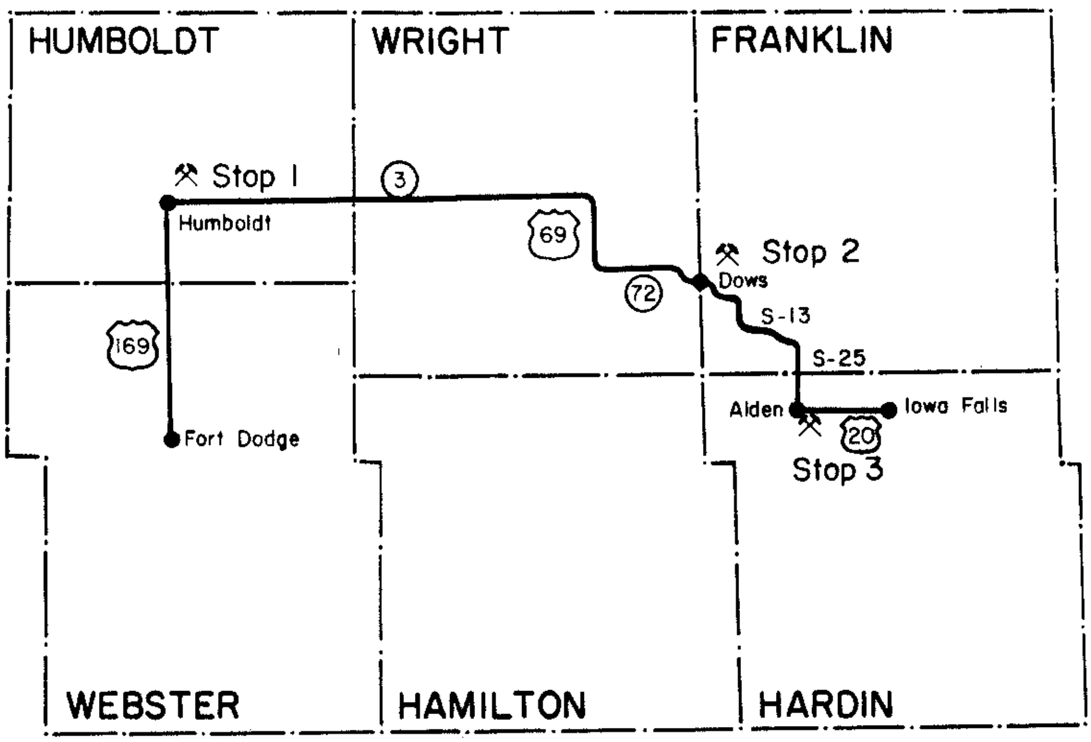
# MISSISSIPPIAN BIOFACIES-LITHOFACIES TRENDS

# NORTHCENTRAL IOWA

## A New Look at an Old Attraction

GEOLOGICAL SOCIETY OF IOWA

April 18, 1982




## GUIDEBOOK 37


Brian F. Glenister and Shirley C. Sixt

Department of Geology

The University of Iowa

Iowa City, Iowa 52242

## ABSTRACT

Graphic correlation using all available paleontologic data affords precise time control for much of the Lower Mississippian section of Iowa. Lithic units formerly interpreted as a temporal succession can be demonstrated to represent isochronous facies equivalents. The type Gilmore City Limestone is Kinderhookian and approximately equivalent in age to the Chapin Oolite of the Le Grand area. By contrast, the type Humboldt Oolite, formerly referred to the Gilmore City, is mainly Osagean and correlates with the Eagle City and Iowa Falls members of the Hampton Formation at Iowa Falls.

The field trip will review lithofacies and biofacies trends in the Osagean strata at Humboldt, Dows, and the Alden-Iowa Falls areas. Trends are displayed best in the type Humboldt Oolite, where they are complicated least by diagenesis. Upward restriction at Humboldt is interpreted as a "fillup" that culminated in evaporite deposition. Decrease in biotic diversity and increase in dolomite percentage from Humboldt SE to Iowa Falls relate to progressively greater restriction in that direction.

## INTRODUCTION

### History of Investigation

Study of the Carboniferous of northcentral Iowa began in 1839 with the pioneering reconnaissance of D. D. Owen (1852). Other early students of these strata, now generally referred to the Gilmore City Limestone, include A. H. Worthen (1858), who worked near Humboldt, and J. D. Whitney (1858), who described exposures in Marshall and Hardin Counties. C. A. White (1870) proposed correlation between the limestone exposures at Humboldt, Alden and Iowa

Falls, and T. H. Macbride (1899) referred the superjacent dolomite and lithographic limestone at Humboldt to the St. Louis Formation (Meramecian).

The age of the Gilmore City Limestone and its stratigraphic relationship with the purportedly subjacent upper members of the Hampton Formation have been of interest since these early studies. Sardeson (1902), Van Tuyl (1925), Laudon (1932, 1933, 1935), Moore (1935), Harris (1947), Thomas and Williams (1956), Wagner (1960), Thomas (1960), Harris and Parker (1964), Carter (1972), Lloyd (1973), Koch (1973), Parker (1973), and Hughes (1977) have contributed to the discussion. Although faunal relations have received sporadic detailed attention, many of the conclusions on age relationships are based primarily on interpretations of physical stratigraphy rather than biostratigraphy. The general consensus has been that both the Hampton and the Gilmore City are referable to the earliest Mississippian Kinderhookian Stage. However, a latest Kinderhookian, pre-Burlington (Osagean) age for the Gilmore City has been suggested by some (e.g. Laudon, 1933; Carter, 1972).

Most recently, the complex lithofacies and biofacies relationships of the Early Mississippian in Iowa have been investigated by a series of graduate students at The University of Iowa (Person, 1976; Hughes, 1977; Hager, 1981; Lawler, 1981). Current studies include sedimentologic investigations of the type Gilmore City by David T. Gross, and of the Humboldt Oolite by Shirley C. Sixt. Paul F. Ressmeyer is investigating the biostratigraphy of a partial time equivalent of the general Gilmore City sequence, the Eagle City Member of the Hampton Formation.

## Biostratigraphy

General faunal analysis has been a part of most of the stratigraphic studies of Mississippian strata in northcentral Iowa. However, each of the several detailed taxonomic investigations involving these strata has been confined to a single biologic group. Laudon's description (1933) of the classic crinoid faunas of the type Gilmore City was followed by accounts of the corals (Carlson, 1964), brachiopods (Carter, 1972) and gastropods (Harper, 1977). Two additional elements are now being studied. Calcareous (endothyroid) foraminifers are abundant in the limsetones of the Gilmore City and Humboldt areas, and are being investigated by Paul Brenckle (AMOCO Research, Tulsa). Additionally, the diverse and abundant ostracode faunas from Humboldt are under study by I. G. Sohn (e.g., 1979). Voluminous collections of known as well as new Gilmore City fossils have been assembled through dedicated efforts of A. J. Gerk (Mason City, Iowa) and C. O. Levorson (Riceville, Iowa) and are being offered for study by specialists (Gerk and Levorson, in press).

Alan B. Shaw (AMOCO Research, Tulsa) has initiated a new phase in biostratigraphic studies with application of his graphic correlation technique (Miller, 1977) to the Lower Mississippian. Adequately documented literature citations of occurrences of all taxa are incorporated with newly-acquired range information to provide the basis for confident precise correlation of sections through the Composite Standard (Shaw, 1964). In this manner, lithic units formerly interpreted as forming a temporal succession (Fig. 1) can be demonstrated to represent isochronous facies equivalents (Fig. 2). As a consequence, the details of the complex Mississippian facies relationships in Iowa are susceptible to resolution for the first time. Many additional data have yet to be assembled and evaluated before the stratigraphy is understood adequately. Satisfactorily precise correlations are now available for the Mississippian exposures from Burlington to Iowa Falls. However, the belt from Iowa Falls to Gilmore City is relatively poorly known. It is this belt that forms the focus of the present field trip.

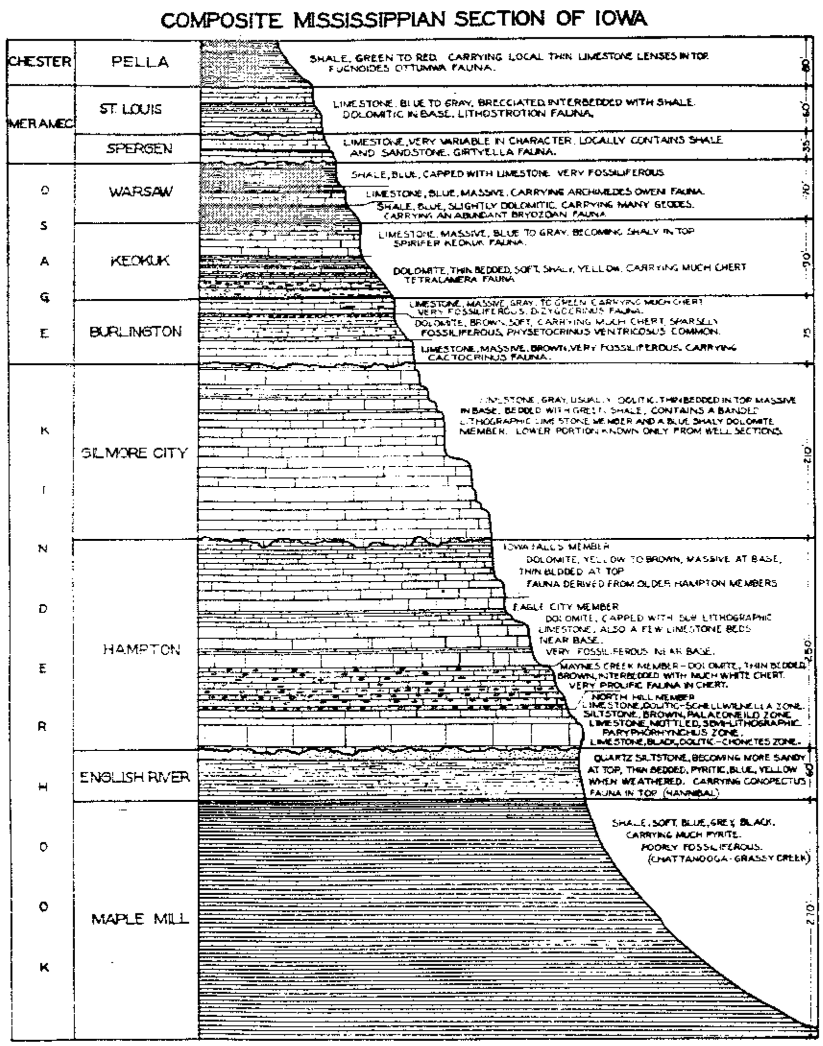



Figure 1. Composite Mississippian succession in Iowa as interpreted by Lowell R. Laudon and other able pioneer stratigraphers, based largely on physical relationships (from Laudon, 1933).

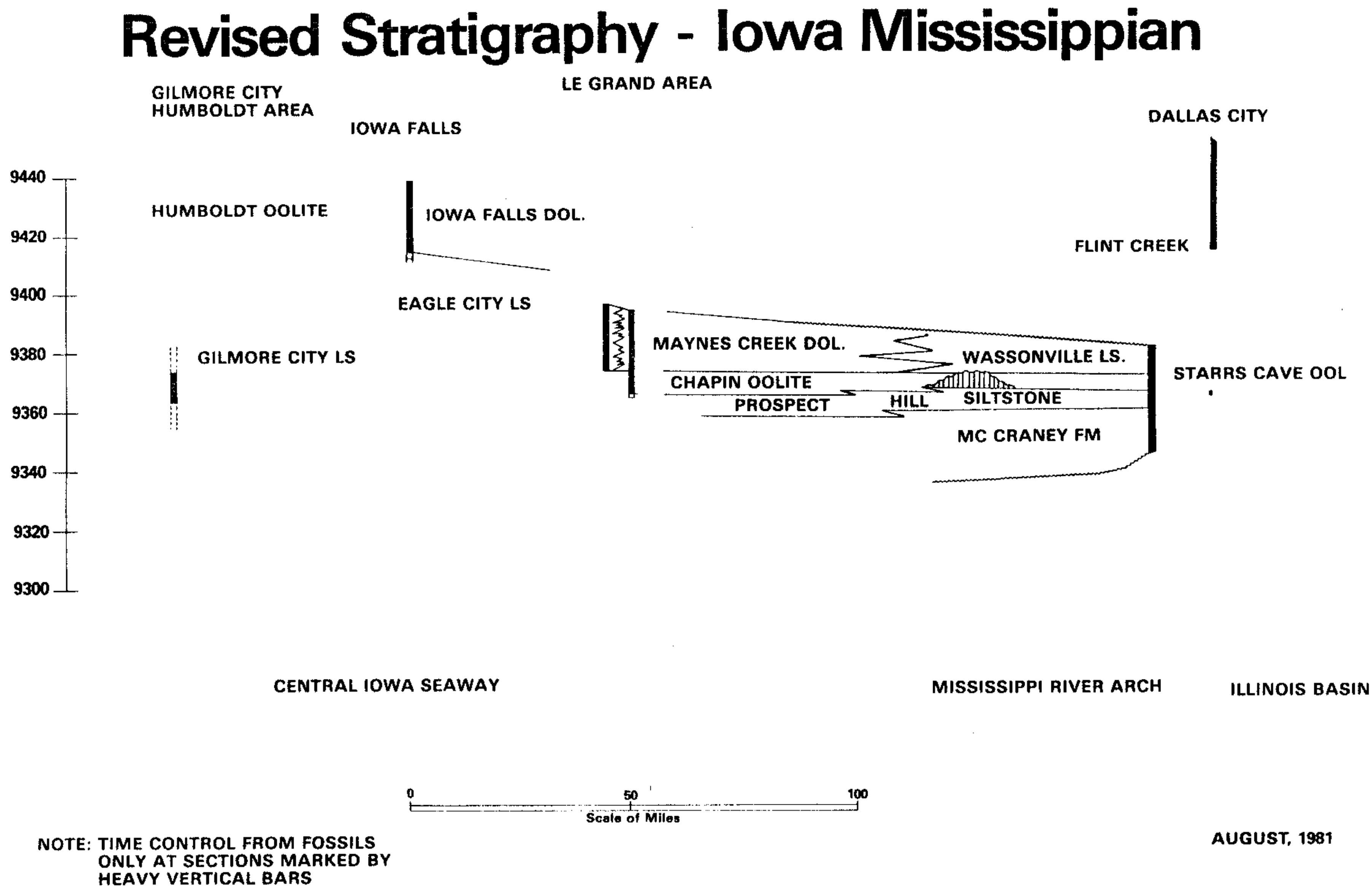



Figure 2. Revised Mississippian stratigraphy based on time correlations. Numbers at left refer to AMOCO Composite Standard Units: 9400 CSU is boundary between Kinderhookian and Osagean stages (A. B. Shaw, August 1981, reproduced with permission of the author and of AMOCO Production Co.).

Current Correlations

Present understanding of correlations can be expressed best by reference to the AMOCO Standard Time Scale. In this scale, the Phanerozoic is estimated as 575 MM years in duration, following the widely-used Elsevier chart. "If this time is divided into 25,000-year increments, there are 23,000 such units. Each such unit is being used at this time as being equivalent to one Composite Standard Unit. According to the same Elsevier chart, the Mississippian began 230 MM years ago, which places the base at 230 MM/25M = 9200 CSU. The "Kinderhookian" is cited as lasting 5 MM years, so its top would be 9400 CSU. These two points have been more or less arbitrarily located and the scale converted accordingly." (A. B. Shaw, personal communication).

Shaw's correlations (Sept. 1, 1981) from southeast to central Iowa verify the anticipated diachronism of lithic units (Fig. 2). For example, the range in age of the oolitic limestone that overlies the clastic Prospect Hill Siltstone is from 9374-9377 AMOCO Composite Standard Units (CSU) at Burlington (Starrs Cave Oolite) and 9365-9373 CSU at Montour (Chapin Oolite). Thus, oolite deposition was initiated earlier and lasted longer in central Iowa than in the Burlington area of SE Iowa. This proves to be one example of a general relationship. Open marine (relatively unrestricted) facies developed sooner and generally lasted longer in the "Central Iowa Seaway" than in the vicinity of the Mississippi River Arch of SE Iowa, or presumably also the Transcontinental Arch to the NW.

Correlations for the Mississippian of northcentral Iowa (Iowa Falls to Gilmore City) are less precise. This is partly because of the relative paucity of useful fossils in dolomite facies, but mainly because available faunas are not yet fully integrated into the Standard Time Scale. Dateable faunas occur in both the Eagle City Limestone and the superjacent Iowa Falls

Dolomite at Iowa Falls. The exposed upper part of the Eagle City there contains calcareous foraminifers, both rugosan and tabulate corals, brachiopods and mollusks, and its range was given as 9411-9414 CSU (Shaw, Sept. 1, 1981), that is, Early Osagean. The dolomite of the type Iowa Falls is generally sparsely fossiliferous, but contains beds crowded with a thick-shelled snail (Euomphalus latus, a species that is common in the Humboldt Oolite) and diverse solitary and compound corals. Shaw listed the age range of the type Iowa Falls as 9414-9443 CSU.

Dateable fossils have not been recovered from either the Iowa Falls Dolomite or the unconformably superjacent "Gilmore City Limestone" at Alden, 6 miles W of Iowa Falls. At Dows, 15 miles NW of Alden, the upper one-half of the quarry succession is sufficiently fossiliferous to permit eventual precise correlation. However, the only taxa whose identities are verified to date are the brachiopod Camarotoechia globosa Weller and the bivalve Palaeoneila microdonta (Winchell), both recorded previously from the Burlington Limestone, and the gastropod Euomphalus latus (noted herin from the type Iowa Falls Dolomite and the Humboldt Oolite). Collectively, the occurrences suggest Early Osagean.

The limestone successions in the vicinity of both Gilmore City and Humboldt, 10 miles distant and some 40 miles W of Dows, are richly fossiliferous and are suitable for eventual integration into the Composite Standard. Calcareous foraminifers and brachiopods are common in both successions and offer great promise for fine correlation, as do the conodonts of at least the type Gilmore City. At present, all that can be stated is that the type Gilmore City is Kinderhookian, and roughly equivalent in age to the Chapin Oolite and Eagle City Limestone of the Le Grand area (Fig. 2). By contrast, virtually all of the exposed Humboldt Oolite is almost certainly Osagean, the approximate equivalent of the type Iowa Falls Dolomite. Lithic correlation in quarry exposures suggests that the same succession available at Humboldt occurs westward to within a few miles of Gilmore City. The precise relationship between the Humboldt Oolite and the Gilmore City Limestone may not be demonstrable in outcrop, and recourse to subsurface data is probably necessary.

Assignment to the Meramecian of the dolomites and breccias that cap the limestone sequence at Humboldt is based on lithology alone, and therefore unacceptably dubious. We suggest elsewhere herein that these upper beds simply represent the culmination of the upward trend of the Humboldt Oolite towards increasing facies restriction.

## Trends in Primary Facies

Lithofacies and biofacies trends are best observed in the Humboldt area, where they are complicated least by diagenesis. A predictable rhythmic "fill-up" pattern is evident in the section now available at P & M Hodges Quarry. However, part of an older rhythm ("Laminated intraclast mudstone," base of section, Fig. 3) may be present in the sump of the W pit at Hodges, and additional rhythms probably occur in the deeper flooded quarries in the northern outskirts of Humboldt (Thomas, 1960).

The exposed section at Hodges Quarry is oolitic throughout, with the exception of the calcitic mudstones associated with the breccia at the top of the succession. However, the proportion of ooids to other grains, and the size, sorting, and degree of coating of these grains varies considerably. In fact, the succession displays marked lateral variation and a spectacular array of depositional and diagenetic features. Bars and shoals, cross-beds, repeated fining-upward sequences, oncolitic coatings and laminar crusts can be recognized in different horizons, and fossils vary greatly in size and in abundance and diversity of the assemblages.

Despite the variety of lithic and biotic features displayed by the exposed section at Hodges Quarry, a simple gross pattern is evident. The sporadic fining-upward trend in lithology coincides with upward decrease in the individual size and assemblage-diversity of fossils. However, abundance of fossils may be greatest high in the section where fine limestones are commonly crowded with representatives of a few ostracode species.

The trends in lithofacies and biofacies at Hodges Quarry can be interpreted as a single "fillup" rhythm. Open circulation conditions at the base of the section imply sufficient water depth to sustain wave motion capable of winnowing mud, to permit growth of a diverse biota that includes large solitary and colonial organisms, and to provide the repeated movement necessary for oncolitic coating of even the largest clasts. Thereafter, the rate of sedimentation outpaced any possible rise in sea level, so that water depth was reduced successively. Decrease in depth impeded wave motion, and winnowing of mud became less effective. With increasing restriction of circulation, assemblages of organisms became progressively less diverse, and individual size decreased. This progressive upward restriction culminated in deposition of lithographic limestones and, finally, evaporites. Subsequent solution of evaporites produced the dolomitized collapse breccia that caps the Humboldt succession.

Presumed time equivalents of the Humboldt Oolite display progressively greater restriction to the SE, from Humboldt through Dows to Iowa Falls. Evidence of this trend is clearest in the decrease in biotic diversity, although SE increase in dolomitization may relate to progressive restriction in circulation. No trend is apparent in the dominantly dolomitic sequence at Iowa Falls. However, both the lithic and faunal successions at Dows suggest deepening-upward conditions. Fossils are rare in the partially dolomitized mudstones and wackestones and sucrosic dolomite that constitutes the bottom one-half of the Dows succession. The overlying calcareous grainstone bed (7 meters, Fig. 4) is crowded with a single species of small ball-shaped rhynchonellid brachiopod, a distinctive stress biota. A superjacent grainstone contains a great monospecific abundance of bivalves. Calcareous grainstones in the upper 5 meters of the succession show progressively greater evidence of more open circulation. Depth here was sufficient for effective winnowing of mud, and relatively open conditions at the top of the succession supported a moderately diverse fauna, including large corals and gastropods.

Observed facies trends at Dows Quarry imply deepening upward conditions in which the rate of transgressive deepening outstripped sediment accumulation.

Diagenesis

Detailed petrographic examination of the rocks at Humboldt has yet to be attempted, so that we cannot discuss diagenesis fully. However, field examination has revealed features that are now considered to be of probable diagenetic origin.

The limestones at Humboldt are calcite spar cemented. Most of the sediments are well cemented, but the fossiliferous grainstone forming the bench at about 6 meters from the base remains friable.

Features observed in polished slabs taken from the brecciated and dolomitized facies at the top of the section (Fig. 3) suggest that more than one episode of dolomitization has occurred. Angular clasts of chert imbedded in the dolomitic matrix add an additional puzzle at this horizon.

Another feature of probable diagenetic origin consists of a series of ellipsoids, longest axes ranging from about 2-10 cm, composed of fine ooids, and defined by concentrations of spar filed tubes. These distinctive

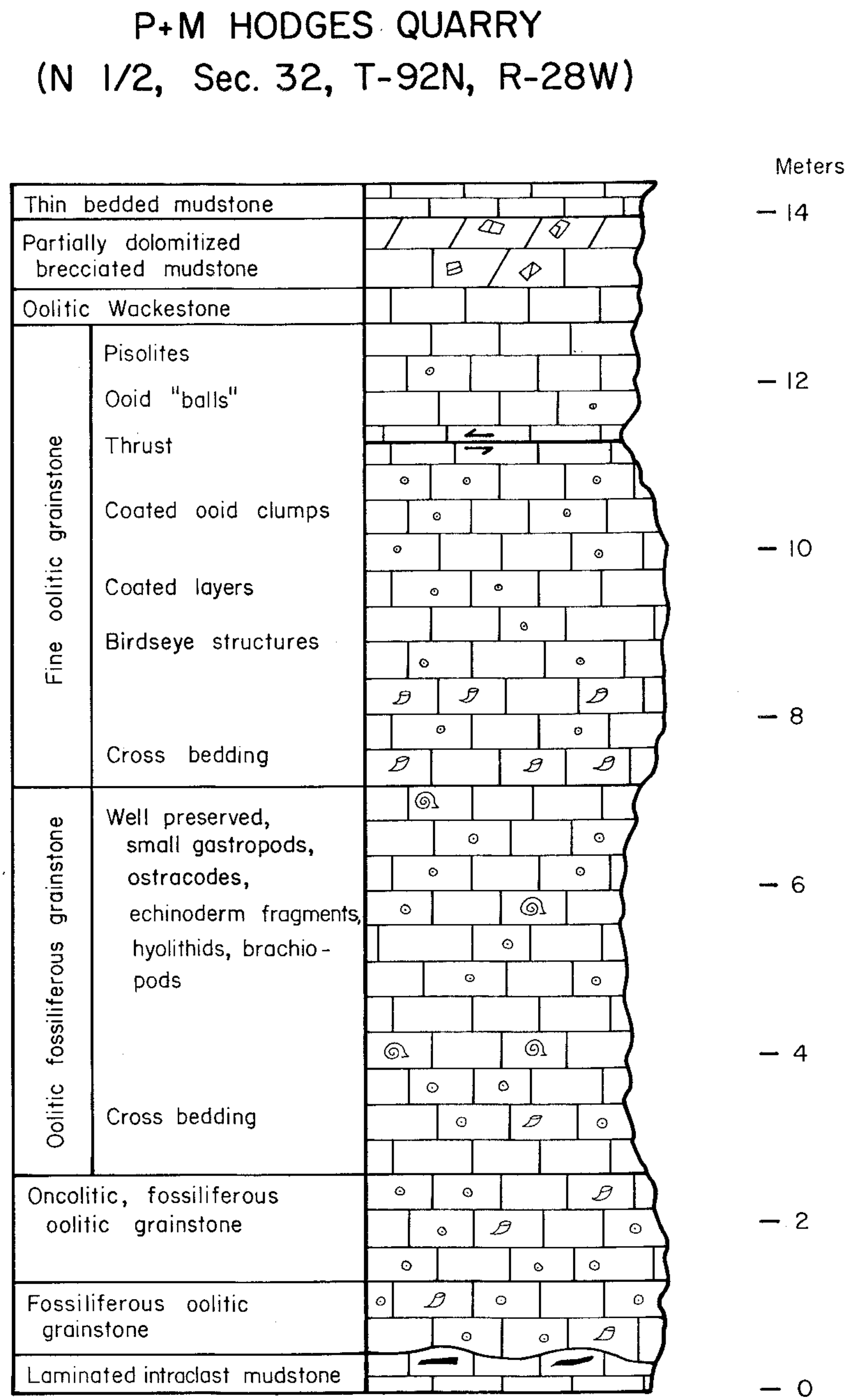

P+M HODGES QUARRY
(N 1/2, Sec. 32, T-92N, R-28W)
Meters
14
12
10
8
6
4
2
0
Thin bedded mudstone
Partially dolomitized brecciated mudstone
Oolitic Wackestone
Fine oolitic grainstone
Pisolites
Ooid "balls"
Thrust
Coated ooid clumps
Coated layers
Birdseye structures
Cross bedding
Oolitic fossiliferous grainstone
Well preserved, small gastropods, ostracodes, echinoderm fragments, hyolithids, brachio-pods
Cross bedding
Oncolitic, fossiliferous oolitic grainstone
Fossiliferous oolitic grainstone
Laminated intraclast mudstone

Figure 3

# DOWS QUARRY
## (NE 1/4, Sec. 30, T-91N, R-22W)

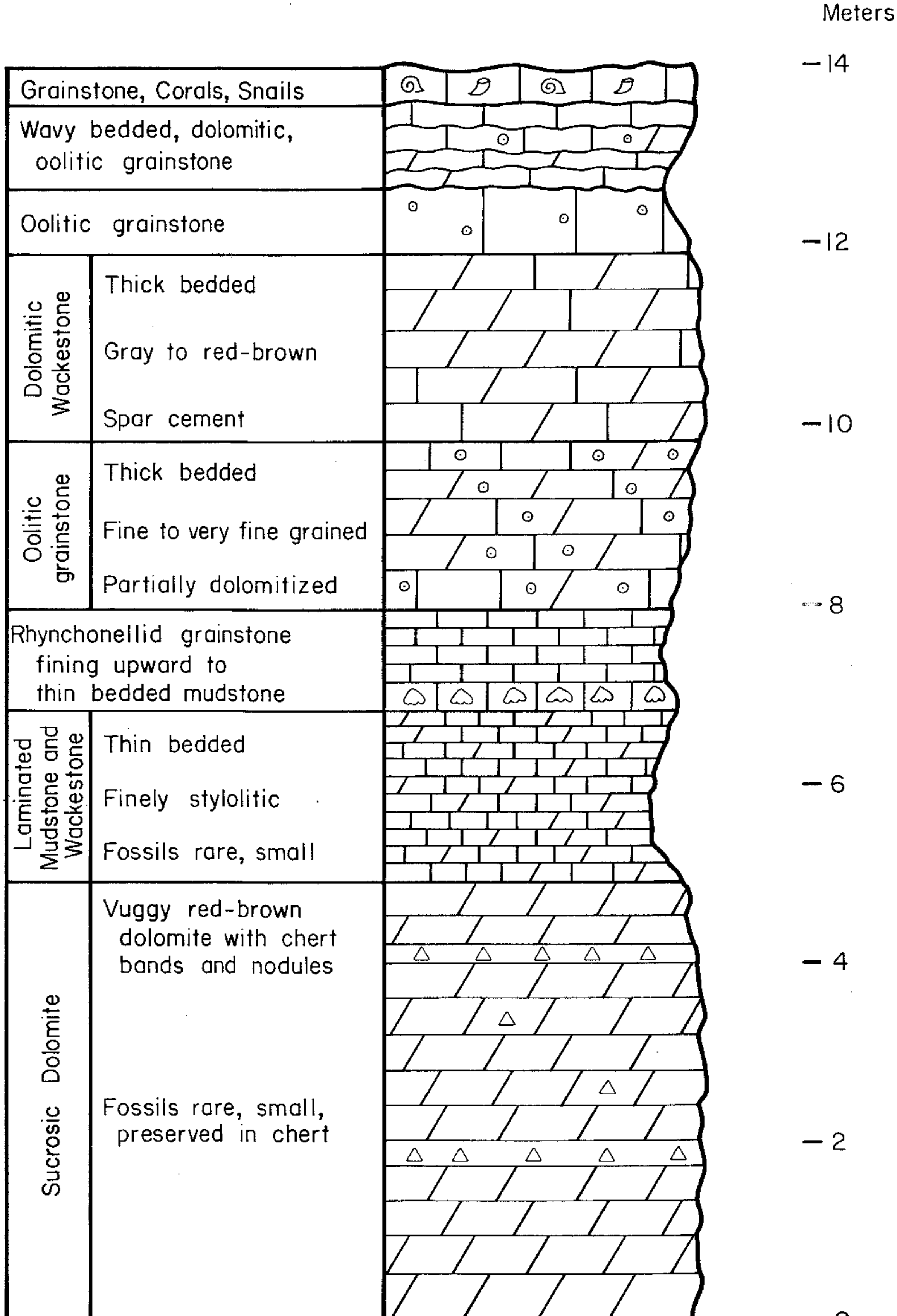



Figure 4

structures may be formed by some "cement-drip" process (A. C. Kendall, AMOCO Canada, personal communication, 1981).

A type of concretion present in at least two horizons within the Hodges Quarry, and generally associated with the features described above, might be best characterized as ooid balls. These discrete bodies range from 1-10 cm in diameter. In one case, they are found at the same level on both flanks of an oolite shoal.

Other prominent features are not as clearly interpretable as either depositional or diagenetic. Pisolites up to 1.5 cm in diameter with laminated outer crusts occur near the top of the section. Such structures have been interpreted both as accretionary bodies formed in a hypersaline lagoon (Esteban, 1976; Wright, 1981), and as secondary features produced in the vadose zone during subaerial exposure (Dunham, 1969; Scholle and Kinsman, 1974).

A final feature, still of questionable origin, also occurs at more than one horizon. Micritic crusts 1-2 mm thick cap repeated fining upwards sequences of about 5-10 cm. The crusts sometimes coat level surfaces, but more often form irregular shapes. Individual crusts may be continuous laterally for several meters.

Two diagenetic features dominate the exposures at Dows Quarry. Extensive dolomitization is the most prominent, particularly at the base of the section although expressed to some extent throughout. Two continuous bands of chert, and beds characterized by presence of nodular chert, are conspicuous features in the lower 5 meters of sucrosic dolomite (Fig. 4).

A 4.5 meter section extending from about the middle of the basal dolomite to the top of the rhynchonellid grainstone in Dows Quarry was examined in thin sections spaced approximately 30 cm apart. Dolomite and calcite were both observed to have distinctly different characteristics at different levels.

Low in the Dows sequence, dolomite crystals exhibit a bimodal size distribution. The larger (200-300μ) rhombohedra are characterized by a clear rim and an amorphous irregular center. They are similar to features termed "hollow rhombs" by Land and others (1975). The small rhombohedra (25-30μ) are clear dolomite. Ferroan calcite cement fills the interstices.

Just above the base, dolomite has been replaced partially by calcite, ferroan calcite, or ferroan dolomite. The amorphous inner portion of the large rhombs is replaced more consistently than is the clear dolomite.

Pyrite is present in a significant amount (3-5%) above the chert band, and large crystals of ferroan calcite fill the many vugs at this level.

The calcite mudstone unit at Dows is characterized by the presence of rhombohedra composed of polycrystalline ferroan calcite. Ferroan calcite spar is the cement in the rhynchonellid unit, and no rhombs were observed there. However, the finer sediment above the brachiopod bed comprises 15-75% of floating rhombs of polycrystalline calcite, ferroan calcite or ferroan dolomite. These relations suggest a series of diagenetic processes requiring very different diagenetic environments.

## FIELD GUIDE

<u>Assembly</u>

Transportation will be by private vehicle, with assembly at 8:30 A.M. at the S side of the Hy-Vee parking lot on Iowa 3 about 1/2 mile E of the intersection with U.S. 169. Please note that hard hats are mandatory and you will be required to sign a liability release.

<u>Stop #1. P & M Hodges Quarry (N 1/2 Sec. 32, T-92N, R-28W).</u>

Time allotted, 3 hours.

Leave Hy-Vee parking lot, turn left (E) on Iowa 3, drive 1 mile. Turn left (N) on P56 1 mile, then E on county blacktop road. Drive 0.8 mile to the quarry entrance gate.

Access to the stratigraphic section (Fig. 3) begins in the pit W of the entrance road, and continues up section along the S quarry wall. Lateral facies variation is noteworthy, but does not obscure the overall lithic and biotic trends discussed earlier.

The basal unit indicated on the section (Fig. 3) is an unfossiliferous laminated intraclast mudstone that has been observed only in the small sump along the N wall of the W pit. The contact with the overlying grainstone is sharp but undulose.

The second unit is a fossiliferous, spar cemented oolitic grainstone containing solitary corals and numerous large gastropods. The matrix has an oolitic appearance, but closer inspection reveals that most grains are angular.

Above this grainstone is a distinctive unit with a fauna similar to that beneath. It is unique, however, in the presence of presumed algal coating surrounding essentially all fossils as well as clumps of matrix. In the W pit, these oncolitic coatings display free-form shapes, whereas in the E exposures they tend to conform more closely to the shape of the coated object.

A laterally-extensive stylolite marks the base of the thick oolitic fossiliferous cross-bedded grainstone. This unit is well cemented at the base, but becomes friable upward. It is noted for an exceptionally well preserved fauna, including 78 species of small gastropods (Harper, 1977). This unit makes up the bench level, and the small gastropods are easily freed from the friable limestone near the S wall.

Above the bench level, along the S wall, a fine oolitic grainstone overlies the friable beds. At the base it is cross-bedded, and contains several thin but continuous coral beds. About 1 meter above the coral beds, "birds-eye" structures are common, as are repeated fining-upward sequences 10 cm thick and capped with a thin micritic crust. A small thrust fault, displacement probably measurable in centimeters, can be observed near the top. Ooid concretions and laminated pisolites occur above the thrust plane. Measurements for the section were made along the S wall, but rock piles further W provide easier access.

The grainstone grades into an oolitic wackestone and then into a thin-bedded unfossiliferous mudstone at the top of the quarry. The mudstone is brecciated, and angular clasts remain undolomitized, or are partially dolomitized, within a heavily dolomitized matrix. These beds can be observed at the top of the section along the W wall. Large blocks can be examined safely in the rubble along the W wall.

Leave the quarry at 11:30 and return to Humboldt. There are several lunch possibilities along Highway 3, including the Hy-Vee Deli, Kentucky Fried Chicken, Dairy Queen and, just W of the intersection with U.S. 169, the Deuseyberger. There is an attractive park along the Des Moines River that can be reached by turning W off U.S. 169 at the first intersection S of Iowa 3.

Reassemble in the Hy-Vee parking lot at 12:30 P.M.

Stop #2. Dows Quarry (NE 1/4, Sec 30, T-91N, R-22W).

Drive E on Highway 3, 29.4 miles to the intersection of 3 and U.S. 69. Turn right (S) on 69. Drive 5 miles and turn left (E) on Iowa 72. Drive 7.9 miles to Dows. Turn left with 72 into Dows, follow it for 0.5 miles, then continue straight on S-13 for 0.5 miles to the Iowa River. Turn left on the gravel road immediately past the bridge, and drive 1.3 miles to the Dows Quarry entrance.

Rocks exposed here are considered to be, at least in part, the temporal equivalent of those at Humboldt. The lithologic succession is markedly different, however. The quarry may be nearly filled with water, and the time allocated will depend on accessibility of the section.

The lower 5 meters of section exposed here is the most heavily dolomitized (Fig. 4). It is red-brown sucrosic dolomite, with little depositional fabric preserved. Chert bands at about 2 and 4 meters preserve some small fossils, mainly ostracodes.

Floating rhombohedra occur in the mudstone unit directly above the dolomite. These rhombs, presumably originally dolomite, are now composed of ferroan calcite.

The rhynchonellid brachiopod bed occurs at about 7 meters. Large blocks along the roadway include this bed, so it can be observed if the water level is too high for *in situ* observation.

The section becomes progressively coarser grained and more oolitic near the top. Along the NW rim, large solitary corals and the gastropod *Euomphalus latus* are found embedded in an oolitic echinoderm grainstone. This facies continues around the SW rim of the quarry.

Stop #3. Weaver Construction Co. Quarry, Alden (NE, Sec. 19, and NW, Sec. 20, T-89N, R-21W.

Leave the Dows Quarry and return to the intersection with S-13. Turn left on S-13, drive 3.1 miles to where S-13 turns to the right. Follow S-13 6.8 miles to the intersection with S-25. Turn right (S) on S-25, and drive 4.8 miles to Alden. Proceed S 0.6 miles to the junction with U.S. 20. Turn left on 20 and drive 1.1 miles to the Weaver Quarry.

The location and duration of Stop 3 will depend upon earlier progress and conditions. The Weaver Quarry and a natural outcrop at Iowa Falls both allow observation of the Iowa Falls Dolomite overlain by the "Gilmore City Limestone."

At Alden and Iowa Falls, dolomite is overlain unconformably by limestone. At other locations, some workers have noted a gradational contact between the dolomite of the Iowa Falls and the Gilmore City Limestone (Thomas, 1960; Stevens, 1959; Lloyd, 1973). The succession seen at Dows is suggestive of this kind of a gradual transition, but the dolomite has been replaced almost entirely by calcite in the upper mudstones.

The limestone is a grainstone often described as an oolite. Again, as at Humboldt and Dows, the grains prove to be mostly angular clasts of micritic calcite and composite coated grains.

Proceed E on U.S. 20 to Iowa Falls if time and conditions permit.

## ACKNOWLEDGEMENTS

Many of the ideas presented in the course of the field trip originated from personnel of AMOCO Production Co., or were developed in collaboration with them. We are especially appreciative of overall support and of availability of unpublished data from A. B. Shaw (AMOCO Research). Paul

Brenckle (AMOCO Research), Leo Carpenter (AMOCO Denver Region), and Alan Kendall (AMOCO Canada) have also contributed substantially. Iowa geologic activists A. J. Gerk and C. O. Levorson shared their experience with us. Iowa Geological Survey personnel Ray Anderson and Greg Ludvigson arranged the logistics, and facilitated preparation of the Guide.

We are indebted to quarry operators who continue to indulge our profession, especially Rocky Weaver of Weaver Construction Co., Iowa Falls, and Clark Williams, Dows.

## BIBLIOGRAPHY

Carlson, K. J., 1964, Corals of the Gilmore City Limestone (Mississippan) of Iowa. Jour. Paleontology, 38:662-666.

Carter, J. L., 1972, Early Mississippian brachiopods from the Gilmore City Limestones of Iowa. Jour. Paleontology, 46:473-491.

Dunham, R. J., 1969, Vadose pisolite in the Capitan Reef (Permian), New Mexico and Texas: In Friedman, G. M., (ed.), Depositional Environments in Carbonate Rocks, Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 14, p. 182-191.

Esteban, M. C., 1976, Vadose pisolite and caliche. AAPG Bull. 60:2048-2057.

Gerk, A. J., and Levorson, C. O., in press, Unusual beach deposits in oolitic carbonate environments, Mississippian and Recent. Iowa Acad. Science, Proc.

Hager, R. C., 1981, Petrology and depositional environment of the Hampton Formation (Kinderhookian) in central Iowa. Unpub. M. S. thesis, Univ. Iowa, Iowa City, Iowa.

Harper, J. A., 1977, Gastropods of the Gilmore City Limestone (Lower Mississippian of north central Iowa. Unpub. Ph.D. dissertation, Univ. Pittsburg, Pittsburg, Pa., 317 p.

Harris, S. E. Jr., 1947, Subsurface stratigraphy of the Osage and Kinderhook Series of southeastern Iowa. Unpub. Ph.D. dissertation, Univ. Iowa, Iowa City, Iowa.

______ and Parker, M. C., 1964, Stratigraphy of the Osage Series of southern Iowa. Iowa Geol. Survey, R. I., 1, 52 p.

Hughes, J. E., 1977, Stratigraphic relationships and depositional environments of the Hampton and Gilmore City Formations, north-central Iowa. Unpub. M.S. thesis, Univ. Iowa, Iowa City, Iowa.

Koch, D. L., 1973, Mississippian stratigraphy of north-central Iowa. Iowa Acad. Science, Proc., 80:1-3.

Land, L. S., Salem, M. R. I., and Morrow, D. W., 1975, Paleohydrology of ancient dolomites: geochemical evidence. AAPG Bull. 59:1602-1625.

Laudon, L. R., 1932, The stratigraphy of the Kinderhook Series of Iowa. Iowa Geol. Survey Ann. Rept., 35:333-451.

_____, 1933, The stratigraphy and paleontology of the Gilmore City Formation of Iowa. Univ. Iowa Stud. Nat. Hist., 15:74 p.

_____, 1935, Supplemental statement on the Mississippian System in Iowa. Kan. Geol. Soc. 9th Ann. Field Conf. Guidebook, 246-247.

Lawler, S. K., 1981, Stratigraphy and petrology of the Mississippian (Kinderhookian) Chapin Limestone of Iowa. Unpub. M.S. thesis, Univ. Iowa, Iowa City, Iowa.

Lloyd, R. L., 1973, The subsurface stratigraphy of the Gilmore City Formation (Mississippian) in Iowa. Unpub. M. S. thesis, Univ. Iowa, Iowa City, Iowa.

Macbride, T. H., 1899, The geology of Humboldt County. Iowa Geol. Survey Ann. Rept., 9:113-154.

Miller, F. X., 1977, The graphic correlation method in biostratigraphy: In Concepts and Methods of Biostratigraphy, Kauffman, E. D., and Hazel, J. E., eds., Douden, Hutchinson and Ross, Inc., Stroudsburg, Penn., p. 165-186.

Moore, R. C., 1935, The Mississippian System in the upper Mississippi Valley region. Kan. Geol. Soc. 9th Ann. Field Conf. Guidebook, 239-245.

Owen, D. D., 1852, Report on the geological survey of Wisconsin, Iowa and Minnesota. Lippincott, Grambo and Co., Philadelphia, p. 90-140.

Parker, M. C., 1973, Missisippian stratigraphy of southeastern Iowa. Iowa Acad. Science, Proc. 80:4-7.

Person, J. A., 1976, Petrology and depositional environments of the Kinderhook Series of southeastern Iowa. Unpub. M.S. thesis, Univ. Iowa, Iowa City, Iowa.

Sardeson, F. W., 1902, The Carboniferous formations of Humboldt, Iowa. Am. Geologist, 30:300.

Scholle, P. A., and Kinsman, D. J. J., 1974, Aragonite and high-Mg calcite caliche from the Persian Gulf--a modern analog for the Permian of Texas and New Mexico. Jour. Sed. Pet., 44:904-916.

Shaw, A. B., 1964, Time In Stratigraphy. McGraw-Hill, New York, 365 p.

Sohn, I. G., 1979, Biostratigraphic significance of the Late Devonian and Mississippian genus Pseudoleperditia Schnieder, 1956 (Ostracoda, Crustacea). Jour. Paleontology, 53:1243-1256.

Stevens, R. L., 1959, Petrology of the Gilmore City Formation (Miss.), Iowa. Unpub. M. S. thesis, Iowa State Univ., Ames, Iowa.

Thomas, L. A., 1960, Guidebook for the Twenty-fourth annual Tri-State Geological Field Conference, Dept. Geology, Iowa State Univ., Ames, 28 p.

_____, and Williams, W. W., 1956, The Gilmore City Formation at Fort Dodge, Iowa. Iowa Acad. Science, Proc. 63:445-449.

Van Tuyl, F. M., 1925, The stratigraphy of the Mississippian formations of Iowa. Iowa Geol. Survey Ann. Rpt., 30:33-374.

Wagner, J. K., 1960, Stratigraphic studies of the Gilmore City Formation at Rutland, Iowa. Iowa Acad. Science, Proc., 67:249-252.

White, C. A., 1870, Report on the geological survey of the State of Iowa. Iowa Geol. Survey Ann. Rpt., 1:319 p.

Whitney, J. C., 1858, County geology-central and northern counties in the eastern half of the state: In Hall, James, Geology of Iowa, Volume 1, Part 1, p. 266-273.

Worthen, A. H., 1858, Geology of the Des Moines Valley: In Hall, James, Geology of Iowa, Volume 1, Part 1, p. 147-182.

Wright, V. P., 1981, Algal aragonite-encrusted pisoids from a Lower Carboniferous schizohaline lagoon. Jour. Sed. Pet., 51:479-489.