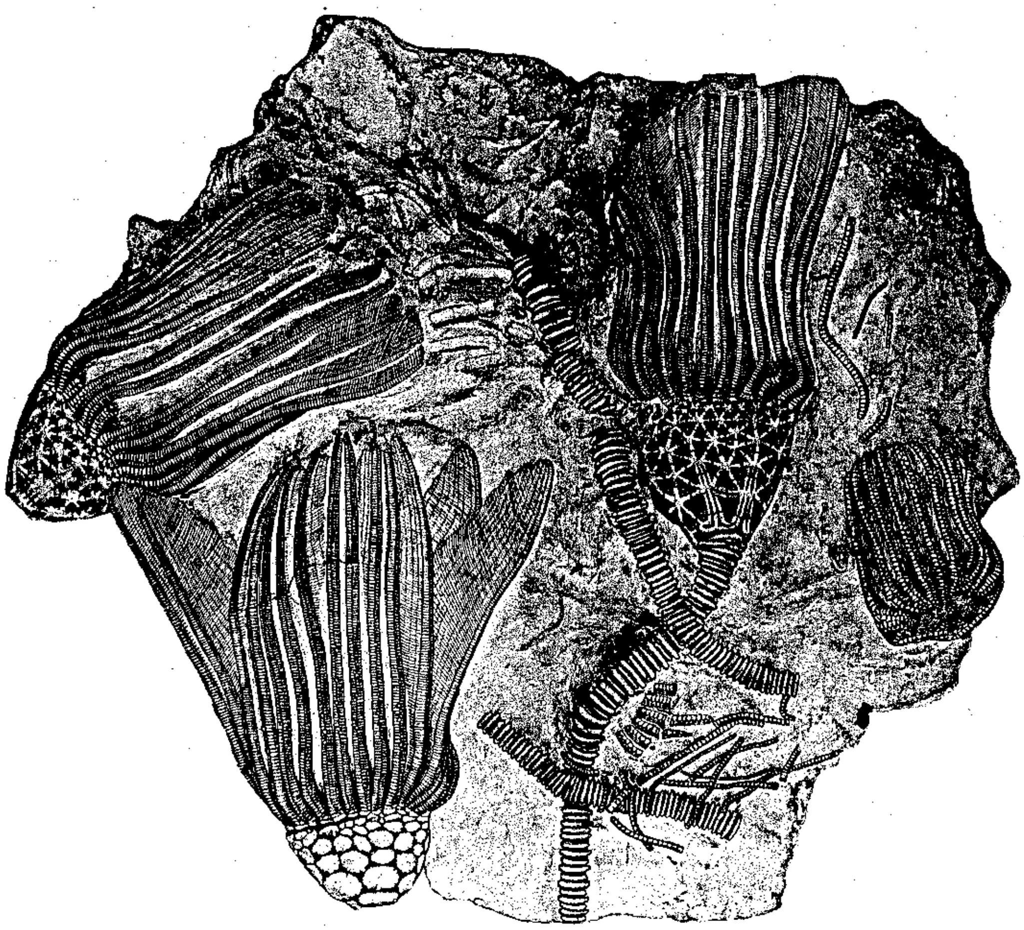
AN EXCURSION TO THE HISTORIC GILMORE CITY QUARRIES

Frederick J. Woodson



Geological Society of Iowa

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"That's what comes from cutting classes!" she exclaimed in her high lilting voice. "Do you know the story?"

"Lowell was in graduate school at Iowa City in 1929 and I was going to school at Lincoln, Nebraska. Our schedules for spring break were not the same, so Lowell cut his classes to drive to Sac City, where my parents lived. Feeling he had to justify missing classes, Lowell asked my father if there were any limestone quarries in the area; and my father being a good farmer replied, 'There are some over at Gilmore City.' So Lowell and I drove over to look around. Lowell wasn't finding much, but after a while I found a piece covered with fossils [sea urchins] and called to Lowell, 'I don't know what it is, but it's something.' We dug out some slabs and found crinoids and more sea urchins. Later that week we became engaged. And *that's* how it happened!"

Florence Laudon's recollection of the discovery of the remarkable echinoderm fauna at Gilmore City, as told to F.J. Woodson, 1988.

Cover: Drawing of slab displaying the holotype (with stem) and 2 paratypes of *Cusacrinus imperator* (Laudon), and an incomplete specimen of *Eretmocrinus tentor* Laudon (on right). Reproduced from Laudon (1933, Plate 3); 3/4 of original size. Original reposited in Department of Geology, University of Iowa, Iowa City.

An Excursion to the Historic Gilmore City Quarries

by

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INTRODUCTION

Although a number of organized geological field trips have visited Mississippian exposures in north-central Iowa [e.g., Thomas (1960), Dorheim et al.(1968), Glenister and Sixt (1982), and Glenister (1987)], this is the first to visit the renowned Gilmore City quarries. Quicklime and dimension stone production began here at least as early as 1882, and was succeeded by cement and aggregate production. The outstanding crinoid fauna was discovered in 1929, and reported by Laudon (1933). These rocks were deposited in a warm, shallow sea about 350 million years ago. Sea animals flourished at Gilmore City during the time that the sediments were deposited, and what is now Iowa was located about 20 degrees south of the Equator. The fossil remains of the marine organisms that lived in the Mississippian sea are abundant in these quarries.

ACKNOWLEDGMENTS

The writers are deeply grateful to the many people who have helped--and continue to assist--in this study. Foremost among these are Larry Moore, President of Midwest Limestone Company, and all the fine people who work with him. Their support of, not only our research, but that of dozens of serious researchers over the years, has been indispensable. Additionally, we thank Paul Brenckle, John Carter, and Gilbert Klapper for fossil identifications and biostratigraphic data. Jim Brower, Brian Glenister, Dave Gross, John Harper, Florence Laudon, Glenn Moore, Larry Moore, Paul Ressmeyer, Shirley Sixt, and Gary Webster contributed discussions and unpublished information. Jim Meyers, Wendell Dubberke, and Brian Gossman (Iowa Department of Transportation) have shared a wealth of subsurface data in the form of core descriptions, cores, and thin-sections. We thank our colleagues in the Iowa Geological Survey Bureau for critically reading the manuscript. Frederick Rogers edited the manuscript, and Jane VaLoy Olson proofread the final version. Lastly, Woodson acknowledges the help, on numerous visits to these quarries, of his faithful field assistant, Ruggo-the-Dog (November 1974--March 2, 1989).

This guidebook, the fiftieth published by the Geological Society of Iowa, is dedicated to
Lowell and Florence Laudon
Fox Bluff, Middleton, Wisconsin

A SHORT HISTORY OF THE QUARRY INDUSTRY AT GILMORE CITY

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Although the exact time and place are uncertain, the limestone industry at Gilmore City probably began about 1880 with development of a small sinkhole in the E1/2, W1/2, NW1/4, section 25, T92N, R31W. In early 1882, samples of building stone from the quarry were taken to Des Moines by a Mr. Carlson. About this time (1881 or 1882), the tracks of the Des Moines Valley Railroad reached Gilmore City.

The Pocahontas County Platbook for 1887 shows a kiln operated by Marble Valley Stone & Lime Company at the locality above and the C.J. Carlson Stone Company quarry immediately to the south. The kiln was used to heat limestone, thus producing quicklime (mortar) that could be used to "cement" blocks of native stone (building stone or dimension stone). Quicklime was also applied to the fields. Even at this early date, a spur nearly one-mile long extended from the main line of the railroad to the kiln.

The distinguished Iowa naturalist, Thomas Macbride, published a geological description of the sinkhole quarry in 1899, noting 30.5 feet of rock with lithographic limestone at the base. Marble Valley Stone & Lime still operated the quarry in 1901, but by 1906 it was owned and operated by Andrew Bull. Dimension stone was produced from an 18-foot face, but the limekiln had been abandoned and was in ruins. Quarrying was entirely by hand (using sledges, chisels, hand drills, and pry-bars) in the early years but, by 1906, was supplemented by steam-driven engines. About "870 cords" of rock were produced in 1904.

The turn of the century was a time of great change in the quarry industry, not only in Gilmore City, but throughout Iowa. The use of quicklime and native rock for construction rapidly declined as quicklime was replaced by a more durable, stronger substance--cement. The first cement plant reported in Iowa was established in Mason City by 1906. Between the years 1911 and 1917, a cement plant was constructed in the SW1/4, SW1/4, section 25 at Gilmore City. The Fort Dodge Portland Cement Company apparently owned the plant during these years and produced crushed stone from a new, larger quarry that was slightly northwest of the old quarries. Beginning in 1917, the plant, one of only four in the state, produced cement using a dry process and two rotary kilns. Cement production apparently continued until the operation was sold to the Northwestern States Portland Cement Company of Mason City on October 7, 1925. The new owners, already having a cement plant in nearby Mason City, closed the plant, using the Gilmore properties primarily as a source of cement stone. Only briefly (in 1928 and again in 1930) did Northwestern States produce cement at Gilmore City. However, crushed stone was produced until 1931, at which time operations seem to have been shut down permanently. The large cement silos were used to store materials used to make cement and, perhaps, the finished product as well. These silos were built in the years 1912-1917. In 1968, the Farmers Cooperative Company purchased the silos for grain storage; almost 800,000 bushels can be stored there.

When Laudon first visited this area (1929-1933) there were two major quarries, one belonging to Northwestern States and the other to the Pennsylvania-Dixie Cement Company. The latter firm apparently purchased 20 acres [W1/2, SW1/4, NW1/4, section 25] in the early 1920s, and developed a quarry that provided cement stone for their plant in Des Moines. Aerial photographs taken in 1940 document the location and shape of the two quarries. Both were oriented north-south and located in the W1/2, W1/2, section 25. The Penn-Dixie was located in the W1/2, SW1/4, NW1/4, only tens of feet east of the county road separating sections 25 and 26. The Northwestern States pit was slightly southeast of the Penn-Dixie. Between 1931 and 1942, there was little or no activity in these quarries.

Founded in 1942, Midwest Limestone Company acquired the Penn-Dixie quarry. Midwest marketed agricultural lime at first, but soon added roadstone and then concrete stone. About 1950, Midwest acquired the adjacent Northwestern States quarry. In 1953, after several changes in leadership, Glenn Moore, who had been with Midwest since its founding, was named president of Midwest Limestone Company, Incorporated. Aerial photographs taken in 1953 document substantial expansion since the previous aerial photos were taken, and show one large quarry. During the 1950s, much rip-rap was produced for flood control projects on the Missouri River. In 1962 Midwest built a new ready-mix plant at Gilmore City. Glenn Moore retired from Midwest in 1978, and Larry Moore was named president.

Missouri Valley Limestone Company opened a new quarry in the southwest part of section 36 in 1961. After operating the quarry for two seasons, they sold it to Hallett Construction Company, who operated it until mid-1981. Since 1981, the Hallett Quarry has been leased by Midwest Limestone, which produces roadstone, concrete stone, asphalt material, rip-rap, and ag-lime there. During 1987, Midwest built a new crushing operation in the Midwest Quarry to supply a new calcium carbonate plant also located there. Calcium Products, Incorporated, as the operation is known, began producing 99.9% pure calcium carbonate for sale to manufacturers of animal feeds. This product, called Supercal, is marketed in Iowa, Wisconsin, Nebraska, Minnesota, and Canada. Additionally, it is used to control sulphur emissions at coal-burning generating plants, as well as in the manufacture of glass, rubber, plastics, paints, and many other products.

The Gilmore City quarry industry has benefited from several factors:

1)The meteorite that created the Manson Structure also caused high-calcium limestones well below the surface to be pushed up roughly 150-200 feet. Had the meteorite not hit, little if any good quarry rock would be present at Gilmore City (see Anderson and Ludvigson, this guidebook, for more information).

2) The nearness of a railroad encouraged development by allowing the convenient and inexpensive distribution of quarry products.

3) The absence of thick, high-calcium limestones farther to the northwest in Iowa put the Gilmore City quarries in a strategic position. Indeed, the next thick limestones to the west occur in the Black Hills of South Dakota.

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LITHOSTRATIGRAPHIC FRAMEWORK OF KINDERHOOKIAN AND EARLY OSAGEAN (MISSISSIPPIAN) STRATA, NORTH-CENTRAL IOWA

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INTRODUCTION

The term Gilmore City Formation was formalized by Laudon (1933), who suggested that the unit trended southwesterly from the type area into Nebraska. Subsequent workers have applied the name to lower Mississippian oolitic, sublithographic, generally non-cherty strata in the subsurface of Nebraska (Carlson, 1963a, p. 17-18), of northwest Missouri (McQueen and Greene, 1938, p. 33; Koenig, 1966, p. 23; Thompson, 1986, p. 64), and in northeast and west Kansas (Lee, 1940, 1956; Goebel, 1968, p. 1751-1752). Collectively, these reports confirm Laudon's interpretation and, furthermore, suggest that the Gilmore City Formation represents a shoaling facies of regional extent. This magnafacies, like those reported by Lane (1978) and Lane and DeKeyser (1980), parallels the southeast side of the Transcontinental Arch, a broad, positive structure during much of the Paleozoic. The upper part of the Gilmore City Formation (cycle IIIb, this report) is interpreted to be an inner shelf conterpart of the Burlington Limestone.

Carlson (1963b, p. 34) noted granular to sublithographic, locally oolitic limestone of the "Gilmore City equivalent" on the opposite side of the Transcontinental Arch, in extreme northwest Nebraska. That occurrence, and the considerable literature detailing depositonal cycles in the Williston Basin, suggest that the type Gilmore City may eventually be correlated with cycles present in the Madison and Banff formations.

REVIEW OF PREVIOUS STRATIGRAPHIC NOMENCLATURE

This section briefly discusses pertinent Mississippian stratigraphic names that previous investigators have utilized in north-central Iowa. All except the Prospect Hill Formation are named for localities in that region. After noting the location of the type section or area, a synopsis of the physical characteristics reported at the type section by the original author is presented. Explanatory comments then follow. This review is not intended as a comprehensive statement. Except for the "St. Louis," neither the age nor the paleontology--both prominent in the work of Van Tuyl and Laudon--are considered here. The reader is encouraged to refer to Laudon's 1931 composite section (Fig. 1) and to the correlation chart (Fig. 2) for different perspectives. Unlike some correlation charts, which attempt to convey how previous workers interpreted the lithostratigraphy, this chart depicts our interpretation of where historically-significant outcrops and quarries occur stratigraphically in the Mississippian sequence.

1. *Prospect Hill Formation* (Moore, 1928, p. 22-23; Workman and Gillette, 1956, p. 30). The unit was named for exposures at Prospect Hill, near Burlington, Des Moines County, southeast Iowa. The interval consists of a thin, fossiliferous, calcareous siltstone bounded below by the McCraney and above by the Starrs Cave in the type area. The term was extended to rocks in north-central Iowa by Anderson (1969). Koch (1973) reported that the Prospect Hill ranged from a dolomitic siltstone to a silty dolomite.

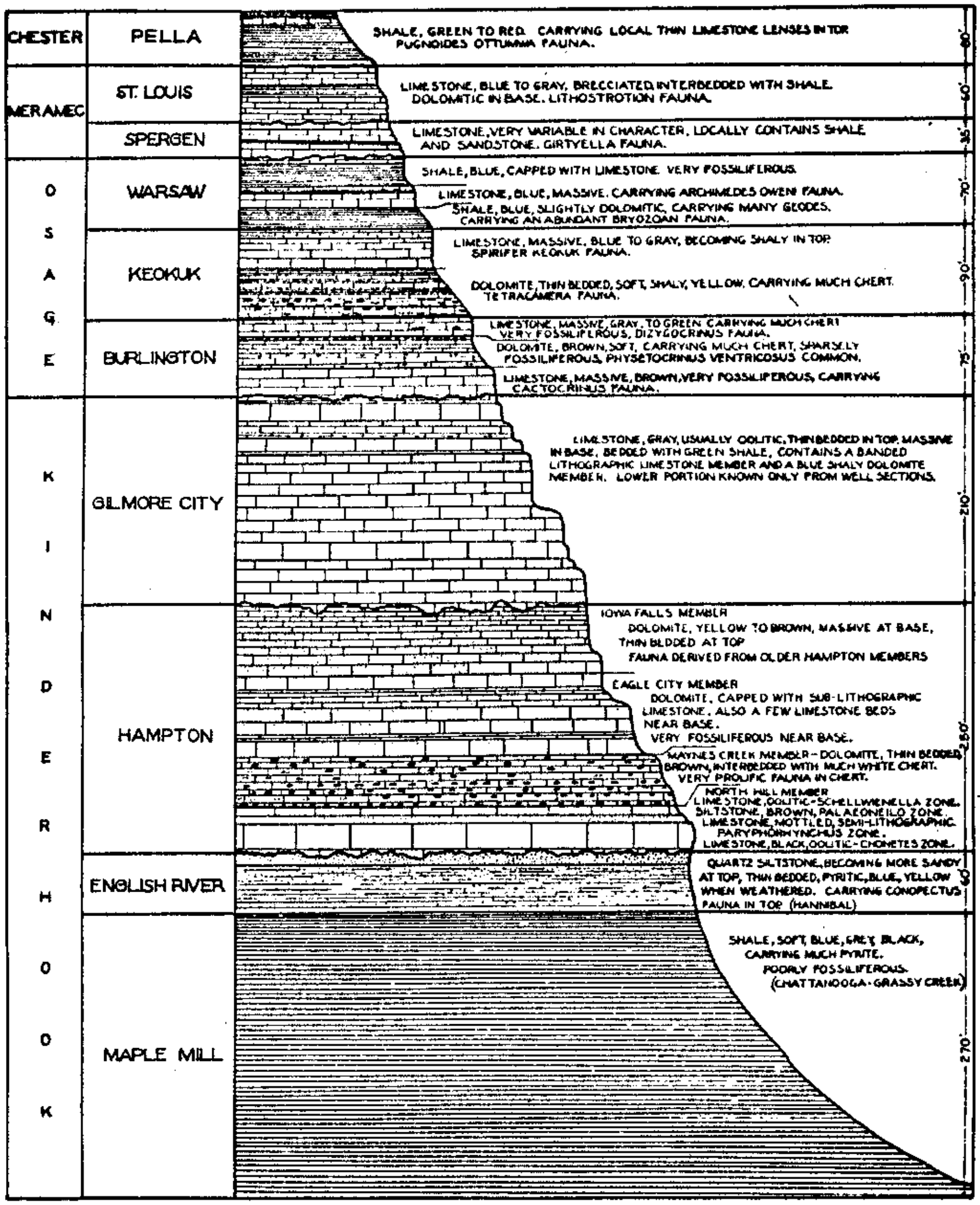
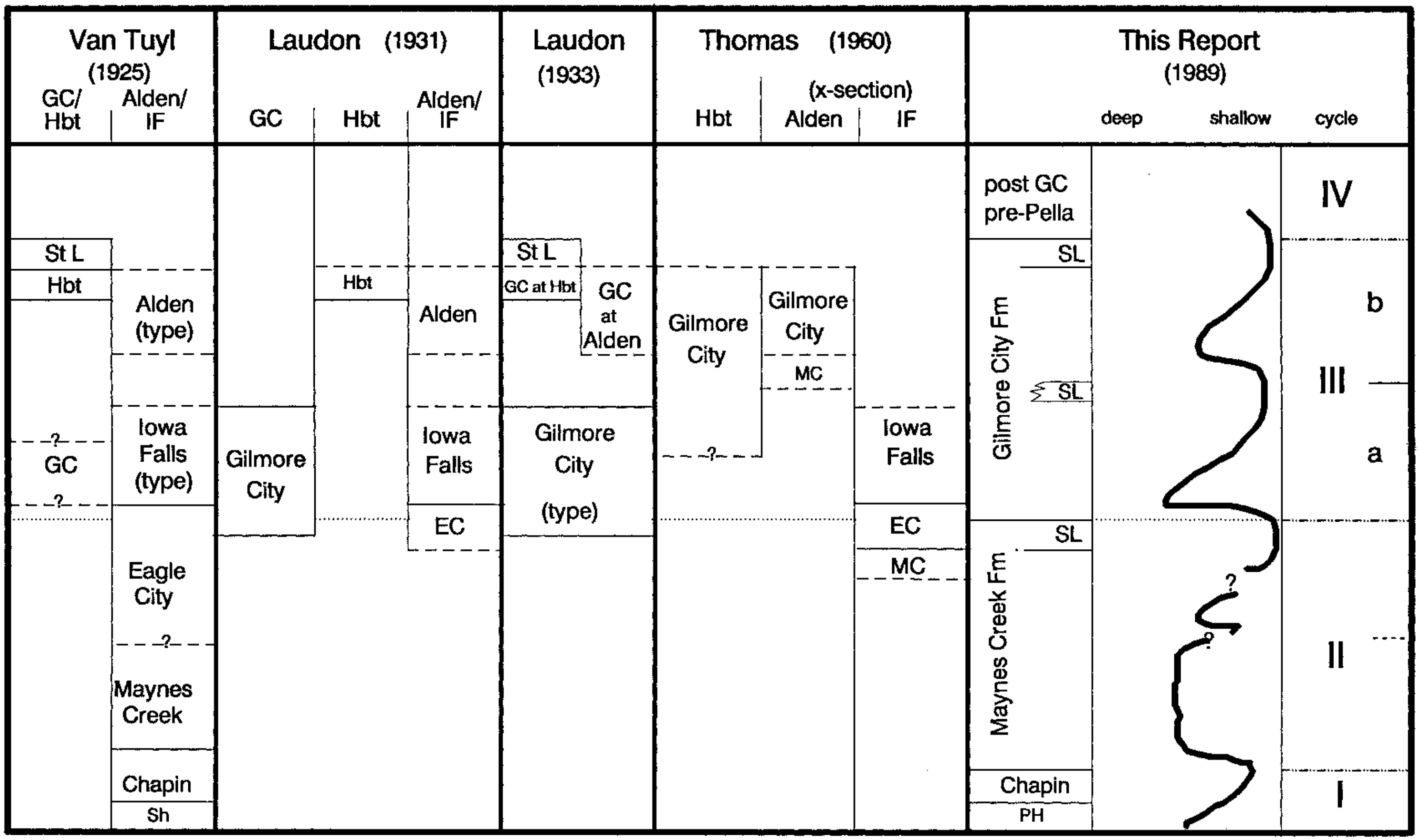


Figure 1. Composite section of the Mississippian of Iowa as interpreted by Laudon (1931, fig. 2, p. 9).

Although a single siltstone--the Prospect Hill--is present throughout most of the study area, review of subsurface data at the Iowa Geological Survey Bureau and at the Iowa Department of Transportation indicates that at least two siltstones occur in Franklin, eastern Hardin, and western Grundy counties. Therefore, the term Prospect Hill should be used with caution in these areas.

2. *Chapin beds/formation* (Van Tuyl, 1925, p. 91-93, 104-105). The type section is located in the southwest corner of section 29, T93N, R20W, Franklin County: 6.5 feet of fossiliferous crinoidal to oolitic limestone are overlain by 6.5 feet of fossiliferous "sandstone" [dolomite]. Van Tuyl designated neither upper nor lower contacts at the type section. Laudon (1931, p. 388-389, 396, 431) placed the upper contact at the top of the limestone, transferring the fossiliferous dolomites at the Chapin type section to the overlying



St L - St. Louis
GC - Gilmore City
Hbt - Humboldt
IF - Iowa Falls
EC - Eagle City
MC - Maynes Creek
PH - Prospect Hill
Sh - Sheffield
SL - sublithographic limestone

Figure 2. Chart depicting approximate relationship of outcrop and subsurface sections noted by previous workers to present interpretation of physical stratigraphy in north-central Iowa. Geographic localities shown below citation. No vertical scale. Present interpretation emphasizes depositional lithologies and cycles while largely ignoring diagenetic dolomites.

Maynes Creek. The relationship of the type Chapin to the basal oolite at LeGrand and other localities is currently under review.

3. *Mayne[s] Creek beds/formation* (Van Tuyl, 1925, p. 91-93, 105-106). The type section is located in [N1/2], NE1/4, section 21, T91N, R20W, Franklin County: 41 feet of dolomite, fossiliferous in the lower part. Van Tuyl described neither upper nor lower contacts at the type section.

As noted above, Laudon (1931) restricted the concept of the Chapin and thereby defined the lower contact of the Maynes Creek. Laudon (1931, p. 396-397) considered the Maynes Creek to be a cherty, fossiliferous dolomite, not exceeding 50 feet in thickness, and bounded above by the basal limestones of the Eagle City.

Based on the study of a core taken about a mile east of the Maynes Creek type section, Burggraf (1981) suggested that strata at the type section occur stratigraphically "higher in the Hampton section; specifically, near the base of the Iowa Falls Member, rather than below the Eagle City Member as currently understood." Burggraf's study provided the first hint that the type Maynes Creek occurs in a higher stratigraphic position than the unit Van Tuyl and Laudon considered Maynes Creek at Iowa Falls and other localities. Based upon Burgraff's report and data in the Iowa Geological Survey Bureau, an expansion of the definition of the Maynes Creek Formation is needed, and will be discussed later in this paper.

4. *Eagle City beds/formation* (Van Tuyl, 1925, p. 91, 93-94, 96). The type section is located at Eagle City [SW corner, section 31, T89N, R20W, Hardin County]; the lower 8 feet are fossiliferous and contain oolitic limestones and dolomite, and the upper 25 feet are fossiliferous dolomite. Van Tuyl designated neither upper nor lower contacts at the type section. At Iowa Falls, both Van Tuyl (1925) and Laudon (1931) noted a lithographic limestone that is overlain by an oolitic limestone containing rhynchonellid brachiopods ["*Camarotoechia subglobosa*"]. Their upper contact of the Eagle City lay between the oolitic limestone and the overlying thick dolomite--the Iowa Falls. In contrast, the formational contact between the Maynes Creek and Gilmore City *as defined in this report* lies between the unfossiliferous lithographic unit and the fossiliferous oolitic bed.

Thomas (1960, stop 5) restricted the term Eagle City to approximately 20 feet of limestone at Iowa Falls [lithographic and oolitic of above] that are "sandwiched" between cherty dolomites below and the Iowa Falls Dolomite above.

5. *Iowa Falls dolomite/formation* (Van Tuyl, 1925, p. 92, 97-98). The type area is in the gorge of the Iowa River at Iowa Falls [parts of sections 13 and 24, T89N, R21W and sections 18 and 19, T89N, R20W, Hardin County]; in the type area there are exposed at least 44 feet of dolomite, in part fossiliferous, and massive except for the highest portion, which is thin-bedded. The lower, but not the upper, contact was noted by Van Tuyl and Laudon in the type area.

6. *Alden limestone/formation* (Van Tuyl, 1925, p. 91-92, 99-100). The type area is at Alden [S1/2, section 18, T89N, R21W, Hardin County]; 32 feet of poorly fossiliferous limestone are exposed in the type area, and are thinner bedded toward the top. Neither upper nor lower contacts at Alden were reported by Van Tuyl, but he did note that the lower contact [with Iowa Falls Dolomite] was exposed nearby in the SE1/4 of section 16.

7. *Humboldt oolite*. This was an informal term of Sardeson (1902, p. 304), Van Tuyl (1925, p. 109-112), Laudon (1933, p. 6), and Zeller (1950, p. 6), all of whom applied the name to oolitic beds exposed at Humboldt.

8. *Gilmore City limestone* (Van Tuyl, 1925, p. 113-114); *Gilmore City beds* (Laudon, 1931, p. 417). Both these were informal names applied to beds exposed near Gilmore City.

9. *Gilmore City Formation* (Laudon, 1933). The type section was located in the northwest corner of the Pennsylvania-Dixie Cement Company quarry [NW1/4, NW1/4, SW1/4, NW1/4, and S1/2, SW1/4, NW1/4, NW1/4, section 25, T92N, R31W, Pocahontas County]. The quarry face exposed 57 feet of strata: sublithographic limestone near the base, crinoidal and oolitic limestones above, and thin-bedded, poorly fossiliferous limestones toward the top (Fig. 3). Laudon defined neither upper nor lower contacts at the type section. Figure 4 shows the stratigraphic sequence underlying the strata at the type area; Devonian shales (not shown) are found beneath the Prospect Hill Formation in the well cuttings.

10. *Hampton Formation* (Laudon, 1931, p. 341, 347-348, 366, 384-385, 387-388). No type section was designated. Laudon named the unit after the "city of Hampton, which is the county seat of Franklin county, in which the formation is best exposed (p. 387)." Laudon applied this name

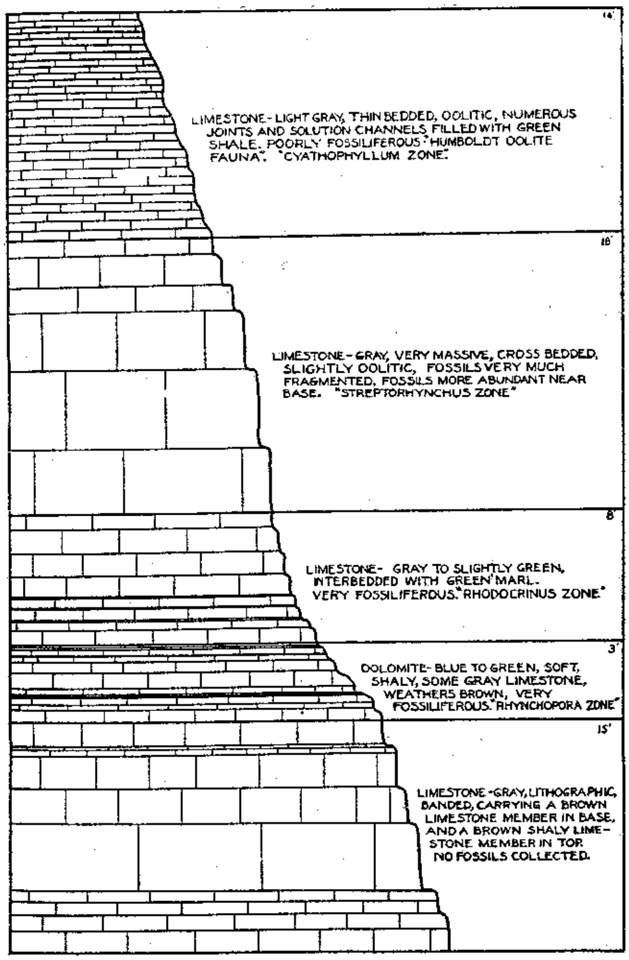


Figure 3. The type section of the Gilmore City Formation (adapted from Laudon, 1933, fig. 3, p. 11)

to strata in southeast and north-central (including LeGrand) Iowa.

In southeast Iowa, the Hampton embraced both the North Hill Member [McCraney, Prospect Hill, and Starrs Cave] and the Wassonville Member, and was bounded below by the English River Siltstone and above by the Burlington Limestone.

In north-central Iowa, strata above the Sheffield formation [the Prospect Hill of later usage] and unconformably below the Alden limestone were designated the Hampton Formation (Laudon, 1931, p. 387). The Chapin, Maynes Creek, Eagle City, and Iowa Falls members constituted the formation.

Laudon (1935) restricted the Hampton by removing the North Hill Member (in southeast Iowa) and the Chapin Member (in north-central Iowa).

Interestingly, neither Van Tuyl nor Laudon, each of whom described the LeGrand area in considerable detail, seemed eager to apply the north-central nomenclature to beds in Marshall and Tama counties. Van Tuyl (1925), following the terminology of Beyer (1897, p. 221-223), used the name LeGrand beds in Marshall County. Although Laudon (1931) initially suggested correlating parts of the Hampton at LeGrand with the Chapin, Maynes Creek, and Eagle City members, subsequent reports recognize only the Chapin [excluded from the Hampton], the overlying strata being referred to simply as the Hampton Formation or LeGrand beds (see Laudon 1935, 1957, 1973; Laudon and Beane, 1937; Laudon et al., 1952; Laudon and Severson, 1953).

Harris (1947, p. 66-68) noted that the term Hampton was preoccupied (see Wilmarth, 1938) and suggested abandonment of the name. It was his intention to replace the term Hampton with the term LeGrand, but this was never formally proposed.

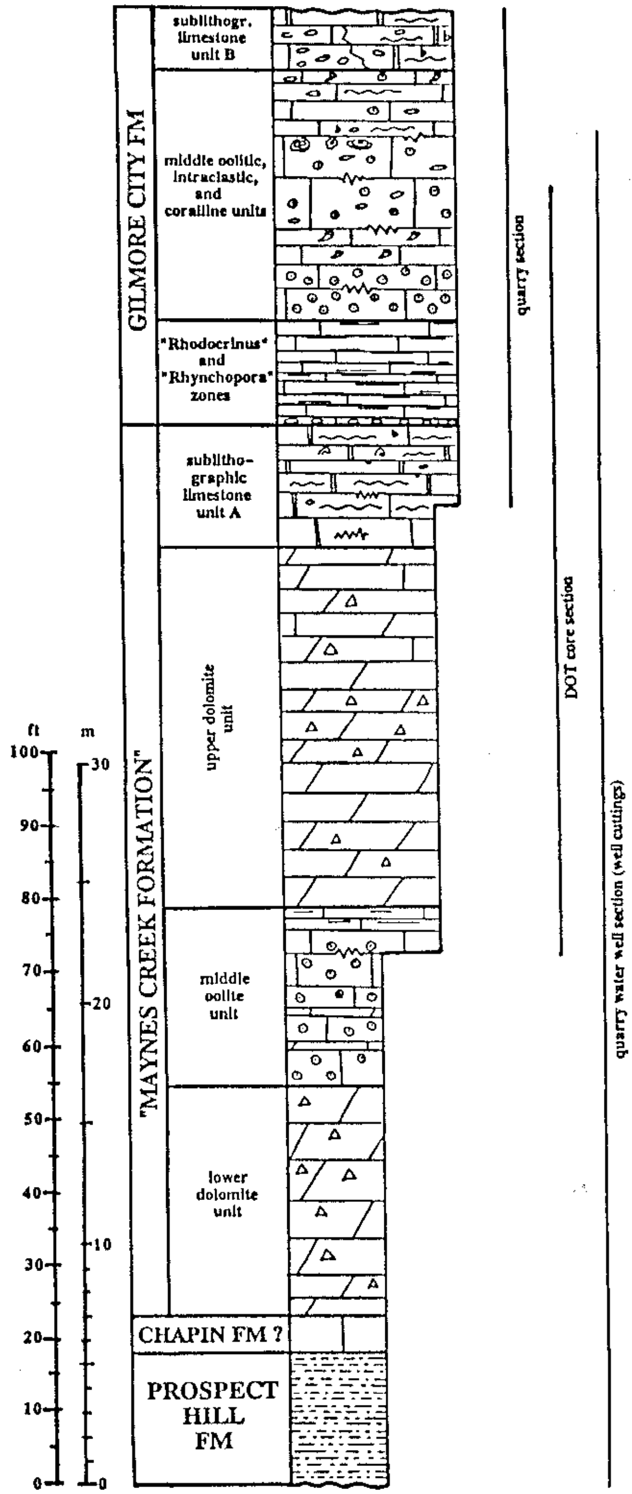


Figure 4. Composite section of the Mississippian sequence at Gilmore City, Pocahontas County, Iowa. Section compiled from the Hallett Quarry section (Stop 2), an Iowa Department of Transportation core log from the Midwest Limestone Quarry, and chip samples from the Midwest Limestone Company water well (W4980, locality 2, Fig. 5).

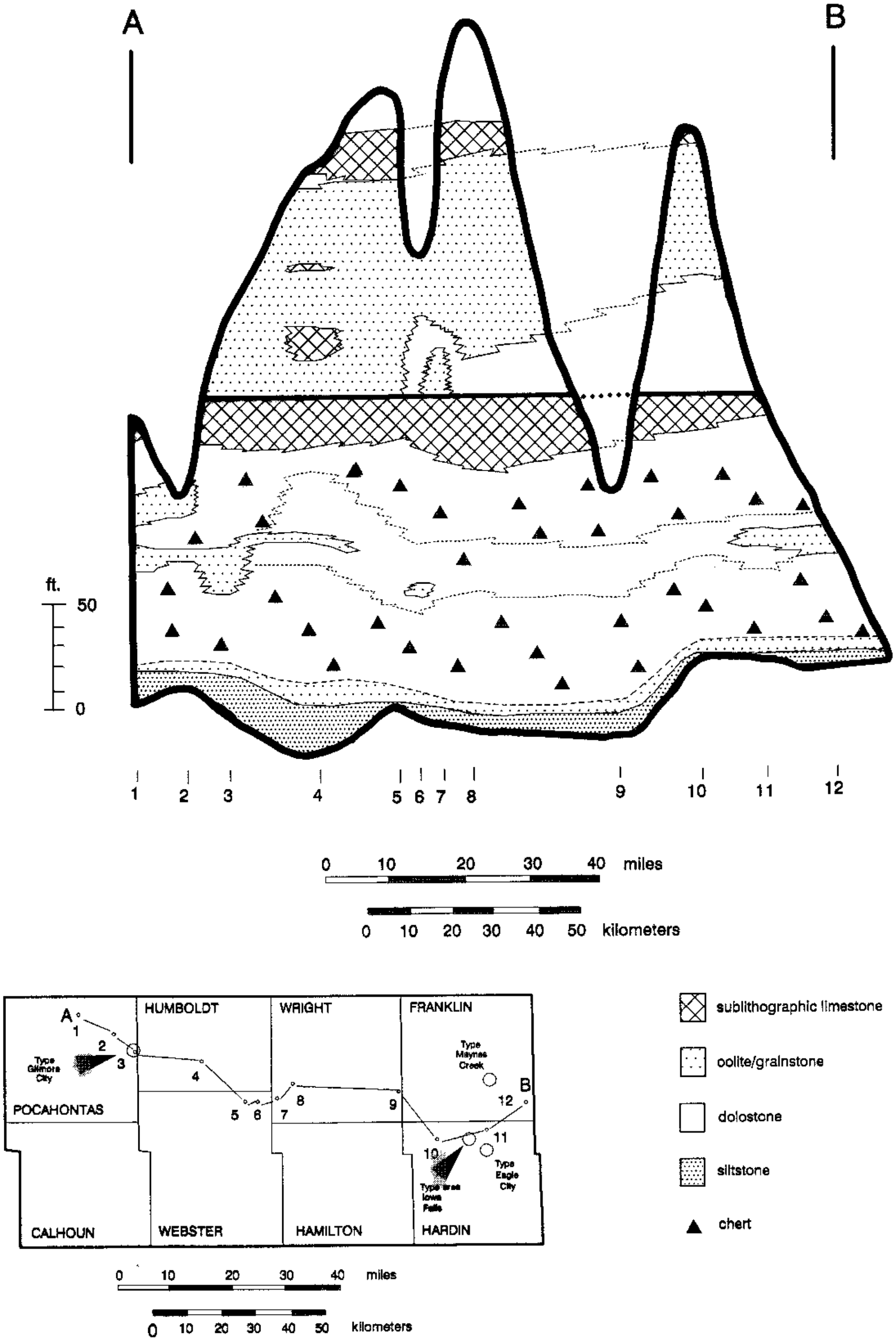


Figure 5. Generalized lithostratigraphic cross-section of the Mississippian sequence of north-central Iowa. Stratigraphic datum is the top of the "Maynes Creek Formation" as interpreted in this report. Cross-section extends from the type area of the Gilmore City Formation to the type area of the Iowa Falls Dolomite.

As initially defined by Laudon (1931), the Hampton Formation included strata representing part of cycle I, all of cycle II, and part of cycle III (see Fig. 2). Subsequent restriction of the term Hampton (Laudon, 1935) eliminated the strata of cycle I. Laudon believed that the Gilmore City occurred above the Hampton (Fig. 1), but as Figure 5 shows, the type Iowa Falls is basically a dolomitized lateral equivalent of the type Gilmore City. Also note (Fig. 5) that the thickness of the Iowa Falls Member and, consequently, the Hampton Formation, varies appreciably throughout the study area. Clearly the term Hampton is ambiguous and is of dubious utility. We believe that abandonment of this stratigraphic name is appropriate at this time.

11. *"St. Louis" limestone*. This name was *provisionally* applied to lithographic and brecciated beds overlying fossiliferous oolitic "Kinderhookian" limestones in Humboldt County by Macbride (1899, p. 127-133) and was subsequently utilized by Sardeson (1902), Beyer and Williams (1907), Beyer and Wright (1914), Van Tuyl (1925), and Laudon (1933).

Macbride apparently considered these strata to be of St. Louis age simply on the basis of lithology. However, his interpretation was reinforced by Stuart Weller's assessment of brachiopods Macbride had collected from a shaley interval [Rhynchopora zone?] in what is now part of the Midwest Quarry (see Short History of the Quarry Industry at Gilmore City, this guidebook). Weller (in Macbride, 1899, p. 132) opined, "All these forms indicate a younger age than Osage, or Augusta, as some prefer to call it, and I think they can safely be referred to the Saint Louis." Because Macbride had noted a lithographic limestone at the base of the Gilmore City quarry that produced the brachiopods, he concluded that the lithographic beds at Humboldt were the equivalent of the "very lowest beds in the Gilmore quarry, or, more likely, of beds still lower down (p. 132-133)." Thus, Macbride considered the beds at Gilmore City to be of St. Louis [Meramecian] age and to occur stratigraphically at or above the horizon of the "St. Louis" beds at Humboldt. Sardeson (1902), Van Tuyl (1925), and Laudon (1933) also noted "St. Louis" overlying the Humboldt oolite.

In fact, the brachiopods are not of St. Louis age (Carter, 1972). The "St. Louis" represents an environment that fortuitously recurs millions of years later in the genuine St. Louis Limestone, and the rocks at Gilmore City occur stratigraphically lower than the strata exposed at Humboldt (see Figs. 2, 5).

Discussion

Considering the very limited subsurface data available, the geographic distribution of quarries and outcrops, and the limited vertical extent of exposures, Van Tuyl and Laudon developed a remarkably accurate concept of the Mississippian stratigraphic succession in north-central Iowa. Because of the factors cited above, correlation was highly inferential and reliant on paleontology. The success Laudon and Van Tuyl achieved probably reflects the lateral persistence of certain lithofacies and biofacies as much as it does the biostratigraphical value of the faunas. In light of recent research relying primarily on subsurface data, however, their interpretations contain some miscorrelations which undermine the integrity and utility of a number of stratigraphic names used in north-central Iowa. A few reasons for the nomenclatural confusion are described below.

1) Stratigraphic units were defined at localities that did not display either the lower or the upper contact of the unit being named (e.g., Chapin, Maynes Creek, Eagle City, Gilmore City, and Alden). The remaining stratigraphic units display only one of the bounding contacts.

2) In areas of widely scattered exposures, dolomites were difficult to correlate paleontologically because of the generally poor preservation of fossils at these exposures. Additionally, at the time these early studies were done, dolostones were considered valid stratigraphic units. What is now considered a diagenetic front within the Gilmore City Formation (cycle III) was considered to be a major unconformity separating the "Iowa Falls Dolomite" from the the "Alden limestone" (see Fig.5, locality 10, Alden type area). Credit should go to Thomas (1960) for realizing that the "Iowa Falls" is only a dolomitized lateral equivalent of a limestone.

3) Because of the paucity of subsurface information, patently reasonable correlations were made between similar lithologies (representing similar depositional or diagenetic environments) that were in different depositional cycles. The miscorrelation of the lithographic limestone at Humboldt (end of cycle III) with the one exposed in the lowest part of the Gilmore City quarries (end of cycle II) was discussed above.

A second example is found in the cross-section of Thomas (1960) (Fig. 6). At Alden, an oolitic limestone (called Gilmore City) overlies a cherty dolomite below (called Maynes Creek) that was apparently used as the datum for construction of Thomas's cross-section. At Iowa

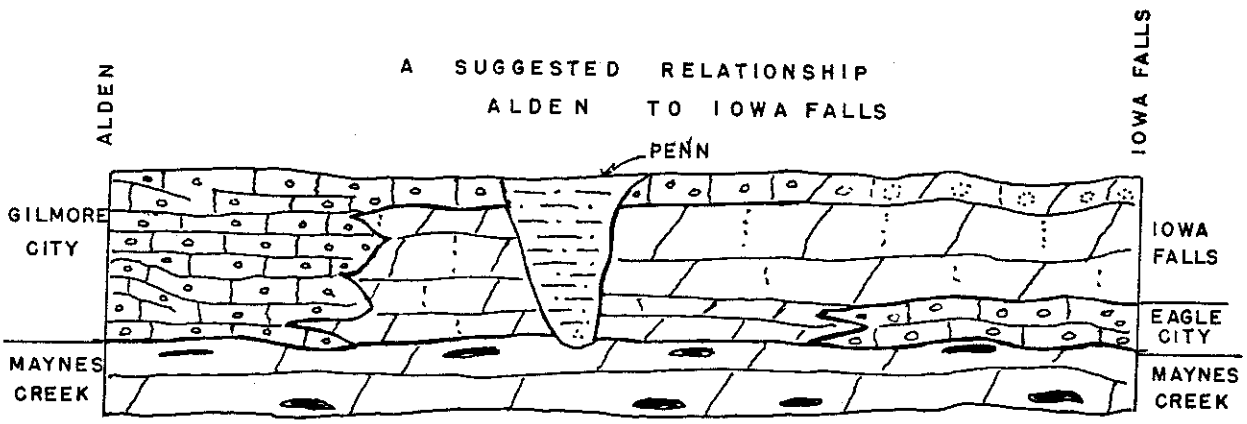


Figure 6. Interpretive cross-section of Thomas (1960), depicting the stratigraphic relationships of the Gilmore City, Iowa Falls Dolomite, and the Eagle City Limestone.

Falls, a similar relationship between lithologies exists although the names of units above the cherty dolomite are different (Eagle City and Iowa Falls). This cross-section quite clearly depicts Thomas's concept of stratigraphic relations: the Eagle City and Iowa Falls are lateral facies of the Gilmore City. But the cherty dolomite at Alden is not the same dolomite that is shown at Iowa Falls. The "Maynes Creek" at Alden is a part of the Iowa Falls as defined by Van Tuyl and Laudon (within cycle III), whereas the "Maynes Creek" at Iowa Falls is a cherty part of the Eagle City as defined by Van Tuyl and Laudon (upper part of cycle II) (see correlation chart, Fig. 2; cross-section, Fig. 5).

Conclusions

Inconsistent usage of stratigraphic terms, inadequate type sections, failure to recognize depositional cycles, and the tendency of many workers to treat dolomites as laterally-persistent units of uniform thickness have collectively created a "stratigraphic nebula" in which names obfuscate as much as they clarify, and in which objective stratigraphic relations are uncertain. We maintain that significant revision of the Mississippian stratigraphic nomenclature for north-central Iowa is a prerequisite to effective communication and to the utilization of the abundant biostratigraphic data already compiled from this area.

DEPOSITIONAL CYCLES AS THE BASIS FOR STRATIGRAPHIC CORRELATION

Marine sedimentary rocks deposited on cratonic platforms typically occur in relatively thin "packages" that are lithologically distinctive and geographically widespread. Lithologic units, in some cases individual beds, may be traced for tens to hundreds of miles in shelf deposits. The Midcontinent Shelf area--which includes Iowa--contains many of these "layer-cake" stratigraphic units. The surface over which the sediments were deposited was very nearly flat, generally sloping only 20-30 cm/km (Wilson, 1975). Because depositional surfaces were of such low relief, stratigraphic contacts within and bounding the rock units tend to be concordant to slightly undulatory, and angular unconformities are conspicuously uncommon. How, then, may such "layer-cake" strata be grouped into stratigraphic units which clarify, rather than obscure, geologic history?

In a shallow-water, cratonic setting, a discrete, laterally persistent and geographically-widespread unit implies deposition in a specific, geographically-widespread environment. Where such a rock unit is directly overlain by a series of different lithologies that are also traceable and widespread, the cause of the pattern is regional, not local, in scope. For deposits on the relatively stable craton, eustatic sea-level change is the most plausible explanation for lithotypes (environments) that repeat through time.

Heckel (1977, 1980) has recognized numerous repetitive sequences (cyclothems) in the Middle and Upper Pennsylvanian of the Midcontinent Shelf area. Although the alternation of carbonates and dark shales in these strata facilitates the recognition of depositional cycles, similar cycles may be inferred from purely carbonate sequences also. For example, in the Iowa Devonian, depositional cycles have been documented that contain thin, basal, fossiliferous marine carbonates (interpreted to be transgressive) overlain by intraclastic, laminated and brecciated subtidal to tidal-flat carbonates (interpreted to be regressive)(Witzke and Bunker, 1984; Bunker et al., 1986; Bunker, 1988; Witzke et al., 1989). Early studies of cyclic deposits of Mississippian age include Laudon and Severson (1953), Spreng (1953), Armstrong (1967), Pohl (1970), and Smith (1972).

The present study confirms the presence of depositional cycles within the Mississippian of north-central Iowa, and it is suggested that a critical review and revision of lithostratigraphic nomenclature utilized in this part of the state is needed. It is within this concept of depositional cycles that formalization of a revised stratigraphic framework for north-central Iowa is discussed.

PRESENT INTERPRETATION OF THE STRATIGRAPHIC SUCCESSION

Kinderhookian and Early Osagean rocks in north-central Iowa may be grouped into stratigraphic units that, presumably, reflect widespread eustatic transgressions and regressions of the Mississippian sea rather than the effects of local structure during Mississippian time. Like the shallow carbonate shelf sequences reported by Coogan (1972, p. 7), the depositional cycles in north-central Iowa are asymmetric, containing a thin, basal, transgressive deposit that lies in sharp contact with the beds of the preceding cycle. The balance of the sequence is regressive, grading from shallow subtidal and shoal carbonates in the lower part to increasingly peloidal lithologies in the upper part, and culminating in laminated to stromatolitic micrites. The last lithology, representing tidal-flat deposition and possibly subaerial exposure, signifies maximum regression (offlap), is quite distinctive in outcrop, cores, and well cuttings, and is laterally persistent at two horizons in north-central Iowa. For these reasons, sublithographic limestones are used as stratigraphic and structural datums in this study.

Brief descriptions of the revised stratigraphic units are given below. Additional work is needed to refine cycles I and II. Interpretations presented herein are based on examination of outcrops, cores, thin-sections, and several thousand well-cuttings logs, as well as the substantial literature.

1. Depositional cycle I consists of a dolomitic siltstone (currently considered the Prospect Hill Formation) overlain by an oolitic to biofragmental limestone (presently called Chapin). The aggregate thickness varies but is appreciably less than either of the overlying cycles. The siltstone overlies Devonian strata, typically shales, and the oolitic limestone is overlain by fossiliferous dolomites of the "Maynes Creek Formation." Because of uncertainties regarding the type Chapin and type "Maynes Creek," the most reliable exposures presently available are in the LeGrand area. Approximately 4 feet of calcareous siltstone and 15 feet of fossiliferous ooid grainstone and packstone (containing numerous large planispiral snails) are exposed at the B.L. Anderson quarry (NW1/4, section 9, T83N, R17W, Tama County). There, the base of cycle I is covered, but the contact with cycle II is well exposed. All of cycle I is present in the Northern Natural Gas Company Peterson #1 core (NW1/4, sec. 10, T90N, R27W, Webster County; locality 6, Fig. 5).

2. The "Maynes Creek Formation" (cycle II) typically consists of 110-140 feet of fossiliferous dolomites and limestones in the study area. Fossiliferous, cherty, dolomitized echinoderm wackestones and packstones characterize the lower part. Oolitic limestones overlain by fossiliferous dolomites that are less cherty than those below characterize the upper portion. The sequence is capped by a laminated, stromatolitic, sublithographic limestone showing birdseye structures. This last lithology is the stratigraphic and structural datum utilized for constructing Figures 5 and 7, and is interpreted to signify the end of a prominent depositional cycle in the region. Gross (1982) described this unit at Gilmore City, and Ressmeyer (1983) described it at Iowa Falls. The laminated micrite contains a meager fauna (ostracods, sponge spicules, and minute gastropods) associated with abundant calcispheres. The unit ranges up to 17 feet thick in places, but thins to the southeast, and is absent at LeGrand--possibly because of erosion, but more probably because a shoal lithology was deposited there in its place.

The Northern Natural Gas Company Peterson #1 core (locality 6, Fig. 5) contains the basal contact and all of cycle II but the highest few feet of sublithographic limestone. The basal contact is

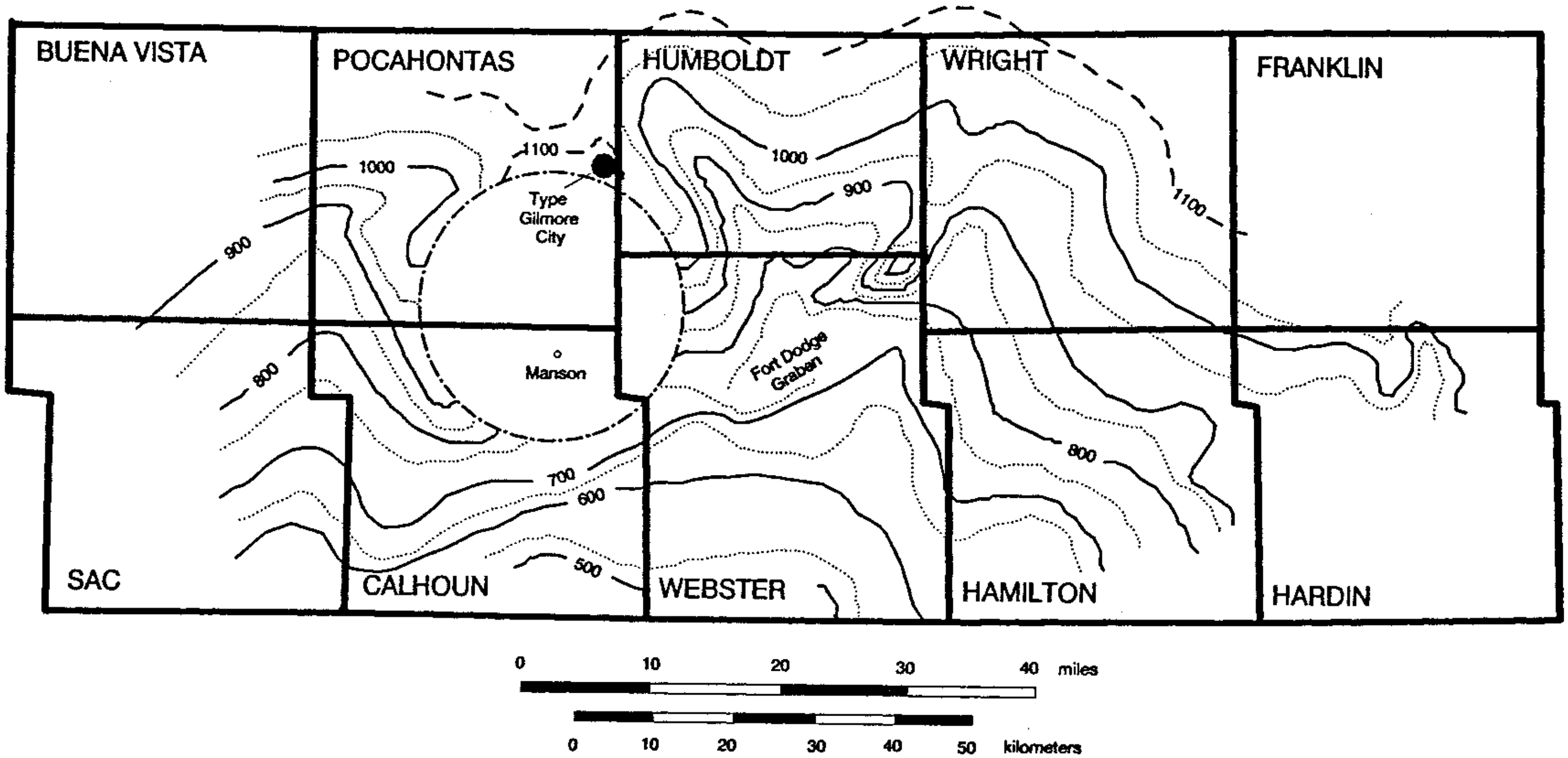


Figure 7. Structure contour map on top of the "Maynes Creek Formation," north-central Iowa. Structure contour interval is 50 ft. Location of the type Gilmore City Formation is indicated along the northeastern rim of the Manson Impact Structure. The town of Manson, after which the structure is named, is shown.

exposed near LeGrand; the upper contact is exposed at Iowa Falls and in sumps in the Midwest Limestone and Hallett quarries at Gilmore City.

3. The Gilmore City Formation (cycle III) consists of 120-140 feet of typically light-toned, peloidal, crinoidal, oolitic, oncolitic, and pisolitic limestones that are partially to completely dolomitized at some localities. Fossils, including large colonial rugosans, are abundant in the lower parts of cycles IIIa and IIIb, but less common toward the top. About 60 feet and all but the highest part of cycle IIIa are exposed in the Gilmore City quarries, whereas about 65 feet and all but the lowest part of cycle IIIb are present in the Martin Marietta (Hodges P&M) Quarry at Humboldt. The Gilmore City Formation is capped by a laminated sublithographic limestone or by a collapse breccia (Sixt, 1983) containing large clasts of laminated micrite. These rock-types occur persistently at this position. A less-persistent laminated micrite occurs about midway in the Gilmore City Formation and is exposed in the Hallett Quarry. This sublithographic unit signifies a regression of lesser magnitude (or shorter duration) than those associated with the end of cycle II and the end of cycle III.

STRUCTURE

In order to properly evaluate the shallow geologic structure in north-central Iowa, a shallow stratigraphic datum of widespread recognition was needed. Within the context of the developing stratigraphic framework for the Mississippian strata of north-central Iowa, the sublithographic limestone at the top of the "Maynes Creek Formation," marking the end of depositional cycle II (Fig. 2), has proven to be a reliable and useful structural datum for this report.

Figure 7 is a structure contour map drawn on top of the "Maynes Creek Formation." The regional structural grain shows a general northwest-southeast regional strike with southwesterly dip in the eastern part of the map area. Likewise, an east-west strike with southerly dip is noted along the north margin of the map area. Several prominent structural features disrupt this structural grain, and have been recognized in Paleozoic and Mesozoic strata across north-central Iowa by previous workers. Van Tuyl (1925) referred to an anticlinal flexure at Iowa Falls, the axis of which exposes the sublithographic unit at the top of the "Maynes Creek Formation" [sublithographic limestone near the top of the Eagle City Member of Van Tuyl (1925) and Laudon (1931)]. This anticlinal feature is shown along the eastern margin of the map area in north-central Hardin County. A similar anticlinal structure [Vincent Dome] is located in northeast Webster County, and was the subject of an exploration drilling program by Northern Natural Gas in the 1960s for possible development as an underground natural gas storage facility. Complex graben-style faulting along the west flank of the dome compromised the integrity of trapping units, and forced the abandonment of the facility (from unpublished records of the Iowa Geological Survey Bureau). Keyes (1916) presented evidence for the existence of a northeast-southwest trending fault in the vicinity of Fort Dodge. Hale (1955) further described the Fort Dodge Fault and showed that the feature includes a small graben (center of Webster County) trending ENE through the Fort Dodge well field.

All of these features are geographically coincident with the buried faults associated with the central horst of the Midcontinent Rift System, an ancient Precambrian rift zone that stretches from the Lake Superior region to north-central Kansas (Van Schmus & Hinze, 1985). The Vincent Dome and Fort Dodge Graben are associated with Phanerozoic reactivation of the Northern Boundary Fault, while the Iowa Falls Anticline is associated with the Thurman-Redfield Structural Zone (the set of shallow geologic structures recording the reactivation of the south faulted margin of the central horst).

The large prominent circular feature noted left of center on the map (Fig. 7) is the Manson Impact Structure. This structural anomaly was first recognized because of the unusual character of the local groundwater around Manson, Iowa (Norton et al., 1912). A driller's log of the Manson town well reported "granite-like rock" at a depth of 1250 ft (380 m). Later investigations determined that a large circular area of disturbed rocks existed around Manson, Iowa, with a central uplift of Precambrian crystalline rocks at its center (Hoppin and Dryden, 1958). Geologists have speculated about the origin of the Manson anomaly since its discovery in 1912 (see Hartung and Anderson, 1988, for a summary of the various theories; also Anderson and Ludvigson, this guidebook). The most recent and widely accepted theory now considers the Manson anomaly to have resulted from impact by an asteroid, which was coincident with the Cretaceous-Tertiary boundary (ibid.). The impact of this asteroid created a nearly circular feature rimmed by uplifted margins, as illustrated on the structure contour map (Fig. 7). The Gilmore City quarries are located on the northeast rim of the Manson Impact Structure. In part because of the local structural displacement of strata at the Gilmore City quarries (approximately 150-200 feet of stratigraphic displacement is indicated on the structure contour map, Fig. 7), the proper stratigraphic placement of these units has been a matter of consternation since Macbride first visited the area in the 1890's.

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TABLE 1

	Zone of Laudon		
	Rhyncho-pora	**Rhodo-crinus**	**Order**
Crinoids			
Aorocrinus iola Laudon*		X	C
Cribanocrinus watersianus (Wachsmuth and Springer) (Rhodocrinus)		X	C
wortheni (Hall) (Rhodocrinus)		X	C
Culmicrinus thomasi Laudon*		X	C
Cusacrinus imperator (Laudon*) (Cactocrinus)		X	C
Dichocrinus douglassi (Miller and Gurley) (D. bozemanensis)		X	C
multiplex Laudon*	X	X	C
Eretmocrinus tentor Laudon*		X	C
Eutaxocrinus dero Laudon*		X	F
Gilmocrinus iowensis Laudon*		X	I
Goniocrinus maximus Laudon*		X	I
Hypselocrinus douglassi (Miller and Gurley) (Decadocrinus)		X	I
Lasiocrinus expressus Laudon*		X	I
Linocrinus compactus (Laudon*) (Zeacrinus)		X	I
Paracosmetocrinus cirrifer (Laudon*) (Pachylocrinus)		X	I
fimbria (Laudon*) (Pachylocrinus)		X	I
Platycrinites cranei Strimple and McGinnis*	X		C
Rhodocrinites cavanaughi (Laudon*) (Rhodocrinus)	X		C
Rhodocrinites douglassi (Miller and Gurley) (Rhodocrinus)			C
douglassi constrictus (Laudon*)	X		C
douglassi excavatus (Laudon*)	X		C
douglassi multidactylus (Laudon*)		X	C
douglassi serpens (Laudon*)	X	X	C
Sostronocrinus superbus Strimple and McGinnis*		X	I
Strimplecrinus campto (Laudon*) (Dichocrinus)		X	C
Blastoids			
Orophocrinus conicus Wachsmuth and Springer	X		
Edrioasteroids			
Lepidodiscus laudoni (Bassler*)		X	
Echinoids			
Archaeocidaris aliquantula Kier*	X	X	
Lepidechinus cooperi Kier*	X	X	
Starfish & Ophiuroids		X	

C = Camerata I = Inadunata F = Flexibila

* type locality is at Gilmore City

THE ECHINODERM FAUNA AT GILMORE CITY

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The type Gilmore City beds are justifiably renowned for abundant, well-preserved echinoderms. Laudon (1933, p.36) commented,"Thousands of specimens of crinoids have been collected from the ledges of the *Rhynchopora* and *Rhodocrinus* zones. A large number are excellently preserved, often showing the most delicate cirri and pinnules." Well-preserved echinoids are also abundant, but specimens belonging to the remaining groups are rare.

Table 1 presents what is thought to be a taxonomically-current listing of the presently-known echinoderm fauna at Gilmore City. The stratigraphic occurrence of *Platycrinites cranei* is taken from Strimple and McGinnis (1970); the remainder of the occurrences are based on research conducted by Crossman. Taxa that have been revised since Laudon's 1933 publication have the name used by Laudon in parantheses on the right.

Laudon (1933, p. 23, 26) sent starfish from the Rhynchopora and Rhodocrinus zones to the U.S. National Museum, but these specimens were apparently never formally described. Starfish and ophiuroids collected by Crossman have been sent to Daniel Blake at the University of Illinois for description. Blake (personal communication) advises that he has an article in press describing a starfish from Gilmore City.

Of the crinoids presently known from the Gilmore City beds, all but two were reported by Laudon (1933). The remaining taxa, *Sostronocrinus superbus* (which, to date, has been found in only a single "nest") and *Platycrinites cranei* (which is represented by a single specimen) were reported by Strimple and McGinnis (1969,1970, respectively). Additional taxa, some new to science and some merely new to the Gilmore City Formation, are probably present in the fauna. For example, Laudon and Severson (1953, p. 519) reported *Hypselocrinus maccabei* (Miller and Gurley, 1894) from Gilmore City, but this form has not been illustrated from the type area.

Laudon's subspecies of the *Rhodocrinites douglassi* group have been retained but may or may not be valid taxa. A morphologic study of the *Rhodocrinites douglassi* group would be most welcome! Lastly, *Aorocrinus iola* Laudon is in need of revision. Laudon et al. (1952, p. 568) comment,"Early Kinderhookian batocrinids are identical with *Aorocrinus* except that they have a long anal tube. The presence or absence of such an anal tube is difficult to determine on specimens in which the arms are preserved." In Crossman's collections, morphologies seemingly transitional from *Aorocrinus iola* to *Eretmocrinus tentor* suggested that the two species might represent different stages of growth within a single species or, alternatively, two species within the same genus. Subsequent examination of Laudon's type material revealed that *Aorocrinus iola* had an anal tube (James Brower, personal communication, 1989). Crossman suggests that *Aorocrinus iola* Laudon (1933, p. 49) should be transferred to *Eretmocrinus* Lyon and Casseday.

Beane (1941) noted that certain colors seem characteristic of certain crinoid taxa present in the Kinderhookian LeGrand fauna. The Gilmore City crinoids also exhibit differences in pigmentation that appear to reflect taxonomic differences. However, oxidation resulting from weathering and ground water can result in colors that are misleadingly light. For example, many *Cusacrinus imperator* appear to be light colored, but specimens recovered from relatively fresh, unoxidized exposures show that its color is brownish. Much of Laudon's type material is "bleached," and this is typical in the west part of the Midwest Limestone pit.

In our experience, the pigmentation on the crinoids is lighter where the enclosing beds are also light colored. Where the strata are less oxidized, exhibiting a greyish to bluish color, the crinoids are better pigmented and display their "true colors."

The Gilmore City assemblage may be divided into groups exhibiting similar tones. Dark tones: *Rhodocrinites, Cribanocrinus, Cusacrinus, Strimplecrinus*. Medium tones: *Eretmocrinus, Dichocrinus*. Light tones: most of the inadunates, *Eutaxocrinus*.

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A SPORE ASSEMBLAGE FROM HALLETT QUARRY, GILMORE CITY, IOWA

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A sample from Hallett Quarry was collected from a karst fill within the Gilmore City Formation and analyzed for spore content to determine the age of the fill. The spore assemblage was found to be dominated by lycopsid-type spores (primarily *Lycopsida pellucida* and *Retispora staplini*) and also contains early Pennsylvanian-age spores such as *Waltzispora sagittata* and *Densosporites annulatus*. These two species, as well as *Retispora staplini*, have been identified within the Caseyville (Morrowan) and Kilbourn (Des Moinesian) formations in Iowa (Ravn, 1986). Both formations have been found to have an abundance of lycopsid-type spores, and although spore assemblages of Kilbourn coals vary greatly, none of the spores that are diagnostic of the Kilbourn Formation were found at Hallett Quarry. Also found at Hallett Quarry were *Knoxisporites semiradiatus* and a spore identified by Ravn as *Verrucosporites* sp. cf. *V. nitidus*. These two species have not been found in deposits younger than Morrowan. The abundance of *Retispora staplini* and the infrequency of saccate miosperms with gymnospermous affinities also suggest floras of Morrowan age. The assemblage is completely consistent with other Morrowan floras found in Iowa, but because previous work has not been undertaken on late Mississippian floras of Iowa or nearby regions, it cannot be ruled out at this time that the deposit may perhaps be late Mississippian in age.

Morrowan-age spores have previously been found in eastern Iowa associated with deposits from the Eastern Interior Basin of Illinois (Ravn, 1986; Nations, 1988). In Dallas County, Iowa, Ravn (1986) reported a flora resembling Caseyville assemblages. Outliers of Caseyville rocks with associated flora have also been reported from Jackson County (Ludvigson, 1988; Nations, 1988). This suggests that Morrowan-age deposits were more extensive in Iowa than has been previously recognized. Thus, Morrowan deposits may have been present further north and west in Iowa but were eroded prior to deposition of the Kilbourn Formation. Low-lying paleolandscape positions, such as the karst fill at Hallett Quarry, are most likely to have survived early Pennsylvanian, pre-Kilbourn erosion.

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QUATERNARY STRATIGRAPHY OF THE HALLETT QUARRY, GILMORE CITY, IOWA
November 1979

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A reconnaissance study was made of the Quaternary stratigraphy of the Hallett Quarry at Gilmore City in November 1979. The Quaternary sequence at that time was not well exposed, and many of the Quaternary deposits were inaccessible because of high walls in the working quarry.

Quaternary deposits in the Gilmore City area are thin, with a maximum thickness of only 3.9 m (12.8 ft) at the Hallett Quarry. All of the Quaternary units were deposited by the late Wisconsinan Des Moines Lobe glacial advance 14 to 12.5 ka. These deposits are lithostratigraphically classified as part of the Dows Formation. The sequence consists of two members of the Dows Formation which at the described section consisted of 1.6 m (5.3 ft) of uniform, massive diamicton (basal till) of the Alden Member (interpreted to have been deposited subglacially) overlain by 2.3 m (7.5 ft) of diamicton interbedded with thin, discontinuous, deformed beds of sand and silt comprising the Morgan Member (interpreted to have been deposited supraglacially). At the time of study, the Dows Formation overlay a fractured, rubbly bedrock surface, not a striated pavement. However, a small area of glacially striated pavement was noted in the northwest part of the adjacent Midwest Limestone Company quarry.

THE MANSON IMPACT STRUCTURE AND ITS EFFECT ON THE ROCKS OF THE GILMORE CITY FORMATION IN THE HALLETT AND MIDWEST LIMESTONE QUARRIES, GILMORE CITY, IOWA

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ABSTRACT

The Manson Impact Structure, with a diameter of about 22 miles, is the largest known impact structure in the United States. Centered about 3 miles north of the Calhoun County town of Manson, it was formed at the end of the Cretaceous, about 66 Ma (million years ago) when the Earth apparently collided with an asteroid. The crater is thought to be the site of an asteroid impact that was responsible, at least in part, for the extinction of up to 75% of all species of animals on Earth at the end of the Cretaceous (Alvarez et al., 1980), the dinosaurs being the best-known group of animals that died off at that time. The explosion produced by the impact of the asteroid vaporized or displaced about 225 cubic miles of rock from the crater, much of which was blown high into the upper stratosphere. Subsequent isostatic rebound, due to the removal of the rock material, uplifted the rocks immediately surrounding the crater by 200 feet or more.

The Hallett and Midwest Limestone quarries, located in Gilmore City in eastern Pocahontas County, lie about 1 mile north of the northern limits of the Manson Impact Structure. The rocks of the Gilmore City Formation exposed in these quarries were uplifted about 200 feet during the episode of isostatic adjustment that followed the impact. The azimuthal trends of a total of 90 joints were measured in the two quarries in an attempt to identify fractures that might be related to the impact shock wave or the subsequent isostatic uplift. The results of the study indicate that a well-developed fracture mode is present at the orientation that would be expected from crack propagation by radial extension about the Manson Impact Structure.

INTRODUCTION

The Manson Impact Structure, as it exists today, is a circular feature about 22 miles in diameter centered about three miles north of Manson (Fig. 1), and is developed in an area where a normal Paleozoic rock sequence (Cambrian through Pennsylvanian) and thin overlying Cretaceous fluvial clastic sequence reach a combined thickness of about 2500 feet. The Precambrian rocks in the region include about 5000 to 20,000 feet of fluvial and lacustrine clastic rocks, deposited during the formation of the Midcontinent Rift about 1 billion years ago, resting on a crystalline surface dominated by metamorphic rocks and granitic plutons. Inside the limits of the structure, the normal stratigraphic sequence has been dramatically disrupted, with large areas of down-dropped blocks preserving Cretaceous marine units that have been erosionally removed outside the crater (Fig. 2). Other areas within the Manson structure display a totally disrupted mixture of rocks of various ages and lithologies in a black or green shaley matrix. At the center of the feature, Precambrian crystalline rocks have been uplifted from their original depths of about 15,000 feet to form the present bedrock surface, about 95 feet below the land surface. The entire region was buried beneath about 100-300 feet of glacial drift deposited by several advancing ice sheets over the last 2.5 million years, and today there is no surface expression of the impact crater, the largest in the United States. The majority of present information concerning the Manson Impact Structure has been obtained by the study of rock samples saved during the drilling of about 100 water wells and three cores within the area of the structure, supplemented with information from gravity, magnetic, and seismic surveys.

ARE K-T BOUNDARY IMPACT-RELATED FRACTURES EXPOSED AT GILMORE CITY ?

One of the effects that might be expected from a major extraterrestrial impact would be the development of a set of high angle extension fractures radiating from the center of the impact site. These structures would result from the radial propagation of a high-magnitude shock wave from the site of impact. It can be safely assumed that the compressive stresses associated with such a wave had sufficient magnitudes to exceed the tensile strength of the country rocks, and that at

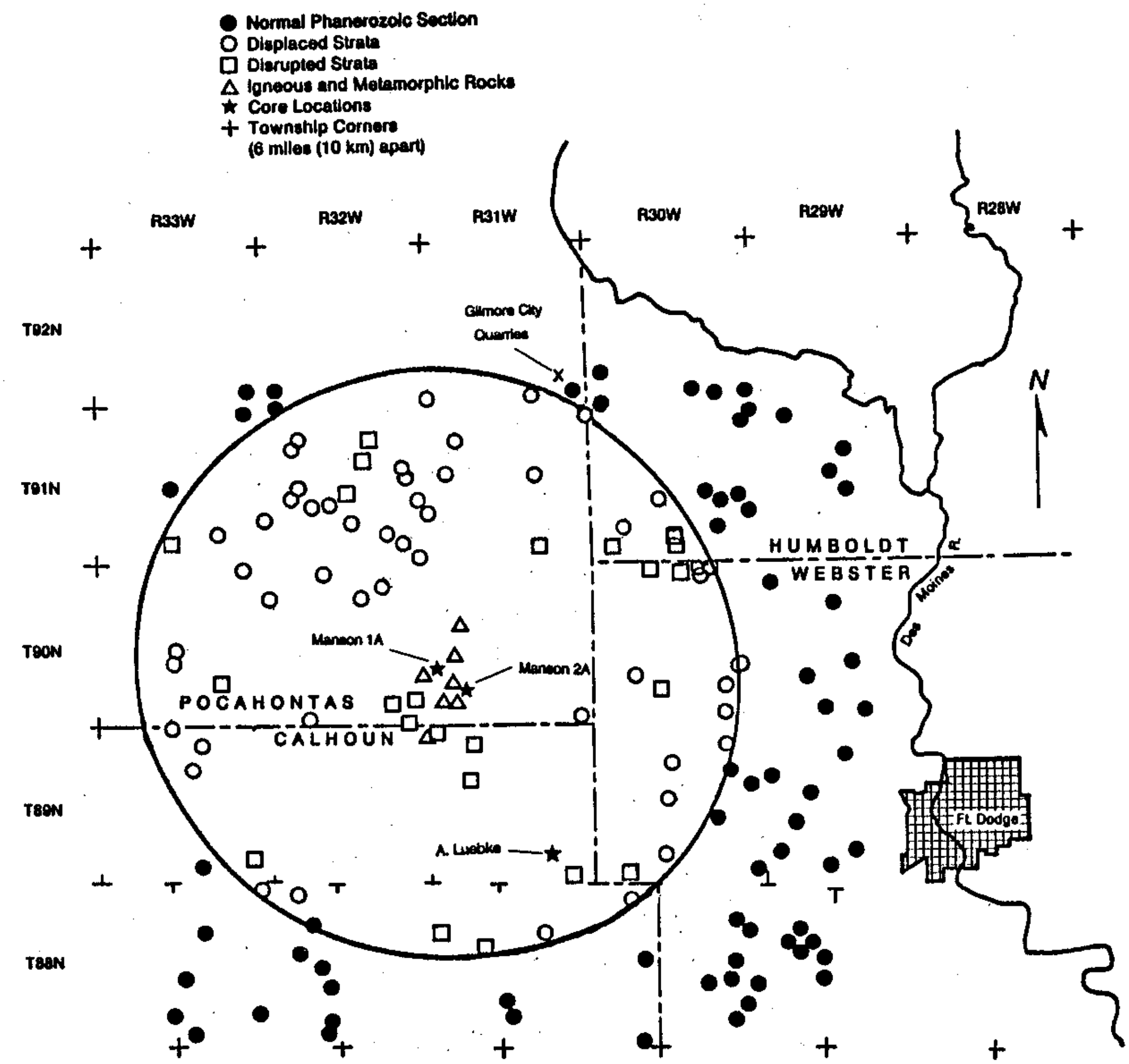

Figure 1. Map of the limits of the Manson Impact Structure, and well data.

each locality around the perimeter of the Manson Impact Structure, a set of fractures would be developed that parallels the line between that site and the center of the impact structure (Fig. 3). Bedrock exposures around the perimeter of the Manson Impact Structure are unknown except for the cluster of limestone quarries at Gilmore City. Therefore, today's field trip locality provides the opportunity to make an independent test of the now well-accepted hypothesis of extraterrestrial impact at Manson, Iowa. The radius between the center of the Manson Impact Structure and Gilmore City has an azimuth of approximately 26°. What can be learned from the quarry exposures at Gilmore City?

Recently the azimuths of 90 fractures were measured from rocks of the Gilmore City Formation exposed in the Hallett and Midwest Limestone quarries at Gilmore City. These quarries lie only about one mile north of the northern mapped limit of the Manson Impact Structure (Fig. 1) in an area that was isostatically uplifted over 200 feet shortly after the structure formed (Fig. 4). The measurements were subsequently analyzed in an attempt to identify fracture sets that might have developed in response to the formation of the impact structure.

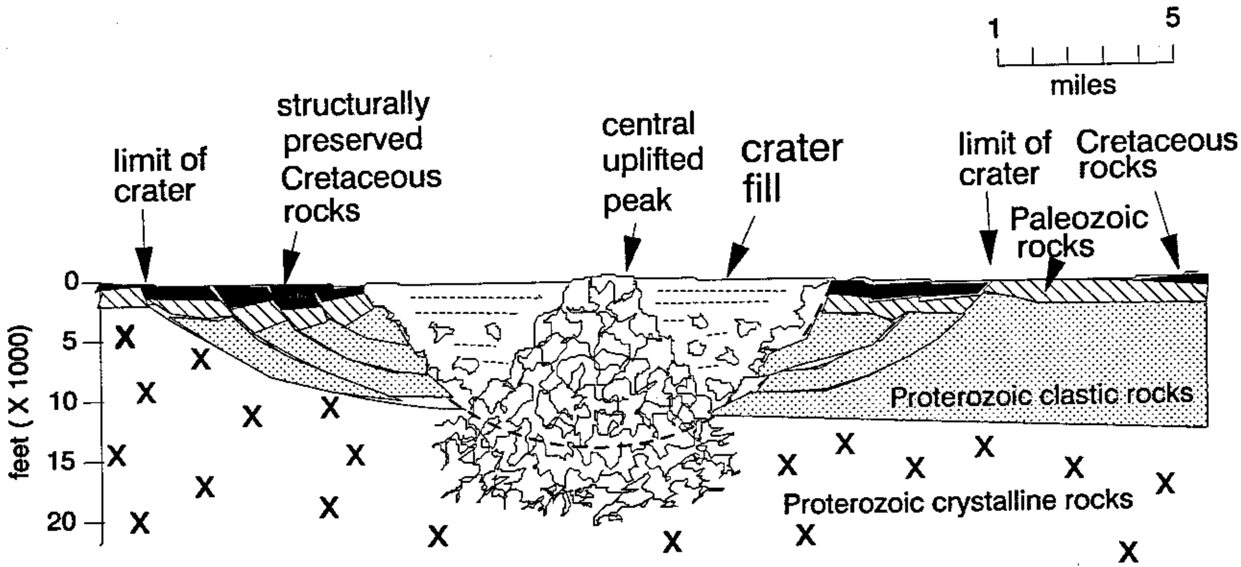

Figure 2. Interpreted cross-section of the Manson Impact Structure.

EARLY STUDIES OF THE MANSON IMPACT STRUCTURE

The area around the town of Manson has long been known to be an area of anomalous geology. The unusual nature of the rocks in this area was first noted by Norton et al. (1912), who commented on the anomalous thick shales and arkosic sandstones encountered during the drilling of the Manson Town Well #1, in a region where relatively thin shales and sandstones should overlie the Paleozoic sedimentary sequences dominated by carbonate rock. They noted that "the well at Manson is the only deep well in the state whose water was found to contain normal carbonates; the magnesium and calcium are very low, the solids being mostly alkaline chlorides and sulfates. It may be questioned whether its comparatively soft water and its alkalinity may not be due to contamination by surface water owing to faulty casing." They also noted that the driller's log from the Manson well reported "granite-like rock" at a depth of 1250 ft., a report that they dismissed, stating that "it is improbable that any deformation exists in this area sufficient to bring the floor of crystalline rocks so near the surface." It is now known that this "improbable" circumstance did occur and the granitic rocks described are the rocks of the central rebound peak of the crater.

The proximity of the edge of the disturbed zone to the limestone quarries at Gilmore City was first noted by T.H. McBride (1899) in his description of the geology of Humboldt County for the Iowa Geological Survey. He stated that "In the town of Gilmore, for instance, a similar rock in the northeast part of the village comes to the surface of the ground, while a few rods west, the town well goes down sixty feet before encountering rock at all." He attributed the disparity to pre-glacial erosion. Norton et al. (1912) noted that "In Gilmore City this limestone surface was found to drop 80 feet between two wells 150 feet apart, and other similar evidence suggests that in some locations there may be a buried limestone escarpment." Little work was done on the feature until the early 1950s when the U.S. Geological Survey Water Resources Branch in Iowa City and the Iowa Geological Survey joined forces to drill three cores in the crater (see Fig. 1 for locations). The first of the cores was drilled on the A. Luebke farm and deepened an existing farm well. The first unit cored (at a depth of 1223-1270 feet) was a red, sandy shale (now known to be Precambrian clastics about 1 billion years old). The core then passed into a Paleozoic dolomite between 1380 and 1428 feet. The anomalous juxtaposition of older Precambrian clastic rocks above younger Paleozoic dolomite is a testimony to the structural disruption within the crater.

The Manson 1-A and Manson 2-A cores were drilled in the Spring of 1955 by the U.S. Geological Survey (USGS) and the Iowa Geological Survey (IGS) about 4.75 miles northwest of Manson. The Manson 1-A hole penetrated through shales encountered at the bedrock surface and into the crystalline rocks encountered in nearby wells. However, the poorly consolidated shales prevented recovery of cored

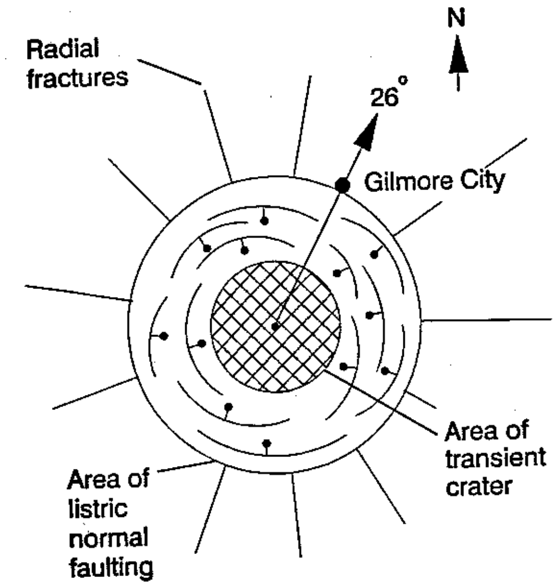

Figure 3. Idealized map of the Manson Impact Structure and radial fracture trends in the rocks around its perimeter.

material and led to the ultimate collapse of the drill hole and the abandonment of drilling at 360 feet. The recovered material is dominated by soft, black and dark gray shale of unknown age, and lesser amounts of dark gray shale (Cretaceous marine shale in part), Paleozoic limestone clasts, and other clasts of dark green siltstone, micaceous sandstone, and igneous rocks. The Manson 1-A core lies at nearly the exact center of the Manson Impact Structure as its shape is presently defined.

After the abandonment of the Manson 1-A hole, the USGS--IGS drilling crew moved to another location about 3 miles north of Manson and drilled a second core, the Manson 2-A. This core encountered brecciated igneous and metamorphic rocks on a bedrock high overlain by only 93 feet of glacial drift. The rocks of the Manson 2-A core were studied by Dryden (1955) and are described in his thesis. Within the chloritized, polymictic breccia he identified clasts of coarse- to medium-grained granite, pink to gray gneissoid granite, phyllonite, and diabase in a sandy, green clay matrix. The brecciated interval continued to about 280 feet where a series of light to dark gray gneisses, including a garnet gneiss and a magnetite-cored augen gneiss, were encountered. These gneisses are the dominant lithology to the bottom of the core at 479 feet, but frequently are cut by veins of coarse- to medium-grained granite.

Based on his study of the Manson 1-A core and examination of logs from surrounding wells within the Manson Impact Structure, Dryden (1955) concluded that the feature was a cryptovolcanic structure, with the igneous rocks of its peak at the bedrock surface in the center of the feature surrounded by a thick sequence of Cretaceous shales over a normal Paleozoic section.

This interpretation prevailed until Short (1966) reported the presence of multiple sets of planar features in quartz grains from the granites of the Manson 2-A core (Fig. 5). These planar features are known to occur in multiple intersecting sets only in rocks that have undergone shock metamorphism from meteorite impacts or nuclear bomb explosions. The presence of this style of deformation in rocks from the Manson Impact Structure is considered by most researchers as definitive evidence of an impact origin for this feature.

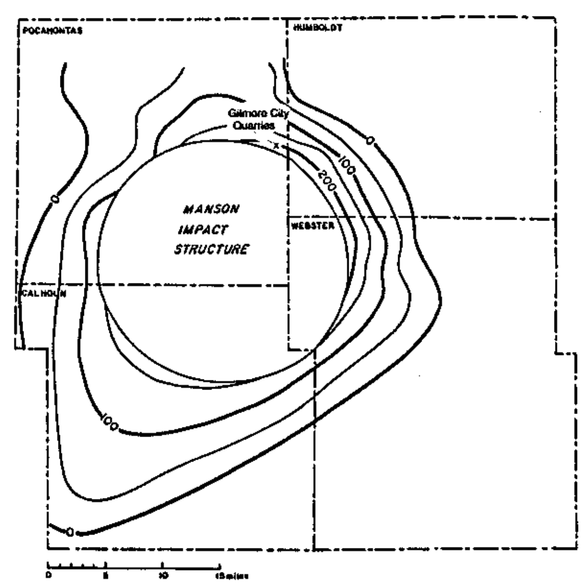

Figure 4. Structural uplift around the Manson Impact Structure.

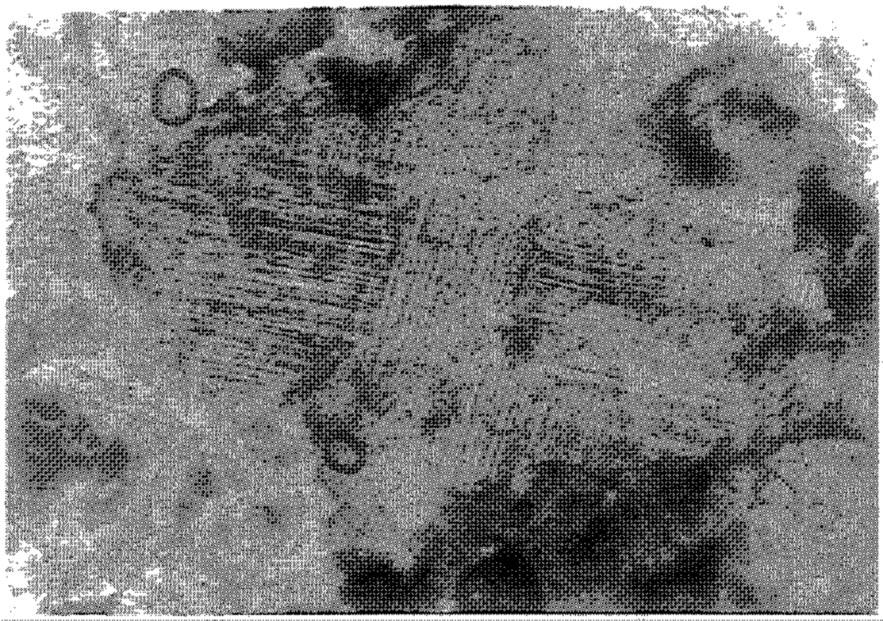

Figure 5. Photomicrograph of a quartz grain in granite recovered from the Manson 2-A core showing multiple sets of intersecting shock lamelli. The scale is about 3 mm in the long direction.

MANSON AND THE K-T BOUNDARY

A recent resurgence of interest in the Manson Impact Structure began with the publication of the work of Alvarez et al. (1980). Walter Alvarez had been working on the Cretaceous-Tertiary (K-T) boundary at exposures in Italy and Denmark. The boundary between these two systems is characterized by the extinction of as much as 75% of all species of animal life on Earth, the best known of which were the dinosaurs (see Fig. 6). Alvarez used changes in species of microfossils in the limestones above and below the boundary to locate the exact rock layers that were deposited during the K-T boundary at the time of faunal change. This boundary layer was represented by a thin (1 cm) layer of claystone, instead of the limestone that was present above and below the boundary. Alvarez concluded that the claystone represented a continuation of slow, background deposition of dust that was overwhelmed by the much greater rates of carbonate deposition above and below the boundary, but became the major source of sediment at the K-T boundary when the carbonate-generating mechanisms were temporarily shut down.

To determine the time that was represented by the deposition of the 1 cm of claystone, Alvarez and his colleagues measured the iridium concentrations in the claystone. Iridium is a platinum group element that is relatively rare on Earth but is much more abundant in extraterrestrial material. Since micro-meteorites enter the atmosphere and burn up at a relatively constant rate, the input of cosmic dust and iridium that rains down on the Earth's surface is relatively constant. Thus by knowing the rate that iridium fell to Earth in a given period of time, and by measuring the iridium concentration in the claystone, the period of time required for the deposition of the claystone could be calculated. However, when the abundance of iridium in the unit was measured, it was determined to be as much as 60 times greater than normal. This iridium anomaly was too large to be explained by slow deposition, Alvarez and his co-workers concluded that the rate of iridium deposition must have been accelerated, possibly by the impact of a large asteroid that could have provided the anomalous amounts of iridium. They estimated that the observed amounts of iridium would require an asteroid of about 6 miles in diameter, and that the impact of such an object would have created a crater about 125 miles in diameter. An impact of this scale would have blown the asteroid and a significant volume of the earth's surface materials, totalling about 4500 cubic miles, into the atmosphere. About 1000 cubic miles of this material would have ended up in the stratosphere, where it would have remained for 2-3 years. All of this dust in the atmosphere would have blocked most of the sunlight (the maximum daytime light intensity would be

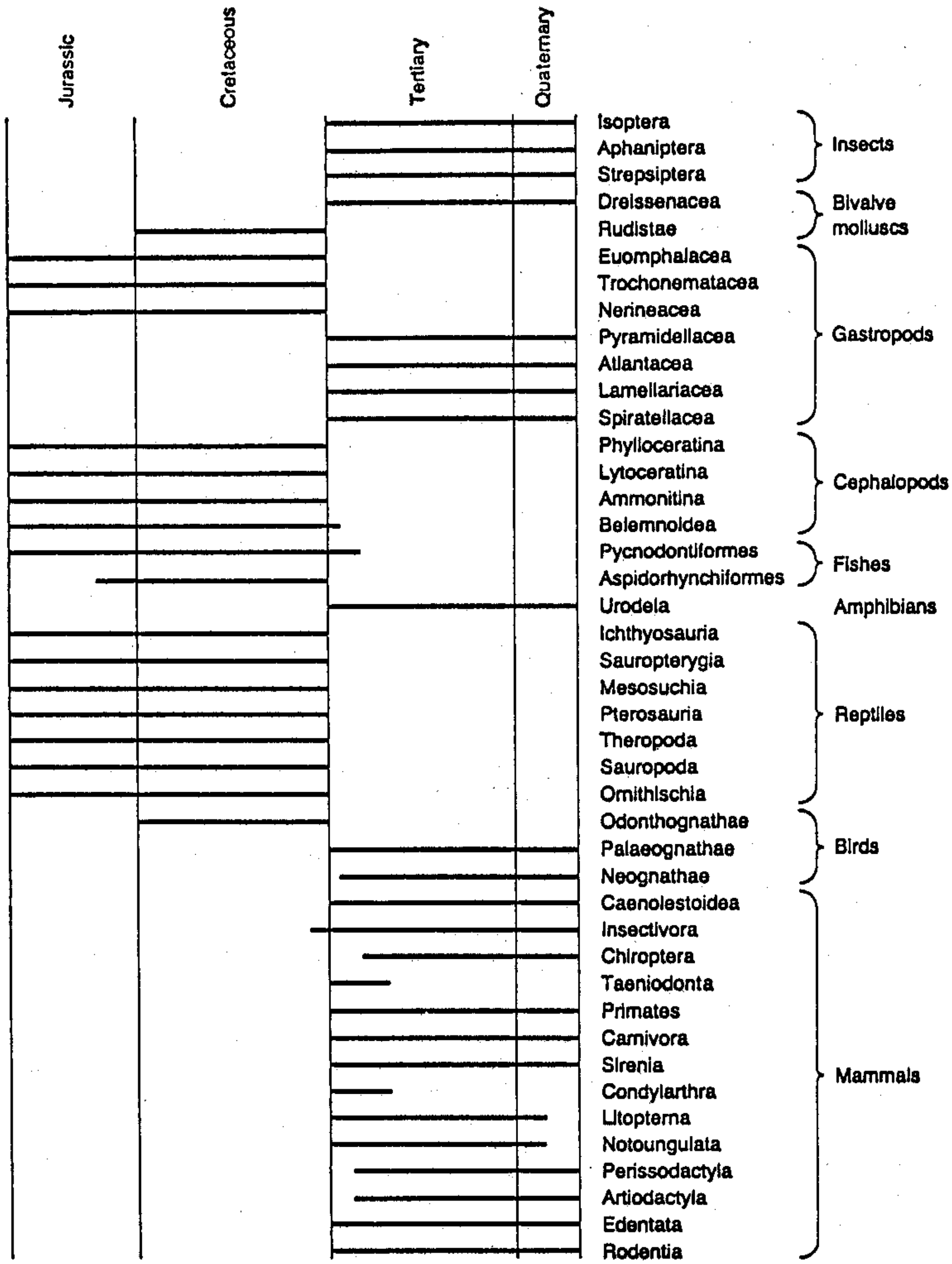

Figure 6. Chart of the extinction and appearance of selected species during the late Mesozoic and Cenozoic.

roughly equivalent to one-tenth the amount of light that reaches the Earth on a night with a full moon). They concluded that the lack of sunlight would have led to the death of photosynthetic organisms that composed the base of the food chain, thus disrupting the entire food chain, and resulting in the extinction of many organisms.

The scenario introduced by Alvarez et al. (1980) sparked immediate and intense scientific debate, and many of the details of their hypothesis are now considered questionable; however, the idea of a K-T impact has prevailed. Their work prompted the search for an impact site, but no craters of the appropriate size could be located. Investigation of K-T boundary exposures in western North America by Glen Izett (in review) of the USGS and others disclosed the presence of shock-metamorphosed quartz grains coincident with the iridium anomaly. These shocked quartz grains must have been thrown into the atmosphere by the impact blast, and since quartz is found almost exclusively on the Earth's continental crust, the impact must have been on a continent and not in an ocean basin where plate tectonic processes would probably have destroyed the evidence for it. Furthermore, the abundance and size of the shocked quartz grains in exposures from western North America are greater than those found in other exposures around the world, suggesting that the impact may be located somewhere on the North American continent (Izett, in review). NASA scientist Bevin French (1984) suggested that the Manson Impact Structure might be the site of the K-T impact, leading USGS scientists to examine samples of granite from the Manson 2-A core and to determine the age of the formation of the crater by measuring the abundance of two isotopes of argon (^{40}Ar and ^{39}Ar). They determined that the Manson crater was formed 66 million years ago, exactly the same age that they had calculated for the K-T boundary (Hartung et al., 1986). Thus it appears that the Manson Impact Structure may have formed coincident with the K-T boundary and may have been partly responsible for the extinctions that occurred at that time. The fact that the Manson Impact Structure (at 22 miles in diameter) is much smaller than the crater postulated by Alvarez and his colleagues (125 miles in diameter) might be explained by modifying the estimated impact velocity or angle of incidence, or by the suggestion of multiple craters. Other workers have suggested that the K-T boundary crater may exist in the Atlantic Ocean (Bourgeois et al., 1988), in the Indian Ocean (Hartnady, 1986), or in Siberia (Kolesnikov et al., 1988).

RECENT DEVELOPMENTS IN MANSON RESEARCH

In 1986 a group of scientists interested in the Manson structure formed MIST (the Manson Impact Study Team). This team was formed to promote and coordinate the study of the Manson Impact Structure and is composed of scientists from the USGS, NASA's Lunar and Planetary Institute, Iowa Department of Natural Resources Geological Survey Bureau (GSB), and researchers from 6 major universities. At the present time there are over 20 research projects in progress, investigating various aspects of the Manson Impact Structure and the rocks within it. These include investigations of the paleomagnetism of granitic rocks from the center of the structure, and petrographic comparison of rock and mineral grains recovered from K-T boundary exposures in the western U.S. with rocks from the Manson Impact Structure. Additional investigations are also focusing on variations in the directions of shock deformation lamellae in quartz grains from the center of the structure, and on gases contained within fluid inclusions along the lamellae.

Another study in progress by Brian Witzke (GSB) has revealed the probable presence of Late Cretaceous marine shales, including the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and the Pierre Shale, within the limits of the Manson Impact Structure. The eastern limits of the outcrop belts of these units have been eroded back to northwest Iowa, or even beyond the state's borders to north of the Sioux Ridge in South Dakota and to central Nebraska, as much as 250 miles from the Manson Structure. These shales apparently were structurally preserved during the formation of the Manson Structure at the very end of the Cretaceous, and their thickness in the Manson Structure indicates that at least 1000 feet, and perhaps as much as 1500 feet, of the rock strata of north-central Iowa have been erosionally removed since the crater's formation.

In another study, Ray Anderson and Bill Bunker (GSB) have mapped the structural configuration of a lithographic limestone at the top of the "Maynes Creek Formation" (Mississippian) in the area around the Manson Impact Structure (see fig. 4 by Woodson and Bunker, of this guidebook). This map has yielded the most accurate depiction of the limits of the Manson Impact Structure, a nearly circular feature (Fig. 1). By removing the regional structural grain that was developed in western Iowa by the formation of the Forest City Basin during the Middle Pennsylvanian, a map was created that approximates the original planar surface at the top of the sublithographic limestone unit at the top of the "Maynes Creek Formation" shortly after its deposition (Fig. 4). Anomalies on this surface define other structural activity in the area since the deposition of the "Maynes Creek Formation." The converted map clearly shows an area of structural uplift circling the Manson Impact Structure. This anomaly apparently represents structural uplift driven by isostatic forces in response to the removal of about 125 cubic miles of materials by the initial blast that formed the impact crater. This post-impact uplift and subsequent regional erosion left the Gilmore City Formation and its valuable high-calcium limestones at the surface in the Gilmore City area. This uplift is also partly responsible for a number of erroneous stratigraphic correlations (see Woodson and Bunker, this guidebook, for details).

WHAT HAPPENED AT MANSON 66 MILLION YEARS AGO?

Examination of the data and interpretations produced by the many investigations of the Manson Impact Structure, exposures of the K-T boundary, and other impact structures, have led to development of a scenario of the events that occurred near Manson, Iowa, 66 million years ago.

At the end of what is now known as the Cretaceous Period a large meteorite, probably an asteroid (Alvarez et al., 1980) about 1 to 2 miles in diameter, impacted the Earth about 4.5 miles north of the present town of Manson. The impact velocity of the asteroid and its angle of incidence are not known, but a fraction of a second after impact the asteroid exploded. This explosion apparently released about ten times the energy to all of the nuclear warheads on Earth today. This huge pulse of energy continued downward, pulverizing and vaporizing rock strata until a crater 12 miles wide and perhaps 4 miles deep was formed. The crater passed entirely through the 4,000 feet or so of Cretaceous and Paleozoic strata, the 11,000 feet of Proterozoic clastic rocks, and as much as 7,000 feet into the underlying Proterozoic crystalline basement rocks. Some of the 125 cubic miles of pulverized and vaporized rock material and asteroid were thrown great distances from the crater, but much of the material was also blown high into the upper stratosphere where it ultimately circled the Earth.

A huge crater like the one formed by the asteroid impact near Manson is gravitationally unstable and the instant it was formed lithostatic pressure and gravity were working to fill it. The lithostatic pressure released by the formation of the deep crater drove the crystalline rocks at the center of the crater upward; the central uplifted peak that was formed is similar to peaks commonly observed in large impact sites on Earth and on the Moon. At the same time, large blocks from the rim of the crater began to tumble inward or slump downward by listric normal faulting. It was this slumping that structurally preserved the Late Cretaceous marine units. The material that was transported into the stratosphere may have reflected some percentage of sunlight, but probably not as much nor for as long as estimated by Alvarez et al. (1980). The larger particles settled out of the atmosphere earliest and most abundantly nearest the impact site, depositing the shock-deformed quartz and other minerals found at K-T boundary sites around the world.

Phenomena related to the impact triggered mass extinction at this time. The blocking of sunlight by airborne impact materials may have been a contributor, but other possible killing mechanisms include acid rain, carbon dioxide, or smoke. Large volumes of nitric acid would have been produced during the disruption of the atmosphere by the passing asteroid and subsequent explosion (MacDougall, 1988). It has been estimated that world-wide rains with a pH of about 1 would have been produced by such an impact. Carbon dioxide released by the vaporization of about 40 cubic miles of Paleozoic carbonate rocks at the Manson Impact Structure could also have been a factor in the extinctions (Baur, 1988). Also, the observation of soot at K-T boundary exposures has suggested the possibility of massive forest fires ignited by the impact (Gilmour et al., 1988). Other extinction mechanisms may be indicated by further studies.

After the gravitational stabilization of the crater, it probably contained a deep lake. The region around the crater would have slowly risen as isostatic forces accommodated the mass of Earth materials lost to the blast. The crater may still have been a topographic depression when the final major Phanerozoic marine transgression deposited the Paleocene Cannonball Formation in the western Midcontinent. Following the regression of the Cannonball Sea, a prolonged period of erosion stripped away as much as 1500 feet of rock strata, removing with it all of the asteroid fragments that were "splashed" out of the crater. Neogene fluvioclastics associated with the rising Rocky Mountains also probably blanketed the area, but they too were subsequently eroded. Finally, a series of continental ice sheets advanced and retreated over the region between about 2.5 million and 12,000 years ago, completely burying the crater and preserving it as it is seen today.

FRACTURE DISTRIBUTIONS IN THE GILMORE CITY LIMESTONE

In order to evaluate possible influences of the K-T boundary impact at Manson, Iowa, on the Mississippian limestones at Gilmore City, a study was made of the natural fractures in the rocks at the Hallet and Midwest Limestone quarries. Fracture measurements in quarries pose special interpretive problems, because blasting and use of heavy equipment can create large numbers of new fractures that are unrelated to the natural fracture population. Special care must be taken to develop criteria which eliminate man-induced cracks from the measurements.

The great preponderance of natural fractures exposed in the Gilmore City quarries are high angle sets that are best studied on bedding plane exposures. All measurements were taken on bedding plane exposures in the quarry workings using a hand-held Brunton pocket transit. We avoided the measurement of quarry-related fractures by eliminating from consideration all those fractures not filled by phreatic aqueous mineral precipitates. Fracture-filling minerals include calcite spar, iron disulfides, and ferric oxides.

Since many of the best bedding plane exposures in the quarry workings are in gray, thinly-bedded, argillaceous lime mudstones, the presence of rust-colored oxidation fronts paralleling open fractures was used as a criteria to recognize natural fractures of ancient origin. These features range from a few centimeters to several meters in width, are characterized by liesegang banding, and generally are symmetric to their controlling fractures. The oxidation fronts are interpreted to result from the diffusion of dissolved oxygen through the argillaceous lime mudstones, away from fracture conduits that guided infiltration of oxidizing groundwaters from recharge at the land surface prior to quarry development. Close inspection indicates that some fractures lined by oxidation fronts contain partially-dissolved calcite cements, and that some fracture-filling ferric oxide cements are genetically related to the formation of the surrounding oxidation fronts. Special care is needed to distinguish ferric oxides that are pseudomorphic after earlier iron disulfide cements from those that are primary fillings by oxide phases. Our preliminary observations indicate that multiple generations of ancient fracturing and vein-filling are probably exposed in the workings at Gilmore City.

Other interesting map-view features of the calcite-filled fractures include the development of *en echelon* segments, and pull-apart vein geometry. All of the *en echelon* fractures we observed had right-stepping offsets. Pull-apart veins (Hancock, 1985) refer to the uneven distribution of vein-filling minerals because of small fault displacements on meandering, curved fracture surfaces. Along some segments, open fractures were closed by displacement, whereas along other segments with different angular trends, fracture dilation was increased by shear displacement. These observations indicate that high-angle fracture systems observed at Gilmore City do not all simply result from pure dilation by extensional mechanisms, but that small-scale strike-slip shearing was responsible for the formation of some fractures. While our preliminary observations do not permit comprehensive interpretation of the fracturing history of the rocks exposed at Gilmore City, it should be noted that techniques have been developed to evaluate such features (see Hancock, 1985).

Results

Measurements of 90 fractures in degrees azimuth were analyzed using ROSENET, an automated plotting program for rosenet diagrams (Williams, 1980). Plots should be interpreted with caution, because of several sources of error. These include: 1) measurement errors of approximately $\pm 5^\circ$ using a hand-held compass, 2) curvature of natural fractures, and 3) a variety of compilation procedures for counting bins in radial histograms (rosenet diagrams) which can result in the same measurement being placed in several different angular increments. For these reasons, hypothesis testing with stringent demands that fracture modes must fall within a given 10° increment are unrealistic.

Our preliminary data support the hypothesis that K-T boundary impact-related fractures are exposed in the workings at Gilmore City. Figure 7 shows a pair of rosenet diagrams, one plotting all fractures measured at Gilmore City, and another plotting only the calcite-filled fractures. Both diagrams illustrate modes in the 10° to 20° increment that are closely similar to the direction that would be expected for radial extension fractures that propagated from the extraterrestrial impact site at Manson. Lesser modes in each diagram, particularly the orthogonal sets illustrated in the data on calcite-filled fractures, are probably older fracture sets that are genetically unrelated to the K-T boundary impact at Manson.

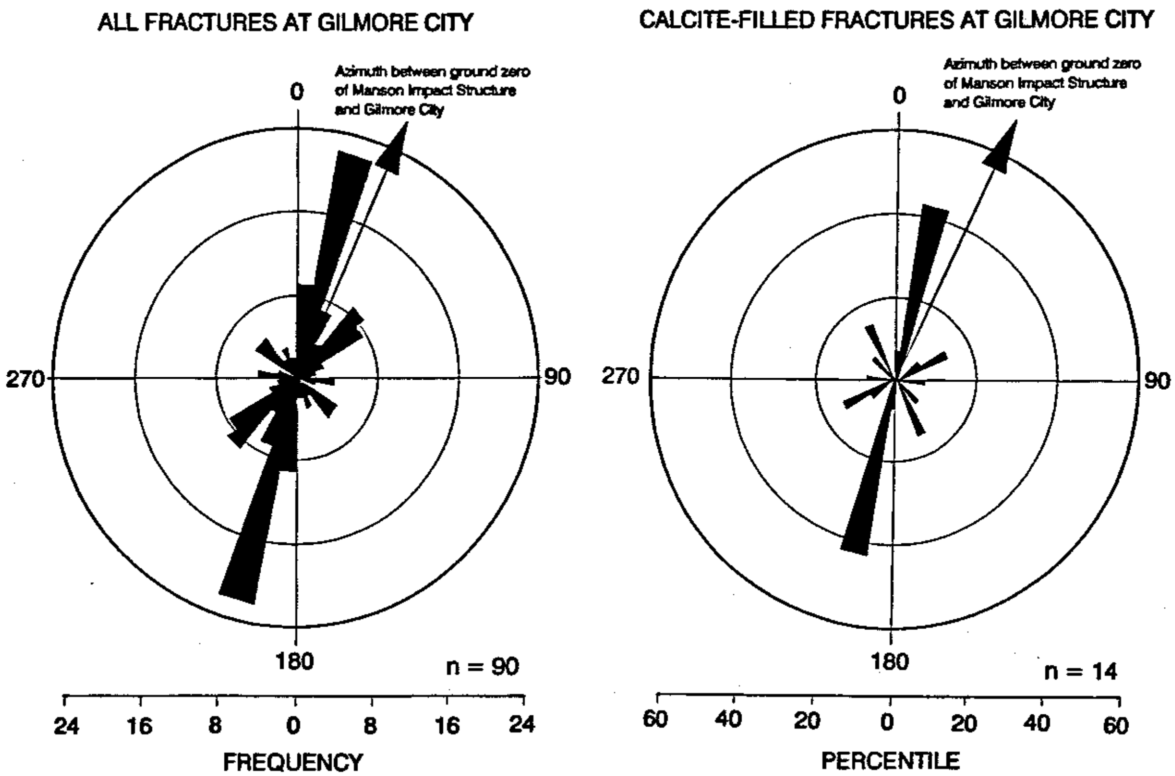

Figure 7. Rosenet diagram of all fractures and calcite-filled fractures in the quarries at Gilmore City.

Further Work Indicated

While the hypothesis of K-T boundary impact-related fracturing at Gilmore City has survived this preliminary test, further work is needed to test the idea with rigor. Detailed mapping of fractures on bedding plane exposures can be used to evaluate temporal relationships between fracture sets (Hancock, 1985). Petrographic and geochemical studies of vein-filling minerals can be used to further identify unique generations of fracturing. Calcite veinlets are especially useful in this regard, as coprecipitated minerals, cathodoluminescent petrography, carbon and oxygen isotopic ratios, and trace element chemistry can be used to characterize geochemical environments during incremental growth and healing of fractures (Ludvigson, 1988a, b, c, and d). Of particular interest is the possiblity of a transient post-impact convective hydrothermal flow system that would be characterized by calcites with depleted $\delta^{18}O$ values. Such phenomena are known from other large impact structures, notably the Siljan Ring in Sweden (Komor et al., 1988). Rocks from Manson are currently being evaluated by the research team at the University of Wisconsin. If isotopic studies confirm the existence of such a flow system at Gilmore City, fluid inclusion studies would be warranted to further evaluate the post-impact thermal history of the Manson Impact Structure.

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STOP DISCUSSION AND DESCRIPTION

STOP DISCUSSIONS

by

F.J.Woodson, B.J. Bunker, and B.J. Witzke

STOP 1

Midwest Limestone Company Quarry, Northwest part
NW1/4, NW1/4, sec. 25, T92N, R30W

This is the oldest part of the quarry and is where Laudon measured the type section. The face to the west, just below the county road, is shown on 1940 aerial photographs. From 1931 to 1942 little, if any, quarrying took place in the Penn-Dixie pit, so the west wall was probably in its present location when Laudon measured the type section here. The limekiln was to the north of us.

Consult Laudon's columnar section (Fig. 3 in Woodson and Bunker, this guidebook) and the columnar section following this page for stratigraphic orientation. Where would you place stratigraphic contacts? Is color a good guide to the stratigraphy? Are there coral-rich zones here? Are Laudon's zones primarily based on paleontology or on physical stratigraphy?

The brachiopods of the type Gilmore City (cycle IIIa) were studied by Carter (1972). At the time he collected, water prevented examination of the lowest beds. Brachiopods collected approximately one foot above the base of cycle III at this locality were identified as follows (John Carter, 1988, personal communication): *Ovatia* sp., *Eomartiniopsis rostrata, Schuchertella humboldtensis, Prospira* cf. *greenockensis, Hemiplethorhynchus subovatum, Eumetria iowensis, Punctospirifer solidirostris, Rhynchopora* sp., and *Rugosochonetes multicostus*. Carter considers this fauna to be allied with that present in the overlying Gilmore City beds, rather than with the fauna present at LeGrand (see Carter, 1971).

After examining this area, move to the east and examine the strata exposed in the northeast part of the quarry.

STOP 2

Hallett Quarry, Northeast part
NE1/4, NE1/4, sec. 36, T92N, R30W

**BE CAUTIOUS NEAR THE QUARRY WALLS,
ESPECIALLY THE HIGHWALL ON THE SOUTH SIDE.**

Most of the section on the following page was measured here. The questions posed at Stop 1 are also pertinent here. Additionally, are the strata structurally undisturbed?

Stelechophyllum microstylum [*Lithostrotionella micra* of literature] is considered a biostratigraphically useful coral (see Sando and Bamber, 1985). This coral occurs at the base of the Rhodocrinus zone and in the Streptorhynchus zone at this locality. It also occurs in strata of cycle IIIb exposed in the Martin Marietta (Hodges P&M) quarry at Humboldt.

Conodonts at this locality are uncommon to rare in the lower part of cycle IIIa (Beds 4-10), and are apparently very rare to absent in the overlying oolitic, peloidal, and oncolitic facies. Sample sizes ranged from 5 to 30 kg. Fragments and juveniles of *Siphonodella* occur with *Patrognathus andersoni* Klapper in Beds 4-10. A sample from Bed 10 contains 1 adult *Siphonodella obsoleta* in association with *Patrognathus andersoni, Polygnathus communis communis, Bispathodus* sp., and *Cudotaxis* sp. (identifications by Gilbert Klapper, 1988).

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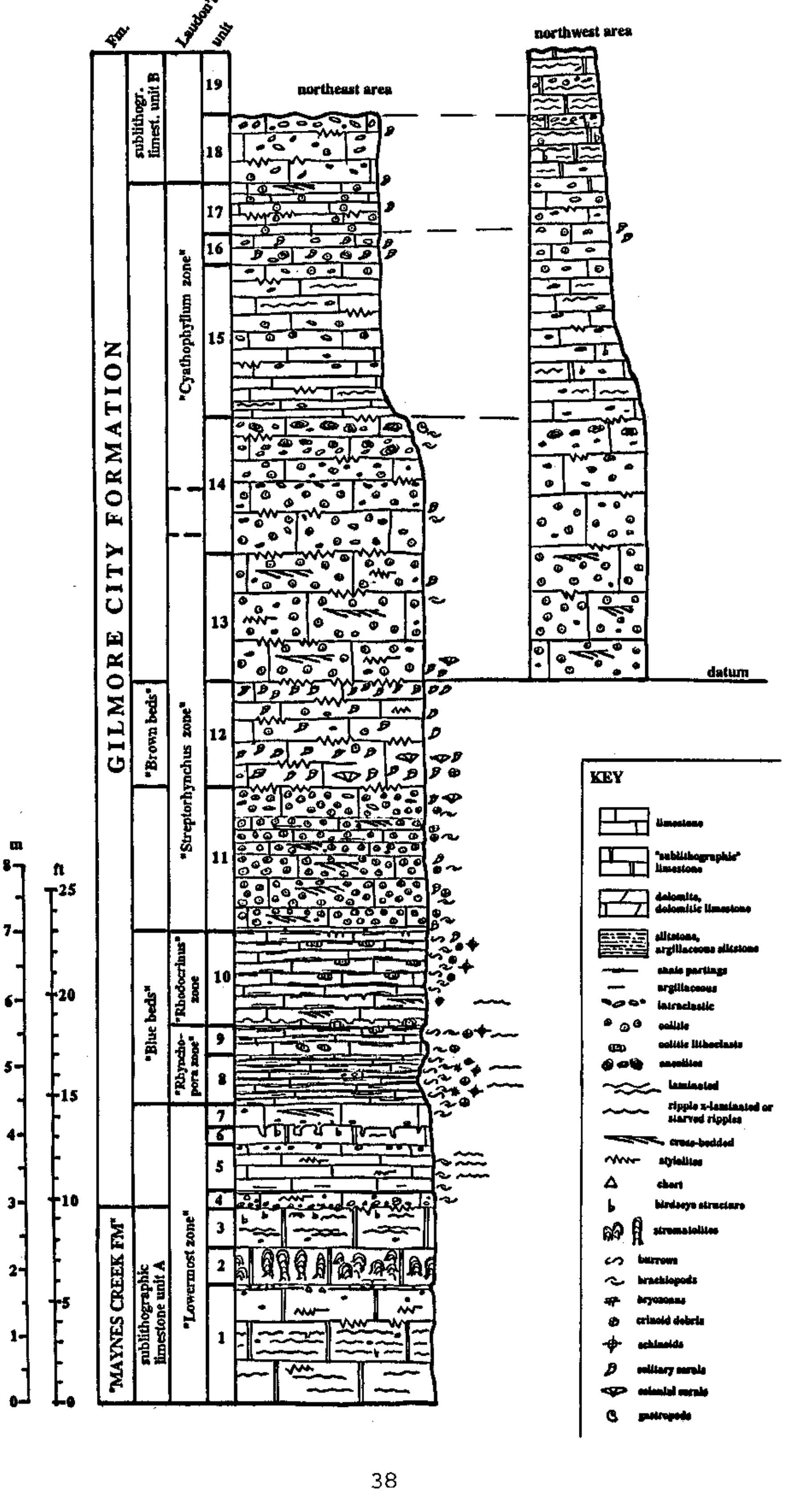
HALLETT QUARRY
GILMORE CITY, Pocahontas Co.
N1/2 NE1/4 sec. 36, T92N, R31W



GILMORE CITY, POCAHONTAS CO., IOWA
HALLETT QUARRY
N1/2 NE1/4 sec. 36, T92N, R31W

Section description by B.J. Witzke and B.J. Bunker; supplemented with additional information from F.J. Woodson and M.S. thesis of D. Gross, 1982. Units 1-18 examined in northeast quarry area; units 13-19 examined in northwest quarry area.

GILMORE CITY FORMATION

UNIT 19
Limestone, pale gray to cream, mudstone to wackestone; part sublithographic, dense, conchoidal fracture; part faintly laminated, peloidal; oolitic to intraclastic near middle, locally with flat-pebble conglomerate; birdseye structures developed in some sublithographic beds; ostracods, calcispheres present; scattered burrows; 1.0 meter.

UNIT 18
Limestone, as above in northwest area, sublithographic, dense, irregular laminae with scattered birdseye, part peloidal to intraclastic, locally with beds of intraclastic conglomerate (especially at top) and oolitic packstone to grainstone; in northeast quarry area the unit is dominated by intraclastic packstone to grainstone, local oncolites, coarsely oolitic near base, becomes more intraclastic upward (locally flat-pebble conglomerate top 40 cm), clasts are fine sand size to 10 cm diameter; common stylolites; includes abraded solitary corals; ostracod, calcisphere, gastropod, and echinoderm grains present; scattered burrows; 1.0-1.2 m.

UNIT 17
Limestone, intraclastic packstone to grainstone, part oolitic, prominent stylolites near middle; in beds 5 to 10 cm thick; northeast area is oolitic, small intraclastic, part crossbedded; northwest area is oolitic to non-oolitic; scattered to common solitary corals; ostracod, gastropod, brachiopod, echinoderm, bryozoan grains and peloids noted; 75 cm.

UNIT 16
Limestone, fine intraclastic packstone to grainstone, non-oolitic to partly oolitic, larger clasts present; scattered to common solitary corals, locally biostromal; scattered to common oncolites and oncolitic coatings around corals; basal 5 cm is coarse intraclastic packstone to conglomerate; ostracod, calcisphere, bryozoan grains and abundant peloids noted; 45-55 cm.

UNIT 15
Limestone, varied lithologies, mudstone and intraclastic wackestone lithologies interbed with intraclastic to oolitic packstone-grainstone intervals; scattered to common stylolites; base of unit forms prominent recessive interval, covered in part; some beds are dense, approaching sublithographic, part with faint irregular laminae (especially near base and upper half), birdseye structures or gypsum pseudomorphs locally seen near base (northeast) or upper half (northwest) of unit; ostracods, calcisphere, echinoderm, brachiopod, coral, gastropod grains and scattered to abundant peloids noted; 2.0-2.3 m.

UNIT 14
Limestone, oolitic to intraclastic and peloidal packstone-grainstone; in four to six beds, massive in lower part, becomes rubbly-bedded and slightly recessive in upper one-third; common stylolites; becomes less oolitic to non-oolitic upward; intraclasts throughout, clast size generally increases upward, some edge-wise conglomerates in lower part, conglomeratic to oncolitic especially in upper half, oncolites best developed in top 40 cm; solitary corals, brachiopods (?*Composita*), gastropods scattered; echinoderm, ostracod, calcisphere grains and peloids (abundant in part) noted; 2.0 m.

UNIT 13
Limestone, finely intraclastic to oolitic packstone-grainstone; in three or more beds, dense resistant unit; stylolitic, prominent stylolite at top; crossbedded in part; rare oncolites; scattered solitary and colonial corals, locally common in lower 25 cm; echinoderm, bryozoan, brachiopod, calcisphere, ostracod, foram (lower part) grains and peloids (abundant in part) noted; 1.9 m.

UNIT 12
Limestone, light to medium brown, oxidized to yellow gray, skeletal-oolitic wackestone-packstone to finely intraclastic skeletal packstone-grainstone, some beds are non-oolitic; in four or five beds separated by stylolitic surfaces; scattered to abundant solitary and colonial corals, biostromal in part, corals most abundant in lower

50-75 cm and upper 20 cm; echinoderm, brachiopod, ostracod, foram grains and sparse peloids noted; 1.5-1.65 m.

UNIT 11

Limestone, cream to buff, dominantly an oolitic and oolitic-finely intraclastic packstone-grainstone; in five to eight beds, some separated by argillaceous to thin shaley partings; prominent stylolite at top; crossbedded in part (prominently in some beds), coarser intraclasts (1-3 cm) scattered through; non-oolitic coarse crinoidal packstone-grainstone crossbeds locally present lower 70 cm; packstone-grainstones are interlaminated with laterally discontinuous dense lime mudstones (part sublithographic) 0.5 to 4 cm thick in lower 30 to 40 cm (rare to 90 cm above base), thin mudstone at base burrowed and bored in part, thin mudstone 21 cm above base locally with irregular upper surface, intraclastic; scattered to common solitary and colonial corals, brachiopod valves scattered (spiriferids, rhynchonellids, *Composita*), echinoderm grains prominent; bryozoan, ostracod, gastropod, foram grains noted; peloids present, abundant in lower part; gypsum pseudomorphs, sometimes paralleling crossbedding common in lower part; 1.8-2.2 m.

UNIT 10

Limestone, blue-gray to light gray or buff when unoxidized, skeletal wackestone-packstone and mudstone-wackestone, argillaceous in part; in about fifteen beds, wavy in part, separated by thin shales or shaley partings (with quartz silt); basal 23 cm in one bed, fine skeletal packstone, calcite-filled voids scattered, low-angle crossbeds and current laminae developed, irregular surface 3-7 cm above base (hardground-like with overhanging edges); interval 15 to 60 cm above base has scattered thin interlaminated lime mudstones (one 40 cm above base has bored upper surface); scattered starved megaripple cross-laminae, megaripple bedform 25 cm above base 8 cm high x 80 cm wide; some packstones form graded beds; locally interbedded with thin oolitic packstone 16 cm below top; scattered to common, irregularly-shaped to nodular oolitic lithoclasts (to 15 cm diameter), especially in upper half; argillaceous bedding surfaces with prominent horizontal burrows in part, trace fossils well preserved; skeletal fossils common to abundant along some bedding surfaces, well preserved, semi-articulated to articulated crinoids and echinoids locally noteworthy (see other discussion for identity), scattered to abundant brachiopods (see other discussion for identity), solitary corals and bryozoans present; fine intraclasts and peloids noted; 1.35 m.

UNIT 9

Limestone, blue-gray to light gray when unoxidized; lower 20 cm is single resistant marker bed flanked by more recessive beds, skeletal packstone with scattered to common intraclasts and oolitic lithoclasts, bioturbated; upper 23 cm is argillaceous thinly-bedded skeletal wackestone and packstone separated by thin shale partings (with quartz silt), some graded beds and possible starved ripple bedforms noted, oolitic lithoclasts locally present (as above); some shaley bedding surfaces with well-preserved horizontal burrows, some bedding surfaces with articulated to semi-articulated echinoderms; brachiopod, bryozoan, echinoderm fossils (see other discussion for identifications); peloids scattered to common; 43 cm.

UNIT 8

Limestone, blue-gray to light gray, argillaceous skeletal mudstone-wackestone and packstone, in beds 2 to 15 cm separated by thin shales and shaley partings (with quartz silt); recessive interval, shaliest in middle part (where limestone beds 1-3 cm thick); horizontal current laminae in some beds, starved ripples noted in middle part (to 5 cm thick, graded, with small intraclasts 1-5 mm at base of bed); some shaley bedding surfaces with common horizontal burrows, trace fossils well preserved; other bedding surfaces display scattered to common skeletal fossils; disarticulated to semi-articulated and articulated crinoids and echinoids noted; brachiopods common, rhynchonellids, spiriferids, strophomenids, *Composita*; fenestellid bryozoans, rare trilobites; peloidal in part; 75 cm.

UNIT 7

Limestone, fine skeletal to peloidal packstone-grainstone, welded onto underlying unit, irregular surface at base with scattered sublithographic limestone lithoclasts (to 4 cm), rare lithoclasts above; unit displays horizontal current laminae and some low-angle crossbeds (6-7 cm high); shale parting at top; *Composita*, rhynchonellid, spiriferid, strophomenid brachiopods present; echinoderm grains noted; 31 cm.

UNIT 6

Limestone, dense, sublithographic in part, lithologic breaks or discontinuities 2 and 19 cm above base; top surface highly irregular (1-10 cm relief), locally burrowed or bored (hardground?); infilling of unit 7 lithologies noted up to 20 cm below top, infilling sediment may include quartz silt; top 8 cm faintly and irregularly laminated, in part with birdseye structures; 27 cm.

UNIT 5

Limestone, fine skeletal to peloidal packstone-grainstone, in four to six beds, scattered stylolites; faint horizontal current laminae, some ripple cross-laminae (2 cm high ripples); top 7 cm is very intraclastic (clasts 1-5 mm), finer-grained mudstone-wackestone; thin shale parting 5 cm above base and at top (2-3 mm); scattered brachiopod valves; echinoderm, bryozoan, ostracod grains noted; 70 cm.

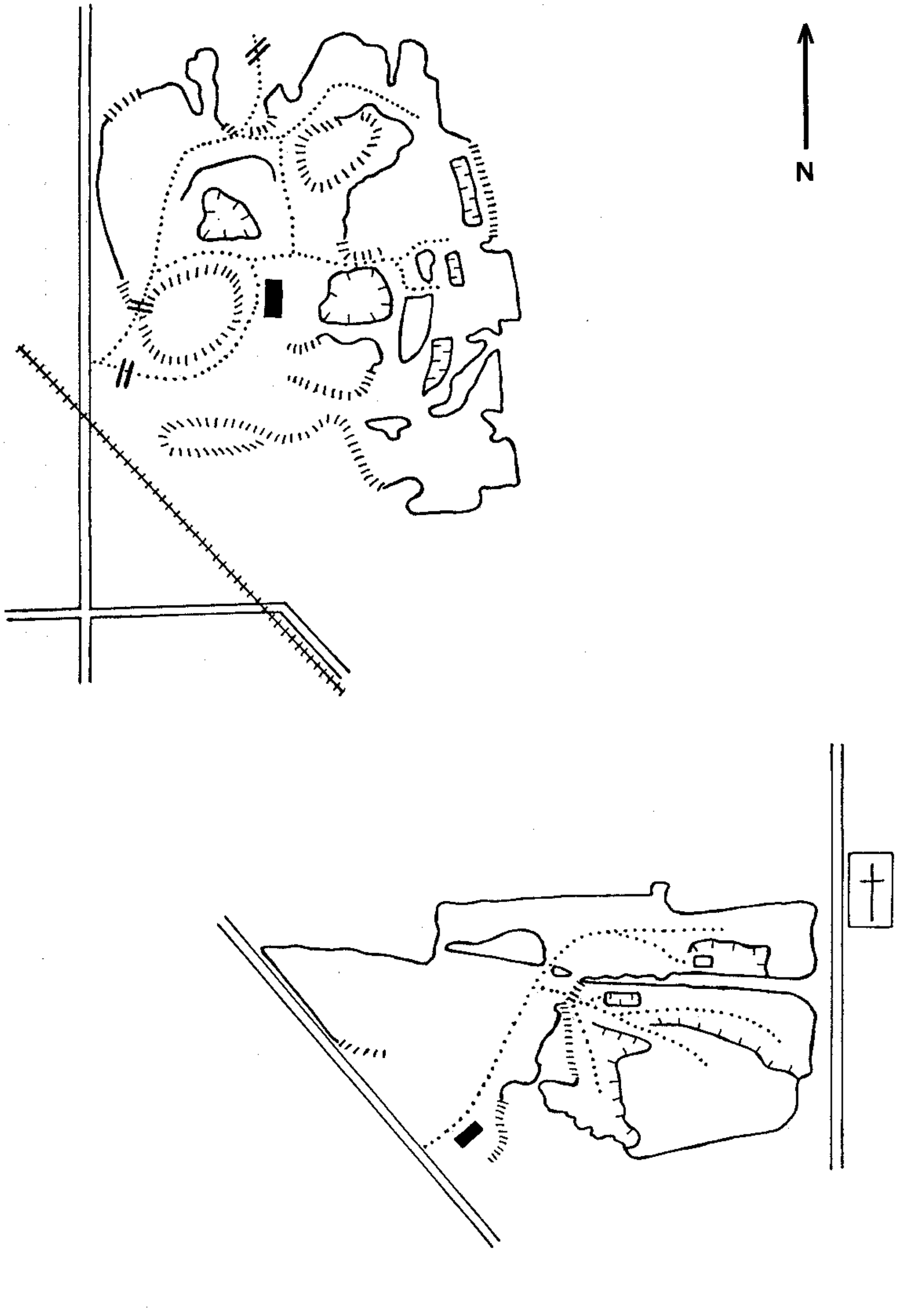
UNIT 4
Limestone, packstone-grainstone as above, one bed, stylolite near middle; lower 5-10 cm is conglomeratic with abundant lithoclasts of dense sublithographic limestone (derived from underlying unit 3), clasts scattered above, clasts range from 1 mm to 15 cm diameter; 2 cm shale at top; 2 cm relief at base; macrofossils include brachiopods (rhynchonellids, strophomenids) and rare tabulate corals; echinoderm, bryozoan, ostracod grains noted; 27 cm.

"MAYNES CREEK FORMATION"

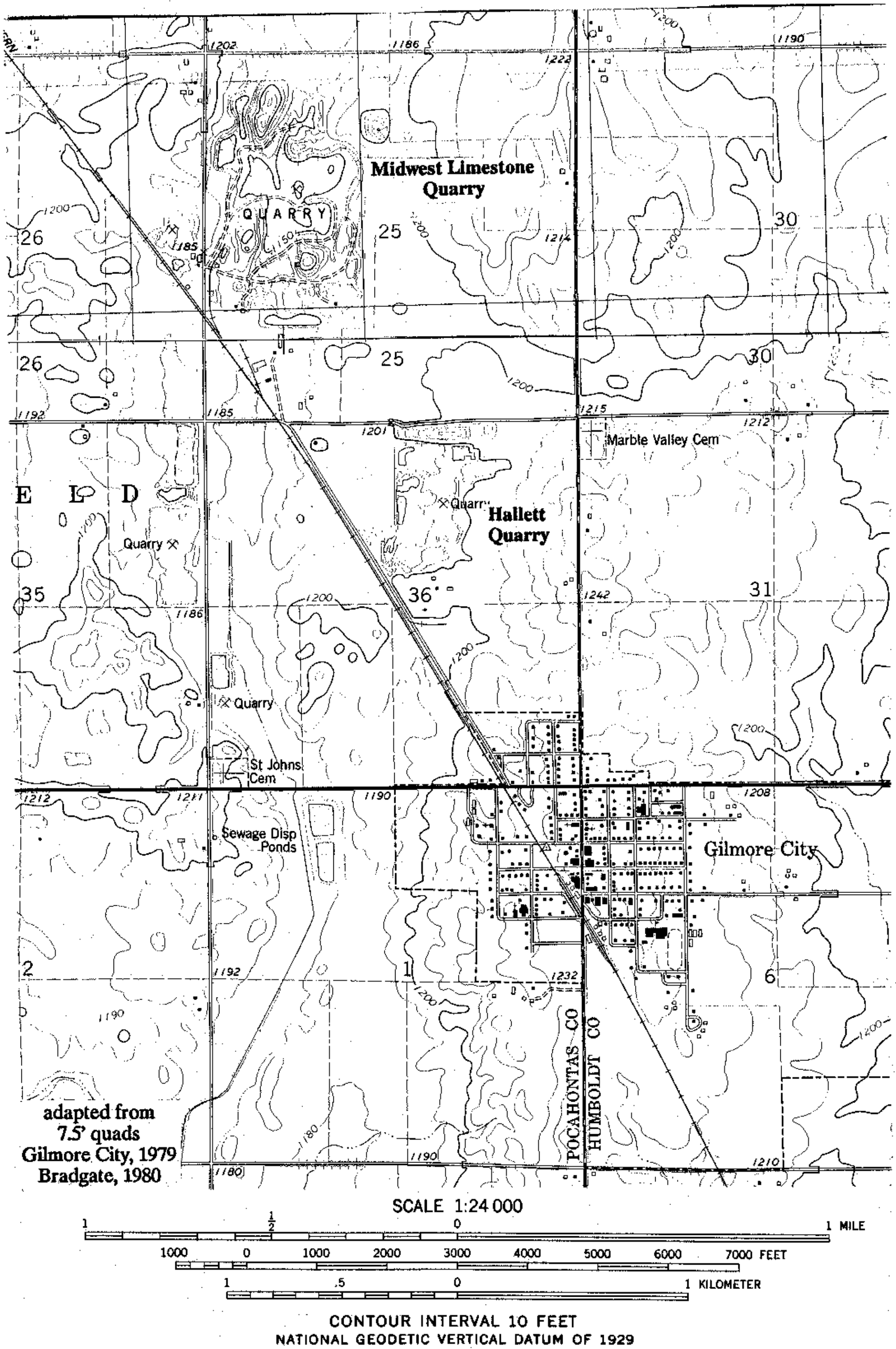
UNIT 3
Limestone, pale brown, mudstone to peloidal wackestone, sublithographic, dense, conchoidal fracture; lower part with scattered small intraclasts (1-5 mm); middle part with very fine faint horizontal laminations; upper part 23 cm with scattered stylolites, faintly laminated, scattered birdseye voids (best developed in top 10 cm); small domal stromatolites (3 cm x 10 cm) locally near top, capped by 1 cm thick birdseye-bearing interval; laminae disrupted at top with scattered intraclasts (1-2 cm); irregular upper surface, stylolitic, locally with thin shale; ostracod and calcisphere grains noted; 60 cm.

UNIT 2
Limestone, mudstone to peloidal wackestone, sublithographic to lithographic, dense, conchoidal fracture, one bed; stromatolitic unit, domal (to 20 cm) to columnar stromatolites (10 cm x 40 cm high) grade laterally into planar to wavy forms (1-5 cm vertical); mudcracked in part near base; uppermost 2-5 cm is dense featureless limestone; some calcite void fill; 50-55 cm.

UNIT 1
Limestone, mudstone to wackestone, sublithographic in part, dense, conchoidal fracture, scattered stylolites, medium to thick bedded; lower one-third is faintly laminated with calcite void and fracture fill (some desiccation fractures?); middle one-third with faint irregular laminae (spaced 1-3 mm) in part, small intraclasts (1-5 mm) along some laminae; upper one-third with scattered shaley stylolitic surfaces, sublithographic to finely crystalline, scattered small intraclasts (1-10 mm) and calcite fracture fills (some fractures display incipient brecciation); top 1-5 cm includes laterally discontinuous sandy to silty limestone stringer; 1.6 m.



Sketch maps of the Midwest Limestone (top) and Hallett quarries (modified from Gross, 1982).



Location map of the quarries at Gilmore City visited in this guidebook.