striking these subterranean streams and thereby secures an abundant flow of water." The above view differs as widely from the conclusions of this paper as does the catastrophic from the uniformitarian school of geology. In the first place it may be said that the hydrographic basin of the older rocks of Iowa is as well defined as any in the world. We use the term "basin," of course, in its common unrestricted sense to include monoclinal as well as synclinal areas. That such crevices as may

*Final report E. S. Nettleton, C. E., Sen. Ex. Doc., No. 41, 52d Congress, 1st Sess. Pt II, pp. 85-87. Washington. 1893.

†Monthly Rev. Iowa Weather and Crop Service, vol. III, p. 6. Des Moines. 1892.

exist are caused by orographic, or mountain making, movements connected with the Rocky mountain uplift is an hypothesis which does not require serious consideration until some evidence is adduced in its favor. Certainly no faults or dislocations of the strata have been left in evidence of such crustal movements and require them for their explanation. So slight are the deformations that have been discovered in Iowa that we must conclude that the deeper strata have been well able to bear the strain to which they may have been subjected from elevatory movements so far away.

Nor is the flow of the artesians in the cities on the banks of the Mississippi so exceptional that a system of fissures caused by orogenic movements must be postulated to account for it. The original discharge of artesians at Sterling and Rockford, Ill., and at Ottumwa, Iowa, equalled the magnificent flow of the well at Sabula. The wells of the interior of the state are many of them non-flowing, and the only known limit to the capacity of a number of them is the capacity of the pumps and pipes. It goes without saying that, other things being equal, the lower the mouth of the well the greater will be its discharge. The wells along the Mississippi, the base level of the state, may be expected to yield more than wells in the interior whose longer tubes tap the same water-bearing strata. The former are also, as a rule, nearer to the area of supply, and their pressures are therefore less diminished by friction. At the same time some evidence has been discovered in their investigation, though not so direct and trustworthy as could be desired, that at one or two points along the Mississippi, artesian water not only is found in sandstones, but also in crevices of limestone beds, into which it has risen from the sandstones beneath.

If it were true that the artesian flow of Iowa is through fissures and extensive underground channels, an expert would never advise the sinking of single bore. It would indeed be only "occasionally that some town or city" would be "fortunate in striking these subterranean streams and thereby secure an abundant flow of water," and enterprises with such large risks of failure could not be encouraged. For, to adopt an illustration of Chamberlin's* if we conceive of any given stratum to be crossed by two sets of vertical fissures, or channels, each six inches wide and only twenty feet distant from the next of the same set, the space of such a stratum covered by the fissures is but one-twentieth of the whole area, and the chances of success of any bore of ordinary dimension tapping a fissure is but one in twenty. With oblique fissures, and in case a formation includes different strata affected by different fissures, the chances of success are increased. But the fact that the drill in Iowa never fails to strike artesian water, when the other conditions are present, corroborates the other evidence offered that the main supply of the state does not flow in the fissures of limestone rocks, but percolates through the interstices of sheets of sandstone.

The chief aquifers of the Iowa field are, then, the saccharoidal sandstones of the Ordovician and Cambrian. In descending order these are:

4. The Saint Peter.
3. The New Richmond.
2. The Jordan.
1. The Basal Sandstone.

To this list may be added the Upper and Lower Oneota limestones, although they probably derive their water locally for the most part from inferior sandstones.

Above the Saint Peter, from the Trenton to the drift inclusive, there is not a single formation, except the Maquoketa and Kinderhook shales, which does not, under local conditions, yield artesian water. The sandstones of the Silurian yield copiously in southeastern Iowa, and may be said to constitute a distinct artesian field of their own. A number of small flowing wells are supplied from sandstones of the Carboniferous.

*Requisite and Qualifying Conditions of Artesian Wells. Fifth Ann. Rept. U. S. Geol. Surv., p 136.

The number of artesians supplied from buried sands of the drift is high in the hundreds.

The artesian wealth of Iowa is largely owing to the attitude of the aquifers. The inclination of the water-bearing strata is everywhere so gentle, as far as now is known, that if they constituted the surface the unaided eye could not detect their departure from a horizontal plane. It is owing to this fact that the Cambrian aquifers remain within drilling distance over about four-fifths of the state. The slight inclination of the aquifers, with their comparative nearness to the surface over a large area, is helpful in another way. It prevents that compacting under pressure, and especially that clogging by deposition of minerals from solution by static waters, which are apt to take place in the deeper strata. The Ordovician and Cambrian aquifers are thus injuriously affected where they are found deepest in the state, as is shown in the description of the strata of the Greenwood park well at Des Moines. Nor is their continuity interrupted by any known fault or slip of the strata, which would bar the progress of their waters. The only serious obstacle in the way of artesian water from the reservoir to the wells is the trench of the Mississippi, which north of the mouth of Turkey river severs the continuity of the Saint Peter, and north of McGregor the continuity of the upper strata of the Saint Croix. Thus the track of the waters above the Jordan sandstone leads from Wisconsin through Illinois rather than directly into Iowa, but so broad is it that the supply is not noticeably impaired.

CONTAINING BEDS.

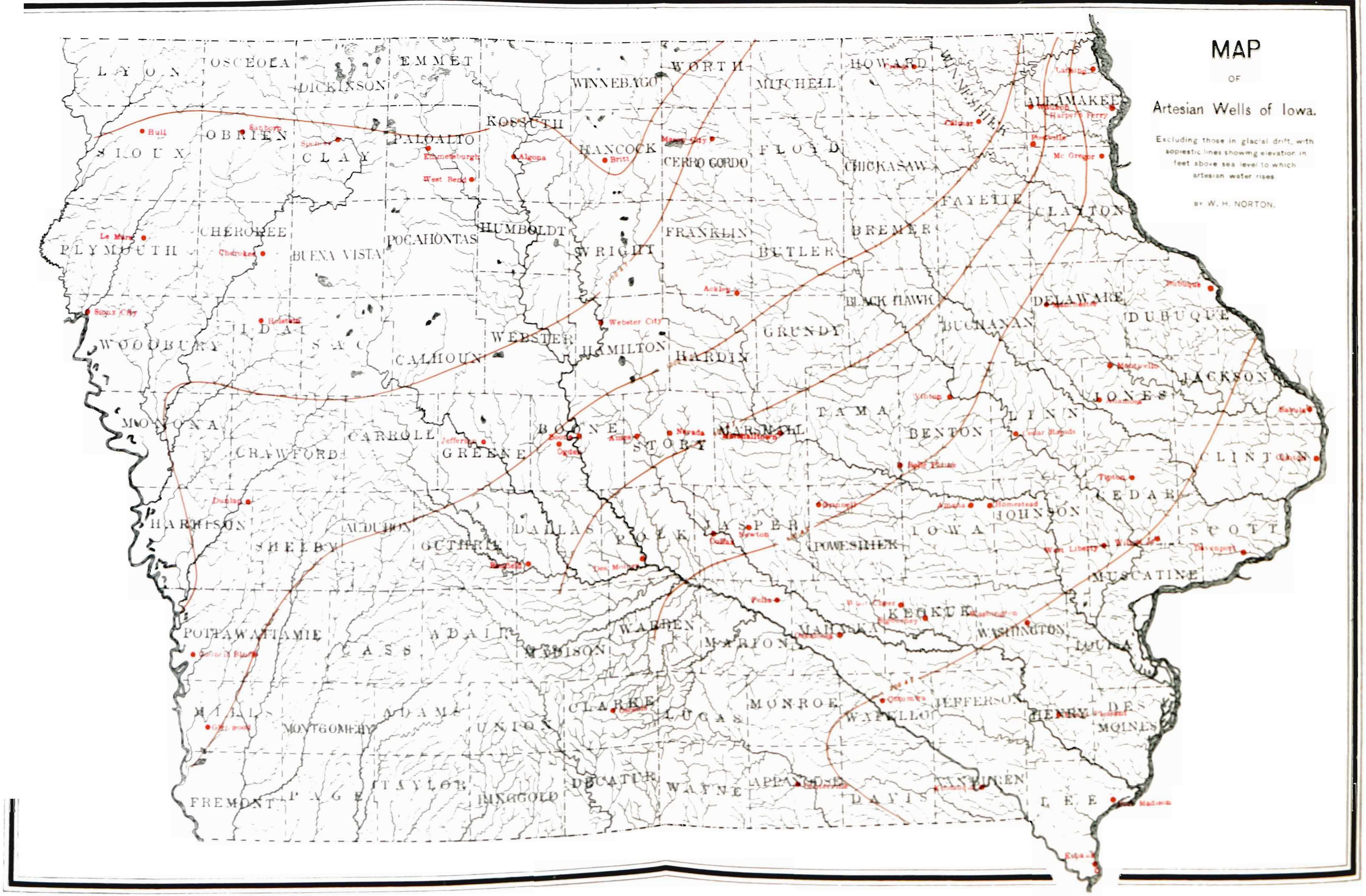
In order that the water transmitted from the reservoir may rise in the wells, it must be confined within the aquifer. This is effected by layers of impervious rock both above and below —or by their equivalents. The best confining strata are heavy clays, since they are practically water-tight; but shales and shaly limestones and fine-grained argillaceous sandstones and all crystalline rocks are also effective.

The entire Ordovicio-Cambrian artesian system is included between the quartzites and gneisses of the Algonkian, which make an excellent bottom, and the heavy shales of the Maquoketa, which effectually prevent upward leakage. Within this complex of strata all the pervious layers are water-logged, except over a small area where they are trenched by rivers. All the deeper waters are under such pressure that they constantly seek escape upward. The water of any stratum thus prevents the downward leakage of the water in the stratum above it, and so far takes the place of a lower containing bed. The impervious layers confine the waters beneath rather than those which are above them.

The Trenton shales confine the water of the Saint Peter, and where they are insufficient artesian water may be expected in the crevices of the Galena-Trenton. The shales of the Upper Oneota confine the water of the New Richmond, and separate from the Saint Peter the waters of the Jordan where it has escaped into the Oneota. The Saint Lawrence seals the Basal sandstone, and this immense assemblage of strata contains different layers, sometimes of great thickness and of so fine a texture that the drill finds them dry, which sheathe the porous water-bearing sandstones with which they are interbedded. In the Silurian artesian field of southeastern Iowa the Maquoketa acts as the upper containing bed.

Strange as it may appear, a couche of water may take the place in part of the upper containing stratum. This was first pointed out by Chamberlin,* who showed the artesian functions of the common ground water in the region, called by him the cover area, which intervenes between the intake area and the region of the wells. "If the subterranean water in this region," says Chamberlin, "stands as high as the fountain head (except at the well, where of course it must be lower) there will be no leakage, not even if the strata be somewhat permeable, for the water in the confining beds presses down as much as the fountain head causes that of the

*Fifth Ann. Rep., U. S. Geol. Surv., pp. 130-141.


MAP
OF
Artesian Wells of Iowa.
Excluding those in glacial drift, with isopiestic lines showing elevation in feet above sea level to which artesian water rises.
BY W. H. NORTON.
LYON
OSCEOLA
DICKINSON
EMMET
WINNEBAGO
WORTH
MITCHELL
HOWARD
WINNESHIEK
ALLAMAKEE
SIOUX
OBRIEN
CLAY
PALOALTO
KOSSUTH
HANCOCK
CERRO GORDO
FLOYD
CHICKASAW
PLYMOUTH
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BREMER
FAYETTE
CLAYTON
WOODBURY
IDA
SAC
CALHOUN
WEBSTER
HAMILTON
HARDIN
GRUNDY
BLACK HAWK
BUCHANAN
DELAWARE
DUBUQUE
MONONA
CRAWFORD
CARROLL
GREENE
BOONE
STORY
MARSHALL
TAMA
BENTON
LINN
JONES
JACKSON
HARRISON
SHELBY
AUDUBON
GUTHRIE
DALLAS
POLK
JASPER
POWESHIEK
IOWA
JOHNSON
CEDAR
CLINTON
SCOTT
MUSCATINE
POTTAWATTAMIE
CASS
ADAIR
MADISON
WARREN
MARION
MAHASKA
KEOKUK
WASHINGTON
LOUISA
MILLS
MONTGOMERY
ADAMS
UNION
CLARKE
LUCAS
MONROE
WAPELLO
JEFFERSON
HENRY
DES MOINES
FREMONT
PAGE
TAYLOR
RINGGOLD
DECATUR
WAYNE
APPANOOSE
DAVIS
VAN BUREN
LEE
Hull
Sanborn
Le Mars
Cherokee
Sioux City
Holstein
Algona
Britt
Mason City
Webster City
Ackley
Nevada
Ames
Ogden
Marshalltown
Vinton
Cedar Rapids
Tipton
Dubuque
Clinton
Davenport
Newton
Colfax
Pella
Oskaloosa
Ottumwa
Centerville
Keosauqua
Fort Madison
Keokuk
Council Bluffs
Glenwood
Sigourney
Washington
Mount Pleasant
Amana
Homestead
West Liberty
Wilton Jct.
Sabula
Cresco
Calmar
Lansing
Harpers Ferry
Postville
Mc Gregor
Emmetsburgh
West Bend
Manchester
Monticello
Anamosa
Belle Plaine
Grinnell
Dunlap
Osceola

porous bed to press up, since both have the same height. * * * * If the water between the well and the fountain head is actually higher than the latter, it will tend to penetrate the water-bearing stratum so far as the overlying beds permit, and will, to that extent, increase the supply of water seeking passage through the porous beds, and will by reaction tend to elevate the fountain head, if the situation permit."

The control exercised by the height of the cover area and its ground water is illustrated in the map of isopiestic lines on plate VIII. The lines of equal artesian pressure show a surprising difference between the artesian head in the eastern, and in the central and northern portion of the state. The hydraulic gradient rises from Clinton to Boone, 310 feet in 190 miles. This higher head of the northwestern half of the state is due in part to the fact, made evident by the trend of the isopiestic lines, that the supply in this region is derived from the nearer and higher Minnesota reservoir, rather than from that in Wisconsin. This cause acting alone would produce an hydraulic gradient with southward inclination. The higher ground of western Iowa, on the other hand, would by the control of its ground water produce a gradient inclined toward the east. The two causes are composed with the result of a southeast gradient and isopiestic lines with northeast-southwest trend.

It must be remembered that on the map referred to the artesian pressures platted are not all from the same aquifers. In some instances waters derived from the higher strata of the well section have access to the tube, These waters may head considerably higher than those of the Cambro-Ordovician aquifers and will stand upon them and though limited in quantity may suffice for ordinary consumption.

FOUNTAIN HEAD.

In order that water may rise in artesians under hydrostatic pressure the elevation of the reservoir must exceed that of the region of the wells, and in sufficient measure to counterbalance the friction encountered en route. The higher the reservoir the stronger is the hydrostatic pressure and the heavier the flow. The gentle inclination of the terranes of the Upper Mississippi valley involves, along with its many advantages, the accompanying disadvantages of a comparatively low reservoir and moderate hydrostatic pressure. Such fountains as are found in the Dakota basin, whose energy flings their waters hundreds of feet in air and can be utilized in large manufacturing enterprises, need not be expected in Iowa. The Dakota reservoir lies 3,300 feet above the sea level, while that of Iowa does not exceed 1,200 feet at the most, the maximum height of the summit of the Cambrian sandstones where they meet the crystalline rocks in central Wisconsin, and of the Saint Peter in the two southern tiers of counties in eastern Minnesota. In southern Wisconsin the Saint Peter rarely rises above the 1,000 feet contour, and the artesian head must be considerably lower than this for the entire region.

In artesian basins situated near the sea and those whose aquifers are cut across and drained by rivers, terminal escape must always be taken into account. In Iowa neither of these features require consideration. The distance of the Upper Mississippi field from the sea is well known. Only in three northeastern counties are the chief aquifers of the state cut by rivers. Even here friction is so effective in preventing the draining out of the strata that wells have been sunk with a degree of success, as at Postville. At this station Saint Peter water rises 135 feet in the shaft, although the formation outcrops six miles away in the valley of the Yellow river. This region, however, properly belongs to the intake area.

RECORDS OF THE WELLS.

The deep wells of Iowa are conveniently grouped together in seven divisions, five of which comprise wells ranged on or adjacent to east-west cross-sections taken along leading lines of railway, the remaining two embracing the wells of southwestern Iowa and the extreme southeastern portion of the state.

There will be found preceding the description of the wells of each division a summary of the geological and artesian conditions of the region. These are also graphically presented in a series of plates, which exhibit our present knowledge of the deeper strata, and which, it is hoped, will be found especially helpful, since the aquifers of each region are plainly indicated, and the depth at which they may be reached by the drill at any point on the traverse can be easily calculated by using the vertical scale on which the sections are drawn.

It goes without saying that in these sections much is hypothetical, much is only probable, and the accuracy of the engineer should not be looked for since it will not be found. For no geological formation is everywhere of the same thickness. The assigned thickness is an approximation only, except in the immediate vicinity of outcrops or of well sections based on reliable data. When these wells are far apart, the boundaries of the formations are drawn about parallel and straight from one well section to the other, leaving the intelligence of the reader to supply the qualification necessary that in the intervening region any stratum may thin or thicken, or deformations, folds, and troughs may occur which find no superficial expression, and are therefore unsuspected, but which place the aquifers nearer or farther away from the surface than here represented. The uncertainty attaching to drillers' records and the difficulties always present in their interpretation have been discussed in a previous paper.* Fortunately we have in hand several well sections of which complete sets of lithological samples of the strata penetrated were saved, and these, though comparatively few in number, render fairly intelligible many other records less authentic.

The geological sections are offered, then, not as demonstrations, but as approximations, correlating and interpreting the

*Thickness of the Paleozoic Strata of Northeastern Iowa. Iowa Geol. Surv., vol. III, pp. 167-174.

data at hand according to our best judgment. They are submitted in confidence that they will prove of practical use to the citizens of Iowa towns in showing the conditions present of success or failure in artesian mining.

The groups in which the deep wells of the state are placed are the following:

I. THE M'GREGOR-FAIRVIEW SECTION.

1. McGregor.	6. Mason City.	11. Hull.
2. Monona.	7. Britt.	12. Lansing.
3. Postville.	8. Algona.	13. Cresco.
4. Calmar.	9. Emmetsburg.	14. Harpers Ferry.
5. New Hampton.	10. Sanborn.	15. Waukon.

II THE DUBUQUE-SIOUX CITY SECTION.

16. Dubuque.	19. Webster City.	22. West Bend.
17. Manchester.	20. Holstein.	23. Cherokee.
18. Ackley.	21. Sioux City.	24. LeMars.

III. THE CLINTON-DUNLAP SECTION.

25. Clinton.	30. Boone.	34 Sabula.
26. Cedar Rapids.	31. Ogden.	35. Tipton.
27. Marshall.	32. Jefferson.	36. Anamosa.
28. Nevada.	33. Dunlap.	37. Monticello.
29. Ames.		38 Vinton.

IV. THE DAVENPORT-DES MOINES SECTION.

39. Davenport.	43. Amana.	46. Colfax.
40. Wilton.	44. Grinnell.	47. Des Moines.
41. West Liberty.	45. Newton.	48. Redfield.
42. Homestead.		49. Saylorville.

V. THE WASHINGTON-DES MOINES SECTION.

50. Washington.	52. Oskaloosa
51. Sigourney.	53. Pella.

VI. THE WELLS OF SOUTHEASTERN IOWA.

54. Ottumwa.	56. Mount Pleasant.	59. Keokuk.
55 Farmington and Keosauqua.	57 Fort Madison.	60. Centerville.
	58. Mount Clara.	

VII. THE WELLS OF SOUTHWESTERN IOWA.

61. Atlantic.	63. Clarinda	64. Council Bluffs.
62. Osceola.		65. Glenwood.

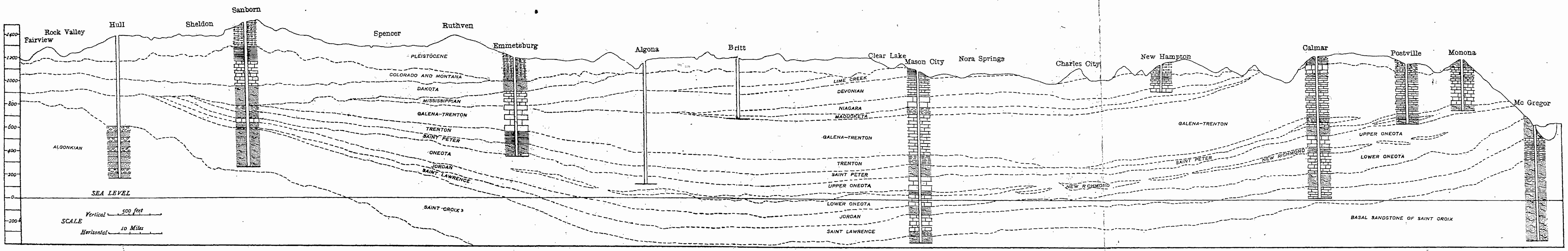
I. THE M'GREGOR-FAIRVIEW SECTION.

This section shows a very gentle syncline, whose axis lies a little to the east of the Des Moines river. From this axis the formations rise to the east with a gradient of about five feet to the mile, until one after another they emerge as the country rock. The lower terranes of this assemblage find their outcrop beyond the limits of the state, in southern Wisconsin, where they are outspread about ancient islands of Algonkian quartzite. To the west they rise with a grade less gentle. A little to the north of the western end of the profile, they are known to rest on the descending surface of an oldland of Algonkian rock, which, in southwestern Minnesota, southeastern South Dakota, and the extreme northwestern part of Iowa rose above the Paleozoic sea during the whole of its long history. These Algonkian areas in Wisconsin and Iowa formed two forelands, or outliers, of an ancient northern continent, and guarded on either side a wide embayment of the Paleozoic ocean. The section, therefore, crosses just in front of this re-entrant. The terranes it portrays were laid down as sediments upon the Algonkian floor of the sea. Like all such sedimentary deposits which retain their original attitude, they rise more steeply as they approach the ancient shores. Their slant is represented as greater on the west in the section than on the east because the western oldland is nearer than is the eastern.

During the long succession of the Paleozoic ages the continent to the north and northeast gradually rose. The Paleozoic ocean retreated southward and southwestward on the east. At the end of the Cambrian, the shore still lay outside of Iowa. At the end of the Silurian, it ran from northwest to southeast from where Cresco now is to Davenport. At the end of the Devonian, another belt had been added to the coast, and the shore stretched a score of miles west of the present Cedar river.

There is little reason to doubt that the Isle of Sioux, the oldland of northwest Iowa, rose during Paleozoic times with the main land to the north and east, and early in that era was joined to it as a peninsula. This is proven, if on the western side of the embayment as well as on the eastern, the formations are found to outcrop in successive belts of which that nearest shore is the oldest. As far as evidence is at hand, such seems to be the case. The section of the Minnesota river from New Ulm eastward to Mankato shows that the ancient gneisses and quartzites of the Isle of Sioux pass beneath the sandstones of the Saint Croix. The Saint Lawrence is succeeded by the Jordan and further to the east outcrops the Oneota. In northwestern Iowa the disposition of the Paleozoic strata is concealed by a thick mantle of later sedimentary and glacial deposits. The evidence from artesian wells is scanty. No drillings of the Paleozoic series have been saved from any of the wells west of Emmetsburg except at Sioux City. Yet such facts as are at hand favor the hypothesis that over the entire embayment from Baraboo, Wis., on the east to near Duluth on the north, and to Rock Rapids at the west, the outcropping strata of the Paleozoic preceding the Carboniferous lie in concentric belts, of which the youngest is central and the oldest peripheral. This is the assumption upon which the section is drawn. At the time of the Coal Measures there occurred a subsidence and a consequent transgression of the sea from the south and west, so that Coal Measure sandstones and shales were widely laid down in eastern Iowa over Mississippian, Devonian and Upper Silurian alike, so far north as Delaware county. We may, therefore, assume that the Coal Measures overlap the inferior terranes in northwestern Iowa also, though there is no evidence that they reach as far north as the line of the McGregor-Fairview section.

Another and greater subsidence occurred toward the close of the Mesozoic, the Middle Age of geological history. The Cretaceous Mediterranean sea which covered the great plains of the west, invaded northern Iowa as far east, at least, as the Des Moines valley, and laid down its marls, shales and



GEOLOGICAL SECTION ALONG CHICAGO, MILWAUKEE & ST. PAUL RAILWAY FROM McGREGOR TO ROCK VALLEY AND FAIRVIEW.

sandstones unconformably upon the older formations, from Fairview nearly to Algona.

THE ALGONKIAN.

Fourteen miles to the north of the section the outcrop of the Sioux quartzite runs parallel with it as far east as Hull. The depth beneath the surface to which the quartzite has dipped in this direction is unknown. At Sioux City the Algonkian occurs at 136 feet below sea level. If the gradient is regular from Granite to Sioux City the Algonkian should be reached at Fairview at a little less than 1,000 feet A. T. In the section it is drawn at something over 800 A. T. on account of its altitude at Hull, and because of the syncline which Bain has discovered along the Sioux river.* In the section and in this discussion it has been assumed—some choice being necessary—that the age of the Sioux quartzites is Algonkian. Stratigraphically they could easily be referred, as N. H. Winchell has done, to the basal sandstone of the Saint Croix, termed by him the Potsdam. At Hull an attempt is made to represent graphically the lava flows described by Beyer.* The location of the duct connecting their intercalary beds is quite unknown, and the only facts relating to their extent are that they do not reach to Sanborn, twenty-four miles to the east, nor to Le Mars, twenty-seven miles to the south. The sandstones at Hull in which the quartz porphyry is imbedded are assumed to be of the same age as the Sioux quartzite. Certainly they cannot be Carboniferous, and no body of sandstone is known to which they can belong of later age than the Ordovician. Between the Algonkian and the Cambrian, the case is somewhat evenly balanced with the fall of the scale tending toward the Algonkian. No volcanic intrusions have been found in the Paleozoic strata elsewhere in the state or adjacent regions; while the Sioux quartzite is cut with dykes of ancient lava, and flows of the same volcanic rock as at Hull occur in the Keweenawan beds of the

*Iowa Geol. Surv., vol. III, p. 103.

*Iowa Geol. Surv., vol. I, p. 163.

Algonkian of Michigan. The sandstones have no physical or lithological characteristics which determine their age. At 800 and 825 feet they consist of moderately coarse grains, imperfectly rounded, mostly of clear quartz, but with many of pink, red, yellow, and greenish color. At 1,228 feet the sandstone is white, of clear quartz, with many grains well-rounded. In their quartzose character these sandstones thus differ from the Keweenawan sandstone of the Lake Superior region; but the lithological nature of the grains of any sandstone is under geographic control rather than that of geological time. Grains of colored quartz are not found in equal numbers in any Paleozoic sandstone in the state with which the author is acquainted. Glauconite, often seen in the Saint Croix, is absent.

SAINT CROIX.

Basal Sandstone.—This terrane is nearly 800 feet thick at Lansing, where its full depth is measured. At McGregor it is in all probability of still greater thickness, although its base was not reached, the drill stopping 744 feet below its summit. In each locality it includes a superior sandstone, the Dresbach sandstone. Medial shales, the Saint Croix shales of C. W. Hall, are well marked at McGregor, but not so distinctly at Lansing. The inferior sandstones include no red strata at Lansing, where they are nearly 400 feet thick, although at McGregor forty-five feet of red sandstone lie within fifteen feet of the bottom of the boring.

The basal sandstone is reached at Mason City at 295 A. T. At Sanborn the 445 feet of shales and sandstones lying below 623 feet A. T. probably include much of this terrane, but with the data in hand no boundaries can be drawn for the formations below the Saint Peter.

Saint Lawrence Dolomite and Shales.—This group of dolomites underlain by shales is distinctly marked in the section. At McGregor it is represented by two feet of arenaceous limestone left uneroded at the bottom of the preglacial channel of the Mississippi, and 113 feet of green shale. At Calmar the upper dolomitic bed only was penetrated. At Mason City both dolomites and shale are clearly demonstrated, the first 116 feet thick, and the other fifty-eight feet. Beyond Mason City nothing is known of their thickness. As they are found outcropping in southwestern Minnesota within a few miles of the Sioux quartzite, it is assumed that they extend to near the western limit of the section. Very possibly much of the shales and sandstones below 623 feet A. T. at Sanborn may belong to this group and the Jordan sandstone.

Jordan Sandstone.—The course of this formation is readily traced from McGregor to Mason City. In this distance it has sunk 780 feet and has thinned to 70 feet. Beyond Mason City its presence and altitude are hypothetical.

ONEOTA DOLOMITE.

This great body of dolomitic limestone retains its thickness of about 300 feet, with its lithological characteristics unchanged, as far west as Mason City. Here and at Calmar the driller has recorded the presence of a medial layer of mixed lime and sandstone, the equivalent of the New Richmond, which divides the formation into an upper and lower member, of which the latter is the thicker. At Emmetsburg the upper only is penetrated.

SAINT PETER SANDSTONE.

There can be but little doubt that the section correctly represents the actual position of this formation in northern Iowa. The physical characteristics of the sandstone, the order of its succession, its association with the dolomite of the Oneota beneath and the shales of the Trenton above, and the agreement of this evidence with that obtained from the stratigraphy of the region, assure that in each well section the sandstone so designated is really the Saint Peter. It is heaviest at Emmetsburg, where its thickness of 110 feet may be compared with its thickness of 180 feet at Freeborn, Minn.,* some seventy miles to the northeast along the strike of the strata.

*Winchell: Bul. No. 5, Geol. Surv. Minnesota, p. 18.

THE GALENA-TRENTON LIMESTONE.

The facts brought to light in this investigation show two most interesting changes which affect this formation as it passes westward from its outcrops in the counties bordering upon the Mississippi river. To the east the formation is composed chiefly of thinly bedded, non-magnesian, or slightly magnesian limestones. At Postville no dolomite appears except in a somewhat doubtful sample from immediately beneath incoherent Pleistocene deposits, although the section includes Galena-Trenton limestone and shales at least 350 feet thick. At Calmar where the Galena-Trenton is 538 feet thick, the dolomitic portion is not over seventy-five feet or 100 feet in thickness, if the base of the Galena limestone is placed at either of the upper shales of the section on page 177. To the south, at Manchester, as we shall see, the entire bulk of the formation escaped dolomitization. But on the west all the samples of the limestones of this terrane on the line of the Chicago, Milwaukee & Saint Paul railway are dolomitic. Along with the increasing dolomitization of the great bulk of the formation, its basal portion becomes more and more argillaceous, until it is as distictively shale as is the Maquoketa, the thickness of whose outcrops it equals. In the deep well at Freeborn, Minn., where the shore line is approached toward the northward, the basal shale of the Trenton, proved to be such by its fossils, measures ninety feet in thickness.

MAQUOKETA SHALE AND NIAGARA LIMESTONE.

According to McGee the Maquoketa and Niagara both occur upon the Calmar plateau. Recent work of Calvin, however, has made it probable that neither formation crosses the Turkey river from the west along the line of our section. The Niagara is best drawn comparatively thin, as it must be near its northern attenuated edge. Calvin has shown in work still unpublished that in this region, the outcrops of dolomite hitherto called Niagara, are really of Devonian age. The Maquoketa is more persistent than the Niagara since it crosses the Minnesota line with a thickness of about seventy feet, while the Niagara is not known to occur in the state.* How far beyond Mason City the Maquoketa continues to the west is quite unknown. Very possibly the fifteen feet of shale at Emmetsburg at 422 feet from the surface may be of this formation; but as no records or samples from the Algona and Britt wells have been preserved, it is impossible to trace it beyond Lime Creek.

DEVONIAN AND MISSISSIPPIAN.

It should be understood that beyond their wide outcrops the stratigraphy assigned to these formations is almost wholly hypothetical. Lithologically the dolomite at Emmetsburg lying immediately beneath the red marl assigned by N. H. Winchell to the Jura Trias may belong, as well, to the Silurian or Devonian, as to the Mississippian. The shale at 422 feet, however, recurs at West Bend, twelve miles east and ten miles south of Emmetsburg, in the same succession at a slightly higher level. As it is thus directed toward the Lime Creek shales of the Devonian, rather than toward the Maquoketa, the Paleozoic rocks above it are assigned to the Mississippian.

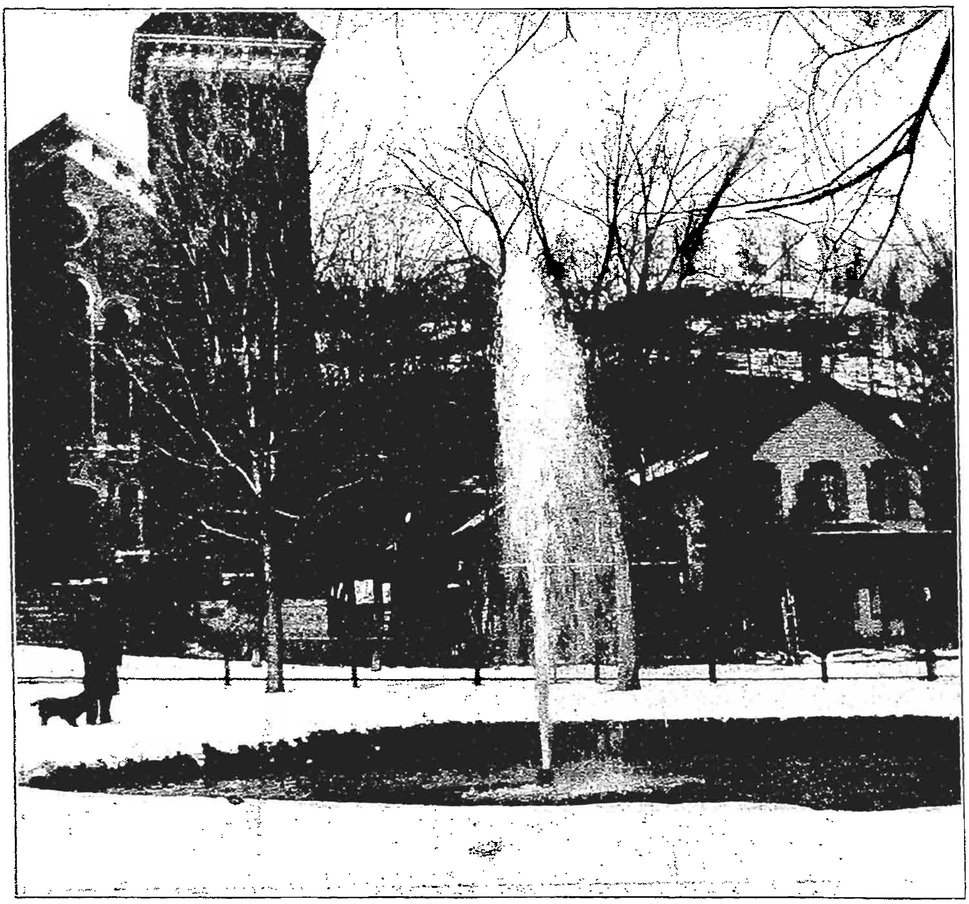
CRETACEOUS.

The basal sands of the Cretaceous are seen to be wide spread upon an ancient peneplain which bevels the successive Paleozoic terranes at an altitude of from 900 to 1,000 feet above sea level. These Dakota sands stretch as far east, at least, as Lotts Creek. The superior members of the series, the Benton and Niobrara, are known to occur on the Sioux river. Their great force at Sanborn is on the authority of the driller's record only. If this is correctly interpreted, the Cretaceous has here a thickness of 515 feet, the greatest measured in Iowa.

*Hall and Sardeson, Paleozoic Formations of Southeastern Minnesota, Bul. Geol. Soc., Am., vol. III. p. 368.

The Artesian Supply of the McGregor-Fairview Section.

To the east of the central trough the main artesian supply lies in the Saint Croix sandstones. The objective point in drilling should be the Jordan, whose depth at any locality can be estimated by reference to Plate No. IX. If sufficient water is not obtained by the time that the Jordan is penetrated, drilling should continue into the basal sandstone. The New Richmond sandstone is probably too discontinuous and thin to carry water. The crevices of the Oneota may yield abundantly, as in wells farther to the south, but to this we have no testimony. The Saint Peter carries a supply usually inadequate for civic purposes, and in Allamakee and northern Winneshiek counties it is so dissected by erosion that it can furnish comparatively little water, and that at a low head. Supplies small, but of great value to villages of few inhabitants and to farmers, may be found within the Devonian and Niagara in the basin formed by the impervious shales of the Maquoketa, and also within the Trenton, in the basin formed by its basal shales; but here, as in all limestones, there is an uncertainty of striking the vein which does not obtain in the case of porous sandstones. It will be remembered that the formations rise to the north, so that towns north of the section can obtain artesian water at less depth and with higher head than their longitude on the section would indicate. It will be sufficiently exact for estimates, if a dip to the south of from seven to ten feet to the mile is allowed. About seven and a half feet is the dip of the formations in the accompanying section from Freeborn, Minn., to near Mason City. For the western side of the trough there is much difficulty in making reliable prognostices. We cannot escape the limitations imposed by the lack of such information as would be in hand if sample drillings and exact records of the deep wells of the northwest had been preserved. Few exact statistics have been obtained as to even the yield of the deep wells of this region. The yields at Emmetsburg and at Mason City are distinctly unfavorable and discouraging.



ARTESIAN WELL AT McGREGOR, IOWA.

Very possibly the porous saccharoidal sandstones of the Saint Croix are largely replaced to the west by sandstones of finer grain, by freestones and by shales. This would seem to be indicated by the record of the Sanborn well. The Saint Peter fortunately seems to thicken to the north and west, and it may be the main source of an acceptable supply. The Dakota sandstone, and Tertiary sandstones, where they may exist beneath the drift, should furnish large supplies, though of poor quality and low head.

Wells of the McGregor-Fairview Section.

I. M'GREGOR.†

	WELL NO. 1.	WELL NO 2.	WELL NO. 3.
Owner.	Town.	Town.	J. Goedert.
When drilled.	1876-1877.	1890.	1889.
Depth.	1,006 feet.	520 feet.	294 feet.
Diameter.	6 in. reduced 3 in.	6 in reduced to 3 in.	6 inches.
Elevation of curb.*	632 feet A. T.	618 feet A T.	622 feet A. T.
Head of water.	694 feet A. T.	638 feet A. T.	644 feet A. T.
Flow per minute.	20 barrels.		
Temperature.	54° Fahr.	52° Fahr.	52° Fahr.

From this locality, including Prairie du Chien, on the Wisconsin side of the Mississippi river, there are reported some twelve artesian wells; and it is gratifying to learn that notwithstanding the great volume of water daily poured from the basin, well No. 1, one of the pioneer wells of the state, has suffered no perceptible change in its flow. In this well four-inch copper casing is used to the depth of forty feet, the original six-inch iron casing having been destroyed within two years by the corrosion of the saline water. No packing was used and it is thought that there is some leakage at the base of the casing. Well No. 2 was also recased, reducing the diameter from six inches to three inches, as the original casing was poorly done and the water leaked out through the joints. The second casing extends to 215 feet, and is packed at the base with a rubber gasket. In each of the wells the first flow was

†Reported By Mr. C. W. Walker and Hon. Horace Beach.

*With the elevation of the Chicago, Milwaukee & St. Paul railway station at 612 feet A. T. according to Gannet as datum.

struck at 315 feet A. T., and from this to the base all sandstone beds were water-bearing. At a little over 520 feet from the surface brine was found in four feet of white sandstone. The two town wells supply fire protection, several public drinking places and the two finest fountains in the state. Three-eighths of a mile of pipe are laid through the business portion of the town, with five hydrants and a number of public taps. The water of the deeper well corrodes iron so rapidly as to be entirely unfit for steam purposes. Although somewhat saline it is palatable to most persons. The water of well No. 2 has no corrosive effect on boilers, but forms a slight scale.

Several chemical analyses have been made of the waters of the McGregor artesians. The following by Joseph Henry of the Smithsonian Institution, is given as published in the North Iowa Times, March 15, 1887.

"The * * * * analysis of the water of the McGregor artesian well No. 1, is found to be a saline water, holding in solution in round figures 136 grains of solid matter to the gallon as follows:

Silica.	Potassium.	Sulphuric acid.
Iron.	Sodium.	Phosphoric acid
Alumina.	Lithium.	Boracic acid.
Lime.	Chlorine.	Carbonic acid.
Magnesia."		

Scarcely more satisfactory is the analysis of the same well made by Hinrichs, January, 1879.

Specific gravity at 19½° C.	1.0014
Total mineral matter, grains per gallon	157. gr.
Carbonate of lime, grains per gallon	22.4 gr.
Sodium carbonate and magnesium sulphate	134.6 gr.

"The water also contains a very small amount of lithium chloride, the lithium lines being visible but faint when the residue of the water is examined by means of the spectroscope."

Official Analyses.

	NUMBER 1.		NUMBER 2.	
	Grains per U. S. gallon.	Parts per million.	Grains per U. S. gallon	Parts per million.
Silica ($Si O_2$)	.323	5.571	0.398	6.857
Alumina (Al_2O_3) / Ferric oxide ($Fe_2 O_3$)	.348	6.000	0.124	2.143
Lime (Ca O)	13.200	227.571	4.524	78.000
Magnesia (Mg O)	2.443	42.286	2.834	48.857
Potash (K_2 O)	----------	----------	Trace	Trace
Soda (Na_2 O)	55.083	949.714	3.695	63.714
Chlorine (Cl)	56.136	967.857	2.088	36.000
Sulphur trioxide ($S O_3$)	22 504	388.000	2 618	45.143
Carbon dioxide ($C O_2$)	10.664	183 857	10.705	184.572
Water in combination (H_2 O)	1.069	18.428	1.732	29.857
Free ($C O_2$)	[9.305]	[160.428]	[4 350]	[75.000]
UNITED AS FOLLOWS.				
Calcium carbonate ($Ca CO_3$)	----------	----------	5.245	90.429
Calcium bicarbonate ($Ca H_2 (CO_3)_2$)	17.930	309.143	4.549	78.429
Magnesium bicarbonate ($Mg H_2 (CO_3)_2$)	----------	----------	9.868	170.143
Calcium sulphate ($Ca SO_4$)	17.002	293.143	----------	----------
Magnesium sulphate ($Mg SO_4$)	7.325	126.286	.332	5.714
Sodium sulphate ($Na_2 SO_4$)	13 539	233 428	4 276	73.714
Sodium chloride (Na Cl)	92.634	1597.143	3.455	59 571
Alumina ($Al_2 O_3$) and Ferric oxide	.348	6 000	0.124	2.143
Silica ($Si O_2$)	.323	5 571	0.398	6.8-57
Oxygen replaced by chlorine (O)	12.677	218 570	.472	8.143
Solids	161.778	2789.284	28 72	495.143

Analyst: Prof. J. B. Weems, Ames, Iowa. Date: June 16, 1896.

RECORD OF STRATA.

The following record of a well at Prairie du Chien* will illustrate the geological section at McGregor.

		THICKNESS.	DEPTH.
16.	Sand and gravel	147	147
15.	Clay, fine, light blue	$\frac{1}{6}$	
14.	Limestone, hard arenaceous	2	149
13.	Grit, blue	6	155
12.	Shale, bluish green, arenaceous	107	262
11.	Sandstone, white, friable, alternating with hard streaks	118	380
10.	Grit, blue	35	415
9.	Slate rock	65	480
8.	Sandstone, reddish and yellow ochery	6	486
7.	Shaly rock	24	510

*Geology of Wisconsin, vol. IV, p. 61.

		THICKNESS.	DEPTH.
6.	Sandstone, white, carrying brine	4	514
5.	Slaty rock	75	589
4.	Sandstone	310	899
3.	Sandstone, red	45	944
2.	Conglomerate, white waterworn quartz pebbles	5	949
1.	Sandstone, coarse	10	959

The curb is near the summit of the Saint Croix. No. 16, the alluvial filling of the preglacial valley of the Mississippi, supplies the place of the upper sandstone of the Saint Croix, the Jordan. No. 14 is the remnant left after erosion of the Saint Lawrence dolomite. Nos. 12 and 13 are the Saint Lawrence shales. Preceding numbers represent the basal sandstone of the Saint Croix. Another well at Prairie du Chien was sunk to a depth of 1,040 feet without reaching the Algonkian.*

II. MONONA.

Owner, Chicago, Milwaukee and Saint Paul Railway Co.
Elevation of curb .... 1,209 feet A. T.
Depth .... 420 feet.
Head of water .... 959 feet A. T.

ANALYSIS.

	GRAINS IN U. S. WINE GALLON.
Calcium carbonate	7 14
Magnesium carbonate	8.95
Calcium sulphate	10.41
Alkaline sulphates	0.63
Alkaline chlorides	1.87
Silica, alumina and oxide of iron	0.10
Total	29.10

Analyst and authority, H. E. Smith, Chemist of C. M. & St. P. Ry. Co., August 31, 1894.

III. POSTVILLE.

This well was drilled by Dickson Bros. from March 11, 1895, to July 26th of the same year, for the incorporated town of Postville.

*Private letter from Hon. Horace Beach.

Depth	515 feet.
Elevation of curb	1,191 A. T.
Head of water	891 A. T.
Diameter	8¾ in
Supply of water per minute	32 gal.
Temperature	48° Fahr.

The casing was sunk to 102 feet. Water was found at 130 feet and stood at this level until the drill reached the depth of 435 feet, the top of the sandstone of No. 8 of the following section. Immediately on striking the vein at this point the water in the well dropped to 300 feet from the surface. If the supply should be found insufficient, the well can be sunk some 400 feet further, thus penetrating the upper sandstones of the Saint Croix with their abundant yield under superior head, and tapping also the veins of the Oneota. If this is done, it will be necessary to case the well from 425 to 460 feet to prevent lateral leakage through the channel which now supplies the well.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
22.	Humus	2	2
21.	Loess, yellow	16	18
20.	Loess, ashen	6	24
19.	Clay, yellow, sandy and pebbly, non-calcareous	4	28
18.	Sand, yellow, sharp and rather coarse	4	32
17.	Clay, dark drab, sandy and pebbly, calcareous	40	72
16.	Limestone, some buff and magnesian, some lighter colored and of rapid effervesence; cherty	13	85
15.	Shale, green, calcareous, soft	12	97
14.	Limestone, blue, earthy, magnesian; eleven samples	106	203
13.	Shale, soft, grey, calcareous	9	212
12.	Limestone, light yellow and white, hard by driller's record, earthy-crystalline, non-magnesian as judged by rapidity of effervescence	138	350
11.	Limestone as above, a little softer; five samples	35	385

		THICKNESS.	DEPTH.
10.	Limestone, greenish grey, argillaceous	10	395
9.	Limestone, light yellow grey, crystalline-earthy; four samples	41½	436½
8.	Sandstone, with usual aspect of Saint Peter; grains rounded and smoothed, of limpid quartz, mostly unbroken; with much limestone, yellow and grey, rapidly effervescing, in angular sand. No trace of imbedded grains noticed in limestone fragments	11½	448
7.	Sandstone as above, with less of limestone	2	450
6.	Limestone, blue grey, argillaceous, in part macro-crystalline, in flaky chips, largely compacted of comminuted fossils; two samples	8	458
5.	Limestone and shale, grey, earthy, in chips	5	463
4.	Limestone, light blue grey, mottled, in flaky chips, compact crystalline-earthy	7	470
3.	Limestone, yellow grey, mottled, macro-crystalline-earthy, fossiliferous, in chips; four samples	17	487
2.	Limestone, light grey, compact, fine grained; four samples	15	502
1.	Sandstone, calciferous, soluble ingredients consist of about one-half by weight of the drillings, some grains of sand imbedded in the minute angular chips of limestone. Other larger fragments show limestone matrix to be large; limestone yellow grey and of rapid effervescence. Loose in the drillings and also seen embedded are many black opaque grains, ferruginous nodules of calcareous clay; and grain-like nodules of pyrite; three samples	13	515

From the starting of the drill samples were carefully saved according to the author's directions at such short intervals that the geological section which they afford is as reliable as that of an outcrop. All the numbers of the section below No. 16, excepting the sandstones at 436½ feet and 502 feet, are in texture and chemical composition as typically Trenton limestone and shale as can be found in any quarry of that stage. Both of the sandstones just designated are regarded by Calvin as Saint Peter, and he has suggested that the fifty-two feet intervening between them represent an ancient cavern in the Saint Peter, now filled with shale and limestone broken down and washed in from the overlying Trenton.*

IV. CALMAR.

This well, owned by the Chicago, Milwaukee & Saint Paul Railway Co., was drilled by W. E. Swan, from February 2, 1880, to July 28th of the same year. No casing was put in as the well was dug to rock.

Elevation of curb	1,261 feet A. T.
Depth	1,223 feet
Diameter of bore	8 inches
Height of water	1,161 feet A. T.

The following record is the driller's log in feet.

		THICKNESS.	DEPTH.
15.	Dug	70	70
14.	Limestone	76	146
13.	Shale	10	156
12.	Limestone	35	191
11.	Shale, gray	25	216
10.	Limestone	305	521
9.	Shale, green	47	568
8.	Limestone	30	598
7.	Shale	10	608
6.	Sand rock	67	675
5.	Lime rock	98	773
4.	Sand and limestone mixed	47	820
3.	Limestone	180	1,000
2.	Sand rock	120	1,120
1.	Limestone	103	1,223

These strata are assigned to the following formations.

		THICKNESS.	A. T.
15.	Pleistocene	70	1,191
7–14.	Galena-Trenton	538	653
6.	Saint Peter	67	586
5.	Upper Oneota	98	488
4.	New Richmond	47	441
3.	Lower Oneota	180	261
2.	Saint Croix, Jordan	120	141
1.	Saint Croix, Saint Lawrence	103	38

*American Geologist, vol. XVII, pp. 195-203. 1896.

ANALYSIS.

	GRAINS PER U. S. WINE GALLON.
Calcium carbonate	9.05
Magnesium carbonate	4.90
Calcium sulphate	2.98
Alkaline chlorides	0.18
Silica, alumina, and oxide of iron	0.13
Total	17.24

Analyst and authority, H. E. Smith, chemist C., M & St. P. Ry. Date, September 24, 1888.

V. NEW HAMPTON.

Although the town well of New Hampton can hardly be classed as an artesian, a brief description is here given as it illustrates the conditions of the water supply of the region.

Depth	235 feet
Elevation of curb	1,154 A. T.
Diameter	10 inches
Head, from surface	65 feet
Temperature	47° Fahr.
Casing, depth to which sunk	125 feet

DRILLERS' RECORD.

		THICKNESS.	DEPTH.
4.	Clay	25	25
3.	Sand	8	33
2.	Clay and shale	104	137
1.	Lime rock	98	235

This well was drilled by Mr. S. Swanson, in September, 1895. For four years previous the town had used surface water from an open well twelve feet in diameter. As the supply (from the sand of No. 3) was insufficient, and as there was some suspicion that it had become contaminated, the present well was sunk, obtaining pure water in abundance in crevices in the hard and solid rock of No. 1.

Mr. T. F. Babcock, to whom we are indebted for all these facts except the log furnished by the drillers, writes that the casing was driven through sand and hardpan, and into the solid rock. "Soft lime rock was struck at 105 feet. At 115 feet clay and rock was found intermixed for a few feet; from there down the rock was hard with occasional crevices."

The hardpan, or till, is the clay of No. 2 of the drillers' record, and its thickness is unknown. The reservoir is Devonian, and the area of supply, its outcrops west of the Little Turkey and to the north.

VI. MASON CITY.*

	C., M. & ST. P.	TOWN WELL NO. 1.	TOWN WELLS NOS. 2, 3 AND 4
Elevation of curb.	1,128 †A. T.	1,077 A. T.	1,077 A. T.
Head of water.	1,126 †A. T.	1,078 A. T.	1,078 A. T
Diameter.	8 and 6 inches.	8 inches.	4 inches.
Depth.	1,473.	1,350.	651.
Temperature.		49° Fahr.	49° Fahr.

Of the five artesian wells at Mason City, the first was drilled for the Chicago, Milwaukee & St. Paul Railway Co., about 1879, by Swan Brothers. The well is not used. The capacity was not sufficient to keep a small steam pump running, and the water was found less suitable for locomotives than that supplied by the town. The well is now used as a cesspool, and the water is supposed to stand now from thirty to seventy-five feet from the curb.

The water works built by the town pumped their supply at first directly from springs and the adjacent creeks. Considerable money—says one of our correspondents—was spent in experimenting with surface water supplies and the process of filtration of water from Lime creek. These experiments of filtration were doubtless of the crudest, and, as the results were unsatisfactory, it was determined to seek an artesian supply. In 1892, therefore, drilling was begun for the town by Henry F. Miller, of Chicago. At 651 feet—or at 540 feet, according to other reports—water was struck which rose to the surface. As the supply was far from sufficient, drilling was continued to 1,350 feet, where a crevice was reached and the flow lost, the water sinking 550 feet. The well was plugged at 651 feet, and three other wells were drilled to this depth. As these wells were begun in rock, no casing was

*Drillings from the railway well were contributed by Division Supt. C. A. Cosgreaves and Dr. Shorland Harris, who also furnished the driller's record. We are also indebted to Civil Engineers Messrs. C. T. Dike and Orin Stanly.

† Approximately.

used. They occupy corners of a parallelogram sixty feet long and forty feet wide, and this space, excavated to the depth of sixteen feet, forms the reservoir into which the wells discharge. The combined natural flow of the four wells is sixty gallons a minute. As this was insufficient, the town at first pumped a portion of the time from the adjacent creek, thus mingling raw and perhaps contaminated water with the pure artesian supply. In August, 1894, the Phole air lift was introduced. Pipes were sunk 200 feet in each well, and the discharge of the wells was increased to 150 gallons a minute. It is reported that the water can be lowered only fifty feet by continuous pumping, and at present the air lift is used about two and one-half hours out of the twenty-four. The supply comes from a porous rock a short distance above the basal shales of the Trenton. The vein is said to be forty inches thick.

ANALYSIS.

	GRAINS IN U. S. WINE GALLON.
Calcium carbonate	10.99
Magnesium carbonate	4.48
Alkaline carbonates	1.21
Alkaline sulphates	.34
Alkaline chlorides	.44
Silica alumina and oxide of iron	.19
Total	17.65

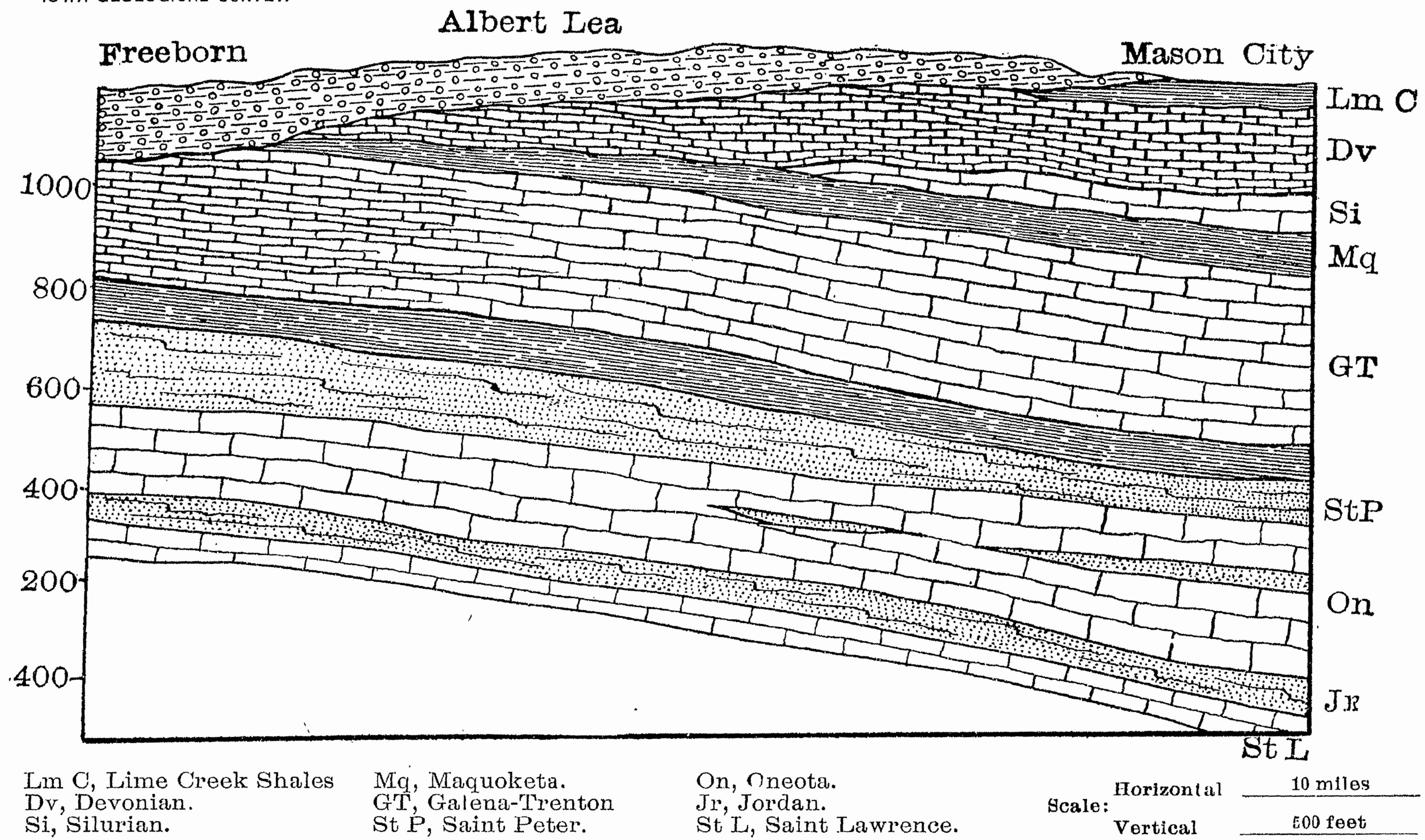
Analyst and authority, H. E. Smith. Date, April 6, 1891

This analysis places the water in the highest rank of potable water in the state. Its mineral ingredients are not large, and they are above suspicion of any injurious effects.

RECORD OF STRATA.

The author's description of the drillings from the deepest well has been already published.* The following summary of the formations is as stated in the manuscript of that paper, with elevations above tide added.

*Iowa Geol. Surv., vol. III, pp. 188-189.



GEOLOGICAL SECTION FROM MASON CITY TO FREEBORN, MINN.

		THICKNESS.	DEPTH.	ELEVATION A. T.
12.	Humus and drift	28	28	1,100
11.	Devonian and Silurian	276	304	824
10.	Maquoketa	57	361	767
9.	Galena-Trenton	405	766	362
8.	Saint Peter	105	871	257
7.	Upper Oneota	113	984	144
6.	New Richmond	50	1,034	94
5.	Lower Oneota	145	1,179	– 51
4.	Saint Croix (Jordan)	70	1,249	–121
3.	Saint Croix (Saint Lawrence)	174	1,423	–295
2.	Saint Croix (Basal sandstone)	45	1,468	–340
1.	Algonkian (?) penetrated	5	1,473	–245

The driller's record of No. 1 of "granite," as reported from Mason City, and "quartzite" as stated by the driller to Prof. C. W. Hall, of Minneapolis, is not substantiated by either of the drillings representing this horizon. These contain none of the constituents of granite except quartz, and this is in the form of rolled grains. No. 1, so far as shown by the drillings, is a glauconiferous sandstone and belongs with No. 2 to the basal sandstone of the Saint Croix.

VII. BRITT.

Owner	C. M. & St. P. Ry. Co.
Depth	684 feet.
Diameter	7 inches.
Elevation of curb	1,236 A. T.
Head of water	1,220 A. T.
Depth to rock	125 feet

ANALYSIS.†

	GRAINS IN U. S. GALLONS. NO. 1.	NO. 2.
Calcium carbonate	12.58	15.30
Magnesium carbonate	7.98	8.15
Calcium sulphate	4.16	.76
Silica, alumina and oxide of iron	.15	.23
Alkaline chlorides	.22	.17
Alkaline sulphates	----	3.23
Total	25.09	27.84

*Information supplied by Messrs. J. A. Carton and J. A. Treganza.

†Dates, No. 1, October 6, 1888, No. 2, May 19, 1894. Analyst and authority, H. E. Smith. Depth of well when No. 1 was made, 533 feet; when No. 2, 684 feet.

VIII. ALGONA.*

Owner	Town(?)
Depth	1,050 feet.
Elevation of curb	1,202† feet.
Head of water	1,133† feet.

DRILLERS' LOG.

		THICKNESS.	DEPTH.
5.		235	235
4.	Sand rock	75	310
3.	Lime rock	125	435
2.	Sand rock	300	735
1.	Shale and streaks of sand rock	315	1,050

This record may be interpreted as follows, but with hardly more than a shade of probability in several of the determinations.

		FEET.
5.	Drift	235
4.	Mississippian	75
2.	Dolomites of Niagara-Trenton (often called "sand rock")	300
1.	Basal shale of Trenton. Shales, dolomites and sandstones of inferior terranes	315

IX. EMMETSBURG.‡

Owner	C., M. & St. P. Ry. Co.
Depth	874 feet
Elevation of curb	1,230 A. T.
Head of water	1,197 A. T.

ANALYSIS.

	GRAINS PER U. S. WINE GALLON.
Calcium carbonate	13.96
Magnesium carbonate	6.46
Alkaline sulphates	2.52
Alkaline chlorides	0.48
Silica, alumina and oxide of iron	0.54
Total	23.96

Date May 16, 1894. Analyst and authority, H. E. Smith.

*Although a full report was sent in of the system of water works by the superintendent, repeated applications to citizens and officials for information as to the well remain unanswered. Possibly nothing whatever is known of the well further than the meagre details kindly supplied by the driller, Mr. S. Swanson.

† Approximately.

‡ A complete set of some eighteen samples of the drillings of the Chicago, Milwaukee & St. Paul railway was saved by Capt. E. B. Soper—the only complete set known of any well in northeastern Iowa, except that at Sioux City. This set was submitted to the author, and his determinations were published in a preceding report of the Survey. (Iowa Geol. Surv., vol. III, pp. 186, 187)

This water is derived from the Saint Peter sandstone, No. 2 of the section given below, and its source lies to the north and probably to the west. The Dakota sandstone, No. 10, also contains a copious supply of water, but it is cased off from this well, as it is so heavily mineralized as to be unfit for boiler use. The town well, 246 feet deep, utilizes this source, whose capacity through a six-inch bore is 120 gallons per minute.

	RECORD OF STRATA.	Thickness.	Depth.	Elevation A. T.
11.	Humus and till	225	225	1,005
10.	Sandstone, incoherent, Dakota	109	234	896
9.	Shale, red, Cretaceous	22	356	874
8.	Dolomite	32	388	842
7.	Shale, blue, Mississippian	4	392	838
6.	Sandstone, identical with 10	30	422	808
5.	Shale, blue, calcareous	15	437	993
4.	Limestone, magnesian and dolomite	224	661	569
3.	Shale, blue, highly calcareous in part. Trenton	95	756	474
2.	Sandstone. Saint Peter	110	866	364
1.	Dolomite, termed "granite" in log. Oneota	6	872	358

The log of the driller, Mr. W. E. Swan, with Dr. N. H. Winchell's interpretation is as follows:*

		FEET.
15.	Yellow clay (loess loam)	16
14.	Blue clay (boulder clay and Cretaceous)	204
13.	Dark sand } (Dakota of the Cretaceous.)	30
12.	Gray sand } (Dakota of the Cretaceous.)	79
11.	Red marl (Jurasso-Triassic)	22
10.	Broken limestone	10
9.	Sandy lime rock	22
8.	Black shale	4
7.	Lime rock	30
6.	Gray shale	15
5.	Magnesian limestone	224
4.	Gray shale	65
3.	Blue shale	30
2.	White sandstone (Saint Croix)	107
1.	Granite (Potsdam quartzite)	6
	Total	869

* Winchell. Bulletins Minn. Acad. Nat. Sc. vol. 1, pp 387, 388.

X. SANBORN.

Owner	C., M. & St. P. Ry. Co.
Depth	1,256 feet
Elevation of curb	1,552 A. T.
Head of water	1,202 A. T.
Capacity in gallons per minute	100

This well was drilled by S. Swanson in less than five months, from December 1, 1895 to April 23, 1896. The bore is 8 inches to a depth of 436 feet, 6 inches to 721 feet, and 4½ inches the remainder of the distance to the bottom. Water was found at 494 feet, 503 feet and 857 feet. The well is cased to 815 feet, thus presumably shutting off all except the lowest vein.

ANALYSIS.

	GRAINS PER U. S. WINE GALLON.
Magnesium carbonate	18.53
Magnesium sulphate	6.70
Calcium sulphate	70.08
Alkaline sulphate	29.82
Alkaline chloride	2.50
Oxides	Trace
Total	127.63

Date, September 17, 1896.

This water which contained 95.31 grains per gallon of incrusting solids, or 13.62 pounds per 1,000 gallons, is well pronounced by the analyst, Mr. H. E. Smith, as unfit for boiler use. It is the strongest selenitic water analyzed in the state and could not be recommended for town supply.

RECORD OF STRATA.

The following is the log of the driller, with such determinations of the formations as seem most probable:

		THICKNESS.	DEPTH.	ELEV. A. T.
9.	Clay, yellow, Pleistocene	75	75	1,477
8.	Clay, blue, Pleistocene	125	200	1,352
7.	Shale, blue, Cretaceous	160	360	1,192
6.	Lime rock in streaks; shale, blue and green, Cretaceous	200	560	992
5.	Sandstone, soft, white (some shale), Dakota	155	715	837

		THICKNESS.	DEPTH.	ELEV. A. T.
4.	Shale, gray and streaks of rock, Trenton	50	765	787
3.	Sandstone, white, Saint Peter	45	810	742
2.	Shale, blue and green, mixed with sandstone } Oneota,	200	1,010	542
1.	Shale, green and white. } St. Croix	240	1,250	302

Unfortunately no samples were saved. Mr. Swanson, who has had much experience in drilling wells in Minnesota, where the Archean rocks are more frequently reached by the drill, writes that "the bottom of the well must be near the Archean formation, according to the similar formations found in wells where granite or the Archean formations are found." In position No. 5 corresponds to the Dakota sandstone, as will be seen by inspecting the general section of Plate IX. The Dakota sandstone is indeed "soft," but it is hardly to be expected that it would be described as "white." This description accords with the Saint Peter, as does the thickness with measurements of that formation in wells in southern Minnesota. Like the Saint Peter also No. 5 is covered with heavy shales.

XI. HULL.

Owner	Town of Hull.
Depth	1,263 feet.
Diameter	10 and 6 inches.
Elevation of curb	1,433 feet ‡ A. T.
Head of water	1,203 feet ‡ A. T.

This well was begun December 10, 1889, and was completed by Rodgers & Ordway, August 17, 1892. Casing reaches the depth of about 800 feet. Water was found between 700 and 800 feet. No analysis has been made. It is described by correspondents as very hard and heavily loaded with sulphate of lime. The supply is stated to be unlimited.

Nothing is known of the strata of the first 755 feet of the boring. Below that depth the drill passed through at least six beds of ancient lava intercalated between saccharoidal sandstones.† This assemblage of strata, unique in the

*Reported by Dr. N. G. O. Coad and Mr. W. M. Boomer.

†Beyer: Iowa Geol. Surv., vol. I, pp. 165-169.

‡ Approximately.

records of the geological history of Iowa, probably belongs to the Algonkian.

The description is inserted here of the wells situated north of the McGregor-Fairview section.

XII. LANSING.*

Owner	Lansing Artesian Well Co.
Number of wells	2.
Depth	676 feet and 748 feet.
Diameter	6 inches.
Elevation of curb A. T	677 feet.
Head of water A. T	719 feet and 709 feet.
Discharge in gallons per minute	700.
Temperature	50°.

This well was bored in 1877 by Swan Brothers. Casing is sunk to a depth of about 165 feet. Unfortunately, no analysis of the water has been made, and we know nothing of its qualities except that, though an excellent drinking water, it is hard and corrodes iron. It is a gratifying fact that, in contrast with many artesians, the flow of these wells is said to have increased. Lansing offers a pleasing instance of a town equipped with a water service at a very moderate cost. The supply of pure water is far in excess of the demand. The pressure at the wells is such that neither engines and pumps, nor standpipe or reservoir, have been considered necessary. The company report a comfortable revenue, and that their annual operating expenses are $165.35. The water rate to dwellings is $10 per annum. The city pays $310 per annum for ten hydrants. It need not be said that no meters are used.

RECORD OF STRATA.

The following description is of drillings taken from a tube.†

As the record had been lost, nothing remained but to assume that the length of the tube and the thickness of the respective drillings were proportioned to the depth of the well and the thickness of the several strata.

*Reported by Messrs. B. F. Thomas and E. Boeckh.

†Donated by Hon. Horace Beache, Ex-U. S. Commissioner of Artesian Wells, Prairie du Chien, Wis.

		ESTIMATED THICKNESS.	ESTIMATED DEPTH.
10.	Clay, yellow, no sample	37?	37?
9.	Shale, chocolate colored, slightly calcareous, with some coarse Pleistocene sand intermixed	35	72
8.	Shale, greenish-yellow, calcareous, arenaceous, with minute angular grains of limpid quartz	35	107
7.	Sandstone, white, yellow and buff, grains varying widely in size	125	232
6.	Shale, light purplish and drab, arenaceous	15	247
5.	Sandstone, fine yellow	5	252
4.	Shale, arenaceous; or sandstone, argillaceous, blue-drab, slightly calcareous	70	322
3.	Shale, red, arenaceous, with a thin stratum of intercalated drab shale as No. 3	45	367
2.	Sandstone, light yellow, moderately fine grains and sub-angular and rounded	381	748
*1.	"Hard crystalline rock" at		748

This entire section above No. 1, and excepting, of course, No. 10, consists of the basal sandstone of the Saint Croix. The same formation as measured by Calvin reaches in the adjacent bluffs to a height of ninety-six feet above the river. Thus compassed, the entire thickness of the formation at this place is seen to be 796 feet. The conjoined geological sections of river gorge and well are as follows:

Oneota limestone		120
Saint Croix.	Jordan sandstone	160
	St. Lawrence dolomite and shales	44
	Basal sandstone	796
Algonkian at		1,120

XIII. CRESCO.

The well at this place, owned by the Chicago, Milwaukee & St. Paul Railroad Co., is 1,158 feet deep. It was drilled about the year 1875, and has not been used for an unknown length of time.

XIV. HARPERS FERRY.

Nothing is known of this well beyond the few facts recorded by White.†

*Calvin: Iowa Geol. Surv., vol. IV, p. 56.

†Geology of Iowa, vol. II, p. 332-356.

XV. WAUKON.

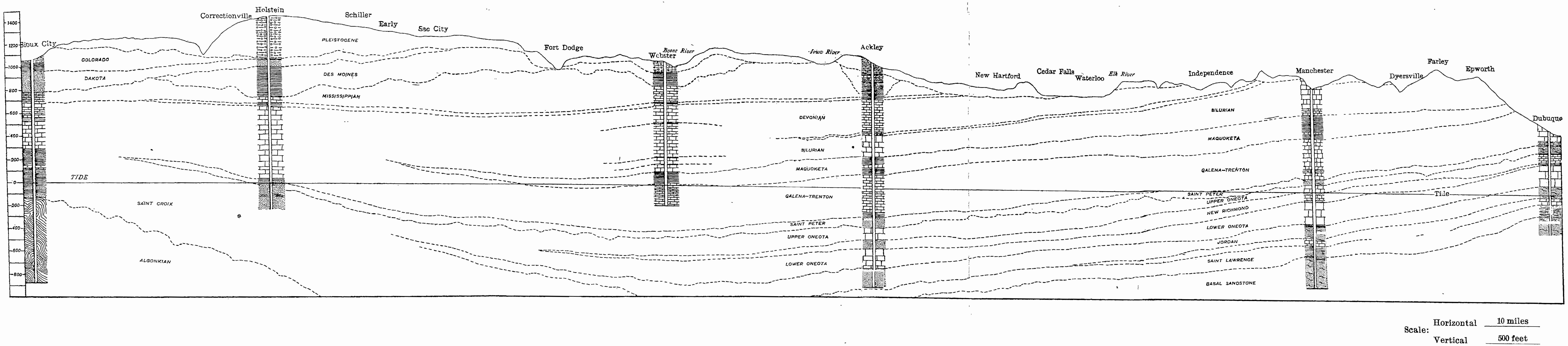
Owner	Incorporated town of Waukon.
Depth	577½ feet.
Bore	8 inches.
Head (depth from curb)	280 feet.
Capacity in gallons per minute	120.
Drillers	Palmer & Sandbo.

The Saint Peter sandstone was struck at a depth of 195 feet, or 132 feet below the grade of the railway at station. At 295 feet the drill is said to have entered the Oneota.

II. DUBUQUE-SIOUX CITY SECTION.

The stratigraphy of this section strongly resembles that of the section from McGregor to Fairview (plate IX), which lies from thirty-five to fifty miles to the north. The synclinal structure persists and the axis of the trough seems still to lie a little east of the Des Moines river. On the eastern side of the syncline, the westward component of the dip amounts to between 5 and 6 feet to the mile, as measured along the summit of the Maquoketa shale from Manchester to Webster City, and along the summit of the Saint Peter from Dubuque to Ackley. The dip on the western side of the trough is not known with any degree of accuracy. The southward component of the dip of the Paleozoic series much exceeds the westward and probably also the eastward. The axis of the trough dips more rapidly than the sides. From Calmar to Manchester, forty-eight miles south and twenty miles east, the Saint Peter declines 500 feet, a southward dip of about 12½ feet to the mile. From Mason City to Ackley the Maquoketa declines 560 feet, at the rate of 14 feet to the mile. At Emmetsburg the Saint Peter lies 460 feet higher than at Holstein, sixty-one miles to the southwest. A dip of 5 feet to the mile from Holstein eastward brings the Saint Peter, at a point directly south of Emmetsburg, 680 feet lower than at that town, a dip of 16 1-5 feet to the mile. The eastward dip from Holstein is probably considerably more than 5 feet to

*Information supplied by Messrs. C. L. Bearce and J. G. Ratcliffe.



GEOLOGICAL SECTION ALONG ILLINOIS CENTRAL RAILWAY FROM DUBUQUE TO SIOUX CITY.

the mile, and the southward dip from Emmetsburg is assumed to be more nearly 20 feet to the mile.

The southward slope of the Algonkian floor is still more steep. The quartzite at Rock Rapids rises as a mountain 1,300 feet in height above the Algonkian at Le Mars, forty-four miles south. The following diagram figures the Algonkian floor on this section.

Lying several hundred feet lower than on the McGregor-Fairview section, the formations below the Niagara fail of outcrop except in the immediate valley of the Mississippi, and the superficial area of the Niagara and the higher terranes is greatly widened. The Coal Measures now appear at Ackley,

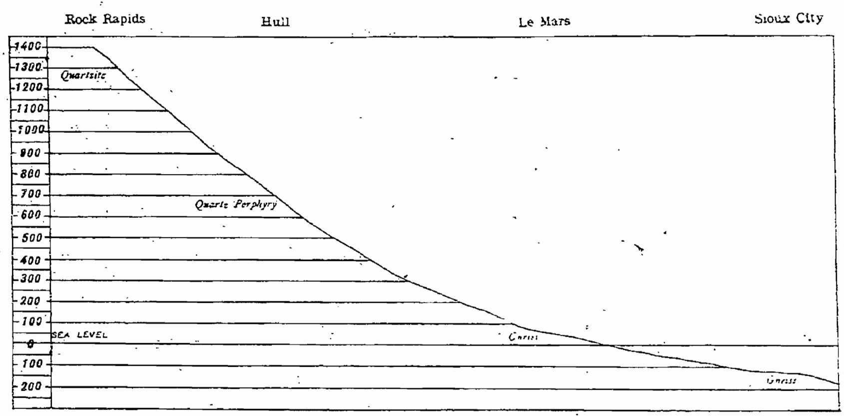


FIG. 39. Profile of the Algonkian floor from Rock Rapids to Sioux City. Scale—8 miles to the inch.

Webster City, and Fort Dodge. Their westward extension beneath the Cretaceous in Woodbury county is hypothetical. The heavy shales at Holstein whose base is at 757 A. T., are best referred to this terrane. The assumption involved that the base of the Coal Measures has thus declined 200 feet westward from Fort Dodge is not unreasonable, since it corresponds in direction, if not in degree, with the dip of the strata in the sections farther to the south.

These shales do not appear at Cherokee, eighteen miles due north of Holstein. At 915 A. T. the drift there gives place to heavy limestones, which seem to correspond to the limestone which immediately underlies the shale at Holstein

With a southward dip of about nine degrees these shales would therefore pass out before reaching Cherokee. At Dunlap, forty-four miles southwest of Holstein, the base of the Coal Measures is placed at 569 A. T., showing a dip in this direction of a little over 4 feet to the mile. It is not impossible that some portion, at least, of these shales at Holstein may be Cretaceous, since their base occupies about the same level assigned to the base of the Cretaceous at Sioux City. This arrangement, however, would give a bulk to the eastward extension of the Cretaceous that is unsupported by evidence, and would destroy the parallel of the first sandstone at Holstein with the Dakota at Emmetsburg and Sioux City.

It cannot be considered certain that the upper shales at Ackley, with their interbedded limestones and sandstones, are not in part, at least, Kinderhook; but the fact that no such body of shale appears at Webster City at the depth at which the Ackley shale, if Kinderhook, would be carried by the western dip, together with the character of the shales, makes it highly probable that they belong to a northern extension of the Carboniferous outlier at Eldora. The magnesian limestone at 803 A. T. is underlain by a thin, highly calcareous and fossiliferous blue shale which occupies the place of the Lime Creek, or the Kinderkook. This is correlated with the shale at 678 A. T. at Webster City, and with much greater possibility of error with that at 707 A. T. at Holstein. The arrangement involves a thickness of between 300 and 400 feet for the Mississippian in the region of the Des Moines river and an unconformity of that group with the underlying Paleozoics of much greater extent in northwestern Iowa than obtains in other parts of the state.

The eastern frontier of the Devonian is crossed by the section a little to the east of Independence, where the basal shale of the Devonian was discovered by Calvin. The Independence shale is now known to extend at least forty miles to the southeast of the place that gave it name. Recent unpublished discoveries of the Independence fauna in the Kenwood shale of Linn county prove the previously assumed identity of the two shales. It probably extends to no great distance to the west, as at Ackley it was not recognized. Beyond Ackley it is impossible to draw, with a sure hand, either the upper or the lower limits of the Devonian.

The Silurian thins gradually from its outcrop westward, and, losing its dolomitic nature, fails of discrimination west of Ackley by any evidence supplied by the powdered rock of the drillings. Where it passes beneath the Devonian, its thickness can fall but little short of 300 feet.

The Maquoketa thickens rapidly from its outcrop at Dubuque. At Manchester it is 205 feet thick, eighty-five feet in excess of any estimated thickness of outcrop in the state. The formation is divided by a thin bed of dolomitic limestone at Manchester, Ackley, Anamosa and Vinton into two divisions, of which the upper is the heavier.

The shale in the Webster City section at 930 A. T. may safely by taken as the Maquoketa. One sample of argillaceous limestone is said to represent 120 feet of rock above it. Apart from the uncertainty attaching to sections constructed out of samples over 100 feet apart, it is possible that the Silurian is here becoming argillaceous. At Webster City is the last recognized appearance of the Maquoketa.

No district is known to the writer where the lithological change in the Galena-Trenton is so rapid and complete as occurs in the forty miles from Dubuque to Manchester. In this distance the whole Galena dolomite, buff, heavily bedded and crystalline, as it fronts the Mississippi river in a wall 250 feet high, has passed into thinly bedded and earthy blue and gray limestones of the ordinary Trenton type. At Ackley the samples of the Galena-Trenton show no dolomite; but the Galena reappears at Vinton and Anamosa.

At Holstein and Sioux City the strata referred to this persistent terrane are exclusively dolomites so far as the samples indicate. The basal shale of the Trenton is thin at Manchester; at Ackley, it is hard, bright green, and slaty, and about thirty-five feet thick; it reappears in thin stratum above the Saint Peter at Holstein.

The Saint Peter is recognized in all the deep borings of the section which reach to its assumed depth, except in the well at Sioux City. Its greatest depth is probably about 400 feet below sea level in Hamilton and Webster counties.

The division of the Oneota is not clearly made out at Dubuque. At Manchester two arenaceous beds occupy the horizon of the New Richmond. At Ackley this sandstone is seventy feet thick, white, saccharoidal and closely resembling the Saint Peter.

The Jordan sandstone thickens at Ackley, nearly to its extreme for the state. The upper portion is calciferous, but toward the base it becomes a soft sandstone of rolled grains.

The Saint Lawrence lies below the bottom of all the wells between Manchester and Sioux City. At the latter extreme it is probably represented, but its exact limits can not be fixed.

The basal sandstone at Dubuque descends below the limits of the section. At the profound depth of 1,248 feet below sea level the drill has not reached the crystalline rocks. Where maximum depth of this sandstone would be found is scarcely even to be conjectured, so great are the irregularities of the Algonkian floor on which it rests. On the western extreme of the syncline it rises on the slope of the gneissoid rocks, and at the Missouri river this sandstone and the terranes above it as high as the Saint Peter are probably all comprised within less than 500 feet.

Artesian Supply.

In only one well from Dubuque to Sioux City have we any definite information as to the water horizons of the section. Nevertheless the experience of drillers in other parts of the state may be utilized here, and borings for artesian water confidently recommended in the two tiers of counties from Clayton and Dubuque on the east to Wright and Hamilton on the west. In the two latter counties and in Franklin and Hardin, great care must be taken to shut out upper sulphurous and ferruginous waters from the Carboniferous. Beyond the Des Moines river no evidence at hand warrants the expectation that a generous yield will be found at any depth. The Holstein well will serve as an example of what may be expected in the western part of this region. Yet towns for which 50 to 100 gallons per minute is adequate may find artesian water, heading even at 200 or 375 feet below the surface, the best available supply. The indications are adverse in Plymouth and Woodbury counties, and doubtful in Cherokee.

The caution must be repeated that especially east of the Des Moines river, the supply must be looked for below the Saint Peter. The synclinal structure, and especially the heavy southward dip of the strata, permit artesian water in the limestones above that sandstone over a large part of the area crossed by this section. At Webster City two such veins were found, one in the Trenton, and one 325 feet above the Maquoketa. Such supplies should always be utilized, if sufficient and acceptable; but as they are at best uncertain no well should be begun unless with the expectation of going as deep as the Jordan sandstone. It may be advisable to go still deeper and tap the stores of the Basal sandstone, but before the drill enters the Saint Lawrence the adequacy of the upper veins should be tested.

On the western side of the trough, a moderate yield may sometimes be found in the Saint Peter. In no case should money be wasted by continuing the search whenever quartzitic or gneissoid rocks are reached. Yet experience shows that samples of the drillings should always be submitted to a geologist, in order to make certain that the drill is really working in crystalline rocks.

XVI. DUBUQUE.*

	Depth.	Bore—inches.	Elevation of curb, A. T.	Original head.	Present head, A. T.	When finished.	Original flow in gallons per minute.	Present flow in gallons per minute.	Casing.	Water horizons, A. T.	Driller.
1. Linwood cemetery.	1,954	3	706	742	707?	1891	40	20	1,025	-297 to-943	1
2. Linwood cemetery.	1,765	......	776‡	753‡	......	.....	......	......	.....	....	..
3. Water Works Co...	1,310	10	607	653	......	1888	2,500?	......	400	107 to-703	1
4. Butchers' Associa'n	1,000	5	607	740	648	1887	580	......	.....	....	1
5. Malting Co.........	999	5	624	......	......	1895	......	......	.....	....	2
6. E. Hemmi, dairy...	973	......	627	......	......	1895?	......	......	.....	....	1
7. Bank & Ins. Bldg Co	973	4½	638	648	648	1894	120	120	150	73 and below.	1
8. J. Cushing, factory	965	5	642	673	642	1888	......	......	.....	42 and below.	1
9. Packing & Prov. Co	955	6	607	662	688	1889	340	......	200	....	1
10. Lorimer house.....	1,057	5	652	709	652‡	.....	400	0	.....	....	..
11. Schmidt brewery...	886	6	630	......	645	1891	......	......	80	130 and below.	2
12. Steam Heating Co..	802	4	617	704	617‡	1894	260	0	.....	264, 1,378–163	1
13. Julien house..	896	4	615	724	712		480	....	222	....	1

1. J. P. Miller & Co.
2. J. Bicksler.

Dubuque probably ranks first among the towns of the state in the output of artesian waters, and is outclassed only by Davenport in the number of its flowing wells.

The first artesian water, so far as reported, springs from the New Richmond horizon of the Oneota at 264 A. T. The second supply mentioned is in the Jordan sandstone from 137 to 107 A. T. Water is reported also from the upper part of the Basal sandstone from 262 to 326 feet below tide, and from 544 to 944 feet below tide. Below the latter depth the Basal sandstone was found to be dry.

The original head of the wells 1,000 feet deep or less seems to have reached from 700 to 740 A. T. In the deeper wells in Linwood cemetery the water rose a few feet higher, perhaps to 753 A. T. In several wells there has been a notable loss of pressure. How far this is due to exhaustion of the local basin is hard to say. In several instances the loss is largely attributable to other causes. After 1887 no well less than 1,000 feet deep headed higher, so far as we know, than 673 feet A. T. The head of the well drilled in 1894 at the Bank and Insurance building was only at 648 A. T., about the height

*For the facts relating to the wells at Dubuque, we are under obligations to Mr. H. S. Hetherington, who donated a tube of samples from the Steam Heating company's well; to Dr. W. Watson, Mr. Jas. Beach, and to several owners of the wells. Mr. W. H Knowlton, city engineer, kindly supplies the elevations of the curbs, except that of No. 2, Linwood cemetery, which is estimated by one of our correspondents.

‡ Approximately.

of the present heads of the other wells of the class except that of the Julien house. If the water of the latter well still rises to the reported height, 712 A. T., it would show that no serious overdraft on the basin has yet been felt. Unfortunately no report of pressures on the new wells of the Malting Co. and Mr. Hemmi's can be obtained from their owners. While it is very probable that the less deep wells have been multiplied beyond the capacity of the local supply, we find little reason to believe that the lower reservoirs from 514 to 944 feet below tide have been overdrawn.

The following analyses show the exceptionally high quality of the artesian waters of Dubuque.

	GRAINS PER U. S. GALLON.				
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Calcium carbonate	7.471	7.2379	9.4559	7.5881	8.096
Magnesium carbonate	3.794	4.4186	4.3775	6.3623	7.179
Calcium sulphate		2.1830	1.2841		
Magnesium sulphate				0.2918	
Sodium sulphate				0.9607	
Potassium sulphate					1.582
Sodium chloride	2.568	2.0488	1.6927	0.3502	0.204
Magnesium chloride	1.926				
Alumina and Ferric oxide					0.035
Silica					0.872
Total	20.429	19.2621	20.4295	15.6432	17.968

No. 1. Malting Co.'s well, from 200 to 300 feet. Analysts, Wahl and Henius. Authority, Schmidt Brothers.

No. 2. Malting Co., at 900 feet. Analysts, Wahl and Henius. Authority, Schmidt Brothers.

No. 3. Malting Co., at 999 feet. Analysts, Wahl and Henius. Authority, Schmidt Brothers.

No. 4. Cushing's well. Analysts, Wahl and Henius. Authority, James Cushing and Son.

No. 5. Steam Heating Co. Analyst and authority, C. F. Chandler.

DUBUQUE BANK AND INSURANCE BUILDING CO.

	GRAINS PER U. S GALLON	PARTS PER MILLION.
Silica ($Si\ O_2$)	.298	5.113
Alumina ($Al_2\ O_3$) and Ferric Oxide ($Fe_2\ O_3$)	.646	11.143
Lime (Ca O)	4.118	71.000
Magnesia (Mg O)	2.378	41.000

	Grains per U. S. gallon.	Parts per million.
Potash (K_2O)	------	------
Soda (Na_2O)	1.665	28.714
Chlorine (Cl)	Trace	Trace
Sulphur trioxide (SO_3)	.996	17.143
Carbon dioxide (CO_2)	11.658	201.000
Water in combination (H_2O)	2.129	36.714
UNITED AS FOLLOWS.		
Calcium bicarbonate ($CaH_2(CO_3)_2$)	9.587	165.287
Calcium carbonate ($CaCO_3$)	1.434	24.714
Magnesium bicarbonate ($MgH_2(CO_3)_2$)	8.625	148.714
Sodium carbonate (Na_2CO_3)	1.533	26.428
Sodium sulphate (Na_2SO_4)	1.765	30.428
Alumina (Al_2O_3) and Oxide of iron	.646	11.143
Silica (SiO_2)	.298	5.143
Solids	23.888	411.857

Analyst, Dr. J. B. Weems. Date, May 30, 1896.

Several engineers report that the water corrodes iron pipes and makes some scale. The deeper waters of the Linwood cemetery wells are said to be poor as drinking water. Sanitary analyses of artesian waters have seldom been asked for, and the following of the well of the Bank & Insurance Building Co., by E. W. Rockwood, is of interest as showing the high organic purity of waters of this class.

	Parts per million.
Total solids	277.000
Loss on ignition (no charring or odor)	62.000
Free ammonia	.016
Albuminoid ammonia	.006
Chlorine	------
Nitrates	------
Nitrites	------
Sediment	------

Color none, odor none, taste good.

Equally significant is a bacterial analysis made by Dr. G. Minges, of Dubuque, of the water of the artesian well of the water company, in which he found but twenty bacteria to the cubic centimeter.

The artesian wells contribute but a portion of the water furnished by the water company. A large amount of excellent water is furnished by an abandoned tunnel in the bluff, two and one-half miles from the city, one mile in length and about 100 feet below the surface, which was once used to drain mines. A third supply is obtained at Eagle Point, 500 feet from the bank of the Mississippi, from 300 drive wells from thirty to sixty feet deep. The impression prevails that this supply is derived from the river by filtration through its banks of sand. This is not the case. The water is common surface or ground water, and its contamination is shown by a bacterial analysis by Dr. Minges, who found as high as 5,290 bacteria to the centimeter in water taken directly from this pumping station. Under these conditions the advice given of late years by some physicians of the town to consumers to boil all drinking water has not been untimely.

Belonging to the same local basin is the town well at East Dubuque, from which 750,000 gallons are pumped daily. The well is 983 feet deep, bore six inches, and registers a pressure of thirteen pounds. One hundred feet of red shale, the Saint Lawrence, were reported as lying near the bottom of the boring.

A curious fluctuation has been noticed in the well of James Cushing & Son, the discharge sometimes being much more than at others. In the deeper well at Linwood cemetery the tubing is sometimes obstructed by a "fibrous sediment," probably crenothrix. The removal of this by churning an iron rod in the tube has doubled the diminished flow.

RECORD OF STRATA.

Driller's log of Steam Heating Co.'s well:

		THICKNESS.	DEPTH.
15.	(Alluvium) "depth to rock"	165	165
14.	"Sandstone"	6	171
13.	"Sand and shale"	5	176
12.	"Limestone, white"	128	304
11.	"Limestone, gray"	42	346
10.	"Sand and lime" (inspection of the tube shows that this includes a cherty limestone, perhaps arenaceous, a gray limestone and lowest a brown cherty, arena-		

		THICKNESS.	DEPTH.
	ceous limestone	135	481
9.	"Sandstone," brown	20	501
8.	"Marl," yellow	3	504
7.	"Sand and lime"	10	514
6.	"Sandstone"	62	576
5.	"Lime"	18	594
4.	"Marl, red"	87	681
3.	"Shale, sandy," green	64	745
2.	"Marl, red"	10	755
1.	"Sandstone," cream yellow	48	803

DESCRIPTION OF DRILLINGS OF SCHMIDT'S BREWERY WELL.

		DEPTH OF SAMPLE.
25.	Sand and gravel	25
24.	Sand, yellow	30
23.	Sand, reddish	56
22.	Dolomite, buff, aspect of Galena, samples at 60 and 65 feet	60 and 65
21.	Limestone, dark bluish gray and buff	80
20.	Limestone, magnesian, or dolomite, dark drab, mottled with lighter color, in small angular fragments, residue after solution large, argillaceous, siliceous and pyritiferous, three samples	100 to 114
19.	Sandstone, white, moderately coarse, grains rounded smooth, and comparatively uniform in size	126
18.	Dolomite, light yellow gray, nearly white, with much sand in drillings	140
17.	Sandstone, as No. 19	156
16.	Dolomite, drillings chiefly chert	189
15.	Dolomite, gray, highly cherty at 250 from	210 to 250
14.	Sandstone, white, many grains faceted, some dolomite chips in drillings	254
13.	Dolomite, light buff, in fine sand, with chert and quartz sand	258
12.	Sandstone, white, with calcareous cement	267
11.	Unknown, no samples or record	---
10.	Dolomite, buff, cherty	426
9.	Dolomite, brown, chippings splintery, mostly of flint with some of drusy quartz	430
8.	Sandstone, cream yellow, moderately fine, calciferous as shown by dolomitic and cherty material in drillings, three samples	465 to 474
7.	Dolomite, buff, in fine sand, with some quartz sand	478
6.	Sandstone, light reddish yellow, fine, calciferous	535
5.	Dolomite, in fine buff sand and gray chips	581 to 584½

	DEPTH OF SAMPLE.
4. Shale, highly arenaceous, glauconiferous, in chips which pulverize into reddish yellow powder (at 632 feet) and reddish brown (at 636 feet), quartzose matter microscopic and angular	632–636
3. Dolomite, highly arenaceous, glauconiferous, in fine brown angular sand at 724 and in coarser sand at 726	724–726
2. Sandstone, yellow, grains moderately fine, the larger rounded and smoothed	730
1. Sandstone, pure, white, grains rounded, moderately fine	841

DRILLER'S LOG OF JULIEN HOUSE WELL.

		THICKNESS.	DEPTH.
10.	Depth to rock	210	210
9.	Sandstone	160	370
8.	Marl	66	436
7.	Sand, marl and lime mixed	50	846
6.	Sandstone	60	546
5.	Limestone	105	651
4.	Marl, red	40	691
3.	Shale, sandy	46	737
2.	Marl, red	7	744
1.	Sandstone	141	885

SUMMARY.

The wells of the lower town pierce the alluvial deposits which fill a preglacial or interglacial channel of the Mississippi river. The elevation of the fluvial floor of rock at the Steam Heating Co.'s well is 452 feet A. T., and at the Julien house, 405 feet A. T. if the record can be trusted. Schmidt's brewery stands near the cliffs of the present gorge and here rock lies at 570 feet A. T.

The record of the Julien house well falls in with the other records only in part, but the samples of the Schmidt well are in close agreement with the record of the Steam Heating Co. Combining these data we have the following section.

	THICKNESS.	BASE A. T.
Galena		550
Trenton	46	504
Saint Peter	58	446

	THICKNESS.	BASE A. T.
Oneota	310	136
Jordan	95	41
Saint Lawrence	179	-138
Basal sandstone	1,110	-1,248

XVII. MANCHESTER.*

Owner	Town
Depth	1,870 feet
Elevation of well mouth, A. T.	926 feet
Head of Ordovician and Cambrian waters, A. T.	776 feet
Head of Niagara water, A. T.	912 feet
Capacity in gallons per minute	200
Date of beginning	June 1, 1895
Date of completion	December, 1896
Drillers	J. P. Miller & Co.

Previous to the completion of this artesian, the water supply of Manchester had been an excellent spring, situated near the business portion of the town on the banks of the Maquoketa river. A reservoir excavated in solid Niagara rock receives the water of the spring, and to develop the flow to the utmost several wells of moderate depth have been drilled within it. As the water was insufficient to supply the increasing population of the town, it was wisely decided to sink an artesian well, and a site was selected adjoining the reservoir and some twenty-four feet higher than the water in it.

While the drilling was in progress to at least a depth of 1,400 feet, water stood in the shaft at about fourteen feet from the surface, and there were indications that this height was due to the influx of water from the spring. When water-bearing strata were reached at 1,200 feet and below, and the well was cased to 260 feet, the water dropped to 150 feet from the surface. On removing the upper casing to a depth of 260 feet, the water again rose to within fourteen feet of the curb, and on the final pumping test of the well, the spring adjacent nearly ceased flowing. The well, therefore, receives a supply of water from the Niagara limestone from the same source as that of the spring. The Saint Peter is cased out, if we are

*We are under special obligations to the painstaking care of Mr. M. J. Yoran, who secured the unusually complete set of samples described, and to Judge A. S. Blair, and Mr. C. O. Torrey for information with regard to the well.

	STAGE	SUB-STAGE	A.T.	ROCK
SILURIAN	NIAGARA–CLINTON	Delaware	926	DOLOMITE, BUFF.
				DOLOMITE, GRAY, CHERTY.
ORDOVICIAN	HUDSON RIVER	Maquoketa	701	SHALE
			556	DOLOMITE
			542	SHALE
	TRENTON	Galena–Trenton	496	LIMESTONE, GRAY
				LIMESTONE, MAGNESIAN
				LIMESTONE, GRAY
				SHALE, 5 FEET, FOSSILIFEROUS.
				LIMESTONE, GRAY
	St PETER		142	SANDSTONE, WHITE
	ONEOTA	Upper Oneota	109	DOLOMITE
		New Richmond		DOLOMITE, SANDY
		Lower Oneota	5	SEA LEVEL
				DOLOMITE
CAMBRIAN	SAINT CROIX	Jordan	280	SANDSTONE, WHITE
		Saint Lawrence	370	DOLOMITE, AND SANDSTONE
			446	SHALE, ARENACEOUS
		Basal Sandstone	599	SANDSTONE

MANCHESTER WELL SECTION.

rightly informed, and it is not known whether or not it is water-bearing. The main flow seems to come from the Jordan sandstone, from 1,200 to 1,296 feet. Below 1,500 feet no water was found.

The lower flow alone was tested with a pump throwing seventy-five gallons per minute for twenty hours without lowering the water. On the final test of all waters with a pump throwing from 160 to 200 gallons per minute from a seven-inch pipe 200 feet deep, the water soon sunk to thirty-three feet from the surface, and there remained during the entire test of twenty consecutive hours. It is expected to increase the capacity of the plant by using a heavy eight-inch casing 200 feet in length as the pump pipe. The diameters of the bore are as follows.

10 inches to 260 feet.
7 inches to 890 feet, seven-inch casing.
6 inches to 1,300 feet, no casing. (Oneota and Jordan.)
6 inches to 1,650 feet, five-inch casing.
5 inches to 1,870 feet. Not cased.

The official analyses show that Manchester possesses an excellent water, of the calcic magnesian-alkaline class. The entire absence of iron is noteworthy.

Number 1 is of a sample taken before the upper waters were cased out, and when there were 980 feet of casing in the well.

Number 2 is of a sample taken when the well was cased to a depth of 260 feet and there were about 1,300 feet of casing in the well.

MINERAL ANALYSIS NO. 1.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\ O_2$)	1.902	32.8
Alumina ($Al_2\ O_3$)	.244	4.2
Lime ($Ca\ O$)	4.848	83.6
Magnesia ($Mg\ O$)	1.595	27.5
Soda ($Na_2\ O$)	.487	8.4
Chlorine (Cl)	.522	9.
Sulphur trioxide ($S\ O_3$)	6.479	111.7
Carbon dioxide ($C\ O_2$)	5.040	86.9
Water in combination ($H_2\ O$)	.830	14.3
Total	22.047	378.4

UNITED AS FOLLOWS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium bicarbonate ($Ca\ H_2(CO_3)_2$)	7.401	127.6
Silica ($Si\ O_2$)	1.902	32.8
Alumina (Al_2O_3)	.244	4.2
Sodium sulphate (Na_2SO_4)	.064	1.1
Potassium chloride (K Cl)	-------	------
Sodium chloride (Na Cl)	.858	14.8
Magnesium sulphate	4.762	82.1
Calcium sulphate	5.562	95.9
Free Carbon dioxide	1.026	17.7
Oxygen replacing Chlorine	.128	2.2
Total	22.047	378.4

Analyst and authority, Prof. J. B. Weems, Ph. D.

MINERAL ANALYSIS NO. 2.

Silica ($Si\ O_2$)	.847	14.6
Alumina ($Al_2\ O_3$)	.580	10.
Ferric oxide ($Fe_2\ O_3$)	-------	------
Lime (Ca O)	4.466	77.
Magnesia (Mg O)	1.131	19.5
Potash ($K_2\ O$)	-------	------
Soda ($Na_2\ O$)	6.009	103.6
Chlorine (Cl)	4.640	80.
Sulphur trioxide ($S\ O_3$)	7.807	134.6
Carbon dioxide ($C\ O_2$)	5.863	101.1
Water in combination ($H_2\ O$)	.754	13.
Total	32.097	553.4

UNITED AS FOLLOWS.

Calcium bicarbonate ($Ca\ H_2(CO_3)_2$)	6.751	116.4
Calcium sulphate	5.179	89.3
Magnesium sulphate	3.376	58.2
Sodium sulphate ($Na_2\ SO_4$)	4.454	76.8
Sodium chloride (Na Cl)	7.656	132.
Silica ($Si\ O_2$)	.847	14.6
Alumina ($Al_2\ O_3$)	.580	10.
Free Carbon dioxide	2.204	38.
Oxygen replaced by Chlorine	1.05	18.1
Total	32.097	553.4

Analyst and authority, Prof. J. B. Weems, Ph. D., Ames, Iowa.
Depth of well 1,870 feet.

RECORD OF STRATA.

The geological section obtained from the deep well at Manchester is one of the reliable sections of the state. From the beginning of the boring, samples were saved according to specific instructions, and at such short intervals that no change in the strata could escape notice. The thickness assigned to each stratum is certain within narrow limits of error.

		THICKNESS.	DEPTH.
45.	Dolomite, buff, six samples	140	140
44.	Dolomite, blue-gray, highly cherty, six samples	60	200
43.	Dolomite, blue-gray, cherty, pyritiferous, slightly argillaceous	25	225
42.	Shale, blue and gray-green and drab, eighteen samples	145	370
41.	Magnesian limestone or dolomite, dark drab subcrystalline, somewhat argillaceous, in flakes, two samples	14	384
40.	Shale, blue and gray-green, seven samples	46	430
39.	Limestone, magnesian, dark drab, argillaceous	10	440
38.	Limestone, light gray, earthy lustre, briskly effervescent in cold dilute HCl, sixteen samples	106	546
37.	Dolomite, light yellow-gray, subcrystalline, stained with ferric oxide in minute, rounded spots, with much of the superior limestone in small fragments	10	556
36.	Limestone, light and darker blue-gray, usually rather soft, earthy lustre, in flakes and chips, twenty samples	142	698
35.	Shale, bright green, fossiliferous, *Orthis perveta, Conrad, Strophomena trentonensis, W. and S.*, and *bryozoa*	5	703
34.	Limestone, light blue-gray, fossiliferous	6	711
33.	Limestone, light blue-gray, earthy-crystalline, eleven samples	66	777
32.	Shale, green, somewhat calcareous	7	784
31.	Sandstone, usual facies of Saint Peter, with small chips of limestone, in which no imbedded grains are noticed	3	787
30.	Sandstone, as above, but free from admixture, four samples	30	817

		THICKNESS.	DEPTH.
29.	Dolomite, buff and gray, in angular sand; most of drillings of quartz sand, probably from above, three samples	18	835
28.	Dolomite, light gray	42	877
27.	Dolomite, slightly arenaceous	5	882
26.	Dolomite, highly arenaceous, grains rounded and some enlarged by crystalline facets, two samples	11	893
25.	Dolomite, gray, arenaceous, with some light drab shale	6	899
24.	Dolomite, arenaceous, with some highly arenaceous shale, two samples	19	918
23.	Sandstone, calciferous	3	921
22.	Dolomite, gray, arenaceous, with argillaceous powder	10	931
21.	Dolomite, gray, eight samples	54	985
20.	Dolomite, light gray, arenaceous, three samples	24	1,009
19.	Dolomite, gray, arenaceous from 1,100 to 1,103, twenty-seven samples	170	1,179
18.	Dolomite, arenaceous, gray	5	1,184
17.	Dolomite, highly arenaceous, or sandstone calciferous, four samples	22	1,206
16.	Sandstone, white, grains rounded and ground, with considerable diversity in size, seven samples	50	1,256
15.	Shale, highly arenaceous and calcareous	4	1,260
14.	Sandstone, as No. 3, five samples	36	1,296
13.	Dolomite, gray, with some sand, probably from above	20	1,316
12.	Sandstone, calciferous, or highly arenaceous dolomite	15	1,331
11.	Dolomite, light yellow-gray	5	1,336
10.	Dolomite, gray, in fine sand mixed with considerable quartz sand, two samples	10	1,346
9.	Dolomite, light gray, in clean chips, with a little sand from above	10	1,356
8.	Dolomite, as No. 10, two samples	16	1,372
7.	Shale, highly arenaceous and calcareous, in fine green-gray powder, six samples. All these samples consist of a pulverulent powder, seen under the microscope to be composed of minute angular particles of quartz, dolomite and chert, with much argillaceous material; all might be termed with about equal propriety argillo-calcareous sandstone	153	1,525

	STAGE	SUB-STAGE		A.T.	ROCK
PLEISTOCENE				1110	CLAY, DRIFT OR ALLUVIUM
CARBONIFEROUS	DES MOINES			1010	SHALES, BLUE, FINE, WITH A LITTLE LIMESTONE AND SANDSTONE
DEVONIAN	LIME CREEK			803	LIMESTONE AND FOSSILIFEROUS SHALE
				775	LIMESTONES
SILURIAN	NIAGARA–CLINTON			475 380	LIMESTONE, BROWN MAGNESIAN. DOLOMITES, IN PART CHERTY
ORDOVICIAN	HUDSON RIVER	Maquoketa		295	SHALES, WITH INTERBEDDED DOLOMITE AT 235 AND 214
	TRENTON	Galena–Trenton		135	SEA LEVEL LIMESTONE
				215	SHALE
		Saint Peter		250	SANDSTONE, SACCHAROIDAL
	ONEOTA	Upper Oneota		335	DOLOMITE
		New Richmond		455	SANDSTONE, WHITE. SACCHAROIDAL.
		Lower Oneota		525	DOLOMITE
CAMBRIAN	SAINT CROIX	Jordan		710 920	SANDSTONE

ACKLEY WELL SECTION.

		THICKNESS.	DEPTH.
6.	Sandstone, fine-grained, in greenish-yellow powder, argillaceous	13	1,538
5.	Sandstone, white, grains fine and rounded	22	1,560
4.	Sandstone, with greenish argillaceous material mixed with drillings	13	1,573
3.	Sandstone, fine light buff, from ferruginous stain	6	1,579
2.	Sandstone, fine	19	1,598
1.	Sandstone, coarser, uniform of grain, of limpid quartz, grains rounded, smooth surfaced	13	1,611
0.	Sandstone, white	79	1,690
00.	Sandstone, yellow, glauconiferous, said to be argillaceous	25	1,715
000.	Shale, light blue, arenaceous, calcareous, somewhat glauconiferous	155	1,870

SUMMARY.

	FORMATION.	THICKNESS.	DEPTH.	A. T.
43–45.	Niagara	225	225	701
40–42.	Maquoketa	205	430	496
32–39.	Galena-Trenton	354	784	142
30–31.	Saint Peter	33	817	109
27–29.	Upper Oneota	65	882	44
22–26.	New Richmond	49	431	– 5
17–21.	Lower Oneota	275	1,206	–280
14–16.	Jordan	90	1,296	–370
7–13.	Saint Lawrence	229	1,525	–599
000– 6.	Basal sandstone, penetrated	345	1,870	–944

XVIII. ACKLEY.*

RECORD OF STRATA—SUMMARY.

	THICKNESS.	DEPTH.	A. T.
Pleistocene	100	100	1,010
Des Moines	207	307	803
Lime Creek	28	335	775
Devonian unclassified	300	635	475
Niagara	180	815	295
Maquoketa	160	975	135
Galena-Trenton	385	1,360	–250

*This well was reported to the author several years ago by Mr. J. A. Carton, now of Britt, Iowa. Repeated requests for additional information since made to officials and citizens of the town have received no attention. Mr. Carton contributed also a fine set of over eighty samples of drillings, supplying one of the most satisfactory of the well sections in the state. A detailed description of these by the author is published in vol. III, pp. 189-192 of the reports of the present Survey.

	THICKNESS.	DEPTH	A. T.
Saint Peter	85	,445	-335
Upper Oneota	120	1,465	-455
New Richmond	70	1,635	-525
Lower Oneota	185	1,820	-710
Jordan	210	2,030	-920

XIX. WEBSTER CITY.*

Owner	Gas Well Co.
Depth	1,250 feet.
Diameter	8 inches–6 inches.
Elevation of curb A. T.	1,048 feet‡.
Head of water A. T.	1,064 feet‡.
Date of beginning	February 3, 1888.
Date of completion	June 28, 1888.

The first flow from this well was obtained at the depth of 675 feet, and its head was six feet above the curb. The source of the present flow, heading sixteen feet above the curb, is at about 1,200 feet. The discharge was originally about seventy gallons a minute. It has since diminished, owing presumably to neglect, but is still strong. The water has both the odor and taste of sulphur, and so rapidly corrodes iron that the best galvanized pipe withstands its constant flow but about two years. For these reasons it is only used in a public watering trough. The well is cased to or near the bottom.

ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si O_2$)	1.889	32.571
Alumina ($Al_2 O_3$)	Trace	Trace
Ferric oxide ($Fe_2 O_3$)	Trace	Trace
Lime (Ca O)	14.285	246.286
Magnesia (Mg O)	2.593	44.714
Potash ($K_2 O$)	-------	-------
Soda ($Na_2 O$)	8.791	151.571
Chlorine (Cl)	.596	10.286
Sulphur trioxide ($S O_3$)	24.890	429.143
Carbon dioxide ($C O_2$)	12.354	213.000
Water in combination ($H_2 O$)	2.494	43.000

* Reported by Mr. L. A. MacMurray, who sent the samples of the drillings here described.

‡ Approximately.

UNITED AS FOLLOWS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium bicarbonate ($Ca\ H_2\ CO_3)_2$)	22.529	388.428
Calcium carbonate ($Ca\ CO_3$)	.265	4.571
Ferrous bicarbonate ($Fe\ H_2\ CO_3)_2$)	Trace	Trace
Calcium sulphate ($Ca\ SO_4$)	15.494	67.143
Magnesium sulphate ($Mg\ SO_4$)	7.747	133 573
Sodium sulphate ($Na_2\ SO_4$)	18,891	325.714
Sodium chloride ($Na\ Cl$)	.994	17.143
Alumina ($Al_2\ O_3$)	Trace	Trace
Silica ($Si\ O_2$)	1 889	32.571
Oxygen replaced by chlorine	.084	1.428
Solids	67.893	1,170.571

Analyst, Prof. J. B. Weems. Date, July 9, 1896.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
20.	"From surface to rock, 180 feet, soil, clay, sand, thin layers of rock, etc."	180	180
19.	Sandstone, gray, of quartz of various colors, yellow, pink and black, grains imperfectly rounded; mingled with the sand is a large quantity of light yellow limestone	20	200
18.	Limestone, light gray, soft, earthy, in flaky chips, fossiliferous	150	350
17.	Shale, blue	10	360
16.	Limestone, dark drab, mottled with white calcite, crystalline	100	460
15.	Limestone, magnesian, hard brown, crystalline	40	500
14.	Shale, calcareous, dark gray, siliceous with microscopic particles of quartz	20	520
13.	Dolomite, or magnesian limestone, dark brown, compact crystalline	30	550
12.	Limestone, dark blue-gray, crystalline, effervescence slow	45	595
11.	Limestone, light yellow-gray, soft, crystalline, effervescence slow	55	650
10.	Dolomite, or magnesian limestone, as No. 13	30	680
9.	Limestone, light gray, saccharoidal	95	775
8.	Limestone, close-grained, no samples	45	820
7.	Limestone, brown, crystalline	60	880

		THICKNESS.	DEPTH.
6.	Limestone, or shale, highly argillaceous, blue-gray	120	1,000
5.	Shale, drab, calcareous	75	1,075
4.	Limestone, magnesian, brown, crystalline	15	1,090
3.	Limestone, in pure, white crystalline sand	40	1,130
2.	"Limestone (?), pure white," no sample	120	1,250
1.	Limestone, light buff, in fine sand at		1,250

SUMMARY.

This section is a difficult one to interpret with the data at hand, and the following assignments are made more for general stratigraphical reasons than because of any direct evidence carried by the drillings themselves.

		THICKNESS.	DEPTH A. T.
19-20.	Alluvium, Drift and Coal Measures	200	848
17-18.	Mississippian	160	668
7-16.	Devonian and Niagara	520	168
5, (6?)	Maquoketa	195	-27
1- 4.	Galena-Trenton penetrated	175	-202

XX. HOLSTEIN.*

Owner	Town.
Elevation of curb, A. T.	1,457 feet.
Depth (August, 1896)	1,853 feet.
Head of water (August, 1896)	1,132 feet A. T.
Driller	J. P. Miller & Co.

This well is still unfinished at the date of writing, August 1, 1896. Eight-inch casing extends to a depth of 387 feet, five-inch to 722 feet, and four-inch to 1,465 feet. Water was found between 400 and 500 feet from the surface. No further record seems to have been kept of where water was struck, and the accounts given vary. One informant states that the water, which since 900 feet had stood at 365 feet from the

*When this well was begun, the officials of the town and the foreman of the well were notified of the very great importance of keeping a full and accurate record, and of taking samples of the drillings at intervals of not over ten feet and at every change in the rocks. From its position, a good geological section at Holstein would go far toward solving the problems of the deeper geological formations in northwestern Iowa. These instructions were at first followed, but, after some months, correspondence indicated that due attention was not being given to the matter, and a personal visit was made to the town. The well had then reached its present depth, where it has stopped for several months, owing to a fastened drill. It was then discovered that, when the well had reached a depth of 900 feet, the foreman, who had carefully saved the drillings, had been transferred to another well. As the supply received no instructions from the town officials, he threw out the samples already taken and saved no more.

surface, rose to 325 feet when the Saint Peter was struck. At 1,500 feet the well was tested, and under a discharge of seventy-five gallons a minute for twenty-six hours the water did not lower. Drilling was continued, not so much because the supply was inadequate, as on account of the long raise to the surface. No flow has been reached so far which clears the hole of drillings.

RECORD OF STRATA.

		Thickness.	Depth.
15.	"Clay"	390	390
14.	"Quicksand," coarse	50	440
13.	"Shale"	260	700
12.	"Limestone"	50	750
11.	"Shale"	50	800
10.	"Limestone"	80	880
9.	Unknown, limestone (?)	20	900
8.	Dolomite, gray, with much white chert, and some rounded, moderately coarse grains of quartz	100	1,000
7.	Unknown, limestone (?)	100	1,100
6.	Limestone, magnesian, or dolomite, brown, with about two feet of red shale at 1,300 feet which is non-calcareous, highly arenaceous, with coarse, imperfectly rounded grains of limpid quartz	300	1,400
5.	Unknown, limestone (?)	15	1,415
4.	Shale, hard, dark green-gray, slaty, non-calcareous	10	1,425
3.	Unknown, limestone (?)	20	1,445
2.	Sandstone, described by driller as white, clean, very soft, caving sand and termed by him Saint Peter	55	1,500
1.	Limestone (?), arenaceous. Described by driller as a "sandy rock which wears the drill." Sand grains are brought up in the slush bucket, while the rest of the drillings is very light and floats up in the water. Drills about one foot per hour, does not cave; to present depth of well	83	1,583

SUMMARY.

It should be remembered that this section is constructed out of only a driller's record to 880 feet, and four samples and a foreman's notes and recollections below that point. The numbers marked "unknown" are assumed to be limestone on the authority of the foreman, whose notes show that they are neither caving shale nor sandstone.

NO.	FORMATION.	THICKNESS.	A. T.
15.	Pleistocene (and Cretaceous clays)	390	1,067
14.	Dakota	50	1,017
13.	Des Moines	260	757
12.	Mississippian	50	707
11.	Kinderhook (?)	50	657
3-10.	Devonian, Silurian and Galena-Trenton	645	12
2.	Saint Peter	55	-43
1.	Oneota penetrated	83	-126

XXI. SIOUX CITY.*

Owner	Sioux City Water Co.
Depth	2,011 feet.
Elevation of curb	1,125 feet.
Head of water	1,125 A. T.‡
Temperature	70° Fahr.

This well was drilled by Marrs & Miller of Chicago, from October 19, 1881, to October 16, 1882. To the depth of 1,270 feet the bore is 6 inches, and a 6-inch casing extends to 444 feet; 230 feet of 4-inch casing is also used in the well, but its place is not stated. Water was found in Pleistocene gravels at 65 feet. At 120 feet the yield was 250 gallons per minute. At 570 feet another vein was struck whose head was 12 feet below the curb or 1,113 A. T. At 1,250 feet, according to Todd, water rose strongly to the surface with a discharge of three gallons to the minute. This was from sandstone immediately overlying the Algonkian. At 1,480 feet, in crystalline rock, a water vein was found, but none other during the continuation of the boring. When the well was finished the discharge was six gallons a minute, but, owing probably to clogging of the bore, the water has since fallen below the surface.

*In securing the facts as to the well at Sioux City, we are especially indebted to the cordial help of Mr. D. A. Magee, Judge G. W. Wakefield, Sheriff W. C. Davenport and Messrs. E. A. D. Parker and J. H. Charles.

‡ Approximately.

The well is the property of a private company and the water is sold mostly in Sioux City, where the market rate is 5 cents per gallon delivered. The company are now erecting a building for the manufacture of ice, and the water of the well will soon be utilized for this purpose also.

ANALYSIS NO. 1.

	GRAINS PER GALLON.
Calcium carbonate	6.654
Magnesium carbonate	5.527
Ferrous carbonate	3.797
Aluminum sulphate	22.173
Magnesium sulphate	10.037
Nickel sulphate	1.141
Calcium sulphate	6.839
Sodium sulphate	3.751
Potassium sulphate	2.115
Persulphate of iron	13.402
Silica "soluble"	1.898
Sodium phosphate	1.667
Organic matter	.864
Total per gallon	79.865

Analyst, Juan H. Wright, M. D., St. Louis. Date, May 31, 1893. Authority, circulars of company.

The above analysis presents some anomalous features which even the great depth of the well in crystalline rocks does not seem to account for. The following official analysis was made, which shows the medicinal nature of this strong mineral water.

ANALYSIS NO. 2.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\ O_2$)	.953	16.428
Alumina ($Al_2\ O_3$)	.638	11.000
Ferric oxide ($Fe_2\ O_3$)	------	-----
Lime ($Ca\ O$)	18.361	316.571
Magnesia ($Mg\ O$)	6.993	120.571
Potash ($K_2\ O$)	------	--------
Soda ($Na_2\ O$)	17.367	299.428
Chlorine (Cl)	4.880	84.143
Sulphur trioxide ($S\ O_3$)	41.528	716.000
Carbon dioxide ($C\ O_2$)	8.501	146.571
Water in combination ($H_2\ O$)	------	--------

UNITED AS FOLLOWS:

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium carbonate ($CaCO_3$)	19.322	333.143
Calcium sulphate ($CaSO_4$)	18.328	316.000
Magnesium sulphate ($MgSO_4$)	20.880	360.000
Sodium sulphate (Na_2SO_4)	30.011	517.429
Sodium chloride (Na Cl)	8.037	138571
Alumina (Al_2O_3) and Ferric oxide	.638	11.000
Silica (SiO_2)	.953	16.428
Oxygen replaced by chlorine	1.052	18.141
Solids	99 221	1,710.712

Sample was murky—filtered before analysis.

Analyst, Prof. J. B. Weems. Date, July 8, 1896.

GEOLOGICAL SECTION.

The following log is furnished by Mr. David A. Magee.

34.	Soil and clay	60	60
33.	Gravel	25	85
32.	Shale	54	139
31.	Sand, white	2	141
30.	Sandstone, brown	34	175
29.	Sandstone, white	100	275
28.		155	430
27.	Sandstone, gray	110	540
26.	Sand and limestone	30	570
25.	Limestone gray	50	620
24.	Sand and limestone	35	655
23.	Limestone, white	100	755
22.	Sandstone, light colored	30	785
21.	Limestone, gray	20	805
20.	Shale rock	98	903
19.	Limestone	10	913
18.	Shale rock	12	925
17.	Limestone	10	935
16.	Shale rock	5	940
15.	Limestone	5	945
14.	Shale, sandy	35	980
13.		50	1,030
12	Limestone	70	1,100
11.	Shale rock	60	1,160
10.	Shale and limestone	30	1,190
9.	Limestone, gray	60	1,250
8.	Marl, red with sand	5	1,255
7.	Sandstone, porous, Saint Peter	15	1,270

6.	Sand and marl	25	1,295
5.	Marl, sandy	20	1,315
4.	Sandstone, micaceous, very hard, crevice giving water	165	1,480
3.	Sandstone, brown, micaceous, and lime very hard	380	1,860
2.	Limestone, light colored	5	1,865
1.	Sandstone and lime, very hard	146	2,011

Soon after the well was bored, Todd examined the drillings, which had been carefully preserved by Mr. Magee, and from them and from notes kept by the foreman he made the section published in the proceedings of the Iowa Academy of Sciences, vol. I, part II, p. 14. In this section the following corrections and interpretations are made.

No. 32. Shale, Benton, 54 feet, from 90 to 144 feet.

No. 28 in part, Nos. 29, 30, 31. Sand and sandstone, Dakota, 191 feet, from 144 to 335 feet.

No. 28 in part. "Chalk rock" 100 feet, from 335 to 435 feet.

No. 27. Limestone, gray, 110 feet, 435 to 545 feet.

No 4. "Hard micaceous limestone and compressed sandstone," 190 feet, 1,320 to 1,510 feet.

Nos. 1, 2, and 3 in part. Granite or gneiss, hard, gray—a five-foot layer of white limestone at 1,860 feet—550 feet, from 1,525 to 2,075 feet.

In a note dated May 12, 1890, Professor Todd* places the base of the Paleozoic at 1,515 feet,† at the summit of the gray granite.

A section of this well has also been published by Bain, which is based upon the notes and drillings of Mr. Magee, and which differs in a few particulars from that of Todd.

The "chalk rock," from 334 to 434 feet, is termed white sandstone, and all below 1,525 feet is designated as micaceous schist. Five hundred and forty feet is suggested as the lower limit of the Cretaceous.

The "hard brown rock," from 1,510 to 1,225 feet, is referred to the pre-Paleozoic, together with the basal schist. Of the strata between this horizon and the base of the Cretaceous, Bain says: "The well diggings at Sioux City and Le Mars

*American Geologist, vol. XV, p. 64. Minneapolis, 1895.

†Iowa Geological Survey, vol. V, p 258.

show, between this underlying pre-Paleozoic complex and the Cretaceous beds, the presence of a series of limestones which have been usually referred to the Carboniferous. Such a series is usually found in wells drilled throughout the region. Whether these beds represent the Mississippian or some later portion of the Carboniferous cannot be definitely stated. It is even probable that they, in part, represent still earlier beds of the Paleozoic."

In order to obtain, if possible, some clue to the age of the strata left undetermined, the drillings were examined with the following results.

RECORD OF STRATA.

		DEPTH.
16.	Sandstone, light yellow, of fragmental quartz grains	210
15.	Dolomite, light yellow-gray, samples contain also much fissile, green shale, in rounded lumps and some quartz sand, both probably from above	530
14.	Sandstone, and limestone, drillings consist mostly of quartz sand, grains of moderate size, imperfectly rounded. There are also considerable limestone, light yellow gray, in small fragments, chips of hard crystalline gray dolomite, and shale as at 530	540
13.	Dolomite, gray, in sand, drillings largely chert	645
12.	Dolomite, light buff, in sand, drillings chiefly white, pyritiferous chert	780
11.	Sandstone, bluish-gray, argillaceous, pyritiferous, slightly calcareous, grains microscopically fine, subangular	840 and 855
10.	Sandstone, white, some grains rounded and polished, but mostly broken	970
9.	Dolomite, highly arenaceous, imbedded grains rounded, pyritiferous and glauconiferous, pyrite in minute nodules	1,000
8.	Sandstone, calciferous, pyritiferous, glauconiferous	1,010
7.	Sandstone, light gray, grains minute, not rounded	1,030
6.	Sandstone, gray, calciferous, with many rounded grains	1,035
5.	Sandstone, medium dark blue-gray, calciferous, grains minute, glauconiferous	1,070
4.	Sandstone, highly calciferous, gray, grains are minute angular particles of quartz, highly glauconiferous, with considerable green shale	1,160

	DEPTH.
3. Schist or gneiss, soft, fine grained, speckled with white and dark green-gray; so friable that a microsection could not be obtained. When pulverized it is seen to be composed of quartz and a lamellated dark green mineral whose flakes are practically isotropic in parallel polarized light, found to be chlorite by Dr. S. W. Beyer, to whom it was referred	1,260
2. Schist or gneiss, contains quartz, feldspar white and pink; black ferro-magnesian mica, and a translucent apple green mineral, probably chlorite, 1,320 and	1,350
1. Schists or gneisses, gray, brown and black, micaceous usually with biotite, often hornblendic, thirty-two samples. At 1,860–1,865, samples composed chiefly of feldspar and quartz	1,727–2,000

SUMMARY.

Upon the whole the most probable distribution of strata seems to the writer to be the following:

FORMATION.	THICKNESS.	DEPTH.	A. T.
Pleistocene	85	85	1,040
Cretaceous	249	334	791
Mississippian	101	435	690
Devonian and Silurian	370	805	320
Ordovician and Cambrian	455	1,260	–135
Algonkian	751	2,011	–885

The base of the Cambrian, at 135 feet below sea level, may be considered as certain. Most, if not all, of the strata between this level and 320 feet A. T. are evidently Saint Croix. The lithological similarity with strata of this terrane elsewhere, which amounts to identity in several samples, and the assemblage of the entire group of shales, calciferous sandstones and arenaceous limestones, agree with the position of the group in referring it to this, the earliest, Paleozoic formation laid down upon the crystalline rocks. The cherty dolomites from 805 feet to 540 feet (320 A. T. to 585 A. T.), are unmistakably Paleozoic, and the suggestion of Bain that they may be pre-Carboniferous is correct without much question. Probably they are largely Trenton, but it is entirely possible as will be seen by inspection of Plate XI that the water-bearing sandstone at 570 feet (555 A. T.) is the same as the water-bearing sandstone at Holstein at 12 A. T. and in this case the dolomite beneath represents the Oneota. It is only for stratigraphical reasons, and these of not very great weight, that the "chalkrock" at 334 feet is placed with the Mississippian. Lying below the Dakota sandstone, it certainly cannot be Cretaceous chalk.

Wells situated south of the McGregor-Fairview Section and north of the Dubuque-Sioux City Section.

XXII. WEST BEND.

Owner	Town.
Depth	381 feet.
Diameter	6 inches and 4½ inches.
Elevation of curb	1,197 feet A. T.*
Head of water	1,166 feet A. T *

This well was drilled in April by Mr. C. P. Thomas, of West Bend, who preserved the samples and made record under instructions from the Survey. Water was found from 290 to 381 feet. The discharge is twenty gallons a minute, at a temperature of 49° Fahr., and supplies the water works of the village.

ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\ O_2$)	.348	6.000
Alumina ($Al_2\ O_3$)	.224	3.857
Ferric oxide ($Fe_2\ O_2$)	-------	-------
Lime (Ca O)	14.127	243.572
Magnesia (Mg O)	3.795	65.428
Potash ($K_2\ O$)	-------	-------
Soda ($Na_2\ O$)	5.361	92.429
Chlorine (Cl)	.331	5.714
Sulphur trioxide ($S\ O_3$)	8.252	142.286
Carbon dioxide ($C\ O_2$)	20.590	355.000
Water in combination ($H_2\ O$)	2.676	46.143
UNITED AS FOLLOWS.		
Calcium bicarbonate ($Ca\ H_2(CO_3)_2$)	12.710	219.143
Calcium carbonate (a CO_3)	17.541	302.428
Magnesium bicarbonate ($Mg\ H_2(CO_3)_2$)	10.175	175.429

* Approximately.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Magnesium sulphate ($Mg\ SO_4$)	2.196	37.857
Sodium sulphate ($Na_2\ SO_4$)	11.882	204.857
Sodium chloride ($Na\ Cl$)	.547	9.429
Alumina ($Al_2\ O_3$) and oxide of iron	.224	3.857
Silica ($Si\ O_2$)	.348	6.000
Oxygen replaced by chlorine	.083	1.428
Solids	55.706	960.428

Analyst, Prof. J. B. Weems, Ames, Iowa. Date, May 27, 1896.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
18.	"Soil"	5	5
17.	"Clay, yellow"	16	21
16.	"Clay, blue"	4	62
15.	"Sand and gravel"	9	71
14.	"Clay, blue; and hard pan, blue"	23	94
13.	"Sand yellow"	112	206
12.	"Marl, red"	20	226
11.	Chert, white, slightly pyritiferous, with some fine green clay	43	269
10.	Sandstone, in fragments of limpid quartz, with considerable chert, and some blue-gray limestone	23	292
9.	Dolomite, white, somewhat arenaceous	6	298
8.	Limestone, blue-gray	4	302
7.	Dolomite, or magnesian limestone, blue crystalline	4	306
6.	Dolomite, crystalline, light blue-gray, blue-gray, and yellowish, three samples	25	331
5.	Dolomite, blue, and light gray, hard, compact, finely crystalline, argillaceous, two samples	8	339
4.	Limestone, varying in color from light yellowish to dark-blue gray, often mottled, in thin flakes, soft, earthy luster	11	350
3.	Limestone, brown and buff, soft and argillaceous at 350 feet, crystalline and cherty below, three samples	12	362
2.	Limestone, magnesian, gray, hard, compact, with some shale, three samples	19	381
1.	Shale, blue, at		381

SUMMARY.

NO.	FORMATION.	THICKNESS.	A. T.
14–18.	Recent and Pleistocene	95	1,103
13.	Cretaceous, Dakota	112	991
12.	Cretaceous	20	971
2–11.	Mississippian	155	816
1.	Kinderhook, or Lime creek, summit at		816

Possibly No. 14 should be added to the Cretaceous. Nos. 12 to 18 are the driller's record without samples.

XXIII. CHEROKEE.

Nothing is known of this boring further than the notes published by Todd in the proceedings of the Iowa Academy of Sciences, for 1890 and 1891. It was drilled in the center of the town and failed to strike artesian water.

RECORD OF STRATA.

	THICKNESS.	DEPTH.	A. T.
Pleistocene and unknown	300	300	915
Limestone, light blue	400	700	515
Shale, blue, or soapstone	260	960	255

XXIV. LE MARS.

Depth	1,560
Elevation of curb	1,275 A. T.

RECORD OF STRATA.

		THICKNESS.	DEPTH.	A. T.
12.	"Soil"	7	7	
11.	"Clay, yellow"	13	20	
10.	"Clay, blue"	44	64	
9.	"Sand and gravel, hardened above	27	91	1,184
8.	"Soapstone and slate"	89	180	1,095
7.	"Sandstone, clays, and some lignites, in alternating strata"	138	318	957
6.	"Sandstone with some shale"	147	465	810
5.	Sandstone, micaceous, of broken grains, non-calcareous, at		860	
4.	Sandstone, as above, many grains pink, reddish and yellow, at		960	
3.	Gneiss (?) constituents orthoclase, quartz and muscovite; color reddish in mass, at		1,060	215

		THICKNESS.	DEPTH.
2.	Gneiss (?) chiefly feldspar and mica, at		1,325
1.	Schist, micaceous, brown in mass, at		1,560

Nos. 1–5 are determinations of drillings by the writer; all other statements are taken from Todd. Proc. Ia. Acad. Sci., vol. I, pt. II, p. 14.

The following is an unusually detailed record of the well at Le Mars, Tp. 92 N., R. XLV W., Sec. 15, furnished by Mr. C. R. Woodard.

		THICKNESS.	DEPTH.
59.	Drift	25	25
58.	Bluish-black clay, with bituminous matter and gypsum	25	50
57.	Bituminous matter and gypsum	10	60
56.	Soapstone and clay, organic matter, colored by iron oxide and carbonate of lime and magnesia	19	79
55.	Bed rock, very hard, ferruginous sandstone, slightly calcareous	$3\frac{2}{3}$	83
54.	Calcareous sandstone, iron oxide, first seam of lignite, one inch; also sulphate of magnesia	$2\frac{1}{2}$	$85\frac{1}{2}$
53.	Arenaceous, chalky, and calcareous stone, with marly partings containing nearly pure calcium carbonate	$7\frac{1}{2}$	93
52.	Calcareous marl	1	94
51.	Calcareous fragments	1	95
50.	Slate, rotten, bituminous, calcareous	6	101
49.	Slate, slightly calcareous	11	112
48.	Shale, calcareous	1	113
47.	Slate, rotten, bituminous, and shale	12	125
46.	Soapstone and slate	6	131
45.	Shale, calcareous	1	132
44.	Shale, calcareous and siliceous, mineral-bearing	5	137
43.	Shale	8	145
42.	Shale, very hard	1	146
41.	Limestone, in bands, hard, bituminous	12	158
40.	Slate, bituminous, and shale, with streaks of coal and limestone	4	162
39.	Shale, hard slate and shale, wind veins blowing sand out of top of well at 175 feet	13	175
38.	Slate and shale, with limestone bands and openings	4	179

		THICKNESS.	DEPTH.
37.	Conglomerate, hard	2	181
36.	Sandstone, hard, ferruginous, calcareous, with slate streaks	6	187
35.	Sandstone, reddish-brown, ferruginous	8	195
34.	Rotten siliceous rocks, slate and black-jack	6	201
33.	Slate and fire clay, with streaks of hard coal	4	205
32.	Sandstone, micaceous, with streaks of fine clay	6	211
31.	Fire clay and slate	4	215
30.	Sandstone, hard, micaceous	5	220
29.	Slate, bituminous	2	222
28.	Upper coal basin	2½	224½
27.	Fire clay 6 feet, sandstone 1 foot	1½	226
26.	Sandstone, dark, organic	5	231
25.	Shale, bituminous	3⅓	234¾
24.	Coal	1¼	236
23.	Fire clay, fine coal	1	237
22.	Soapstone and slate, limestone and coal streaks	5	242
21.	Shale, arenaceous, coal in streaks	⅔	242⅔
20.	Black oxide of iron (magnetic) hard, solid	6	248⅔
19.	Same with soapstone	6	252⅔
18.	Gypsum and soapstone	6	258⅔
17.	Soapstone, hard ferruginous, with gypsum	4½	263⅙
16.	Coal and slate	½	263⅔
15.	Slate and fire clay, pyrite	4⅓	268
14.	Soapstone	15	283
13.	Chert	½	283½
12.	Soapstone	6½	300
11.	Slate, bituminous, with pyrite	6	306
10.	Slate, bituminous, siliceous, with pyrite	9	315
9.	Slate, fine grained, with pyrite	8	323
8.	Sandstone, brown, ferruginous, with streaks of coal and slate	11	334
7.	Sandstone, brown, ferruginous with heavy spar	---	----
6.	Shales, quartz crystals	6	340
5.	Shale, ferruginous, calcareous	10	350
4.	Quartz rock and spar	14	364
3.	Sandstone, ferruginous, with fluor spar	6	370
2.	Shales, siliceous, with streaks of carbon	6	376
1.	Coal, solid vein	5	381

NOTES.

Todd, who examined the records and drillings, doubtfully referred the strata from 64 feet to 91 feet to the Tertiary, from 91 feet to 180 feet to the Niobrara, from 180 feet to 318 feet to the Benton, and from that limit to 465 feet to the Dakota. Bain, who also examined the drillings and who obtained for us the Woodward record, and whose practical acquaintance with both the Cretaceous and Carboniferous rocks of the state is large and intimate, would favor the reference of these strata to the Cretaceous, although he suggests the possibility of an outlier of the Carboniferous in the region. Placing the base of the Cretaceous at 810 A. T. agrees very well with the assignment made of it at 791 A. T. at Sioux City and 837 A. T. at Sanborn. The floor of crystalline rocks was unquestionably reached at 1,060 feet, or 215 A. T. The sandstones at 860 and 960 feet are, with little doubt, Cambrian.

III. THE CLINTON-DUNLAP SECTION.

The synclinal structure so strongly marked in the northern sections is here well nigh obliterated by the depression of the strata of the western limb. The eastern monocline extends to the Des Moines river. From Ogden to Jefferson there is a rise of seven and one-third feet to the mile, as measured along the summit of the Saint Peter, which at Boone is –705 A. T., at Ogden –722 A. T., and at Jefferson –590 A. T. From Jefferson to Dunlap the dip seems much more gentle. If the entire Dunlap section lies above the Saint Peter, or if that sandstone occurs at the base of the Dunlap section, the altitude of the Saint Peter cannot be higher than –435 or –417 A. T. at that station. But it is possible that the bright green shale at 194 A. T. at Dunlap is the basal shale of the Trenton and, the Saint Peter having feathered out, the underlying arenaceous dolomites belong to the Oneota. In this case the dip continues west of Jefferson at about the same rate as for a few miles to the east of that town. From the latitude of the Dubuque-Sioux City section the southward dip of the strata is moderate. From Ackley to Marshalltown, thirty-five miles south and six miles east, the summit of the Maquoketa declines 335 feet, about ten feet to the mile for the southward component. From Manchester to Tipton the Saint Peter dips south at the rate of about nine feet to the mile.

The southwestern dip of the Saint Peter is but little greater. From Manchester to Grinnell it declines 814 feet, or a little less than ten feet to the mile. From Ackley to Boone the Saint Peter dips southwest at about eight and one-half feet to the mile, but from Dubuque to Cedar Rapids the same sandstone falls 796 feet in sixty-two miles, or about twelve and one-half feet to the mile.

The Ames anticline is a marked stratigraphic feature, which at that station lifts the Saint Peter about 300 feet nearer the surface than would obtain were the usual monoclinal dip of the strata uninterrupted.

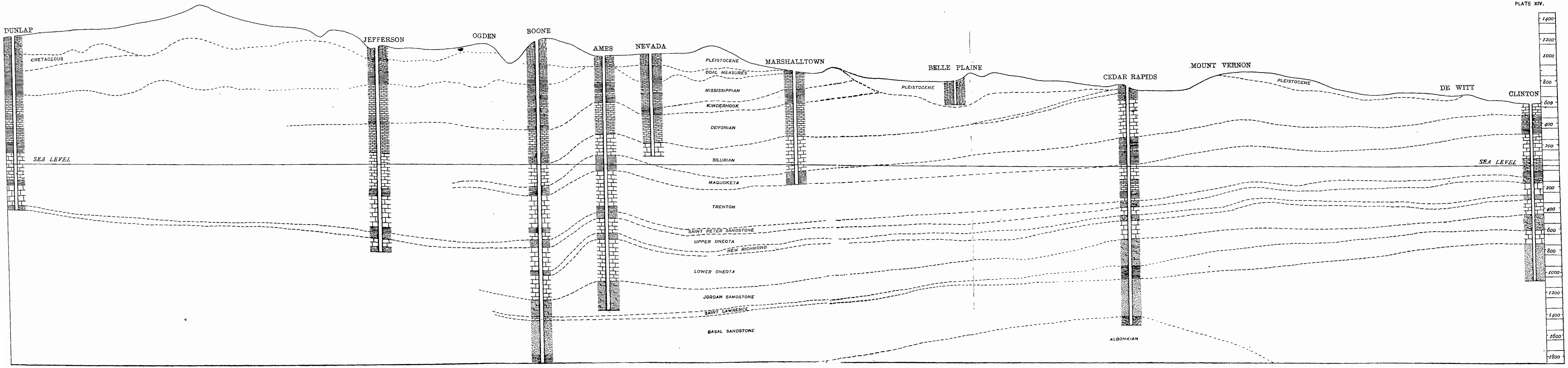
The relief of the section is comparatively moderate. Following the line of a railway, it avoids all local elevations. Yet certain contrasts are strongly marked. Such is the high relief of the Silurian outcrop from Stanwood to Mount Vernon, due not only to its position on a divide, but also to the obduracy of the rock and to anticlinal structure; the low relief of the area of the weak Devonian and Kinderhook rocks from Cedar Rapids to Le Grand, and the accentuations of the relief of the western part of the section by the heavy deposits of the Wisconsin drift sheet.

Over much of the section the thickness of the Pleistocene was drawn without accurate data. Much help was afforded by the officials of the Chicago & Northwestern Railway Co., whose wells, especially east of Boone, frequently show the depth to rock. A most interesting feature of the sub-topography is the deep preglacial river channel at Belle Plaine.

The Coal Measures.—No division is made between the different stages of the Coal Measures. They extend east as far as Marshalltown, and an outlier too small for delineation on the

IOWA GEOLOGICAL SURVEY.

PLATE XIV.



GEOLOGICAL SECTION ALONG CHICAGO & NORTH-WESTERN RAILWAY FROM CLINTON TO DUNLAP.

Scale: Vertical 500 feet
Horizontal 10 miles

section occurs at Cedar Rapids. At Dunlap more or less of the space assigned to them may belong to the Cretaceous.

The Mississippian.—At all points where penetrated the upper beds of the Mississippian are cherty, and in places contain chalcedonic silica also. The "blue granite" of the driller's record at Nevada is probably a geode bed of this series, and it is an interesting coincidence that, at a scientific meeting at an early date in Iowa, drillings from this same bed were exhibited by a professor of geology as samples of Archean granite, which he thereby proved was reached in central Iowa at less than 500 feet! The place of this chert indicates that the Kinderhook passes below its level rather than above it. Otherwise the first heavy shales at Boone below the Coal Measures might be taken as Kinderhook, thus greatly increasing the thickness of the Devonian. The Kinderhook shale is clearly delimited at Marshalltown, and the limestone above it belongs also to the Kinderhook, as shown shown by its fossils in natural outcrops. At Nevada no shales appear in the driller's log, but a "blue limestone," from 482 to 583 feet from the surface, may owe its color to argillaceous admixture.

The Devonian.—The basal members of the Devonian, the Independence shale and the Otis limestone immediately beneath it, dip beneath the surface at Cedar Rapids. The Otis is too thin for graphic representation on the scale of the section. The shale is not reported at Marshalltown and Nevada. At Vinton a non-magnesian limestone of the type of the Otis occurs at a depth of 115 feet from the surface and below a preglacial channel of the Cedar river. The Spirifer pennatus beds of the Cedar valley limestone outcrop in quarries near the wells. The Independence shales and Fayette breccia, which immediately succeed the Otis, probably extend as far west as Vinton, and are found in place on the Wapsipinicon a little south of where it is crossed by the Manchester-Grinnell section.

The Silurian.—The Silurian exhibits several features of special interest. On this section it attains its greatest known thickness in Iowa. At Cedar Rapids the Niagara and the Coggan and Bertram beds aggregate 410 feet in thickness.

The high relief of the Cedar-Maquoketa divide has already been mentioned. The anticline to which this is partly due had previously been inferred from the stratigraphy of the region, and it finds expression in the strike and outcrop of the strata.

Near Mount Vernon, the upper 100 feet of the Niagara consists of the Le Claire in mounds, with strong quaquaversal dips, the Anamosa beds occupying depressions in the Le Claire. Interesting lithological variations are exhibited in the section of the Silurian at Vinton.

		THICKNESS.	DEPTH.
6.	Limestone, magnesian, buff, porous, crystalline	15	150
5.	Limestone, magnesian, pinkish, cherty, argillaceous	18	168
4.	Limestone, non-magnesian, white, cherty, arenaceous	82	250
3.	Dolomite, white and bluish-gray	35	285
2.	Clay and sandstone	10	295
1.	Dolomite, gray	55	350

Numbers 4 to 6 were listed as Devonian in the author's previous report,* but it seems far more probable, with a more thorough study of the questions involved, that No. 4 is a bed of the Silurian that escaped dolomitization. Such beds have been found, undoubtedly Niagara in age, within the area of outcrop of that formation in Iowa.

At Marshalltown the Silurian suffers a still more interesting lithological change. Its place is held by cherty and gypseous dolomites and limestones, whose gypsum suggests the Onondaga rather than the Niagara.

At Boone the upper limit of the Silurian is in doubt. Considering its thickness at Des Moines, it may well extend upward to 930 feet from the surface, the point where buff

*Iowa Geol. Surv., vol. III, pp. 192-194.

magnesian limestones begin, giving it a thickness of 405 feet. The more conservative view adopted makes the heavy shale at 1,080 feet the base of the Devonian, below which lie brown, gray and buff dolomites and limestones, in places cherty and even arenaceous. At Jefferson, two or three samples of dolomite were taken from the place where the Silurian would naturally lie, and at Dunlap, at the same horizon, occur light yellow, argillaceous, magnesian limestones, resembling the Silurian at Pella.

The Maquoketa.—This formation reaches here its greatest known thickness. At Monticello and Tipton, its thickness, measured to the lowest sample of shale, preserved by the drillers, is respectively 195 and 185 feet; measured to the first samples of the Trenton, it is 285 and 295 feet. At Vinton the recorded thickness is 269 feet, and at Cedar Rapids samples prove it 276 feet thick. At Boone, it still measures 100 feet. The few samples preserved at Jefferson include no shales that can be referred to the Maquoketa, and the shales at Dunlap assigned to this terrane may really be Trenton. The division of the Maquoketa by a medial bed of dolomite, noted in the Dubuque-Sioux City section, reappears in this as far west at least as Vinton and Cedar Rapids.

The Galena dolomite, absent at Manchester and unrepresented in the Vinton samples, reappears at Clinton, Monticello, Anamosa, Tipton and Cedar Rapids. At Ames the Galena-Trenton limestones are non-dolomitic, while at Boone, with the exception of one stratum, all the limestones of the Galena-Trenton are dolomites, and only dolomites occur in the samples of the limestones from this horizon from the wells west of the Des Moines river. The basal shales of the Trenton are persistent throughout the section.

The Saint Peter maintains its ordinary physical characteristics and thickness as far west at least as Jefferson.

The division of the Oneota is not clear at Clinton, where we have no complete set of samples. The New Richmond is well defined in wells further west. At Boone the change that seems to affect the magnesian series to the west has taken place. The dolomite beneath the Saint Peter is less than 150 feet thick. Below that limit extend, so far as samples show, some 350 feet of shales and marls, which are added to the Oneota mainly because to the south, at Des Moines, where the series of drillings is complete, dolomite recurs at about that depth.

The Algonkian quartzite was struck at but one point in the section—at Cedar Rapids, 1,417 feet below sea level. This quartzite, it will be remembered, was reached at Lansing, eighty miles to the northeast, at a depth of seventy-one feet below sea level. The descent of the quartzite in this distance corresponds to the dip of the Paleozoic rocks; but it should not be supposed that the Algonkian gradient is even. Its relief is doubtless uneven in the extreme. The Cedar Rapids quartzite represents a considerable local elevation of the pre-Paleozoic surface. It slopes to the southeast, since the drill did not pierce it at Tipton at 1,886 feet below tide, and probably to the west also, since it was not struck at Boone at 1,860 feet below tide. But between these two stations there is room for much diversity of this surface. In the author's former paper on the deep wells of northeastern Iowa it was suggested that the lower 451 feet of red sandstone at Tipton might represent the Algonkian quartzite at Cedar Rapids. An interview has since been had with the foreman in charge of the Tipton drilling, who states that while these sandstones were hard, they were not unusually so. They are, therefore, here placed with the Paleozoic.

Artesian Conditions of the Clinton-Dunlap Section.

In no parts of this section is the boring of artesian wells interdicted by what is known of the deeper strata.

East of the Iowa river such wells are strongly recommended as a water supply for all except the largest towns. The drill will rarely need to go deeper than the Jordan sandstone, in which, and in the overlying Oneota, the best supply may be expected. Few, if any towns in this eastern district are situated too high for practicable pumping. Whether fountain wells may be expected and the height of the head may be readily calculated from the data on Plate XIV.

Near the Des Moines, the necessary depth to reach artesian water is shown in the wells at Boone and Ogden. While artesian water is here an expensive luxury, it may be the cheapest and most available satisfactory water supply for towns remote from available rivers and streams.

West of the Des Moines river the gentle rise of the Cambrian and Ordovician strata is a favorable indication. If these formations continued to descend in western Iowa, at the same rate as in the eastern part of the state, they would in a short distance beyond the Des Moines river be carried below practicable exploitation with the drill. As it is, even upon the highest ground of the Des Moines-Missouri divide, 2,500 or 2,700 feet should reach the main water-bearing strata which supply the artesian wells of eastern Iowa. The distance necessary to pump the water will constitute a difficulty that must be taken into account. Both at Jefferson and Dunlap the capacity of the wells is encouraging. West of the Iowa river the utmost pains should be taken to exclude all waters above the Maquoketa shale.

XXIV. CLINTON.*

OWNER.	No.	Depth.	Diameter, inches.	Elevation of curb, A. T.	Original head of water, A. T.	Present head, A. T.	DISCHARGE IN GALLONS PER DAY. Original.	1893.	1896.	Temperature.	Date of completion.
Water Works Co	1	1,035 1,400	5 8	588	632	623	500,000	700,000	2,500,000 (Nos. 1–4)	64°	1886
Water Works Co.	2	1,246	5	588	632	623	500,000	400,000		64°	1886
Water Works Co.	3	1,675	8-6	588	632	623	900,000	900,000		64°	1890
Water Works Co.	4	1,497	10	588	......	......	....	600,000		63°	1893
Paper Co.	....	1,065	.....	588†	630	596	....	....	....	59°	1883
Lamb & Son	....	1,230	.....	588†		623	....	....	....	65°	1888
C. & N. W. Ry. Co.		1,159	.....	588†	600	600	....	....	....	.....	1896

Driller of all the above wells, J. P. Miller & Co.

*The facts relating to the wells at Clinton were furnished by their respective proprietors. Especial mention should be made of the kindness of Dr. P. J. Farnsworth, who collected data of the Dewitt park well, and of the helpful suggestions of Supt. S. M. Highlands, of the Water Co.

† Approximately.

The artesian water supply of Clinton has been widely known as one of the finest in the United States. The yield of the artesian wells is abundant, and the water has ranked among the best of potable waters. Unfortunately the supply, exceptionally large as it is, is not commensurate with the increase in population, and symptoms are not wanting that it is already being overdrawn. All of the wells show loss of pressure, in some amounting to about fifteen pounds. With these indications that new wells would further diminish the yield of the present wells, and that they would fail to increase the discharge in proportion to the additional expense, the water company resolved to supplement the artesian supply with filtered water from the Mississippi river. About 300,000 gallons a day are drawn from this source, passing through a mechanical filter recently erected by the National Filter Co. with a capacity of 1,000,000 gallons a day. From five to twenty-five grains of alum are used to the thousand gallons, an amount quite too small to remove bacteria.

WATER HORIZONS.

The Galena-Trenton furnishes the first flow—a moderate yield at depths of from 330 to 400 and 460 feet beneath the surface. The temperature, 60° to 62° Fahr., is about that of the deeper flows. Sulphureted hydrogen is obviously present in the water as it flows from the wells, but under aeration it vanishes in a few hours, leaving no trace. Heavier flows are encountered in the Saint Peter, the Oneota, the Jordan and the Basal sandstone. In the deeper well of the water company Superintendent Highlands reports these flows as follows:

From 625 to 725 feet, 150 gallons per minute, 8-inch bore.
From 1,025 to 1,150 feet, 400 gallons per minute, 8-inch bore.
From 1,400 to 1,675 feet, 700 gallons per minute, 6-inch bore.

In this well the pressure from each of these flows was tested, not during the progress of the boring, but after the completion, by packing a tube at different depths. Strangely enough, it is said to have been found to be the same at all depths. In the Park well, Dr. Farnsworth reports that from observation of the water in the ditch as the well was drilled he judged that the full flow was reached at 1,100 feet.

Well No. 3 of the water company is cased to 135 feet from surface, and there packed with lead ring. Well No. 4 was cased to 700 feet in order to cut off caving sands in the Saint Peter. In the well of the Chicago & North-Western Rail-

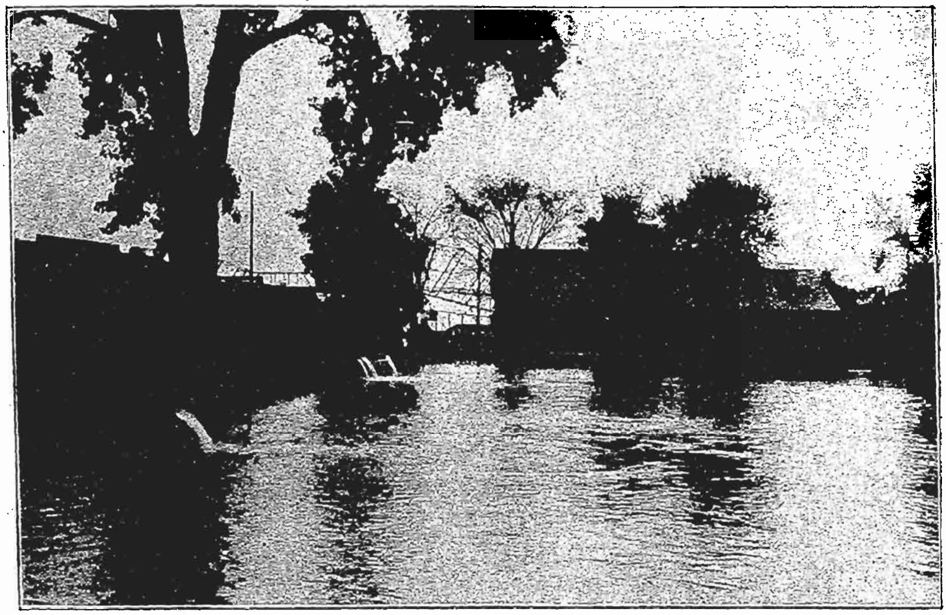


FIG. 40. Reservoir at Clinton, Iowa, fed by artesian wells. The smallest stream, the second on the left, is of filtered water from the Mississippi river.

way Co., an eight-inch casing extends 200 feet from the surface. At 765 feet caving sands were encountered in the Saint Peter; forty-two feet of six-inch casing was inserted, ending below at 767 feet, and the bore changed to five inches. In the well of Lamb & Son, casing reaches to 125 feet and is packed with rubber packing. In the Paper Company's well the casing extends to eighty-four feet and no packing was used. This well showed considerable loss of head three and four years after it was drilled. It had been closed nights and Sundays, and it was thought that, on account of the consequent pressure on the sides of the boring, much of the water was forced into cracks and crevices of the rock and thus escaped. In 1893 it was attempted to repair the well by reaming it and inserting another casing. At the bottom of the first casing the rock was found to be so eroded by the water that the reamer here dropped seven feet. A five-inch tubing was then put in, reaching to 160 feet, and packed with rubber, but without increasing the flow.

QUALITY OF THE WATER.

The Paper Mill Co. reports a gratifying decrease in hardness of the water. As a boiler water the Clinton artesian water is superior to that of the Mississippi river. Although it rapidly destroys wrought iron pipes, it does not corrode boilers. Carrying its own boiler compound with it, it is said to form no scale, although containing considerable of the scale-forming constituents. The following analysis appears to be that of the combined waters of wells No. 1 and No. 2 of the Water Co., before the former was bored to its present depth. The water, therefore, represents all yields as far as that from the Jordan sandstone.

ANALYSIS.

	GRAINS PER U. S. WINE GALLON.
Calcium bicarbonate	11.2291
Magnesium bicarbonate	7.4267
Sodium bicarbonate	6.2824
Sodium sulphate	6.6266
Sodium chloride	6.6616
Alumina and Ferric oxide	.0174
Silica	.6124
Total	38.8552

Analyst, Prof. E. G. Smith, Beloit. Date, March 20, 1887. Authority, published report of Water Co. to mayor, April 1, 1893.

The embarrassment of riches of more than one artesian record at any one locality is illustrated in the following table. Record No. 1 is that of Supt. S. M. Highlands, of the first artesian well of the city Water Co.; No. 2 is that of Mr. D. W. Mead,* of the same well; No. 3 is by Dr. J. P. Farnsworth, of the Dewitt Park well; No. 4, of the same well by Supt. Highlands; No. 5, the driller's record of the well of the Chicago & North-Western Railway Co.; No. 6, of the well of the Clinton Paper Co. The wells are on about the same level. Drift and superficial deposits are slight and are included in the Niagara.

	No. 1.	No 2.	No. 3.	No. 4	No. 5.	No. 6.
Niagara base	120	300	90	150	130	224
Niagara thickness	120	300	90	150	c 130	224
Maquoketa base	300	450	230–270	450	425	399
Maquoketa thickness	180	150	140–180	300	295	175
Galena-Trenton base	625+	b	680	700	700	Lime rock to 1,075 feet.
Galena-Trenton thickness	325	----------	450–410	250	275	
Saint Peter base	725	Omitted	720	760	760	
Saint Peter thickness	a 100 *	----------	40	60	60	
Oneota base	1,025	1,000	Mixed limestone and sandstone, 800 feet; sandstone at 1,000 feet.		1,140	
Oneota thickness	300	----------			380	
Jordan base	1,150	1,100				
Jordan thickness	125	100				
Saint Lawrence base	1,400	1,275				
Saint Lawrence thickness	250	175				
Basal sandstone base	1,700	1,649				
Basal sandstone thickness	300	374				

* Or less. *a* "Shale and sand," Trenton shales apparently being included. *b* The so-called "Trenton" and "Galena" are each made 275 feet thick. The latter corresponds to the Oneota, and the Jordan is called the Saint Peter. *c* "100 feet of shelly rock," "30 feet of hard rock."

The following samples of the drillers are in evidence:

DEPTH.

10–80 Dewitt Park well..................... Dolomite, buff.

"300–350" Dewitt Park well..................... Dolomite, gray, somewhat porous.

400. C. & N.-W. Railway Co. well.......... Dolomite, hard, gray.

500. Dewitt Park well..................... Dolomite, buff.

575. C. & N.-W Railway Co. well.......... Limestone, fossiliferous, and reddish shale.

680–720. Dewitt Park well..................... Sandstone, pure, white, soft, numerous larger grains about 0.37 mm. in diameter.

At about 769 C. & N.-W. Railway Co. well. Sandstone, white, saccharoidal, rounded grains.

790, 830 and 900. Dewitt Park well.......... Dolomite.

960. Dewitt Park well..................... Dolomite, white, with considerable chert and grains of quartz sand.

1,025. Dewitt Park well..................... Dolomite, gray, cherty.

1,135. Dewitt Park well..................... Dolomite, arenaceous.

As the Maquoketa shales outcrop about two miles north of the wells at about the same level, it seems best to accept

*Notes on Hydrogeology of Illinois, table XL.

that record—No. 3—which places them nearest the surface, at ninety feet.

The base of the Maquoketa is less certain. The samples show that it cannot lie lower than 400 feet from the surface, or even than 350 feet. The formation probably extends at least to 270 feet from the surface.

The records are so uniform in the upper limits of the Saint Peter where it is mentioned, that serious discrepancies between the records of different wells in other formations cannot be accounted for by the assumption of a fault. Three records unite in placing the summit of the first sandstone below the Saint Peter, the Jordan, at 1,000 or 1,125 feet. This may be included between the dolomite of the samples at 1,025 and 1,135 feet from the surface. Certainly it is followed by dolomite, the Saint Lawrence, which gives way to sandstone, the Basal sandstone, at 1,275 feet in one record and at 1,400 feet in another.

XXV. CEDAR RAPIDS.*

OWNER.	Depth.	Diameter, inches.	Elevation of curb.	Head A. T.	Flow in gallons per minute.	Temperature.	DRILLERS.
Water Works Co	2,225	5	733	761	250	62°	J. P. Miller & Co.
Water Works Co	1,450	5	733	761	250	62°	J. P. Miller & Co.
Water Works Co.	1,450	5	733	761	250	62°	J. P. Miller & Co.
Y. M. C. A.	1,450	5	733	735½	-----	------	A. K. Wallen.

Previous to the installation of water works the town depended for fire protection and water supply upon storage cisterns and surface wells. In December, 1875, the plant of the water company was so far completed that pumping was begun from a filter well on the bank of the Cedar river, adjacent to the mill pond. This supply was used for about thirteen years, when three artesian wells were put down, from 100 to 200 feet apart, forming the apices of a triangle. At 85 feet the first two wells pierced a channel in rock from

* The Survey is indebted to Mr. C. B. Soutter, president of the Cedar Rapids Water Co., and to the superintendent, Mr. C. J. Fox, who contributed the facts at hand and sets of drillings from two of the wells.

SYSTEM	STAGE	SUB-STAGE	A.T.	ROCK
DEVONIAN	WAPSIPINICON	Otis	704	LIMESTONE
SILURIAN	COGGAN AND BERTRAM		638	LIMESTONE
	NIAGARA-CLINTON	Anamosa		SOFT BUFF DOLOMITE
		Le Claire Delaware	289	DOLOMITES SUBCRYSTALLINE, OFTEN VESICULAR
ORDOVICIAN	HUDSON RIVER	Maquoketa	13	BLUISH SHALE WITH THREE BEDS OF INTERCALATED LIMESTONE SEA LEVEL
	TRENTON	Galena Trenton		DOLOMITE MAGNESIAN LIMESTONE EARTHY LIMESTONE AND SHALES.
	SAINT PETER		292 312	SANDSTONE WHITE, ROLLED GRAINS.
	ONEOTA	Upper Oneota	437	
		New Richmond	492	SANDSTONE CALCIFEROUS.
		Lower Oneota	667	DOLOMITE, IN PLACES ARENACEOUS
CAMBRIAN	SAINT CROIX	Jordan	957	WHITE SANDSTONE SANDSTONE, CALCIFEROUS IN PLACES.
		Saint Lawrence	1057	SHALES
		Basal Sandstone	1417	SANDSTONE, LIGHT REDDISH AND YELLOW
ALGONKIAN		Sioux?	1492	QUARTZITE, REDDISH BROWN

CEDAR RAPIDS WELL SECTION.

which water rose to the surface and overflowed. The Saint Peter sandstone furnished water, and the flow reached its maximum from the Oneota and Jordan, from 1,300 to 1,425 feet. At some lower depth the first boring set free a highly mineralized salty water of which, unfortunately, no analysis is on record. This water was found impracticable for boiler use and highly corrosive. At the end of five years the wrought iron casing was taken out in the condition illustrated in accompanying photograph. In 1894 the well was reamed to eight inches to a depth of 1,450 feet and there plugged to

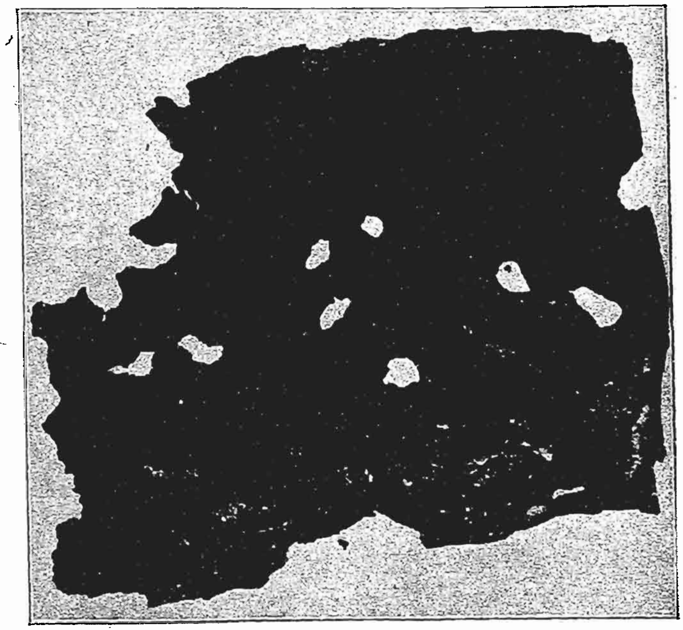


FIG. 41. Corroded casing from Cedar Rapids well.

shut off the lower water. No increase in flow was noticed. In the same year an artesian well was drilled for Mr. C. B. Soutter at the Y. M. C. A. building and presented by him to that organization. The pressure was unexpectedly light and a hydraulic ram was employed to raise the water to the required height. The flow from this well did not favor the extension of the artesian system. The yield of the other wells had not for years met the demands of the growing city, making it necessary to mingle with the artesian waters raw water from the river. A large part of the manufacturing trade had been lost to the water company on account of the hardness of the water. For these reasons an expensive mechanical filter plant was erected in 1895-1896, and the water of the river will hereafter be so treated as to insure, it is hoped, the patrons of the company immunity from all diseases of whose germs drinking water is the vehicle.

The first three wells were cased to eighty-five feet, using lead packing with rubber. The well at the Y. M. C. A. building was first cased to 1,372 feet. As it was found to shut off a large part of the flow, the casing was withdrawn and the well recased to eighty-five feet.

The strata of the Cedar Rapids wells are described by the author in papers previously published.*

(Y. M. C. A. WELL) MINERAL ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\,O_2$)	.149	2.571
Alumina ($Al_2\,O_3$) and Ferric oxide ($Fe_2\,O_3$)	1.036	17.857
Lime ($Ca\,O$)	5.684	98.000
Magnesia ($Mg\,O$)	3.000	51.714
Soda ($Na_2\,O$)	7.076	122.000
Chlorine (Cl)	.025	.428
Sulphur trioxide ($S\,O_3$)	10.026	172.857
Carbon dioxide ($C\,O_2$)	14.434	248.857
Water in combination ($H_2\,O$)	2.966	51.143
Free ($C\,O_2$)	[3.082]	[53.143]

UNITED AS FOLLOWS.

Calcium bicarbonate ($a\,H_2\,(CO_3)_2$)	16.439	283.429
Magnesium bicarbonate ($Mg\,H_2\,(CO_3)_2$)	9.181	158.284
Magnesium sulphate ($Mg\,SO_4$)	1.409	24.286
Sodium sulphate ($Na_2\,SO_4$)	16.141	278.286
Sodium chloride ($Na\,Cl$)	.041	.714
Alumina ($Al_2\,O_3$) and Ferric oxide	1.036	17.857
Silica ($Si\,O_2$)	.149	2.571
Solids	44.396	765.427

Analyst, Prof. J B. Weems, Ames, Iowa. Date, April 1, 1896.

* Iowa Geol. Surv., vol. III, pp. 195-197. Proc. Iowa Acad. Sci., vol. II, p. 195.

XXVIII. MARSHALL.*

A deep boring at this point, drilled by a local company for gas and coal, is here included on account of the interesting succession of strata. The depth of the boring is 1,020 feet, the elevation of the ground at surface is about 885 feet A. T.

		THICKNESS.	DEPTH.
13.	Limestone, light gray, in fine sand, with many angular fragments of limpid quartz, at 68 feet		70
12.	Limestone, light yellow, compact, earthy lustre, three samples	45	115
11.	Limestone, brown, crystalline, cherty, at 115 feet	30	145
10.	Shale, soft, light green, calcareous	175	320
9.	Limestone (?), no samples	145	465
8.	Limestone, hard, brown gray and brown, crystalline, rapid effervescence, samples at 465 and 560 feet	155	620
7.	Dolomite, yellow, gypseous and cherty	55	675
6.	Limestone, magnesian, brown, samples at 675, 690 and 700 feet, cherty at 675 feet	95	770
5.	Dolomite, cherty, gypseous, drillings consist mostly of white and translucent chert	30	800
4.	Chert, white and translucent, sample at 800 feet	75 (?)	875
3.	Limestone, rapid effervescence, drillings consist almost wholly of chert, with some gypsum, samples at 875 and 900 feet	25	900
		15	915
2.	Dolomite, white, in powder, with some chert and gypsum	10	925
1.	Shale, blue and green-gray, non-calcareous in sample at 925 feet, to bottom of boring	95	1,020

SUMMARY.

NOS.	FORMATION.	THICKNESS.	A. T.
11–13.	Mississippian	145	740
10.	Missisippian-Kinderhook shale	175	565
8–9.	Devonian	300	265
2–7.	Silurian	305	–40
1.	Maquoketa, penetrated	95	–135

*Samples of the drillings were contributed by Dr. W. S. McBride.

XXVIII. NEVADA.*

Owner	Nevada.
Depth	980 feet.
Diameter	11 in., 8 in., 6 in.
Elevation of curb A. T.	1,005 feet.
Head of water A. T.	902 feet.
Capacity in gallons per minute	200 feet.

This well was drilled from March 15, 1895, to October 14th of the same year. Casing was used to 810 feet. Water is derived from 940 feet, apparently from a vein in the Niagara limestone, but possibly water from the Mississippian is not wholly shut out.

ANALYSIS.

	GRAINS IN U. S. GALLON.
Calcium carbonate	24.500
Magnesium carbonate	25.978
Magnesium sulphate	137.346
Sodium sulphate	17.840
Potassium sulphate	5.568
Sodium chloride	5.609
Silica	1.113
Iron carbonate	.473
Alumina	.862
Total	219 289

Analyst, Mr. George H. Briggs, Nevada, Iowa. Authority, report of mayor.

In the amount of incrusting solids which this water carries, it ranks among the worst in the state. Our correspondents report that it thickly lines boilers with scale, making daily blowings out necessary; but with such precautions it seems that it can be used as a steam water.

Its medicinal effect is specially marked, and a number of cures have already been brought about by its use in a variety of diseases. Physicians state that it is prescribed to relieve plethora, overcome constipation, and to act as a depletary and sedative remedy in various febrile and inflammatory affections. It is used, they state, with benefit in dyspepsia, kidney diseases, rheumatism, gout, blood poisoning, scrofula and other diseases. It acts as a laxative—and strongly upon some,

*Reported by Mr. William Gates and by Messrs. Palmer & Sandbo, drillers of the well.

—and as a continuous diuretic. One physician writes that on account of this effect it is not yet known whether it can be continued in general use for domestic supply.

DRILLER'S RECORD.

	STRATA.	THICKNESS.	DEPTH.
28.	Clay, yellow	30	30
27.	Clay, blue	6	36
26.	Clay, yellow	10	46
25.	Sand	55	101
24.	Clay, tile	20	121
23.	Shale	50	171
22.	Clay, black	75	246
21.	Slate	3	249
20.	Coal and slate	3	252
19.	Clay, light gray	15	267
18.	Shell lime rock	15	282
17.	Lime rock, white, mixed with flint	50	432
16.	Granite, blue	50	482
15.	Limestone, blue	93	575
14.	Shale, red	8	583
13.	Limestone, blue	80	663
12.	Soapstone	8	671
11.	Limestone, white	90	769
10.	Limestone, blue	40	801
9.	Clay, blue	3	804
8.	Limestone, blue	55	859
7.	Limestone, white	40	899
6.	Sand rock, dark	35	934
5.	Sand rock, white	10	944
4.	Sand rock, red	12	956
3.	Sand rock, white	8	964
2.	Sand rock, red	4	968
1.	Limestone, white	12	980

SUMMARY.

This section is a difficult one with the data at hand. Its interpretation must be guided by the general stratigraphy of the region and can depend only in part on the description of the strata just received.

NOS.	FORMATION.	THICKNESS.	A. T.
25–28.	Pleistocene	101	904
19–24.	Coal Measures	166	738
16–18.	Mississippian	215	523
15.	Kinderhook	93	430
7–14.	Devonian	324	106
1– 6.	Silurian, penetrated	81	25

XXIX. AMES.

At present writing the deep well at the Iowa Agricultural College is not completed, and the report of it is therefore deferred.

XXX. BOONE.*

Owner	Town.
Depth	3,010 feet.
Diameter	8, 5⅝, 4½, 3½, 3 in.
Elevation A. T.	1,140 feet.
Head of water A. T.	940 feet.
Capacity in gallons per minute	70
Temperature	68° Fahr.

This well is the deepest in Iowa, and indeed ranks among the deep borings of the world. It is cased with 5⅝-inch tubing to 1,400 feet; with 4½, from 1,300 to 1,875 feet, and with one of still less diameter from about 1,975 to 2,073 feet. The capacity given is really that of the pump, which has never been able to draw down the head. Water was found at forty-five feet. At 195 feet a vein was struck yielding 40,000 gallons per day and standing at thirty-five feet from the surface. At 1,875 feet a small vein was found in the Saint Peter rising to within sixty feet of the surface, or heading at 1,080 feet A. T. With the same head at Clinton, water from the Saint Peter would rise 500 feet above the river, with a pressure of about 210 pounds to the square inch! The main vein lies 2,700 feet from the surface and 1,560 feet below sea level. The artesian pressure which lifts the water 2,500 feet equals, at the level of the vein, 1,082 pounds to the square inch, or over seventy atmospheres.

This well was begun in 1889, and at 1,875 feet it was taken over by J. P. Miller & Co., who carried it successfully to completion in 1890.

As the supply is insufficient for the town, and the quality of the water of the shallow well used to supplement it, from which about 1,700 gallons a day are now drawn, is not above

*We are under special obligations to Mr. E. E. Chandler, who, as the work of drilling the second well went on, had samples saved for the Survey at frequent intervals, and also to Mr. J. Crary.

suspicion, a second deep well was begun in 1894 by the same firm.

It is situated a few yards from the first, and the purpose is to carry it to 2,700 feet. At present writing it lacks about 500 feet of that term. This boring is fifteen inches in diameter to 200 feet, twelve inches to 300 feet, ten inches to 500 feet and six inches to 2,000 feet.

RECORD OF STRATA: SUMMARY.*

FORMATION.	STRATA.	THICKNESS.	THICKNESS.	A. T.
Pleistocene	Drift clays, sand and gravels	200	200	940
Des Moines (?)	Clays, sandy	70		870
Des Moines	Shales of various colors	145	215	725
Mississippian	Cherts, with limestone and shale	30		
	Limestone, gray, crystalline	45		
	Marlite, drab	37		
	Limestone, brown and gray, in places highly cherty	38		
	Sandstone, fine	10		
	Shale	40		
	Limestones, blue and gray, mostly argillaceous	165	365	335
Kinderhook	Shale	10	10	325
Devonian	Limestone, gray	115		
	Limestone, magnesian	98		
	Limestone, argillaceous	22		
	Shale	15		
	Limestone, magnesian	15		
	Shale	40		
	Limestone and bituminous shale	10	315	10
Silurian	Limestone, dolomitic, cherty in places	90		
	Shale	20		
	Limestone, dolomitic	20		
	Limestone, argillaceous	22		
	Clay, red, with silica	16		
	Limestone, with green shale	17		
	Limestone, dolomitic	20	205	–195
Maquoketa	Shale	100	100	–295
Trenton	Dolomite and magnesian limestone	55		
	Limestone, earthy	20		
	Dolomites	130		

*The excellent detailed description published by Beyer, Iowa Geol. Survey, vol. V, pp. 194-199 renders unnecessary here anything beyond a summary of the section. This is based also upon personal examination of the samples.

FORMATION.	STRATA.	THICKNESS.	THICKNESS.	A. T.
	Shale	20		
	Dolomite	70		
	Shale	15	310	–705
Saint Peter	Sandstone	5		
	Shale	30		
	Sandstone	20	55	–760
Oneota	Shale	10		
	Dolomite	65		–835
	Unknown	70		–905
	Shale and marls	355	500	–1,260
Saint Croix	Sandstones, shales and marls	610	610	–1,870

(WELL NO. 1) ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si O_2$)	.688	11.858
Alumina ($Al_2 O_3$) Ferric Oxide ($Fe_2 O_3$)	.580	10.000
Lime ($Ca O$)	12.603	217.285
Magnesia ($Mg O$)	6 214	107.143
Potash ($K_2 O$)	.025	.428
Soda ($Na_2 O$)	31.718	546.858
Chlorine (Cl)	8 866	152.858
Sulphur trioxide ($S O_3$)	50.046	862 857
Carbon dioxide ($C O_2$)	11.269	194.285
Water in combination ($H_2 O$)	2.519	43.428

UNITED AS FOLLOWS.

Calcium bicarbonate ($Ca H_2(CO_3)_2$)	18.933	326.429
Calcium carbonate ($Ca CO_3$)	2.278	39.286
Calcium sulphate ($Ca SO_4$)	11.708	201.857
Magnesium sulphate ($Mg SO_4$)	18.883	325.571
Sodium sulphate ($Na_2 SO_4$)	54.661	942 429
Sodium chloride ($Na Cl$)	14.765	254.571
Potassium chloride ($K Cl$)	.041	.714
Alumina ($Al_2 O_3$) and Ferric oxide	.580	10.000
Silica ($Si O_2$)	.688	11.857
Oxygen replaced by chlorine	1.989	34.286
Solids	124.526	2,147.000

Analyst, Prof. J. B. Weems, Ames, Iowa. Date, May 26, 1896.

The physicians of Boone generally regard the introduction of artesian water as a distinct sanitary improvement. One believes it "the most healthful water in this part of the state;" another, "one of the greatest blessings that has been visited upon the community." After using it for some time other water becomes less unpalatable. There is a division of opinion as to its physiological effects. It is both affirmed and denied that it is laxative and diuretic, and that it may produce disorders of the digestive tract. The affirmative, at least as to its laxative character, is supported by the analysis, which shows some seventy-three grains to the gallon of Glauber and Epsom salts. One physician states that the bilious diethesis is benefited by its use. The quantity available at present does not seem to be sufficient to keep the mains properly flushed, a condition which will be remedied when the new well is completed. The water corrodes iron and forms a heavy scale. New water pipes for boilers are sometimes eaten out in six months, and boiler flues are occasionally equally short-lived from this cause. When treated in a heater the water deposits there about one inch per week, and in the same time forms about one-sixteenth of an inch scale in the boiler.

XXXI. OGDEN.

Repeated applications to the officials of the town for information as to the deep well now being drilled for the corporation have received no attention. From the drillers, Mr. J. P. Miller & Co., we learn that the well at present writing has nearly reached its expected limit of 2,700 feet. The Saint Peter sandstone was struck at about 1,820 feet, or 722 feet below sea level, and yielded about eighteen gallons a minute.

XXXII. JEFFERSON*.

Owner	Town.
Depth	2,026 feet.
Diameter	8 inches.
Elevation of curb, A. T.	1,110 feet.
Head of water, A. T.	1,070 feet.
Capacity in gallons per minute	200.

This well was drilled in 1886 by J. P. Miller & Co., and casings sunk to 1,400 feet. It constitutes the water supply of the water works and is used by about 150 families.

*Information regarding this well was supplied by Mr. M. E. Hall and Dr. F. M. Dean. The common council devoted all the drillings which had been preserved to the uses of the Survey.

ANALYSIS.

	GRAINS PER GALLON.
Calcium carbonate	5.6627
Magnesium carbonate	3.2075
Sodium chloride	11.0046
Sodium sulphate	46.3220
Ferric oxide	.4141
Silica	.7931
Total	67.4040

Analyst, Prof. A. A. Bennett, Ames, Iowa. Date, May 17, 1894. Authority, copy by city clerk.

RECORD OF STRATA

		DEPTH OF SAMPLE.
18.	Sandstone, dark buff, moderately fine, grains imperfectly rounded	260
17.	Shale, dark, unctuous, non-calcareous	270
16.	Sandstone, argillaceous, slightly calcareous, grains of pure quartz, varying in size from fine to coarse and but little rounded by attrition	340
15.	Chert, gray, with large to small grains of limpid quartz, probably from above, and a little white limestone	350
14.	Limestone, white, non-magnesian, drillings highly arenaceous with minute quartzose particles and some rounded grains	355
13.	Limestone, dark and light drab, hard	525
12	Shale, green-gray, pyritiferous, calcareous	700
11.	Limestone, light buff, crystalline, pure	800
10.	Limestone, magnesian, in white powder, pure	1,000
9.	Limestone, magnesian, or dolomite, with some shale in brown powder, residue cherty	1,100
8.	Limestone, magnesian, brown in fine sand, effervescence rather rapid	1,200 and 1,300
7.	Limestone, magnesian, light blue-gray, lustre earthy	1,350
6.	Dolomite, light buff, in fine sand, highly cherty	1,450
5.	Dolomite or magnesian limestone, brown, cherty, effervescence somewhat faster than Racine beds and Galena	1,500
4.	Shale, green, slightly calcareous	1,670
3.	Sandstone, fine, white, clean, rolled grains, 50 feet thick	1,700
2.	Dolomite, in fine sand of deep brown color, with some chert	1,745
1.	Sandstone, in yellow powder and sand of angular particles of quartz with a few round grains	1,800 and 1,880

SUMMARY.

NOS.	FORMATION.
16–18.	Des Moines (Coal Measures).
13–15.	Mississippian.
12.	Kinderhook.
5–11.	Devonian, Silurian and Ordovician.
4.	Trenton.
3.	Saint Peter.
2.	Oneota.
1.	Saint Croix.

XXXIII. DUNLAP.*

Owner	Town.
Depth	1,535¾ feet.
Diameter	6¼ inches.
Elevation of curb, A. T. (railway station)	1,101 feet.
Head of water, A. T.	1,054 feet.
Casing, lower limit	400 feet.

This well was drilled in 1887 by J. P. Miller & Co. When finished, continuous pumping for seventy-two hours failed to lower the water more than six inches. The supply is supposed to be practically inexhaustible. Water works have recently been installed. The physiological action of the water has not been tested.

ANALYSIS.

	GRAINS PER U. S. WINE GAL.
Carbonate of lime	15.05
Carbonate of magnesia	.68
Sulphate of magnesia	20.64
Sulphate of lime	14.02
Alkaline chlorides	3.84
Alkaline sulphates	33.48
Oxides of iron and alumina	.06
Silica	.52
Total	88.29

Analyst and authority, Mr. G. M. Davidson, C. & N.-W. railway, April, 1895.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
23.	Unknown	50	50
22.	Sand	20	70
21.	Gravel, pebbles of northern drift and sand	25	95

*For information of this well we are indebted to Messrs. B. F. Philbrook and I. L. Pease. Samples of the drillings belonging to Messrs. L. G. Tyler and David Miers were loaned to the Survey.

	Thickness.	Depth.
20. Gravel, pebbles of northern drift at 150.		
19. Shale, drab, at 225	75	300
18. Shale, pink	92	392
17. Sandstone, grains varying widely in size and imperfectly rounded	8	400
16. Shale, dark drab	50	450
15. Shale, black, non-calcareous	30	480
14. Shale, pink and purplish	52	532
13. Limestone, white, soft, chalky, with gray-green shale	68	600
12. Limestone, white, hard, of finest grain	50	650
11. Limestone, light yellow-gray, cherty, samples at 650 and 703 feet	127	797
10. Limestone, gray, finely crystalline, fracture subconchoidal	23	820
9. Limestone, magnesian, or dolomite, samples at 820, 875 and 890 feet, brown and buff	150	970
8. Shale, light green-gray, calcareous, samples at 970 and 980	36	1,006
7. Limestone, magnesian, light yellow-gray, and shale, green, all in concreted powder	4	1,010
6. Limestone, highly argillaceous, yellow, in almost white powder, samples at 1,010, 1,050, 1,093, 1,184 and 1,241, with gray-green calcareous shale at 1,150 feet	285	1,295
5. Shale, bright green, non-calcareous	80	1,375
4. Dolomite, buff, pyritiferous, slightly arenaceous	25	1,400
3. Dolomite, buff, with much chert carrying disseminated crystals of pyrite, with a few grains of limpid quartz, some of which are rounded, and a little chalcedonic silica	117	1,517
2. Dolomite, highly arenaceous, or calciferous sandstone, grains varying in size, many coarse, imperfectly rounded	18	1,535
1. Dolomite, white, in fine powder, with arenaceous rounded grains, quartzy and cherty residue; at bottom of well at	...	1,535¾

SUMMARY.

On account of their lithological characteristics these strata may be referred to the following formations, not indeed with any certainty, but with a possibility resting on the agreement of all the indications at hand.

NOS.	FORMATION.	THICKNESS.	A. T.
20–23.	Pleistocene	---	---
14–19.	Cretaceous and Coal Measures	---	569
10–13.	Mississippian	288	281
8– 9.	Devonian	186	95
6– 7.	Silurian	289	–194
1– 5.	Ordovician, penetrated	241	–435

XXXIV. SABULA.*

Owner	Town.
Depth	973 feet.
Diameter	6 to 8 inches.
Elevation of curb A. T.	582 feet.
Head of water A. T.	656 feet.
Flow in gallons per minute	720.
Temperature	59° Fahr.

Water began to flow from this well, from the Saint Peter, at about 400 feet. The flow was reinforced at 525 feet from the upper Oneota, and at 700 feet from the lower Oneota. From these sources the discharge was about 350 gallons per minute. At 950 feet, in the Saint Croix, a still stronger vein was struck, and at the completion of the well the discharge measured, as stated, 720 gallons a minute—a magnificent fountain, unequaled by any in the state. The artesian pressure of thirty-two pounds is sufficient for water supply and fire protection in all parts of the village. Eight-inch casing reaches 163 feet to rock, and six-inch galvanized tubing extends to 173 feet, where it is packed with rubber packer. The well was begun by J. P. Miller & Co. in November, 1894, and finished by this firm in March, 1895.

ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica (SiO_2)	.174	3.000
Alumina (Al_2O_3) and Ferric oxide (Fe_2O_3)	.332	5.714
Lime (CaO)	4.350	75.000
Magnesia (MgO)	3.107	53.571
Potash (K_2O)	------	-------

*All the information with regard to the well at Sabula was collected and placed at the disposal of the Survey, together with a series of samples of the drillings by Mr. W. R. Oake, then mayor of the town.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Soda (Na_2O)	1.127	19.428
Chlorine (Cl)	Trace.	Trace.
Sulphur trioxide (SO_3)	.994	17.143
Carbon dioxide (CO_2)	10.158	175.143
Water in combination (H_2O)	1.284	22.143

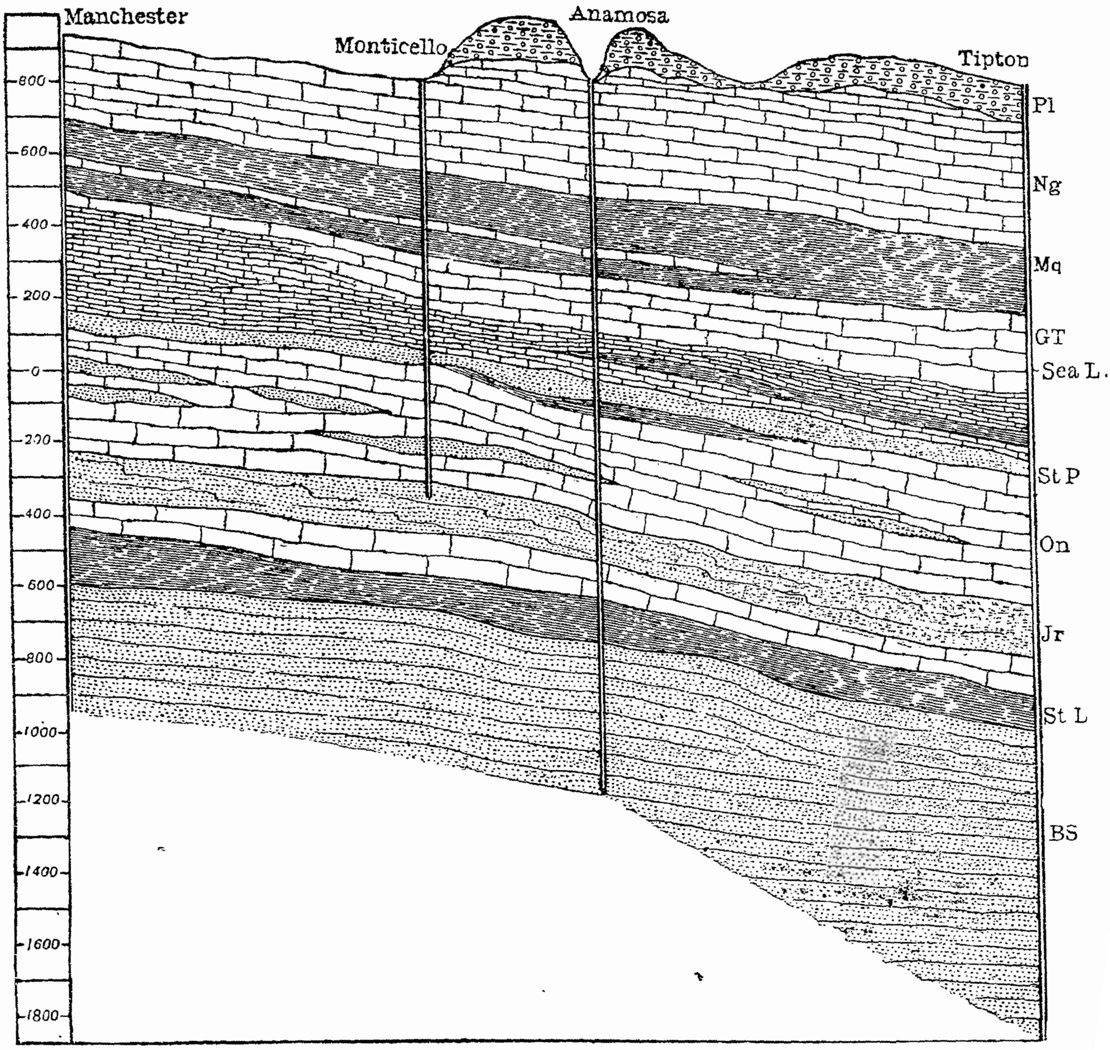
UNITED AS FOLLOWS

Calcium carbonate ($CaCO_3$)	7.764	133.857
Magnesium carbonate ($MgCO_3$)	.522	9.000
Magnesium bicarbonate ($MgH_2(CO_3)_2$)	10.374	178.857
Sodium carbonate (Na_2CO_3)	.605	10.428
Sodium sulphate (Na_2SO_4)	1.756	30.286
Potassium chloride (K Cl)	------	------
Alumina (Al_2O_3) and Ferric oxide	.331	5.714
Silica (SiO_2)	.174	3.000
Solids	21.526	371.142

Analyst, Prof. J. B. Weems, Ames, Iowa Date, April 12, 1896.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
16.	Sand, alluvial	163	163
15.	Dolomite, hard, rough, crystalline, buff and gray, some vesicular, ten samples	212	375
14.	Sandstone, argillo-calcareous; drillings consist of light green-gray powder, with fragments of dark gray sandstone, calciferous, grains not so well rounded and uniform in size as is common with the Saint Peter	25	400
13.	Shale, green, fissile, arenaceous, slightly calcareous	25	425
12.	Sandstone, grains moderately fine, rounded and ground; a large proportion of drillings consist of angular chips of gray dolomite; much green shale is also present, probably from the superior shale	25	450
11.	Dolomite, medium dark gray, in angular fragments, clean except for a few pieces of green shale	15	465
10.	Sandstone, light to yellow-gray, highly calciferous, or dolomite highly arenaceous; drillings consist of rounded grains of quartz and minute angular fragments of dolomite, in some of the larger of which quartz sand is seen imbedded	10	475



Pl, Pleistocene. GT, Galena-Trenton. Jr, Jordan.
Ng, Niagara. St P. Saint Peter. St L, Saint Lawrence.
Mq, Maquoketa. On, Oneota. BS, Basal Sandstone.

Scale: Horizontal 10 miles; Vertical 500 feet

GEOLOGICAL SECTION FROM MANCHESTER TO TIPTON.

9.	Dolomite, gray and light brown; drillings contain sand probably from above, two samples	35	510
8.	Dolomite, light brown, arenaceous	15	525
7.	Dolomite, gray and buff, three samples	50	575
6.	Sandstone, argillaceous and calciferous	25	600
5.	Chert, in fine white powder, calciferous, two samples	50	650
4.	Dolomite, gray, cherty	90	740
3.	Dolomite, white, highly arenaceous and cherty	10	750
2.	Dolomite, white, cherty, slightly arenaceous	25	775
1.	Sandstone, white, calciferous, cherty, grains of sand mostly fragmental but many rounded, three samples	35	810

NOTES AND SUMMARY.

The curb is not far below the horizon of the base of the Niagara, in whose massive dolomite the river gorge is here cut to a depth of nearly 200 feet. No. 16 of the above record, therefore, represents a preglacial channel of the Mississippi, excavated in the Maquoketa and in the upper strata of the Galena-Trenton. Below 810 feet no samples were saved on account of the strong flow.

NOS.	FORMATION	THICKNESS.	DEPTH.
16.	Alluvial filling of ancient river channel	163	419
15.	Galena-Trenton	212	207
12–14.	Saint Peter	75	132
7–11.	Upper Oneota	125	7
6.	New Richmond	25	–18
2– 5.	Lower Oneota	175	–193
1.	Saint Croix, penetrated	198	–391

XXXV. TIPTON.*

Owner	Town
Depth	2,696½ feet.
Elevation of curb A. T.	810 feet.
Head of water A T.	745 feet.
Diameter, reported	8 inches.
Temperature	57° Fahr.

The supply is large. It is said that the water cannot be lowered by the largest pump that can be used. It certainly

*Reported by W. H. Treichler. We are indebted also to Rev. Dr. Charles Gould, Capt. John Moffit and others.

is far in excess of the consumption, which in 1890 was 5,000 gallons per day. It is a matter of regret that the water of this interesting well, one of the deepest in the United States, has never been analyzed. The quality for drinking purposes is reported as good. By the use of heaters scale in boilers is said to be prevented. "The water appears to change; at times it is comparatively soft and again it becomes hard," a phenomenon probably due to the exhaustion by pumping of some vein of moderate yield but under strong pressure.

RECORD OF STRATA.

The following summary is published with some changes from the author's paper on the thickness of the Paleozoic formations of eastern Iowa, in which the different specimens of the drillings are fully described.

FORMATION.	THICKNESS.	DEPTH.	A. T.
Pleistocene	125	125	685
Silurian (Niagara)	325	450	360
Maquoketa	195	645	165
Unknown	100	745	65
Galena	60	805	5
Galena-Trenton	225	1,030	-220
Saint Peter	55	1,085	-275
Oneota	377	1,462	-652
Jordan	154	1,616	-806
Saint Lawrence	186	1,802	-992
Basal sandstone	894½	2,696½	-1,886½

XXXVI. ANAMOSA.*

Owner	State Penitentiary.
Depth	2,007 feet.
Elevation of curb A. T.†	816 feet.
Head of water A. T.	760 feet.
Capacity in gallons per minute	300.

This well was drilled by J. P. Miller & Co. in ninety-nine days, beginning January 9, 1896, an average of over twenty

*The facts concerning this well are furnished by the officials of the penitentiary and the foreman in charge of the drillings. Samples were contributed by Mr John Archibald of the institution.

†The well curb is thirteen feet lower than the grade at the Chicago, Milwaukee & St. Paul railway station, according to levels made under the supervision of Mr. C. M. Brown The elevation of the station is given by Gannet at 930 A. T. That this is incorrect was first suspected in platting the geological section from Manchester to Tipton, on account of the abnormal dip of the strata. The Chicago, Milwaukee & St. Paul Railway Co.'s profiles were then obtained, showing the true elevation of the station to be 829 A. T.

feet per day. The boring is 10 inches in diameter for 96 feet, 8 inches to 290 feet, 6 inches to 997 feet, and 5 inches to 2,007 feet. Ten-inch casing is driven into rock at the bottom of the ten-inch bore, and the well is also cased between 820 feet and 997 feet. At the first sandstone at 860 feet, the water, which so far had stood thirty feet below the curb, sank to fifty-six feet below the same datum. In the lower Oneota, between 1,070 and 1,215 feet, strong flows washed all drillings away.

As the deep pumps are not yet in, no water can be obtained for analysis. It is to the taste an excellent drinking water, and its introduction will certainly improve the health and lower the death rate in the institution.

RECORD OF STRATA.

		THICKNESS.	A. T.
41.	"Clay, yellow"	30	30
40.	"Clay and sand"	46	76
39.	"Quicksand"	2	78
38.	Dolomite, light bluish-gray, crystalline, vesicular, five samples; at 145 feet, dark brown-gray and more compact	137	215
37.	Dolomite, as above, cherty	20	235
36.	Dolomite, light grey, crystalline, two samples	30	265
35.	Dolomite, cream colored and buff, cherty, four samples	60	325
34.	Dolomite, gray, in flaky chips, argillaceous, lustre earthy, with some chert, two samples	30	355
33.	Dolomite, blue-gray, highly argillaceous	5	360
32.	Shale, green-gray, slightly calcareous, four samples	130	490
31.	Dolomite, brown, somewhat bituminous, blackens in closed tube	10	500
30.	Shale, in moulded masses, two samples	35	535
29.	Dolomite, buff and gray, hard, rough, crystalline, ten samples; at 675 feet, cherty	205	740
28.	Limestone, magnesian, blue-gray, granular, crystalline, two samples	30	770
27.	Shale, blue; and dark brown, bituminous	30	800

		THICKNESS.	A. T.
26.	Limestone, magnesian, or dolomite, buff-gray, fine-grained, crystalline; samples at 800 and 820 feet; in the latter sample are found fragments of magnesian limestone which may extend from that depth to 852 feet	52	852
25.	"Shale," no sample	8	860
24.	Sandstone, clean white quartz, sand rounded and ground, moderately fine	55	915
23.	Shale, green, non-calcareous, finely laminated, containing some rounded grains of quartz*	40	955
22.	Dolomite, light yellow-gray	15	970
21.	Shale, in large fragments, non-calcareous, green, finely laminated	20	990
20.	Dolomite, gray and white, five samples	260	1,250
19.	Sandstone, light blue-gray, calciferous	55	1,305
18.	Sandstone, clean white, grains rounded	20	1,325
17.	Sandstone, white, calciferous	20	1,345
16.	Dolomite, yellow-gray, rough	35	1,380
15.	Dolomite, cream-yellow, with rounded grains of quartz in drillings, two samples	35	1,415
14.	Dolomite, from white to brown	75	1,485
13.	Sandstone, red, argillaceous and calcareous, of microscopic grain, with green grains like glauconite	5	1,490
12.	Shale, light green-gray, but slightly calcareous	50	1,540
11.	Dolomite, fragments mottled pink and gray	40	1,580
10.	Sandstone, cream-yellow, buff and white, fine-grained, four samples; softest sandstone in well by driller's log	180	1,760
9.	Shale, green, fissile	10	1,770
8.	Sandstone, buff, very fine, glauconiferous, three samples	45	1,815
7.	Sandstone, brick red, very fine-grained, argillo-calcareous, glauconiferous	40	1,855
6.	Sandstone, as above, but very slightly calciferous	20	1,875
5.	Sandstone, gray and buff, fine, argillo-calcareous at 1,890, three samples	20	1,895

*The exceptional thickness assigned to these shales is supported by the driller's record that the worst "cave-rock" of the well was from 920 to 990 feet.

		THICKNESS.	A. T.
4.	Sandstone, coarser, with green shale	5	1,900
3.	Sandstone, gray, moderately fine grains, angular, hard	50	1,950
2.	Sandstone, white, rounded unbroken grains, soft	45	1,995
1.	Sandstone, light pink, sample of rounded grain mostly unbroken, hard, two and one-half hours to drill five feet, sample not a quartzite	12	2,007

SUMMARY.

NOS.	FORMATION.	THICKNESS.	A. T.
39–41.	Pleistocene	78	738
33–38.	Niagara	282	456
30–32.	Maquoketa	175	281
25–29.	Trenton	325	–44
24.	Saint Peter	55	–99
20–23	Oneota	335	–434
17–19.	Jordan	95	–529
11–16.	Saint Lawrence	235	–764
1–13.	Basal sandstone	427	–1,191

XXXVII. MONTICELLO.*

Owner	Town.
Depth	1,198
Elevation of curb A. T.	820
Head of water A. T.	780

This well is one of the pioneer artesians of the state, having been drilled in 1875. About 200 gallons per minute could be pumped at first. In 1893, on account of the insufficiency of the supply from the well, a new well was drilled 120 feet deep and connected with the pumps. Two hundred and fifty gallons per minute can be pumped from the dual supply without lowering the water. The average amount pumped is about 175 gallons per minute and thirty or forty hours pumping per week suffices for the needs of the town. The water of the artesian is one of the best in Iowa, as shown by the following analysis.

*For information respecting this well we are indebted to Rev. E. G. Waite. Messrs. O. R. Ricker and Robert Earhart, Jr., and especially to the generosity of Mr. George W. Lovell, who was largely concerned in putting down the well and who contributed a set of samples of the drillings.

ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\ O_2$)	1.334	23 000
Alumina ($Al_2\ O_3$) and Ferric oxide ($Fe_2\ O_3$)	1.467	25.286
Lime ($Ca\ O$)	7.946	137.000
Magnesia ($Mg\ O$)	.439	7.571
Soda ($Na_2\ O$)	3.033	52.286
Chlorine (Cl)	.340	5.857
Sulphur trioxide ($S\ O_3$)	.804	13.857
Carbon dioxide ($C\ O_2$)	10.498	181.000
Water in combination ($H_2\ O$)	.952	16.429

UNITED AS FOLLOWS.

Calcium carbonate ($Ca\ Co_3$)	10.059	173.429
Calcium bicarbonate ($Ca\ H_2(Co_3)_2$)	6.711	115.714
Magnesium bicarbonate ($Mg\ H_2\ (Co_3)_2$)	1.591	27.428
Sodium carbonate ($Na_2\ Co_3$)	3.596	62.000
Sodium sulphate ($Na_2\ So_4$)	1.425	24.572
Sodium chloride ($Na\ Cl$)	.555	9.571
Alumina ($Al_2\ O_3$) and Ferric oxide	1.467	25.286
Silica ($Si\ O_2$)	1.334	23.000
Oxygen replaced by Chlorine (O)	.075	1.286
Solids	26.813	462.286

Analyst, Prof. J. B. Weems. Date, July 26, 1896.

GEOLOGICAL SECTION.*

FORMATION.	THICKNESS, FEET.	A. T. FEET.
Pleistocene	85	735
Niagara	180	555
Maquoketa	195	360
Trenton	315	45
Saint Peter	25	20
Oneota	340	-320
Jordan	58	-378

XXXVIII. VINTON.†

Description of the drillings of well No. 1 and record of well No. 2 will be found in the author's report (Iowa Geol. Surv., vol. III, pp. 192–195).

* Drillings are described in full in author's report (Iowa Geol. Surv., vol. III, pp. 202-203).

† For information respecting these two wells we are indebted to Mr. G. B. Hayes, Dr. A. R. Fellows and the late Rev. J. W. Clinton.

	NO. 1.	NO. 2.
Owner	Town.	Town.
Depth	1,287 feet.	1,425 feet.
Diameter	6 inches.	6 inches.
Elevation of curb A. T.	780 feet.	780 feet.
Head of water A. T.	808½ feet.	808½ feet.
Flow in gallons per minute	62.	50.
Temperature	56° Fahr.	56° Fahr.
Date of completion	1889.	1892.

Drillers, W. N. Casey & Son, A. K. Wallen.

These two wells form the supply of the water works of the town and are thus used by about one-third of its inhabitants. They have shown no change in their flow from the first. Casing in each extends to 620 feet, packed in No. 2, with a lead sleeve at bottom. At 125 feet a sulphurous water was struck, which rose to eight feet from the surface. This is from the horizon of the Independence shale, which is highly pyritiferous. The excellent supply was found in the Saint Peter and underlying sandstones.

ANALYSIS.

	GRAINS IN U. S GALLON
Calcium carbonate	6.940
Magnesian carbonate	4.827
Calcium sulphate	5.7[illegible]6
Sodium sulphate	8.605
Sodium chloride	.128
Silica	.349
Oxide of iron and alumina	1.401
Total solids	27.996

GEOLOGICAL SECTION OF WELL NO. 1.

FORMATION.	THICKNESS, FEET.	A T. FEET.
Pleistocene and Recent	115	665
Devonian (Wapsipinicon)	20	645
Niagara	215	430
Maquoketa	269	161
Trenton	401	-240
Saint Peter	55	-295
Upper Oneota	210	-505
New Richmond penetrated	2	-507

IV. THE DAVENPORT-DES MOINES SECTION.

In this section, as in the one from Clinton to Dunlap, there is exhibited a gentle anticline at the east, the crest trending from northwest to southeast. To the south it connects with an anticline of Ordovician strata extending from east of Washington to Keokuk. From Homestead to Des Moines, a distance of ninety miles, the summit of the Maquoketa and that of the Saint Peter each seems to descend nearly 700 feet, a dip of about seven and one-half feet to the mile. This dip is increased by the fact that Des Moines lies thirteen miles south of the latitude of Homestead, and doubt is cast upon its exactness by the lack of accuracy of the Homestead record. From Grinnell to Des Moines the dip of the summit of the Maquoketa is over eleven feet to the mile. Measures of the southward dip from the Clinton-Dunlap section are obtained on the Maquoketa shale of nearly eleven and a half feet to the mile from Boone to Des Moines, and of six and one-third feet to the mile from Vinton to Homestead. The dips of the Saint Peter between these stations are about the same as those of the Maquoketa, except from Vinton to Homestead, where it is only six feet to the mile.

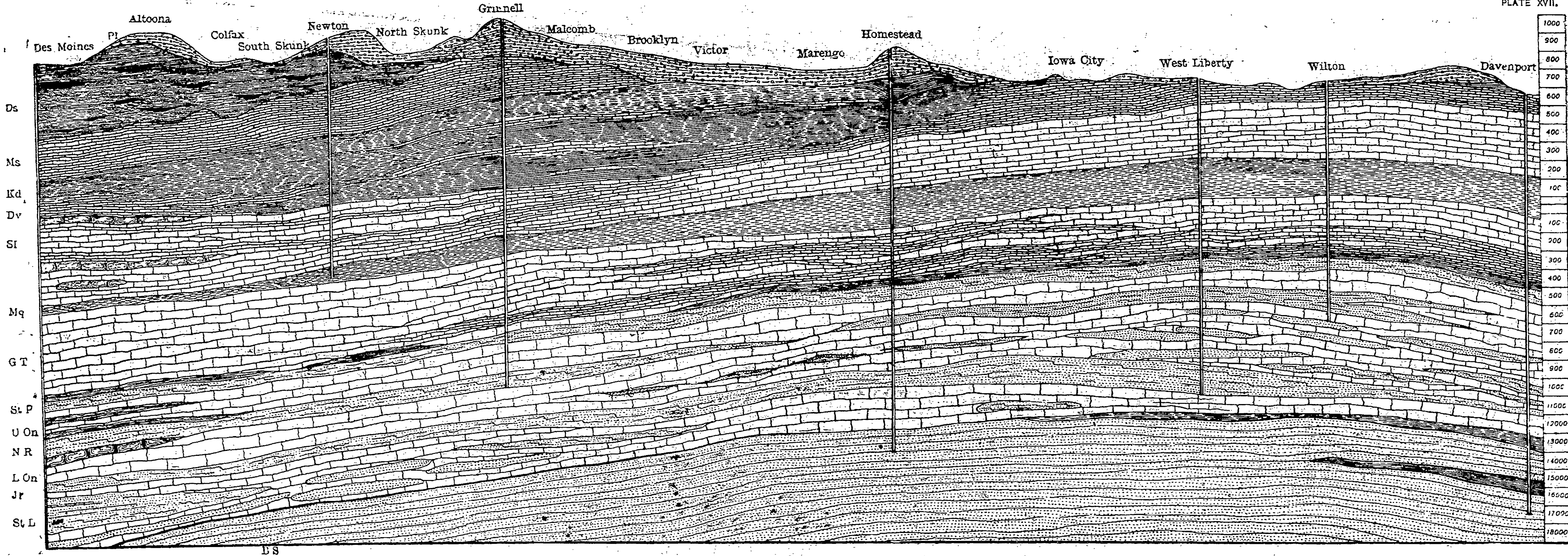
CARBONIFEROUS.

The section graphically presents the attitude of the Coal Measures in Central Iowa. The Western coal field extends eastward nearly to Grinnell; the Central coal field extends from Illinois to Davenport, and the lie of the land shows how readily both may have met and joined in such outliers as those near Homestead and Iowa City.

No attempt is made to subdivide the Mississippian above the Kinderhook. At Des Moines, if the section is rightly interpreted, the heavy limestones of the series have disappeared, leaving for the most part cherty shales.

DEVONIAN.

The Devonian is exposed nearly to its basal strata on the Mississippi river at Davenport, where calcareous shales



Pl, Pleistocene.
Ds, Des Moines.
Ms, Mississippian.

Kd, Kinderhook.
Dv, Devonian.
Sl, Silurian.

Mq, Maquoketa.
GT, Galena-Trenton.
St P, Saint Peter.

U On, Upper Oneota.
N R, New Richmond.
L On, Lower Oneota.

Jr, Jordan.
St L, Saint Lawrence.
B S, Basal Sandstone.

Scale: Vertical 500 feet; Horizontal 10 miles

GEOLOGICAL SECTION ALONG CHICAGO, ROCK ISLAND & PACIFIC RAILWAY FROM DAVENPORT TO DES MOINES.

characteristic of the Cedar Valley stage rest upon limestones of the Wapsipinicon stage. Of these, the upper Davenport and the lower Davenport extend downward to the level of low water.* Beneath this level one may expect the Independence shale and the Otis limestone. Shales doubtfully referred to the Independence were disclosed in one boring. The Devonian probably extends about forty-five feet below low water in the Mississippi, a dimension about two-thirds of the thickness of the Independence and Otis in Linn county. The exceptional width of the Devonian outcrop west of Davenport is due largely to the low anticline already referred to. To the westward the Devonian seems to pass rapidly into shales which cannot be separated from the Kinderhook except by arbitrary divisions. At Grinnell this great body of shale is about 500 feet thick, and the division made rests on slight grounds of stratigraphic probability only. The probabilities in its favor will best be seen if the sections crossing Grinnell from Manchester and Marshalltown are compared with Plate XVII. In the Manchester-Grinnell section, especially, the control is apparent which is exercised by the accepted areal distribution of the Mississippian and Devonian.

SILURIAN.

The Silurian preserves the usual characteristics of the Niagara dolomite as far west at least as Homestead. At Grinnell less than fifty feet assigned to the series is dolomite, but much of the remainder is cherty. At Des Moines there rest upon the Maquoketa fifty-five feet of buff cherty dolomite. To this succeed twenty-two feet of cherty and arenaceous limestone, and to this some 430 feet of limestone, in part cherty and magnesian, but whose special characteristic is the presence at several horizons of more or less gypsum. No other method of division offering itself, the gypsum beds are all included in one formation, and that referred to the Silurian, the only Paleozoic series in Iowa known to contain

*Proc. Iowa Acad. Sci., pt. IV, pp. 22-24.

gypsum in association with limestone. The thickness thus given to the Silurian is in excess of that expected, but it presents no serious stratigraphic difficulty. Together with the Silurian, the Trenton thickens to the westward, and, notwithstanding the related thinning of the Maquoketa, the effect is to nearly fill level the Des Moines trough from Grinnell westward.

MAQUOKETA.

The western attenuation of the Maquoketa gives it a thickness of but thirty-three feet at Des Moines. Beyond the constant uncertainty of our records, the only doubt attaching to the placing of this shale in the section is concerned with the shale at Grinnell at 1,260 feet. If this is Maquoketa, the limestone above represents the intermediate dolomite so frequently seen on the other sections, but elsewhere absent from this.

TRENTON.

The Galena-Trenton gradually increases in thickness towards Des Moines, until at that station it reaches its maximum in Iowa—unless it be at Calmar—a thickness of 508 feet. At Davenport the Galena is distinguished. At Homestead three samples only are furnished, all of lower Trenton type, and one of these is from near the top, where Galena dolomite would be expected. At Grinnell the non-magnesian limestones of the Trenton have nearly disappeared and at Des Moines the entire formation consists of dolomites and shales. Curiously the thin band of highly fossiliferous green shale near the base of the Trenton, noted at Manchester and Ames, recurs at Grinnell and at Des Moines.

THE MAGNESIAN SERIES AND THE BASAL SANDSTONE.

One or both of these terranes are deeply penetrated by four wells on the line of this section, but unfortunately we have a complete set of samples of rocks from but one, the Greenwood Park well at Des Moines. At Davenport the record permits no division of the magnesian series. At West Liberty and

Homestead the New Richmond and Jordan sandstones are fairly well defined. The resemblance of the grains of the New Richmond at West Liberty in their secondary crystalline enlargements, to those of the same horizon in Allamakee county noted by Calvin* is striking, even though accidental. It is possible that the Jordan at Homestead and West Liberty is continuous with the sandstone below -1,400 feet A. T. at Davenport, but more probably they belong above -1,300 feet A. T. at the latter station but are not mentioned in the drillers' records. From West Liberty to Des Moines the Upper Oneota maintains a thickness of from 100 to nearly 200 feet, and at the latter point is noticeably shaly. The Lower Oneota is highly arenaceous at West Liberty. At Homestead it appears to be nearly 300 feet thick. Its lower limit is drawn with great difficulty at Des Moines. The main body of 175 feet of uninterrupted dolomite ends at -1,546 A. T. and this is here taken as the lower limit of the Oneota. Beneath this occur thin beds of interstratified sandstones, shales and dolomites ending at -1,608 A. T. in thirty feet of arenaceous dolomite, and we should have few objections to extending it to this depth. This is practically the limit of the dolomites of the section. From the New Richmond downward, no saccharoidal sandstone occurs at Des Moines, until the depth of -1,878 A. T. is reached. This sandstone, 130 feet thick, may perhaps represent the Jordan, but it seems best, on the whole, to place it with the Basal sandstone, leaving 332 feet above it to the undifferentiated Saint Croix. At Davenport the Basal sandstone was penetrated nearly 400 feet, at Des Moines 250 feet. The distance to the Algonkian at either point cannot be conjectured.

Artesian Conditions.

The conditions governing the artesian supply along this section are practically the same as in the section from Clinton to Boone. Small flows valuable for medicinal purposes occasionally may be secured from the Mississippian. The

*Iowa Geol. Surv., vol. IV., p. 63.

Niagara and Galena-Trenton may yield a larger quantity which exceptionally may prove sufficient for town supply. Apart from the immediate vicinity of the Mississippi valley, the Saint Peter can not be depended upon to furnish a sufficient yield, and recourse should be had to the Oneota and Jordan. East of Grinnell these will yield generously, but toward Des Moines the sandstones below the Saint Peter largely lose their open texture. The Basal sandstone is found at such depths over much of the section that the expense of reaching it must be considered. The chemical analyses of the artesian waters along this section show that west of Wilton artesian water will not be found carrying in solution less than from sixty to one hundred grains of solids to the gallon, and the mineralization may be still greater if all waters above the Saint Peter are not excluded.

XXXIX. DAVENPORT.*

OWNER.	Depth.	Diameter in inches.	Elevation of curbs A. T.	Original head A. T.	Present head A. T.	Original discharge.*	Present discharge.*	Water horizons A. T.	Temperature	Date of completion.	Driller.†
Witts' Bottling Works	780	....	575	657	634	300	....	....	....	1891	...
Woolen Mills	1053	3½	564	651	....	....	....	479 ft.; −136 ft.; n'rbot'm	....	1890	2
Crystal Ice Co	1067	6 −4	590	605	602	250	240	−10 ft. and St. Peter.	60° F	1893	2
Malt and Grain Co	1076	5	592	627 631	602 607	....	....	−108 ft.; −464 to −474.	....	1892	2
Kimball House	1100§	8 − 4	579	637	599	....	....	−131 ft., and St. Peter.	....	....	2
Tri-City Packing and Provision Co.	1100	8 − 5	564	610	610	250	250	−236 to bottom.	....	1893	1
Gas company, two wells	1200	5 − 4	564	612	612	....	....	....	....	1891	2
Schmidt building	1200	4	576	600 606	....	45 28	....	....	....	1892	2
City park	1797	....	704	682	670	‡125	....	....	....	1888	1
Glucose Manufacturing Co	1500	5	562	....	620	....	230	....	60° F	1880?	...
Glucose Manufacturing Co	2101 2105 2107	5	562	....	643	....	380 400 400	....	64° F	.... 1889 1892	1

*In gallons per minute. †1, J. P. Miller & Co.; 2, A. K. Wallen. ‡By pumping. § Approximately.

In number of artesian wells Davenport slightly outranks any other town in the state. The exploitation of the field is

* Few local artesian basins of the United States have been so thoroughly studied as has the district of Davenport, Moline and Rock Island by Prof. J. A. Udden, of the latter town. Professor Udden's paper will soon appear in the Seventeenth Annual Report of the United States Geological Survey, and he very generously placed in our hands the notes upon which his manuscript is based. We are also indebted to the owners of several wells for information and to Mr. A. S. Tiffany, F. G. S. A., who loaned his sets of drillings from the Kimball house and the city park wells.

comparatively recent. Nine of the fourteen wells were drilled during the present decade. This extension of the use of artesian water has taken place in the face of the fact that the city water supply, drawn from the Mississippi river, passes through one of the largest mechanical or rapid filtering plants in the United States. The preference for artesian water on the part of large consumers is probably due in part, in the majority of instances, to its relative cheapness. In one instance a well was put down simply "to bring the water company to terms."

The first flow of the wells of this district rises from about 479 feet A. T., near the base of the Devonian. This may represent the natural springs which rise from the Independence shale in other counties, and indeed the shale near this level of the Kimball house record, preserved by the Davenport Academy of Science, may be the Independence rather than a cavern filling as held by Udden. The water is corrosive in quality and insignificant in quantity. A second flow is obtained in the Galena limestone, at depths from -108 A. T. to -242 A. T. This is the so-called "upper water," and is impregnated with sulphureted hydrogen. To enjoy the characteristic taste and odor of the gas, the water must be taken immediately from the well. Aeration and relief from pressure permit an escape of the gas so rapid and so complete that chemists rarely find traces of its presence in samples sent to their laboratories for analysis. The water is usually separated by tubing from the lower flows. The yield is generous, amounting in the Witts' well to 300 gallons a minute, and at Carbon Cliff, Ill., to 400 gallons. At Davenport the head is reported somewhat lower (less than ten feet) than that of the water from the Saint Peter. At Carbon Cliff the reported pressure equals a head of 684 feet A. T.

The third water horizon lies in the Saint Peter sandstone, whose depth is variously reported in different wells at from -376 feet A. T. for the summit to -577 feet A. T. for the base. This flow has furnished so far most of the discharge of the

Davenport basin. Other flows unspecified in the extant records, occur in the Oneota and the sandstones of the Saint Croix, and under greater pressure and with heavier discharge if we may judge from the wells at the city park and the glucose factory.

ANALYSES.

The following analyses indicate the qualities of the waters from their different horizons, excepting that from near the base of the Devonian. The first of the Witts' well is from the Galena. The second, of the Crystal Ice Co.'s, is from the Saint Peter only, all upper waters being shut off by tubing 1,067 feet in depth. The analyses from the glucose factory well probably represent admixtures with the deeper waters below the Saint Peter.

WITTS' BOTTLING WORKS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium carbonate	2.1480	36.80
Magnesium carbonate	1.6034	27.47
Iron carbonate	.4488	7.69
Sodium carbonate	16.4457	281.75
Sodium sulphate	23.4069	401.01
Sodium chloride	26.1753	448.40
Silica	.4377	7.50
Total	70.6658	1212.50

Analyst, E T. Burghausen, chemical works, Cincinnati. Authority, J. A. Udden.

CRYSTAL ICE AND COLD STORAGE CO.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\ O_2$)	.497	8.571
Alumina ($Al_2\ O_3$) Ferric oxide ($Fe_2\ O_3$)	.182	3.143
Lime ($Ca\ O$)	1.624	28.000
Magnesia ($Mg\ O$)	.530	9.143
Potash ($K_2\ O$)	------	------
Soda ($Na_2\ O$)	31.834	548.857
Chlorine (Cl)	15.859	273.429
Sulphur trioxide ($S\ O_3$)	13.282	229.000
Carbon dioxide ($C\ O_2$)	9.139	157.571
Water in combination ($H_2\ O$)	.829	14.286
Free (CO_2)	[1.110]	[19.143]

UNITED AS FOLLOWS.

	GRAINS PER U. S GALLON.	PARTS PER MILLION.
Calcium bicarbonate ($Ca H_2 (CO_3)_2$)	4.690	80.857
Magnesium bicarbonate ($Mg H_2 (CO_3)_2$)	1.922	33.143
Ferrous bicarbonate ($Fe H_2 (CO_3)_2$)	.406	7.000
Sodium carbonate ($Na CO_3$)	12.677	218.571
Sodium sulphate ($Na_2 SO_4$)	23.705	408.714
Potassium chloride ($K Cl$)	------	------
Sodium chloride ($Na Cl$)	26.266	452.857
Alumina ($Al_2 O_3$)	Trace.	Trace.
Silica ($Si O_2$)	.497	8.571
Oxygen replaced by chlorine (O)	3.613	62.287
Solids	73.776	1272.000

Analyst, Dr J. B. Weems, May 27, 1896.

The waters of the Wagner Brewery well at Rock Island, Ill., the Paper Mill well at Moline, 1,628 feet deep, and of the East Moline well, 1,340 feet deep, are similar in chemical composition to those of the Witts' well and the Crystal Ice Co.'s. If the "upper water" is not mixed with the lower in all these wells (excepting, of course, Witts'), this marked similarity, closely approaching in some instances practical identity, strongly suggests that the upper water from the crevices of the Galena really rises from the horizon of the Saint Peter or even from still lower veins, and this assumption is reinforced by the volume and head of the Galena water. On the other hand, the presence of sulphureted hydrogen in the upper water supports the assumption that it is native to the Galena.

GLUCOSE FACTORY (WELL UNKNOWN).

COMPOUNDS.	GRAINS IN U. S. GALLON.
Calcium bicarbonate	5.132
Magesium bicarbonate	4.770
Calcium sulphate	5.540
Sodium sulphate	16.096
Sodium chloride	28.080
Alumina	0.361
Silica and unsoluble residue	0.216
Total	60 195

Analyst, Chemist of Co. (?). Authority, D. W. Mead, Hydrogeology of Illinois. Table X.

GLUCOSE FACTORY (WELL UNKNOWN).

COMPOUNDS.	PARTS PER MILLION.
Calcium carbonate	202.0
Magnesium carbonate	110.0
Sodium carbonate	7.0
Sodium sulphate	364.0
Sodium chloride	833.0
Insoluble	226.0
Total	1,742.0

Analyst, E. Guteman, Davenport. Authority, J. A. Udden.

PERMANENCE OF THE PRESENT SUPPLY.

The original head of the earlier wells, from 1,000 to 1,200 feet deep, is exemplified in that of the Kimball House and of the Woolen Mills wells—a head of from 637 to 651 feet A. T. The wells drilled in 1891 and 1892 show no original head higher than 631 feet, and in two wells the head was only 60 and 612 feet A. T. From 1893 to 1895 the water rose in new wells of this depth to from 606 to 615 feet A. T. In old wells it is impossible to state how much of the loss of pressure is due to leakage from various causes. The well at the woolen mill, for example, lost sixty-two feet of head in the first three years after it was drilled. About 300 feet of casing was then taken out, much corroded and in places perforated. When new tubing to that depth was adjusted, the water rose to a tank ten feet higher than the head before repairs were made. How much higher it would rise was not tested. That any overdraft is local, is shown by the fact that in 1894 the village well at Milan, three miles south of Rock Island, headed at 635 feet A. T. In Davenport, at least the deeper wells, from 1,800 to 2,100 feet deep, maintain nearly their original pressures.

In summation, we may say that the supply available to wells less than 1,200 feet deep is being overdrawn. All wells should be kept in thorough repair. Any considerable increase in the number of the wells in the district will probably make pumping necessary in all the wells of this depth. But the larger reservoirs below the Saint Peter show little or no signs of exhaustion, and the limit of their supply may be far from being reached.

GEOLOGICAL SECTION.

The first attempt to interpret the relations of the deeper strata at Davenport was made by Mr. A. S. Tiffany.* This was based upon samples obtained by him from the well at the city park. As an illustration of the pains sometimes needful to secure these valuable data, it may be said that Mr. Tiffany made fifty trips to the well, involving some 300 miles of travel. Abridged and slightly rearranged, and the elevations A. T. being added, Mr. Tiffany's section is as follows.

FORMATION.	THICKNESS.	DEPTH.	ELEVATION A. T.
Drift	100	100	604
Coal Measures	30	130	574
Corniferous	390	520	184
Lower Helderberg (Le Claire)	80	600	104
Niagara	175	775	-71
Cincinnati and Trenton	300	1,075	-371
Saint Peter, Calciferous	100	1,175	-471
Other groups, Calciferous	622	1,797	-1,093

The samples from this well and from that at the Kimball house were kindly placed by Mr. Tiffany at the service of the writer and have been described by him in detail.* It was found impracticable to reconcile the records of the two wells, and a large part of each section was left undetermined as to the age of the strata. For example, the horizon of the Maquoketa shale, although 242 feet thick at the Kimball house well, was represented in the samples of the Park well only by several samples of non-argillaceous dolomite. The presence of interbedded layers of dolomite in the Maquoketa is not strange, but the absence of any shale, or record of shale, is singular. The following was the author's section based upon these data.

* American Geologist, vol. III, pp. 117-118.

* Iowa Geol. Surv., vol. III, pp. 200-202.

FORMATION.	THICKNESS.	ELEVATION A. T.
Pleistocene or recent	13	566
Devonian	115	451
Upper Silurian	320	131
Maquoketa	242	-111
Galena-Trenton	425	-536
Saint Peter sandstone	90	-626

Thus the great body of the strata referred by Tiffany to the Corniferous was placed with the Niagara, the base of the Devonian being lifted 267 feet.

Since the publication of the author's paper, Prof. J. A. Udden, of Rock Island, has collected and most skillfully collated a large amount of data from the three adjoining cities, including some well records and series of drillings from the Illinois towns that are specially complete and reliable. The general geological section which he has constructed from these must be a close approximation to the fact.

	FORMATION.	THICKNESS.	ELEVATION A. T.
14.	Devonian	55	500
13.	Niagara	340	160
12.	Maquoketa	223	-63
11.	Galena	244	-307
10.	Trenton	100	-407
9.	Shale	41	-448
8.	Sandstone	76	-524
7.	Shale	66	-590
6.	Lower magnesian	800	-1,390
5.	Sandy shale	35	-1,427
4.	Arenaceous limestone	27	-1,452
3.	Sandstone	145	-1,597
2.	Calcareous shale	75	-1,672
1.	Sandstone	97	-1,769

Nos. 1-5 are referred by Professor Udden to the Potsdam and Nos. 7-9 are included in the Saint Peter.

After a close examination of all the facts in the case, involving the conflicting records of about a dozen wells, we find few changes to suggest, and these in points of minor detail. We should incline to place the base of the Devonian at about 475 A. T., relying upon the recorded samples of the Kimball House well, and other data, and would follow these same sources of information and the records of the Davenport Academy of Science in placing the limits of the Maquoketa at 131 A. T. and -109 A. T. The records of the Saint Peter are singularly conflicting. The reported top of this sandstone varies from -376 A. T. to -485 A. T., and its base from -456 A. T. to -577 A. T. It will be noted that while we limit the Saint Peter to the sandstone, Professor Udden joins with it the shales immediately below and above, which we have allotted to the Trenton and to the Upper Oneota. Below the Saint Peter the section rests upon the records of three wells.

GLUCOSE FACTORY, DAVENPORT, 562 A. T.

STRATA.	THICKNESS.	DEPTH.	A. T.
Surface material	52	52	510
Limestone, bluish	---	410	152
Shale	---	635	- 73
Limestone	---	970	-408
Shale	30	1,000	-438
Sandstone, Saint Peter	42	1,042	- 480
Limestone, sandy	530	1,572	-1,010
No record	258	1,830	-1,268
Shale	40	1,870	-1,308
Limestone, sandy	20	1,890	-1,328
Sandy rock	160	2,050	-1,488
Shale	50	2,100	-1,538

MOLINE PAPER CO, 564 A. T.

STRATA.	THICKNESS.	DEPTH.	A. T.
Sandstone (Saint Peter)	65	1,141	-577
Red marl and limestone	316	1,457	-893
Sandstone	121	1,578	-1,014
Limestone	50	1,628	-1,064

MITCHELL & LYNDE'S BUILDING, ROCK ISLAND, 558 A. T.

STRATA.	THICKNESS.	DEPTH.	A. T.
Sandstone, Saint Peter	145	1,104	-546
Limestone	811	1,915	-1,357
Sandstone, compact	30	1,945	-1,387
Limestone	35	1,980	-1,422
Sandstone	130	2,110	-1,552
Shaly limestone and shale	75	2,185	-1,627
Sandstone	97	2,282	-1,724

According to these records, the base of the Lower Magnesian cannot well be below -1,357 feet A. T. and may more probably be placed not below -1,268 feet A. T. with the glucose factory record, which is more exact in other details than that of the Mitchell and Lynde's boring. Nor will these records allow us to extend the section below -1,724 A. T. In the absence of frequent samples showing the true nature of the different strata from the base of the Saint Peter to -1,268 A. T., in view of the character of the strata of Magnesian series, which often causes even a geologist to hesitate as to whether to call them limestones, sandstones or shales, and in view of the 121 feet of sandstone included in the record of the Moline Paper Co., it seems preferable to leave indeterminate the base of the Oneota, or Lower Magnesian, and to place the base of the entire Magnesian series, including the Saint Lawrence, at -1,328, the base of the last limestone in the glucose factory record. The sandstone and shales below this will fall in with the Basal sandstone of the Saint Croix.

XL. WILTON.*

Owner	Town.
Depth	1,360 feet.
Elevation of curb A. T	683 A. T.
Head of water A. T	694½ A. T.
Diameter	8 inches-6 inches.
Discharge in gallons per minute	300.

This well, begun in 1887 and finished in 1891, is cased to 900 feet, at which depth the first flow was obtained. In the absence of record or samples of the drillings it is impossible to state whether this flow at 217 below tide is from the Galena or the Saint Peter. The water is more generally used by the inhabitants of the town than is common among Iowa villages of its size having water works; the number of taps being 110. The flow continues undiminished.

ANALYSIS.	GRAINS PER U. S. GALLON.
Calcium carbonate	10.47
Magnesium carbonate	6.45
Sodium chloride	18.56
Sodium sulphate	33.45
Iron oxide and alumina	Traces
Total	69.49

Analysts, Mariner and Haskins, Chicago. Authority, letter of Mr. J. L. Giesler.

*Reported by Mr. J. L Giesler.

Physicians of the village report that the water is laxative and diuretic, and beneficial in cases of rheumatism. Its continued use is stated by one physician not to bring on any disorders of the digestive tract or the kidneys; another cannot say whether a continued use of it for years would not be detrimental to health. On account of its corrosive action on iron the water cannot be used in steam boilers, and it soon rusts out ordinary tinware.

XLI. WEST LIBERTY.*

Owner	Town.
Depth	1,768.
Elevation of curb A. T	696.
Original head of water A. T	705.
Present head of water A. T	696 or less.
Diameter	6 inches–$4\frac{3}{16}$ inches.
Discharge, original, in gallons per minute	120.
Temperature	65° Fahr.
Driller	A. K. Wallen.
Date of beginning well	June 20, 1887.
Date of completion	November, 1888.

During the drilling of the well the water stood at forty feet from the surface for over 1,000 feet. At 1,040 feet, 349 below tide, the horizon of the Saint Peter, it rose twenty feet. Rising a little higher each day, it overflowed when the drill reached the depth of 1,345 feet, and the flow increased as the drill went deeper still. The well is cased to 128 feet. A tubing sunk to 1,100 feet and packed decreased the flow and was taken out. The water is very generally used by the people of the town. There are twenty-nine hydrants, nine meters and 330 taps. The consumption is 75,000 gallons daily.

ANALYSIS.

	COMPOUNDS.	GRAINS IN U. S. GALLON.
1.	Sodium chloride	11.659
2.	Ferrous carbonate	Trace
3.	Sodium carbonate	38.152
4.	Potassium carbonate	18.125
5.	Sodium sulphate	43.738
6.	Sodium chloride	9.302

* Reported by Mr. C. M. Barnes, city engineer.

	COMPOUNDS.	GRAINS IN U. S. GALLON.
7.	Magnesium phosphate	.077
8.	Magnesia	0.019
9.	Silica	7.678
10.	Alumina	0.222
	Total	128.972

Analyst, Floyd Davis, Des Moines. Date, June 14, 1889. Authority, rules of town water works.

The water is said to have increased in hardness since the well was drilled. As a boiler water it gives very little trouble in stationary boilers, but foams badly in locomotive boilers. Scale forms a certain thickness, and then falls off of its own weight. No boiler compound is necessary, and cleaning the boiler once in three months suffices. Although it does not corrode boilers, it eats out the threaded ends of gas pipe in about three years. Physicians report a marked decrease in zymotic diseases since its introduction. It is slightly laxative to those unaccustomed to it, and its continued use has been known to affect the kidneys unfavorably. The analyst of this water, Mr. Floyd Davis, then chemist for the State Board of Health, states under the analysis that "from a sanitary standpoint the water is of excellent quality," perhaps referring to its organic purity. In the amount of alkaline carbonates it exceeds any artesian water in the state.

RECORD OF STRATA.

	STRATA	DEPTH OF SAMPLES.
14.	Dolomite, light bluish-gray	400
13.	Sandstone, very fine, white, particles angular	1,000
12.	Sandstone, coarser, larger grains rounded, from 1,040 to 1,080	1,050
11.	Sandstone, moderately coarse, white. Even to the finger this sand is unusually sharp, and under the microscope many of the grains are seen to be faceted with secondary crystalline enlargements	1,160
10.	Dolomite, gray, with considerable arenaceous admixture in drillings	1,250
9.	"Flint" twelve inches thick, no sample	1,260
8.	Dolomite, white, with considerable admixture in drillings of finest particles of quartz	1,290

STRATA.	DEPTH OF SAMPLES.
7. Dolomite, highly arenaceous	1,310
6. Dolomite, white, porous	1,380
5. Sandstone, larger grains rounded, but consists mostly of angular particles, with some dolomite	1,400
4. Sandstone, matrix calciferous	1,450
3. Sandstone, in fine powder of particles of quartz and a few of dolomite	1,500
2. Sandstone, saccharoidal, rather coarse, white grains usually rounded, some faceted	1,600
1 Dolomite, hard, pinkish	1,765

SUMMARY.

	FORMATIONS.
14	Niagara.
12-13	Saint Peter.
11	New Richmond.
6-10	Lower Oneota.
2-5	Jordan.
1	Saint Lawrence.

XLII. HOMESTEAD.*

Owner	Amana Society.
Depth	2,224 feet.
Elevation of curb	868†.
Head of water	751†.

The well was finished in 1895, by J. P. Miller & Co. The diameters of the bore are as follows: 10 inches to 340 feet, 7⅝ inches to 750 feet, 6 inches to 1,560 feet, 5 inches to 2,023 feet, 4 inches to 2,224 feet. The well is cased for the first 340 feet, from 335 to 525 feet, and from 750 to 1,000. No packing was used. Water is reported at 600 feet rising to within 150 feet of the curb, and at 1,700 feet with the head given above. The first flow proceeds from the Niagara, and the second from the Jordan.

ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si\ O_2$)	.969	16.714
Alumina ($Al_2\ O_3$) } Ferric oxide ($Fe_2\ O_3$) }	.572	9.857
Lime (Ca O)	8.178	141.000
Magnesia (Mg O)	3.132	54.000

* Information furnished by Dr. Wm. Moershel and the foreman of the well.

† Approximately.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Potash (K_2O)	-------	-------
Soda (Na_2O)	14.508	250.143
Chlorine (Cl)	1.922	33.140
Sulphur trioxide (SO_3)	24.749	426.714
Carbon dioxide (CO_2)	10.407	179.429
Water in combination (H_2O)	1.973	34.000
Free (CO_2)	[2.585]	[44.571]

UNITED AS FOLLOWS.

Calcium bicarbonate ($Ca H_2 (CO_3)_2$)	19.173	330.572
Calcium sulphate ($CaSO_4$)	3.347	57.714
Magnesium sulphate ($MgSO_4$)	9.379	161.714
Sodium sulphate (Na_2SO_4)	29.331	505.714
Sodium chloride (Na Cl)	3.165	54.572
Potassium chloride (K Cl)	------	-------
Alumina (Al_2O_3) and Ferric oxide	.572	9.857
Silica (SiO_2)	.969	16.714
Oxygen replaced by chlorine (O)	.474	8.143
Solids	66.410	1,145.000

Analyst, Prof. J. B. Weems. Date, May 26, 1896.

RECORD OF STRATA—DRILLER'S LOG.

	STRATA.	THICKNESS.	DEPTH.
10.	Clay	300	300
9.	Shale	205	505
8.	Limestone	245	750
7.	Shale	250	1,000
6.	Limestone	300	1,300
5.	Sandstone	100	1,400
4.	Sandy limestone	370	1,770
3.	Sandstone	100	1,870
2.	Limestone	230	2,100
1.	Sandstone	124	2,224

RECORD OF SAMPLE DRILLINGS.

		DEPTH.
18.	Shale, greenish-yellow, with many siliceous pebbles	275
17.	Shale, yellow, with numerous small brick red ochre nodules, ferruginous, arenaceous, practically non-calcareous	285
16.	Shale, light green-gray, fissile, slightly calcareous, with some red ochreous nodules and a few fragments of limestone, chert, quartz and dark shales	475

		DEPTH.
15.	Limestone and shale, light blue-gray; chips of light gray compact limestone of earthy lustre and highly argillaceous in highly calcareous concreted powder	500
14.	Dolomite, blue gray, vesicular, in small chips	600
13.	Dolomite, in white powder 690 and	750
12.	Shale, greenish 775 and	805
11.	(Sand and gravel superficial and recent	970)
10.	Limestone, drab, in thin flakes, earthy, fossiliferous	1,010
9.	Shale	1,030
8.	Shale, calcareous	1,250
7.	Sandstone, fine, white	1,345
6.	Sandstone, calciferous, drillings chiefly quartz sand with considerable dolomite and chert	1,475
5.	Sandstone, cream yellow, coarser than at 1,345 feet, grains mostly rounded	1,800
4.	Sandstone, very fine white angular quartz sand with considerable dolomite and chert	1,825
3.	Sandstone, in white powder of microscopic quartz	1,850
2.	Dolomite, gray	2,025
1.	Sandstone, red, highly calciferous, argillaceous and calcareous "from 2,100 to 2,200"	

SUMMARY.

	FORMATIONS.	THICKNESS.	DEPTH.	A. T.
15–18.	Pleistocene, Carboniferous and Devonian	505	505	363
13–14.	Niagara	245	750	118
12.	Maquoketa	250	1,000	-132
8–10.	Galena-Trenton	300	1,300	-432
7.	Saint Peter	100	1,400	-532
6.	Oneota (New Richmond No. 6)	370	1,770	-902
3-5.	Jordan	100	1,870	-1,002
2.	Saint Lawrence	230	2,100	-1,232
1.	Basal sandstone, penetrated	124	2,224	-1,356

The wells at Homestead and Amana are less than four miles apart, but their records are gravely inconsistent. The summit of the Maquoketa in one is at 180 feet A. T., and in the other at 118 feet A. T. The summit of the first sandstone in one is at 290 feet below tide, in the other 432 feet below tide. The record of the Homestead well, inexact as it may be, is used in the geological section from Davenport to Des Moines.

XLIII. AMANA.

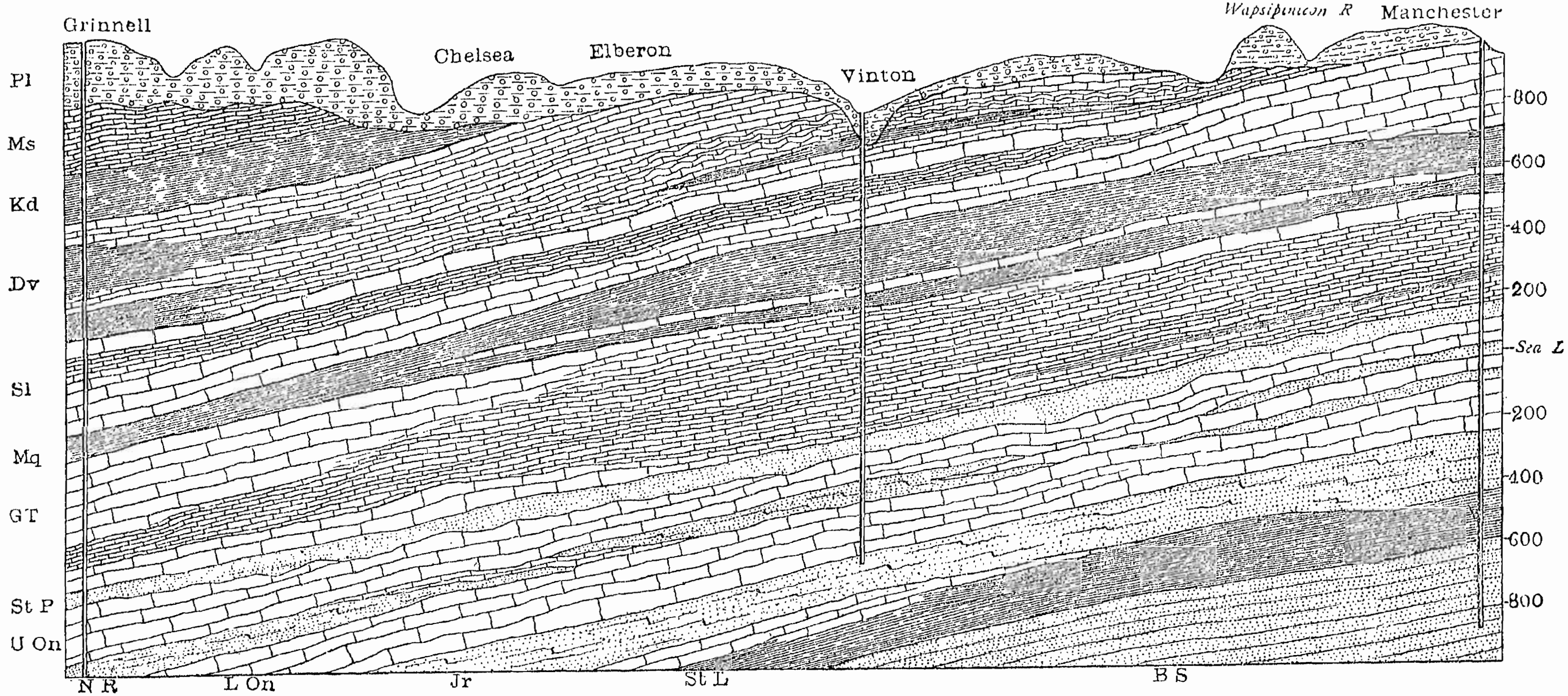
Owner	Amana Society.
Depth	1,640 feet.
Elevation of curb A. T.	730 feet.
Head of water A. T.	760 feet.
Original discharge in gallons per minute	200.
Present discharge in gallons per minute	100.
Temperature	68° Fahr.

This well is located on the southwestern quarter of the northwest quarter, Sec. 36, Tp. 81, N., R. IX W. From the start in 1881 to the finish in 1883, it was drilled wholly by the labor and skill of the society. It was cased to 400 feet originally with six-inch casing. This withstood the corrosive action of the water about four years, when a four-inch pipe of equal length was inserted and made tight at the bottom with secure packing.

Water began to flow at about 400 feet, 330 A. T., about the horizon of the Independence shale. Like the flow from this horizon at Davenport, the yield was very small, not over eight gallons per minute. A slight augmentation, raising the discharge to sixteen gallons per minute, said to be in the Maquoketa shale, was the only other water met with until the Saint Peter, eighty feet thick, was reached at 1,020 feet. The discharge here rose to thirty gallons. At about 1,200 feet, 440 A. T. in the Jordan sandstone, there was a rapid increase, and the full flow was reached at 1,640 feet. The water is used only for scouring purposes in the woolen mill of the society.

ANALYSIS.

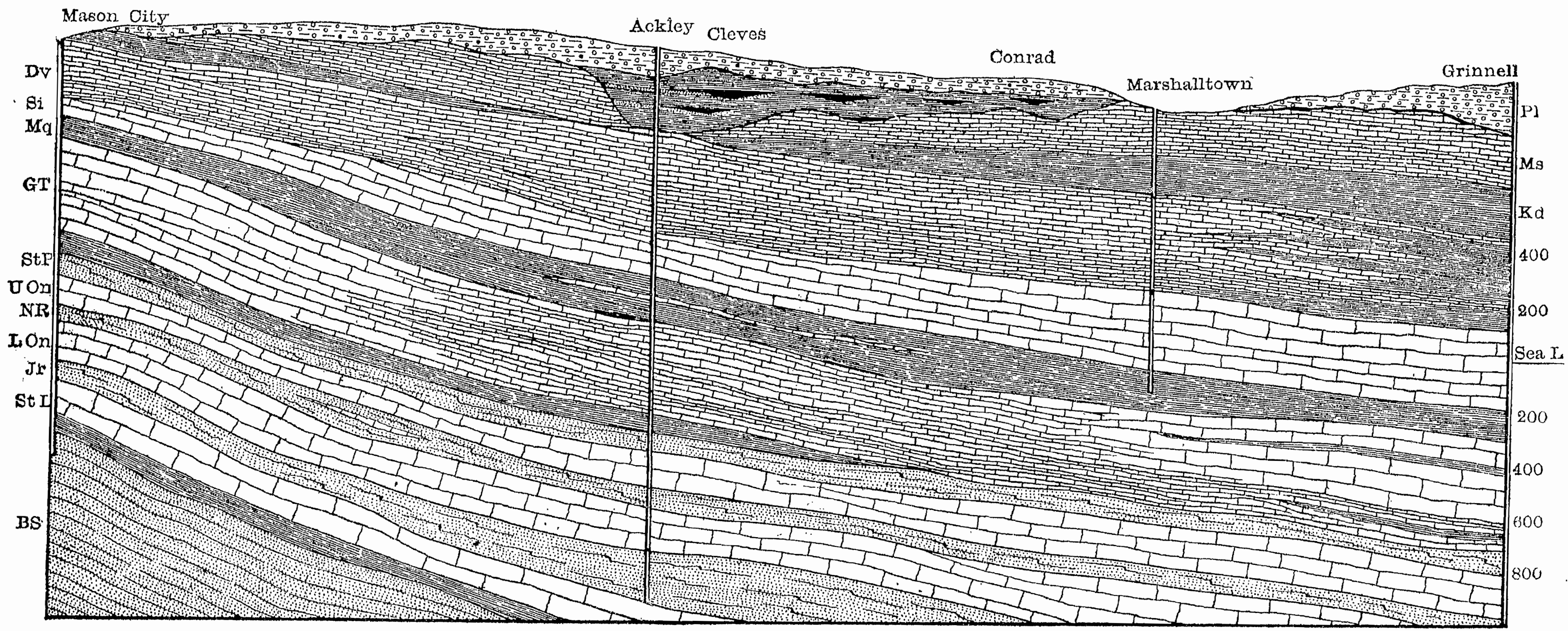
	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Silica ($Si O_2$)	.265	4.574
Alumina ($Al_2 O_3$) Ferric oxide ($Fe_2 O_3$)	.373	6.428
Lime (Ca O)	8.427	145.285
Magnesia (Mg O)	4.077	70.285
Potash (K_2 O)	------	-------
Soda (Na_2 O)	14.152	244.000
Chlorine (Cl)	1.069	18.428
Sulphur trioxide ($S O_3$)	25.006	431.143
Carbon dioxide ($C O_2$)	13.630	235.000
Water in combination (H_2 O)	2.402	41.428
Free (CO_2)	[1.201]	[20.714]



Pl, Pleistocene.	Sl, Silurian.	U On, Upper Oneota.	Jr, Jordan.
Ms, Mississippian.	Mq, Maquoketa.	N R, New Richmond.	St L, St. Lawrence.
Kd, Kinderhook.	GT, Galena-Trenton	L On, Lower Oneota.	B S, Basal Sandstone.
Dv, Devonian.	St P, Saint Peter.		

Scale: Vertical 600 feet; Horizontal 10 miles

GEOLOGICAL SECTION FROM MANCHESTER TO GRINNELL.



Pl, Pleistocene.
Ms, Mississippian.
Dv, Devonian.
Kd, Kinderhook.
Si, Silurian.
Mq, Maquoketa.
GT, Galena-Trenton.
St P, Saint Peter.
U On, Upper Oneota.
N R, New Richmond.
L On, Lower Oneota.
Jr, Jordan.
St L, Saint Lawrence.
B S, Basal Sandstone.

Scale: Horizontal 10 miles; Vertical 500 feet

GEOLOGICAL SECTION FROM MASON CITY TO GRINNELL.

UNITED AS FOLLOWS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium bicarbonate ($Ca H_2(Co_3)_2$)	24.277	418.572
Magnesium bicarbonate ($Mg H_2 (Co_3)_2$)	.663	11.428
Magnesium sulphate ($Mg SO_4$)	11.683	201.428
Sodium sulphate ($Na_2 So_4$)	30.160	520.000
Sodium chloride (Na Cl)	1.740	30.000
Potassium chloride (K Cl)	------	-------
Alumina ($Al_2 O_3$) and Ferric oxide	.373	6.428
Silica ($Si O_2$)	.265	4.572
Oxygen replaced by chlorine	.240	4.143
Solids	69.401	1,196.571

Analyst, Prof. J. B. Weems. Date, May 26, 1896.

RECORD OF STRATA.

		THICKNESS.	DEPTH.	A. T.
8.	Pleistocene deposits	50	50	680
7.	Shales, Carboniferous and Devonian	300	300	380
6.	Limestone, Niagara	200	550	180
5.	Shales, Maquoketa	220	570	-40
4.	Limestone, Trenton	250	1,020	-290
3.	Sandstone, Saint Peter	80	1,100	-370
2.	Limestone, Oneota	200	1,300	-570
1.	Limestone, Oneota in part	340	1,640	-910

XLIV. GRINNELL.*

Owner	Town.
Depth	2,003 feet.
Elevation of curb A. T	1,028 feet.
Head of water A. T	798 feet.
Capacity in gallons per minute	105.
Date of beginning	October, 1892.
Date of completion	August 8, 1893.
Driller	J. P. Miller & Co.

The diameters of the bore are as follows: Ten inches to 208 feet, six inches to 408 feet, five inches to 1,185 feet and four inches to 2,003 feet. Ten-inch casing occupies the ten-inch bore, 450 feet of five-inch casing is located at a depth of from 408 feet to 958 feet, covering the shales of the Mississippian and Devonian, and forty feet of four-inch casing from 1,145 feet to 1,185 feet from the surface.

*For the information concerning the Grinnell well we are indebted to the report of the well by Mr. A. J Jones; Proc. Iowa Acad. Sci., vol. II, 1894, pp. 31-35; to Mr. B. S. Morrison, and specially to Professor H W. Norris, who furnished a set of the drillings.

Water was first found at 212 feet, at the top of the Saint Louis limestone, strongly mineral, almost yellow in color, and rising to within ninety feet of the surface. The inflow of this water could not be checked for a long time, but before the well was completed it was entirely shut off. The second water was found at 1,530 feet from the surface in the Trenton. A third flow was encountered in the Saint Peter at 1,700 feet. This was a strong vein, and "as the drill penetrated the sandstone a roaring noise was heard, and the drillings were washed away by the strong current of water." The water in the tube, which had remained at about 100 feet below the surface, immediately sunk, and this was no doubt the cause of the roaring noise reported. After some time the water returned to nearly the same level. The head of the Saint Peter and Trenton water is in this region apparently about 928 feet, but this high level is probably due to a filling of the well with the higher waters faster than it could be drawn off through the lower outlet. More or less water was found all the way from 1,700 feet to 2,003 feet, and on completion of the well the head was found to be 230 feet from the surface.

ANALYSES.

The quality of the water at different depths was carefully tested during the progress of the boring. Four separate analyses were made. No. 1 is of the combined water of the first, the second and third flows. No. 2 is of the second and third flows, the first being shut off. These are both by Prof. L. W. Andrews, of Iowa City, and were made when the well had reached a depth of 1,770 feet, when water was first pumped from the well. No. 3 and No. 4, by Mr. Luther Verbeck, of Grinnell, represent the constitution of the combined waters of all flows, except the first, to their respective depths of 1,940 feet and 2,003 feet.

COMPOUND.	NO. 1.	NO. 2.	NO. 3.	NO. 4.
Calcium carbonate	9.70	9.60	5.89	7.00
Calcium sulphate	45.25	41.25	42.55	41.10
Magnesium sulphate	41.60	41.00	24.60	30.00

COMPOUND.	NO. 1.	NO. 2.	NO. 3.	NO. 4.
Sodium sulphate	24.75	23.35	24.60	30.00
Sodium chloride	0.05	0.05	0.50	0.87
Iron	------	------	0.17	------
Silica	------	------	0.65	------
Silica, iron and alumina	------	------	------	0.70
Total dissolved solids	121.35	115.25	------	------
Total suspended solids	14.55	2.85	------	------
Total solids	135.90	118.10	112.30	120.75
Hardness	78°	74.1°	41°	44°

The similarity of the first two analyses is certainly surprising, if the strong mineral water present in the water of No. 1 were really excluded from the water of No. 2; and the same may be said of the uniformity in the amount of calcium sulphate in all the waters and of sodium sulphate in the first three.

The water is said to be universally liked and very generally used. Physicians report that there has been a marked decrease in zymotic diseases since its introduction, and that it seems to be beneficial in cases of chronic rheumatism. It is at first laxative and diuretic to those unaccustomed to its use, but the diuretic effect ceases and the laxative effect is changed to constipation. Patients with chronic diarrhoea can not take it at all. It is one of the strongest selenitic waters in the state.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
41.	Soil, loess and drift	212	212
40.	Limestone, rather soft, buff, in chips mixed with sand and small pebbles of northern drift	8	220
39.	Shale, dark gray, fissile, with fragments of impure chert, in light drab argillo-calcareous powder	20	240
38.	Limestone, cherty, arenaceous, argillaceous; after washing is seen to contain many minute crystals of selenite		270
37.	Limestone, gray, as fine sand in argillo-calcareous powder		315
36.	Limestone, cherty, and shale; as chips in argillo-calcareous powder	125	365

	THICKNESS.	DEPTH.
35. Shale and limestone, soft, fissile, dark drab; in powder with a few minute fragments of limestone and considerable chert	35	400
34. Shale, blue, calcareous, in powder concreted into readily friable masses containing microscopic particles of quartz		415
33. Shale, hard, green-gray, with compact, light yellow, calcareous, siliceous fragments; siliceous in the form of angular grains of transparent quartz, mostly from .054 to .09 mm in size, but many much smaller		435
32. Shale, fine-grained, calcareous, greenish		440
31. Shale, brownish-drab		450
30. Shale, light blue-gray, somewhat calcareous, two samples		550
29. Shale, as No. 31		570
28½. Limestone, fine-grained (report A. J. Jones) at		570
28. Shale, light blue-gray, seleniferous, calcareous, with a few particles of limestone		600
27. Shale, light drab and bluish, somewhat calcareous, with a little finely divided quartzose residue after washing, five samples	400	800
26. Limestone, light yellow-gray, granular, subcrystalline, briskly effervescent in cold dilute H Cl, with much shale	10	810
25. Shale and limestone, in light blue-gray argillaceous powder containing a few fragments of limestone		825
24. Shale, light blue and green-gray, somewhat calcareous, seven samples, last at 900		940
23. Limestone, magnesian, medium dark gray, earthy, argillaceous		949
22. Limestone, magnesian or dolomite, with considerable hard, finely arenaceous, greenish shale		969
21. Shale, light gray, argillo-calcareous		990
20. Limestone, highly cherty		1,012
19. Limestone, white, soft		1,065
18. Limestone, highly cherty, two samples		1,150

		THICKNESS.	DEPTH.
17.	Limestone, cherty		1,175
16.	Dolomite or magnesian limestone, light buff, in fine sand		1,200
15.	Shale, light drab, calcareous		1,260
14.	Shale, light brown, pyritiferous, two samples, last at 1,280		1,320
13.	Magnesian limestone or dolomite, buff; residue cherty and microscopically arenaceous		1,380
12.	Shale, brown, darker than No. 14		1,400
11.	Magnesian limestone or dolomite, ferruginous, in dark buff powder; residuary quartzose particles .018 to .18 mm. in diameter, four samples		1,475
10.	Unknown		1,610
9.	Limestone, magnesian, cherty, light yellow, in powder		1,630
8.	Limestone, light gray, fossiliferous, in flaky chips		1,640
7.	Shale, green, non-calcareous, "fossiliferous"		1,655
6.	Limestone, magnesian, in buff powder		1,700
5.	Sandstone, calciferous, quartzose particles from 018 to .18 mm. in diameter; particles of white dolomite mingled with the quartz in the drilling		1,706
4.	Sandstone, white, grains rounded and smooth, usual size about .55 mm., maximum seen 92 mm. in diameter		1,740
3.	Sandstone, light reddish-buff, fine grains, mostly broken, many stained with film of ferric oxide, size .18 to .28 mm in diameter		1,740
2.	Unknown		2,002
1.	Sandstone, highly calciferous or limestone arenaceous; sand grains angular with some rounded and up to 1 mm. in diameter, matrix of dolomite white, at		2,002

SUMMARY.

	FORMATION.	THICKNESS.	DEPTH.	A. T.
41.	Pleistocene	212	212	816
29–40.	Mississippian and Kinderhook	358	570	458
24–28.	Devonian	370	940	88
16–23.	Silurian	260	1,200	-172

	FORMATION.	THICKNESS.	DEPTH.	A. T.
14-15.	Maquoketa	120	1,320	-292
6-13.	Galena-Trenton	380	1,700	-672
3- 5.	Saint Peter	40	1,740	-712
2.	Upper Oneota (?)	262	2,002	-974
1.	New Richmond (?) at		2,002	

This arrangement differs from the assignment of Mr. A. J. Jones only above the Maquoketa. Mr. Jones placed the base of the Mississippian at 800 feet and the base of the Devonian at 990 feet. Any divisions made in the almost uninterrupted body of shales from 465 to 940 feet must be more or less arbitrary.

XLV. NEWTON.*

Owner	Town.
Depth	1,400.
Elevation of curb A. T.	952†.
Head of water A. T.	862†.
Diameter	5 inches.
Date of completion	1890.

The water is described as poor as a potable water and bad in its effects upon boilers. It seems to come from the Saint Louis at 550 feet, reinforced by lower flows above the Maquoketa. Rock was struck at 90 feet. Between 1,300 and 1,400 feet a shale was encountered that caved badly and caused the loss of a drill. Failing to extricate it, the first well was abandoned and a second begun anew. In this also a drill was lost at about the same depth and the attempt to carry the boring deeper was given up. The supply is abundant, continued pumping failing to lower the level. The shale between 1,300 and 1,400 feet is aligned with the Maquoketa of the Grinnell and Des Moines sections as is seen in Plate XVII.

* Data contributed by Messrs. J Meyer and A. G. Gates

† Approximately.

XLVI. COLFAX.

	Depth.	Diameter, inches.	Head A T.	Discharge in gallons per minute.	Date of completion.	Temperature.	Water horizon, depth from surface.
Hotel Colfax	325	3	----	3	--	54° Fahr.	----
Frye's Hotel	315	3	841	3	1882	51° Fahr.	310
Mason House	over 300	4	824	4	1881	52° Fahr.	over 200
Mineral Water Co.	300	4	----	2	1890	52° Fahr.	200
Town of Colfax	300	4	823	4	1892	52° Fahr.	200

Besides those described in the above table, there are five other artesian wells in Colfax from which reports have not been received; but the statistics just given probably represent the entire group of wells of the locality. The moderate yield seems to be derived from the Saint Louis limestone. No record of the strata is extant.

Colfax water, like good wine, needs no bush. Its fame is wide, and the number of testimonials vouching for its curative properties in various diseases are large. The village has become the chief sanitarium of Iowa and the center of an extensive trade in the bottled water. The following analysis of the water will indicate its therapeutic qualities.

	GRAINS IN U. S. GALLON OF 231 CUBIC INCHES.	
	No 1.	No. 2.
Calcium carbonate	17.51	- ----
Magnesium bicarbonate	-----	25.939
Iron carbonate	0.67	------
Iron bicarbonate	-----	0.258
Calcium sulphate	13.07	31.759
Magnesium sulphate	31.87	10.239
Sodium sulphate	78.86	77.344
Potassium sulphate	0.41	0.620
Sodium chloride	3.85	3 842
Silica	0.29	0.058
Alumina		0.710
Lithia	Trace	------

	GRAINS IN U. S. GALLON OF 231 CUBIC INCHES. NO. 1.	NO. 2.
Carbon dioxide	7.18	------
Organic matter	-----	Trace
Total	153.71	150.769

Analysis No. 1, of Old M. C. Spring, Hotel Colfax, by G. Hinrichs, Iowa City. Authority, Bulletin U. S. Geol. Surv., No. 32, p. 162.

Analysis No. 2, of Magnetic Rock Spring, Colfax Bottling Works, by W. S. Haines, Chicago. Authority, circulars of company.

Professor Haines mentions also that the water contains free carbonic acid gas in large quantities.

The water is classed by Peale as saline chalybeate. The chief therapeutic agents are the laxative sulphates, of which the water contains about 120 grains to the gallon. The absence of calcium carbonate in one analysis and of magnesium bicarbonate in the other seems to result from different methods of combination by the two chemists, the lime all being combined in the form of sulphate in one analysis, and the magnesia in magnesium sulphate in the other.

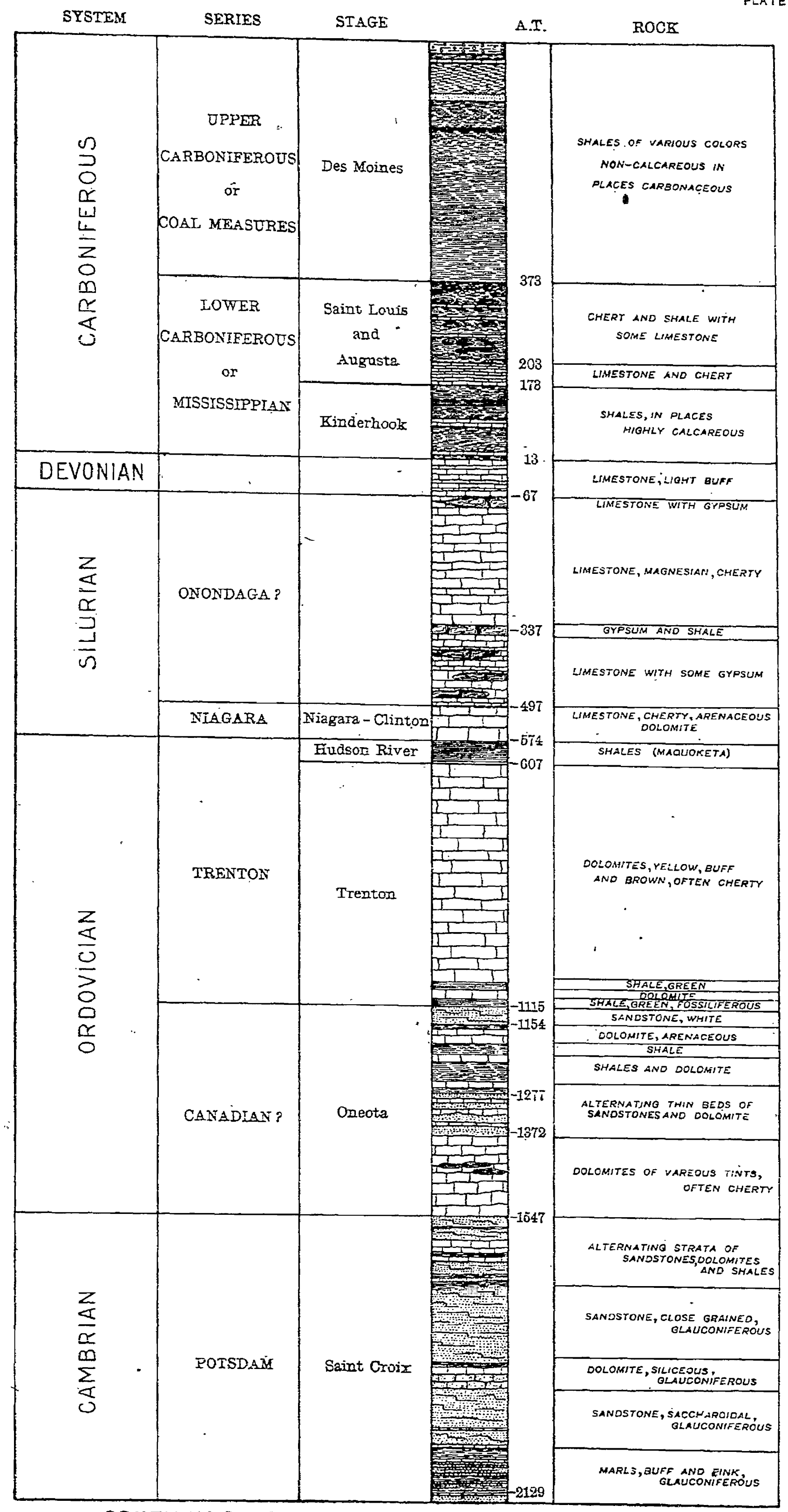
XLVII. DES MOINES.*

GREENWOOD PARK WELL.

Owner	Park Commissioners.
Depth	3,000 feet.
Elevation	872 feet.
Head of water A. T	827 feet.
Temperature (Saint Peter water at 2,025 feet)	65° Fahr.
Diameter	10 inches to 3 inches.
Capacity in gallons per minute	400.
Date of beginning well	March 1, 1895.
Date of completion	July 24, 1896.
Driller	J. P. Miller & Co.

Water first entered the tube from the Mississippian beds between 498 and 668 feet from the surface. This water rose to within thirty feet of the curb, or 842 A. T., and was

*In volume II of the Geology of Iowa, White mentions an artesian well at Des Moines, bored to obtain water for a brewery, and of which little or nothing could be learned from its proprietors. In fortunate contrast the new well at Greenwood Park was drilled from the start under a skilled superintendent, attentive to every fact of scientific interest. The utmost pains were taken to obtain a full series of samples of the drillings. When these were so fine as to be held in suspension they were secured in several instances by boiling down the water. For a set of these drillings and for copious notes of the progress of the boring we are indebted to Mr. T. Van Hyning, who supervised the drilling of the well.



GREENWOOD PARK (DES MOINES) WELL SECTION.

strongly impregnated with sulphureted hydrogen. Fluctuations of water in the tube indicated minor flow from 1,011 to 1,208 feet; and from the Niagara at 1,425 feet water rose to the surface and overflowed "in a quarter of an inch stream." Another reservoir was tapped at 2,025 feet in the Saint Peter, of which Mr. Van Hyning writes: "Here the flow increased, flowing steadily one and one-half gallons per minute. When we tested the flow with a deep well steam pump throwing fifty-two gallons per minute, an eighteen hour steady run lowered the water 125 feet, but on stopping the pump it raised immediately to within six feet of the top and ceased to flow."

At 2,208 feet in the New Richmond, a stream was struck with a lower head and the water fell to fifty feet from the surface, 822 A. T. At 2,330 feet the water fell to within eighty feet of the curb, indicating a vein in the lower Oneota. No other fluctuations are reported, but on the completion of the well the water was found to stand at 827 feet A. T. forty-five feet below the curb.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
78.	Till, buff, sandy, with a few pebbles, non-calcareous	14	14
77.	Shale, black, brittle, carbonaceous	1	15
76.	Shale, gray, "fossiliferous"	1	16
75.	Shale, black, carbonaceous, calcareous, highly pyritiferous	3	19
74.	Shale, gray	4	23
73.	Shale and limestone, bluish-gray, highly fossiliferous	15	38
72.	Shale, vari-colored	67	105
71.	Shale, bluish-gray, highly and finely arenaceous, hard	10	115
70.	Shale, bluish-gray, slightly calcareous	60	175
69.	Shale, dark drab and black, carbonaceous	11	186
68.	Shales, gray, drab and purplish, practically non-calcareous; one foot of gray chert at 284 feet	312	498
67	Chert and shale, heavy bed, very hard to drill; the most of the sample is an		

		THICKNESS.	DEPTH.
	argillo-calcareous powder; of 250 dg 34 dg remain after washing as sand of white chert, flint and limestone; of this residue 8 dg. are soluble in acid; of the 216 dg. washed out as powder 62 dg. are soluble in acid; the shale is reported as caving in from above, but its calcareous nature indicates that it is in part interstratified with chert and limestone	170	668
66.	Limestone and chert, brownish-gray	30	698
65.	Shale, light blue and gray	40	738
64.	Shale, terra cotta-red, highly calcareous	10	748
63	Shale, light blue-gray	25	773
62.	Shale, light gray, highly calcareous, fine cherty residue	85	858
61.	Limestone, light buff, with much gray chert	80	938
60.	Limestone, light blue, gray, crystalline, saccharoidal, effervescence slow, with considerable white gypsum	20	958
59.	Limestone cherty, crystalline, blue-gray, effervescence moderately rapid	53	1,011
58.	Limestone, cherty, crystalline, saccharoidal, dark blue-gray and buff; effervescence indicates magnesian limestone, but not dolomite	197	1,208
57.	Gypsum and shale; gypsum gray and white, in flakes; shale green, perhaps from above	15	1,223
56.	Limestone, light blue-gray, highly selen-iferous, with some flakes of gypsum	145	1,368
55.	Limestone, cherty, arenaceous; grains of sand, minute rounded; much shale in rounded fragments, perhaps from above	22	1,390
54.	Dolomite, buff, crystalline, granular with much chert and some chalcedonic silica, three samples	55	1,445
53.	Shales, in large fragments. purplish-yellow and green Non-calcareous, finely laminated	33	1,478
52.	Dolomite, in yellow-gray powder, cherty	260	1,738
51.	Dolomites, yellow, buff and brown, mostly cherty, and residue finely quartzose, five samples	155	1,938
50.	Shale, green, very slightly calcareous	8	1,946

		THICKNESS.	DEPTH.
49.	Dolomite, brown, arenaceous	30	1,976
48.	Shale, dark green, hard "fossiliferous," practically non-calcareous	10	1,986
47.	Sandstone, fine. white, grains moderately well rounded	39	2,025
46.	Shale, drillings consist of greenish powder of dolomite, chert, fine quartz sand, green shale and pyrite	7	2,032
45.	Dolomite, arenaceous, and cherty	30	2,062
44.	Shale, drab, calcareous, in finest powder, containing grains of buff, cherty dolomite	23	2,085
43.	Dolomite, gray	5	2,090
42.	Dolomite, same, with minute rounded vesicles resembling matrix of oolite from which grains have been dissolved	5	2,095
41.	Dolomite	5	2,100
40.	Shale, as No 44, "exceedingly hard to drill"	40	2,140
39.	Dolomite, arenaceous, gray; two samples	8	2,148
38.	Shale, drab, calcareous	6	2,154
37.	Sandstone, white fine, calciferous	10	2,164
36.	Dolomite, buff	7	2,172
34.	Sandstone, clean white quartz sand; grains ronnded	10	2,182
33.	Dolomite, buff	15	2,197
32.	Sandstone, buff, grains broken, with much dolomite	11	2,208
31.	Sandstone, friable, white, fine	2	2,210
30.	Shale, drab, slightly calcareous	4	2.214
29.	Sandstone, white	5	2,219
28.	Dolomite, buff, white, much quartz sand	3	2,222
27.	Shale	2	2,224
26.	Sandstone, gray and buff, calciferous grains largely broken	14	2,238
25.	Shale, light blue	5	2,243
24.	Dolomites of various tints, often cherty, argillaceous at 2,250, 2,272, 2,333, 2,340; arenaceous at 2,270 and 2,333; at 2,305 there are 17 feet of chert of various colors, white, blue and green; 32 samples	175	2,418
23.	Sandstone, white, fine grains, mostly rough surfaced; with some dolomite	12	2,430
22.	Dolomite, brown, in chips	2	2,432
21.	Sandstone	4	2,436

		THICKNESS.	DEPTH.
20.	Dolomite, rough, gray and brown	4	2,440
19.	Sandstone, fine white and reddish, three samples	12	2,452
18.	Shale, light blue-gray	2	2,554
17.	Sandstone, calciferous, buff	4	2.458
16.	Dolomite, arenaceous, gray, buff and brown, six samples	30	2,488
15.	Shale, light blue-gray	10	2,498
14.	Dolomite, gray and buff, quartzy	9	2,507
13.	Sandstone, gray, fine. calciferous	27	2,534
12.	Marl, highly quartzose, dolomitic, argillaceous yellowish powder, two samples	19	2,553
11.	Sandstone, calciferous, gray and white, three samples	12	2,565
10.	Sandstone, in sand and small chips resembling superficially dolomite, calciferous, glauconitic, close grained, grains white, gray and buff, ten samples	145	2,710
9.	Shale and dolomite, shale hard, dark bright green, slaty. Dolomite white, highly siliceous, with much greenish, translucent amorphous silica, two samples. Of the second, over one-half of the weight of the samples is soluble in acid	20	2,730
8.	Sandstone, buff in color, in powder, glauconiferous This rock is termed sandstone although composed chiefly of light colored particles of impure cryptocrystalline silica which effervesce freely in acid; fragments of crystalline quartz form but a small proportion of the drillings	20	2,750
7.	Sandstone, saccharoidal, dark with purplish tinge, dark color owing to numerous grains of glauconite, purplish tinge to ferruginous stains on quartz sand. Sand grains, rough surfaced, imperfectly rounded, many fractured, of crystalline silica	130	2,880
6.	Dolomite, dark gray, greenish tinge, macrocrystalline, glauconiferous, sparingly arenaceous	5	2,885
5.	Sandstone, greenish, grains microscopic	5	2,890
4.	Shale, dull gray, fine grained and exceedingly finely laminated	5	2,895

		THICKNESS.	DEPTH.
3.	Sandstone, glauconiferous, calciferous, grains imperfectly rounded, with hard, dark green slaty shale	15	2,910
2.	Marl, in buff flour, microscopically arenaceous, calciferous, glauconiferous	50	2,960
1.	Marl, pink, calciferous, arenaceous, one-third of drillings by weight insoluble in acid; to bottom of well	40	3,000

SUMMARY.

	FORMATION.	THICKNESS.	DEPTH.	A. T.
78.	Pleistocene	14	14	858
68–77.	Des Moines	484	498	374
66–67.	Mississippian	200	698	174
62–65.	Kinderhook	160	858	14
61.	Devonian	80	938	–66
54–60.	Silurian	507	1,445	–573
53.	Maquoketa	33	1,478	–606
48–52.	Galena-Trenton	508	1,986	–1,114
47.	Saint Peter	39	2,025	–1,153
39–46.	Upper Oneota	124	2,149	–1,277
25–38	New Richmond	94	2,243	–1,371
24.	Lower Oneota	175	2,418	–1,546
8–23.	Saint Croix	332	2,750	–1,878
1– 7.	Basal sandstone	250	3,000	–2,128

POLK COUNTY COURT HOUSE WELL.

Of this well nothing additional has been learned beyond the facts noted by Call.* It is 380 feet deep and probably draws its supply from the Mississippian. The following analysis of the water was made by Prof. Floyd Davis. The figures represent grains per gallon.

Calcium carbonate	9.529
Iron carbonate	Trace
Calcium sulphate	34.389
Magnesium sulphate	27.709
Sodium sulphate	97.012
Sodium chloride	10.333
Potassium chloride	Trace.
Magnesium phosphate	.332
Alumina	.440
Silica and insoluble residue	8.628
Total solids	181.372

*Iowa Weather and Crop Se vice. February, 1892

XLVIII. REDFIELD.*

A boring made in search of oil or gas at Redfield struck a strong flow of artesian water at a depth of 280 feet. It is highly chalybeate and runs unused into the Middle Raccoon river. The well curb is about 900 feet A. T.

Another artesian well located on the South Raccoon, in Section 7, Township 78 N., Range 29 W., seems to draw its supply from the same source. The record is as follows.

	THICKNESS.	DEPTH.
5. Shales, alternating red and blue	65	65
4. Sandstone	6	71
3. Slate and shale, carbonaceous	200	271
2. Sandstone, water-bearing, white and pure	20	291
1. Limestone, very hard, drilled with great difficulty	8	299

XLIX. SAYLORVILLE, POLK COUNTY.

A boring 1,800 feet deep is reported from R. 24, Twp. 79, Sec. 12, Se. qr., Nw. ¼. No intelligible record has been obtained. A flowing mineral well less than 400 feet deep is situated in Sec. 3, Ne. qr., Se. ¼. The discharge is about 5,000 gallons per hour and the source of the water is probably in or immediately above the Mississippian.

V. WASHINGTON-DES MOINES SECTION.

This section is exceptionally satisfactory, since it is based upon four wells, at no great distance apart, and of which we have full and reliable records. It joins the preceding section at Des Moines. The attenuation of the limestones of the Mississippian toward the west, noted in the preceding section, is equally striking in this. The Kinderhook shales are in great force on the eastern side of the section, but diminish toward the west. The Devonian limestones are thin, but it must be remembered that no line can be drawn between any upper shales of this formation and the shales assigned to the Kinderhook. The thickness given the Devonian at Pella may be too great. Crystals of selenite found in the samples of

*Reported by Mr. A. G. Leonard.

some of the limestones, here placed with the Devonian, would suggest an alliance with the gypseous beds beneath. If the western border of the superficial area of the Devonian is correctly drawn east of Washington at the Cedar river, its elevation there can scarcely be less than 600 feet A. T. If the base of the heavy shales at Washington designated as Kinderhook is really the summit of the Devonian, then the dip of this formation from its outcrop at Columbus Junction is over 300 feet in less than twenty miles. This gradient is relatively so great that it adds some weight to the argument for the inclusion of at least a part of the Kinderhook shales with the Devonian.

The assignment of the seleniferous limestones at Des Moines to the Silurian is corroborated by the recurrence of gypsum and gypseous marl at the same horizon at Pella and Oskaloosa. At Pella the marls are particularly heavy, and scarcely any doubt can attach to their age. At Sigourney the Silurian retains its northern facies of a cherty dolomite, and at the base for a few feet is minutely arenaceous. To the east, at Washington, the arenaceous element has largely increased, and the formation, as described by Calvin, consists of over 100 feet of sandstones more or less calciferous.

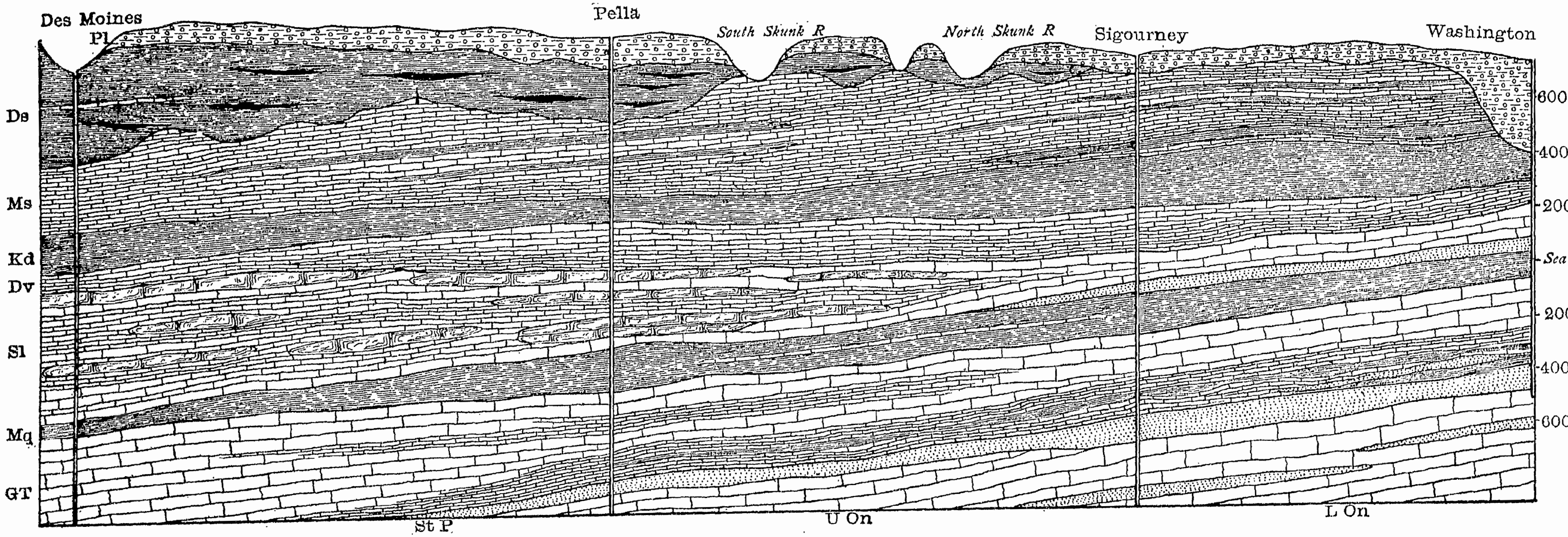
The Maquoketa here loses something of the excessive thickness it attains in east central Iowa, its maximum here being from Sigourney to Pella from 159 to 190 feet.

The Trenton thickens from Washington, where it is about 300 feet thick, to Des Moines, where it is 508 feet thick. Throughout the section the upper Trenton is magnesian or dolomitic. These beds, which may be termed the Galena, are everywhere much heavier than the basal shales and non-magnesian limestones. At Washington the easy passage into the Saint Peter is illustrated, where the basal Trenton includes a thin sandstone resting upon an arenaceous shale.

The attitude of the Saint Peter in southeastern Iowa is of special interest. The regular southwestward dip of the strata is here reversed, and a low dome of Ordovician and Cambrian terranes forms a marked stratigraphical feature. From Davenport to Washington, forty-eight miles west southwest, the Saint Peter rises about 100 feet and the summit of the Trenton about 50 feet. From Aledo, Illinois, fifty miles west of Washington, the Saint Peter rises, perhaps, 100 feet, its position at Aledo being not accurately known. The Saint Peter is nearly horizontal from Washington to Ottumwa, but on the southeast it rises toward Keokuk. The attitude of the formation will be more readily seen on the map (Plate XXII).

Over the eastern part of the section the magnesian series probably continues to hold the immense thickness which it has been seen to attain in the region of Davenport. At Sigourney the drillers report over 850 feet of "sandstone" underlying the Saint Peter.

Gordon and Bain both interpret this as limestone, and the two samples preserved, and the evidence from other wells, corroborate their judgment. The probability, however, is not excluded of the presence within the 850 feet of the intermediate sandstones, the New Richmond and the Jordan. The records of a deep boring at Aledo, Illinois, confirm the great thickness assigned to the magnesian series. In a private letter Mr. Frank Leverett, of the United States Geological Survey, describes eight samples of limestone extending from 1,300 feet from the surface to 2,100 feet, interrupted so far as the samples show, only by 15 feet of red marl at 1,330 feet, and by white sandstone at 2,000 feet. The magnesian series may then be estimated as 800 or 900 feet thick in the region of Aledo, its base lying at about 1,350 or 1,450 feet below sea level. At 2,200 feet from the surface samples of sandstone begin, which continue to 3,130 feet, giving place to gray calcareous shale at 2,400, feet, and to a caving shale at 2,442 feet. From 2,500 feet to the bottom of the boring, the sandstone is prevailingly brownish and of loose texture. These sandstones undoubtedly are the continuation of those we have designated as the Basal sandstone, and their thickness of at least nearly 1,000 feet, together with the massiveness of the Magnesian



Pl, Pleistocene.
Ds, Des Moines.
Ms, Mississippian.
Kd, Kinderhook.
Dv, Devonian.
Sl, Silurian.
Mq, Maquoketa.
GT, Galena-Trenton.
St P, Saint Peter.
U On, Upper Oneota.
L On, Lower Oneota.

Scale: Horizontal 10 miles; Vertical 500 feet

GEOLOGICAL SECTION FROM WASHINGTON TO DES MOINES.

series, shows the task set before the adventurous driller who would discover the Algonkian in this district.

While the profile does not represent with accuracy of detail the surface of the country, it sets forth the significant difference between recent river erosion and that of Quaternary or still earlier geological time. The present rivers that cross the section must cut their valleys 300 feet deeper before they reach the level of the fluvial floor of the drift-filled valley at Washington.

Artesian Conditions in Southeastern Iowa.

Along the line of the Washington-Des Moines section, and southeastward, the artesian indications are, on the whole, favorable. There are several formations which may furnish artesian water. The Niagara yields bountifully at Keokuk and Ft. Madison, and largely at Centerville. The Galena-Trenton seems to afford part of the supply at Pella, although from this town our reports as to water horizons are vague. The flow at Ottumwa rises from the Saint Peter, if our information is correct, and a strong current was found in the same formation at Sigourney. The Magnesian series is water-bearing and in large quantities. The Basal sandstone here lies so deep that the expense will probably prevent borings being carried so far beneath the surface. Its capacities are illustrated in the well at Aledo, Ill. Water was here obtained in the first 100 feet of the Basal sandstone, and another flow was found below 2,910 feet from the surface with a head at 708 feet A. T., forty-five higher than the head of the water of the Saint Peter. Especially along the Mississippi and Des Moines valleys deep borings for artesian water are recommended with the utmost confidence. In quality the deeper waters will be found better than the veins above the Saint Peter. Each flow should be carefully measured and should be analyzed quantitatively by an expert chemist. Water from the Carboniferous series, both Coal Measures and Mississippian, should be effectively cased out.

L. WASHINGTON.*

	NO. 2.	NO. 3.
Owner	Town.	Town.
Depth	1,611.	1,217.
Head of water, original	44 feet †	58 feet.†
Head of water, present	54 feet.†	
Capacity in gallons per minute	95.	62.
Temperature, reported	72°.	
Bore	10 to 4½ in.	12 to 6 in.
Date of beginning	Nov. 5, 1890.	Nov. 20, 1896.
Date of completion	Nov. 12, 1891.	Feb. 1, 1897.
Driller	J. P. Miller & Co.	O. G. Wilson.

The casing of No. 2 is as follows: to 244 feet, 10 inches; from 220 to 461 feet, 6¼ inches; from 563 to 818 feet, 5½ inches; from 1,400 to 1,468 feet, 4½ inches.

ANALYSIS OF NO. 1, OR OF NO. 2.

COMPOUND.	GRAINS PER GALLON.
Calcium carbonate	2.811
Magnesium carbonate	8.961
Ferrous carbonate	Trace
Calcium sulphate	14.402
Sodium sulphate	31.952
Sodium chloride	5.325
Potassium chloride	1.015
Sodium phosphate	Trace
Silica and insoluble residue	2.049
Alumina	.103
Total solids	66.618

SANITARY ANALYSIS.

Loss on ignition	8 606
Chlorine	3.716
Free ammonia	.010
Albuminoid ammonia	.003
Nitrogen in nitrates and nitrites	None
Total hardness, Clark's scale	24.0
Temporary hardness	13.4
Permanent hardness	10.6

The author of both of the above analyses is Prof. Floyd Davis, Des Moines. Authority, report of city clerk.

*Reported by Messrs. St. Clair Lewis and J. J. Kellogg.

† Below surface.

RECORD OF STRATA.

The following is an abstract of the description of the section in the article by Calvin,* and seems to be of a still earlier well not reported by our correspondents.

FORMATION.	THICKNESS.	DEPTH.
Drift and modified drift, forest bed at 115 feet	350	350
Shale, dark, in part calcareous, lower part of *Kinderhook*	82	432
Unknown	25	458
Limestone and shales; light colored; at 458 feet of rather fine texture, with fragments of Devonian fossils. Samples at 500. *Devonian*	-	532
Sandstone, calciferous at 532, passing into a purer sandstone at 585, last sample at 632. *Niagara*	---	702
Shale, bluish or greenish, sometimes with an admixture of sand, and again with some calcareous matter, last sample at 793. *Maquoketa*	---	803
Limestone, magnesian, grayish, last sample at 963. *Trenton*	---	1,020
Limestone, characteristics of Trenton; at 1,020 dark, fine grained, and mixed with considerable carbonaceous shale, last sample at 1,059	---	1,082
Sandstone. *Trenton*	2	1,084
Shale, arenaceous *Trenton*	16	1,100
Sandstone, usual characteristics of *Saint Peter*	100	1,200
Unknown	28	1,228
Shale, bluish	2	1,230
Sandstone, gray, at	---	1,230

LI. SIGOURNEY.†

Owner	Town.
Depth	1,888 feet.
Elevation of curb	756 A. T.
Head of water	726 A. T.
Diameter	6 to $4\frac{1}{6}$ inches.

Mr. Bain gives the following history of the well: "A moderate flow was obtained, but has never been used to any great extent. At 1,320 feet, in the Saint Peter sandstone, a

* American Geologist, vol. I, p. 28.

† We are indebted for the facts relating to the well at Sigourney to an article upon it by Bain. Proc. Iowa Acad. Sci., vol. I, part IV, pp. 36-38, and to a report made by Capt J. T. Parker.

vein of water was struck which contained mineral matter and possessed a strong odor. At 1,360 feet, in the same formation, an opening was struck and the drill suddenly dropped two feet. A strong current of fresh water carried off all the samples, and the water increased to the depth of 1,388 feet, when it flowed over the top of the well while drilling and stood within thirty feet of the top when the drill was at rest. No more water was struck from here to the bottom of the well." The water corrodes iron badly. The majority of the people do not like its taste, and even stock will not drink it freely. The casing is said to extend to a depth of 1,091 feet. This cuts off all water above the Maquoketa.

RECORD OF STRATA.

	STRATA.	THICKNESS.	DEPTH.
50.	Drift	50	50
49.	Shale, blue, with a few pebbles of the drift fallen from above	18	68
48.	Clay, brown, fine, non-calcareous, in flakes; disaggregates in water with about ten times the difficulty of blue till; quartzose and cherty residue; drillings contain some pebbles of glacial derivation	30	98
46.	Limestone, brown-gray, arenaceous	22	120
45.	Limestone, gray, arenaceous, cherty, samples at 120 and 125 feet	15	135
44.	Shale, calcareous; with much gray flint in flakes	20	155
43.	Limestone, highly siliceous, highly argillaceous, with much flint and blue shale, drillings consist largely of chert	10	165
42.	Limestone, bluish gray, drillings mostly chert of the same color	5	170
41.	Limestone, bluish gray or shale, highly cherty, quartzose and argillaceous	17	187
40.	Shale, blue, calcareous, highly siliceous	3	190
39.	Limestone, blue-gray, highly cherty	5	195
38.	Limestone, soft, blue-gray	10	205
37.	Limestone, blue-gray, with much chert	5	210
36.	Limestone, light bluish, earthy luster, in large flakes, highly siliceous	15	225
35.	Limestone, blue-gray	15	240
34.	Limestone, drab, granular	10	250

STRATA.	THICKNESS.	DEPTH.
33. Limestone, brown, somewhat cherty	6	256
32. Chert, blue-gray	14	270
31. Limestone, brown, somewhat cherty	15	285
30. Limestone, light gray, soft, angular, crystalline	25	310
29. Shale, hard, greenish, calcareous, microscopically siliceous, in fragments, samples at 310 and 315	20	330
28. Shale, dark greenish, in large fragments, calciferous; so highly siliceous with microscopic particles of limpid quartz, that it might perhaps be called sandstone, samples at 330, 331 and 335	12	342
27. Limestone, light and darker blue-gray, in flaky chips, argillaceous and microscopically arenaceous	14	356
26. Shale, greenish, soft, slightly calcareous, fine grained, samples 3..6, 387, 388 and 422	198	554
25. Limestone, green-gray, argillaceous	31	585
24. Shale, indurated, calcareo-siliceous	21	606
23. Shale, calcareous; or limestone, argillaceous, highly fossiliferous; drillings largely fragments of spirifera, orthis, and perhaps other brachiopods, and of crinoid stems	12	618
22. Limestone, blue-gray, earthy luster, fossiliferous	12	630
21. Limestone, brown and buff, earthy luster, fossiliferous	25	668
20. Limestone, soft, yellow, earthy luster, four samples	25	668
19. Limestone, gray, cherty	5	673
18. Limestone, white, in powder	52	725
17. Limestone, magnesian, buff, in sand, two samples	5	730
16. Dolomite, gray buff, in chips, subcrystalline, with much white chert, samples at 730 and 750	56	786
15. Dolomite, yellow, buff and gray, mostly cherty, samples at 786, 795, 805, 830, 835	79	865
14. Limestone, magnesian; drillings mostly of white and translucent chert, with interbedded cubes of pyrite, and a large number of minute rounded grains of limpid quartz	6	871

	STRATA.	THICKNESS.	DEPTH.
13.	Shale samples at 871. 876, 882, 890, 920, 990, and 1,005; blue, green, gray and drab	159	1,030
12.	Dolomite, brown, hard, argillaceous	25	1,055
11.	Limestone, light yellow-gray	34	1,089
10.	Dolomite, brown	---	----
9.	Limestone, magnesian, cherty, white, gray, buff and brown; all effervesce more rapidly than Galena dolomite	149	1,238
8.	Chert	17	1,255
7.	Limestone, light yellow-gray, cherty	5	1,260
6.	Limestone, as No 7, with a little shale	15	1,275
5.	Shale, green, soft, calcareous	6	1,281
4.	Limestone, gray	9	1,290
3.	Limestone, magnesian, brown	25	1,315
2.	Sandstone, fine grained, white and light gray in mass; mostly in angular fragments with some rounded grains, samples at 1,315, 1,320, 1,329, 1,340, 1,360, 1,388, 1,430	115	1,430
1.	Dolomite, samples at 1,800 and 1,828	28	1,828
	The same reported to continue to	60	1,888

SUMMARY.

This section is based largely upon the determinations of Bain, published in the article to which reference already has been made.

	FORMATION.		THICKNESS.	DEPTH.	A. T.
50.	Pleistocene		50	50	706
42–49.	Mississippian	Saint Louis	137	187	569
28–41.	Mississippian	Augusta	169	356	400
27.	Mississippian	Kinderhook	198	554	202
18–26.	Devonian		171	725	31
14–17.	Silurian		146	871	–115
13.	Maquoketa		159	1,030	–274
3–12.	Galena-Trenton		285	1,315	–557
2.	Saint Peter		115	1,430	–674
1.	Oneota		458	1,888	–1,132

LII. OSKALOOSA.*

At some time previous to 1888, a deep well was bored at Oskaloosa to a depth of 2,800 or 3,000 feet. Several companies were engaged in it, litigation ensued, and the well was

*Reported by Hon. Ben. McCoy and Mr. F. E. Wetherell.

abandoned. The record of the strata for the first 1,200 feet is as follows.

STRATA.	THICKNESS.	DEPTH.
34. Soil, black	5	5
33. Clay, joint	33	38
32. Sand and gravel	3	41
31. Clay, blue	9	50
30. Fire clay	13	63
29. Slate, black	34	97
28. Coal	10	107
27. Sulphur [Pyrite]	½	
26. Limestone	20	127
25. Soapstone	12	139
24. Sandstone, gray	9	148
23. Plumbago, traces [?]	½	149
22. Sandstone, gray	12	161
21. Flint	4	165
20. Limestone	15	180
19. Sandstone	9	189
18. Plumbago, traces [?]	1	190
17. Sandstone	10	200
16. Slate, black	50	250
15. Slate, white	20	270
14. Porous rock	10	280
13. Limestone	336	610
12. Slate	110	720
11. Marble, Iowa, hard	150	870
10. Limestone, very dark, hard, with streaks of sandrock, and mica, also fossils at 935 feet	100	970
9. Sandstone, hard, gray	7	977
8. Gypsum and magnesia	5	982
7. Feldspar [Calc-spar ?]	15	997
6. Sandrock, porous	5	1,002
5. Unknown	74	1,076
4. Slate, black	19	1,095
3. Slate, blue	20	1,115
2. Limerock	35	1,140
1 Slate, blue	60	1,200

SUMMARY.

	THICKNESS.	DEPTH.	A. T.*
31–34. Pleistocene and Recent	50	50	793
22–30. Des Moines	111	161	682
13–21. Mississippian	455	610	233

*The elevation of the C., R. I. & P. station, 843 A. T. is taken as probably near the elevation of the curb.

		THICKNESS.	DEPTH.	A. T.
12.	Kinderhook	110	720	123
11.	Devonian	150	870	- 27
5-10.	Silurian	276	1,076	-233
1- 4.	Maquoketa	124	1,200	-357

The thickness assigned to the Coal Measures may be too small. If No. 16 is really the black fissile shale called by miners "slate," they may extend to 573 A. T. But in No. 4 the driller seems to use the phrase as equivalent to dark shale. By comparisons of elevations with the Washington-Des Moines section, which passes six miles north of Oskaloosa, it will be seen that No. 12, which is evidently the Kinderhook, lies about fifty feet lower than it is there drawn. On the other hand the Maquoketa falls in place with a gratifying exactness, and the gypsum of No. 8 assists in the correlation of this part of the section with the Silurian.

LIII. PELLA.*

Owner	Town
Depth	1,803 feet.
Elevation of curb A. T.	868 feet.
Head of water A. T.	768 feet.
Capacity in gallons per minute	250.
Date of beginning	May 20, 1895.
Date of completion	May 30, 1896.
Drillers	J. P. Miller & Co.

Water was found at 150 feet; from 1,300 to 1,685 feet, Trenton; and from 1,685 to 1,803, Saint Peter and Oneota. From the first source water rose in the tube to within 100 feet of the surface, where it remained without fluctuation to the end. By packing it was found that the lower source alone was entirely inadequate. No complete analysis has been reported. An analysis made to ascertain the quality of the combined flow as a boiler water proved it entirely unsuited to this use on account of the large amount of calcium sulphate present. If, as reported, the total dissolved solids amount to 490.70 grains to the U. S. wine gallon, the water is also unfit for a town supply.

*Reported by Mr. J. D. Gaass, who also secured for the Survey one of the most complete sets of drillings in the state.

The diameters of the bore are reported as follows: 12-inch, 200 feet; 10-inch, 102 feet; 8-inch, 220 feet; 7-inch, 317 feet; 6-inch, 230 feet; 5-inch, 124 feet. Tubing is sunk to the depth of 1,293 feet.

RECORD OF STRATA.

NOS.	STRATA.	THICKNESS, FEET.	DEPTH, FEET.
62.	Humus	6	6
61.	Till, yellow, mottled with gray; clay predominant ingredient, ochreous nodules, calcareous	54	60
60.	Till, blue, dense, tough, calcareous	50	110
59.	Sand and gravel, pebbles mostly buff, impure limestone and greenish and black siliceous clay stone, a fragment of coal noted and one of fossil wood	25	135
58.	Clay, dark, yellow-gray, sandy, with a few small pebbles, and fragments of gray unctuous shale	55	190
57.	Sand, very coarse, with fragments of gray and black shale	2	192
56.	Gravel, coarse, up to 5 c m. in diameter, surfaces stained with ferric oxides, in a matrix of black ferruginous clay or shale; greenish-black, argillo-siliceous pebbles, 22; clay ironstones, 13; flints, 6; limestones, 16; jasper and quartz, 6; sandstones, 2	3	195
55.	Shale, black, gravelly at 235 and 245 feet; fissile and gravelly at 272 feet; at the latter the pebbles of the sample comprise the following: Limestone, 9; green argillo-siliceous pebbles, 6; flints, 12; red and yellow jaspers, 3; five samples	90	285
54.	Shale, dark gray	2	287
53.	Shale, hard, black, finely laminated, pebbly, two samples	43	330
52.	Limestone and shale, in bluish-gray concreted argillo-calcareous powder, containing a few minute fragments of light gray limestone, some chalcedony, drusy quartz and quartz crystals	5	345
51.	Limestone, in fine cream-colored powder	30	375

NOS.	STRATA.	THICKNESS. FEET.	DEPTH. FEET.
50.	Limestone and shale, in concreted powder, washing discloses gray limestone sand, discs of crinoid stems, chalcedony, and white chert, and particles of hard blue-green shale	25	400
49.	Shale, blue, highly calcareous	5	405
48.	Shale, blue-gray, slightly calcareous	15	420
47.	Shale and limestone, in light blue-gray argillo-calcareous powder containing some limestone and chert	30	450
46.	Limestone and shale, in light blue-gray, argillo-calcareous powder, containing some limestone and chert	10	460
45.	Shale and limestone in powder as above, containing some fragments of dark gray flint and a few particles of limestone	20	480
44.	Limestone (?), sample consists of highly argillaceous calcareous powder, containing many chips of blue and gray flint, a few of light yellow-gray limestone, and some of shale	30	510
43.	Limestone, drillings consist of chips of blue and gray flint, drusy quartz, chalcedony, blue shale, and many chips of an earthy buff limestone	5	515
42.	Limestone, light yellow-gray, in sand, with argillaceous powder, with some chalcedony	85	600
41.	Shale, green, fissile, some drab	100	700
40.	Shale, green, somewhat calcareous, in moulded masses	25	725
39.	Limestone, nearly white, soft, earthy lustre, rapid effervescence	10	735
38.	Limestone, as above, with sand of hard brownish-gray magnesian limestone or dolomite	10	745
37.	Limestone, magnesian, light brown, coarsely crystalline, close textured, effervescence slow, a few fragments of selenite noted; residue dark brown, argillaceous; four samples	55	800
36.	Limestone, soft, in part chalky, effervescence rapid	20	820
35.	Limestone, light gray-brown, magnesian, with some "clod" shale of same color; two samples	20	840

NOS.	STRATA.	THICKNESS. FEET.	DEPTH. FEET.
34.	Limestone, light gray, crystalline, highly cherty, drillings rusted so as to appear buff in mass	10	850
33.	Limestone, blue-gray, in large flakes	10	860
32.	Limestone, light brown-gray and gray; at 860 a few crystals of selenite; four samples	30	890
31.	Marl, gypseous, in gray-white, concreted powder largely composed of gypsum, with some limestone, argillaceous matter, and microscopic crystals of quartz, two samples	35	925
30.	Limestone, light gray, mottled with dark drab, in large flaky chips, with numerous crystals of selenite	10	935
29.	Dolomite, in chips, hard, gray; two samples	20	955
28.	Marl, gypseous or gypsum; in light yellow, nearly white powder, concreted into tough masses, breaking with smooth, slightly conchoidal fracture, difficultly friable with fingers. In acid does not disaggregate, though slightly calcareous. Under the microscope anhydrite is seen to be an important constituent and some pyramidal crystals of quartz are observed	15	970
27.	Shale, blue-gray, strongly calcareous; two samples	45	1,015
26.	Limestone, magnesian, light brown, crystalline	11	1,026
25.	Limestone and shale; limestone gray, earthy pyritiferous. Shale, light green, fossiliferous	19	1,045
24.	Limestone, magnesian, light brown, crystalline	5	1,050
23.	Limestone, mottled gray, crystalline, highly gypseous	5	1,055
22.	Marl, gypseous, as No. 28, with some light gray impure limestone, and some shale	25	1,080
21.	Marl, gypseous, as No. 28; four samples; at 1,110 a few thin flakes of limestone	50	1,130
20.	Limestone, magnesian, buff, gypseous	5	1,135
19.	Limestone, in flaky chips, earthy, soft, gypseous, light gray	3	1,138
18.	Dolomite, light blue-gray, hard, irregular fracture, micro-crystalline, two samples	7	1,145

NOS.	STRATA.	THICKNESS. FEET.	DEPTH. FEET.
17.	Shale, green, green-gray, drab and slightly purplish, slightly or non-calcareous, hard and fissile, four samples	115	1,260
16.	Shale, in moulded masses, drab, somewhat calcareous, with fine dolomitic sand	75	1,335
15.	Dolomite, gray, crystalline, cherty, in fine sand, four samples	90	1,425
14.	Limestone, rather soft, with much gray flint and a little brown bituminous shale	10	1,435
13.	Limestone, magnesian, in light buff sand, two samples	20	1,455
12.	Limestone, soft, white, effervescence rapid	5	1,460
11.	Limestone, magnesian, yellow-gray	5	1,465
10.	Limestone, light brown, crystalline, effervescence rapid, two samples	10	1,475
9.	Limestone, magnesian, buff, crystalline	5	1,480
8.	Dolomite, cream-yellow, and buff, and brown; mostly cherty; residue after digestion in acid microscopically arenaceous or quartzose in several samples. Chert usually pyritiferous with imbedded crystals, eleven samples	103	1,593
7.	Limestone, brown, cherty, with some small chips of dark brown bituminous shale, two samples	32	1,615
6.	Limestone, magnesian, gray, crystalline, with hard, slaty, blue-green shale	15	1,635
5.	Limestone, magnesian, light buff	15	1,650
4.	Limestone, gray, earthy, crystalline, of rapid effervescence; two samples	35	1,685
3.	Sandstone, clean, white quartz sand, usual facies of Saint Peter, two samples	15	1,700
2.	Dolomite, drillings highly arenaceous, cherty, gray and buff, three samples	40	1,740
1.	Dolomite, buff	20	1,760

SUMMARY.*

NOS.	FORMATION.	THICKNESS FEET.	DEPTH FEET.	A. T. FEET.
59–62.	Pleistocene	135	135	733
53–58.	Des Moines	195	330	538
42–52.	Mississippian	270	600	268
40–41.	Kinderhook	125	725	143

*It is suggested by Mr. Bain that the local stratigraphy favors the reference of Nos. 56–58 to the Pleistocene. It is possible that the coal measure material of the samples belongs to a till unusually rich in such fragments. The glacial material of the samples, which we have taken to have fallen in from above, may belong to till at the horizons stated.

NOS.	FORMATION.	THICKNESS FEET.	DEPTH FEET.	A. T. FEET.
32–39.	Devonian	165	890	-22
18–31.	Silurian	255	1,145	-277
16–17.	Maquoketa	190	1,335	-467
4–15.	Trenton	350	1,685	-817
3.	Saint Peter	15	1,700	-832
1–2.	Oneota, penetrated	60	1,760	-892

WELLS OF SOUTHEASTERN IOWA.

Geological Notes.

The salient feature disclosed by the present investigation in the geology of the deeper strata in southeastern Iowa is the Ordovician dome, to which reference already has been made. The areal and vertical extent of this elevation is exhibited in map (Plate XXII), by isometric lines, showing the height of the summit of the Saint Peter sandstone above the sea level as datum. The steepest slope lies apparently on the west, where the Saint Peter declines with a comparatively steep gradient to the great trough of south central Iowa. To the northwest the descent is gentle, and to the north a col connects with the much higher elevations of the lower Ordovician in northeastern Iowa. Toward this dome the Silurian and Devonian strata grow measurably thinner. At Keokuk the entire thickness of the strata from the base of the heavy shales assigned to the Kinderhook to the Saint Peter is only 380 feet, as contrasted with an assemblage of the same strata 640 feet thick at Centerville and nearly 1,000 feet thick at Pella.

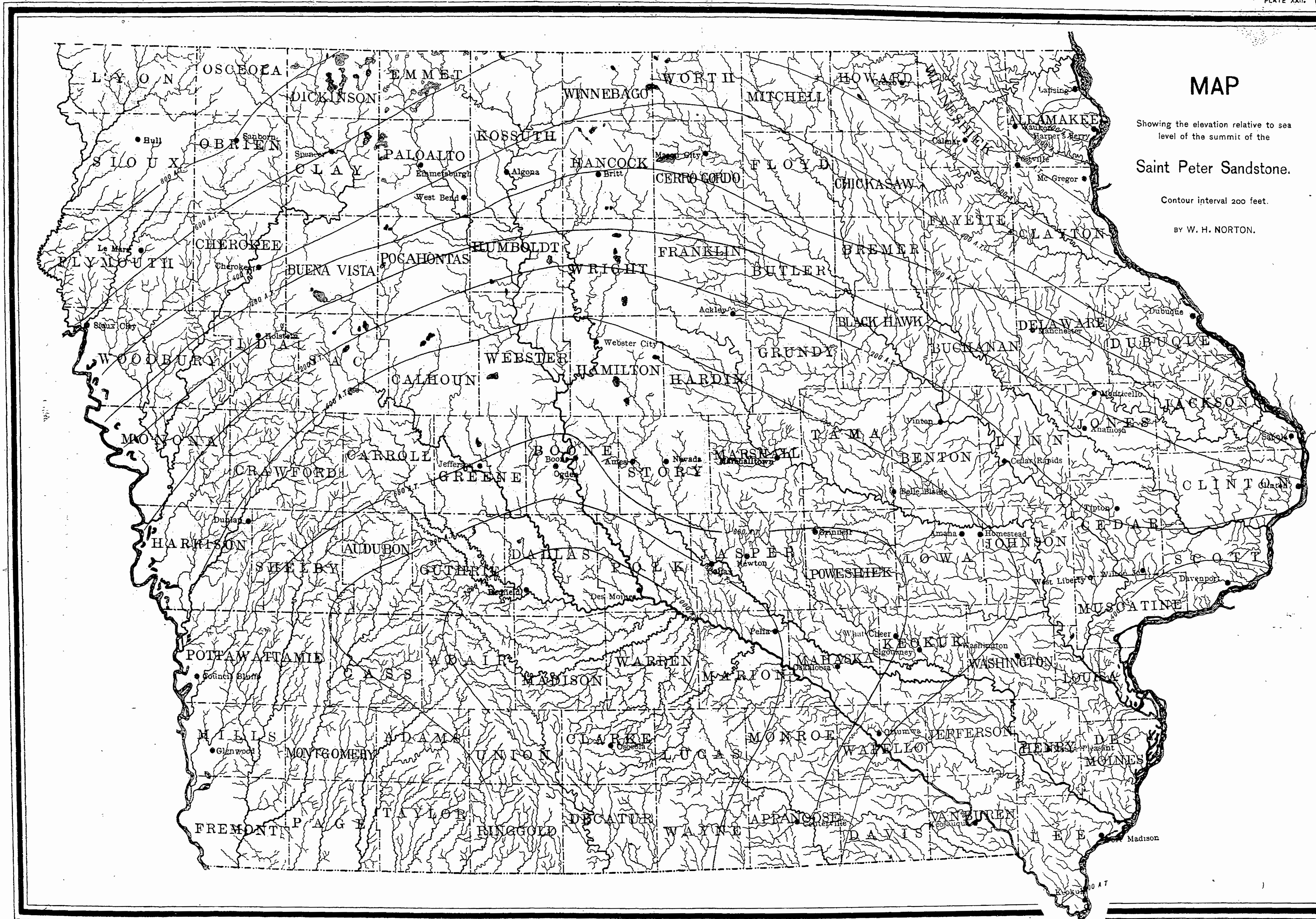
None of the wells in this group are known to reach the base of the Magnesian series. At Centerville the drill had not discovered the Basal sandstone at a depth of 715 feet below the Saint Peter. This is not, however, a massif of dolomite. One hundred and ten feet of comparatively pure dolomite is followed by thin interbedded dolomites and sandstones passing into the heavier beds of sandstone which make up the New Richmond. Below these arenaceous beds lie dolomites, arenaceous or interbedded with sandy layers, passing in places into purer sandstone, in all so far as penetrated 370 feet.

At Ottumwa 870 feet of limestone and shales are referable to the Oneota, and in one record the New Richmond is represented by 122 feet of sandstone lying 120 feet below the Saint Peter. At Keokuk there are reported below the Saint Peter 755 feet of limestone alternating with sandstone. The conclusion of Gordon that the maximum thickness of this formation within the limits of Iowa can not be less than 1,000 feet may well be verified hereafter by some deeper boring. It is in southern Iowa, and probably in southeastern Iowa, that the Magnesian series attains its maximum thickness in the state.

The Saint Peter retains its usual facies at Centerville. No samples of it or of other formations are at hand from the other wells of this group. The Galena-Trenton at Centerville embraces dolomitic limestones only. The Maquoketa does not seem to be present at this station, and the only line of demarkation between Silurian and Ordovician is one drawn tentatively, according to the presence or absence of arenaceous admixture. At Ottumwa the absence of the Maquoketa is probably due to imperfection of record, since it is present at Pella and at Keokuk, in thickness not less than that of its outcrops in northeastern Iowa.

To the southern border of the state the Silurian retains the arenaceous characteristics discovered at Washington by Calvin. At Ottumwa, Keokuk, Fort Madison and Centerville, it includes calciferous sandstones, which furnish a plentiful yield of artesian water.

A certain Devonian datum, as proven by its fossils, is afforded in the limestones at Washington which intervene between the arenaceous Silurian and the shale called Kinderhook. The strata occupying this place in Lee county do not exceed eighty-five feet in thickness. At Centerville we have assigned to the Devonian 260 feet. As the upper portion of this is shaly, it may be equivalent to the lower strata of the Kinderhook shales as reported in other wells.


MAP
Showing the elevation relative to sea level of the summit of the
Saint Peter Sandstone.
Contour interval 200 feet.
BY W. H. NORTON.

The artesian well sections on the line of the Mississippian syncline, named by Keyes the Keokuk syncline, are not sufficiently exact to show how deeply the strata of other groups are effected by the deformation. The following table states the elevations A. T. of the two most plain horizons.

	KEOKUK POULTRY CO.	KEOKUK HUBINGER.	MONTROSE.	FORT MADISON.
Summit of Kinderhook shales	251	272	366	344
Base of Kinderhook shales	45	72	11	94

At neither Montrose or Fort Madison is the Maquoketa on record, although the wells extend, the one sixty, the other 160 feet below the level of the top of the shales at Keokuk.

Artesian Conditions.

The artesian conditions of this district are included in the discussion of the same for southeastern Iowa, on page 303.

LIV. OTTUMWA.

OWNER.	MORELL & CO.	ARTESIAN WELL CO.
Depth	1,554 ft.	2,047 ft.
Elevation of curb	643 ft. A. T.	
Original head of water	700⅝ ft. A. T.	108½ ft. above curb.
Present head of water	692¼ ft. A. T.	108½ ft. above curb.
Original discharge in gallons per minute	1,000	over 700.
Present discharge	------------------------	
Depth of water-bearing strata	1,085 ft.	1,015 feet.
Date of completion	July, 1892	March, 1889.
Temperature	64° Fahr.	70° Fahr.
Driller, J. P. Miller & Co.		

The Morrell & Co. well is ten inches in diameter for 25 feet, 9⅝ to 97 feet, 8 inches to 540 feet, 6 inches to 994 feet, 5 inches to 1,320 feet, and 4 inches to 1,554 feet. It is cased from surface to 25½ feet, from 437 to 540 feet, from 842 to 994 feet, and from 1,244 to 1,320 feet. The water is unsuitable for boilers, as it forms scale rapidly. It is used only at the packing house of the company.

The well of the Artesian Well Co. is reported as an eight-inch bore, but judging from the discharge compared with that of the other well, it is probably considerably less than eight inches at the depth of the water-bearing stratum. The water is supplied to 176 store buildings by pipes, and is delivered two gallons daily (Sundays excepted) at the rate of $1.50 per month to any part of the city. It is said to be used by over 2,000 persons. It supplies a swimming pool and is used for sprinkling the streets. The following testimonial, dated September 1, 1893, is signed by fifteen of the physicians of the town.

"We recommend the Ottumwa artesian water as absolutely pure, and coming from a depth of 2,047 feet, free from all organic matter. The exclusive use of it would do away with typhoid fever entirely, so far as danger from drinking water is concerned, and greatly reduce the amount of sickness from other diseases. It is not only of great value as drinking water, but has a remarkably beneficial effect on cases of chronic rheumatism, constipation, and many forms of stomach and kidney troubles."

Special reports from several physicians of the town state that the water is found to be slightly laxative and diuretic.

ANALYSIS.

As examples of the character of local waters from the Mississippian we add analyses of two waters belonging to the Mineral Springs Sanitarium at Ottumwa. No. 2 is from a depth of 314 feet, and No. 3 from a depth of eighty-five feet. Analysis No. 1 is of the water of Artesian Well Co.

COMPOUND.	GRAINS PER GALLON NO 1.	NO 2.	NO. 3.
Calcium carbonate	13.20	22.265	7.844
Magnesium carbonate	3.27	30.802	5.294
Iron carbonate	----	2.940	.184
Sodium carbonate	----	------	10.212
Calcium sulphate	----	38.230	------
Magnesium sulphate	6.10	------	------
Sodium sulphate	33.83	200.875	13.105
Potassium sulphate	----	2.231	Trace
Sodium chloride	11.48	51.805	2.700
Silicia	----	7.299	1.443
Alumina	----	Trace.	Trace.

COMPOUND.	GRAINS PER GALLON NO. 1.	NO. 2.	NO. 3.
Organic matter	----	Trace.	Trace.
Loss	----	-------	.662
Total	68.	*356.477	*41.444

No. 1. Analyst, Prof. L. W. Andrews, Iowa City. Date, December 12, 1893. Authority, circulars of company. (There seems to be some omission in the published analysis, as the total of the compounds named is 67.88, instead of 68.

No. 2. Analyst, D. D. Carter, Omaha. Authority, circulars of company.

No. 3 Analyst, S. R. Macy. Authority, circulars of company.

RECORD OF STRATA.

The following is a copy of the original record of Mr. J. W. Garner of the Artesian Well Co., with geological formations and elevations above sea level added.

		THICKNESS	DEPTH	A. T.
18.	Loam, Pleistocene	21	21	639†
17.	Limestone, Mississippian	21	42	608
16.	Shale, Mississippian	14	56	594
15.	Sandstone, Mississippian	30	86	564
14.	Limestone, Mississippian	60	146	504
13.	Shale, Mississippian	20	165	484
12.	Sandstone, flinty, Mississippian	40	206	444
11.	Sandstone, Mississippian	30	236	414
10.	Limestone, Mississippian	195	431	219
9.	Shale, Mississippian-Kinderhook	160	591	59
8.	Limestone	200	791	-141
7.	Limestone	180	971	-321
6.	Limestone mixed with sand, Devonian, Silurian and Ordovician	96	1,067	-417
5.	Sandstone, white, Saint Peter	110	1,177	-527
4.	Shale and limestone, Oneota	200	1,377	-727
3	Slate Oneota	19	1,396	-746
2.	Limestone Oneota	320	1,715	-1 065
1.	Limestone, water-bearing, Oneota	332	2,047	-1,397

The above differs in several particulars from the record furnished Mr. C. H. Gordon by one of the residents of the town. In the latter record Nos. 14 to 12 are replaced by "limestone, 14 feet; shale and limestone, 116 feet." No. 10 is divided into "limestone, 180 feet, and limestone, 15 feet." No. 8 is "limestone mixed with sand." Below No. 5 the record is as follows.

* Also free and half combined carbonic acid gas.

† Approximately.

Slate	20	1,158
Limestone	100	1,258
Sandstone	122	1,380
Limestone	697	2,077

LV. FARMINGTON AND KEOSAUQUA.

White* reported flowing wells at these two localities in Van Buren county. The Farmington well is 705 feet in depth, and it probably taps the same veins that supply the wells at Keokuk and Fort Madison.

LVI. MOUNT PLEASANT.†

Owner	Iowa Hospital for the Insane.
Depth	1,125 feet
Head of water	30 feet below curb.
Capacity in gallons per minute	165.
Temperature	62° Fahr.
Depth at which water was found	990 feet.
Date of beginning	September 1, 1861.
Date of completion	February, 1862.

The water is said to be very disagreeable, and so corrosive that it can not be used. A battery of boilers and all the steam radiators in the hospital were destroyed by it before the well was abandoned. The author of the following analysis is not stated.

ANALYSIS.

	PARTS PER MILLION.
Lime	332
Magnesian	78
Peroxide of iron	32
Sulphuric acid	37
Carbonic acid	106
Silica	Trace.
Strontia	Trace.

RECORD OF STRATA.

	THICKNESS.	DEPTH.
Limestone	295	295
Shales, soft, passing into hard	300	595
Limerock	295	890
Unknown	100	990
Sand rock penetrated	135	1,125

*Geology of Iowa, vol. II, pp. 331-332. 1870.
†Reported by Mr. H. A. Gilman.

If the dip of the Saint Peter is uniform from Keokuk to Washington, that sandstone should be reached at Mount Pleasant at about 340 feet below tide, or 1,069 feet below the grade at station of the Chicago, Burlington & Quincy Railway.

LVII FORT MADISON.*

OWNER	DEPTH.	EL'V. A.T	HEAD A.T.	DIAM.	DIS. IN GAL. PER M.	TEMP.	DEPTH OF VEIN.	DATE OF COMPLETION.	DRILLER.
S. & J. C. Atlee, 2 well...........	720	553	638 (?)	6 in.	...	55°	......	1889	
	740	...	...	....	...	...	......	....	
A., T. & St. F. Ry	764	553†	573†	4 in.	...	60°	......	1892	Tweedy Bros.
Columbian Straw Paper Co.......	689	528	548	6 in.	600	62°	680†	1888	G. W. Adams & Co.

The Atlee wells are reported to head 85 feet above the surface and to be used by 1,500 people. The Atchison, Topeka & Santa Fe Railway Co.'s well is used only at the company's hospital. The pressure is said to be sufficient to carry the water to the third floor of the building. The well is cased to a depth of 184 feet, and there are also 200 feet of four-inch tubing in the well not located. The water of all the wells is highly corrosive to iron; it blackens brass and forms scale. The flow seems to be constant so far as reported. The Paper Co. report a slight decrease in hardness in the water. The following analysis of the water of the Paper Co.'s well was made some years since by the chemist of the Atchison, Topeka & Santa Fe Railway Co.

COMPOUND	GRAINS PER U. S. GALLON.
Calcium carbonate	14.318
Magnesium bicarbonate	7.817
Calcium sulphate	10.217
Sodium sulphate	40.071
Sodium chloride	41.329
Silica	0.390
Alumina and Iron oxide	.807
Organic matter	.180
Total solids	115.129
Chlorine combined	24.940

* For information regarding these wells we are indebted to their owners and to Mr. Frank Leverett of the United States Geological Survey, and to Mr J R Robinson. The record of the well of the Columbian Straw-Paper Co., is taken from Keyes' report of the Geology of Lee County (Iowa Geological Survey, vol., III, p. 405), but the author is responsible for the assignment of the formations.

† Approximately.

RECORD OF STRATA, PAPER CO.'S WELL.

	STRATA.	THICKNESS.	DEPTH, FEET.	A. T. FEET.
5.	Black loam, quicksand and blue clay, not separated in the record—doubtless largely the last, Pleistocene	145	145	379
4.	Limestone, Augusta	35	180	344
3.	Shale, blue and white, Kinderhook	250	430	94
2.	Limestone, Devonian and Silurian	180	610	-86
1.	Sandstone, water-bearing, Silurian	77	687	-163

LVIII. MOUNT CLARA, NEAR MONTROSE.

Little of this well has been learned further than the following geological section of which all except the elevations A. T. and the assignment of the geological formations is taken from Keyes'* report.

STRATA.

	FORMATION.	THICKNESS. FEET.	DEPTH. FEET.	A. T. FEET.
12.	Clay	250	250	429
11.	Sand	55	305	374
10.	Limestone, white, Augusta-Burlington	25	330	349
9.	Shale, white, Augusta-Burlington	8	338	341
8.	Limestone, Augusta-Burlington	5	343	336
7.	Shale, Kinderhook	325	668	11
6.	Limestone, Devonian	115	783	-104
5.	Limestone, Devonian (?)	10	793	-114
4.	Limestone, flinty, Silurian	25	818	-139
3.	Limestone, Silurian	40	858	-179
2.	Limestone, hard, Silurian	5	863	-184
1.	Samples carried away by water	76	939	-260

Mr. Bain informs us that a flow was encountered at about 800 feet. When the well was first drilled water flowed 200 gallons per minute, but at the present time the head is ten feet below the surface, or 670 feet A. T.

LIX. KEOKUK.

Information is furnished by the proprietors of the wells and Mr. F. Z. Goenisch. The elevation of the Poultry Co.'s well is from special survey by Mr. G. M. Walker. The record of same is by Mr. Geo. M. Crofts from examinations

*Iowa Geol. Surv., vol. III, p. 406.

of the drillings. The record of the Hubinger wells are taken from Gordon's* and from Keyes'† reports.

OWNER.	Depth.	Elevation of curb A. T.	Head of water.	Discharge in gallons per minute	Diameter—inches	Temperature—degrees Fahr	Date of completion.
J. C. Hubinger & Co, 3 wells	2,000	637	667 A. T.	1,700	12–10	65	------
J. C Hubinger & Co, 1 well	2,230	637	667 A. T.	300	10	65	------
Keokuk Pickle Co.	710	------	35*	250	6	64	1892
Keokuk Poultry Co.	700	541	545 A. T	250	6	60	1895
Kertz Brewery	700	600	--------	------	3	65	------
City Park	1,800	637	--------	------	5	60	------
Hubinger Tile works	800	620	667 A. T.	----	6	50	------

*Above curb.

The blanks in this table are the most to be regretted, as the Keokuk basin is one of the most interesting in the state. The water springs from Silurian sandstones at a reported depth in the Hubinger wells of 113 feet below sea level. The contributions of deeper strata are not on record. So far as known, this is the only town in Iowa in which the artesian water power is mechanically utilized. "The Hubinger wells," says Mr. Gordon, "are located on the bluff overlooking the Mississippi and the water is received in an artificial lake. * * * From this lake the water is then carried in a chute down the face of the bluff about 130 feet, where it is utilized in running two dynamos for furnishing incandescent lighting to the city." At the date of Mr. Gordon's writing, 1889, only two of the Hubinger wells had been completed, and these supplied about 1,300 gallons per minute. When the four wells were in operation, they at first discharged 2,000 gallons per minute, and at the same time the flow of the park well nearly ceased. The Kertz Brewing Co. well, whose first flow was "very good," has "hardly any" discharge at present. In 1894 the Hubinger wells also had fallen to 1,500 and in 1896 to 900 gallons per minute.

Several of the wells were drilled by Tweedy Brothers, of Keokuk.

*American Geologist, vol. IV, pp. 237-239.
†Iowa Geol. Surv., vol. III, pp. 323-324.

ANALYSIS.

	NO. 1— KEOKUK PICKLE CO.		NO. 2— KEOKUK POULTRY CO	
	Grains per U. S. gallon.	Parts per million.	Grains per U. S. gallon	Parts per million
Silica ($Si\ O_2$)	.406	7.000	.340	5 857
Alumina ($Al_2\ O_3$) / Ferric oxide ($Fe_2\ O_3$)	.447	7.710	.050	.857
Lime (Ca O)	13.920	240.000	16.356	282.000
Magnesia (Mg O)	8.327	143 576	3.339	57.572
Potash ($K_2\ O$)	Trace	Trace.	----------	----------
Soda ($Na_2\ O$)	65.400	1,127 571	81.581	1,406.571
Chlorine (Cl)	36.714	633.000	38.092	674.600
Sulphur trioxide ($S\ O_3$)	74.729	1,288 428	76.800	1,324.143
Carbon dioxide ($C\ O_2$)	5 079	87 572	14.003	241.429
Water in combination ($H_2\ O$)	1.044	18 000	2.676	46.143
Free (CO_2)	[7 896]	[136.142]	----------	----------
UNITED AS FOLLOWS				
Calcium bicarbonate ($Ca\ H_2\ (Co_3)_2$)	9.338	161.000	23.971	413.286
Calcium sulphate ($Ca\ SO_4$)	25.993	448.143	15.834	273.000
Magnesium sulphate ($Mg\ SO_4$)	24.874	428.857	9.984	172.143
Sodium sulphate ($Na_2\ SO_4$)	76.129	1,312.574	108.054	1,863.000
Sodium chloride (Na Cl)	60.593	1,044.714	64 562	1,113.143
Potassium chloride (K Cl)	----------	----------	2.660	45.857
Silica ($Si\ O_2$)	.406	7.000	.340	5 857
Alumina (Al_2O_3) and oxide of iron	.447	7.710	.050	857
Oxygen replaced by chlorine	8 286	142.859	8 783	151.428
Solids	206.066	3,552.857	234.237	4,038.571

Analyst, Prof. J. B. Weems. Date of No. 1, May 25, 1896; No. 2, July 19, 1896

RECORD OF STRATA.

Well of Keokuk Poultry Co.

The following record is made by Mr. George M. Crofts of Keokuk, from examination of drillings and driller's record. The summary is by the author.

	STRATA.	THICKNESS	DEPTH
28.	Drift, promiscuous material	5	5
27.	Limestone, magnesian	2	7
26.	Dolomite (magnesium limestone), in which lime carbonate predominates	5	12
25.	Same, with chert (flint)	5	17
24.	Same, in which magnesian carbonate predominates, and traces of iron	18	35
23.	Limestone slightly siliceous	15	50
22.	Limestone, rather highly siliceous, yields traces of iron	18	68

	STRATA.	THICKNESS.	DEPTH.
21.	Limestone, light colored, rather pure, slightly siliceous	30	98
20.	Limestone, gray, rather highly siliceous, yields traces of iron	23	121
19.	Limestone, gray, slightly mixed with shale	14	135
18.	Dolomite (magnesian limestone), with a large amount of chert (flint)	11	146
17.	Chert, mostly, and fossil limestone	19	165
16.	Limestone, with white sand (siliceous limestone)	17	182
15.	Limestone, with chert, slightly siliceous	5	187
14.	Shale, almost pure	10	197
13.	Shale, blue, highly siliceous	6	203
12.	Shale, as No. 14	5	208
11.	Limestone, gray, quite pure	17	225
10.	Dolomite (magnesian limestone), in which magnesia carbonate greatly predominates	46	271
9.	Limestone, light colored, almost pure	19	290
8.	Shale, blue, would weather into a tenaceous clay	73	363
7.	Shale, bituminous	39	402
6.	Shale, gray, would weather into a tenaceous clay	94	496
5.	Limestone, light gray color, almost pure	15	511
4.	Limestone, light colored, almost pure	10	521
3.	Limestone, gray, almost pure	60	581
2.	Limestone, siliceous	47	628
1.	Sandstone, gray, calcareous, yields traces of iron	73	701

SUMMARY.

	FORMATION	THICKNESS	DEPTH.	A. T.
28.	Pleistocene and Recent	5	5	536
19 27	Keokuk	130	135	406
17–18.	Montrose cherts, Mississippian	30	165	376
15–16	Upper Burlington, Mississippian	22	187	354
9–14.	Lower Burlington, Mississippian	103	290	251
6–8.	Kinderhook, Mississippian	206	496	45
3-5.	Devonian	85	581	–40
1–2.	Silurian	120	701	–160

HUBINGER WELL.

In the following record the strata, with their thickness and depth, are as given by Gordon.*

*American Geol, vol. IV, p. 238

The assignment of formations is based largely upon that by Keyes.*

STRATA.

	FORMATION.	THICKNESS FEET	DEPTH FEET.	A. T. FEET.
20.	Bluff [loess] Pleistocene	25	25	---
19.	Boulder clay, Pleistocene	3	28	609
18.	Limestone, Saint Louis, Mississippian	5	33	---
17	Sandstone, Saint Louis, Mississippian	5	38	599
16.	Limestone, Augusta, Mississippian	12	50	--
15.	Shale, Augusta, Mississippian	58	108	---
14.	Limestone, Augusta, Mississippian	62	170	---
13.	Shale, Augusta, Mississippian	10	180	---
12.	Limestone, Augusta, Mississippian	110	290	347
11.	Shale, calcareous, Augusta(?), Mississippian	65	355	---
10.	Limestone, Augusta, Mississippian	10	365	272
9.	Shale, Kinderhook. Mississippian	195	560	77
8.	Limestone (?) Devonian	65	625	12
7.	Sandstone, Silurian	20	645	---
6.	Limestone, sandy, Silurian	55	700	---
5.	Sandstone, Silurian	37	737	-100
4.	Shale, Maquoketa	63	800	-163
3.	Limestone, sandy below, Trenton	140	940	-303
2.	Sandstone, Saint Peter	110	1,050	-413
1.	Limestone alternating with sandstone, Oneota and Saint Croix	755	1,805	-1,168

LX. CENTERVILLE.†

Two deep borings have been sunk by the incorporated town of Centerville. The first, No. 1 of the following table, was drilled some years ago in the public square; the second, No. 2, was begun by J. P. Miller & Co., in May, 1895, and was finished by them in October of the same year, a short time considering the difficulties of the strata of the region.

*Iowa Geol. Surv., vol. III, p. 323.

†For an unusually large set of sample drillings from the first well, and also for the information regarding it, we are indebted to Col. E. C. Haynes. The second well is reported by Mr. H. F. Bain and by Messrs. Clark and Peatman.

			A.T.	
			1017	
PLEISTOCENE		90	927	TILL
CARBONIFEROUS	Des Moines	526	-491	SHALES, WITH A FEW THIN SEAMS OF LIMESTONE AND COAL, NONE OVER FIVE FEET THICK.
	Saint Louis and Augusta	560		"ROCK", PROBABLY LIMESTONE.
		610		SHALES, VARIEGATED ABOVE, ARENACEOUS BELOW
		640		LIMESTONE, ROUGH, GRAY, SILICEOUS.
		705		SHALES, SELENIFEROUS, WITH SOME LIMESTONE AND CHALCEDONY.
		760		LIMESTONE, HIGHLY CHERTY, WITH SHALE.
		815		SHALES CHERTY WITH LIMESTONE.
		855		LIMESTONE WHITE, HIGHLY CHERTY, CHALCEDONY.
		1041	-24	LIMESTONE WHITE, GRAY, AND BROWN, MOSTLY CHERTY, WITH SHALE.
	Kinderhook	1100	-83	SHALE, BLUE AND GREENISH GRAY.
DEVONIAN		1160		SHALE, WITH WHITE AND GRAY LIMESTONE.
		1200		WATER.
		1360	-343	LIMESTONE, NON-MAGNESIAN, WITH SOME SHALE.
SILURIAN		1380		LIMESTONE, BUFF, MAGNESIAN.
				SHALE AND BLUE LIMESTONE.
		1480		SANDSTONE, FINE, CALCIFEROUS, BUFF.
		1540	-523	LIMESTONE, MAGNESIAN, SILICEOUS.
ORDOVICIAN	Trenton	1740	-723	LIMESTONES, MAGNESIAN AND DOLOMITIC, IN PLACES CHERTY, UNDERLAIN WITH SHALE.
	Saint Peter	1780	-763	SANDSTONE, ROUNDED GRAINS, CLEAN.
	Upper Oneota	1890	-873	DOLOMITE.
	New Richmond	1995		SANDSTONE AND DOLOMITE.
		2060	-1043	SANDSTONE, FINE, ANGULAR, GRAY.
	Lower Oneota	2140 2352 2500	-1483	DOLOMITE, CHERTY AND ARENACEOUS IN PLACES.

CENTERVILLE WELL SECTION.

NUMBER.	Depth	Elevation of curb A. T.	Head of water A. T.	Capacity per minute.	Depth of water horizon.	From surface.
1	2,495	1,0[illegible]9	759	200	1,200	2,450
2	1,540	1,017	737	350	1,439	1,540

The casing in No. 1 is as follows: 12-inch to 55 feet; 10-inch to 95 feet; 9-inch to 155 feet; 8-inch to 335 feet; 7-inch to 492 feet; 6-inch to 616 feet; 5-inch to 804 feet. The bore continues 5 inches to 2,335 feet, and 4 inches the remainder of the distance to the bottom. The water is a mineral water, but not unpleasant to the taste. Bored long before water works were installed, the well never was used; and when a complete system of works was begun in 1895, it was found best to sink a new well at a more convenient location.

Well No. 2 is cased to 860 feet with tubing varying from 14 inches to 7 inches and 90 feet of casing is inserted between 1,100 and 1,200 feet. The water seems to be satisfactory to the town; it is said to be largely used and well liked. As a steam water it is excellent, causing neither corrosion nor scale.

The following analyses will indicate the physiological effects that may be expected from its use.

ANALYSIS, WELL NO. 2.

	GRAINS PER U. S. GALLON	PARTS PER MILLION.
Silica ($Si O_2$)	.596	10.285
Alumina ($Al_2 O_3$) and Ferric oxide ($Fe_2 O_3$)	.174	3.000
Lime ($Ca O$)	21.319	367.571
Magnesia ($Mg O$)	8.650	149.143
Potash ($K_2 O$)	Trace.	Trace.
Soda ($Na_2 O$)	58.994	1,017.143
Chlorine (Cl)	22.537	388.571
Sulphur trioxide ($S O_3$)	94.772	1,634.000
Carbon dioxide ($C O_2$)	3.853	66.429
Water in combination ($H_2 O$)	17.690	305.000
Free (CO_2)	[8.576]	[147.857]

UNITED AS FOLLOWS.

	GRAINS PER U. S GALLON.	PARTS PER MILLION.
Calcium bicarbonate (Ca H_2 $(CO_3)_2$)	7.067	121.857
Calcium sulphate (Ca SO_4)	45.870	790.857
Magnesium sulphate (Mg SO_4)	25.818	445.143
Sodium sulphate (Na_2 So_4)	89.859	1,549.286
Potassium chloride (K Cl)	Trace.	Trace
Sodium chloride (Na Cl)	37.195	641.286
Silica (Si O_2)	.596	10.285
Alumina (Al_2 O_3) and Ferric oxide	.171	3.000
Combined water (H_2 O)	16.895	291.286
Oxygen replaced by chlorine	5.112	88.143
Solids	228 585	3,941.143

Analyst, Prof. J. B. Weems. Date, April 10, 1896.

This water is very similar to the heavily mineralized waters at Keokuk, drawn also from the beds of the Silurian. In the first well it does not seem to have been shut off, and the following analysis probably shows the chemical constitution of a mixture of the Silurian with purer and deeper waters. The well had been closed for years when the analysis was made.

ANALYSIS, WELL NO. 1.

COMPOUND.	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium carbonate	10.4657	179.3
Calcium sulphate	3.3621	57.6
Sodium sulphate	41.6878	714.2
Sodium chloride	13.2150	226.4
Magnesium chloride	3.3970	58.2
Silica	4.7338	81.1
Volatile matter	5.4167	92.8
Ammonia	------	Trace.
Nitrites	------	Faint traces.
Totals	78.8811	1409.6

Analyst, J E. Siebel, Chicago Date, March 30, 1895

WELLS OF SOUTHWESTERN IOWA.

Geological Notes.

The country rock of southwestern Iowa consists of the Coal Measures, except only where these are overlain by patches of the Cretaceous. Their thickness is a matter of practical interest. It concerns the miner of coal, the prospector for gas and oil, and the driller in search of artesian waters. It may be estimated by several methods. Assuming a uniform dip of the strata and knowing the width of outcrop along the line of this dip, a short trigometrical calculation gives the thickness of the series. The further assumption is involved, however, which may or may not be true, that the assumed or ascertained dip of the strata corresponds to the inclination of the floor on which the series rests.

Again, the thickness may be measured of each of the successive beds outcropping along the line of the dip, and thus their aggregate thickness may be obtained by addition. This method is especially unreliable, if not wholly impracticable, where, as in southwestern Iowa, the country is heavily mantled with drift, and in case of a series like the Coal Measures where strata are affected with rapid lithological changes. It is largely by these methods that the following estimates have been made of the thickness of the Coal Measures in southwestern Iowa and adjoining counties of Missouri.

1858	Hall	Iowa	1,000
1872	White	Iowa	600
1891	Winslow	Missouri	1,900
1894	Broadhead	Missouri	2,000
1893	Keyes	Iowa	1,600
1894	Keyes	Missouri	1,600
1894	Lonsdale	Iowa	2,000

In a recent paper on the thickness of the Paleozoic rocks of the Mississippi basin, from which the above table in part is taken, Keyes seems to return toward the earlier and lower estimate, and states that the maximum thickness of the Coal Measures in the central part of the basin is considerably less than his previous estimates as given in the table.*

The third method of obtaining the thickness of any formation is the practical test of the drill. This is especially reliable when the formation has distinct lithological characteristics and limits, and when the boring is made by a diamond drill, or, if made by a plunge drill, where the drillings are taken at close intervals.

* American Geologist, vol. XVII, pp. 169-173. 1896.

It need not be said that the Coal Measures are readily recognized by their lithological characteristics, by the predominance of shales, by the rapid alternation of limestones and shales and sandstones, and by the presence of carbon in coal and carbonaceous shales. And not only in Iowa, but from Kansas to Indiana and to Tennessee, the rocks forming the floor of the Coal Measures, the Mississippian series, include heavy beds of chert and cherty limestone and shales. In the interpretation of the records of deep wells the passage from the Coal Measures to the Mississippian is therefore one of the most readily recognizable of geological horizons. Fortunately we have the data of four wells which pass through the Coal Measures in or near the district in question, the drillings from three of which form in each case a practically continuous section. At Atlantic the shales, limestones, and sandstones of the Coal Measures extend to 300 feet A. T., a thickness of 725 feet. At this depth there succeed 420 feet of chert and highly cherty limestones and shales. Chalcedonic silica is often present in the drillings from this immense body of rock, and in several instances constitutes the bulk of the sample. Below these rocks, evidently Mississippian, at 120 feet below tide, the drill passed into forty feet of shale and limestone which may belong to the Devonian.

Under this interpretation the Mississippian floor is practically at the same level at Atlantic as at Des Moines.

At Omaha the lowest shale reported in the well of the Willow Springs distillery* that could be assigned to the Coal Measures ends at 1,030 feet below the surface, or about at sea level. At 1,055 feet below the curb there begins a series of Magnesian limestones and dolomites which continues to 1,780 feet, interrupted, so far as our data shows, only by a thin shale at 1,250 feet and a white sandstone at 1,430 feet. The Coal Measures here can scarcely exceed 1,000 feet in thickness. The third well record in evidence is that sunk at Lincoln, Neb., by the state, between 1885 and 1888. In

* Drilling from this well were kindly presented to the Survey by the proprietors.

this boring the diamond drill was employed. Every foot of the section is represented by a solid core of rock. The report of the well is made by an official geologist. As the record is so exceptionally reliable, and as it so directly concerns the interpretation of the well records of southwestern Iowa, we may here introduce a summary of the determinations of Mr. B. P. Russell, the geologist in charge of the boring.*

		THICKNESS.	DEPTH.
12.	Sandstone, Dakota	240	240
11.	Limestone, sandstone and shales, Carboniferous	840	1,080
10.	Magnesian limestone, age undetermined	138	1,218
9.	Sandstone, gray, age undetermined	15	1,233
8.	Magnesian limestone, age undetermined	194	1,427
7.	Shale, red, age undetermined	13	1,440
6.	Magnesian limestone, age undetermined	373	1,813
5.	Limestone, Trenton	134	1,947
4.	Sandstone, Saint Peter	61	2,008
3.	Limestone, Magnesian, Lower Magnesian	113	2,121
2.	Sandstone, red, Potsdam	72	2,193
1.	Quartzite, varying to a much metamorphosed shale, traversed in places by quartz veins at angles from 75° to 85°, from flesh tint to dark red, Algonkian	270	2,463

Here less than fifty miles west of the supposed center of the Carboniferous basin placed at the intersection of the Missouri river by the southern boundary of Iowa, the entire Carboniferous is included within 840 feet. Interpreted in the light of the Lincoln section, the samples of dolomitic limestone in the Omaha well saved at intervals from 1,055 to 1,782 feet may be taken to belong to a series of such limestones extending between these limits with but few and slight interruptions.

The Glenwood section is less satisfactory than that at Lincoln only in that the boring was made by a plunge drill and inasmuch as it fails to reach an Algonkian *terminus ad quem*. Two hundred and ten samples, carefully preserved by a trained civil engineer, leave little room for doubt as to the

*Sixth Biennial Report of Commissioner of Public Lands and Buildings, pp. 59-84. Lincoln, Neb., 1888.

exact nature of the strata penetrated. The record of the well was first published by Mr. R. E. Call, who referred the entire section, 2,000 feet deep, to the Carboniferous, placing the base of the Upper Coal Measures, or Missourian stage, at 317 feet from the surface.* Not having examined the drillings he evidently was misled by the original record, which, as we shall see, often fails to describe the real nature of the samples. The section has been recently reviewed by Mr. E. H. Lonsdale.† He not only follows Call in considering the whole section Carboniferous, but even takes it all to belong to the Coal Measures. At 2,001 feet he considers that the lower Carboniferous, or Mississippian, was nearly reached. The base of the Missourian is drawn at 1,400 feet. The record of the strata published on pages 342–7 shows that the determinations of both Call and Lonsdale are without foundation in fact. The first notable change which can be taken as the base of the Missourian occurs at 845 feet, where the succession of alternating limestones, calcareous shales and sandstones gives place to one of sandstones and argillaceous shales, the latter predominating.

Nearly 400 feet lower a still more marked change occurs and here must be the base of the Coal Measures. From this horizon at 1,235 feet cherts and cherty shales and limestones, in places chalcedonic, extend to 1,465 feet, interrupted only by twenty-five feet of sandstone at 1,210, and twenty feet of argillaceous sandstone at 1,280 feet. It seems highly improbable that these cherts can belong to the Coal Measures. If this is the case it is a singular fact that beds of such thickness and obduracy should fail of outcrop in the Coal Measure areas. Limestones with more or less chert, occur indeed, in the Missourian stage, as for example in Montgomery county, whose western line is less than twenty miles east of Glenwood. But it will not be seriously held that the superficial cherty limestones of this county are the equivalent of the

*Proc. Iowa Acad. Sci., vol. I, pt. II, pp. 60-63. Des Moines, 1892.
†Proc. Iowa Acad. Sci. vol. II, pp. 198-199. Des Moines, 1895.

cherts of Glenwood and Atlantic lying 1,200 feet deeper. The former, as shown by deep prospect holes in the county are part of a series of thinly bedded alternating limestones and shales similar to the Missourian stage in the Glenwood section. The latter are underlain by magnesian limestones which are certainly pre-Carboniferous.

If the latter are included in the Coal Measures, no good reasons can be given for excluding similar beds of chert in several well sections of Iowa and the cherts which have been taken by the University Survey of Kansas to form the Mississippian floor in that state. The natural interpretation of the Glenwood section limits the thickness of the Coal Measures to 1,060 feet, the maximum measured thickness of the series in Iowa.

The lower limit of the Mississippian at Glenwood cannot be drawn with precision. Certainly it must be placed as low as the base of the cherts at 1,465, giving a thickness to this formation of 230 feet. Whether the forty-five feet of limestone and the 134 feet of shale that underlie the cherty beds are in whole or in part Devonian cannot be determined. At 1,668 feet from the surface there begins a series of limestones, almost wholly magnesian and dolomitic, which extend with little interruption to 2,000 feet. The drillings from these beds, as is usual in the case of dolomites, are taken out in the form of hard, sparkling, crystalline angular sand, and it is doubtless for this reason that they have been listed as fine sandstones in the previous reports of the well and, as sandstones, are included in the Coal Measures. The microscope and the test tube demonstrate at once that they are as purely calcareo-magnesian as are the outcrops of the Niagara or Galena in northeastern Iowa. To what age do they, then, belong? The presence of the Algonkian at Lincoln, Neb., fifty miles west, at a level about 200 feet below the base of the Glenwood well would indicate that the latter may have penetrated the Magnesian series. That series, however, is commonly arenaceous and these dolomites are not. The gypsum that they carry from 1,930 to 2,000 feet points strongly to the Silurian, which is noticeably gypseous at Pella, Oskaloosa and Des Moines. The shale in which the boring stopped may therefore be Maquoketa. At Omaha the greater thickness of the Magnesian limestones indicates that the drill may there have reached lower geological horizons than at Glenwood; on the other hand the lower waters of both wells were struck at about the same levels.

At Atlantic the Mississippian cherts end at 1,270 feet below the surface, with a thickness of 420 feet, and are underlain by a thin shale and limestone, which may be Devonian.

Artesian Conditions of Southwestern Iowa.

Artesian water in this section may be found in the Coal Measures, at their base, and in the heavy Magnesian limestones which underlie the Carboniferous. Along the immeadiate valley of the Missouri experience fully warrants the sinking of wells. The water of the Coal Measures of the Missourian stage will be small in quantity and may be salt with the fossil brines of the ancient ocean in which these sediments were laid. The yield of the Magnesian limestones will be much more ample, and should be reached within at least 900 feet below tide, unless it be in Fremont county, where the drill may have to go deeper.

The possibility that additional water will be found in the Ordovician and Cambrian is sufficient to warrant the experiment of continuing borings to 2,500 or 3,000 feet from the surface, although before the latter depth is reached the Algonkian will probably be met, beyond which point no exploitation should proceed.

As to the quality of the water too much should not be expected. After casing out the brines of the Coal Measures, the water will still be found heavily impregnated with mineral matters, but probably not beyond the limits of potable water. The analyses of the wells at Glenwood and Council Bluffs indicate the nature of the artesian waters of the district.

Outside of the Missouri valley the sinking of deep wells can not be encouraged. Nor, on the other hand, can it be asserted that they will be failures. Under the former theory that the thickness of the Coal Measures in this region was read in thousands of feet, every attempt to discover artesian water was naturally condemned. The view here presented of their thickness offers more hope. At the same time, no boring should be begun without the expectation of prosecuting the work to at least 1,000 feet below tide, if artesian water is not found before. Any wells like the borings at Clarinda and Atlantic, the first of which does not penetrate the Coal Measures, and the second of which scarcely goes beyond the Carboniferous will, in all probability, also be fruitless. At Osceola, however, no artesian water was discovered in quantity, so far as we are informed, although the well was drilled to nearly 2,000 feet from the surface, to 821 feet below tide. Here the Silurian was probably passed through, but not the Ordovician; and we can not assert that success would not have crowned the carrying on of the work 700 or 800 feet further.

A complete geological section of this important well would have afforded data for a reliable prognosis of artesian conditions for all this region, and it is a distinct loss to the state that the record and samples of the drillings were not kept. With the scanty facts at hand we may infer that the Ordovician and Cambrian continue to sink southward from Des Moines and westward from Centerville. The well section at Lincoln, Neb., if rightly read by Russell, shows that the strata again rise to the west of the Missouri river. If the gradient is alike on both sides, the center of the trough lies near the Nodaway. Taking the base of the Silurian, instead of the Saint Peter, in the surrounding wells as data, the center will be shifted to the Tarkio or Nishnabotna. We may, therefore, expect that the base of the Silurian, above which lie the artesian waters of Glenwood and perhaps Omaha, should be reached along the Chicago, Burlington & Quincy railway, at 1,000 feet below tide at the farthest.

The formations below the Silurian, as shown by the Lincoln section, thin toward the west. Their thickness in southwestern Iowa, and whether they carry artesian water suitable for town supply, are matters of conjecture. A 3,000-foot boring might be successful in reaching artesian water, and if carefully observed would certainly help to solve the stratigraphic and hydrographic problems of the region.

Another factor to be taken into account is the elevation above sea level. The high altitude of towns on the divide not only increases the necessary expense of reaching the deeper artesian horizons, but renders it questionable whether the water will rise within profitable pumping distance. The head at Glenwood is 1,006 A. T., and at Council Bluffs 1,090 A. T. The pressure of ground water may increase this on the higher ground to the east, but 1,100 or 1,200 feet A. T. would seem to be the most that can be reasonably expected at the best.

LXI. ATLANTIC.*

Prospect boring of Atlantic Coal & Mining Co. Elevation of well water 1,150 A. T.

		THICKNESS, FEET.	DEPTH, FEET.
72.	Pleistocene? (no sample)	125 ?	125 ?
71.	"Shale, blue"	35	160
70.	"Shale, gravelly"	35	195
69.	"Shale, red and blue, gravelly"	5	200
68.	"Limestone, gray, sandy'	15	215
67.	"Shale, red and blue, with soapstone"	5	220
66.	"Shale, gravelly"	5	225
65.	Shale, purple, dark drab and green, fine, unctuous; with pebbles (five noted of limestone, one of vitreous sandstone, one of coal)	35	260
64.	"Shale, gravelly"	50	310
63.	"Clay, mottled, red and blue"	30	340
62.	"Shale, blue"	15	355
61.	"Shale, red and blue, with gravel"	5	360
60.	"Shale, blue, with slate"	5	365
59.	"Sandstone and shale"	50	415

*Samples of the drillings of this well were placed at the disposal of the Survey by the generosity of Mr. Seth Dean of Glenwood.

		THICKNESS.	DEPTH.
58.	"Slate, black; soapstone blue and green"	5	420
57.	Shale, varicolored, green and reddish, fissile, practically non-calcareous	10	430
56.	"Sandstone"	5	435
55.	"Shale"	15	450
54.	"Shale and limestone"	15	465
53.	"Shale, as No. 57"	--	---
52.	"Clay and soapstone"	15	480
51.	"Sandstone"	25	505
50.	"Shale, blue"	12	517
49.	Shale, dark gray, very finely laminated, somewhat calcareous	23	540
48.	"Sandstone, or sandy limestone"	10	550
47.	Shale, dark gray	15	565
46.	Shale, dark brown-gray, non-calcareous, arenaceous, pyritiferous	20	585
45.	Sandstone, brown, highly ferruginous	5	590
44.	"Sandstone"	10	600
43.	"Shale, sandy"	30	630
42.	"Sandstone, very fine"	30	660
41.	"Shale and slate"	15	675
40.	Shale, iron gray, finely laminated, non-calcareous	10	685
39	"Sandstone, white, very fine"	10	695
*38.	Clay, blue, with gravel	15	710
*37.	Shale, sandy	15	725
*36.	Sandstone	5	730
35.	Shale, finely arenaceous, ochreous, some black	10	740
34.	Shale, black, Carboniferous	10	750
*33.	Shale, blue and slate	10	760
*32.	Shale, yellow, gravelly	40	800
31.	Sandstone, gray, of finest grain, with much black shale, samples at 800 and 1,815	25	825
*30.	Limestone, sandy	5	830
*29.	Sandstone, brown	5	835
*28.	Sandstone, gray	15	850
27.	Limestone, white, non-magnesian, with much white chert, which constitutes the bulk of the sample	35	885
26.	Limestone, blue-gray, argillaceous, quartzose residue; with large fragments of dark shale, probably from above	75	960

*Determinations in quotations are supplied by Mr. Seth Dean; those marked with a * are from the MS. record of Mr. E. H. Lonsdale.

		THICKNESS.	DEPTH.
25.	Limestone, yellow-gray, sample composed chiefly of dark brown, flint with some chalcedonic silica; a very little quartz sand is present	5	965
24.	Flint, brown-gray, calcareous, with some chalcedonic silica; sample contains much shale in fragments	10	975
23.	Flint, gray and black, chalcedony, drusy quartz, some shale	5	980
22.	Flint, brown, calcareous, some chalcedony, a little shale	5	985
21.	Flint and chalcedony, five samples, drillings largely milk white, translucent chalcedony, with brown calcareous flint and some limestone	45	1,030
20.	Limestone, nearly white, with much white chert, two samples	15	1,045
19.	Chalcedony and flint. Mass of drillings so far as now remains after original washing is made up of chalcedonic silica and blue-gray and yellow siliceous fragments which effervesce in cold dilute H. Cl., but do not disaggregate; particles of pure limestone practically absent	30	1,075
18.	Shale and flint; shale, blue-gray, somewhat calcareous	5	1,080
17.	Limestone, soft, light yellow gray, with silica as above, and some fragments of shale, 4 samples	40	1,120
16.	Limestone, brown with much white chert	5	1,125
15.	Limestone, lighter colored, drillings chiefly chert; only finest sand is limestone and even this is siliceous	5	1,130
14.	Limestone, light yellow, nearly pure, considerable shale present in small fragments	5	1,135
13.	Limestone, as above, with much chalcedony and chert	5	1,140
12.	Limestone, white, chalky, and light yellow	5	1,145
11.	Chert, drillings consist of chert and chalcedony; at 1,145 a few rounded grains of crystalline quartz and particles of a fine-grained sandstone are present. Four samples, all these in mass effervesce freely in acid	25	1,170

		Thickness.	Depth.
10.	Flint, sample consists of black, yellow, and red flint and jasper, with sand of rounded grains of limpid quartz, and fragments of limestone, chert, and chalcedony	10	1,180
9.	Limestone, blue-gray, cherty and argillaceous	10	1,190
8	Chert, white and brown, some shale in sample	10	1,200
7.	Limestone, cherty, drillings gray in mass	25	1,225
6.	Limestone, siliceous material constitutes $\frac{1}{10}$ of sample by weight	20	1,245
5.	Chert and shale; chert effervescent; shale pink in fine grains, but slightly calcareous, color of sample buff	10	1,255
4.	Limestone, highly arenaceous and siliceous, with chert and chalcedony; $\frac{2}{5}$ of sample by weight insoluble	5	1,260
3.	Sandstone, highly calciferous; limestone arenaceous, quartz in minute angular particles; white and yellow-gray, two samples	10	1,270
2.	Shale, fine, light blue-gray, calcareous	15	1,285
1.	Limestone, cream yellow, rather hard, in angular sand	25	1,310

SUMMARY.

Number.	Formation.	Thickness, feet.	Depth, feet.	A. T., feet.
72.	Pleistocene	125 ?	125 ?	1,025 ?
28–71.	Coal Measures	725	850	300
3–27.	Mississippian	420	1,270	-120
1–2.	Devonian (?)	40	1,310	-160

LXII. OSCEOLA.

At this place a boring was sunk 1,953 feet. Artesian water was not found. Unfortunately no data of the geological section are extant. As the bottom of the boring is 821 feet below sea level, it evidently fell short of reaching the Saint Peter, whose depth here may be estimated at over 1,200 below tide.

LXIII. CLARINDA.

A boring was here sunk to a depth of 1,002 feet in search for coal. Water flowed from the top for a short time during the progress of the work, indicating local artesian conditions in the Coal Measures. The record, which seems to have been carefully kept, contains forty entries of shale of various kinds, limestone, marl and coal. The Mississippian does not appear to have been reached by the driller.

LXIV. COUNCIL BLUFFS*

OWNER.	Depth.	Elevation A. T.	Head A. T.	Capacity in gallons per minute.	Bore—inches.	Date of completion.
School for the deaf	1,091	1,040†	1,090†	59	4	1886
Incorporated town (?)	1,114					
Chicago, Milwaukee & St. Paul Railway Co.	860					

ANALYSIS OF WELL AT SCHOOL FOR THE DEAF.

COMPOUND.	GRAINS PER U. S. WINE GALLON.
Calcium bicarbonate	9.363
Magnesium bicarbonate	3.272
Sodium bicarbonate	12.155
Sodium sulphate	55.723
Potassium sulphate	.478
Sodium chloride	7.503
Magnesium sulphate	Trace
Silica and insoluble residue	.543
Alumina and oxide of iron	.123
Total solids	89.433

Analyst, Floyd Davis, Des Moines. Authority, Seth Dean.

LXV. GLENWOOD.

The facts given below are taken from an article on the Glenwood well by Mr. Seth Dean,‡ who has generously donated to the Survey a full set of drillings from the well.

Owner	Town.
Depth	2,000 feet.
Elevation of curb A. T.	1,132 feet.
Head of water A. T.	961 feet.

*For the information here published we are indebted almost wholly to Mr. Seth Dean, of Glenwood. Repeated inquiries made to the owners of the wells were not answered. The depth of the wells, other than that at the school for the deaf, is given on the authority of Mr. R. E. Call. (Iowa Weather and Crop Service, vol. III, p. 8. March, 1892.)

† Approximately.

‡Proceedings of Iowa Civil Engineer and Surveyors' Society, Des Moines, 1895, pp. 33-39.

Diameter	10 in., 4¾ in.
Depth of tubing	1,733 feet.
Capacity original in gallons per minute	60
Capacity present in gallons per minute	83
Date of beginning	February 20, 1889.
Date of completion	January 5, 1891.
Drillers	American Well Works Co.

DEPTH OF WATER HORIZONS FROM SURFACE.

CHARACTER OF WATER.	HEAD BELOW SURFACE.	DEPTH.
Fresh	---	154
Salt	176	716
Salt	15	825
Fresh	40	1,008
Fresh	126	1,210
Fresh	100	1,668
Fresh	40	1,794
Fresh	171	1,836

"The following interesting facts," says Mr. Dean, "were developed at the pumping tests made after the drilling was done. The first test was made by pumping ten hours continuously at about 3,000 gallons per hour. After the water standing in the well had been exhausted, a standard thermometer was inserted in the discharge pipe and the temperature noticed as follows. January 28, 1890, pump started at 10 A. M., speed 3,000 gallons per hour.

HOURS.	TEMPERATURE—FAHR.
10:15 A. M.	60°
11:30 A. M.	66°
12:00 M	68°
3:15 P. M.	69°

"Second test made July 26 and 27, 1892, pump started at 4:30 P. M., speed 3,600 gallons.

HOURS.	TEMPERATURE—FAHR.
July 26th, 4:50 P. M.	60°
July 26th, 5:00 P. M.	62°
July 26th, 5:40 P. M.	66°
July 26th, 6:00 P. M.	69°
July 26th, 8:17 P. M.	72°
July 27th, 2:45 A. M.	72½°
July 27th, 9:45 A. M.	72½°
July 27th, 11:00 P. M.	72½°

"The first test was made before the salt water had been excluded. The second test was made afterward. The tests seem to show quite a difference in the temperature of the water between the 1,668 feet and the 1,336 feet veins, and that about four hours pumping at 4,800 gallons per hour are required to exhaust the upper vein, or so nearly to exhaust it that it has no more effect on the temperature of the water pumped."

ANALYSIS.

	GRAINS PER U. S. GALLON.	PARTS PER MILLION.
Calcium carbonate	5.1372	88.089
Magnesium carbonate	1.8309	31.395
Iron carbonate	.2519	4.320
Sodium bicarbonate	50.5179	866.252
Sodium sulphate	31.0916	533.139
Sodium chloride	106.2845	1,822.500
Silica and insoluble residue	.6009	10.305
Alumina	Trace.	Trace.
Total anhydrous salts	195.7149	3,356.000
Loss on ignition	4.1189	70.800
Chlorine	64.4997	1,106.000
Free ammonia	.0483	.826
Albuminoid ammonia	.0042	.072
Nitrogen in nitrites	None.	None.
Nitrogen in nitrates	Trace.	Trace.

Total hardness of water, Clark's Scale, $7\frac{3}{10}$ degrees.

Analyst, Floyd Davis, Des Moines. Date, September 2, 1892. Authority, Mr. S. Dean.

Owing to the excellent domestic water supply at Glenwood and the peculiar taste of the city water, the latter is used for drinking purposes by but few families. Physicians report it slightly laxative and diuretic. In dyspepsia it has been prescribed with good results, and chronic dyspeptics who, for years, could use only the simplest farinaceous diet have recovered by its constant use. It has also been found of great benefit in kidney diseases. It will be noted in the analysis that, although the water is so highly mineralized, the compounds which are specially deleterious when used habitually, such as calcium and alkaline sulphates, are present in comparatively small quantity. The water is softer than some river waters of the state.

RECORD OF STRATA.

		THICKNESS.	DEPTH.
106.	Soil	2	2
105.	Loess	152	154
104.	Gravel and coarse sand, water-bearing	6	160
103.	Sand, coarse	5	165
102.	Till, yellow; pebbles, greenstones and other kinds	10	175
101.	Limestone, soft, light and darker gray, cherty	2	177
100.	Limestone, dark blue, argillaceous, pyritiferous	10	187
99.	"Shale, black carbonaceous"	1½	188½
98.	Clay, blue, shaly	6½	195
97.	Shale, iron gray	8	203
96.	Limestone, gray, earthy lustre	22	227
95.	Shale, dark blue-gray, fissile, with discs of crinoid stems and fragments of a productus	5	232
94.	Limestone, gray; lustre, earthy; compact, moderately hard, with crinoid stems, echinoid spines, and fragments of brachiopods	8	240
93.	Shale, black, carbonaceous	4	244
92.	Limestone, soft, yellow-gray, with fuselina	13	257
91.	Shale, blue	7	264
90.	Limestone, light yellow, fossiliferous	9	273
89.	Shale; dark red	16	289
88.	Limestone, brecciated, sample consists of two large unfractured masses of very hard limestone breccia; limestone gray, sometimes of reddish tint, matrix green-gray, and argillaceous, but hard	25	314
87.	Sandstone	9	323
86.	Limestone, argillaceous, bluish-gray	17	340
85.	Shale, blue	2	342
84.	Limestone, compact	5	347
83.	Shale, green-gray, arenaceous, calcareous	3	350
82.	Limestone, hard gray—highly cherty at 358	13	363
81.	Shale, hard, green-gray, highly calcareous	10	373
80.	Limestone, light green-gray, highly argillaceous	5	378

		Thickness.	Depth.
79.	Limestone, light yellow-gray, compact, fine grained	18	396
78.	Shale, black, carbonaceous; and hard, green-gray	9	405
77.	"Marl, white"	2	407
76.	Limestone, hard, gray	8	415
75.	Shale, gray, and limestone, argillaceous	4	419
74.	Shale, varicolored	19	438
73.	Limestone, gray, close textured	18	456
72.	Limestone, hard, blue, highly argillaceous, with crinoid stems and fragments of brachiopods	11	467
71.	Shale, black, carbonaceous, with impure gray limestone	3	470
70.	Sandstone	6	476
69.	Limestone, white and light gray, close textured, earthy lustre	15	491
68.	Slate, black	5	496
67.	Limestone, yellow-gray, fossiliferous, crystalline-earthy	12	508
66.	Shale, dark and green-gray, with chonetes	11	519
65.	Limestone, light yellow-gray, soft, fossiliferous	10	529
64.	Shale, green, calcareous	21	550
63.	Limestone, white, soft, crystalline-earthy	20	570
62.	Shale, gray, highly calcareous, fossiliferous	10	580
61.	Shale, black, carbonaceous and dark drab	15	595
60.	Limestone; white and light colored, in places fossiliferous, with one foot of "coal (?)" at 612 feet, and brown chert at 635 feet, nine samples	43	638
59.	Shale, varicolored, arenaceous with minute angular particles of limpid quartz, two samples	47	685
58.	Sandstone, green-gray, close and fine-grained, argillaceous, calcareous; with some siliceous limestone, hard, subconchoidal fracture, with much shale at 706 and 711, vein of salt water at 716	35	720
57.	Coal and black shale	1	721
56.	Shale, blue	4	725
55.	Limestone, gray, hard, fracture subconchoidal, close textured, fossiliferous and flinty at 732; with four feet of shale, blue, at 730	15	740

		THICKNESS.	DEPTH.
54.	Slate	12	752
53.	Limestone, arenaceous	3	755
52.	Shale, dark blue, calcareous; and black, carbonaceous	3	758
51.	Sandstone, dark brown gray. Calcareous, ferruginous, argillaceous, fossiliferous, with chonetes and other brachiopoda	6	764
50.	Limestone, lighter yellow-gray, highly fossiliferous in places, with shale at 733	27	791
49.	Shale, black, slaty	2	793
48.	Shale, gray	7	800
47.	Limestone with shale	15	815
46.	"Shale, blue, with sandstone band"	10	825
45.	Sandstone, fine gray, micaceous, vein of salt water	20	845
44.	Shales, some fossiliferous, in places carbonaceous, mostly non-calcareous, of various colors, with limestone at 868 and 885 and 956, coal at 956, pyrite at 901, 17 samples	117	962
43.	Limestone	3	965
42.	Sandstone and shale, fossiliferous	24	989
41.	Sandstone, gray, soft, argillo-calcareous, fine-grained	9	998
40.	Shale, hard, brittle, non-calcareous, green and brown	10	1,008
39.	Sandstone, gray	17	1,025
38.	Shale, hard, brittle, of various bright colors, finely laminated, fracture splintery, non-calcareous	20	1,045
37.	Shale, arenaceous	36	1,081
36.	Shale, black, carbonaceous	7	1,088
35.	Fireclay, in moulded masses, gray	6	1,094
34.	Shale, black and gray, with some sandstone	8	1,102
33.	Limestone	2	1,105
32.	Shales, of various colors, hard, brittle, non-calcareous	23	1,128
31.	Sandstone, fine-grained, with shale; two samples	22	1,150
30.	Shale, mostly black, brittle, splintery	10	1,160
29.	Sandstone, four samples	30	1,190
28.	Shale, black, hard, fissile	5	1,195
27.	Chert, gray, with shale, limestone and sand	10	1,205

		THICKNESS.	DEPTH.
26.	Sandstone, gray, grains of moderate size, imperfectly rounded; two samples	30	1,235
25.	Chert, with limestone, chalcedonic, silica and quartz sand; the latter sometimes seen imbedded in the chert; five samples	45	1,280
24.	Sandstone, argillaceous, in dark gray powder	20	1,300
23.	Chert with chalcedony, limestone, and at 1,305 much shale; five samples	70	1,370
22.	Shale, highly calcareous, in blue-gray concreted powder, residue after washing of pyritiferous chert, quartz sand, a little glauconite, and non-magnesian limestone; three samples	35	1,405
21.	Limestone, cherty, argillaceous, drillings blue-gray; three samples	60	1,465
20.	Limestone, gray; two samples	45	1,510
19.	Shale, highly quartzose and calcareous, in light blue-gray powder; three samples; quartz particles minute	90	1,600
18.	Shale, green, massive	44	1,644
17.	Limestone, in flakes, light yellow-gray, some soft and white, non-magnesian, compact, with some chert at 1,649	24	1,668
16.	Limestones, magnesian, or dolomites, crystalline, drab, buff and brown, largely in sand; effervescence somewhat more rapid than Le Claire dolomite; four samples	41	1,709
15.	Limestone, brown and gray, with considerable green shale at 1,720	24	1,733
14.	Limestone, magnesian, or dolomite, brown, rough crystalline; four samples	32	1,765
13.	Sandstone, gray, grains of limpid quartz imperfectly rounded, with some crystals	19 (?)	1,784
12.	Limestone, magnesian, or dolomite, buff and yellow; three samples	28	1,812
11.	Limestone, somewhat magnesian, moderately rapid effervescence, in brown and buff crystaline sand; two samples	20	1,832
10.	Limestone, magnesian and dolomites, crystalline, vesicular, brown and buff	68	1,900
9.	Dolomite, light yellow-gray, cherty, three samples	24	1,924
8.	Dolomite, greenish-gray, argillaceous residue	6	1,930

		THICKNESS.	DEPTH.
	Dolomite, light gray, with much gypsum, water-bearing	8	1,938
	Gypsum, in light yellow concreted powder, now highly indurated, which disaggregates with difficulty in boiling HCL., in which most of it is soluble	3	1,941
5.	Dolomite, gray, with flakes of gypsum and selenite; four samples	39	1,980
4.	Limestone, gray, somewhat magnesian, seleniferous, argillaceous	10	1,990
3.	Shale, soft, greenish, calcareous	5	1,995
2.	Dolomite, gray, in powder, highly seleniferous	5	2,000
1.	Shale, hard, green, very slightly calcareous, at	--	2,000

SUMMARY.

		THICKNESS.	DEPTH A. T.
102–106.	Pleistocene	175	175
45–101.	Missourian	670	845
26–44.	Des Moines	390	1,235
21–25.	Mississippian	230	1,465
19–20.	Devonian (?)	135	1,600
2–18.	Silurian	400	2,000
1.	Maquoketa (?) at	--	2,000

Flowing Wells in Glacial Drift.

It does not come within the scope of this report to describe the drift artesians of Iowa, and this not because they are either few or unimportant. It has been estimated by one investigator that there are nearly a thousand of these wells in the state, and they constitute a specially valuable natural resource in a number of counties, affording a generous and inexpensive supply to villages and farms. But they are so essentially local in their character that their investigation and description may well be left to the local geological work in the counties in which they occur.

The areal distribution of drift artesians is by no means uniform over the state. They are most numerous, as noted by Call,* on whose work we freely draw, in drift of the Wisconsin

*Iowa Weather and Crop Serv., vol. III, No. 3, pp. 1-15.

stage, within the Altamont Moraine, whose loop of hills extends south as far as Des Moines, although they occur also

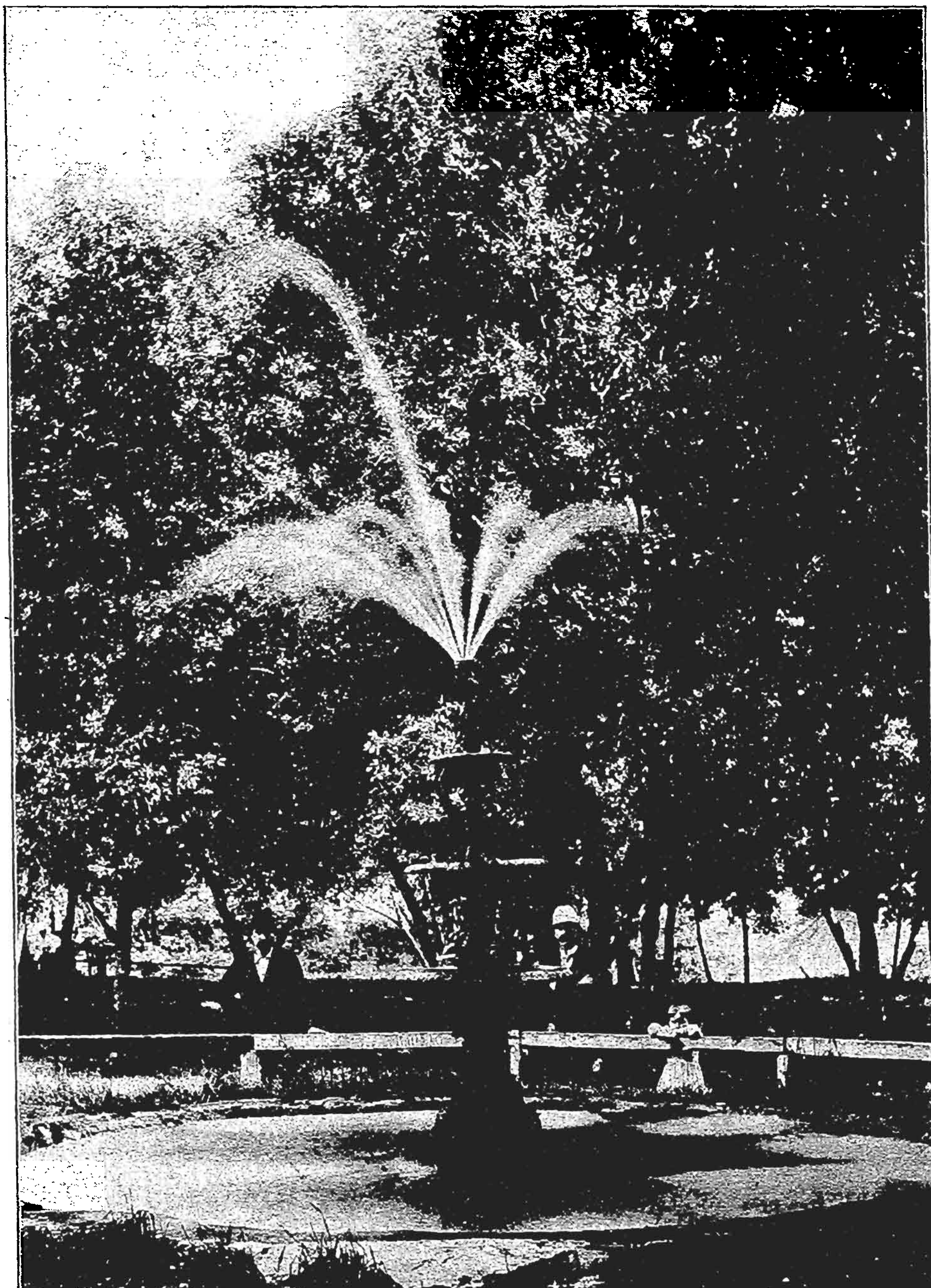


FIG. 42. Fountain at Eagle Grove, Iowa, supplied by artesian well in glacial drift.

upon areas of the Iowan drift. They are aggregated in detached areas which, for the most part, occupy low lands adjacent to rivers. The most important of these areas are found in Bremer county, in the valley of the Wapsipinicon; on the Iowa river, in a district including parts of Benton, Tama, Iowa and Poweshiek counties; in the valley of the Boone river in Hancock and Wright counties; in Greene county, in the valley of the Raccoon; and on the Chicaqua in Story county.

The aquifers in all instances are beds of sand or gravel covered with impervious till; and these water-logged sheets of sand must often be of considerable size, since they must be practically continuous over the whole of each of the areas mentioned. The origin, place and formation will be readily understood if it is recalled to mind that, during the geological epoch immediately preceding the present, Iowa was thrice invaded from the north by ice sheets, comparable in size with that which mantles Greenland to-day. During the retreat, and also during the advance of each of these continental glaciers, vast bodies of water were unlocked by melting along the entire front of the ice. The natural discharge of these waters was southward along the waterways of the country, and in these they left the sand and gravel with which their torrents were loaded. Wherever the ice invasions were co-extensive, these accumulations of valley drift—excepting that formed at the final retreat of the ice—were either removed by a later ice invasion or were covered with the impervious clays of its subglacial moraine, and when so covered with till, such valley drift was fitted to become the channel of artesian water, heading either up the valley, or on higher ground on the valley sides.

Artesians of this class are directly dependent upon the rainfall of the region, and should show corresponding fluctuations with it, so soon as the accumulation of the local reservoir is once drawn off. When largely multiplied in any region they may affect the amount of ground water available for springs and common wells in the adjacent area of intake.

Even so short a sketch as this of drift artesians will be considered incomplete if mention is not made of that most famous of all Iowa wells, which for its brief day attracted a popular notice almost as wide as that of the Charleston earthquake, to which the outburst of its waters was attributed. The notoriety of "Jumbo" of Belle Plaine* was strictly that of a member of the criminal classes, and began with his resistance to control, and lasted only until his final imprisonment. Six artesian wells had previously been drilled in the drift at Belle Plaine. In depth they varied from 210 to 301 feet, and the common head of their water was from 3 feet below the surface to 45 feet above it, according to the lie of the ground.

The record of the strata as given by Call is as follows.

		THICKNESS.	DEPTH.
6.	Soil with humus	4	4
5.	Sandy clay	12	16
4.	Gravel and sand	8	24
3.	Yellow clay	13	37
2.	Blue clay, with layers or pockets of sand and gravel	172	209
1.	Gravel and sand, water-bearing, at	...	209

In one well stratum No. 1 was penetrated to a depth of 25 feet without passing through it.

The seventh well, "Jumbo," was drilled on lower ground than any of the others and reached the water-bearing stratum of sand and gravel at 193 feet.

Local historians of the well, which they please to term "the eighth wonder of the world," state that the beginning of trouble lay in the fact that the driller attempted to use the force of the flow in reaming out the two-inch bore which he had put down for want of a larger drill, to three inches, the dimension specified in the contract. This task the water speedily accomplished in the unindurated clays and sands, but not stopping there went on and soon enlarged the bore to over three feet in diameter. Through this shaft the water boiled up in a fountain five feet in height—the press reports

*The author is here indebted especially to an article on this well by Dr. T. C. Chamberlin, Science, vol. VIII, p. 276, and to local data and pamphlets kindly supplied by Mr. S. B. Montgomery, as well as to the article by Call already cited.

giving several hundred feet as the height of this fountain were exaggerated—flooding streets and yards and covering them with sand. It is estimated that from 500 to 1,000 car loads of sand were discharged from the well. The quantity was certainly so great that only with the greatest effort could the ditches be kept open to carry off the water. Gravel and small pebbles of northern drift were thrown out, and some pieces of fossil wood two and three feet long. The maximum flow of water was variously estimated at from 5,000,000 gallons to 9,000,000 gallons per diem. Two weeks after the well

FIG. 43. Artesian well in glacial drift, Belle Plaine, Iowa. Jumbo while uncontrolled.

was drilled Chamberlin calculated its discharge at 3,000,000 gallons for the same period. The enormous flow rapidly drew down the head of the other wells until it sank beneath the surface.

The attempts to case and control the well continued from August 26, 1886, the date when water was struck, to October 6, 1887, when the task was successfully accomplished.

During this time the well, 193 feet deep, devoured, as local historians tell us, 163 feet of eighteen-inch pipe, seventy-seven feet of sixteen-inch pipe, sixty feet of five-inch pipe, an iron cone three feet in diameter and twenty-four feet long, forty carloads of stone, 130 barrels of cement, and an unestimable amount of sand and clay.

The well was supposed by many to tap an aqueduct leading from some large and distant body of water; but with such vagaries the reader will have little patience. Of this artesian field Call says that "there are indications which point toward the existence in this area either, first, of a great preglacial valley which has become filled with morainic materials, or, second, to the existence of a great fault." He further suggests "that the water may be derived from the Cedar river, which he considers may be tapped below Waterloo, the water finding its way southward through a very wide and deep channel, from which rises the water at Belle Plaine. "Certain it is," says he, "that some unusual and abundant water supply prevails in that section. The rainfall is not above the mean of the state, and no other subterranean source seems probable."

On the other hand, Chamberlin states after a personal examination of the wells, that "it is not necessary to suppose any unusual subterranean source, either in area or kind. Nor is it necessary to suppose a distant origin. The head is not greater than could be supplied by the country adjacent on the north, which is the probable supply-ground.

"It is simply a flowing drift well, run rampant for want of control. It has its phenomenal feature in its magnitude and its lesson in its expensive and destructive career through injudicious handling."

This conclusion is based on careful estimates, which show that the upper edge of the water-bearing stratum, the area of intake which supplies the Belle Plaine well, need not exceed 400 acres in extent.

It is probably unnecessary to add that the author regards the Belle Plaine area as a normal artesian basin in glacial drift, and does not sympathize with any view of the derivation of its waters through a great fault or by the subterranean diversion of a river.

The Chemistry of Artesian Waters.

It is not the aim of this chapter to present anything of novelty to the chemist, but only to set forth such facts relating to the subject as may be of value to citizens who are interested in knowing the nature of the water which they drink and upon whom the selection of a public supply may devolve. Any treatment of the subject of artesian wells must be incomplete which omits the chemical composition of their waters; for upon this, and not directly upon their geological conditions, depend their potability, healthfulness and availability for many municipal uses. There are areas in the United States in which artesian waters are accessible and abundant, but not available; they may consist of strong brines; they may carry hydrocarbons in either fluid or gaseous form; they may be highly ferruginated; on account of their chemical constituents they may be distinctly injurious to the human system.

INTERPRETATION OF CHEMICAL WATER ANALYSES.

The mineral analyses of many of the artesian waters have been given under the records of the wells in the preceding sections. Unfortunately nothing is less intelligible than a chemical analysis to one not a student of chemistry. It may therefore be useful to supply here a brief interpretation of water analyses, the methods by which they are obtained, the meaning of their symbols and terms, and their relation to matters of practical utility and sanitation. Our experience shows also the need of directions for taking samples for analyses. We strongly urge that while the drilling of a well is in progress a quantitative analysis of each flow should be secured as soon as possible after it is reached. Only with this knowledge in hand can an intelligent selection be made, and any veins cased off which may injure the quality of the water of the well. Since the substances to be detected exist in minute amounts in the small quantities of water taken for analysis, the utmost care must be paid in bottling the samples. The following directions sent out by the Survey illustrate the precautions which must be taken in order to insure a successful and reliable analysis.

1. Use a new, clean, two-gallon glass demijohn or jar stopped with a new cork, or glass stopper.

2. Rinse both three or four times with the water of which an analysis is to be made. See that no foreign substances, such as straws, remain in the demijohn.

3. Draw the water for analysis from the tap nearest the well. If the well is not a flowing artesian, do not fill demijohn until the pumps have been running several hours.

4. Leave a very small air space between the cork and the water.

5. Use no sealing wax. Avoid fingering cork or mouth of jug. Tie over the neck a piece of stout muslin to hold in the cork. This may be sealed with a wire and metal seal to prevent tampering.

The sample should be expressed at once to a competent chemist and nothing less than a full quantitative analysis should be accepted. Amateur tests resulting in statements that such and such elements are present in the water have practically no value. Complete mineral analyses state what mineral constituents the water contains, and in precisely what quantities. Thus they indicate its physiological effects and mechanical qualities, and afford means of comparison with table or mineral waters whose properties are certified by long experience. Except in instances where there is suspicion of surface contamination, a sanitary analysis is usually unnecessary.

In comparing the analyses of artesian and other waters, a difficulty is met in the fact that as yet chemists have not reached a uniform method of analysis and expression of results. "As a matter of fact," says Dr. Peale,* "the analyses of mineral waters have been made upon almost as many plans as there have been chemists making the analyses. An inspection of about 1,000 analyses of mineral waters of the United States shows that at least forty-two methods of stating the results have been employed."

Quantitative results are stated in the following ways:

*Fourteenth Annual Rept. U. S. Geological Survey, p. 69.

A. Comparison of weights of constituents to weights of water. This comparison is made on a decimal basis, and is employed in the reports of the United States Geological Survey, by the National Board of Health, and the Boards of many states, in Great Britain by the Royal Rivers Pollution Commissioners, and commonly in Germany and France. It may indicate.

a. So many parts per 1,000 (or grams per kilo).
b. So many parts per 10,000.
c. So many parts per 100,000.
d. So many parts per 1,000,000 (or milligrams per kilo).

Which of these four ratios is chosen is a matter of convenience only and is of little importance, since they are so readily interconvertible. "a" and "b" are more often employed in heavily mineralized waters, and "c" and "d" in surface and potable waters, whose mineralization is slight; "c" is in favor with many eminent chemists as a golden mean, and is recommended by the committee of the British Association of Science for 1889; "d" is recommended by the Chemical Society of Washington, 1896, and is used in the official analyses of this Survey.

B. Comparison of weights of constituents to measures of water.

a. On a decimal basis of so many milligrams per liter. As a liter of pure water weighs 1,000 grams, this would be equivalent to so many parts per million by weight, if the water analyzed were the same specific gravity as pure water, and is practically equivalent to that method in the case of many potable waters the excess of whose weight over pure water is very slight. In the case of strong mineral waters, brines and sea water, the difference in weight between a liter of the water and 1,000 grams must be taken into account and a special computation is required in converting one scale into the other.

b. On the basis of so many grains to the imperial gallon.

c. On the basis of so many grains to the United States standard wine gallon of 231 cubic inches. This method is commonly used in the United States and, as to most readers it will at least seem more intelligible than the others, it is employed in this report. Nearly all the analyses of artesian waters reported to us were already expressed in this scale, and the few otherwise stated are reduced to it.

A complete chemical analysis states, first, the acids and bases uncombined as they were found by the chemist. This record is a matter of fact, subject only to errors in manipulation and measurement. Unfortunately this record is only seldom furnished. It is given in all the official analyses of the Survey, but in scarcely any of the other analyses here published could it be obtained, even by special request to the different chemists. An analysis states, secondly, the hypothetical combinations in which, according to the chemist's best judgment, the acids and bases occur. This record is a matter of judgment and method. For example, nearly all the analyses of Iowa artesian waters record the presence of sodium chloride, or common salt. Yet the chemist does not find and measure the quantity of sodium chloride directly by his reagents and instruments. He finds the elements that combine to form sodium chloride, *i. e.*, chlorine and sodium. If no other elements are present the combination is simple and sure. But this is seldom, if ever, the case. Other elements, acids and bases are present, for example, potassium and sulphuric acid. Are these four bases and acids combined as sodium chloride and potassium sulphate, or as sodium sulphate and potassium chloride, or are all four compounds present, and if so, in what proportions? These are questions which cannot receive an exact and definite answer. There must be taken into consideration the relative amounts of all the constituents, their solubilities, the relative strength of different acids and bases, and the strength of the solution in which they occur. At the best, the combination must be hypothetical. Different chemists may combine the same radicals in different ways. In order that a series of chemical water analyses should have the highest value, it should be made by the same chemist, or at least by chemists working by uniform methods. The series of official analyses made for the Survey by Prof. J. B. Weems, Ph. D., of the Iowa Agricultural College at Ames, has thus a special value. It comprises both records, that of the radicals, and that of their hypothetical combinations; and we can only regret that arrangements could not be made by which all the artesian waters of the state could be included in the series.

MINERAL INGREDIENTS OF ARTESIAN WATERS.

Water as it issues from an artesian well is never the pure compound of hydrogen and oxygen represented by the familiar formula H_2O. It is composed of other substances also. A flask of it does not differ in appearance from a flask of distilled water chemically pure; and yet the two are unlike in weight, in taste, and in chemical reactions. The waters from no two artesian wells are precisely the same. Minerals present in one are absent in the other, or are present in different proportions. Pure water, indeed, is not found in nature, unless it be at the very moment of its condensation from invisible vapor. The drops which form clouds have absorbed gases from the air about them. The raindrop falls to earth carrying with it, washed from the air on its way, spores of bacteria, shreds from the waste of life, and the various mineral and organic particles which form the dust of the atmosphere. When the rain has reached the earth and goes on its way to the sea either under the sunlight in the brook and river or by those long, slow and dark courses from which it rises in our deep wells; everywhere it is taking up into solution the mineral substances with which it meets. The soil on which the rain gathers into the rill, the bed of the stream, the rocky walls of underground ways, all are laid under contribution by this universal solvent, and made to furnish materials to alter its composition.

a. Dissolved Gases.

The substance found in solution in artesian waters are either gases or solids. Both vary widely among themselves in their solubility, and each gas and solid dissolves in definite amounts and proportions under like conditions of temperature and pressure. In gases, solubility increases with increase of pressure, and diminishes with increase of temperature. Familiar illustrations of this general law are found in the soda fountain, where the water is charged in the reservoir with large quantities of carbonic acid gas under great pressure,—the gas escaping from the water as soon as the pressure is removed—and in the well known fact that water may be freed by boiling from all its gases held in solution at ordinary temperatures. The coefficient of absorption of different gases, or the volume of the gas soluble in water, varies greatly. Thus one cubic centimeter of water, at 59° Fahr., at a pressure of 760 mm. of mercury, will dissolve the following volumes, expressed in fractions of a cubic centimeter, of the following gases.

OXYGEN.	NITROGEN.	CARBON DIOXIDE.	AMMONIA.
0.02989	0.01478	1.00200	727.20000

At this temperature and pressure water dissolves about twice as much oxygen as nitrogen, over thirty-three times as much carbon dioxide as oxygen, and 24,329 times as much ammonia as oxygen.

OXYGEN.

Free oxygen has not been observed in artesian waters. It is universally present in all surface and ground waters, except where consumed by decaying organic matter. So complete is the circulation of the waters of the ocean, that dissolved oxygen is found even in samples taken from the greatest depths. But in the underground courses of artesian waters, all oxygen seems to be consumed in oxidizing whatever organic matter they may have contained originally. No sufficient tests however, have been made of the artesian waters in Iowa to absolutely prove the absence of oxygen in them.

AMMONIA.

The presence of this gas in artesian waters is of especial interest. In nature it is an immediate product of the decay of organic matter. From rotting wood and leaves and putrefying animal tissue nitrogen is constantly supplied to the atmosphere in the form of ammonia. That the quantity present in the air is excessively minute, not exceeding one one-hundredth of a grain in a cubic foot,* is not due to any deficiency in the supply, but rather to the constant absorption and consumption of nitrogen by the vegetable world. The solubility of ammonia, as has been seen, is excessive, and rain and snow both serve as vehicles by which it is conveyed from the air to the earth. By oxidation, ammonia rapidly passes first into nitrites and then into nitrates. Wherever it is found free in natural waters, it is understood to signify either the immediate presence of decomposing organic matter or the remoter presence of organic matter, the further processes of change into nitrites and nitrates having been suspended in the latter case by various causes.

In surface waters, where no such causes are present to suspend oxidation, free ammonia is a proof and measure of pollution. Harmless in itself, it demonstrates the presence of animal or vegetable tissue in the very process of putrefaction. Surface waters are condemned which contain over .08 parts of free ammonia to the million. Artesian waters, however, which are above reasonable suspicion of possible contamination, occasionally contain free ammonia in quantities sufficient to condemn them at once, by the ordinary standards of purity for surface waters. Prof. E. G. Smith thus found in one of the wells at Davenport .9 grains of free ammonia to the United States gallon. It is reported also from other wells of the state, although in much smaller amounts.

What is its origin? Certainly not the presence of organic matter in the process of decay, since in this case it could hardly fail to be accompanied by albuminoids, nitrites and nitrates, all of which are absent. Three possible sources may be mentioned. As all artesian waters were at one time storm

*Bloxam's Chemistry, 4th Ed., p. 123. London, 1880.

and surface waters, it may be considered that the ammonia derived from the atmosphere and soil along the intake area was retained in part unchanged, as the waters descended to their deepest levels, wherever the co-operation of other causes prevented its oxidation. Again, it may be conjectured that the surface waters of the intake area carry with them in their descent as artesian waters organic matter whose gradual decomposition supplies the ammonia in question. In most instances perhaps, the total amount of nitrogen present in artesian waters is not too large to be so accounted for. Its concentration in free ammonia instead of the usual distribution in other forms is anomalous.

A third hypothesis that may be suggested is that of the derivation of the ammonia by the breaking up of fossil organic matter in the rocks. When we remember that the ammonia of commerce is largely manufactured from the ammoniacal liquor resulting from the distillation of coal, it does not seem improbable that the nitrogen of coal seams and beds of shale containing carbonaceous matter supplies, at least in part, the free ammonia in question. Its association with hydrogen sulphide supports this view.

Whatever may be its origin, its preservation is due to two facts. As we have seen, free oxygen is absent in deep well waters. After the oxygen absorbed from the air at the area of supply is once consumed in chemical changes, the oxidation of any free ammonia is impossible, and nitrites and nitrates are thus never found in uncontaminated artesian waters except in traces.

A second and still more significant fact has been noted by Prof. E. B. Smith, of Beloit, Wis., in a paper read before the American Water Works Association, in 1883. After showing the presence of sulphureted hydrogen in various artesian waters containing free ammonia, he says: "The extraordinary ammonia can be explained on the basis that the sulphureted hydrogen has exerted its well known reducing action, either reducing the higher oxidized compounds of nitrogen back to ammonia, or preventing entirely their formation. This explanation seems to me perfectly satisfactory and reasonable and to meet the case. It may be that other agencies as the iron oxide dissolved in these waters, also lend their assistance to the final result, but probably the sulphureted hydrogen is the principal one at work."*

HYDROGEN SULPHIDE.

Hydrogen sulphide or sulphureted hydrogen is not uncommon in the artesian waters of Iowa, although seldom, if ever, mentioned in water analyses. This gas of disgusting odor is to the highest degree evanescent, and waters from this cause too offensive to drink as they issue from the well become palatable by the escape and oxidation of the sulphide after standing for a short time in reservoir or tank. Hydrogen sulphide would be readily generated by the reaction of hydrocarbonaceous matter in the strata accessible to artesian water with such alkaline sulphates as are usually present in solution in the water.

When the Saint Peter water carries sodium sulphate and carbon dioxide and the Trenton shales immediately above are bituminous and pyritiferous, it may be expected to rise charged, as at Davenport and Clinton, with hydrogen sulphide.

CARBON DIOXIDE.

Carbon dioxide, or carbonic acid gas, is reported from a few artesian wells in the state. Usually no pains are taken to retain it in samples for analysis, and it doubtless is more commonly present in artesian waters than our records show. It is specially noted in the wells at Colfax and McGregor.

In itself, it is a welcome constituent of any drinking water; since it imparts an agreeable pungency and flavor, and acts as a stimulant to the digestive organs. As a solvent, it often increases the amount of other and less desirable minerals.

Carbon dioxide is one of the five gases which form the atmosphere, and it is thence absorbed by all surface waters.

*Artesian Wells as a Source of Water Supply, p. 7, Technics Publishing Co., New York, 1893.

The soil also constitutes a vast laboratory for its generation by means of decomposing vegetal matter. Fifty-seven cubic feet of carbon dioxide to the acre are present in a layer fourteen inches thick of the surface soil of forests, according to the estimates of Boussingault and Levy. Constantly generated in all unfrozen soils, it is constantly removed and carried downward by percolating waters and thus in all phreatic and artesian waters it is found as an unfailing constituent. These well nigh universal sources are not sufficient, however, to account for highly carbonated springs and wells, or even for some of the more strongly carbonated artesian waters of Iowa. The chief source is unquestionably volcanic. The evolution of carbonic acid gas is one of the first events in the life history of a volcano, preceding even the building of the volcanic mountain. It is also one of the latest phenomena in that long history, and indicates the near approach of the final extinction of volcanic activity in any region. Vulcanism assists in the production of this gas in several ways. As limestone "burned" in the lime kiln gives off large volumes of carbonic acid gas, so rocks consisting of the carbonates, when invaded by equal volcanic heat, are supposed to be similarly decomposed with the evolution of the same gas. Bischof has also shown that carbon dioxide is expelled where carbonate of lime, magnesia, and ferrous oxide, occurring with silica, are subjected to the action of water at 212° Fahr.* It is quite possible, however, that volcanic carbon dioxide is not only disengaged by the action of heat upon sedimentary strata, but is also a primary constituent of the original magma of the earth, and that its presence in volcanic phenomena of all degrees of intensity is due largely to its extravasation.

In a region so far and long removed from volcanic centers as the upper Mississippi valley, the evolution of carbon dioxide can hardly be attributed to vulcanism. In places it may be due to the reaction upon limestone of persalts of iron derived from the decomposition of iron pyrites, as suggested

*Chemical and Physical Geology, p. 237. London, 1854, vol. I.

by Stein and approved by Bischof.* It is also evolved by the oxidation of organic matter more or less deeply buried, as in coal seams and vegetal accumulations of Pleistocene age. Such is the origin of the carbonic acid gas ejected by the "blowing wells" of the state, the source being either Cretaceous lignites, or, more commonly, deposits of forests or marsh growths buried in the drift.

b. *Dissolved Solids.*

Excluding a few compounds of exceedingly doubtful authenticity, and those of which only traces are reported, the solids in solution in the artesian waters of Iowa are the following.

Calcium bicarbonate, $CaH_2(CO_3)_2$.
Magnesium bicarbonate, $MgH_2(CO_3)_2$.
Sodium bicarbonate, $NaHCO_3$.
Potassium carbonate, K_2CO_3.
Ferrous carbonate, $FeCO_3$.
Magnesium phosphate, $Mg_3(PO_4)_2$.
Sodium phosphate, Na_2HPO_4.
Calcium sulphate, $CaSO_4$.
Magnesium sulphate, $MgSO_4$.
Sodium sulphate, Na_2SO_4.
Potassium sulphate, K_2SO_4.
Ferric oxide, Fe_2O_3.
Magnesium chloride, $MgCl_2$.
Sodium chloride, $NaCl$.
Potassium chloride, KCl.
Silica, SiO_2.
Alumina, Al_2O_3.

All of the above compounds are directly or indirectly derived from the constituent and accessory minerals of soils and rocks. Some are taken up by the immediate decomposition of rocks under the agency of precolating waters. Others result from the interaction of minerals in solution in different mineral waters when they meet, and their reaction with chemical compounds present in the strata through which they flow. In these reactions and in the solution of rocks, the absorbed gases which we have already noted as present in phreatic water

*Chemical and Physical Geology. London, vol. I, pp. 240-241, 1854.

play an important part. In pure water ordinary limestone, for example, is so slightly soluble that it has been stated to be insoluble in popular scientific writings*. Probably upwards of 5,000 imperial gallons would be required to dissolve one pound of limestone.† But limestone is readily dissolved in water saturated with carbon dioxide, the maximum amount that can be dissolved being 0.1 per cent. It has been further shown by Bischof‡ that water containing but one-tenth of the carbon dioxide required for saturation is able to dissolve as much calcium carbonate as is a saturated solution, and that this amount of the gas can be furnished to natural waters by the atmosphere and soil. Magnesium carbonate is somewhat more soluble in water saturated with carbonic acid gas than is calcium carbonate, and the experiments of W. B. and R. E. Rogers§ have shown that in water so charged very many of the minerals of the crystalline rocks, such as are present in the drift of the state in boulders, pebbles, sand, and rock meal and flour, are decomposed and dissolved. Of these may be mentioned feldspar, hornblende, augite, mica, chlorite and epidote.

No surface waters, whether of slough, river or lake, are found which have failed to attack rocks and soils and rob them of a portion of their substance. The following analyses indicate the maxima and minima of mineralization in the river waters of Iowa according to the exceedingly limited data at hand. The variations are caused in part by local differences of the country rocks of the river basin, and in part are due to the season and stage of water. Rivers, after the long drouths of summer are fed by springs, and are naturally then more highly mineralized than in the spring floods, when fed by rains and melting snows.

*Le Conte, Elements of Geology, p. 77. New York.
†Dr. Thomas Clark, Journal of Society of Arts, 1856.
‡Chemical and Physical Geology, vol. III, pp. 171-172. London, 1859.
§American Journal of Science and Arts, vol. LV, p. 401, 1848.

MINERAL ANALYSES OF RIVER WATERS OF IOWA.

RIVERS.	STATIONS.	Calcium carbonate.	Magnesium carbonate.	Alkaline carbonate.	Iron carbonate.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.	Potassium sulphate.	Alkali sulphates.	Sodium chloride.	Alkali chlorides.	Silica.	Oxides of iron and alumina	Oxides of ir'n, alumina and silica.	Alkalies by difference.	Lime and magnesia salts.	Total.	ANALYST.	DATE.
Cedar.........	Cedar Rapids.....	*10.33	*5.78	....	0.08	0.55	.....	0.30	0.52	....	0.20	......	0.38	0.04	......	......	......	18.18	Prof. E. G. Smith	Aug. 25, 1893
Cedar..........	Cedar Rapids.....	6.56	2.48	....	...	0.29	1.07	....	....	0.28	....	0.64	0.28	0.28	..	......	......	12.49	C. O. Bates *a*.....	Average *b*.
Des Moines, E. [fork	Dakota City......	14.00	7.52	....	....	Tr'ce	......	....	....	5.61	....	0.60	......	.....	0.29	......	......	28.02	G. M Davieson *c*	Feb. 12, 1889
Des Moines, W. [fork	Algona...........	2.49	1.66	....	....	0.22	.....	....	....	0.77	......	0.30	......	......	0.10	.....	.....	5.54	G. M. Davieson..	Feb 10, 1889
Des Moines.....	Moingona........	11.66	3.79	....	....	0.42	5.20	....	....	2.15	....	0.57	0.58	0.09	....	......	......	24.46	G. M. Davieson..	May 24, 1894
Coon, N. fork...	Maple River Jct..	6.09	3.08	...	....	0.32	......	..	....	2 88	......	0.82	......	......	0.31	......	......	13.50	G. M. Davieson..	Feb. 10, 1889
Boyer..........	Early.............	8.44	4.62	....	....	0.90	......	....	...	4.49	....	1.14	.....	......	0.13	......	......	19.72	G. M. Davieson..	Feb. 10, 1889
Wapsipinicon...	Anamosa........	5 99	2.02	0.44	....	......	......	....	...	0.53	.....	0.17	......	......	0.08	.....	......	9.23	George Gibbs *d*..	June 10, 1893
Missouri.......	Council Bl'ffs (c'y [water w'ks)	6.84	3 49	....	...	2 88	....	....	....	5.31	......	0.73	.....	.....	0.31	......	.....	19.56	George Gibbs....	Dec. 16, 1891
Mississippi. ...	Burlington.......	6.053	2.455	....	..	0.262	0.694	....	....	....	......	......	0.146	0.251	.....	1.721	9.464	10.2[illegible]8	G. H Ellis *e*.....	Jan. 10, 1887
Mississippi.....	Dallas............	9.026	5.091	....	....	0.134	0.764	....	....	....	......	.....	1.598	0 280	......	0.544	15.015	17.202	G. H. Ellis.......	Dec. 27, 1886
Mississippi.....	Fort Madison.....	5 091	2.327	....	....	0.251	0.676	....	..	....	......	......	0.991	0.222	......	0.659	8.345	10.124	G. H. Ellis.......	Feb. 8, 1887
Skunk..........	Rome...........	4.018	1 032	....	...	0.676	1.015	....	....	....	....	......	0.939	0.350	......	1.627	6.741	8 868	G. H. Ellis......	Jan. 26, 1887
Des Moines.....	Ottumwa.........	8.165	2.222	....	....	0.752	2.105	....	....	....	......	......	0.834	0.233	......	2.525	13.244	15.092	G. H. Ellis. ...	Jan. 26, 1887
Des Moines.....	Des Moines.	8 592	0.688	....	....	2.076	0.134	....	....	....	......	......	3.412	0.758	.....	2 185	11.490	16.494	G. H. Ellis.......	March 17, 1887
Chariton........	Chariton..........	3.242	1.819	...	....	0.723	0.262	....	....	....	....	......	1.662	0.525	......	1.407	6.046	10.105	G. H. Ellis.......	March 30, 1887
Grand..........	Davis City.......	5.418	1.522	....	....	0 630	0.641	..	..	....	......	......	1.067	0.315	......	0.677	8.211	10.625	G. H. Ellis.......	April 16, 1887
Nodaway... ...	Massena.........	7.599	3.318	....	....	0.443	1.376	...	....	....	......	......	1.085	0.350	......	0 175	12.736	14.544	G. H. Ellis......	June 11, 1887
W.Nishnabotna	Anderson........	7.663	2.683	....	....	0.268	0.251	.. ..	....	...	......	.....	1.843	0.169	......	2.694	10.865	15.676	G. H. Ellis.......	Sept. 16, 1887
Missouri.......	Council Bluffs....	8.847	1.866	....		2 251	3.505	....	....	....	......	......	1.522	0.233	......	6.462	16.469	24.843	G. H. Ellis.......	Dec. 17, 1887
Average.	....	7.306	2 973		....	0.702	0 885	....	....	....	......	.....	....	......	......	......	.....	15.200		

* Bicarbonate. *a* Chemist of Burlington, Cedar Rapids & Northern railway *b* Average of several analyses at different seasons of the year. *c* Chemist of Chicago & North-Western railway. *d* Chemist of Chicago, Milwaukee & St. Paul railway. *e* Chemist of Chicago, Burlington & Quincy railway.

MINERAL ANALYSES OF RIVER WATERS OF IOWA.

The average quantity of solids in solution in the twenty samples of Iowa river waters whose analyses are reported is 15.2 grains to the gallon. Nearly 50 per cent of this amount consists of calcium carbonate, and about 20 per cent of magnesium carbonate. Unexpectedly, the alkaline sulphates, the sulphates of soda and potassa, prevail over the sulphates of the alkaline earths, the sulphates of lime and magnesia.

Alkaline carbonates are reported from but one river, the Wapsipinicon. Sodium chloride is reported in minute amounts from several rivers, and complete analyses would no doubt detect it in the waters of all rivers of the state. The quantity of silica in several analyses is unusually large, exceeding that of the Ottawa* with 1.442 grains to the gallon and in the analysis of the Des Moines river at Des Moines equaling the quantity of silica carried by the Rhine near Strasburg, according to Deville.†

With longer and more intimate contact with the earth the mineralization of natural waters increases, as is exhibited in the following table of the mineral constitution of nineteen shallow wells of the Chicago & Northwestern railway and fourteen similar wells of the Chicago, Milwaukee & Saint Paul railway. All these draw their water from surface sands and gravels; in no case is glacial till or rock reported as penetrated. It will be seen that the total solids in solution, and the carbonates of lime and magnesia, average about 50 per cent higher than in river waters.

*Hunt, Chemical and Geological Essays, p. 127. Boston, 1878.
†Bischof, Chemical and Physical Geology, vol. I, p. 76. London, 1854.

MINERAL ANALYSES OF WATERS OF SHALLOW WELLS.

	Depth in feet.	STRATA.	Calcium carbonate.	Magnesium carbonate.	Calcium sulphate.	Magnesium sulphate.	Alkali sulphate.	Alkali chloride.	Silica. — Oxides of iron and aluminum.	Alkaline carbonate.	Non-incrusting solids—Magnesium chloride.	Total solids.
1. Tama, C. & N-W. Ry.	23	1 ft. clay, 22 ft. sand	11 30	2.60	0.78	1.70	1.74	1.11	.....—0.12	.....	....	19.35
2. Missouri Valley, C. & N-W. Ry.	80	Sand and gravel	14.78	6.37	....	0.53	0.17	1.92	1.48—0.05	.....	....	25.25
3. Alton, C. & N-W. Ry.	32	12 feet gravel; 8 feet black muck; 12 feet quicksand	12.54	5.56	0.69	......	4.11	0.76	1.63	.....	....	25.39
4. Bancroft, C. & N-W. Ry.	19	Sand and gravel	13.38	6.20	0.25	......	3 94	0.32	0.64	.....	....	24.73
5. Bradgate, C. & N-W. Ry.	10	Through gravel to clay	9.77	4.95	Trace.	......	3 01	0.22	0.71	.....	....	18.66
6. Correctionville, C. & N-W. Ry.	24	Sand and gravel	12.44	5.70	Trace.	......	2.49	0.40	0.41	.....	....	21.44
7. Dunlap, C. & N-W. Ry.	25	Sand and gravel	15 51	6.58	....	......	4.26	1.53	1.28—0.12	.....	....	29.28
8. Galva, C. & N-W. Ry.	30	Sand	12.35	5.07	0 29	......	2.49	0.47	0.58	.....	....	21.25
9. Garwin, C. & N-W. Ry.	19	Sand and clay, 15; sand, 4	3.60	2.81	2.58	......	3.84	0.72	0.37	.....	....	13.92
10. Gifford, C. & N-W. Ry.	49	All gravel except ten feet in limestone	11.23	6 65	0.23	......	2.66	0.13	0.90	.....	....	20.99
11. Havelock, C. & N-W. Ry.	10	Gravel	9.03	4.68	Trace.	......	0.53	0.19	0.62	.....	....	15.05
12. Hawarden, C. & N-W. Ry.	22	Sand and gravel	14.47	6.57	Trace.	......	7.09	0.13	0.11	.....	....	28 37
13. Laurens, C. & N-W. Ry.	9	Gravel in supposed outlet of lakes	11.43	5.41	Trace.	......	1.21	0.31	0.16	.....	....	18.59
14. Mapleton, C. & N-W. Ry.	24	Sand and gravel	10.72	5.83	0 10	......	2.15	0.65	1.69	.....	....	21.14
15. Moville, C. & N-W. Ry.	22	Sand and gravel	9.53	4.89	Trace.	......	1.17	1.84	0.96	.....	....	18.39
16. Onawa, C. & N-W. Ry.	20	Gravel	10.67	7.61	Trace.	......	3 47	0.71	0.23	.....	....	22.69
17. Sac City "Y," C. & N-W. Ry.	12	Gravel	10 40	5.04	0.15	......	2.32	0.53	0.95	.....	....	19 39
18. Sioux Rapids, C. & N-W. Ry.	18	Gravel	11.62	6.62	Trace.	......	3.01	0.47	0 56	.....	....	22 28
19. Waterman Siding, C. & N-W Ry.	.....	....	12.36	5.44	0.72	......	2.43	0.24	0.62	.....	....	21.81
Average	.....	....	11.43	5.56	0.30	0.12	2.74	0.66	0.78	.....	....	21.47
20. Cascade, C., M. & St. P. Ry	12	Gravel	3.60	2.58	1.99	......	0 91	0.27	0.41	.....	....	9.76
21. Clear Lake, C., M. & St. P. Ry.	32	Gravel	15.08	9.55	7.12	......	2.29	0.62	0.66	.....	....	35.32
22. Cylinder, C., M. & St. P. Ry.	15	Gravel and sand	10 90	5.45	0.40	......	1.94	0.92	0.50	.....	....	20.11
23. Decorah, C., M. & St. P. Ry.	28	Gravel and sand	11.09	4.93	....	......	1.43	0.82	0 75	.....	....	19.02
24. Everly, C., M. & St. P. Ry.	13	Gravel	8.54	3.74	....	......	0.81	0.25	0.51	0.98	....	14.83
25. Maquoketa, C., M. & St. P. Ry.	34	Gravel	11.21	6.87	1.32	......	0.12	3.21	0.42	.....	....	23.15
26. Perry, C., M. & St. P. Ry.	16	Gravel and sand	7.40	5.07	4.53	......	0.95	0.25	0.62	.....	....	18.83
27. Plymouth, C., M. & St. P. Ry.	20	Gravel	11.09	4.93	....	......	1.43	0.82	0.75	.....	....	19.02
28. Rock Valley, C., M. & St. P. Ry.	25	Sand	9 74	6.09	13.91	......	5.26	0.69	0.45	....	....	36 14
29. Ruthven, C., M. & St. P. Ry.	20	Sand	13.49	5.85	....	......	3.30	0.07	0.31	.....	....	28.02
30. Sanborn, C., M. & St. P. Ry.	13	Sand	11.32	5.14	1.05	......	1.32	0 65	0.13	....	....	19.61
31. Spencer, C., M. & St. P. Ry.	18	Gravel	10.73	4.68	2.71	......	1.75	0.60	0.30	....	....	20.77
32. Saint Olaf, C., M. & St. P. Ry.	14	Sand	18.92	2.22	3 77	......	......	2.70	0.24	.....	3.26	31.11
33. Waukon, C., M. & St. P. Ry.	8½	....	12.20	4.64	9.96	......	0.58	2.23	0.18	.....	....	29.79
Average	.....	....	11.09	5.12	3.34	......	1.58	1.01	.44	.....	....	22.89

MINERAL ANALYSES OF WATERS OF SHALLOW WELLS.

As ground water sinks from the surface it encounters, over nearly the whole of Iowa and Minnesota and over the eastern part of the artesian area of intake in Wisconsin, the formation popularly known as the drift. Shallow wells usually lie in its rearranged sands and gravels. Deeper wells are fed by waters which have percolated through one or more of its sheets of till. It is composed for the most part of a heterogeneous mixture of boulders, pebbles, sands and clays, the grindings of the glacial mills. Much of the material is finely triturated; much is partially decayed: so that it is particularly open to the chemical attack of the water which it receives from rain and stream and gives over to spring and well and the underlying rocks.

In the drift are represented rocks of all ages, from the Archean to the Cretaceous, and of all kinds, organic and clastic, stratified and unstratified, aqueous and igneous: Thus the chemical constitutents of the drift are as diversified as are those of the rocks and minerals of which it is composed. Its waters are, therefore, highly and diversely mineralized, and by its springs and its control over soils, it greatly increases the mineralization of all surface and ground waters as well. The following table of drift wells of the Chicago & Northwestern railway exhibits with approximate correctness the degree of mineralization of many of our drift waters, but as the analyses were made solely for the purpose of testing the availability of the waters for use in locomotive boilers, they can not be expected to discriminate closely, or to set forth the complete chemical constituents of the waters. It will be noted that these drift waters contain between 40 and 50 per cent more solid ingredients, than the ground waters of the shallow wells, and that the same proportion holds in the increase of the carbonates of lime and magnesia.

MINERAL ANALYSES OF DRIFT WATERS.

WELLS.	Depth.	STRATA.	Calcium carbonate.	Magnesium carbonate.	Alkaline carbonate.	Calcium sulphate.	Magnesium sulphate.	Alkali sulphate.	Alkali chloride.	Silica.	Oxides of iron and aluminum.	Total solids.
Boone, railway well (C. & N.-W. Ry.)...	60	Yellow and blue clay..............	15.68	6.76	......	0.81	1.31	0.81	1.51	0.52		28.22
Eagle Grove, railway well (C.& N.-W.Ry.)	72	Blue clay into gravel..............	16.61	9.38	......	....	......	6.06	0.64	0.34		33.03
Gowrie, railway well (C. & N.-W. Ry.)...	138	Through clay and sand............	27.51	13.93	......	0.34	......	19.88	0.93	0.81		63.40
Hubbard, railway well (C. & N.-W. Ry.).	54	Blue clay..........................	13.11	7.23	......	....	.....	1.16	0.75	1.86		24.11
Jewell Junction	46	Blue clay..........................	14.10	6 02	......	Trace	.....	2 62	0.26	1.17		24.17
Lake City	69	18 ft. yellow clay; remainder blue [clay to gravel	15.47	8.55	......	Trace.	.....	4.10	0 26	0.31		28.69
Missouri Valley	90	Last 16 feet sand..................	16.35	5.69	0.89	....	3.78	1.32	1.63	1.31—0.15		31.12
Radcliffe	86	Yellow and blue clay............ ...	13.73	7.22	......	Trace.	......	3 88	0.19	0 27		25.29
Renwick, artesian........................	81	Blue clay into gravel.	15.63	8.21	......	0.14	......	8.12	0.48	0.74		33.32
Sac City, old well........................	40	Clay and gravel......	14.36	8.77	......	Trace.	....	3.44	1.60	1.10		29.27
Webster City.............................	86	Blue clay to gravel................	14 09	9.43	.	Trace.	......	5.59	0.72	0.40		30.23
Average		....	16.06	8.29	.08	0.12	0.46	5.18	0.82	0.82		31.89

Many waters of the drift are much more strongly mineralized than are any in the table. This might be expected since the analyses are of wells especially chosen for boiler waters on account of their low per cents of mineral ingredients. The following analyses exhibit the nature of the stronger drift waters of the state. No. 1, by Prof. L. W. Andrews, of Iowa City, is of the celebrated artesian well at Belle Plaine, and No. 2, by Prof. A. A. Bennett, of Ames, of an artesian well at Luzerne.

	GRAINS PER U. S. GALLON. NO. 1.	NO. 2.
Calcium carbonate	------	-------
Calcium bicarbonate	------	32.4470
Magnesium carbonate	13.111	-------
Magnesium bicarbonate	------	23.4476
Iron proto carbonate	.735	-------
Calcium sulphate	99.946	16 7082
Magnesium sulphate	39.270	8.7892
Sodium sulphate	6.251	8.9410
Potassium sulphate	------	14.3876
Sodium chloride	.616	1.9213
Potassium nitrate	------	3.1185
Iron salts	------	2.1841
Silica	.112	2.2425
Alumina	Trace	Traces
Potassium	Trace	-------
Phosphates	------	Traces
Organic matter	Trace	-------
Total solids	160.314	114.1870

Authority, R. E. Call, Iowa Weather and Crop Service, p. 3. February, 1892.

Incomplete as are these data of the surface and ground waters of the state, they yet indicate something of the kind and something of the degree of the mineralization of our artesian waters, even at the beginning of their downward journey, and before they have reached the rocks of the artesian reservoir. When artesian waters are comparable in their mineralization with surface and ground waters, rather than with the waters of the drift, it may be assumed that they have passed directly into the reservoir without percolating through Pleistocene deposits of any thickness. To this class belong the wells at Mason City, Sabula, Calmar, and several wells at Dubuque.

Artesian water is rendered still more complex in its chemical constitution in its passage through the indurated rocks from the area of intake to the region of the wells. The degree of mineralization stands in direct ratio to the solubility of the rocks with which it meets, the distance which it traverses, and the length of time of its journey. It is not an accident that the purer artesian waters of Iowa are from wells situated near the northern border of the state, and that the waters are especially strong in dissolved minerals which rise from far below sea level, where the circulation of underground waters may reasonably be held to be most impeded.

CLASSIFICATION OF ARTESIAN WATERS.

Since the classification of artesian waters must depend upon their chemical constituents, we may introduce here a grouping whose use will be found convenient in the further discussion of the subject. Since the time of Aristotle and Pliny, systems almost as many in number as the writers upon this theme have been proposed for the classification of natural waters. No one of these schemes seems entirely adapted to set forth plainly the facts under present discussion. Most of them include several groups of waters here unrepresented. Many of them are expressed under a somewhat abstruse terminology. Names are employed in special meanings apart from their popular usage, and may therefore mislead. Intricate in their details, many of these classifications require for their understanding and application more effort on the part of the uninitiated than the value of the result reached will perhaps warrant. For these reasons no attempt is made to apply any of these formal systems to the deep waters of Iowa. It will suffice if we merely group these waters together in accordance with their common ingredients. Under this method of presentation the groups are not mutually exclusive, and the same water may be found under several divisions. Iowa mineral waters, therefore, fall into the following classes:

1. Calcic-magnesian alkaline waters. In this class calcium and magnesium carbonates are predominant, or largely present.

2. Sodic alkaline waters. These contain marked quantities of sodium carbonate.

3. Saline waters, so named from the presence of common salt, sodium chloride.

4. Selenitic waters, containing sulphate of lime, or gypsum, in its crystalline form known as selenite.

5. Magnesic sulphated waters, containing magnesium sulphate, or Epsom salt.

6. Sodic sulphated waters, differentiated by the presence of sodium sulphate, or glauber's salt.

7. Chalybeate waters, or those containing the salts of iron.

Before taking up each of these natural groups we may mention some divisions of our deep waters based on other qualities than solids in solution. Such is the division of natural waters into thermal and non-thermal. Strictly speaking, any water would fall into the first class whose temperature was higher than the average annual temperature of the locality, and thus all the artesian waters of the state would be thermal waters, since each receives an increment of heat from the strata lying below the plane of seasonal and yearly variation in temperature. But convenience makes sensation of heat and cold the arbiter, and draws the line of demarkation between the two divisions at 70° Fahr. Under this classification the only thermal waters of Iowa are those of the Washington deep well, whose temperature is reported at 74° Fahr., an abnormal temperature for which we cannot account, and the lower waters at Glenwood, whose temperature is 72½° Fahr. Approaching the limits of 70° are the following wells.

Sioux City	"About 70°"
Homestead	66¾°

Classifying natural waters into gaseous and non-gaseous, according to whether or not they contain dissolved gases other than those of the atmosphere, which are found in all waters to which the air has access, or the same gases in larger quantity, the former category may be divided into the following classes.

Carbonated waters, containing carbon dioxide.

Carbureted waters, containing carbureted hydrogen.

Sulphureted waters, containing hydrogen sulphide, sulphureted hydrogen.

Azotized waters, containing free nitrogen.

Some reference has already been made to the gaseous ingredients of Iowa waters.

CALCIC MAGNESIAN ALKALINE WATERS.

We have seen that in the waters of Iowa rivers and shallow and drift wells, calcium carbonate constitutes about one-half of the total solids in solution, and magnesium carbonate about one-quarter. These high proportions are due largely to the presence of partially decayed limestone particles in the drift, proved by the usual ready effervescence of its clays in acid. Artesian waters draw these salts also from limestones and dolomites, calcareous and calcareo-magnesian shales and calciferous sandstones, whenever such strata are traversed by the courses of these waters. We may therefore expect that artesian waters of this class will carry higher per cents of these carbonates than are found in surface and ground waters. In the waters listed in the accompanying table lime and magnesian carbonates average nearly four-fifths of the total solids in solution and range from about fourteen to nearly forty and one-half grains to the gallon.

CALCIC MAGNESIAN ALKALINE WATERS.

TOWNS.	OWNERS.	Calcic carbonate.	Calcic bicarbonate.	Magnesian carbonate.	Magnesian bicarbonate.	Sodium carbonate.	Alkaline carbonates.	Calcium sulphate.	Magnesian sulphate.	Sodium sulphate.	Potassium sulphate.	Alkaline sulphates	Sodium chloride.	Alkaline chlorides.	Silica.	Oxides of Fe. and Al.	Oxides of Fe., Al. and Si.	Total lime and magnesia carb.	Total.
Calmar	C., M. & St. P. Ry.	9.050	....	4.900	....	....	....	2.980	....	....	....	....	....	0.18	....	....	0.130	13.950	17.240
Dubuque	Malting Co	9.456	....	4.377	....	....	....	1.284	....	....	....	....	1.693	....	....	....	....	14.334	20.4295
Dubuque	Cushing	7.588	....	6.362	....	....	....	....	0.292	0 961	....	....	0.350	....	....	....	....	13.950	15.648
Dubuque	Steam Heating Co	8.096	....	7.179	....	....	....	....	....	....	1.582	....	0 204	....	0.872	0.035	....	15.275	17.968
Mason City	City	10.990	....	4.480	....	....	1.210	....	....	....	....	0.34	....	0.440	....	....	0.190	15.470	77.650
Monticello	City	10.059	6.711	....	1.591	3 596	....	....	....	1.425	....	....	0.555	....	1.334	1.467	....	18.361	26.813
Clinton	Water Works Co	....	11.229	....	7.427	6.282	....	....	....	6.627	....	....	6.6616	....	0.612	0.017	....	18 656	38.855
Sabula	City	7.764	....	0.522	10.374	0 605	....	....	....	1.756	....	....	....	....	0.174	0.331	....	18.620	21.526
Dubuque	Bank and Ins. Bldg. Co.	1.434	9.587	....	8.625	1.533	....	....	....	1.765	....	....	....	....	0.298	0.646	....	19.646	23.888
McGregor	No. 2, city	5.245	4 549	....	9.868	....	....	....	0.332	4 276	....	....	3 445	....	0.398	0.124	....	19.662	28.720
Emmetsburg	C., M. & St. P. Ry	13.960	....	6.460	....	....	....	....	....	....	....	2.520	....	0.480	....	....	0.540	20.420	23.960
Britt	C., M. & St. P. Ry	15.300	....	8.150	....	....	....	0.760	....	....	....	3.230	....	0.170	....	....	0.230	23.450	27.840
West Bend	City	17.541	12 710	....	10.175	....	....	....	2.196	11.882	....	....	0.547	....	0.248	0.224	....	40.426	55.706
Average	....	8.952	3.445		....	....	....	....	....	....	....	....	....	..	....	....	..	19.405	25.849

While the average of these carbonates is about twice that in the river waters of the state, river water occasionally is found—as the water of the Des Moines at Dakota City, on February 12, 1889, according to the analyses of Mr. George M. Davidson—which is harder with these carbonates than is the average artesian water of this class, harder in fact than any listed in it with two exceptions.

The water of the West Bend well is sharply distinguished by its hardness from the others of its class. It is not a sandstone water, as are most of the others, and its excess of the carbonates is due to the limestones through which its flows.

A distinct group is formed by the neighboring wells of Dubuque, Sabula, Clinton and Monticello. These waters are identical in the amount of calcium and magnesium carbonates they contain, and are similar in the fact that each carries more or less of sodium carbonate and sodium sulphate.

This class of waters is surpassed by none other. As table waters they are of the highest excellence. In all respects they fully equal the celebrated Waukesha waters of Wisconsin, and are indeed superior to them in that they are softer. Eight of the most famous of the Waukesha springs average 24.17 grains of lime and magnesium carbonates to the gallon, a larger amount than that carried by any of the waters of this class except that of the artesian at West Bend.

At the recommendation of this office some of these waters have recently been placed upon the market, and we see no reason why with due advertisement of their merits a large export trade in them may not be secured.

The manner in which calcium and magnesium carbonates are held in solution are of special interest. We have seen that these compounds are but very slightly soluble in pure water. Were it not for the presence of carbonic acid gas, all our well waters would be nearly as soft as that of cisterns. The process by which this gas effects the solution of the carbonates may be conceived in two ways. The carbonates may be considered either as being held in solution by the presence of free carbon dioxide, or as uniting with it forming new and soluble compounds, the so-called bicarbonates of lime and magnesia. In the first instance the chemist calculates the amount of calcium carbonate, and so enters it in his analyses; in the second he reckons the amount of calcium present as bicarbonate. The latter method is employed in the official analyses of the Survey, but many analyses herein published were reckoned in the other way, and can not now be conveniently recalculated with the data at hand.

In either view of the process the amount of calcium carbonate held in solution depends upon the amount of carbon dioxide in the water. Under pressure, as in the deep sources of certain springs, great quantities of the gas may be absorbed and correspondingly large amounts of calcium carbonate taken into solution. On the emergence of such waters at the surface, the carbon dioxide escapes with the release of pressure, and the calcium carbonate is freely deposited, petrifying whatever the waters may touch. Whenever by any process carbon dioxide is removed from water, the carbonates of lime and magnesia are thrown down as insoluble precipitates. When hard water is boiled in heater, steam boiler or tea kettle, and its absorbed gases are thus expelled, the carbonates settle, forming the white—or reddish, if iron is present—scale, furring or sludge with which every housewife and engineer is too well acquainted. If we conceive of the salts as present in the form of bicarbonates, then we will consider that these compounds have been broken up by boiling, the extra carbon and oxygen being returned to the air as carbon dioxide, and the calcium and magnesium being precipitated as carbonates as before.

A frequently noted effect of the bicarbonates so universally present in the ground and deep waters of the state is to render the water hard. Since these carbonates are removable by boiling, such hardness is termed temporary or removable hardness. But hardness may be caused also by other minerals removable only by chemical means, and such is termed permanent hardness. Hardness of either sort is tested and measured by means of soap. This chemical compound of various fatty acids with an alkali is decomposed by the mineral salts which harden water, the fatty acids of the soap combining with the salts of the water to form insoluble curdy compounds. In washing with hard water, sufficient soap must first be destroyed to precipitate the salts of the water, before any additional soap produces lather and has its natural effect as a detergent. The amount of soap necessary to throw down these salts and render any water soft is thus a measure of the hardness of the water. The oldest scale of hardness, and the only one which has been employed upon Iowa waters, is Clark's scale. In this, each degree of hardness is determined by the presence in every hundred imperial gallons of the waters of sufficient mineral salts to neutralize two ounces of the best hard soap. This is practically equivalent to one grain of calcium carbonate to the gallon. Very few of the waters of the state have been tested in this respect; but a tolerably accurate idea of their relative hardness may be obtained by noticing the amount of the carbonates and sulphates of the alkaline earths given in the analyses. It will thus be seen that the waters of the calcic magnesian alkaline class are less hard than for those of any other class of the deep waters of the state. The physiological and mechanical effects of calcium and magnesium carbonates in waters will be treated under another head.

SODIC ALKALINE WATERS.

The ultimate source of sodium carbonate, commonly known as sal soda, found in artesian waters, is to be sought in the crystalline rocks, in which alkaline silicates, such as the soda feldspars, are among the most common of rock-making minerals. By their decay are formed clay shales, which retain something of the original alkaline constituents. T. S. Hunt has remarked the prevalence of sodic springs in argillaceous strata, and he explains the formation of the carbonate of soda which they contain by the reaction of silicate of soda with lime and magnesia carbonates. Bischof suggests also that a solution of sodium chloride may produce the same alkaline carbonate by reaction with carbonate of lime.

The deeper strata of Iowa supply both means, both shales and saline waters, yet sodic alkaline wells are rare. Omitting several in which this constituent is present in very small amounts, the following is the entire list.

TOWN.	OWNER.	SODIUM CARBONATE, GRAINS TO U. S. GALLON.
Clinton	Water Co.	6.628
Council Bluffs	Asylum	12.155
Davenport	Ice Co.	12.677
Davenport	Witts	16.446
West Liberty	Town	38.152
Glenwood	Town.	50.518

All these waters are sodic-sulphated also, and their full analyses are given with the waters of that class. All contain common salt, but not in amounts proportional to the soda they carry.

Calcium and magnesium carbonates are poorly represented. Omitting the Clinton wells, these salts average about eight and one-third grains to the gallon, and compose less than eight per cent of the total solids. Magnesium sulphate is wholly absent. Although waters containing sodium carbonates are natural solvents of silica, no notable excess of this mineral is noticed.

SALINE WATERS.

The artesian waters of Iowa, as well as those of the springs, are notable for the absence of brines. The waters strongest in salt are the following. Even the most saline contain only about one-fifth as much salt as the Hathorn Springs of Saratoga.

SALINE WATERS.

TOWNS.	OWNERS.	Sodium chloride.	Potassium chloride.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.	Calcium carbonate.	Calcium bi-carbonate.	Magnesium carbonate.	Sodium carbonate.	Iron carbonate.	Silica.	Oxides of iron and aluminum.	Total.
Glenwood	City	106.284	....	....	....	31.092	5.137	....	1.831	50.517	0.252	0.601	Trace.	195.715
McGregor	No. 1, city	92.634	....	17.002	7.325	13.539	....	17.930	....	....	....	0.323	0.348	161.778
Keokuk	Poultry Co,	64.562	2.660	15.834	9.984	108.054	....	23.971	....	....	....	0.340	0.050	234.237
Keokuk	Pickle Co	60.593	....	25.993	24.874	76.129	....	9.338	....	....	....	0.406	0.447	206.066
Fort Madison	Paper Co	41.329	....	10.217	....	40.071	14.318	....	7.817	....	....	0.390	0.807	115.029
Centerville	No. 2, city	37.195	....	45.870	25.818	89.859	....	7.067	....	....	....	0.596	0.174	228.585

The following also contain over ten grains of salt to the gallon.

Davenport, glucose	28.080
Davenport, ice factory	26.266
Davenport	26.175
Wilton, city	18.560
Boone, No. 1, city	14.756
Centerville, city, No. 1	13.215
Ottumwa	11.480
Jefferson, city	11.004
Des Moines, court house	10.333

The source of the salt in these waters is to be sought in the fossil brines of saline deposits of ancient seas. The Silurian supplies the salt of the wells at Keokuk, Fort Madison, Centerville and Glenwood from strata probably equivalent to the Onondaga salt group of New York. At McGregor the salt is derived from a thin layer of the Cambrian.

Salt water also occurs in the strata of the Missourian stage of the coal measures.

The composition of the saline waters is complex, and they rank among the most heavily mineralized waters in the state. They are particularly rich in the sulphates. Calcium chloride and magnesium chloride are absent.

SELENITIC WATERS.

Calcium sulphate is well known in its hydrated form as gypsum, and in the commercial product, plaster of Paris, derived from gypsum by the expulsion of two-thirds of the water of crystallization by heating. In the form of transparent, lozenge-shaped or tabular crystals it is known as selenite, readily distinguishable from limespar by its softness. Calcium sulphate is an ingredient of sea water, and, as it is but slightly soluble in concentrated brine, it is the first mineral to be precipitated when sea water is evaporated. It is a common accessory mineral of the sea-laid sedimentary strata of the state. The argillaceous shales of the Devonian, Carboniferous and Cretaceous are specially rich in gypsum, and the present investigation has brought to light extensive gypseous marls and limestones in strata of Silurian age probably referable to the Onondaga salt group.

Gypsum is readily soluble; only 460 parts of water are required to dissolve it. It is, therefore, a common constituent of phreatic waters, and on account of its physiological and mechanical reactions it is one of the least desirable. The selenitic artesian waters of the state all belong to the sulphated waters also, and their analyses will be given with others of that class. The following waters contain over ten grains of calcium sulphate to the gallon.

Sanborn, C., M & St. P. Ry	70.080
Centerville, No. 2, city	45.870
Grinnell, city	41.100
Des Moines, court house	34.389
Colfax, M. R. springs	31.759
Keokuk Pickle Co.	25.993
Sioux City	18.328
McGregor, No. 1	17.002
Keokuk Poultry Co.	15.834
Webster City	15.494
Washington	14.402
Dunlap	14.020
Colfax O. M. C.	13.070
Boone, city, No. 1	11.708
Fort Madison, Paper Co.	10.217

It will be noted that with one exception, the well at McGregor, all of these wells are situated west of the eastern border of the Carboniferous. Three of the wells, those at Colfax and Des Moines, draw their water directly and only from strata of this age. The wells at Fort Madison, Keokuk, and Centerville owe their calcium sulphate to the Silurian, and the Sanborn well probably to the Cretaceous.

SULPHATED WATERS.

Under this head may be conveniently treated both the waters which contain in large or predominant quantity sodium sulphate, and those which contain magnesian sulphate also. Sulphate of soda or Glauber's salt occurs in gypseous marls and in beds of rock salt. In many parts of the world it is found as an efflorescence or incrustation, as on the steppes of Russia adjoining the Caspian sea, in Hungary, and near Bahia Blanca in southern Argentina. Its constituents are present in sea water, and it may, therefore, be expected in strata which are charged with the results of the evaporation of ancient sea basins.* Sodium sulphate in artesian waters may thus result from direct solution of the salt in sedimentary strata, or it may be produced from the reaction of gypsum, sulphate of lime, with either silicate of soda, or carbonate of soda. The conditions for its production are supplied by the association of gypsum and alkaline marls, or by the mingling of selenitic and sodic alkaline waters.

Sulphate of magnesia, or Epsom salt, occurs in nature as an efflorescence upon certain limestones. It is produced in dolomites containing gypsum by the reaction of magnesium carbonate and calcium sulphate. In other instances it results from the reaction of ferrous sulphate, formed from decomposing iron pyrites, with the magnesium carbonate of magnesian limestones.

*Hunt. Chemical and Geological Essays, p. 105. Salem, 1878.

SODIC-MAGNESIC SULPHATED WATERS.

WELLS.	Magnesium sulphate.	Sodium sulphate.	Potassium sulphate.	Calcium sulphate.	Calcium bicarbonate.	Calcium carbonate.	Magnesium bicarbonate.	Magnesium carbonate.	Sodium bicarbonate.	Sodium carbonate.	Potassium carbonate.	Iron carbonate.	Sodium chloride.	Potassium chloride.	Magnesium phosphate.	Silica.	Oxides of iron and alumina	Total sul. of magn., soda and potas.	Total sulphates.	Total solids.
Nevada, town	137.346	17.840	5.568	......	......	24.500	......	25.978	......	......	......	0.473	5.609	......	......	1.113	0.862	160.754	160.754	219.289
Des Moines, court house	24 709	97.012	......	34.389	......	9.529	......	......	......	......	......	Tr'ce	10.333	Tr'ce	0.332	......	0.440	121.721	156.110	181.872
Keokuk	9.984	108.054	......	15.834	23.971	......	......	......	......	......	......	......	64.562	2 660	......	0.340	0.050	118.038	133.872	234.237
Centerville, No. 2, town.	25.818	89.859	...	45 870	7.067	......	......	......	......	......	......	......	37.195	Tr'ce	......	0.596	0.174	115.677	161.547	228.585
Colfax, O. M. C. spring	31.870	78.860	0.410	13.070	.....	17.510	......	......	......	......	......	0.67	3.850	......	......	0.	29	111.140	124.210	153.710
Keokuk, No. 1	24 874	76.129	......	25.993	9.338	......	......	......	......	......	......	......	60.593	......	.....	0.406	0.447	101.003	126.996	206.066
Colfax, M. R. spring	10.239	77.344	0.620	31.759	......	...	25.939	......	......	......	......	0.258	3.842	......	......	0 710	0.580	88.203	119 962	150.769
Boone, No. 1, town	18.883	54.661	......	11.708	18.933	2.278	......	......	......	......	.....	......	14.765	0.41	......	0.688	0.580	73.544	85.252	124.526
Grinnell, town	30.000	27.340	......	41.100	......	7.000	......	......	......	......	......	......	ʕ.87	......	......	0.	700	57.340	98.440	120.750
Dunlap, town	20.64	33.	48	14.020	......	15.050	.....	0.680	......	......	......	......	3.	84	.....	0.520	0.060	54.120	68.140	88.29
Sioux City	20.880	30.011	.....	18.328	......	19.332	......	.....	......	......	......	......	8.037	.....	......	0.953	0.638	50.891	69.219	99.221
Amana	11.683	30.160	......	......	24.277	....	0.663	......	......	......	......	......	1.740	......	......	0.265	0.373	41.843	41.843	69.401
Ottumwa, Art. Well Co.	6.100	33.830	......	......	......	13.200	......	3.270	......	......	......	......	11.480	......	......	......	......	39.93	39.93	......
Homestead	9.379	29.331	......	3.347	19.173	......	......	......	......	......	......	......	3.165	......	......	0.969	0.572	38.710	42.057	66.410
Webster City	7.747	18.891	.....	15.404	22.529	0.265	......	......	......	......	......	Tr'ce	.994	......	......	1.889	Trace	26.638	42.132	67.893
Sanborn	6.700	29.	82	70.08	......	......	.....	18.53	......	... ..	......	......	2.	50	.....	......	ac e	36.52	106.60	127.63

SODIC SULPHATED WATERS.

WELLS.	Magnesium sulphate.	Sodium Sulphate.	Potassium sulphate.	Calcium sulphate.	Calcium bicarbonate.	Calcium carbonate.	Magnesium bicarbonate	Magnesium carbonate.	Sodium bicarbonate.	Sodium carbonate.	Potassium carbonate.	Iron carbonate.	Sodium chloride.	Potassium chloride.	Magnesium phosphate.	Silica.	Oxides of iron and alumina	Total sul. of magn., soda and potas.	Total solids.
Centerville, No. 1	......	41.689	......	3.662	......	10.456	......	......	......	......	......	......	13.215	......	......	4.731	......	45.351	......
Council Bluffs, asylum	......	55 723	0.478	......	9.363	......	3 272		12.155	......	......	......	7.503	......	Tr'ce	0.543	0.123	56.201	89.433
Jefferson, town	......	46.322	......	......	......	5.663	......	3.207	......	......	......	......	11 005	......	......	0.793	0.414	46.322	67.404
West Liberty, town	......	43.733	......	......	......	11.659	......	0.019	......	38.152	18.125	Tr'ce	9 302	......	0 077	7.676	0.222	43.738	128.972
Fort Madison, Paper Co.	......	40.071	......	10.217	......	14.318	......	7 817	......	......	......	......	41.329	......	......	0.390	0.807	50.288	155.129
Wilton, town	......	33.450	......	......	......	10.470	......	6.450	......	......	......	......	18.560	......	......	0.560	Tr'ces	33.450	69.490
Washington	......	31.952	......	14.402	......	2 811	......	8.961	......	......	......	Tr'ce	5.325	1.015	......	2.049	0.103	46.354	......
Glenwood	......	31.092	......	......	......	5.137	......	1.831	......	50.518	......	0 252	106.284	......	......	0.601	Trace	31.092	195.715
Davenport, Ice Co.	......	23.705	......	......	4 690	......	1.922	......	......	12.677	......	0.406	26.266	......	......	0.497	Trace	23.705	73.776
Davenport, Witts	......	23.407	..	......	......	2.148	......	1.603	......	16.446	..	0.449	26.175	......	......	0.438	......	23.407	70.666
Davenport, glucose factory	......	16.096	......	5.540	5.132	...	4.770	......	......	......	......	......	28.080	......	......	0.216	0.361	21.636	60.195
Vinton	......	8 605	......	5.746	......	6.940	......	4.827	......	......	......	......	0.128	......	..	0.349	1 401	14 351	27.996

Comparing the analyses of the two classes of sulphated waters as given in the accompanying tables, the reader will observe some distinct differences between them. On the whole, the sodic waters are less highly sulphated than the sodic magnesian waters. In the first class magnesium carbonate is usually present and calcium sulphate usually absent, In the second class the reverse obtains, magnesium carbonate usually being absent and calcium sulphate usually being present. While all except two of the sodic sulphated waters rank below 50 grains of all sulphates to the gallon, all except four of the sodic magnesian waters rank above this grade. While the latter excel as medicinal waters, the sodic waters are distinctly superior for town supply, and indeed the best of this class should be placed in the highest rank of potable waters.

CHALYBEATE WATERS.

The quantity of iron carbonate in any water necessary to produce therapeutic effects and to place it in the class of chalybeate waters is extremely small. The celebrated Leuk chalybeate springs of Switzerland contain but 1.10 grains of ferrous bicarbonate to the gallon. The chalybeate springs of Missouri range as low as .092 grains to the same measure. The only artesian waters in Iowa in which iron carbonate has been found, so far as our analyses show, are the following.

TOWN.	IRON CARBONATE, GRAINS PER U. S. GALLON.
Colfax, O. M C. springs	.670
Nevada, town	.473
Davenport, Witts	.449
Davenport Ice Co.	.406
Colfax M. R. spring	.258
Glenwood, town	.252

Ferrous carbonate or bicarbonate, like the carbonates of lime and magnesia, is held in solution in natural waters by carbonic acid gas. On reaching the surface the gas escapes and the iron is precipitated as ferric oxide. In this way are produced reddish stains and accumulations in drinking vessels, deposits of ochre, and brittle, iridescent films, often mistaken for oil, on the surface of springs.

Qualities of Artesian Waters.

The qualities here to be considered are not those belonging to water itself in a pure state, but those which are produced by the presence in solution of various foreign ingredients. According to their kind and amount, these ingredients give to the water of deep wells widely different reactions in several lines, each of which modifies the availability of the water as a municipal supply. These will be treated in the following order.

1. The medicinal qualities of artesian waters, or their therapeutic reactions upon the human system in the case of specific diseases.
2. The wholesomeness of artesian waters, or their physiological reactions upon the human system under conditions of health.
3. The industrial qualities of artesian waters, that is, their reactions upon different industrial products in process of manufacture. Under this head will be considered their qualities as steam-producing waters in stationary and locomotive engines.

THERAPEUTICS OF ARTESIAN WATERS.

A large number of the artesian waters of the state may be considered as mineral waters, using that term in the narrower sense as connoting those waters which have, or are supposed to have, medicinal effect upon the animal body by reason of their mineral ingredients. The minerals dissolved in the deep waters of Iowa are those which give their efficacy, their fame and their commercial value to many of the celebrated springs of the world. In degree of mineralization our stronger waters compare favorably with many of the highest repute in other states and countries. The physiological effect of several of our waters is marked upon those not accustomed to their use even in the small quantity of the ordinary daily ration in health. Of many more, a free use, such as is usual in water cures, is beneficial or curative in certain diseases, and in but few, if any of these waters, is the quantity requisite to produce the desired effect too large for easy digestion.

There are two points of approach to the treatment of the special therapeutic qualities of Iowa deep waters; the one the physiological action of the different materia medica which they contain, the other the accredited virtues of similar waters. The former is somewhat difficult for a layman, while the latte rraises the vexed question of the real curative properties of mineral springs. Without question psychical factors, besides the peculiar qualities of the waters, enter into the innumerable well attested cures made by medicinal springs. Rest from routine and care, change in climate, in altitude, in diet and habits of life, these and other concomitants have their remedial effects. Water itself, apart from the minerals it may contain, is a known therapeutic agent. When freely drunk it increases the action of the kidneys and the rate of removal of injurious products of change. When taken hot, it further acts as a stimulant to other vital organs of thc body.

After making all these deductions, there still remains a considerable component of the cures made at watering places that must be attributed directly to the medicinal qualities of mineral waters. Clinical experience attests here the popular belief.

In Europe, where strong mineral waters are either more abundant or have been longer used, their values have been most thoroughly investigated and are more widely appreciated than in America, where their place is largely taken to our disadvantage by deleterious patent medicines of unknown composition.

CALCIC AND MAGNESIC WATERS.

The carbonates of lime and magnesia are antacids and the latter salt is also laxative. It is administered in doses of from thirty to 320 grains.* Strong calcic waters are said by Coan to be found useful in cases of chronic diarrhœa, and milder calcic waters in cystitis.

*H. C. Woods. Therapeutics, p. 757, 9th Ed. Phil., 1894.

SODIC ALKALINE WATERS.

The presence of sodium carbonate renders these waters antacids of great value. In cases of acid dyspepsia this salt is used by the profession in preference to any other alkali, and is administered in doses of from ten to twenty grains, amounts contained in one-fifth to two-fifths of a gallon of the Glenwood water. Waters of this class when freely taken render the urine alkaline, and possibly, though not demonstrably, other secretions also. They are indicated in several affections of the bladder. They are prescribed also for bronchial and nasal catarrhs, and catarrhal conditions of the digestive organs, since they act beneficially on the secretions of the mucous membrane by making them more fluid. They are indicated also in gout, obstructions of the gall ducts and in hyperæmia of the liver; but are forbidden in anæmia, consumption, and inflammations and lesions of the vital organs. During treatment the use of acidulous fruits is injurious, in that it counteracts the alkaline effect of the waters. Long continued or excessive use of strong waters of this class tends to deplete the blood and impair digestion.

While the sodic alkaline waters of Iowa are weak compared with several of the sodic springs of Europe, such as Vichy and Ems, which carry respectively 319 grains and 129 grains to the gallon, yet they compare very favorably with waters of the same class in the eastern United States. In Peale's Mineral Waters of the U. S., Washington, 1886, only eighteen localities are mentioned east of the Missouri river the waters of whose springs contain over ten grains of sodium carbonate to the gallon. Five of the artesian waters of Iowa exceed this amount and two go far beyond it. The Glenwood well with fifty grains to the gallon is surpassed in this respect by but three springs in the territory named, the Geyser Spouting springs of Saratoga, N. Y.; the Saint Louis Magnetic springs of Missouri, and the Vichy springs of Owatonna, Minn.

SALINE AND SELENITIC WATERS.

Saline waters stimulate the secretions of the digestive tract, and are said to be valuable in flatulent dyspepsia and some other diseases. None of the waters of the state contain salt to a degree even approaching the limit of potability. Their weakness in this respect is seen by comparing the most saline water in the state, that of Glenwood, containing 106 grains of salt to the gallon with true saline springs, such as the Congress at Saratoga and the Artesian Lithia of Ballston Spa, N. Y., which carry respectively 400 and 750 grains of this ingredient to the gallon. As the normal daily ration for an adult is some 300 grains of salt, no ordinary potations of our deep waters will so increase it as to affect health. Selenitic waters are said to be laxative when used freely.

SULPHATED WATERS.

The characteristic constituents of these waters are the sulphates of magnesia and of soda, well known as Epsom anp Glauber's salts, each a most active hydrogogue cathartic in the doses usually administered. On account of harsher action and more nauseous taste, Glauber's salt is but little used in medical practice upon the human subject.

In no analyzed deep water of the state are the solutions of these salts so concentrated as to be more than mildly laxative when taken in considerable quantity. Sulphated waters are alkaline in their reaction and are indicated in dyspepsia accompanied by an excess of acid in the digestive tract, and in chronic catarrh. They are sometimes recommended in constipation and are said to be often serviceable in diabetes. Since they aid in the oxidation of fat and reduce the weight of the body they are prescribed for the reduction of obesity, for gout, scrofula, rheumatism, diseases of the liver, and, in general, for diseases caused by over-feeding. Contra indications are poverty of the blood, weakness of the constitution, and inflammation and lesions of the lungs and heart.

CHALYBEATE WATERS.

We have seen that the amount of ferrous bicarbonate necessary to give water a distinct therapeutic value is very small. Even in such quantities of a fraction of a grain to a gallon as obtain in several Iowa wells it may be expected to produce its customary effect upon the human system. Its physiological function is well known in reinforcing the red corpuscles of the blood. Chalybeate waters are indicated in conditions of depleted blood and enfeebled constitution, and the many chronic and nervous diseases that result therefrom.

CARBONATED WATERS.

Carbonic acid gas is regarded as a mild stimulant, aiding digestion and slightly increasing peristalsis and diuresis. It occurs in several of the mineral waters of the state, and can be artificially added with little expense to any waters bottled for export.

THE WHOLESOMENESS OF ARTESIAN WATERS.

The healthfulness of any drinking water is in inverse ratio to its medicinal value. It is a plain fact that medicines good for a sick man, while he is sick, are not good for a well man as a constant diet.

The most strongly mineralized waters of the state, especially those containing the various sulphates in large quantities, cannot be said to be wholesome for daily use; nor can they be recommended for water supply, when less heavily mineralized waters are available. At the same time, it must be admitted that no artesian water in Iowa is condemned by the experience of the physicians of the town, so far as that has been gathered. In but few instances has any water been pronounced unwholesome in any respect by a physician, and in these instances his judgment usually contravenes that of others of the same profession. The evidence of the fraternity to the physiological effects of several of the worst waters has already been given. But this evidence is incomplete for different reasons. In several cases the wells have been drilled so recently that time has not been given for any adequate test. Families owning private wells to whose water they have become accustomed, are slow to change to the city water, requiring artificial cooling, unless the hygienic superiority of the latter is clearly proven; and so it is usually the case that city artesian water of the stronger kinds is drunk by but a small proportion of the citizens. The disorders of the system expected to result from the use of such waters are often obscure, tardy in their development, and may be attributed to other causes. Moreover, the common well water to which the population has become habituated, may be similar in mineral character to that of the artesian well and equally unwholesome. The evidence of physicians, while of great value, is largely based upon impressions instead of upon statistics gathered for a series of years and embracing large populations. For these reasons the experimental evidence, so far as it is before us, cannot be said to be at all conclusive, and we revert to the general principle of the essential difference between medicine and food. Certainly waters are not wholesome which are so strong in Glauber's salt, Epsom salt, and sulphate of lime, that they are, when first used, distinctly laxative in ordinary rations, especially when this effect is afterward followed by constipation. Such waters should be taken with strict reference to the *materia medica* they contain, and they should be discontinued in time to avoid the well known "crises" which attend the prolonged use of medicinal waters. In certain conditions of the system, to certain diatheses, they may be tolerable or beneficial; but they cannot be considered a wholesome water supply.

HARDNESS OF WATER.

Apart from the healthfulness of laxative sulphated waters, there remains the question of the healthfulness of hard water in general.

In most localities in Iowa the selection of a public water supply involves a choice between waters of considerable or extreme hardness, and waters which relatively may be said to be soft. In this selection the factors of purity, adequacy, and expense will usually carry most weight, but the element of the relative wholesomeness of hard and soft water should always be considered and sometimes should be decisive. Unfortunately sanitarians have been divided by wide differences of opinion upon this subject. As to the wholesomeness of soft water, there never has been any dispute. Its great solvent power, its freedom from constituents whose healthfulness might not be held as demonstrated, place it above suspicion and lead to its prescription in the sick room. But the wholesomeness of hard waters has often been questioned, and medical authorities are not yet agreed as to the physiological effects of waters of certain kinds and degrees of hardness.

On the one hand, hard waters have been claimed to be even superior to soft, in that their lime salts contribute to the growth and nutrition of the body. French and Austrian commissioners have reported that hard water districts in these countries supplied conscripts of larger stature, of stronger bones, and of better form. This claim is now disallowed by the consensus of medical opinion. Many common kinds of food furnish for the building and renewal of bone tissue calcareous material in a far more available form than the lime of water, and in excess of any possible demand.

On the other hand, the hardness of drinking water has been held responsible for grave diseases: goitre, cretinism, calculus, anæmia, dyspepsia, diarrhœa and various disturbances of the digestive organs. If this were true, the hardness or softness of the water supply should affect the death rate of cities to a degree perceptible in large aggregates. The investigations on this line of evidence by the rivers pollution commissioners of Great Britain were unusually complete, and the following table summarizes the result as applied to the cities of the United Kingdom:*

* 6th Rept. Rivers Poll. Comm., p. 194 London, 1876.

CLASS.	Number of cities.	Average population.	Hardness of water in parts per 100,000.	Hardness of water in grains U. S. gallon.	Death rate per annum per 1,000.
I.	26	73,366	Not exceeding 5°.	Not exceeding 2.9.	29.1
II.	25	81,655	5°–10°	2.9 to 5.8	28.3
III	60	44,794	Above 10°	Above 5.8	24.3
IV.	London.	3,254,260	16°–32°	9.3–18.7	24.6

Certainly this summary does not support the claim that hard water is unwholesome. Nor does it prove, as it appears to do, that hard water is superior to soft. Other causes affecting public health are so potent that their effects mask that due to the mineralization of water supply. It will also be noticed that none of the maxima mentioned are waters of extreme hardness from the point of view of this discussion, although such waters are doubtless included in class III. All of the four classes embrace waters which would here be popularly called soft. The least hard London water is that taken from the Thames and Lea rivers, and the hardest, drawn from deep chalk wells, is comparatively unobjectionable because its hardness is due almost wholly to carbonate of lime. The conclusion of the commissioners may be stated in the words of De Rance,* "Where sanitary conditions prevail with equal uniformity, the rate of mortality is practically uninfluenced by the degree of mineralization."

Falling back upon the experience of physicians, we find in evidence a mass of statements more or less conflicting. Goitre, for example, has been defined as "a specific affection of the thyroid gland, induced by the persistent use of water that has percolated through magnesian limestone rocks or strata containing the soluble salts of lime in solution." † Yet this view of the cause of goitre may be said to be now obsolete or obsolescent, investigations in several countries having showed that the disease is not confined to districts of limestone whether magnesian or non-magnesian.

* Water Supply of England and Wales, p. 41. London, 1882.

† Aitken, Science and Practice of Medicine, 6th Ed., vol. II, p. 658. 1872.

In the case of calculus diseases, the evidence against hard waters as their cause is sufficient at least to direct suspicion. Testimony was before the rivers pollution commissioners showing that in the opinion of eminent physicians a marked diminution of cases of urinary calculus followed the change from hard water to soft in several large cities and public institutions.*

Dr. E. A. Parkes,† after referring to the popular opinion that drinking lime waters gives rise to calculi and stating that "several medical writers held the same opinion and have adduced individual instances of calculi being apparently caused by hard waters and cured by the use of soft or distilled water," goes on to say that so far as he knows "statistical evidence on a large scale is wanting." Among recent authorities in hygiene who regard the evidence against hard water as the cause of calculi as insufficient or unreliable are Rohe,‡ and Coplin and Bevan.§

There is a substantial agreement among experts that calcium sulphate is the deleterious ingredient of hard water, rather than calcium carbonate. Of the latter Dr. L. C. Parkes‖ says: "Waters cantaining calcium carbonate in solution, the temporarily hard waters, are not in any way injurious to health." Of the former the same author remarks: "Waters with permanent hardness exceeding 7° or 8° (Clark's scale) often cause dyspeptic symptoms and diarrhœa, especially amongst those who are not used to them."

The following extracts from the evidence before the rivers pollution commissioners are quoted at length because of their interest, weight, and direct bearing upon the wholesomeness of the deep waters of Iowa, and also on account of the fact that the reports of the commissioners are inaccessible to the majority of our readers.

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* Fourth Rept. Rivers Pollution Comm, vol. II, pp. 183-193. London, 1868.

† Manual of Practical Hygiene, 5th Ed., p. 42. London, 1878.

‡ Text-Book of Hygiene. Baltimore, 1885.

§ Practical Hygiene, p. 192. Philadelphia, 1893.

‖ Hygiene of Public Health, p. 66. Second Ed., Am. Ed. Philadelphia, 1890.

Dr. Francis Ogston,* medical officer of health of Aberdeen: "I am positive that soft water is preferable to hard. Hard water generally produces bowel complaints, principally diarrhœa."

Dr. John Sutherland, of Liverpool:† "In certain susceptible constitutions * * * the hard water tends to produce visceral obstructions; it diminishes the natural secretions, produces a constipated or irregular state of the bowels and consequently deranges the health. I have repeatedly known these complaints to vanish on leaving the town (Liverpool) and to reappear immediately on returning to it, and it was such repeated occurrences which fixed my attention on the hard selenitic waters of the New Red Sandstone as the probable cause, as I believe, of these affections."

Dr. Leech of Glasgow: "The comparative value of the new soft supply over the old hard supply has been a matter of discussion at the Glasgow Southern Medical Society, of which I was president two years ago. It was the unanimous opinion of the medical profession that great benefits of a sanitary kind had followed on the substitution of the soft water. * * * So far as experience has gone my own opinion is that dyspeptic complaints have become diminished in number.‡

Prof. John Thomas Way:§ "I do not attach anything one way or the other to the question of health, that is to say, where the hardness is in moderation, where carbonate of lime is the hardening ingredient; but when you have water with eighty or ninety grains of sulphate of lime in a gallon [sixty-seven or seventy-five grains in U. S. standard gallon] as you sometimes have, that is another question entirely.

The following report was in evidence of the commissioners appointed to investigate the quality of the water available for the supply of London. The hardness of the London supply has already been given. "It may be safely stated that no

* Fourth Rept. Riv. Poll. Comm., vol. II, p. 180. London, 1868.
† Sixth Report Riv. Poll. Comm , p. 184. 1876.
‡ Ibid, p. 185.
§ Ibid, p. 185.

sufficient grounds exist for believing that the mineral contents of the water supplied to London are injurious to health. * * The only observations from which an interference of the lime in water, in deranging the processes of digestion and assimilation in susceptible constitutions has been conjecturally inferred, have been made upon waters containing much sulphate of lime or magnesia * * * or the hard selenitic water of the New Red Sandstone, and have no force as applied to the Thames, and its kindred waters as the earths exist in these principally in the form of carbonates."*

Dr. E. A. Parkes, F. R. S.:† "I do not think with regard to pure chalk water that there is evidence that a moderate amount of carbonate of lime in the water does any harm. Certainly not on a large scale; in some individuals it produces indigestion. I think that that degree of hardness (16° or 20° Clark's scale) would be certainly prejudicial. I think that very probably it might disagree with a great many persons, but supposing it reached to eight, or ten or twelve degrees of hardness from carbonate of lime it might be considered probably good water as far as that was concerned, but I should draw a marked distinction between that and the hardness arising from sulphate of lime, or sulphate of magnesia, or chloride of calcium, which would certainly disagree in much smaller quantities; so that the goodness of water for drinking purposes, I would estimate according to its temporary hardness. With fifteen or sixteen degrees of carbonate of lime hardness, I should say that it would be hard water, and with some persons it would disagree and produce dyspepsia. I think it should not exceed ten or twelve degrees if possible. At the same time I should wish to state that one would prefer water free from even that if it were possible to get it."

On the other hand Sir Dr. Benjamin Brodie, Bart., professor of chemistry, Oxford university,‡ testified that he had no

*Ibid, p. 185.
†Ibid, pp. 189-190.
‡Ibid. p. 191.

reason to think that the use of hard or soft water as a drinking water produces any difference of effect upon health.

Prof. William Allen Miller, M. D., F. R. S.,* professor of chemistry, King's college, inclined toward the same view. "Chalk waters, I consider, are waters perfectly wholesome, but waters which have a similar degree of hardness from sulphate of lime, there appears to be some reason to believe, are found occasionally to disagree with persons. Still, there are waters which are supplied to large populations containing sulphate of lime and very hard sulphate of lime water. For instance the populations of Wolverhampton and Birmingham are supplied with waters of this kind. It is certainly objectionable, but what I was going to say was that the evidence in that case is that there is no sensible injury to health directly traceable to the water as far as observation goes."

The conclusion of the royal commissioners is expressed as follows:

"*On the alleged influence of the hardness of water upon health.*—The question of the comparative wholesomeness of soft and hard waters has, for many years past, received the attention of the highest medical and chemical authorities. The general result appears to be that whilst, on the one hand, opinions have differed considerably as to the wholesomeness of hard water, on the other there has been and now is an almost complete unanimity as to the wholesomeness of soft water."†

We add a few extracts from recent authorities which show that these doubts and differences of opinion have not become resolved at the present time.

Dr. Thomas Stevenson, F. R. C. P.,‡ of London, writes as follows:

"It is now generally accepted that excessively hard waters are injurious to the digestive processes, though proof of this is difficult and the conclusion has been doubted. All are agreed that where the hardness of water is due to the

*Ibid, pp. 191–192.
* Ibid, p. 184.
* Stevenson and Murphy, Treatise on Hygiene, Amer. Ed. Phil., 1892.

presence of carbonate of calcium, and, to a lesser degree, of carbonate of magnesium, *i. e.*, where the hardness is temporary and removable, little harm ensues; but that when the hardness is permanent, and due to the presence of the sulphates, nitrates and chlorides of calcium and magnesium the dietetic value of a water is greatly impaired. How far this opinion is based upon a solid basis of facts is at least uncertain. The waters of the valley of the River Trent and very many of those derived from wells and springs in the New Red Sandstone formation, are intensely seleniferous, *i. e.*, abound in sulphate of calcium, and yet are not generally considered harmful. Some of our town supplies as, *e. g.*, those of Bristol and Sutherland are very hard, the water supply to Sutherland containing magnesia and sulphates the equivalent of fourteen grains anhydrous, and twenty-eight grains crystallized sulphate of magnesia per gallon [imperial], yet the medical officer of health has not been able to trace any inconvenience to health, much less disease, to its use, and it is believed to be a good, wholesome water, though having a hardness of 25°."

"Limestone water," says Dr. W. M. Johnson,* "may produce temporary disturbances of the bowels, but is wholesome. Carbonate and sulphate of lime and magnesia in solution are more cathartic, but not so much so as selenitic waters which contain an excess of sulphate of lime."

Coplin and Bevan conclude that sufficient evidence is wanting in proof that hard water gives rise to disturbances of the digestion and other diseases.†

Rohe states that "it is undoubtedly true that calcareous waters produce gastric and intestinal derangements in those unaccustomed to their use."‡

Prof. William Riply Nichols,§ professor at the Massachusetts Institute of Technology, and author of perhaps the best

* Pepper's System of Medicine, vol. II, p. 673. Phil., 1885.
† Practical Hygiene, p. 192 Phil., 1883.
‡ Text-book of Hygiene Baltimore, 1888.
§ Water Supply, pp. 13 and 14. N. Y., 1886.

manual of water supply, considered from a chemical and sanitary standpoint, says: "It appears that distilled waters, soft surface water, and moderately hard spring or well water, are all wholesome and may be drank without inconvenience by persons accustomed to their use. It is, however, true that a person who is in the habit of drinking a soft water generally experiences some derangement of the digestive organs on beginning to use hard water, and vice versa. * * It is, however, the result of general observation that a hard water of which the hardness is due to salts of magnesia, or to sulphate of lime, is not well suited for drinking and is injurious to most persons."

INDUSTRIAL QUALITIES OF ARTESIAN WATERS.

In many industries the quality of the water is of special importance. Chalybeate water, for example, can not be used in the manufacture of fine papers on account of the stains which it is liable to produce. Soft water is often preferable to hard; as in sugar refineries, where its employment effects a saving in parchment used in osmosis and an increase in the rendering of the waters of diffusion; in the manufacture of extracts; and in laundries for the obvious economy of soap.

Artesian water is particularly valuable in several manufactures on account of its organic purity. It is specially adapted for the supply of ice factories in that its freedom from malignant bacteria renders the ice formed from it entirely safe for use in any manner. On the other hand, as Drown* has shown, in the freezing of entire masses of water there is liable to be an objectionable concentration of the mineral ingredients in the portion of each block last frozen. The brewer also prizes artesian water highly, for it carries no bacilli to interfere with those of his own cultures. For the use of paper mills it is superior to stream water, other things being equal, since it is not subject to floods and times of turbidity.

*The Purification of Water by Freezing. Jour. New Eng. Water Wks., Assoc., vol. VIII, No. 1, pp. 46–52.

ARTESIAN WATER AS A BOILER SUPPLY.

The availability of any water for municipal use depends in part upon its qualities as a steam water. In villages in which there are no large manufacturing plants, this factor may be omitted from consideration, but it can not be neglected in towns which are already manufacturing centers and whose progress depends upon the development of manufacturing industries. In towns of the latter class the use of a poor boiler water involves a direct financial loss, which is either borne by the consumer, or by the water company through the reduction of revenue from mills and factories which have been compelled to seek an independent supply. Instances could be cited in which this loss of revenue has been largely influential in moving water companies to change their supply to softer waters.

The discussion of the topic at this place is pertinent also from the fact that a number of artesian wells have been drilled for no other purpose than for boiler supply. These are especially numerous in the northern counties of the state, in which seven artesians have been drilled by the Chicago, Milwaukee & Saint Paul Railway Co., for the supply of the locomotives of that line.

Waters of extreme hardness are unsuitable for boilers, although their use for this purpose is often unavoidable. By the evaporation of such waters in boilers various minerals held in solution are thrown down, forming deposits termed incrustation, scale, furring, or scurf. The chief scale-forming minerals are:

1. Calcium sulphate.
2. Calcium carbonate.
3. Magnesium carbonate.

Of less importance are alumina, silica and the salts of iron. The other minerals usually present in deep waters are readily soluble, and do not contribute to the formation of scale except after chemical recombination. Magnesium sulphate is often reckoned as a scale-forming mineral and is in our tables included among the incrusting solids.

The amount of deposit which may accumulate in a boiler in a few weeks is much larger than one would suppose. A boiler of 100 horse power, for example, will evaporate 30,000 pounds of water in ten hours, or 390 tons per month. If the water used were of the character of the Kent artesian well, whose incrusting solids amount to 42.140 grains per gallon, the incrusting deposits produced in this period would weigh over 560 pounds.

But the gross weight of scale is one of the least of its evils, as will be seen if the manner of its formation is considered. When feed water which has not been previously treated enters the boiler, carbon dioxide is expelled by the heat and calcium and magnesium carbonates are at once precipitated. Thus the feed pipe is furred, obstructed, and at last entirely choked. Most of the precipitate however, is thrown down in the boiler, as a fine insoluble powder, which is carried at first to the surface by the rapid ebullition of the water. Forming here a scum, it retards the ready escape of the steam bubbles. Mingling with the water it increases its viscosity and may cause foaming or priming. As the name implies, this is a violent ebullition of the water owing to the retention of the steam within its mass. Thus water and scum may be driven together with the steam into the cylinders, where the lime salts collect upon cylinder covers and pistons to their injury and possible destruction. Beneath this sediment laden water, steam bubbles may form, lifting the water from the plates and allowing them to become overheated in much the same way that viscous fluids, from which steam cannot readily escape, overheat and "burn on" the bottoms of cooking utensils. As the precipitate settles in sludge upon the plates, it forms a layer of comparatively little heat-conducting power, causing a loss of heat and waste of fuel.

Various estimates have been made of the loss of heat resulting from scale. Some of these are excessive, and all are large. By Nystrom's formula it is calculated that a loss of about 15 per cent of heat is caused by scale one-sixteenth of an inch in thickness and of 23 per cent by scale three times as thick. The presence of this layer of poor conductivity on the inner side of plates or tubes allows overheating and warping and its unequal distribution produces unequal expansion and contraction, one of the principal causes which shorten the lifetime of a boiler. This stony incrustation into which sludge is soon baked unless blown out at frequent intervals is so closely adherent to the iron that it can be removed only by use of acids or by chipping processes, both more or less injurious. In contact with the plates the calcium and magnesium carbonates of the scale are changed to caustic oxides by the intense heat,* and, according to Lewes, if magnesium chloride is present the same result may be reached by reaction with calcium carbonate. So long as heated these oxides remain anhydrous, but are changed to hydrates by access of water on cooling.

The effect of calcium sulphate when present in feed waters is much the same as that of the carbonates of lime and magnesia. Unlike them it is freely soluble in water without the aid of carbon dioxide. According to Regnault its solubility is greatest at 95° Fahr. when 178 grains are required to saturate one imperial gallon. At 212° Fahr. 152 grains are still soluble in the same quantity, an amount so large that were no higher temperatures than this reached in boilers, no calcium sulphate would be deposited except by the progressive concentration of the salt by the evaporation of the water, a process easily prevented. But calcium sulphate becomes less and less soluble with increase of temperature. When water in a boiler reaches a temperature of 271° Fahr., nearly the whole of the calcium sulphate in solution is thrown down, and the entire amount is precipitated at or before a temperature of 303°, reached at a pressure of seventy pounds to the square inch.† Unlike the deposits of calcium and magnesium carbonates, which remain soft and readily removable for a

*T. B. Stillman, Journal of Analytical Chemistry. Jan., 1890.

†Armstrong, Construction and Management of Steam Boilers, p. 176. London, 1878.

considerable time, the sludge of calcium sulphate rapidly hardens into a peculiarly intractable scale, cementing with it all other scale-forming minerals present in the waters.

Taking into account all sources of loss in fuel, in labor, and in wear and tear, it has been estimated by the Railway Master Mechanics' Association of the United States that the extra expense due to the use of hard waters by the locomotives on the railways of the middle and western states amounts per annum to $750 for each locomotive*. The expense is little less for stationary engines evaporating equal quantities of water.

So great is the evil of boiler scale, and so universally present in the artesian waters of Iowa are the ingredients that constitute it that a brief resumé of the remedies employed in its treatment may not be without value.

None of the many nostrums advertised for the mitigation and removal of boiler scale—and over two hundred patents are on record in England for this purpose—are more effective than the simple remedies that a chemical and mechanical study of the subject suggests. No panacea exists. Treatment that would prove effective for one water will be useless or injurious in the case of another. A chemical analysis of water is necessary before any special prescription can be made.

As prevention is better than cure, the drift of opinion among experts at the present time is toward the removal of scale-forming substances as far as possible from the feed water before it enters the boiler. This is accomplished in vessels of various designs, heated by exhaust steam or by waste heat from boilers or flues. Temporary hardness is thus readily removed, but permanent hardness cannot be reduced except at pressures and temperatures reached in the boiler itself. Remedies applied directly to boiler water may be chemical or mechanical. The first look to the precipitation of lime salts as carbonates in a soft sludge, rather

*Edwards' Practical Steam Engines Guide, p. 120, 3d Ed. Phil., 1894.

than as sulphate, which sets, as we have seen, in an obdurate and tenaceous scale. Whenever calcium sulphate is present in boiler water, the best remedies, considering the element of cost, are caustic soda and carbonate of soda. Caustic soda, although more expensive than salsoda and soda ash, is doubly effective. Combining first with calcium bicarbonate, it unites with the excess of carbon dioxide to form sodium carbonate while the calcium carbonate is precipitated. The sodium carbonate then reacts with the calcium sulphate forming calcium carbonate and sodium sulphate. The resulting sludge is readily blown out.

Mechanical remedies are intended to prevent the aggregation adhesion and hardening of scale. These are quite beyond enumeration, and the writer is not prepared to recommend any of them. Chips or sawdust of heavy wood have been introduced into boilers to serve as separate nuclei for the concretion of the scale. The particles of the sludge may be prevented from adhering and cohering by admixture with finely divided materials like clay, or by being coated with thin pellicles of oily or slimy substances like petroleum, starch or molasses.

Remedies for scale may either be placed in quantity in the boiler at the beginning of the working week, or, far more effectually, may be brought in with the feed water either continuously or at short intervals by means of patented appliances.

No remedy is without possibility of harm, and none is effective without frequent blowings out, which alone go far in mitigating the evil. By the use of simple means specially adapted to its chemical composition, even the hardest artesian waters in the state, with scarcely an exception, may be used with safety, if not economy, and without recourse to any nostrum of unknown composition.

In order to obtain the practical experience of engineers in the use of artesian waters of the state, blanks were sent out to the proprietors of the wells and much of the information thus furnished is entered with the records of the wells given on preceding pages. According to these reports a number of the wells supply exceptionally good boiler water. Thus the water of the Clinton wells is said to be non-corrosive and to produce no scale and to be superior to the waters of the Mississippi river. The waters from the Kimball house well, Davenport, the new Centerville well and the well of the Bank and Insurance Building, Dubuque, are said to form no scale, and boilers are found to be perfectly clean after months of usage, with no further attention than the usual blowings out. The Glenwood water is said to have no effect on boilers so long as air is excluded, and the waters of Jefferson and the McGregor well No. 2, are reported to be very good for boiler use.

In several cases deep well waters supply their own remedy for scale. Such are the sodic alkaline waters, as those of Clinton, West Liberty and Council Bluffs. Although these waters contain also incrustive solids, the anomalous equibrium is broken up upon heating and the lime and magnesian salts are thrown down in sludge. Whatever scale may form is soft and, after reaching a certain thickness, is said to fall of its own weight. With such waters no chemical treatment is necessary or useful.

A number of wells carry waters which are reported as highly corrosive, eating out iron pipe, and boilers at rivets, and destroying boiler flues in some instances in as brief a time as three months. Several well waters are reported to foam badly, the latter belonging to the sodic alkaline class.

The following table presents the number of grains of incrusting solids to the gallon in the artesian waters of the state so far as they have been analyzed, and their rating on this basis as steam waters. The rating is that adopted by the American Association of Railway Chemists, Buffalo, 1887, except that the rating of "good" is here divided into good and "very good," according to the usage of the Chicago, Burlington & Quincy railway.

a VERY GOOD.

Waters with less than eight grains of incrusting solids per gallon.

Davenport, Witts' well	4 638
Davenport, Ice Co.	7.697
Glenwood, city	7.821

b GOOD.

Water with from eight to fifteen grains of incrusting solids per gallon.

Jefferson, city	10.077
Council Bluffs, asylum	13.301
Dubuque, Cushing's	14.242

c FAIR.

Waters with from fifteen to twenty grains of incrusting solids per gallon.

Dubuque Malting Co.	15.117
Mason City, city	15.660
Davenport, Glucose Factory	16.019
Dubuque Steam Heating Co.	16.182
Calmar	17.060
Wilton	17.480
Vinton	17.513
Clinton, Water Co.	19.286
West Liberty	19.578
Sabula	19.166

d POOR.

Waters with twenty to thirty grains of incrusting solids per gallon.

Emmetsburg, Chicago, Milwaukee & St Paul railway	20.960
McGregor, No. 2, town	20.516
Dubuque, Bank and Insurance Building	20.590
Centerville, No 1	21.959
Monticello, town	21.162
Ottumwa, Artesian Well Co.	22.570
Britt, Chicago, Milwaukee & St. Paul railway	24.440
Monona, Chicago, Milwaukee & St. Paul railway	26.600
Cedar Rapids, Y. M. C. A.	28.214
Washington, town	28.526

e BAD.

Water with thirty to forty grains of incrusting solids per gallon.

Ft. Madison, Paper Co.	33.549
Homestead, Amana Society	33.440
Amana, Amana Society	37.261

f VERY BAD.

Waters containing over forty grains of incrusting solids per gallon.

McGregor, town No. 1	42.928
West Bend, town	43.194
Webster City	47.924
Dunlap, town	50.970
Keokuk, Poultry Co.	50.179
Boone, town No. 1	53.050
Sioux City	60.121
Keokuk Pickle Co.	61.058
Colfax, M. R. spring	68.963
Grinnell, town	78.800
Centerville, town No. 2	79.525
Sanborn, Chicago, Milwaukee & St. Paul railway	95.310
Nevada, town	190.272

Artesian Waters as a Public Supply.

Several aspects of the suitability of artesian water for the supply of cities and towns have been treated in the sections upon its chemical, remedial and sanitary qualities and its industrial uses. There are left to consider the adequacy of artesian supply, its cost, and its organic purity. A few notes will be added giving some hints as to the drawing of contracts and the preservation of records, and a brief description of the methods of well-drilling as now practiced in the state.

ADEQUACY OF ARTESIAN SUPPLY.

It is the good fortune of Iowa that her climatal conditions are such that the adequacy of artesian supply for other than public uses need not be considered. In less humid climates, in regions of rainfall too scanty or uncertain for agricultural purposes, the question of the sufficiency of artesian water for the irrigation of farm lands becomes one of prime importance. So limited must artesian waters always be compared with the vast volumes of the rainfall, that geological experts are practically unanimous in their judgment that it can never be used to make good the deficiencies of rainfall, except in restricted areas. It has been graphically stated by Powell,* late director of the United States Geological Survey, that "if all the artesian wells in the world, which are used for irrigation, were assembled in one county * * * they would not irrigate that county."

Any diversion toward irrigation must seriously restrict the use of artesian water for municipal supply. In Iowa practically the entire volume of artesian water is available for its highest and most appropriate function.

While the volume of water stored in the geological formations of the Iowa field under artesian conditions is enormous, as we have seen in a previous section, the quantity available at any one place is so limited that it may readily be overdrawn. The evidences of such overdraft have already been considered, and for a statement of them the reader is referred to the description of the wells of Dubuque, Davenport, Cedar Rapids, Clinton and Keokuk. While the facts at hand do not point to any such exhaustion of local areas as have frequently occurred outside of the state, they are sufficient to show that the amount that can be drawn through porous strata at any point is limited, and too much must not be expected of it.

Without going into details we may conclude from the evidence at hand that, in the most advantageous positions, in those nearest the large Wisconsin reservoir and at the lowest levels, artesian wells may be safely depended upon as a permanent supply for towns of about 10,000 inhabitants. In less favored localities, on higher ground, and more remote from the reservoir, they can hardly be expected to meet the demand of towns of more than one-half the size mentioned.

* U. S. Irrig. Surv., Second Ann. Rep., p 260. Washington, 1890.

It must be remembered that the consumption of most Iowa towns is still comparatively small. The population is usually extended over a relatively large area. The expense of laying mains throughout this area is great compared with the population served and the revenue received, and the whole town is therefore but seldom supplied. Even on streets where mains are laid, it is often the case that many families use domestic wells and cisterns. The consumption ought therefore to increase with the extension of mains and the larger use of city water by the people at a higher rate than the probable future increase in population would indicate. On the other hand, there is often a waste of city water which progress in the use of meters will reduce. In England it has been found possible by strict regulation to limit domestic supply to about thirteen imperial gallons daily per inhabitant.

In America, the consumption seldom falls below thirty gallons, and often it exceeds 100 gallons. Counting the entire population of a town, an average of fifty gallons per day should be sufficient under present conditions in Iowa, especially if meters are included in the plant. But the consumption of water is not constant. It varies with night and day, and especially with the seasons. The supply must be competent to meet the maximum draft, and this may be estimated at 100 gallons daily for each inhabitant. With this estimate, an artesian well may be expected to serve 1,000 inhabitants with each seventy gallons of its discharge per minute.

In several towns of rapid growth where artesian wells have been found inadequate to meet the demands of the increasing population, this supply has been supplemented with raw and probably impure water drawn from adjacent rivers. Consumers should understand that by this procedure the sanitary value of the mixed water which they drink is reduced nearly, if not entirely, to that of the impure constituent. It is not a chemical mixture, as of hard water with soft, in which the mean resulting quality can be calculated. It is a pollution of water bacterially pure with water which may contain malignant micro-organisms capable of reproduction in enormous ratios during the few hours or days in which the water remains in the reservoir. This objection does not obtain when the water used to supplement the artesian supply has been made organically pure by proper treatment in a filter plant. But the cost of filtered water is great. To the interest on the investment in the filter plant must be added the running expenses of filtration. It is therefore an interesting and important question as to the comparative cost of such a double supply, and one obtained from filtered water only. This will depend upon the cost of artesian wells, and this varies with the depth at which artesian water can be reached and with other factors. But if our correspondents who have had practical experience in the use of both supplies are correct, the cost of artesian water in eastern Iowa is sufficiently less than that of filtered water to make artesian wells a profitable investment, even though they are not capable of furnishing all the water a town may need either in the present or in the future.

Under the head of the adequacy of artesian supply may be included the methods used in obtaining the maximum discharge. If several wells are drilled, these should be aligned as nearly as possible at right angles to the general direction of the creep of the water in the water-bearing strata, since, with this arrangement, water will find way to the tubes more readily than with any other. Wherever overdraft is feared, it will be found advantageous to place the wells as far apart as possible. Where the wells are flowing artesians this distance may be as great as the cost of piping and the contour of the country permits. In the case of sub-artesians the cost of extra pumping stations will usually prevent the separation of the wells. When the discharge of a well is found unexpectedly slight, it probably can be increased by torpedoing the water-bearing stratum, especially if this is a limestone delivering its water through crevices. This method is commonly employed in oil wells, but so far as known has never been used in the artesians of the state.

The discharge even of flowing wells may be greatly increased by the use of deep pumps. The effect is to shorten the short arm of the siphon, whose long arm is formed by the channel of the water from the higher ground of the intake area. In a number of artesian wells outside of the state and in the artesians of Mason City the Phole Air Lift is used successfully for this purpose.

In the case of old wells whose flow has seriously diminished the special cause of the decrease must be known before any prescription can be made. The tubing may have been corroded, the packing may have been insecurely placed, and the water under strong pressure may be forcing its way out of the well at greater or less distances below the surface and escaping through natural water-ways in the strata. It may also effect an escape by opening or enlarging by its solvent power crevices in limestone where the shaft was left uncased. Again, a stricture in the bore may have resulted from the creep of plastic or mobile strata under the enormous pressure which they sustain. The well may have become clogged with detritus, and rare instances are known where this seems to have been effected by organic growths. In order that the difficulty may be diagnosed and suitably remedied, a complete record should be kept of the diameters of the bore, the exact nature and limits of all the strata penetrated, the depth of the water veins and the precise location of all the tubing in the well. Since such data are liable to be lost they have been placed on permanent record in this volume, as far as they could be obtained.

THE COST OF ARTESIAN WELLS.

The charges of drillers depend, not only upon the diameter and depth of the well, but also on the certainty, or the degree of probability, that artesian water can be found, and the nature of the strata through which the drill must pass. When drillers contract to furnish acceptable artesian water within certain depths, it is entirely just that their prices be higher where the drilling is an experiment in an untried field, than where the depth, quality and quantity of the artesian waters of the region are known, as well as the exact nature and probable thickness of each stratum of rock which the drill will encounter. It may reasonably be expected the Iowa Geological Survey will thus save to the state, by means of the present investigation, which sets forth for the first time the deeper geological structure of the state and its artesian conditions, many times more than the cost of the work.

The prices charged for drilling vary with the nature of the rock expected, being highest where heavy shales occur which obstruct the work by casing, and where there are thick beds of chert difficult to penetrate. The cost of wells depends also on the amount and quality of the casing put in. Exact estimates of the cost of any projected well can always be obtained on application to any well drilling firm, and we need add to what has been said only the cost of some recent and representative wells in different parts of the state.

At Cedar Rapids the well of the Y. M. C. A., 1,450 feet deep, five-inch bore, cost $1.65 per foot, besides the coal used in drilling, and the casing. The total cost of each of the other wells, 1,450 feet deep, was $3,205. The well, 2,225 feet deep, cost $6,065.

At Clinton the well of C. Lamb & Son, 1,230 feet deep, cost $2,126. The well at the Anamosa penitentiary was contracted at the following prices, including casing, the penitentiary furnishing only coal and water and the work of two men.

	PER FOOT.
From 1 to 1,200 feet	$ 1.75
From 1,200 to 1,400 feet	2.00
From 1,400 to 1,600 feet	2.25
From 1,600 to 1,800 feet	2.50
From 1,800 to 2,000 feet	2.75

From 2,000 to 2,500 feet an extra charge was contracted for of 25 cents per foot for each additional 100 feet.

The Holstein well was contracted at the following scale.

	PER FOOT.
From 1 to 500 feet	$ 2.00
From 500 to 1,200 feet	2.25
From 1,200 to 1,500 feet	2.75
From 1,500 to 2,000 feet	3 00

The town here furnished only water for the boiler.

At Glenwood the contractors furnished everything except some extra casing, and the well, 2,000 feet deep, cost $7,215, distributed as follows.

From 1 to 500 feet, at $4	$ 2,000
From 500 to 1,200 feet, at $2.71	1,900
From 1,200 to 2,000 feet, at $3.75	3,000
Extra casing	315
Total	$ 7,215

The Postville well, 515 feet deep, cost $1,260, and the Manchester well, 1,870 feet deep, cost $4,667.50.

THE PURITY OF ARTESIAN SUPPLY.

The question of the cost of artesian wells, or of any good water supply is not the main question. Any public supply of pure water is costly. Effective filtration, whether by the newer and best methods of natural sand filtration, or by the rapid mechanical filters, is by no means cheap; and unfiltered surface or stream water is in no case fit to drink. Domestic supply, where every householder pays for his own well and cistern, may be the most expensive system of all. In this connection the words of Burton* are specially pertinent.

"There is, however, a growing feeling that the supply of water to towns should be municipal work; that a matter of such vast importance to the public health is not one which should be left in private hands; and, indeed, that it is not a matter from which profit should be made at all—that is to say a direct money profit for individuals or even a municipality. The profit of a most solid kind to the community is undoubted. There should, in fact, in connection with water supply be much less consideration than there is of pounds, shillings and pence, except in the matter of prevention of waste water. The question should not be, 'How cheaply can we get a supply of water?' but 'What is the very best supply of water that we can get at any price that it is practicable for us to

*The Water Supply of Towns, p. 4. London, 1894.

pay?' That is, so far as providing a plentiful supply of wholesome water for domestic purposes is concerned, so that the public health may be kept as good as possible. It is different in the case of supplying water for manufacturing purposes or for purposes of luxury, such as gardens and fountains. There is no reason why the municipality should not make a profit out of water supplied for those and the like purposes."

The chief merit of artesian water as a municipal supply, its point of special superiority over rival sources, lies in its organic purity. Other waters may be pure, other waters if impure may be purified, but the purity of artesian waters is above suspicion. Its use not only renders consumers practically immune from many diseases, but it imparts a comfortable sense of security, which is also of distinct value. It is regretted that a complete series of chemical and biologic sanitary analyses can not be offered in demonstration of the organic purity of the deep wells of the state. But it surely may be taken for granted that artesian water can not become infected with the waste of life and pathogenic bacteria during its long journey deep under ground. Only as it rises near to the surface, is there the possibility of sewage contamination and this is easily prevented by the proper adjustment of casings.

The artesian wells of Iowa are in evidence that in many towns of the state the organic purity of their drinking water has been made the chief consideration in the choice of a supply. Innocent water has been given the preference over various repentant waters, to adapt the language of an eminent sanitary authority.

Pure water is not a luxury but a necessity. It is indispensable to healthy and decent living. A more exact and ready civilization-meter can hardly be suggested than the condition of the water supply affords in any country or city. A community that tolerates a contaminated supply is a community that willingly drinks human excrement. Polluted water supply is not only a filthy disgrace, it is a crime against both person and property. No conclusion of sanitary science is more firmly established than that the contagium of several of the most deadly diseases is carried in drinking water.

With regard to the mortality from cholera and typhoid fever the Rivers Pollution Commissioners of Great Britain use the following guarded and moderate language: "It is humiliating to reflect on the vast amount of premature deaths and misery which is thus carelessly permitted to exist in the midst of a civilized community. In England and Wales alone the average yearly number of deaths from zymotic poisons is 120,000, representing a total number of cases of more or less intense suffering which is certainly not over-estimated at 1,200,000. But even this enormous number only includes the persons actually poisoned. It takes no cognizance of the misery of families reduced to pauperism or worse by the death or long illness of those upon whom they are dependent for support. * * * The means of preventing much of this death and torture are now well known and capable of practical application. Their neglect signifies the destruction of the people by parasitic organisms which we have the means but not the will to exterminate, and it will not much longer be regarded as involving less national disgrace than would attach to the annual loss and mutilation of vast numbers of our population by beasts of prey which we were too apathetic to destroy."*

Yet the death rate from typhoid fever in England is relatively low. In London, with a population of 4,250,000 this rate in 1890 was but seventeen to the 100,000, slightly less than for the whole of England and Wales. The London rate is indeed high compared with the typhoid death rate of many cities of western Europe, but it seems surprisingly low when we consider the death rate of American cities, as shown in the following table.

Typhoid death rate of cities of the United States with population of 200,000 or over. Census of 1890.

*Sixth Rept. Rivers Pollution Comm., p. 189. London, 1874.

	Typhoid death rate per 100,000.	Number of deaths from typhoid above the standard of 25 per 100,000.
Pittsburg	127	245
Washington	87	143
Philadelphia	74	509
Chicago	72	519
Cleveland	63	99
San Francisco	56	91
Baltimore	47	93
Boston	39	62
Saint Louis	32	32
Buffalo	31	16
Milwaukee	30	10
Brooklyn	24	--
New York	23	--
New Orleans	19	--
Detroit	19	--
Total deaths in the above cities above normal rate		1,819

In eleven of the large cities of the United States the deaths from typhoid fever due to lack of proper civil sanitary precautions thus amounted in 1890 to at least 1,819, nearly as many as the killed of the Federal army in the battle of Antietam. Nothing need be said as to the moral aspect of this mortality. The economic loss is computable. The cost of the typhoid epidemic at Plymouth, Penn., in 1885, was calculated in detail, and may be used as a datum. The estimated loss from this epidemic involving the loss of 114 lives is as follows.

Cash actually expended in care of sick	$ 67,100 17
Wages lost by those who recovered	30,020.08
Annual earnings of those who died capitalized at 5 per cent	368,390.40
Total	$ 465,510.65

At this low valuation of a human life the preventable deaths in 1890 from typhoid fever in only the eleven cities named involved a financial loss of nearly $7,500,000. Nor was the year 1890 one of exceptionally high mortality from this disease. In Chicago alone in 1891, there were 1,997 deaths from typhoid fever. Assuming again twenty-five deaths from this disease to the 100,000 as a normal rate, there are left 1,722 deaths in this year in this city which must be laid to an impure water supply. At the usual life-value of $5,000, the equivalent of the sum of $8,610,000 was thus destroyed, beside the loss of wages and sickness expenses of those who recovered.

These illustrations of the cost of an impure water supply from one disease only, are drawn from outside of Iowa for obvious reasons. Among these is the fact that no reliable and complete statistics on the subject are on record from the towns of the state. But without any elaborate calculations or local data it is evident that a pure water supply is financially a profitable investment. Artesian wells or expensive filters cost less than epidemics, and less than the constant loss of life at a rate which, though unnoticed in America, would be considered an epidemic in almost any European city.

Typhoid fever is by no means the only disease due for the most part to contagium carried in impure water. So far is cholera due to this cause that a city with a water supply free from possibility of contamination is practically immune and needs no quarantine against the scourge. By the same vehicle of drinking water, as is strongly suspected, though not yet decisively proven in all instances, access is had to the human system by the germs of many other diseases; dysenteries, diarrhœa, and various fevers recurrent and malarial. But in the opinion of eminent sanitarians the greatest injury resulting from the use of impure water lies not so much in well marked zymotic diseases as in the general malaise, the insidious undermining of the health, the weakening of the constitution, which leaves the system ready to succumb to the first attack of a serious disease.

The drinking water of any fully civilized community must then in the first place be pure water. But the emphasis which has been laid upon this fact does not at all imply that artesian wells furnish the only water organically pure, and that they should always be selected for municipal supply.

THE CONTRACT.

A few hints are offered simply in the interest of that definite understanding between contracting parties which experience shows is always advantageous. Both parties, the owner and the driller alike, are interested directly in the success of the well. Indeed this success is often guaranteed by the driller, and sometimes where a geologist would be reluctant to assume any financial risk in the case. It is to the business interest of all responsible well drilling firms to give as complete satisfaction as possible, and it need not be expected that such firms will take unfair advantage of the technical ignorance of their patrons.

It sometimes occurs that drillers are too closely bound by their contract and are not given sufficiently free hand. Thus in two recent contracts the Saint Peter was set as the lower limit of the boring, although in neither instance could that formation be expected to furnish a supply. Such strict limitations really leave the owner a good deal at the mercy of the driller, who can either collect his pay and leave an unfinished and unsatisfactory well when the Saint Peter is reached, or can charge an advanced price for continuing the work.

Contracts seldom fail to specify whatever labor or material, water for boilers, steam pumps for tests, or casing, the owner expects to furnish. It is often more satisfactory for the owner to furnish the casing necessary, since this is usually an unknown quantity until after the well is drilled. He can thus place it in the well wherever it may be thought best in order to prevent possible leakage in the future, as well as wherever it may be indispensable in the construction of the well.

Tests of the capacity of the well are almost always specified in contracts. Sometimes one, two, or three tests are to be furnished by the driller, free of charge, during the progress of the work, and such other tests as the owner may direct from time to time at the reasonable charge of $1 an hour while the test is being made.

For want of such provisions in the contract a suspicion occasionally arises, which is unfortunate even if it is without foundation, that, although there is really plenty of water in the well, the driller is going deeper because it is not for his financial advantage to stop. Negative, or non-flowing artesians should be tested whenever the rise or the fall of water in the tube, or the clearing up of the water by the washing away of the drillings, indicates that any considerable water vein has been reached. In one instance this office was consulted as to the advisability of going on with the work on a non-flowing well, whose boring had already crossed the most important water horizons of the district. Yet no account had been kept of the fluctuations of the water in the well, and the drillers declined to make any test except at its completion. In this case an additional clause in the contract providing for tests would have been economical. A fair test usually is extended for at least twenty-four consecutive hours and should, of course, be made by a pump of sufficient capacity, throwing 300 or 400 gallons of water per minute. The cost of tests and chemical analyses of different flows is a trifle compared with their value to the owner. Flowing wells also should be gauged for pressure or tested for head, at the first flow and at each increase thereafter.

In non-flowing wells the drilling should stop wherever a test shows sufficient water of good quality, unless an expert advises its continuance. To go on indefinitely in order to obtain a flow is absurd. Although in a few wells in the state several thousand dollars have been wasted in carrying borings to unnecessary depths, on the whole our artesian borings stop within reasonable limits.

Contracts wisely provide that samples of the drillings be preserved, and it should be specified that these be taken at intervals of not more than ten feet, and at every change in the strata. These samples are of great scientific value, for by means of them the geologist determines the thickness and lithological characteristics of the different strata pierced by the drill. He thus discovers, not only the extension, the thickness, and the structure of the various geological formations represented, but also the conditions which encourage or discourage the search for coal, for oil, for gas, and for artesian water in the region. But it cannot be too strongly emphasized that the series of samples must be complete. A dozen or so specimens from a deep well, each supposed to represent formations a hundred or so feet thick, are not without value. They make up an interesting puzzle and give play to an ingenious imagination in guessing the real geological status of the section. A geologist very seldom can tell to what formation a piece of unfossiliferous rock belongs merely by its looks. So far as its texture goes, a piece of shale or limestone or sandstone may belong to any one of many geological groups. But a series of a hundred or more samples taken so frequently that no layer of any thickness is unrepresented, exhibits the order of succession of the strata as well as their lithological characteristics. With these facts in hand a competent geologist will usually feel little more hesitation in drawing the geological section of the boring than he would of an unfossiliferous natural exposure of equal vertical extent, and equally distant from well recognized outcrops.

Great care should be observed in taking the samples to prevent their admixture with any foreign matter. They are best poured into cigar boxes or fruit cans directly from the sand pump at its last haul for any clearing out. The receptacle should be marked in several places with the depth, or a tag may be placed within it similarly marked. The foreman in charge of the drilling will usually give this matter careful attention, if so directed. With scarcely an exception, we have found persons having charge of such work intelligent and obliging. But some citizen, a friend of science, will readily be found to give the matter his personal supervision, furnishing the driller with boxes or cans, removing them from time to time when filled, and seeing to the permanent mounting and final disposition.

Drillings are variously mounted according to the preferences of their owners. The most common and one of the worst ways is to pack them in a tube of glass. Very striking and pretty at first, the samples soon become mixed, the finer material sifts down into any coarser sample beneath and covers it in whole or part from view. Critical study is impossible without destroying the tube. The legend or description, giving the character and thickness of the strata, is usually written on paper and pasted on the back of the tube and soon comes loose and is lost. The chances are that in a few years the tube itself will be broken and its invaluable record wholly destroyed.

Sometimes drillings are even set up in lamp chimneys, sometimes in a long narrow box with glass face and sliding back and partitions. The mounting should in any case insure permanence, freedom from possibility of intermixture, and ready access for examination. This is best obtained by mounting each sample in a separate bottle. The Survey uses for this purpose one ounce bottles of wide mouth and of clear glass. All labels should be in india ink or cut in the glass.

If an ordinary quantity of each sample is secured, a duplicate set can always be spared, and thus the chances of the destruction of this record will be very much lessened. The duplicate set will be welcomed by any museum, and will be received with special interest and gratitude by the Iowa Geological Survey. In the geological collections of the Survey such series are practically safe from all danger, and their value is enhanced by the fact that they are at all times available for examination and for comparison with many similar series which have already been placed under this care.

The Art of Drilling.

To drill an even and straight tube a quarter or a half a mile in depth requires experience and a high degree of mechanical skill. Deep well drilling has become a special trade. In only one instance in the state has a deep boring been put down by amateur labor, and this proved a costly experiment whose repetition is not recommended. Most of the wells in Iowa have been drilled by firms whose territory is much wider than the limits of the state, and the methods and the machinery which they use here present nothing that is novel. In all cases, so far, the drill has been the ordinary plunge or churn drill, and is essentially the same in action as that employed in sinking common drilled wells. The diamond drill has been used only in search for coal and building stone.

The rig differs slightly from that seen in the oil fields of Pennsylvania and Ohio so fully described by Carll,* and by Newell.†

The derrick tower is commonly about eighteen feet square at the base and sixty feet high. An adjoining shed contains the forge at which the tools are dressed and an engine of fifteen or twenty horse power by which the drill is operated and the tools raised and lowered in the well. The drill consists of a steel chisel-shaped bit, screwed to an iron auger stem, to the upper end of which is fastened the "slips" or "jars." These consist of two slotted iron links joined together by a cross head and crotch slot admitting of a vertical play or slip, one upon the other, of about thirteen inches, in about the same manner as the play of two links of a chain. The bit, the auger stem and the lower member of the jars, thus fastened together, fall with each downward stroke about twenty inches, and deliver a cutting and crushing blow of about 3,500 foot pounds upon the rock. On the upward stroke the weight of the rig above the union of the two members of the jars delivers an upward blow whose purpose is to jar loose the drill beneath. No sinker bar is used above the jars. In some Iowa wells the string of drilling tools just mentioned was swung from a rope, but in most instances rods of wood have been used, each about thirty-three feet in length, with iron couplings. The string of rods and drill is attached by a swivel and heavy iron

*Penna. Sec. Geol. Surv. Oil Region, vol. III, pp. 284-330.
†Geol. Surv. Ohio, vol. VI, pp. 476-497.

chain to the end of the walking beam, which plays up and down above the mouth of the tube. This chain is wrapped several times about the end of the beam and is let out little by little as the drill cuts deeper and deeper into the rock.

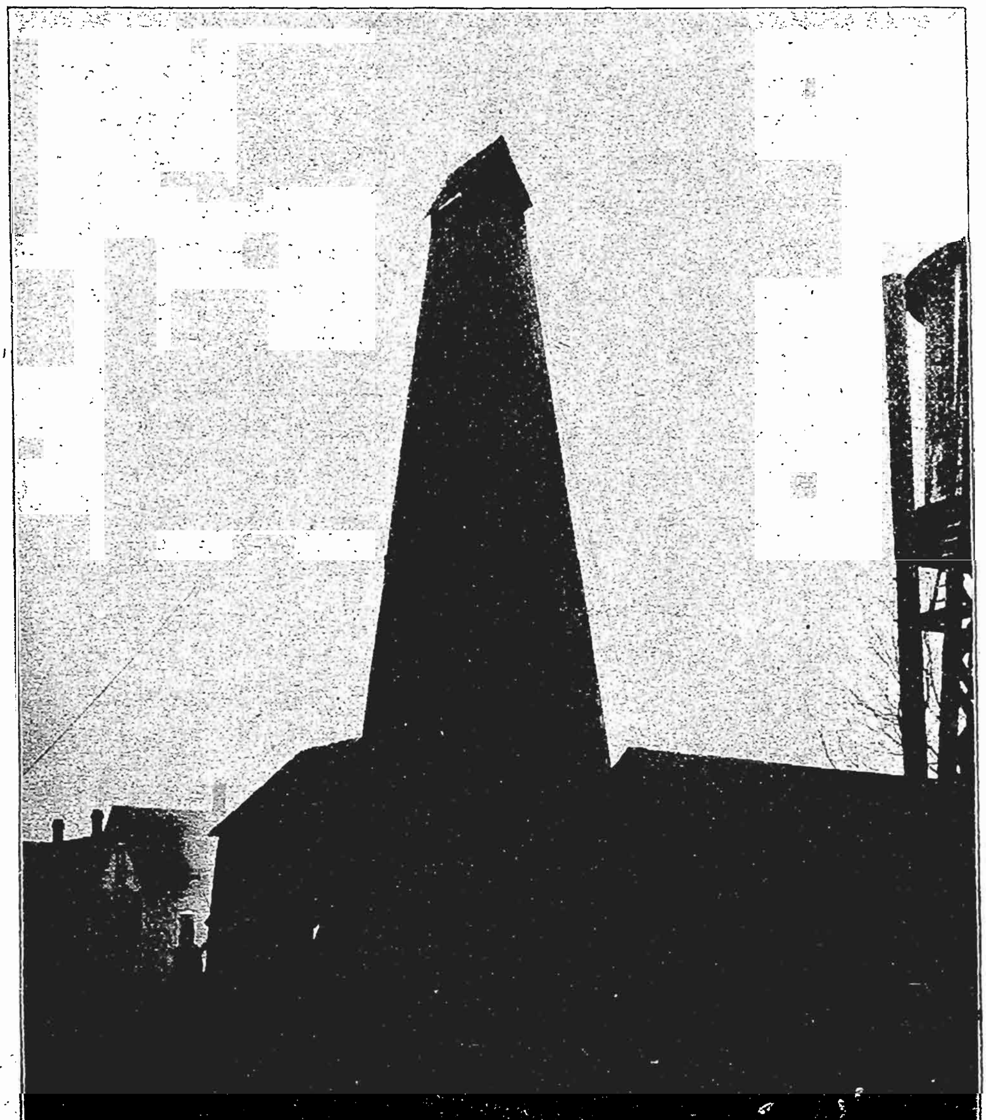
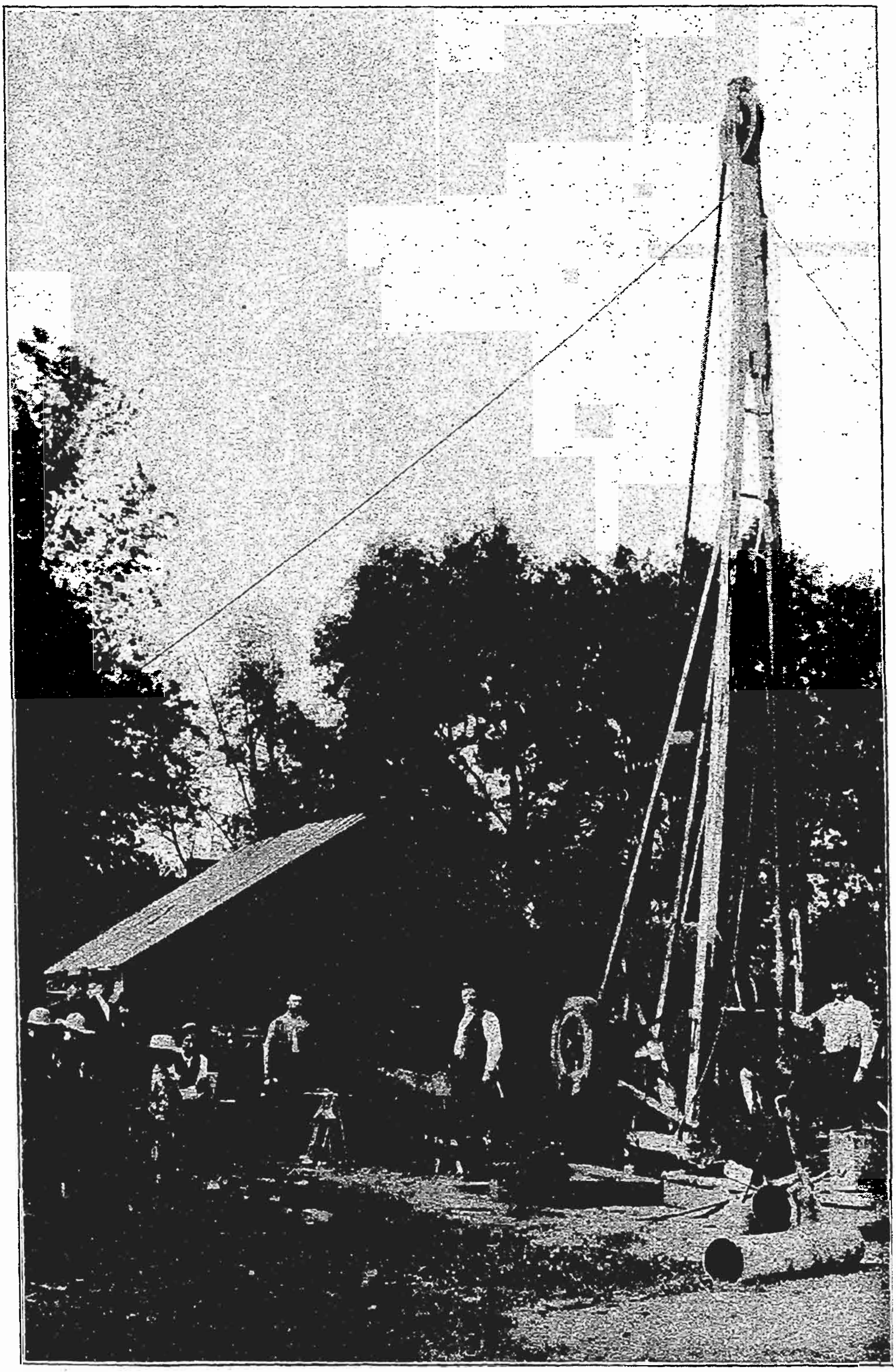


FIG. 44. Derrick Tower of J. P. Miller & Co., at Holstein, Iowa.

We have not seen in the Iowa field the temper screw used for this purpose in the oil regions.

As the work progresses the curious citizen who gains admission into the dimly lighted tower sees month after month the same tedious routine. Night and day a driller sits at the bench over the boring. As the rods rise and fall with the monotonous motion of the walking-beam, he slowly twists them round and round so that the drill may strike every portion of the bottom in its rotation and drill the hole round and true. So simple is this apparently, that a boy could do it. But the experienced driller feels every stroke of the drill and movement of the jars, and interprets each vibration passing upward from a thousand feet below. A tyro in his place would churn the water without striking bottom and never know it. When no accidents delay, the drill cuts its way downward with surprising rapidity, making sometimes sixty or seventy feet a day. Every few feet the bore becomes clogged with the chips from the drill. The whole string is then hoisted and the hole cleaned out with the sand pump—a bucket with a suction valve at the bottom--and the drill is again lowered. This interruption takes less time than one would suppose. In hoisting the string the foreman sits with his left hand on the hoist lever and his right on the brake. The scaffold man stands on a platform in the tower about the length of a rod above the bench. The third man of the shift stands at the bench, catch wrench in hand. The string is rapidly hoisted by the engine; as soon as the upper end of the second rod from the top appears above the bench the brake is applied to the hoist, the string stops, the second rod is grasped by the wrench under the collar of the upper end. The weight of the string thus resting on the wrench and bench, the scaffold man and the man at the bench together uncouple the upper rod from its connections above and below and set it at one side. The swivel whirls down and is coupled to the second rod, the hoist lever is pulled, the string rises, the third rod is caught fast, the second uncoupled, and so the work goes on. To hoist 1,600 feet of rods and tools needs only twenty minutes and less time is taken in lowering them again.

Scarcely a well is drilled without more or less time being lost on account of accidents. Fragments of rocks becoming



RIG OF DICKSON BROS., LUANA, IOWA.

detached from the side of the shaft fall and are wedged in with the string preventing the slips from doing their work in jarring loose the drill. As soon as the drill stops, the sediment, with which the water is thick, settles about it fastening it so securely that it cannot be dislodged without special instruments. Fishing for drills and other lost tools is, on the whole, the longest and most costly part of the operation of drilling the average deep well.

Occasionally the drill strikes a slanting crevice and slips to one side. If this difficulty is not met at once, the boring is deflected from vertical and the drill soon becomes fast. Sometimes the crevice can be filled but usually it must be passed by a special tool or by casing.

In no instance has it been found practicable to drill a deep boring of the same diameter throughout. Through the incoherent deposits of the Pleistocene the bore is relatively large —often ten or twelve inches in diameter—and casing of this size is driven firmly into the underlying rock to shut off all surface and drift waters. In rare instances Pleistocene gravel, mingled with the drillings from lower horizons, has indicated that this work was not effectively done. Changing the drill to one of smaller diameter, the work proceeds until rock so incoherent or fissile is reached that it caves into the boring. The only remedy is to case this portion of the shaft. The method of inserting the casing is well told by Mr. Seth Dean* in his description of the Glenwood well.

"On the lower end of the pipe a cast steel shoe with a cutting edge was fitted, the outside diameter of the shoe being a little larger than the coupling bands that connected the joints of pipe so as to give clearance room. Fitted in this way it was possible to drive a line of pipe through most of the strata after they had first been pierced by the drill, the shoe cutting out a portion of the rock somewhat in the manner that a carpenter enlarges a hole in a piece of wood with a gouge. When the harder beds of limestone were struck, the pipe was raised

* Proc. Iowa Civ. Eng. and Surv. Soc. 1895, p. 36.

a few feet with jacks, and the hole enlarged by what is known as an expansion reamer, a tool so constructed as to pass down inside the casing and open when it meets with the resistance afforded by the rock bed under the pipe. When the friction of the mass of earth and shale against the sides of the pipe became so great that it could not be driven further without danger of crushing or collapsing, it was bedded firmly in some stratum of rock and a pipe of smaller size inserted inside this and driven in the same way. The rate of progress made in driving pipe was, of course, dependent on the nature of the material being worked. Sometimes in soft shales the weight of the pipes alone was enough to sink it, and at other times six hours' driving would not settle it more than three or four inches."

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RELATIONS OF THE

WISCONSIN AND KANSAN DRIFT SHEETS

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BY

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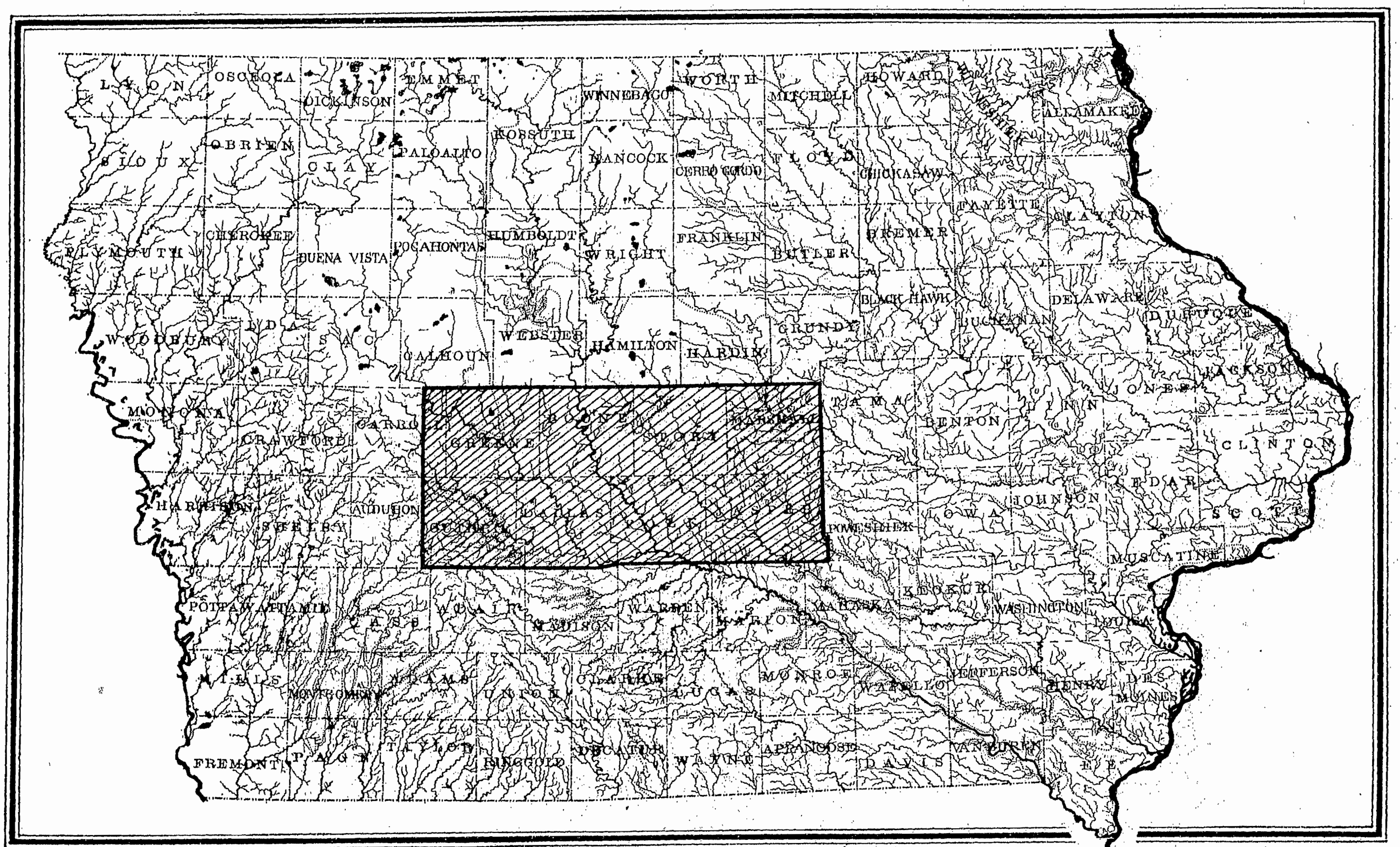
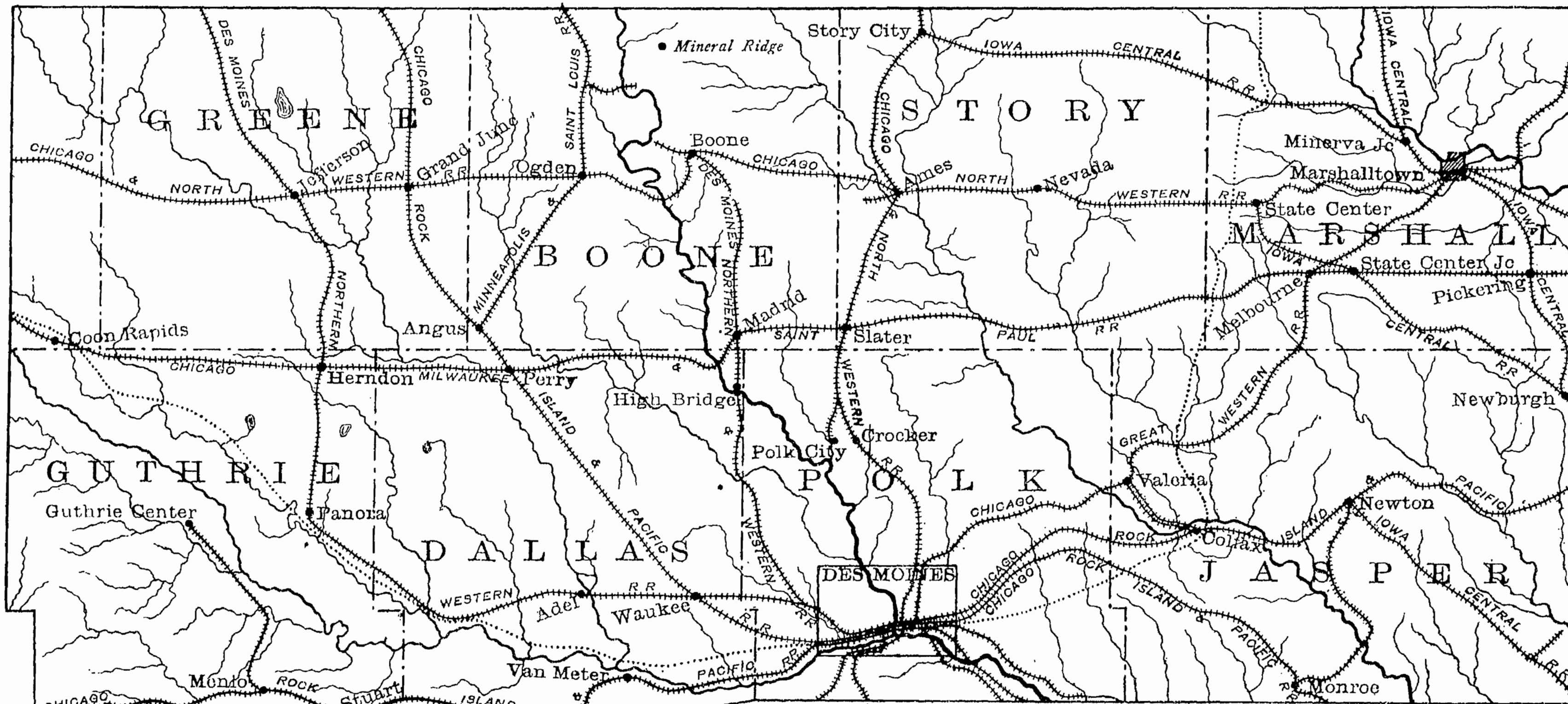
CONTENTS.



THE REGION DISCUSSED.



THE SOUTHERN END OF THE DES MOINES LOBE.

DEFINITION OF REGION.

The area which has been studied in the preparation of the following memoir lies in central Iowa and includes Marshall, Story, Boone, Greene, Guthrie, Dallas, Polk and Jasper counties and a portion of Carroll. Its geographic features are represented upon the accompanying map (plate xxvii) and its relations to the state as a whole, are shown upon plate xxvi. It is an area of prairie plain with moderate relief, the altitude varying from 810 to 1,042. The country rock of the region includes both the Des Moines and Missourian divisions of the Upper Carboniferous and the Dakota formation of the Cretaceous. The distribution of these beds may be seen upon the geological map of the state published by the Iowa Survey* and the details of the geology may be learned from the county reports issued by the same organization.† It is intended here to treat only of certain specific problems connected with two of the drift sheets of the region; for fuller details the reader is referred to the reports just cited, and particularly to the author's reports upon Polk and Guthrie counties. In the following paper no attempt will be made to cite the portions of each of these reports which bear out individual statements since the number of such citations would be so great as to to become cumbersome.

The author's particular studies have been in Polk and Guthrie counties, in which he has mapped in detail the surface formations.‡ These counties lie on the southern and southwestern border of the Des Moines lobe, and within their borders the relations herein discussed were first made out. The remaining portions of the area have been repeatedly visited, at times in company with other members of the Survey, and the results obtained in Polk and Guthrie counties have thus been compared with the phenomena in various portions of the larger area.

*Iowa Geol. Surv., vol. VI, plate v. Des Moines, 1897.

†Marshall; (Beyer) vol. VII. Boone; (Beyer) vol. V, pp. 175-240. Polk; (Bain) vol. VII. Guthrie; (Bain) vol. VIII. Dallas; (Leonard) in preparation.

‡See maps of surface deposits accompanying the county reports mentioned.

The region outlined includes the southern termination of the Des Moines lobe of the Wisconsin ice sheet, and it is the relation of the latter to the outlying drift which it is proposed to discuss. The Des Moines lobe was a long tongue of ice eighty to 100 miles wide, running almost due south from the Minnesota line to the central portion of the state. It overrode and buried certain earlier drift sheets and loess deposits which now appear along its edge coming out from under the later drift. With the exception of certain reconnoissance work, but little had been done on the drift of the region previous to the detailed work results of which are given herein. This paper is in a sense preliminary, as not all the area has yet been mapped, but the general results are believed to be final.

Acknowledgments are due to Dr. Beyer and Mr. Leonard for field assistance and for notes generously contributed, and to State Geologist Calvin, of Iowa City, and Head Professor Chamberlin of Chicago, for valuable suggestions both in the field and the office. Professor Salisbury of the University of Chicago, has also been so good as to read the manuscript, and has made many valuable suggestions and criticisms.

DEFINITION OF TERMS.

In the earlier geological work in this region no attempt was made to separate the drift into different formations. As was true in all the work of the period the attention was concentrated upon the underlying rocks and the drift received but little attention. Nicollet* speculated some upon the origin of the boulders. Owen† recognized and correctly interpreted the loess along the Des Moines river, and made many observations of value upon the drift throughout the state. The Hall survey‡ neglected entirely the superficial deposits and did little within the area outlined. White§ studied both the drift and the loess. In consonance with the thought of the time the drift was treated by him as a single

* Sen. Doc., 26th Cong., 2d Sess., vol. V, pt. ii. No. 237. Washington, 1841.

† Geol. Surv. Wis., Iowa and Minn., p. 121. 1852.

‡ Geol. Iowa., vol. I, pts. i and ii. Albany, 1858.

§ Geol. Iowa, vols. I, II. 1870.

formation. Such differences as were noted in the distribution of the boulders and in the character of the drifts were explained by other hypotheses. The striking differences at Des Moines were supposed to be the result of a change in the direction of the ice currents.* Many observations upon the drift were published and these have, to some extent, formed the basis of later generalizations. All these earlier investigations were pursued under severe limitations as regards time and money, and it was but natural that the rich field of Pleistocene geology should be passed over for the better known problems connected with the indurated rocks.

In the neighboring states and throughout America it was long after the glacial nature of the drift was accepted that the complexity of the processes through which it originated was fully recognized. It was long the custom, and it is one perhaps not yet wholly obsolete, to consider the glacial period as consisting of (1) a time of transition, (2) the glacial period proper, (3) the Champlain epoch of submergence and melting, and (4) the recent epoch of terrace work and stream cutting. As the studies became more detailed and the results were better organized, it became recognized that the simplicity of this classification was not in accord with the complexity of the facts. At several points opposing phenomena were noted, and several observers at about the same time began to emphasize the necessity for finer discriminations. The pioneer in this work was Professor T. C. Chamberlin who, in the course of his work in Wisconsin, recognized two well-marked divisions in the drift series; the later, or inner drift, being bordered by the Kettle moraine. In the final reports of the Wisconsin Survey he definitely recognized two drift sheets,† though in the earlier descriptive portions of the reports no such distinction was observed. In a paper read before the International Congress of Geologists at Paris in August, 1878,‡

* Op. cit., vol. I, p. 91.

† Geol. Wisconsin, vol. I, pp. 271, 272 1883.

‡ La Moraine terminal du Amerique du Nord, Compte Rendu Cong. International Géol. Paris, 1878.

he correlated the Kettle moraine of Wisconsin with certain moraines in the other states, including Iowa, and gave an approximate outline of the Des Moines lobe. This outline was based in part upon personal observations and in part upon information derived from the reports of the White survey. An earlier paper,* revised and published in English about 1878, contained much the same matter. The drift within the Kettle moraine was recognized as distinctively later than that without, and an interglacial interval of unknown extent was tentatively suggested. It is this later drift which is now known as the Wisconsin and the earlier which is recognized as Kansan.

At about the same time Mr. W J McGee was carrying on his studies of the Pleistocene in northeastern Iowa. In a series of papers,† extending from 1878 to 1893 when his monograph upon the region was issued, he showed that the forest bed found in the region was a definite horizon and that two drift sheets were present.

In 1882, apparently the upper drift of northeastern Iowa was considered to be the same as that contained within the Kettle moraine.‡ It was not until later that the difference in age was appreciated. Eventually McGee's upper till became the Iowan, and his lower till has very naturally been considered to be the Kansan.

THE DES MOINES LOBE.

Early work.—White§ in his summary of results doubtfully recognized certain ranges of hills as morainic. Among them was Mineral Ridge in Boone and Story counties, now known to form a portion of the Gary moraine, and certain hills in Hancock county belonging to the Altamont moraine. No

* On the Extent and Significance of the Wisconsin Kettle Moraine, Trans. Wisconsin Acad. Sci., Arts and Letters, vol. IV, pp. 201-234. 1876-77.

† Amer. Jour. Sci., (3), XV, 339-341, 1878; Proc. Amer. As Adv. Sci., XXVII, 198-231, 1878; Amer. Jour. Sci., (3), XVIII, 301-303, 1879; Geol. Mag., (2), VI, 353-362, 412-420, 1879; Proc. Iowa Acad. Sci., 1875-1880, 19, 1880; Ibid., 25. 1880; Bull. Philos. Soc. Washington, VI, 93-97, 1883; Pam. 14 pp., 1884; Trans. Iowa State Hort. Soc., XVI, 227-240, 1884; Proc. Amer. As. Adv. Sci., XXXVII, 248-249, 1890; *The Pleistocene History of Northeastern Iowa*, U. S. Geol. Surv., Eleventh Ann. Rept., 190-577, (1891) 1893.

‡ Am. Jour. Sci., (3), XXIV, pp. 204, 206, 215, 222.

§ Geol., Iowa, vol. I, p. 98. 1870.

attempt was made to trace these ridges from point to point, and their significance was not at that time fully recognized. Chamberlin was, as has been seen, the first to draw a crude outline of the Des Moines lobe. He regarded Mineral Ridge as marking its southern limit.* The range of hills was described as not being continuous and well defined, but suggestive rather of a half buried moraine. The presence and significance of the lakes within the area was recognized, and the fact that outside the moraine the existing surface contour was formed in the presence, and to some extent, under the modifying influences of a fairly established drainage system, while in the interior the drainage system has not even yet become fully established, was definitely stated.

In 1880 Mr. Warren Upham, in connection with his work in Minnesota, traced out definitely the limits of the Des Moines lobe† and to him our knowledge of it is mainly due. He recognized a continuous moraine, now known as the Altamont,‡ around most of the border of the lobe, though the extreme southern limit was not visited. Mineral Ridge was considered to be most probably an inner belt of the terminal moraine. This inner moraine is now known as the Gary. The Altamont moraine was studied by him in this region at Coon Rapids and in neighboring portions of Guthrie and Carroll counties.

Subsequently the southern limit of the lobe was studied by McGee and Call,§ while general correlations of interest in this connection have been published by Chamberlin.‖

Topography.—The area included within the Des Moines lobe has the characteristic drift-plain topography well developed. The landscape shows a predominant flatness. There are no prominent elevations and no marked valleys. In detail the flat plain breaks up into a series of low, rounded, often circular swells, irregularly disposed, and separating a series

*On the Extent and Significance of the Wisconsin Kettle Moraine, p. 15.

†Geol. Nat. Hist. Surv., Minnesota, Ninth Ann. Rept. (1880), pp. 298-314

‡Chamberlin: Third Ann. Rep. U. S. Geol. Surv., p. 388. 1883.

§Loc. cit.

‖U. S. Geol. Surv., Third Ann. Rept., pp. 291-404. 1883. Ibid, Seventh Ann. Rept., pp. 147-248. 1888.

of interlocking saucer-shaped basins which are in contour the reverse of the swells. The relief, except near the larger streams, is slight and is normally less than thirty-five feet. The low swells do not have sharp contours and are hardly pronounced enough even to deserve the name of hills. They have little individuality and are not arranged according to any order or system. Between them lie ill-defined basins occupied usually by shallow ponds, swamps or swales—areas of slough or shallow water. There are very many basins without outlets and the whole is clearly a region of immature drainage. At many points springs and shallow artesian wells attest the superabundance of water. The streams present are usually small. They wander aimlessly through the basins and are, in most instances, finally lost in some small swamp or miniature lake. Much of the land is not sufficiently drained to allow cultivation, and much more is worked only as a result of artificial drainage. The larger streams, such as the Des Moines river, have narrow recent channels and very limited tributary drainage. Near the edge of the area some of the rivers, among them the Skunk, flow in wide old valleys, but even in such a case the tributary drainage is very slight. The numerous lakes and ponds, the undrained sloughs, the peat bogs, the narrow river valleys, the incomplete drainage, the undissected upland between the rivers, some of which flow 200 feet below the general plain, and many other features all point to one conclusion—that the topography is extremely young and that it was formed by glacial agencies.

The drift.—The sheet of till which was formed by the Des Moines lobe of the Wisconsin ice possesses certain characteristics which usually allow its ready recognition. They are not always so distinctive as sharply to differentiate it from the till of the other ice sheets, and in such cases attendant phenomena must be relied upon in making the discrimination. In general, however, the till itself is such as to prevent confusion. As seen near Des Moines, the Wisconsin till usually shows a buff color at surface exposures. It has much the same color as the loess and is in this regard sharply contrasted with the reddish brown common at the surface of the Kansan, as well as the yellow, which usually marks the Iowan. When the Wisconsin is buried the color is usually a drab or gray. The pebbles contained in it are very largely fresh and hard, and show very little weathering. This is true of those occurring in all portions of the till. There are some which show advanced stages of decay but the proportion is relatively small. It is believed that many of the decayed pebbles were derived from the older drift and have merely been worked over into the newer. As contrasted with the Kansan drift the Wisconsin contains less local material, but if the two sorts of material occurring in the Wisconsin itself be compared, the proportion which is extra-limital is found to be much inferior to that which might have come from within the state. Lime concretions, such as are known as loess-kindchen when found in the loess, are widely distributed in the Wisconsin drift, whereas localities at which they occur to any extent in the Kansan are, in this region at least, quite rare. Occasionally, not only pebbles derived from the lower drift are incorporated in the upper, but blocks of the lower till itself. In such cases the newer drift frequently shows foliation around the older material.

As contrasted with the Kansan, the Wisconsin drift is characterized by numerous surface boulders. In this vicinity these are not usually so large nor are they so numerous as over areas covered by the Iowan in eastern Iowa, and yet they often afford a valuable means of discrimination. In the region studied, one of the most ready means of recognizing the Wisconsin drift is the absence of the covering of loess which is so universal throughout the Kansan areas. The absence of loess is a general characteristic of the Wisconsin* and in this regard the formation as exposed near Des Moines has the normal characteristics. At a few points a thin surface sheet of silt of undetermined origin occurs, but in

*Salisbury: Jour. Geology, vol. IV, p. 929-937. 1896. Chamberlin: Third Ann. Rept. U. S. Geol. Surv., p. 395. 1883.

most instances the pebbles of the drift are turned up by the plow.

The drift border.—Perhaps the most characteristic and significant feature of the Wisconsin drift of the region, aside from its topography, is the character of its border. That the Wisconsin was a moraine-forming ice sheet is shown wherever deposits of this age occur.* This feature is characteristic of the Des Moines lobe down almost to its termination. In Guthrie county the moraine is in places quite well developed though it is not continuous. In Polk and Dallas counties

FIG 45. Pond on Wisconsin drift at south end of kame near Kelsey.

there is nothing answering to a moraine. The drift becomes thinner and thinner until it disappears altogether. This is not a result of later erosion as is readily determined in the field, but it is an original difference. It forms a notable exception to the border of the rest of the lobe and of the Wisconsin drift in general.

Kames have been, to some extent, developed in connection with the Wisconsin ice. In Polk county there are no well defined kames near the ice edge, but near High Bridge and Corydon, some ten to fifteen miles back from the edge, they

*Chamberlin: Third Ann. Rept. U. S. Geol Surv., pp. 291-494. 1883.

occur. The Kelsey kame is quite perfectly developed. It stands upon a drift plain which is about 150 feet above the Des Moines river. The plain is fairly smooth and is dotted with swales some of which contain small ponds, one being represented in figure 45. Above this plain the kame rises forty feet. It forms an irregular ridge three-quarters of a mile long and a little more than one-quarter wide. At its southern end, and partially separated from it, is an oval hill which does not rise quite so high. The upper surface of the kame is smooth but is somewhat hummocky. Its direction is not rectilinear but sinuous. It is cut off rather abruptly at

FIG. 46. Kame near Kelsey.

the ends and the whole ridge forms a prominent landmark. It general appearance from the west is shown in figure 46.

In composition the kame is made up of Wisconsin material. Large boulders are found on its surface, and pits at three points show that, to a depth of four feet at least, it is made up of coarse water-laid gravel. Stratification is partial only. The pieces of gravel are one-half to three-quarters of an inch or more in diameter. The kame is manifestly the result of combined ice and water work and is better developed than any other known to occur in central Iowa. Others of less perfect form occur near Crocker in Polk county, and Panora in Guthrie. Opposite the latter place on the main Guthrie Center road, water-laid gravels of kame-like character are found well toward the top of the hill. The gravels are shown at several points in the vicinity, and at one or two take an imperfect kame-like form with a general northwest-southeast direction of axis. South of town and at lower levels, though considerably above the terrace found along the river, are similar kame-like aggregations. In other portions of the state large and well developed kames are found along the edge of the Des Moines lobe.

Within the area studied overwash plains have not been found to any great extent, though a faint expression of the overwash occurs along the drift border on the low plain between Capitol Hill and Fair Ground Ridge at Des Moines. In Beaver and other abandoned portions of the older Des Moines valley there are gravel and sand accumulations aside from the ordinary river terraces. The material in all these cases is coarse and shows stratification which is furthermore marked by cross-bedding.

Gravel trains constitute one of the most obvious phenomena connected with the Wisconsin border. They are found all along the southern edge of the Des Moines lobe stretching down the rivers whose head waters were cut off by the ice. They occur in Polk county on Camp, Mud and Four Mile creeks, and on the Des Moines river. In the counties farther west the Raccoon bottoms are underlain by gravel. In all these cases the material is firm and hard and the pebbles are of the sort found in the Wisconsin drift. Occasionally boulders, which might have come from the Kansan, are incorporated. In the case of Four Mile creek and the Des Moines river the gravel trains may be traced up the valley, taking the form of a terrace for several miles inside the drift limits.

The gravel terraces are not conspicuous features. They are frequently covered in their lower portions by later alluvium, as at the Avon gravel pits, or they rise ten to twelve feet above the modern bottom land, as at the newly opened pits in Highland Park. Their origin as valley trains is better seen in Polk than in Guthrie county. In the latter the edge of the Wisconsin ice stood approximately parallel to the Middle Raccoon river, and the drainage was effected by the latter. Instead of a gravel train there is, in this valley, a well-developed gravel terrace. It rises usually twenty-five to thirty feet above the river and may be seen very sharply defined at Rocky Bluff, near Fansler, in the vicinity of Clark's mine (Tp. 80, N., R. XXXI W., Sec. 24, Ne. qr.), and near Panora. It is usually about a quarter of a mile wide and is clearly a terrace of aggradation.* The material of which it is composed is moderately coarse water-laid gravel with more or less coarse sand. In this region it contains a large amount of material derived from the Cretaceous gravel beds, but in all other respects it is similar to the gravel trains and corresponding terraces in Polk county.

These gravel trains show the same relations to the drift border and are in all essential particulars, save the feebleness of their development, similar to those which are so characteristic of the Wisconsin drift in other states. In Wisconsin† the Green Bay glacier filled up the old valley of Rock river to a depth of 350 feet (including earlier drift) with a deposit of finely assorted sand and gravel, producing a level plain three to five miles wide and extending forty miles or more southward from the moraine. The Iowa gravel trains rarely extend ten miles from the drift border and do not often, so far as can be positively known, show a thickness of more than thirty feet of gravel.

As has been suggested, some of these trains are found not only outside the area covered by the Wisconsin ice, but they may be followed up the streams to well within the Wisconsin area. The gravel trains of Camp and Mud creeks are abruptly terminated at the upper end by the Wisconsin till. This is not, however, true of those of Four Mile creek, and the Des Moines river. The pits of the Chicago Great Western

* Salisbury: Geol. Surv. N. J., Ann. Rept. 1892, pp. 102-105. 1893.

† Chamberlin: Geol. Wisconsin, I, 284. 1883.

railway at Berwick, are about six miles within the limits of maximum extension of the ice. The Polk City pits are fully twice as far from the drift border, and the gravels are present along the Des Moines river well up toward High Bridge.

Along the Delaware river a somewhat similar series of phenomena occur. The explanation in this case has been worked out by Salisbury.* The deposit on the Delaware is not a single continuous train, but is rather a series of individual trains each of which was formed successively farther up the river, and each corresponding to one of a series of moraines of recession. Apparently this explanation is equally good for the case in hand, except that here all the phenomena are more feebly developed, and there are no moraines. The ice seems to have retreated, not by definite stages, but continuously, so that the terrace is practically unbroken. That there were minor stages in the retreat is of course altogether probable, and future study may render it possible to discriminate them.

There is a well marked forest bed which is frequently encountered in wells all along the edge of the Wisconsin drift. North of Yale, in Guthrie county, the Eastwood well passed through two feet of wood and muck with drift below. Near Berwick, in Polk county, the forest bed is frequently encountered, and at many points within the area studied it is present. It seems in this place to mark a definite stratigraphic plane, the base of the Wisconsin drift.

Relations to the loess.—Loess of normal character and abundantly fossiliferous is found around the southern edge of the lobe.† It does not occur within the limits of the lobe, but is in these counties everywhere present without it. It spreads out in a thin sheet over the outlying drift, covering the hills and running down into the valleys. Such a relation is susceptible of two interpretations. The loess may have been washed out from the front of the ice and deposited around its

*Geol. Surv., N. J., Ann. Rept., 1894, pp. 21-23. 1895.

†It has been especially described by Call: Amer. Nat., XV, 585-586, 782-784. 1881; Ibid, XVI, 369-391, 542-549. 1882.

edge, or it may have been previously present and overriden by ice and buried beneath the later drift. Upham was inclined to the former view. He suggested* that the presence of the loess immediately west of the moraine in Guthrie, Carroll, Sac and Buena Vista counties, and the fact observed by him that in places the loess rises fifty feet above the drift hills, proved the contemporaneity of the loess and the moraine. To the writer it does not seem that this interpretation is necessary or indeed well in accord with the other observed phenomena.

In Guthrie and the other counties studied no cases have been observed in which the loess stands higher than the Wisconsin drift. Such phenomena, if present, would however be equally susceptible of explanation by the second hypothesis. There seems no necessity for assuming that the ice was present and acted as a retaining wall at the time of the loess deposition. The deposit laps up over and covers the Missouri-Mississippi divide which lies west of the moraine; the two being in this region, roughly parallel. The land rises from the east to the divide, and this was apparently true before the Wisconsin ice invaded the region. The land west of the moraine would, therefore, be expected to be higher, and where the moriane approaches the divide, the difference might be locally great. This would be equally true if the rise to the west were mainly a function of recent elevation, for which belief there is some evidence. In either case, if the loess were older than the Wisconsin drift, the fact would afford a satisfactory explanation of its local elevation above the drift plain.

If the explanation offered by Upham be the correct one, it would be expected that the loess should be found along the eastern front of the moraine as well as its southern and western. That it does not occur in this position has been shown by Calvin in his report on Cerro Gordo county.† The loess is well developed outside the Des Moines lobe, where

*Geol. Nat. Hist., Surv., Minnesota, 1880, p. 338.

†Iowa Geol. Surv., vol. VII.

the latter has overlapped the Iowan, but not, so far as now known elsewhere.

Again, it has just been shown that the Wisconsin drift is persistently fringed by gravels and similar deposits indicative of free drainage, whereas the loess is itself indicative of conditions under which the water could not, or at least did not, carry anything but the finest material. The two deposits are mutually antagonistic. A drift sheet which is constantly fringed by gravel is to be differentiated from one constantly fringed by loess. Loess and gravel require different conditions for their deposition. The general attitude of the land was in one case such as to make vigorous, and in the other sluggish streams. This is not of course to be interpreted as meaning that local exceptions may not occur, but applies to causes where the conditions along the entire drift border are taken into account. In the case in hand there is the additional fact that the loess passes directly under the Wisconsin drift whenever the relations have been made out.

In 1882 Messrs. McGee and Call,* in a valuable and suggestive paper, brought out the fact that at Des Moines the loess passes under the upper drift, which is now known as the Wisconsin. Since knowledge of the drift formations was not then so well organized, the fact was interpreted as being of local import only and as due to a slight re-advance of the ice. By inference the loess was correlated with the Wisconsin, since the upper drift of McGee, which we now know as the Iowan, was distinctly stated to occur south of the city. In the course of the present work the fact that the loess passes under the Wisconsin as stated by McGee and Call has been abundantly verified. The exposures mentioned by the authors are now obscured, but others equally good may be found wherever the drift on either the West Hill or in Highland Park is dug through. During the summer of 1896 the relations were particularly well shown at the top of the Sixth Avenue hill, in the cuts along Grand Avenue, near Greenwood Park, and in the

* Amer. Jour. Sci. (3), XXIV, 202-223.

street railway cuttings in Hamilton street in Oak Park, Des Moines. The relations are unmistakable, and the facts may be verified at any time. The upper drift is quite distinctive, and the buried loess may be recognized with equal ease, particularly as it is very frequently fossiliferous.

The relations found to obtain in the city are equally true of the loess to the north. In the wells near Saylor, in Polk county, the normal section is as follows.

3. Yellow and blue boulder clay
2. Fine pebbleless clay with shells.
1. Blue clay with pebbles and streaks of gravel.

Loess fossils have been obtained from No. 2 of this section at several points. On the farm of Mr. Tom Saylor, thirty feet of pebbleless clay containing "periwinkle shells" is reported below twenty-two feet of Wisconsin drift, which forms the surface soil. Near the mouth of Beaver creek a roadside ravine shows the loess, with its usual characteristics, outcropping below the drift. The same phenomena may be seen along the Des Moines river valley west of Polk City. In Guthrie county the kame gravels west of Panora are clearly deposited over the loess, and well records near Herndon, as well as at certain points in Dallas county, show that the loess extends back under the drift for fifteen or twenty miles at least. In view of these facts, and the phenomena are believed to be general, it is clear that the loess is earlier than the Wisconsin drift, and, if differences in surface erosion be taken as a guide, it must be considered to be considerably more ancient.

THE OUTLYING DRIFT.

General characteristics.—The outlying drift is that known as the Kansan. The Iowan does not appear upon the southern and southwestern borders of the Des Moines lobe. The drift present agrees in character with that which has been called Kansan by the Iowa Survey.* It is fundamentally a

*Norton: Iowa Geol. Surv., IV, 169. 1895. Bain: Ibid. V, 153. 1896. Beyer: Ibid. V, 203. 1896. Calvin; Ibid. V, 63. 1896.

blue boulder clay weathered above into a yellow, which in turn is usually a deep reddish brown at the surface. It contains a large proportion of pebbles derived from local sources, with many varieties from outside the state. An examination at one point showed quartzite, probably from the Sioux formation, sandstone from the Cretaceous, quartz pebbles from the same formation, shale and limestone from the coal measures, light gray granites, pink quartz, porphyry, greenstones, vein quartz and other varieties of rock from outside the state. Another examination showed bits of chert, limestone, sandstones, coal, quartzite, badly weathered gray granite, diabase, fine-grained greenstone, mica-schist, dark green slate, etc.

The greenstones are predominant among the particles from foreign sources. The pebbles are largely striated and flattened, much more frequently than in the case of the Wisconsin. The granite boulders are badly rotted and easily break to pieces. The upper surface of the drift shows marked ferrugination and leaching. The ferrugination has gone on to such an extent that the horizon is a dark reddish brown and resembles in color the red fields of the south. It is easily recognized when seen in road cuts some distance away, and is a convenient horizon of reference in field work. The red color fades gradually below, but it is cut off sharply above when the Kansan is covered by loess or later material. The drift has suffered prolonged leaching as acid tests show no reaction to a depth of several, in places as much as fourteen, feet. In the case of the Wisconsin and even the Iowan, reaction may usually be obtained up even to the grass roots.

The till has all the physical characteristics of an old drift long exposed to weathering agencies *in situ*. In these particulars it is contrasted not only with the Wisconsin but with the Iowan as found in eastern Iowa. The latter is likewise of different color, a light yellow, carries many large surface boulders, shows many fresh cobbles, and only a few that are badly decomposed. It has a smaller percentage of local material and a higher percentage of gray granite, and shows almost no leaching or ferrugination. Upon these differences alone there would be ground for separating the two.

Topography.—The topography gives farther warrant for such a separation. That of both drift sheets is a river erosion topography and the drainage is complete. The Kansan topography has, however, a much greater relief than the Iowan. The latter is characterized by a series of wide, shallow river valleys having no river trenches. The marked, though not easily expressed, contrast between the typical river valley of the Iowan drift and that of the Kansan affords an excellent means of discriminating the two.

The land forms in the area covered by the Kansan are, as has been said, erosion forms. They have been developed upon the drift surface by the action of weathering and running water. In part this water has been collected in gullies and ravines and has taken the form of rivulets, creeks and rivers. In part it has acted as a broad sheet over wide surfaces. By these two methods of erosion the topography has been developed. The two different modes of action have produced different forms of surface which in cross-section yield different curves. These curves, as developed in the region under discussion, are so well developed, so characteristic, and reveal this region so clearly that a brief analysis of their mode of production may not be out of place.

ANALYSIS OF EROSION CURVES.

The materials in which the erosion has taken place, while somewhat diverse, are in a general way homogeneous. They include drift, soft sandstone and shales. These materials weather and erode differentially, and yet in a broad way the action is uniform. The differences induced by differential weathering are slight, are not at first operative, and in the end serve merely to modify the general results. The erosion dates in the main from the retreat of the Kansan ice, and with exceptions to be noted later the surface may be considered to have been a fairly even drift surface.

The problem then is that of the action of erosive and weathering forces upon a fairly even plain of homogeneous material. It will be simpler to consider first the action of weathering and pluvial or sheet-water erosion. Stream action may be considered as merely a special case of the latter. Let us assume then that the stream channels are already cut. They form narrow gashes dividing the plain into a series of blocks. Our problem becomes that of the retreat of the valley sides. The cutting down of the valleys is the equivalent of the lifting of the inter-stream areas. For certain reasons it is clearer to look at the problem as if the latter were the true relation. Of course pluvial erosion and weathering do not wait till the streams have corraded to grade before begin-

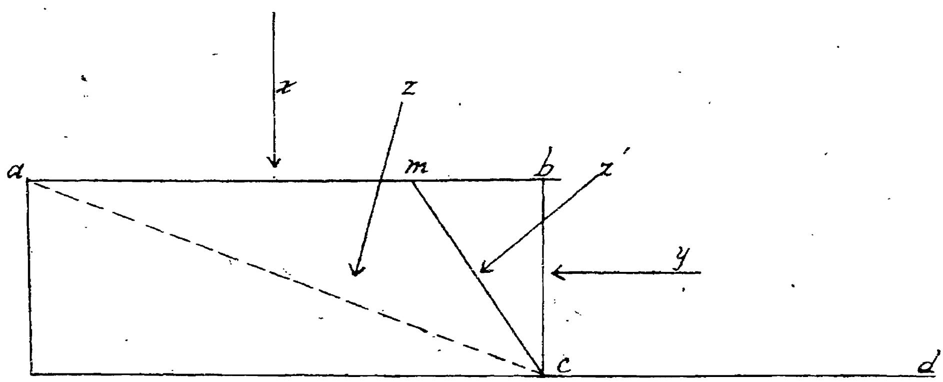


FIG. 47. Case 1.

ning their work, but the problem is exactly the same when a stream has an abrupt bank one foot high as when the latter is many times that height. The bank will be attacked by the same agencies acting in the same manner. While in nature the corrasion of the river bed and the retreat of the valley sides take place *pari passu*, it is after all not so far wrong to make the opposite assumption since the latter action does not become prominent, and never becomes dominant, until the former is accomplished.

Case 1.—Let us assume a block of homogeneous material elevated a certain distance above a level plain. Let *a–b–c–d* be a cross-section normal to the edge of this block. Weathering and intermittent showers attack it. Consider first the action of the former. The complex series of forces which together produce the effect known as weathering tend to soften or disintegrate rock. Other things being equal they act normal to the surface exposed. In Case 1, the weathering would then act along the lines *x* and *y*. Running water with a given load erodes in proportion to its volume and velocity. Conceive a slope extending from *a* to *c* such that water may traverse the entire distance. Suppose the rain to fall equally along the line *a–b*. At any given point upon the slope the amount of water passing would be the sum of all that has fallen on the slope above. Past the point *c* must run all the water which has fallen between *a* and *b* and hence there will be maximum erosion at *c*. At *a*, the head of the slope, will be minimum erosion. The relative amounts of erosion at intermediate points may be represented by the line *a–c*, and the effect of this component of erosion may be considered as a force acting normal to this line or in the direction *z*. It should be kept clearly in mind that only the portion of the area which has become slope is subject to this force. Hence when the slope only extends back as far as *m*, z^1 represents what may be called the volume component. In the retreat of the slope *z* occupies different positions and acts in various directions; that is, *z* is a variable, whereas *x* and *y* are constants.

The second factor of water erosion is its velocity which, with given friction, is dependent upon volume and slope. The effect of volume we have just seen. The effect of slope must be simply to accentuate previous inequalities. Steep slopes, because they induce greater velocity and hence greater erosion, tend to perpetuate themselves and to increase their steepness. The effect of velocity is then to reinforce the action along the line *z* and to increase the steepness of any slope resulting from the other forces.

Case 2.—The action of simple weathering upon such a block would be to disintegrate the material. The point *b*, being exposed to attack upon two sides, is affected more than either of the points *e* and *c*. The result is that the line between the fresh and the disintegrated material becomes the arc of a circle, *e–f–c*. The line *b–c* is a stable line of slope for solid rock, but not for loose material. The action of gravity forces the latter to rearrange itself until the slope *m–m*$^{\prime}$ is reached, that being the slope of stable equilibrium for

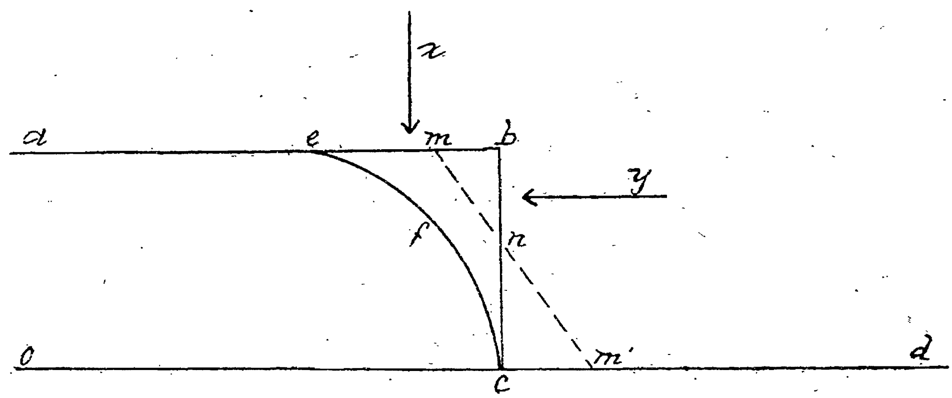


FIG. 48. Case 2.

the loose material in question. The inclination of *m–m*$^{\prime}$ against *c–d* varies with the character of the material and the fineness of its texture. If no running water were taken into account, the process would stop at this point. The result would be a flat table land bounded by talus slopes.

Case 3.—Conceive for the present the point *e* to be a fixed

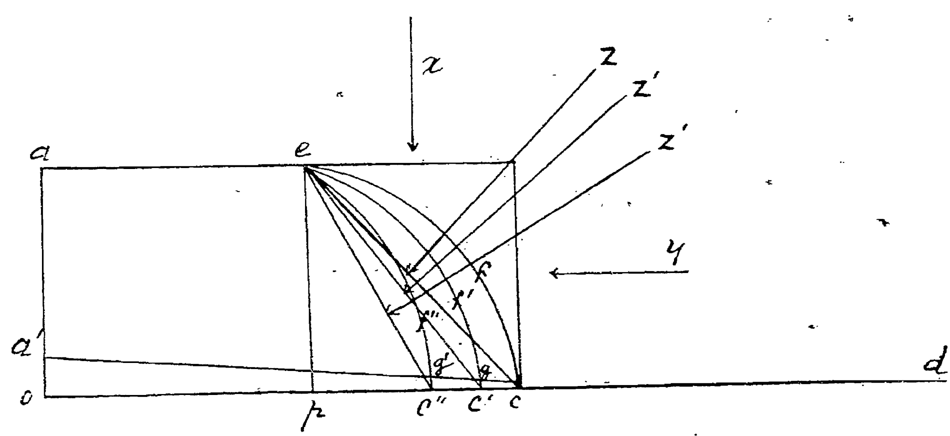


FIG. 49. Case 3.

point beyond which erosion cannot go, introduce the action of running water and neglect the detritus, then x and y are equal and starting with the curve e–f–c, z is normal to e–c and bisects the angle between x and y. The tendency of the velocity to increase with the slope disturbs the equilibrium by producing relatively more rapid erosion at c, and e–c retreats along the lines e–f^{I}–c^{I}, e–f^{II}–c^{II}, z occupying the positions z, z^{I}, z^{II}, etc.

Water will not erode down to an absolute level. There must be a slight slope in order to allow the water to remain in motion. Let a^{I}–c represent the slope beyond which there is no erosion. It is evident that the retreat of the lower portion of the curve is along the line a–c rather than o–c and the point c really moves through the positions g–g^{I} rather than c^{I}–c^{II}.

Case 4.—If the material be conceived to be carried away as fast as it is brought down so that no talus slope is formed, and if, furthermore, the action of the volume and the velocity components of erosion be neglected, the curve e–c may be

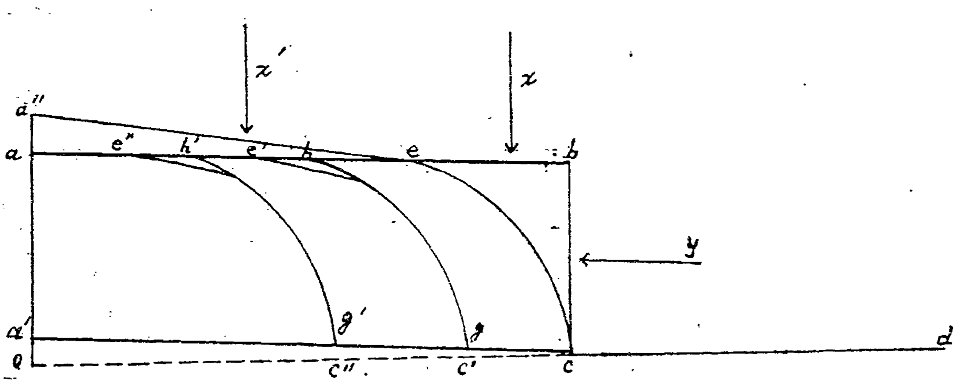


FIG 50 Case 4.

thought of as retreating toward a–o in a series of parallel curves h–c^{I}, h^{I}–c^{II}. Since, however, the force x^{I}, active from the beginning of the process, has prepared the material along the plane a–e, there would be a tendency to produce more rapid results along the upper portion of the curve and the retreat would be by e^{I}–c^{I}, e^{II}–c^{II} rather than by h–c^{I}, h^{I}–c^{II}. As has just been shown the base of the curve would in fact occupy the position g–g^{I} instead of c^{I}–c^{II}. The tendency of the upper portion of the curve toward a more rapid retreat would be accentuated by a second factor. During the time the curve *e–c* is formed the surface *a–e* is still an uninvaded flat. There is no slope, and hence the water falling upon it is largely without motion. It is not, however, true that water on a flat surface has no tendency to move. If we conceive an inch of water spread upon the surface, it must be true that at the edge the water stands with a perpendicular face an inch high, or that it flows. The latter is obviously the correct hypothesis. If then we have one inch of rainfall we have one inch for the perpendicular element of slope along a^{I}–e. In consequence the flat becomes a very slight slope, and a portion of the water falling upon it runs off at the point *e*. The water running past this point has a certain erosive force and the process leads to a flattening of the upper portion of the curve *e–c*.

Case 5.—At the point *c* the water must cease eroding and confine its attention to transportation, since by hypothesis the slope ends at this point. As will be shown later, deposition begins here, so that instead of *c* being the point of great-

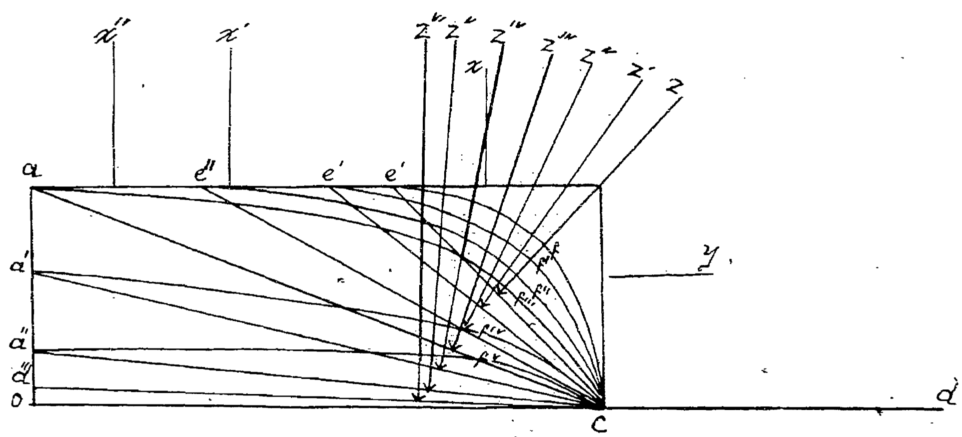


FIG. 51. Case 5.

est, it is, as a matter of fact, the point of least erosion, and the hypothetical conditions of the last case are very nearly the true field conditions. In this case *e–f–c* becomes e–f^{I}–c, e–f^{II}–c, a–f^{III}–c, etc. The point *a* is fixed by the intersection of the curve a–f^{III}–c with a corresponding curve, developed from the opposite side of the block, and not figured; that is, *a* marks the position of a divide. If the divide be stable the curve progresses through a–f^{III}–c, a–f^{IV}–c, a–f^{V}–c, etc., until it becomes the straight line a^{III}–c, which represents the trace of the plane having only such slope as will allow rain water to overcome the friction against its base without carrying any load. In this progress z passes through the positions z, z^{I}, z^{II}, etc., retreating from y and continually approaching x. If c be conceived to have a certain very slow rate of retreat the retreat must occur along the line a^{III}–c as noted previously.

Case 6.—In turning to consider what becomes of the eroded material under the action of sheet water let us assume as before an elevated block a–b–c–o, over the edge of which at b water, loaded with debris, passes in the direction of the arrow m. This debris-laden water takes the direction m^{I} along the

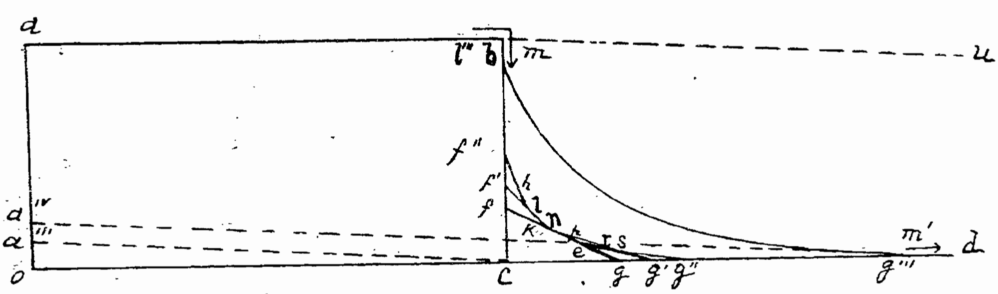


FIG. 52. Case 6.

plane c–d. In the direction b–c, water is falling perpendicularly, and hence has an infinite carrying power. Along c–d, it is running over a horizontal surface and can carry nothing. In changing from m to m^{I} it must lose all its load. The first water which comes over the cliff drops all its load at the foot of the latter. Let f–c–g represent this material. Now more debris-laden material comes over the bluff. The water strikes the slope f–g, and runs down on it. Water on the slope f–g can carry some material, but not so much as when following the line b–c; hence a portion of its load is deposited, forming the increment f^{I}–f–k. The partially burdened water upon reaching the level surface at e must deposit another increment making e–g–g^{I}. The water following finds now four points at which it parts with its load and so deposits the bodies f^{II}–f^{I}–h, l–k–n, p–e–n, and s–g^{I}–g^{II}. Successive portions of water find more points at which to deposit till the number becomes infinite, and a concave curve b–k^{I}–g^{III} results. Continued deposition builds up the curve to the line m–u parallel to a^{III}–c, already defined.

Case 7.—The development of the curve a–f^{III}–c of Case 5, and the curve b–k^{I}–g^{III} of the last case would of course be *pari passu*. When e–f is developed above, f^{VI}–l is developed below; e^{I}–f^{I} corresponds to f^{V}–l^{I}, and so on until a–f^{III} meets f^{III}–l^{III} and there is a continuous slope.

One very important element has so far been omitted. If rain falls along the line a–b it must also be supposed to fall along the line c–d. The rain falling along the latter line

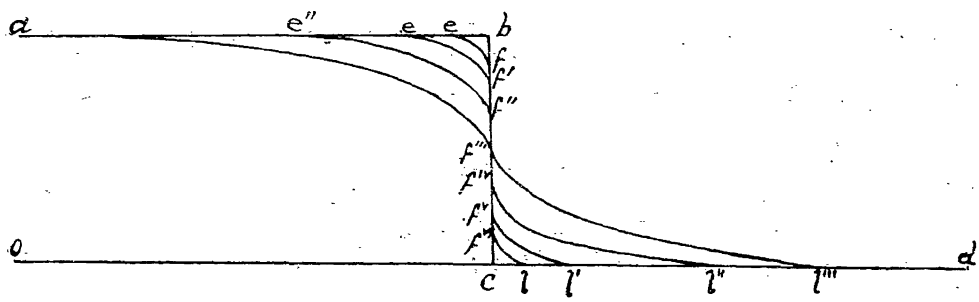


FIG. 53. Case 7.

would be free from load and hence free to erode. The volume would progressively increase from f to l and with it the tendency to erode. The slope would, however, decrease in the same direction, and hence there would be a decreased tendency to erode. The relative values of the two factors would determine which portion of the curve would suffer most rapidly, but it seems probable that erosion would occur along almost its entire length. There could be no erosion at d, since beyond that point there is no slope and hence the waters deposit. The final result must be the destruction of the curve f^{III}–l^{III}, and the spreading of the material f^{III}–c–l^{III} over the plain in a sheet whose upper surface would be a plane with a slope equal to that of the line a^{III}–c of the preceding case, but slightly above it. In final result then the base level would take the line a^{IV}–d of Case 6. The erosion along the lower portion of this double curve is the factor which releases the point c and allows its slight retreat as previously noted.

Case 8.—If between c and d a river capable of transporting the eroded material be introduced, we have a limit to the extension of the curve of deposition. Above it is a long convex curve of erosion which decreases in convexity as the distance from the cliff increases. This is the normal curve for cliff recession under the conditions obtaining in the area under discussion. The base of the cliffs is marked by a concave

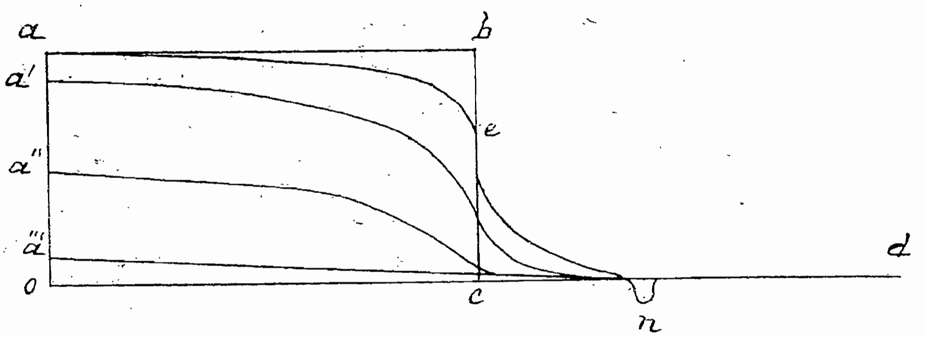


FIG. 54. Case 8.

curve of deposition above which is a sharp convex curve merging beyond into one of decreasing intensity.

It has been customary to speak of the concave curve as the normal curve of erosion,* and the convex curve has been believed to be the result of weathering forces. In the area under discussion this law does not hold true and from the analysis given it will be seen that it is very unlikely to be true in any case where the conditions are the same. This immediate region, while old as compared with the area covered by the younger drift, is young as compared, for example, with the driftless area. In the latter, as has been shown by Chamberlin and Salisbury,† the country has been reduced to a series of ridges whose major slopes are concave.

*Gilbert: Geology Henry Mountains, p. 110. 1880. Hicks: Bull. Geol. Soc. Amer., vol. IV, p. 135. 1893.

†Sixth Annual Report, U. S. Geol. Surv., 234-235.

In a sense these slopes are analogous to the longitudinal profiles of river valleys which are normally concave. Owing to the excess of water which in a stream passes the point *c*, the erosion there becomes most active, and the major portion of the erosion is transferred to the concave portion of the curve. This concave portion once established tends to perpetuate itself and the relative insignificance of the convex curve at the head of the stream causes it to be overlooked.

In all normal erosion it is the concave portion of the curve which tends to lengthen, and so in a very old topography the long concave curves are predominant, and the short convex curves over the divide are insignificant. In the production of these curves the retreat of the point *c* is probably in a curve first rising toward the divide and later falling. The concave curves, however, are originally established as a result of deposition and the normal curve of erosion is convex, not concave.

This does not, of course, apply to the curves produced by the erosion of alternating beds of hard and soft strata where concave curves are often produced in the manner discussed by Noe and Margerie.* In this immediate region the sandstones of the Dakota, the limestones of the Missourian, and the sandstones and limestones of the Des Moines all tend to break up the general curves developed in the drift and to produce such abnormal curves.

River changes.—As has already been pointed out the areas covered by Wisconsin drift show immature drainage. The streams present are, with few exceptions, of very recent age. Occasionally a portion of their course is through an older valley, but in the main, for the region studied this does not seem to hold true. The valleys are sharp, narrow gorges, the tributary streams are short, have high gradients and show active headwater erosion. The rivers are simple consequent streams, and in most cases have not yet cut through the drift to the underlying rock. The streams of the outlying drift

*Les formes du Terrains, pp. 24-28, et seq. Paris, 1888.

are of a sharply contrasted type. The completeness of the drainage system has already been noted. The upland is quite generally dissected. The major streams show regularly developed secondaries, and these in turn support tertiaries of almost equal regularity. The whole forms a complex dendritic system which has required long time for its development. The major streams, and many of their branches, are flowing in preglacial valleys. They have maintained themselves with often only slight modifications, since before the ice invasion. Almost the whole of the present drainage system of the outlying drift area was developed before the deposition of the loess. The latter forms merely a wash over the old drift surface. The streams are not consequent upon the loess, but represent rather the type of rivers for which McGee has proposed the name resurrected.* They differ from the simple consequent rivers in that their direction is really determined by an older land surface than the one over which they now flow. They are not merely revived streams, since between the earlier and later stages of their history there have been periods of total inactivity; times when the river was completely destroyed. The same fact prevents their being considered as merely antecedent streams, though they belong to that general class. The later river is, however, a direct descendant of the one before, and has inherited its channel from its predecessor. After a period of non-existence such a stream is re-formed and takes up the work of the earlier stream. In view of their history the name seems particularly appropriate.

The rivers here, in a certain sense, represent an extreme type of the resurrected river, since they have survived at least two glacial invasions and one submergence. They are not to be thought of as persisting throughout these various vicissitudes, but rather as being re-formed after each. Where the ice has crossed a wide valley it has in many instances failed entirely to fill up the old rock trough, and a broad

* Bul. Geol. Soc., Am., I, 549. 1890.

shallow sag now appears at the surface. Beaver creek in Polk county affords an excellent example of such a sag, and others are not infrequently encountered. In those cases in which the valley may be supposed to have been filled entirely, there would probably still be a tendency for it to be reproduced on the surface. If one imagine a valley 200 feet deep, and suppose drift to be deposited fifty feet thick over the upland at the same time that the valley is filled to the same level, then there would be 250 feet of drift in the valley with only fifty feet over the adjoining upland. Drift as now exposed, and probably as deposited, is not so compact as rock. One of the important processes in the solidification of rocks is the compacting of the loose material and a portion of this change results from settling.* However unimportant this factor may be, it is evident that there would be more settling in 250 than in fifty feet of drift, so that in time the old valley would show at the surface as a depression and would afford most favorable opportunity for the development of a stream. The two factors of original inequality of deposition and of secondary settling work together and become cumulative. Together they make it possible for a river to be resurrected time and again.

The rivers on the older (Kansan) drift are of the resurrected type. Some of them, the lower Des Moines and Raccoon for example, have histories reaching back into preglacial time. Most of the streams are younger, but all save the smallest are pre-loessial. Probably the largest number are post-Kansan and pre-loessial. Among the latter are the Raccoon rivers and Bushy Fork in Guthrie county.

The invasion of the Wisconsin ice produced important changes in many of the rivers. Thus the upper portion of the older Des Moines valley is now deserted by the main stream and is occupied by the smaller Beaver creek. A portion of the valley near the old mouth of the river is deserted altogether and a new connection with the Raccoon has been

*Van Hise: Principles of Pre-Cambrian Stratigraphy, p. 684.

established. Above the mouth of Beaver creek the Des Moines is engaged in cutting an entirely new valley.

Correlation of outlying drift.—An erosion such as outlined would necessarily require a considerable lapse of time for its accomplishment and this is one of the best evidences of the antiquity of the older drift. The complexity of the drainage system points in the same direction as does the physical condition of the drift, and all these features unite in proclaiming the high antiquity of the Kansan as contrasted with the Wisconsin. Some of the reasons for correlating the outlying drift of Polk, Dallas and Guthrie counties with the Kansan rather than the Iowan have already been suggested. The stratigraphy of the region, particularly the relations of the loess, affords others.

The loess found in the region has been referred to the Iowan since it is believed to be in this region the equivalent of the Iowan drift farther north and now in part buried under the Wisconsin. It is believed that loess of widely different ages occurs in the Mississippi valley, and there is some evidence of an older loess in this immediate region, so that the qualifying term has been added for the purpose of definitely fixing the age of this particular loess. The basis of the correlation is the fact that loess, apparently the same, may be traced around the southern limit of the Wisconsin to Marshall county, where it comes into contact with and laps upon the Iowan. It follows the border of the latter southeast, never extending far up on the Iowan, to Johnson county, where its genetic relationship to the latter is excellently shown.* Furthermore the Iowan ice sheet, as shown by its non-morainic border and other phenomena, marked a period of low level and clogged drainage, such as is known from the relations of the loess to the river valleys to have occurred in the region under discussion. This period was, in each case, between the Kansan and the Wisconsin, as is shown by the fact already mentioned, that the loess covers the Kansan and passes beneath the

*Calvin: Geol. Johnson County. Iowa Geol. Surv., vol. VII.

Wisconsin in the one region and was connected with the Iowan in the other. It is separated from the Kansan by a considerable interval since the major portion of the erosion of the outlying drift was accomplished before the loess was deposited. The time between the loess and the Wisconsin was also considerable, as the loess had been quite deeply eroded before the gravel trains of the Wisconsin were formed. The difference in the character of the two deposits is itself suggestive. The gravel trains contain both fine and coarse material, while the loess consists of fine material only. Such a difference in deposits is indicative of a difference in the competency* of the waters. This in turn depends upon declivity and volume, mainly upon the former. A change in declivity, with a resulting change in the grade of the streams is another indication of a considerable time interval between the two, since the conditions noted here are such as are true in the neighboring states and over a considerable portion of the drift area of the United States. Such general changes of level are not rapidly accomplished and in themselves are indicative of a considerable time interval.

The loess of this region was then deposited at a time between the Kansan and the Wisconsin and separated from each by a considerable interval. Conditions favorable to loess deposition prevailed when the Iowan ice occupied eastern Iowa, and this time accords well with that suggested by the facts in the present case, and the whole point to the Iowan age of the loess at the southern borders of the Des Moines lobe.

There is in the northwestern portion of the state a drift which in physical constitution and topographic development resembles the Iowan of eastern Iowa, and it has been provisionally correlated† with that formation. There are many reasons in support of the view that this correlation is correct so that the headwaters of the pre-loessial streams of the region were doubtless cut off by the Iowan ice. In a period

*Gilbert: Geol. Henry Mts., p. 110. 1877.

†Chamberlin: Great Ice Age (Geikie), pl. XV. 1894. Calvin: Iowa Geol. Surv., VII, 20. 1897.

of general low level, contemporaneous with that ice, the rivers became greatly expanded and the conditions for the distribution of the loess over the territory in question were afforded.

As has been seen the preliminary classification of the drift deposits recognized but two major drift sheets earlier than the Wisconsin.* This was the view current when the present work was taken up in the summer of 1895. The Des Moines lobe was recognized as belonging to the Wisconsin, and the Iowan was assigned no definite limits to the south.† McGee and Call, as well as Chamberlin‡ had considered it to be present south of Des Moines. In 1895 Calvin began his work in Johnson county and quickly recognized that the drift sheets present in the northern and southern portions of the county respectively were radically different in age. If the surface drift of the paha region were Iowan, that of southern Johnson county must be something earlier, and he accordingly referred it to the Kansan. After spending some days in Johnson county in company with Professor Calvin, the present writer extended the work into Washington county and assigned the drift there to the Kansan and the loess to the Iowan.§ These were known to be in all respects identical with that previously studied in Keokuk and Mahaska counties‖ and present throughout much of the southern portion of the state¶ and accordingly the deposits of Appanoose and Warren counties were placed with those of Washington.**

Since the upper drift at Afton had been considered to be Iowan a number of visits to the locality were made for the purpose of studying the relations of the drift sheets at that point. The drift found in Polk county was traced southward and found to be the same as the upper drift at Afton Junction. At the latter point it showed the upper zone of ferrugination, the leaching, the weathered boulders, and all the physical

*Chamberlin: Great Ice Age (Geikie), pp. 773, 774. 1894. Jour. Geol., III, 270-277. 1895.
†McGee: Eleventh Ann. Rept. U. S. Geol. Surv., 472-496. 1893.
‡Chamberlin: Loc. cit.
§Geol. Washington County. Iowa Geol. Surv., vol. V, pp. 153-156. 1896.
‖Iowa Geol. Surv., vol. IV, 287, 288, 342, 343. 1895.
¶Iowa Geol. Surv., IV, 230-234. 1895.
**Iowa Geol. Surv., V, 320, 406. 1896. Ibid., V, 318-320, 406-408. 1896.

characteristics which had come to be recognized as peculiar to the Kansan in the surrounding region. Its relations to the loess were the same, as was also its topographic development. In short the upper drift at Afton was found to be the same as that which was elsewhere recognized as Kansan. The Aftonian beds accordingly were found to be below rather than above the Kansan, and a still lower pre-Kansan drift sheet was recognized. A preliminary examination as far south as Kansas City seemed to show that the older drift did not come to the surface, and accordingly the upper drift at Afton Junction is presumably the surface drift of eastern Kansas, though the matter has not been fully studied. The older pre-Kansan drift is known to be present at a number of points in southern Iowa and adjacent portions of Missouri, and has more recently been found in northeastern Iowa. Beds probably representing this horizon outcrop near Hastie, in Polk county, and there is some evidence of their presence in Guthrie county

The pre-Kansan drift is probably the equivalent of the Albertan as described by Dawson* though the connection has not yet been worked out and quite probably never can be placed beyond dispute.

About the time these studies were being carried on in central Iowa Leverett† determined the fact that a drift sheet invaded Iowa from Illinois at some time between the Kansan and the Iowan, and another member was added to the series. As now recognized by Chamberlin‡ the entire drift series is as follows:

9. Wisconsin till sheets (earlier and later).
8. Interglacial deposits (Toronto, perhaps).
7. Iowan till sheet.
6. Interglacial deposit.
5. Illinois till sheet (Leverett).
4. Interglacial deposit (Buchanan of Calvin).
3. Kansan till sheet.
2. Aftonian beds. Interglacial.
1. Albertan drift sheet (Dawson).

*Jour. Geol., III, 507-511. 1895.
†Jour. Geol., IV, 756, 874. 1896.
‡Jour. Geol., IV, 872-876. 1896.

Calvin* has given essentially the same section summarizing the Iowa formations as follows:

I. First stage of glaciation, Albertan. Invasion of Iowa by glaciers and distribution of lowest sheet of till.

II. First interglacial stage, Aftonian. Melting and retreat of glaciers and deposition of gravels, followed by a long period of forest growth, development of soils and modification of the original drift.

III. Second glacial stage, Kansan. Cold more intense and glaciation more general than during the first stage. Distribution of McGee's lower till.

IV. Second interglacial stage, Buchanan. Introduced by deposition of gravels in Buchanan, Black Hawk, Floyd, Cerro Gordo and other counties. This stage was very long, and the surface of the second drift sheet was profoundly modified by erosion, oxidation and leaching before it came to a close.

V. Third stage of glaciation, Illinois. During this stage only a small part of Iowa, embracing portions of Louisa, Des Moines and Lee counties, was invaded by glaciers. The ice came from the northeast, bringing boulders from the eastern shores of Lake Huron.

VI. Third interglacial stage (unnamed), during which the modification of the second drift sheet proceeded over the greater portion of Iowa. The small area occupied by the third deposit of drift also suffered more or less of modification.

VII. Fourth glacial stage, Iowan. During this stage the northern half of Iowa was overrun by glaciers. The southern limit of this incurson may be traced a few miles north of a line drawn from Iowa City to Des Moines, and then deflected northwestwardly to Plymouth county. It was during this stage that the enormous granite boulders so conspicuous in Bremer, Black Hawk, Buchanan and other counties in northeastern Iowa were transported and deposited where they now lie.

*Iowa Geol. Survey, VII, 18, 19. 1897. Amer. Geol., XIX, 270-272. 1897. Annals of Iowa, (3), III, No. 1, 1-22. 1897.

VIII. Fourth interglacial stage, Toronto (?). This fourth interglacial stage was short as compared with the second, and probably the third. The amount of erosion, oxidation and leaching which, during this interval took place in the surface of the fourth sheet of drift, is altogether inconsiderable. The amount of change that has taken place since the beginning of the interval up to the present time is comparatively small.

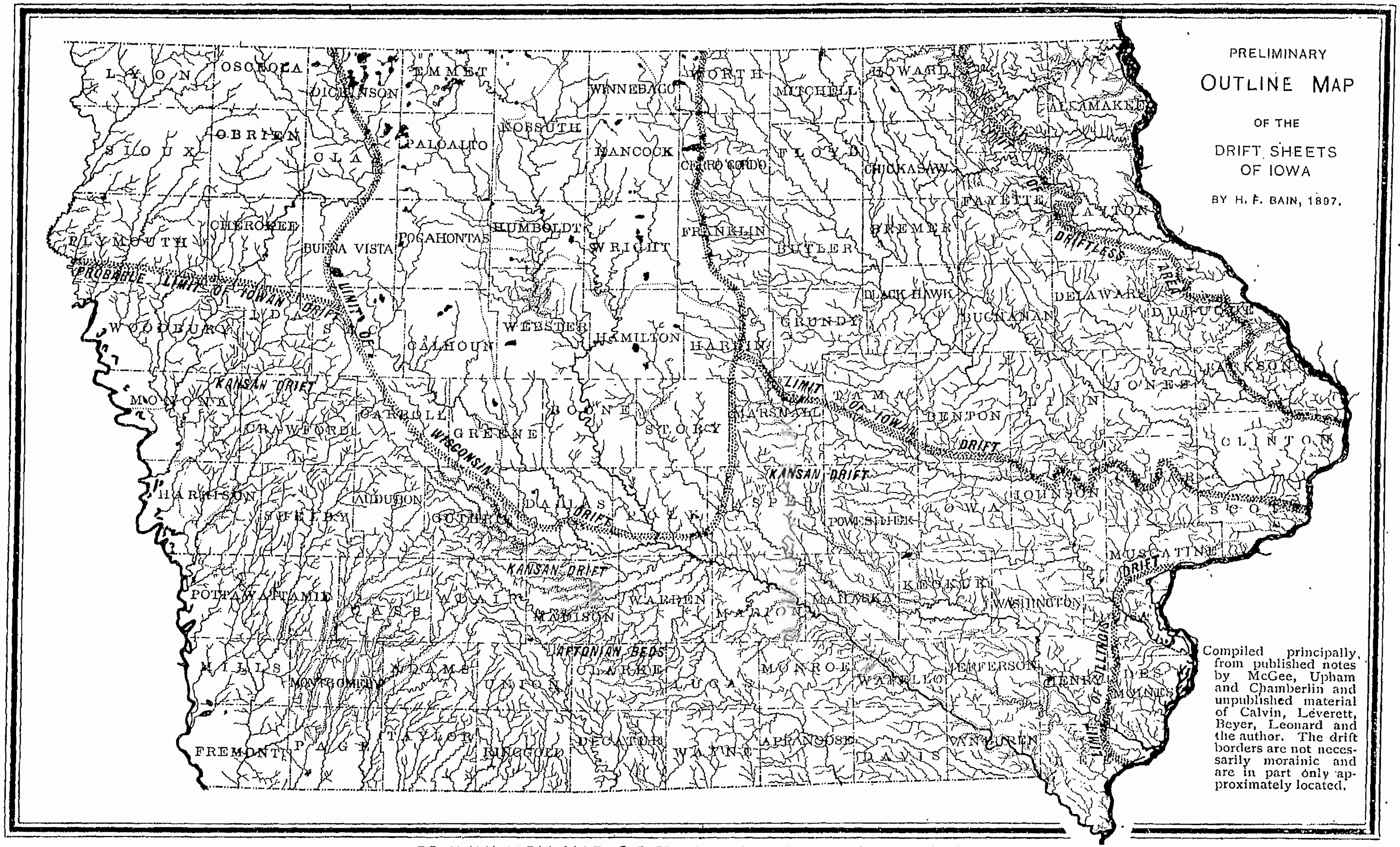
IX. Fifth glacial stage, Wisconsin. The last invasion of Iowa by glacial ice occurred in times so recent, geologically speaking, that the youngest sheet of till exists practically in the condition in which the glaciers left it. The area in Iowa affected by this last invasion is nearly triangular in shape, the base of the triangle coinciding with the north line of the state from Worth to Osceola counties, with the apex located at Des Moines. In the northern part of this area there are numerous stretches of ill-drained lands, the surface is only very gently undulating, and the stream channels, where defined at all, have cut only a foot or two into the prairie sod.

X. The recent stage, since the retreat of the Wisconsin ice, brings Pleistocene history down to the present. The recent stage, while long as measured in years, has been too short to produce any appreciable effect in the surface of the Wisconsin drift.

The Kansan has heretofore been correlated with the lower till as recognized by McGee* but certain recent observations seem to indicate that the latter may find its correlative in the pre-Kansan rather than the Kansan. At Oelwein in Fayette county, some excavations made by the Chicago Great Western railway have revealed the presence of a well developed till below the Kansan and separated from it by an important peat bed. Above the Kansan the Iowan is characteristically displayed though its thickness is small. The three drift sheets with representatives of the Buchanan and Aftonian interglacial beds are shown in the one section.† Pre-Kansan beds

*Chamberlin: Iowa Geol., III, 273. 1895.

†This section and its relations were quite fully discussed at the winter meeting of the Iowa Academy of Sciences, December, 1896. See proceedings for 1896; also Science, p. 317, Feb. 19, 1897.



PRELIMINARY MAP OF THE DRIFT SHEETS OF IOWA.

have been found also in Marshall county and at other points. A review of sections published by McGee* makes it more than doubtful whether the forest bed which he has so clearly shown to be present does not mark the Aftonian rather than Buchanan horizon. In plate xxviii is given a preliminary outline map of the drift formations of the state as they are now understood.

TIME RATIOS.

The problem of the length of the interglacial intervals has attracted considerable attention, though as yet but few numerical estimates have been made. The data are not such as readily lend themselves to this manner of expression. It is obvious that no very exact results can be obtained where so many factors are uncertain. At best, approximations are all that one can hope for. Yet for certain purposes these, when supported by a fair degree of probability, are of quite large value; and in all cases, in the absence of anything better, they perhaps serve a useful purpose.

The problems which it is hoped may be solved, or to whose final solution the correct determination of the length of the interglacial periods contributes, are principally two: (1) the taxonomic rank of the divisions of the glacial series, and (2) the larger problem of the age of the earth.

Whether the ice age is to be considered as consisting of one, or two or more periods, as the term period is used in geology, has provoked much discussion.† It is not proposed to review what has been brought out in this discussion but simply to indicate the bearing upon this problem of certain of the phenomena exhibited in the Des Moines region. It should first be pointed out that for purposes of this question evidence

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*Eleventh Ann. Rept., U. S. Geol. Surv., 514-542.

†Chamberlin: Geol. Wisconsin, I, 271-391; Am. Jour. Sci. (3) XLV, 171-200; Jour. Geol., III, 270-278: Geikie's Great Ice Age, chapt. XLII: Bul. Geol. Soc. Am., I, 469-480; V, 16. Coleman: Jour. Geol. III, 622-645. Hershey: Am Geol. XII, 314-323 Lewis: Glacial Geol., Great Britain and Ireland, 51-52 Leverett: Jour. Geol. I, 129-146. Bul. Geol. Soc. Am., V., 17. McGee: Pleistocene History of Northeastern Iowa, loc. cit., Bul. Geol. Soc. Am., V, 17. Russell: Mon. XI, U. S. Geol. Surv., 254-268. Salisbury: Ann. Rept. State Geol. N. J. 1892, 60, 72; Jour. Geol., I, 61-84; Bul. Geol. Soc. Am., III, 173-182. Upham: Minn. Geol. Surv.. 1879, 48; Am. Nat. XXIX, 235-241; Am. Jour. Sci. (3), XLVI, 358-365; Bul. Geol. Soc. Am., V, 16. Williams, E. H.: Bul. Geol. Soc. Am., V, 281-296. Wright, A. A.: Bul. Geol. Soc. Am., V, 7-15 Wright, G. F.: Great Ice Age in N. Am. 475 et seq (with citations): Man and the Glacial Period, 106 et seq; Amer. Jour. Sci., XLIV, 351-373; Ibid, XLVI, 161-187.

may be admitted, and even accepted as conclusive, which from its very nature is of much less value in any discussion of the other problem mentioned. It is not the absolute length of glacial and interglacial time which is wanted so much as their relative lengths.

Estimates of the actual length of time since the retreat of the ice have been made at a number of points.*

In all cases the results are obtained by assuming that some process, such as erosion, has progressed in the past at its present or at some known rate. It is obvious that the absolute results are uncertain to the extent of the unknown error in the assumed value of the rate. This error may be, and in some cases undoubtedly is, large. For purposes of comparing different portions of the glacial period this error is not so important. If, judged by the same test and making the same assumptions, a given interglacial period is found to be as long as, or a certain number of times longer than, the time since some fixed event of the glacial period, the fact has an independent value. The assumed rate of erosion may, it is true, have varied in one case and not in the other, or the two rates may have varied together or in opposite directions, and yet unless such variations be proved or probable they may be neglected without seriously impairing the value of the result. The latter, of course, increases with the difference between the total result and the possible effect of a wrong value for the variable. If, for example, it be found by comparative erosion that the length of a given interglacial stage was as long as the stage since the retreat of the ice from a given point, a variation of one-half in the rate of erosion during the glacial stage reduces or increases largely the force of the argument for the duality of the glacial period. If, however, it be found that with the same assumptions comparative erosion shows the interglacial stage to have been twenty times as long as the postglacial, a doubling of the erosive activity in interglacial times still leaves the stage ten times as long as the postglacial.

*Wright: Great Ice Age in N. A., 448-475, with citations.

Studies of comparative erosion constitute as yet the only method appealed to to furnish numerical data as to the length of the interglacial stages. Ferrugination, oxidation, leaching, changes in altitude and other phenomena have been used in making up general impressions and have frequently been emphasized as showing that the earlier drifts are vastly older than the newer. In a few cases these general impressions have been put in mathematical form. Thus McGee states that if the period of written history represent a day then a month or a year will measure the period which has elapsed since the first Pleistocene ice sheet invaded northeastern Iowa.*

Chamberlin,† after consultation with various workers in the Mississippi valley, has given the following:

	UNITS.
From later Wisconsin to the present	1
From earliest Wisconsin (Shelbyville moraine) to the present.	2½
From Iowan to the present	5
From Illinois invasion of Iowa to the present	8
From Kansan to the present	15
From sub-Aftonian (Albertan) to the present	x

N. H. Winchell‡ has carefully compared the amount of erosion shown by the present gorge of the Mississippi from Fort Snelling to Minneapolis with that necessary for the excavation of a neighboring gorge, believed to be interglacial. Assuming that the conditions of erosion were the same except for 25 per cent greater erosion in the case of the interglacial channel, allowed as a factor of safety, he finds that if postglacial time be 7,800 years, interglacial time would be 9,750. With regard to the estimate it may be pointed out that the allowance of 25 per cent is wholly a matter of opinion. One might make it greater or less, and, aside from a desire for a conservative attitude in discussing disputed questions, there would seem no sufficient reason for fixing the amount of the allowance, or perhape any inherent reason for making any

*Eleventh Ann. Rept. U. S. Geol. Surv., p. 507.
†Jour. Geology, vol. IV, p., 876. 1896.
‡Amer. Geol. vol. X, pp. 67-80. 1892.

allowance. The estimate lacks also in value in that there is no evidence as to which of the interglacial stages it pertains to. Since the region has probably been occupied successively by the pre-Kansan, Kansan, Iowan and Wisconsin ice sheets one has wide latitude in interpreting the phenomena. The estimate is of a great value, however, as showing that by the same tests which the advocates of the unity of the glacial period have used to determine the length of post-glacial time, it may be proven that during the ice age there was at least one interval fully as long as post-glacial time. This fact is of more significance since the measurements were made by the same observer, in the same region, and using the same methods that he used in making an estimate of the length of post-glacial time which has been widely quoted and approved by all, including advocates of the unity of the glacial period.*

It does not, of course, follow that the ice age consisted of two or more rather than one glacial period because of a long interglacial period. The passage of time alone, and aside from any climatic changes would not be sufficient to warrant a separation. There might be one or many interglacial stages fully as long as all post-glacial time, but if the climate remained much the same the whole might well be considered a unit. The long interglacial stages are, however, strongly confirmatory of all independent evidence† of climatic changes, and, though not sufficient to warrant a division of the ice age, they are strong presumptive evidence of climatic changes. It is hardly likely that the climate would for a long time hover so close to the point of glaciation without reaching it. The value of this latter presumption increases with the length of the interglacial periods and for that reason certain results obtained in the course of the present work may be offered.

In the eastern portion of Polk county there are certain streams which antedate the Wisconsin ice. The latter cut off their head waters, and from its front gravel trains stretched

* Wright: Ice Age in North America. pp. 458-466; Man and the Glacial Period, 310-342. Upham: Amer. Naturalist, vol. XXIX, p. 238. 1895.

† Leverett: Proc. Boston Soc. Nat. Hist., XXIV, 455-459. See also previous citations.

down the old valleys. These gravel deposits have since been cut through and remain as terraces along the river. Their age can be definitely fixed as being that of the maximum extension of the Wisconsin ice. The valleys themselves are earlier than the loess as is shown by the latter mantling their sides and partially filling the bottom of the troughs. This is not a result of later creep as was ascertained by careful study in the field. The drift under the loess is Kansan and shows all its normal characteristics. In such a valley one has an opportunity to measure the amount of erosion required to cut out the larger valley in terms of that required to excavate the smaller channel cut since the terrace was formed.

Camp creek, south of Nobleton (Tp. 79, N., R. XXII, N., Sec. 26) show such relations in typical form. A cross section of the stream is shown in figure 55. With such an outline it is

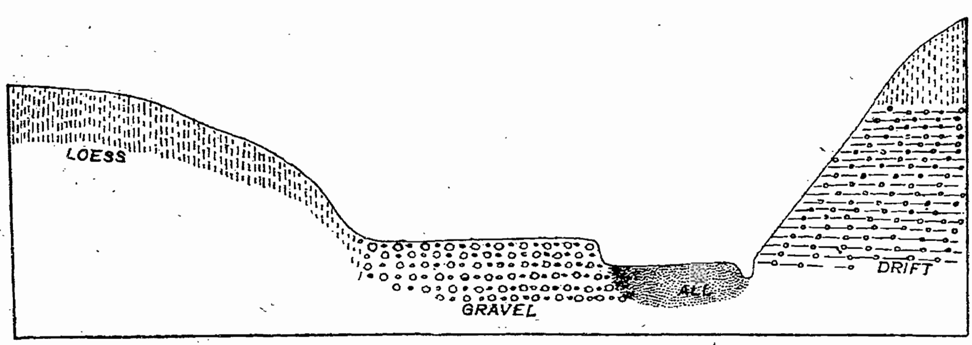

FIG. 55.

clear that there is some latitude with regard to the interpretation of the past history of the stream.

It may simply be assumed that the valley before the terrace was formed was cut down to a depth indicated by the present slopes of the old valley sides, and that before the present alluvium was filled in the recent valley had been cut to a depth indicated by the sides of the recent valley. Such a history is suggested by the accompanying sketch. (Fig. 56.)

If now the amount of loess filled in over the upland be taken as equivalent in this cross-section to that cut out of the valley, added to the amount of drift cut off the upland before the loess was laid down, and extended observations upon the streams of the region indicate that the assumption is perhaps approximately correct, the old section *a–a–a* may be taken as equivalent to the post-Kansan section. The line *a–b–b–a* would

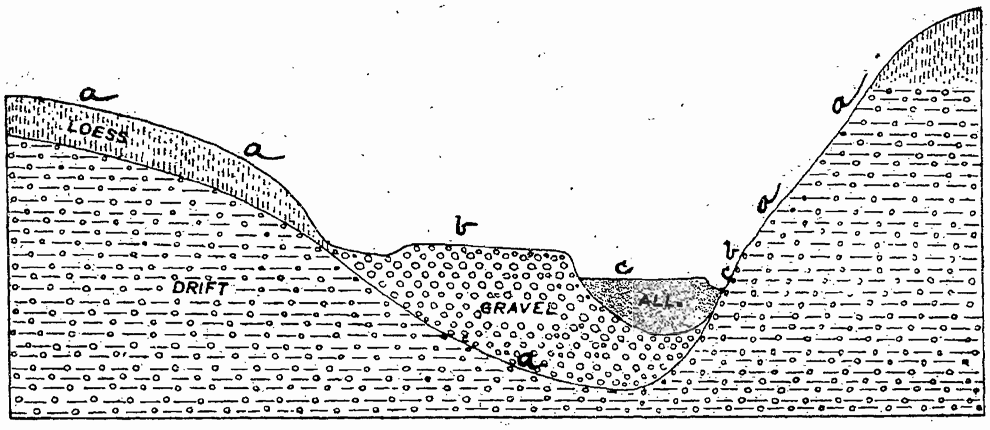

FIG. 56.

represent the cross-section after the terrace was formed, and *a–a–b–b–a* would represent it when the newer stream ceased to cut down and began to build up, while *a–a–b–c–c–a* would represent the present cross-section. The actual cross-section has been carefully measured and is plotted in figure 57.

The figures given are dimensions in feet. The line *a–b–c–d–e–f–g–h* represents the present cross-section. Following out

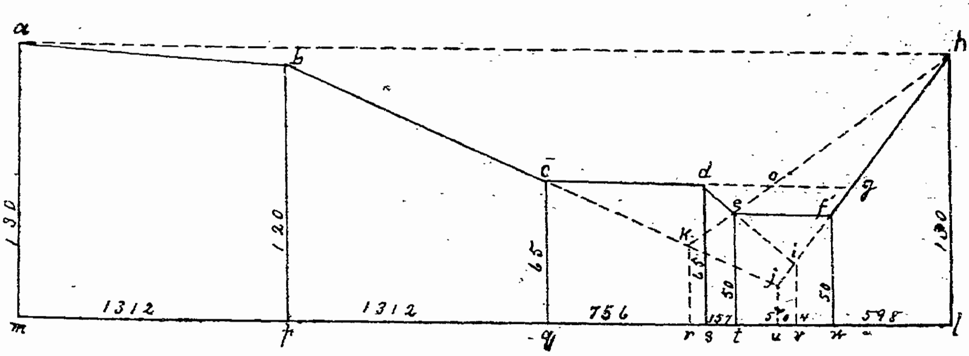

FIG. 57.

the history of the stream just suggested let it be assumed that the post-Kansan surface be *a–h*. It may have been higher, as one can not tell exactly how much was cut from the upland before the loess was laid down over it, nor what is the average thickness of the latter on the upland. If, as has been suggested, we assume that the amount of Kansan eroded from the upland before the loess, and the amount of loess eroded from the valleys before the Wisconsin, together equals the amount of loess left on the upland, then *a–b–c–k–j–g–h* may be taken as the post-Kansan valley and its cross-section equals 254,285 square feet. Before the retreat of the Wisconsin ice the valley was filled up to the level *c–d–g*. Now if it be assumed that the time occupied in this filling was equal to the time necessary for the equivalent erosion, then this area 51,282 should be added to the previous figures and the major erosion may be taken at 305,567. Let the secondary valley be *d–i–g*, equal to 16,442 square feet. It was filled up to *e–i–f*, equal to 6,930 square feet. Assume that the deposition of the alluvium required the same time as the erosion in the gravel, and the secondary erosion equals 23,352. Under these assumptions the older valley shows 13.09 times the erosion of the present valley.

If it be objected that the gravel filling would take place more rapidly than the previous erosion, though it seems probable that the larger supply of water from the oncoming ice would increase the action of the erosion enough to compensate any error here, an allowance of a double rate may be made for the deposition. Then the ratio is 1:11.98.

It may be objected, however, that the history sketched is improbable in some particulars. The presence of the loess capping the east bank and not running down the slope, with the greater steepness of the western bank shows that the pre-loess shape of the valley has been considerably altered. It may also be urged that the amount of alluvial filling is unknown. Ten feet only is shown by the stream, and under some circumstances no more need be assumed. Keeping these objections in mind the following estimates may be made.

Let the assumptions as to the loess be the same as before. Let the original stream be supposed to have begun its work upon the level plain *a–h*. Let it be assumed to have cut to *k*, leaving a nearly symmetrical valley before the Wisconsin. Let the terrace be assumed to have filled the valley *a–b–c–k–h* to the present line *c–d–o*. Let the resurrected stream have begun its work at the most westerly point *d*, and have cut continually against its east bank; an assumption which involves the least time for the work of producing an asymmetrical valley. Take the alluvial filling as equal to ten feet. Then take the major valley *a–b–c–k–h*=175,316. The filling (deposition equalling erosion) *c-k–o*=33,300, and the total major erosion =208,616. The secondary valley *d–e–f–g*=9,492. The alluvial filling taken twice=10,080, and the minor erosion=19,572, giving a ratio of 1:15.55. If *o–g–h* be added to the recent erosion the figures become 33,590 and 208,616, and the ratio is 1:6.21.

By varying the assumptions, ratios as high as 1:18 may be obtained, the whole series calculated being 1:6.21, 1:11.98, 1:13.09, 1:15.55, 1:17.43, 1:18.60. It is believed that the truth in this case lies between 1:10 and 1:15, and nearer the latter than the former figures. This is less than the writer would have given as a result of general field impressions.

While, as has been suggested, these are essentially calculations of relative erosion and the actual time ratio may have been widely different, it is believed that with the allowances made for the building up of the terraces as well as their destruction, the estimates may be taken as fairly accurate guides to the time relations. Whatever errors there are on one side are probably counterbalanced by similar errors on the opposite. For example, if it be suggested that the stream which cut the later gorge did not work so rapidly as the one which excavated the earlier valley, since it was a smaller stream after the ice had cut off its head-waters, it may be urged that when the antecedent stream began its work upon the Kansan drift plain it was probably as puny as the stream now working. The first stages of valley erosion are accomplished by small forces, and if there be any difference it is possible that the resurrected stream had more water in its earlier stages than its antecedent since it received water from the melting glacier, while the older stream probably excavated this portion, at least, of its valley by simple head-water erosion.

The whole of the evidence derived from comparative erosion indicates that the time since the Kansan, as compared with the Wisconsin of this region, was long; at least ten and probably fifteen or more times. It points unmistakably to the conclusion that the two drift sheets were widely separated in time, and in connection with other evidence of less specific character, warrants their separation theoretically, as they must be separated practically in any detailed mapping.

With regard to the broader question of the total time consumed in the Pleistocene, it should be remembered that the ratio here derived is between the retreat of the Wisconsin from this region and the beginning of erosion after the retreat of the Kansan. In using the ratio it must be kept in mind that Des Moines stands at the extreme southern limit of the Wisconsin ice west of the Mississippi. The estimates of the length of post-glacial time most commonly quoted all date from much later events than the retreat of the ice from this region.

Three of the estimates which seem most reliable and most widely accepted, those of Gilbert,* Andrews† and Winchell‡ are based respectively upon the life of Niagara Falls, the rate of wave cutting and sand filling on Lake Michigan, and the life of the Falls of St. Anthony. The results arrived at respectively give 7,000, 10,000 and 7,800 years as length of post-glacial time at three points if the observed present rate has remained constant in the past, which is not true in the case of Niagara at least.§ The birth of Niagara and St. Anthony Falls and the beginning of wave work on Lake Michigan are

*Proc. A. A. A. S., XXXV, 1886, 222, 223; Sixteenth Ann. Rept, Com. State Res. Niagara, Smithsonian Report, 1890, pp. 231-257.

†Am. Jour. Sci., XCVIII, p. 172. 1864.

‡Geol. Nat. Hist. Surv., Minnesota, Fifth Ann. Rept. 1876, pp. 75-189; Final Rept., vol. II, 1888, pp. 313-341; Quart. Jour. Geol. Soc., XXXIV, 886-901. 1878.

§Gilbert: Nature, vol. L, p. 53. Spencer: Amer. Jour. Sci., (3), XLVII, 455-472; Appleton's Pop. Sci. Mon., XLIX, 1 20.

very recent events and if the figures obtained in these cases be applied to the region under discussion an unknown quantity must be added for the length of time during the retreat of the ice from Des Moines. For calculating the total length of the glacial period more must be added for the length of Kansan and pre-Kansan time so that for the final result certain portions of the data are not yet known. Stated as a formula the present state of knowledge is

$$\text{Pleistocene time} = x + 10 \text{ to } 15\,(y + 7{,}800)$$

in which x = the length of pre-Kansan and Kansan time, and y = the length of time occupied in the retreat of the ice from Des Moines, the multiple 10 to 15 is from the calculations here given and 7,800 is Winchell's estimate of the life of St. Anthony's Falls. It will probably be possible to get an approximate value of y, but the value of x seems not so easy to estimate.

INDEX.