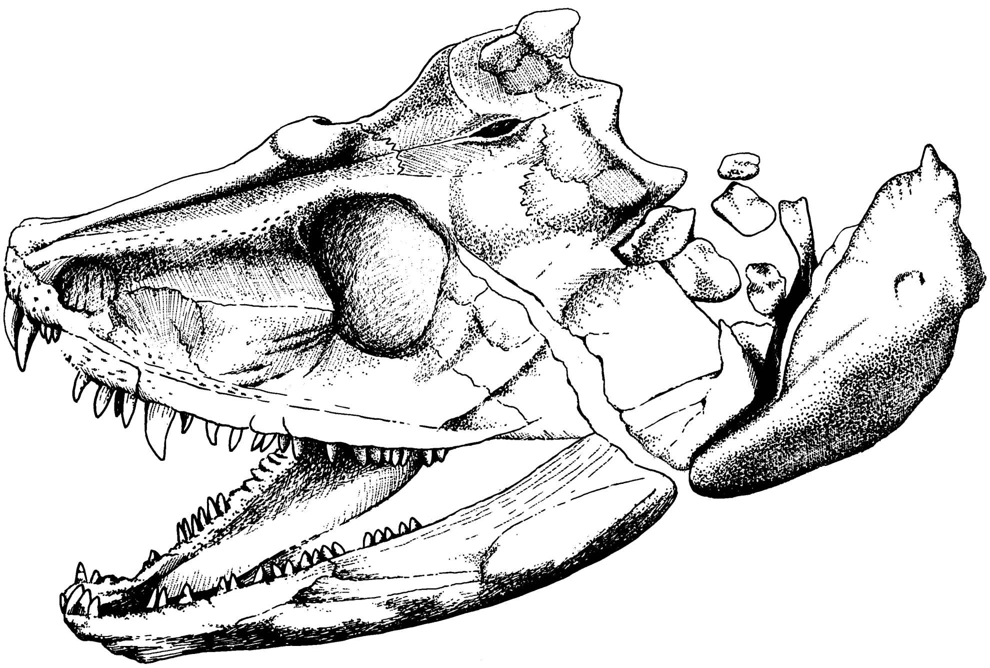
STRATIGRAPHY AND PALEOENVIRONMENTS OF MISSISSIPPIAN STRATA IN KEOKUK AND WASHINGTON COUNTIES, SOUTHEAST IOWA

Guidebook Series No. 10



Iowa Department of Natural Resources

Larry J. Wilson, Director

October 1990

COVER ILLUSTRATION:

Proto-anthracosaur fossil, Waugh Member, "St. Louis" Formation, Heimstra Quarry (STOP 4). Length 30 cm.

Drawn by Kay Irelan

Fossil prepared by W. Simpson, Field Museum of Natural History

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STRATIGRAPHY AND PALEOENVIRONMENTS OF MISSISSIPPIAN STRATA IN KEOKUK AND WASHINGTON COUNTIES, SOUTHEAST IOWA

Guidebook Series No. 10

Prepared by

Brian J. Witzke, Robert M. McKay, Bill J. Bunker
Energy and Geological Resources Division
Geological Survey Bureau

and

Frederick J. Woodson
University of Iowa
Department of Geology

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PART I.

Mississippian Stratigraphy and Paleoenvironments

INTRODUCTION

The Mississippian System as a chronostratigraphic concept is strictly North American in origin, and was initially based on the sequence of rocks exposed in the Mississippi River Valley between Burlington, Iowa, and St. Louis, Missouri (Williams, 1891; see summary in Collinson et al., 1979). As such, southeast Iowa includes part of the "body stratotype" for the Mississippian System (Glenister et al., 1987). The progression of stratigraphic, biostratigraphic, and other geologic investigations of Mississippian rocks in the Iowa area, therefore, takes on added historical significance. An overview of the Mississippian stratigraphy of southeast Iowa is provided in this guidebook to acquaint the reader with the succession of rocks they will see on the field trip. Problems and interpretions, some highly speculative, are further discussed. The Mississippian System remains essentially a provincial term rarely applied outside of North America. It roughly equates with the Lower Carboniferous of the Old World, and the Mississippian is sometimes regarded as a subsystem of the Carboniferous System. The Mississippian is subdivided into four provincial series whose names derive from localities in Missouri and Illinois.

This field trip will visit exposures in Washington and Keokuk counties (Fig. 1), an area that lies about 80 to 125 km (50-75 mi) northwest of the classic Mississippi River Valley sections at Burlington. The field trip area was selected for several reasons: 1) a virtually complete Mississippian stratigraphic succession is accessible, 2) its separation from the classic Mississippi Valley sections provides needed geographic perspectives, 3) none of the trip stops have ever been visited by a Tri-State Geological Field Conference, and 4) outstanding discoveries have been made in the area in recent years, particularly the Mississippian amphibian site near Delta (Bolt et al., 1988). Numerous geologic and paleontologic problems remain in the area for motivated researchers, and we encourage and invite additional study.

The Mississippian sequence of southeastern Iowa has long been famous for its rich paleontologic resources, and exceptional crinoid (e.g., Wachsmuth and Springer, 1897) and brachiopod (e.g., Weller, 1914) faunas have been described. Many Mississippian studies in southeastern Iowa have concentrated on exposures in Des Moines and Lee counties (Fig. 1), but pioneering studies of Mississippian strata in the field trip area of Washington and Keokuk counties deserve special mention. The state geological surveys of Hall (Hall and Whitney, 1858) and White (1870) made preliminary observations of Mississippian rocks in these counties, and Bain (1895, 1896) undertook more comprehensive county surveys. Van Tuyl's (1925) impressive study of Mississippian rocks in Iowa included many important observations made in Washington and Keokuk counties. Laudon (1931, 1937), Harris (1947), and Harris and Parker (1964) included sections from these counties in their regional Mississippian studies, and Kinderhookian biostratigraphy in Washington County was specifically addressed by Straka (1966, 1968). Additional aspects of Mississippian stratigraphy, petrography, and paleontology in these counties were considered in several graduate studies (Johnson, 1967; Person, 1976; Rollins, 1975; Harris, 1982).

The discovery of Mississippian amphibian and fish fossils near Delta, Keokuk County (STOP 4), in 1985 attracted immediate attention, and exceptional fossil material was recovered during joint Field Museum (Chicago) and Geological Survey Bureau (Iowa Department of Natural Resources) excavations at this site in 1986 and 1988 (see McKay et al., 1987). This locality is debatably the most important paleontological site in the state of Iowa, and it attracted international attention after preliminary results were published in *Nature* (Bolt et al., 1988). The site has produced the oldest well-preserved tetrapod fauna known from North America, and ongoing studies of this fauna will contribute to a broader understanding of early tetrapod evolution and the origins of land vertebrates. The "proto-anthracosaur" recovered from the site (ibid.; see cover illustration) provides evidence of a previously unknown group of tetrapods that is potentially ancestral to all higher vertebrates, including ourselves. We will visit the site on this field trip, and consider the unusual geologic occurrence.

Three previous Tri-State field trips examined Mississippian strata in southeast Iowa (see Anderson, 1980), including the 9th (Tri-State, 1941), 21st (Tri-State, 1957), and 51st (Glenister, 1987), but no Tri-State trip until now has specifically visited Mississippian exposures in Washington or Keokuk counties. Two other

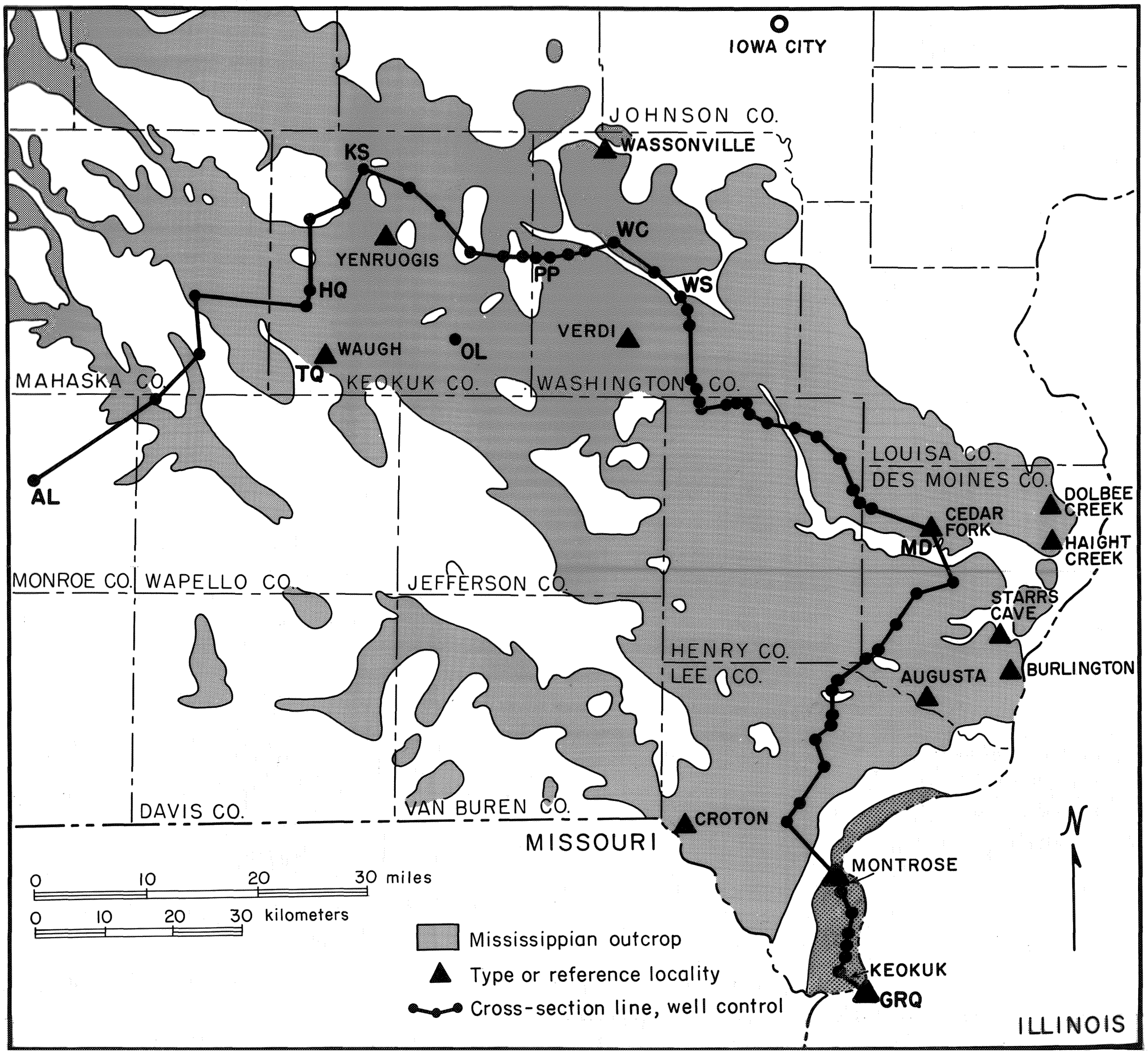

Figure 1. General location map for southeast Iowa showing county outlines, Mississippian outcrop, reference localities, and cross-section line (for Figure 3).

Tri-State trips visited Mississippian exposures adjacent to southeast Iowa in the Mississippi Valley of western Illinois Collinson, 1964; McCracken, 1976). Other organizations have sponsored trips to examine Mississippian rocks in southeast Iowa, including the Geological Society of Iowa (Parker et al., 1967) and the Geological Society of America (Parker et al., 1968). The type Wassonville section in Washington County was visited (Glenister and Rexroad, 1968), and Mississippian strata in Keokuk County were the focus of a recent field trip (McKay et al., 1987). Of note are additional field trip guidebooks to classic Mississippian sections in Illinois and Missouri (Koenig et al., 1961; Collinson et al., 1979).

This guidebook emphasizes the fine exposures of Kinderhookian, Osagean, and Meramecian rocks in Keokuk and Washington counties, well to the north and west of the classic Mississippi River Valley sections. Virtually the entire Mississippian sequence present in southeast Iowa will be viewed during the field trip. The stops have been, as practically as possible, arranged to guide the participants through the Mississippian sequence, from older to younger strata. Features of special note include: 1) storm-induced sedimentary features in the Wassonville; 2) articulated echinoderms and abundant brachiopods in the Wassonville; 3) multiple hardgrounds present at and near the Wassonville-Burlington contact; 4) the prominent glauconitic interval marking the base of the Haight Creek Member; 5) the sub-"St. Louis" unconformity; 6) siliciclastic and carbonate facies of the "St. Louis" interval; 7) the geologic setting of the Delta amphibian site; and 8) outstanding invertebrate fossil collecting in the Pella Formation.

REGIONAL STRUCTURAL SETTING OF SOUTHEAST IOWA

The Mississippi River Arch has been an ambiguous term in the geologic literature concerning the Upper Mississippi Valley region. Its varied placement on structure and isopach maps has led to confusion as to its exact location, extent, structural history, and general regional geologic importance. Howell (1935) originally defined the Mississippi River Arch as "a broad corrugated fold extending from south-central Wisconsin to a point north of St. Louis, Missouri." The term has generally been applied to the broad area separating the Forest City and Illinois basins. Unfortunately, the term has been badly misused, and some previous usage has included other previously-named structural elements, in particular the Savanna-Sabula Anticlinal System of east-central Iowa and northwest Illinois, and the Lincoln Fold System of northeast Missouri.

The Mississippi River Arch has generally been considered to be Middle Pennsylvanian in age, having formed concurrently with structural movements along the Nemaha Uplift and maximum subsidence in the Forest City Basin (Lee, 1943, 1946; Anderson and Wells, 1968; Bunker et al., 1981; Bunker, 1982; Bunker et al., 1985; Bunker et al., 1988). Lower Pennsylvanian (Morrowan; Caseyville Formation) rocks in the Quad-Cities area of Iowa and Illinois were deposited in an isolated structural depression as evinced by their physical separation from Caseyville strata in the Illinois Basin area. The presence of Morrowan rocks along the supposed axis of the arch runs contrary to the concept of a long-lived structural arch (i.e. Mississippi River Arch) in the region (Bunker et al., 1985).

The present-day regional structural setting of southeasternmost Iowa shows the Mississippi River Arch to be a northeast to southwest trending "structural saddle." It is bounded by more positive structural elements to the northeast (Savanna-Sabula Anticlinal System) and the south (Lincoln Fold System). It also appears as a relative structural high between the Illinois Basin to the southeast and the Forest City Basin to the west-southwest. The hinge of the arch lies on the Illinois side of the Mississippi River along the southeastern border of Iowa. A series of northwest-southeast oriented anticlines and synclines are superimposed on the crest of the arch and parallel the Lincoln Fold System of northeastern Missouri.

The presence of an east-west trending structural anomaly in the Savanna, Illinois, area has been noted by many previous workers. Chamberlin (1882, p. 425-426) first described an east-west axis of flexure in the Savanna area, but provided little detailed discussion of the anomaly. In summarizing the geology of Jackson County, Iowa, Savage (1906, p. 640-641) described a low arch extending westward from Savanna, Illinois into Iowa for a distance of 32 km (20 mi). In 1920, Cady first applied the term "Savanna-Sabula Anticline" to this structural feature.

Original interpretations of the Savanna-Sabula Anticline were hampered by an inability to perceive the regional dimensions of the structure. Stratigraphic relationships of the Silurian strata in east-central Iowa were poorly understood, thus limiting structural interpretations in the area. More recent structural mapping (Bunker et al., 1985) delineated a broad east-west trending feature corresponding to the southern upthrown side of the Plum River Fault Zone. The feature extends into northwestern Illinois where it merges with the northwest-southeast trending LaSalle Anticlinal System, Ashton Arch, and Wisconsin Arch. A series of smaller domes, anticlines, and synclines have also been noted superimposed on the Savanna-Sabula Anticlinal System (Kolata and Buschbach, 1976; Bunker et al., 1985). Scattered outliers of Pennsylvanian rocks across eastern Iowa and northwestern Illinois overstep uplifted and erosionally truncated Mississippian, Devonian, Silurian, and Ordovician rocks. This relationship clearly delineates the pre-Pennsylvanian uplift of the Savanna-Sabula Anticlinal System.

The Lincoln Fold System is a prominent structural feature that influenced deposition during the Late Devonian and Early to Middle Mississippian in southeastern Iowa, west-central Illinois, and northeastern Missouri. Local doming and erosional truncation along the axis of the fold system is suggested by the local occurrence of older Mississippian formations in contact with Middle Pennsylvanian rocks. Searight and Searight (1961) indicated that the Lincoln Fold was not a significant topographic feature during the Lower Pennsylvanian, but was somewhat elevated later during the Desmoinesian, as evinced by the eastward overlap onto and across the fold by successive formations during that time. The later history of the fold is obscure, because of erosion of the younger Pennsylvanian beds (Bunker et al., 1985).

The field trip area, which encompasses Washington and Keokuk counties, occupies a region to the west-northwest of the Mississippi River Arch, to the southwest of the Savanna-Sabula Anticlinal System, and a position along the northeastern periphery of the Forest City Basin. A southwestward regional dip is apparent from the geologic outcrop pattern. Outcrop studies in southeastern Iowa by McGee (1891), Keyes (1893), Gordon (1895), and Norton (1911) indicated a pattern of parallel anticlines with their axes trending northwest-southeast (i.e. parallel to regional strike).

The prominent glauconite-bearing interval at the base of the Haight Creek Member of the Burlington Formation was utilized by Harris and Parker (1964) and in this report as a structural mapping datum (Fig. 2). This interval is especially useful because glauconite is unaffected by dolomitization, thus permitting recognition of this horizon over broad areas across diagenetic facies transitions. The structure contour map shows a general northwest-southeast regional strike with a southwesterly dip in the eastern half of the map. Several small parallel anticlinal structures are noted in the northeastern part of the map area. Harris and Parker (1964) suggested that development of these northwest-trending folds pre-dated uplift of the Mississippi River Arch, and were contemporaneous with the development of the Lincoln Fold System. The coincidence of the structural lows and the areas of thicker preserved Burlington strata as shown on isopach maps (Harris and Parker, 1964, plates 1, 3, & 6) is intriguing. Along the crests of some anticlines, Burlington strata are thinner than in the bordering synclines. This suggests that southeastern Iowa had undergone deformation prior to and/or contemporaneous with deposition of the Burlington. Isopachs of both the Starrs Cave-Wassonville-Dolbee Creek interval and of the Haight Creek Member show a general thinning to the east and northeast and thickening to the west and southwest. However, the data for both of these relatively thin intervals are inconclusive regarding possible contemporaneous structural movements during this part of the Mississippian.

PETROLEUM GEOLOGY OF SOUTHEAST IOWA

The prominent domal feature adjacent to the Washington-Keokuk county line, near the center of the map (Fig. 2), is the Keota Dome. The structure was named after the town of Keota, in eastern Keokuk County. The dome was discovered as a result of subsurface geological investigations, since there are few natural exposures in the immediate area. An exploration program was undertaken by Natural Gas Pipeline Company of America (NGPCA) in order to confirm the existence of the structure and determine its capability for storage of natural gas. Between July and September, 1962, fourteen structure tests were drilled at various locations to provide necessary structural control. Geologic studies of drill-cuttings and core recovered from the Keota Dome indicate that the structure originated from the draping of Paleozoic units over a buried erosional ridge of Proterozoic quartzite (Anderson and Ludvigson, 1986). Drilling operations on the Keota Dome were commenced in January, 1963, on the W.F. Flynn farm (SW NE sec. 20, T76N, R9W, Washington Co.; *1 on Fig. 2). The hole was drilled on the crest of the dome to a total depth of 335 m (1097 ft) and encountered approximately 1.5 m (5 ft) of oil-saturated rock in the basal Pecatonica Member of the Platteville Formation (Middle Ordovician; Proctor, 1964). W.F. Flynn P-1 initially produced approximately 15 barrels/day and rapidly dropped to 1.5 barrels/day, yielding a total of only 404 barrels of oil over an eight month period. Although many tests in the Keota Dome area have shown traces of oil,

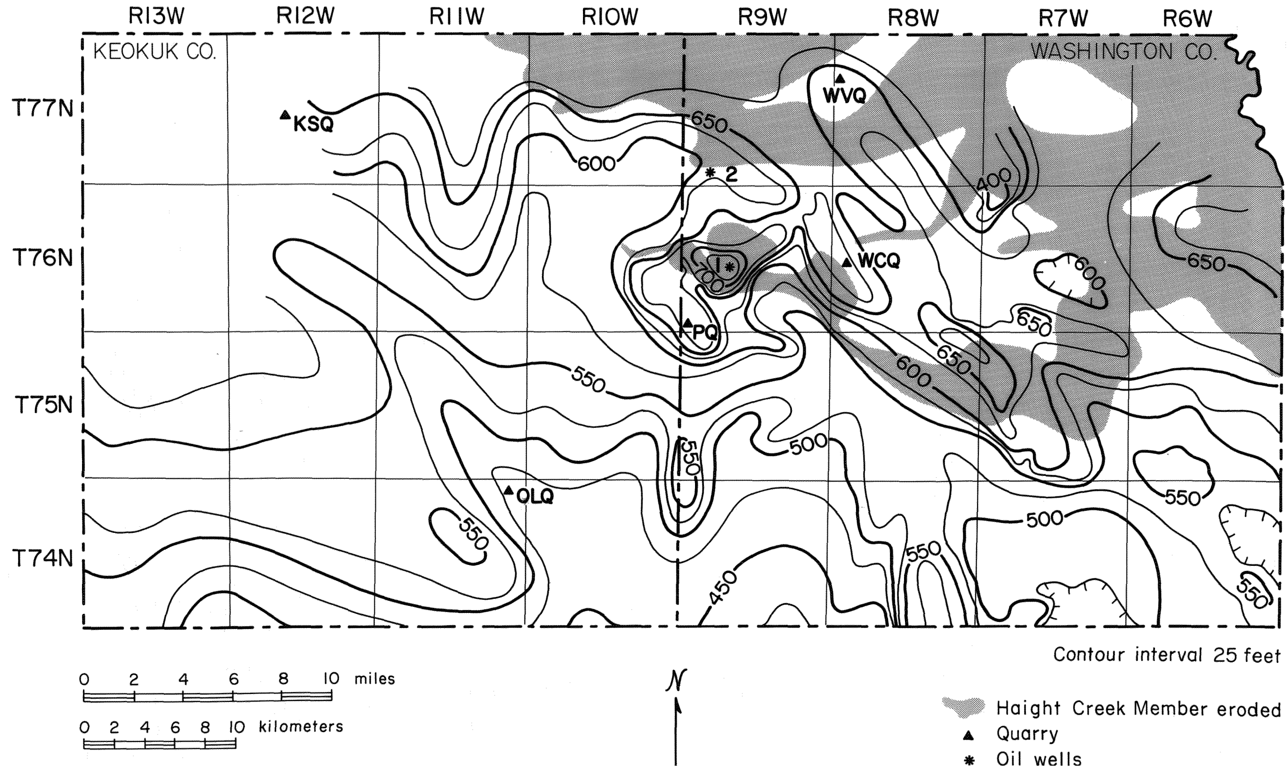

Figure 2. Structure contour map drawn on base of Haight Creek Member of the Burlington Formation, Washington and Keokuk counties, Iowa. Datum is sea level. Location of productive oil wells and selected quarries shown [PQ-Keota-Pepper Quarry (STOP 1); KSQ-Keswick Quarry (STOP 2); WVQ-Wassonville Mill Quarry; OLQ-Ollie Quarry; WCQ-West Chester Quarry; *1-W.F. Flynn P-1 oil well; *2-Leonard Bombei #1 oil well].

Leonard Bombei #1 is the only other well to have produced oil besides W.F. Flynn P-1. Leonard Bombei #1 (SW NW sec. 32, T77N, R9W, Washington, Co.; *2 on Fig. 2) was drilled in late 1985-early 1986, by CST Oil & Gas Corporation, and produced a total of only 71 barrels of oil over a five month period. These two wells constitute Iowa's total historical oil production.

Crude oils recovered from the Keota Dome were generated from Middle Ordovician source rocks (Hatch et al., 1987). Oils generated by Middle Ordovician rocks are found throughout the Midcontinent and east-central United States. Gas chromatographic characteristics of these oils include a relatively high abundance of n-alkanes with carbon numbers less than 20, a strong predominance of odd-numbered n-alkanes between C_{10} and C_{20}, and relatively small amounts of branched and cyclic alkanes (ibid.). The wide ranges in $\delta^{13}C$ for oils and rock extracts reflect a major, positive excursion(s) in organic matter $\delta^{13}C$ in the late Middle Ordovician (ibid.). This excursion event has at least regional significance in that it has been recognized in sections 773 km (480 mi) apart in south-central Kansas and east-central Iowa (ibid.). The distinctive Middle Ordovician oils are known to be associated with rocks containing the organic-walled microfossil *Gloeocapsamorpha prisca*, an organism whose biologic affinities and paleoenvironmental significance remain controversial (Jacobson et al., 1988). Diagenetic studies of carbonate strata spanning the $\delta^{13}C$ excursion (Ludvigson et al., 1990) show that virtually no stratigraphic changes occur in the primary $\delta^{13}C$ compositions recorded by the carbonate-secreting shelly benthos. This implies that the carbon isotope excursion originated from "photic pumping" (Berger and Vincent, 1986), the removal of ^{12}C from surface waters by the physical settling of organic matter produced by photosynthesis.

MISSISSIPPIAN STRATIGRAPHY OF SOUTHEAST IOWA

STRATIGRAPHY OF THE KINDERHOOKIAN SERIES

The "Kinderhook Group" was originally proposed (Meek and Worthen, 1861) for a sequence of rocks in the Mississippi River Valley that included "all strata from the base of what is now the Grassy Creek Shale to the base of the Burlington Limestone" (Thompson, 1986, p. 14). North American stratigraphers in the late 1800s to mid 1900s made little or no distinction between rock-stratigraphy and time-stratigraphy, and the "Kinderhook Group," a lithostratigraphic term, became virtually synonymous with the "Kinderhookian Series," a chronostratigraphic unit. In Iowa, Kinderhookian strata initially encompassed the interval from the base of the "Maple Mill" or Sweetland Creek shales to the base of the Burlington (see Laudon, 1931). Subsequent conodont studies revealed that historic "lower Kinderhook" strata are of Devonian age, and Kinderhookian strata were thereby restricted to include only the post-Devonian and pre-Burlington interval (Collinson, 1961). In Iowa, this re-definition constrained the base of the Kinderhookian sequence to the base of the McCraney Formation or, in the absence of the McCraney, to the base of the Prospect Hill Formation. As such, the Iowa Kinderhookian sequence became exactly equivalent to Laudon's (1931) original concept of the "Hampton Formation," a preoccupied stratigraphic nomen (Harris, 1947; Woodson and Bunker, 1989).

Laudon (1931) divided the Hampton in southeast Iowa into a lower "North Hill Member" and an upper "Wassonville Member," but he (Laudon, 1935) subsequently excluded the North Hill from the Hampton. Workman and Gillette (1956) later elevated the North Hill to group status, which included, in ascending order, the McCraney, Prospect Hill, and Starrs Cave formations. Our current understanding of this sequence suggests that these formations cannot be consistently grouped because they are marked at the top by a poorly-constrained facies transition. However, the Starrs Cave can be more consistently grouped with the overlying Wassonville interval (see subsequent section). We propose to exclude the Starrs Cave from the grouping of Laudon (1931) and Workman and Gillette (1956), and further suggest that the "North Hill Group" has little or no stratigraphic utility in southeast Iowa or elsewhere. Its continued use artificially separates the Starrs Cave from the overlying Wassonville, and creates an impression of stratigraphic ordering that obfuscates facies relationships.

McCRANEY FORMATION

The McCraney Formation, an irregularly "banded" limestone and dolomite interval, unconformably overlies Devonian strata (usually English River siltstones) over much of southeast Iowa, marking the base of the Kinderhookian in the area. McCraney carbonate strata are absent to the north and west in Iowa, including portions of the field trip area in Washington County. Strata presently assigned to the McCraney were first described by Weller (1900; Kinderhook "beds 3 and 4") at Burlington, and Laudon (1931) termed these strata the "*Chonetes* zone" and "*Paryphorhynchus* zone" of the North Hill Member. The McCraney was proposed by Moore (1928) for exposures in western Illinois near Kinderhook, but the term was not used in Iowa until later (Collinson, 1961). McCraney-like lithologies may occur at more than one stratigraphic position in the Kinderhookian sequence of northeast Missouri (Thompson, 1986, p. 63), and potential stratigraphic problems may exist along the Missouri-Iowa border area in distinguishing intervals variably termed "Louisiana," "McCraney," and "McCraney-like."

"The McCraney is composed of alternating beds of sparsely fossiliferous, buff-colored, sublithographic limestone, and dark brown, coarser-grained unfossiliferous dolomite. A thin chonetid brachiopod-rich and oolitic layer is present at the base of the McCraney in Des Moines County" (Person, 1976, p. 21). The alternation of light and dark lithologies imparts a "strikingly banded appearance" on outcrop that is of diagenetic origin (Glenister et al., 1987). This banded appearance is reminiscent of that seen in the Upper Devonian Louisiana Limestone in northeast Missouri. The McCraney is locally capped by an oolite in western Illinois (Workman and Gillette, 1956). Fossils are generally sparse, except in the basal chonetid layer, although the known fauna includes brachiopods (chonetids, rhynchonellids, spiriferids), bivalves, gastropods, ostracodes, coral and echinoderm fragments, arenaceous foraminifera, and conodonts (*Siphonodella cooperi*) (Weller, 1900; Van Tuyl, 1925; Workman and Gillette, 1956; Person, 1976). The fauna "indicates that the McCraney is not earliest Mississippian" (Glenister et al., 1987), and that the type Kinderhook sequence lacks strata of earliest Kinderhookian age (sub-McCraney unconformity). The McCraney in Iowa ranges in thickness from 0 to 20 m (65 ft), but commonly is about 3 or 4 m (10-15 ft) thick. It is sharply overlain by the Prospect Hill Formation at most localities.

PROSPECT HILL FORMATION

Weller (1900; Kinderhook "bed 5") described a fine-grained fossiliferous "sandstone" interval at Prospect Hill (now Crapo Park) in Burlington. The exposure subsequently became the type locality of the Prospect Hill Formation (Moore, 1928; Workman and Gillette, 1956). Strata presently assigned to the Prospect Hill in northern Washington County were originally included within the type sequence of the "English River gritstone" (Bain, 1896; Straka, 1968). The type English River sequence, at least in part, includes strata of Kinderhookian age, although the supposed "English River Siltstone" at Burlington is entirely of Devonian age (Collinson, 1961; Straka, 1968). Usage through much of southeast Iowa has restricted the "English River" interval to the Devonian siltstones below the McCraney, thereby modifying the original definition. The historical development of stratigraphic nomenclature in this area has led to the current realization that much of the type English River in Washington County interval is probably correlative with the type Prospect Hill in Des Moines County. Formal re-definitions of these terms may be in order, or, alternatively, a new term for the "English River" at Burlington may be proposed. For convenience, the Prospect Hill Formation encompasses the Mississippian siltstone and shale interval found above the McCraney or, in the absence of the McCraney, above the Devonian unconformity (Straka, 1968).

The Prospect Hill is characteristically a dolomitic quartz siltstone, although green and gray shales commonly interbed, especially near the base. Where the formation is thickest, the lower half is commonly shale-dominated, and in some sections the entire formation is represented by silty shale. Siltstone beds commonly display horizontal laminations, and low-angle cross-stratification and rippled bedforms are present. The basal contact is sharp, with concentrations of fish bones and teeth noted at many localities. Vertical and horizontal burrowing fabrics commonly are well displayed in the silty facies, and fossil molds are scattered to abundant in many beds. Faunas are relatively diverse, commonly molluscan-dominated with infaunal and epifaunal bivalves, gastropods, and rare scaphopods and cephalopods. Brachiopods are common and diverse in some beds (Van Tuyl, 1925; Moore, 1928), and bryozoan and crinoid debris molds occur. Conodont faunas are relatively diverse (Straka, 1968; Collinson, 1961). The Prospect Hill Formation is commonly 1 to 3 m (3-10 ft) thick in southeast Iowa, although thicknesses between 12 and 27 m (40-90 ft) are known in Lee, Van Buren, and Henry counties. The Prospect Hill is generally thickest in the same area of southeast Iowa where the McCraney is also thickest (Fig. 3), although complementary thickness relations between the two formations are suggested by some closely-spaced well penetrations. The Prospect Hill is locally absent in Des Moines County where the Starrs Cave overlies the McCraney (Person, 1976, p. 87). Prospect Hill strata may merge with part of the Hannibal Formation in northeast Missouri.

STARRS CAVE FORMATION

Oolitic limestone strata first described in the Burlington area (Kinderhook "bed 6" of Weller, 1900; "*Schellwienella* zone" of Laudon, 1931) were formally designated the Starrs Cave Formation by Workman and Gillette (1956) for exposures on Flint Creek near Burlington. The Starrs Cave is characteristically a fossiliferous oolitic grainstone. However, oolite bodies appear to be discontinuous in southeast Iowa, and in many sections the Starrs Cave is represented by sparsely oolitic to non-oolitic skeletal (crinoidal) packstones and grainstones (Lawler, 1981; Person, 1976). Pelleted and intraclastic grainstones are observed at some localities. The Starrs Cave is locally absent or unrecognizable in Washington County, where dolomites of the Wassonville Formation directly overlie Prospect Hill siltstones (e.g., type Wassonville, Fig. 4). However, thin dolomitized oolitic strata at the base of the Wassonville in that area indicate that Starrs Cave equivalents are locally present (Straka, 1968). In addition, skeletal grainstone lithologies indistinguishable from those

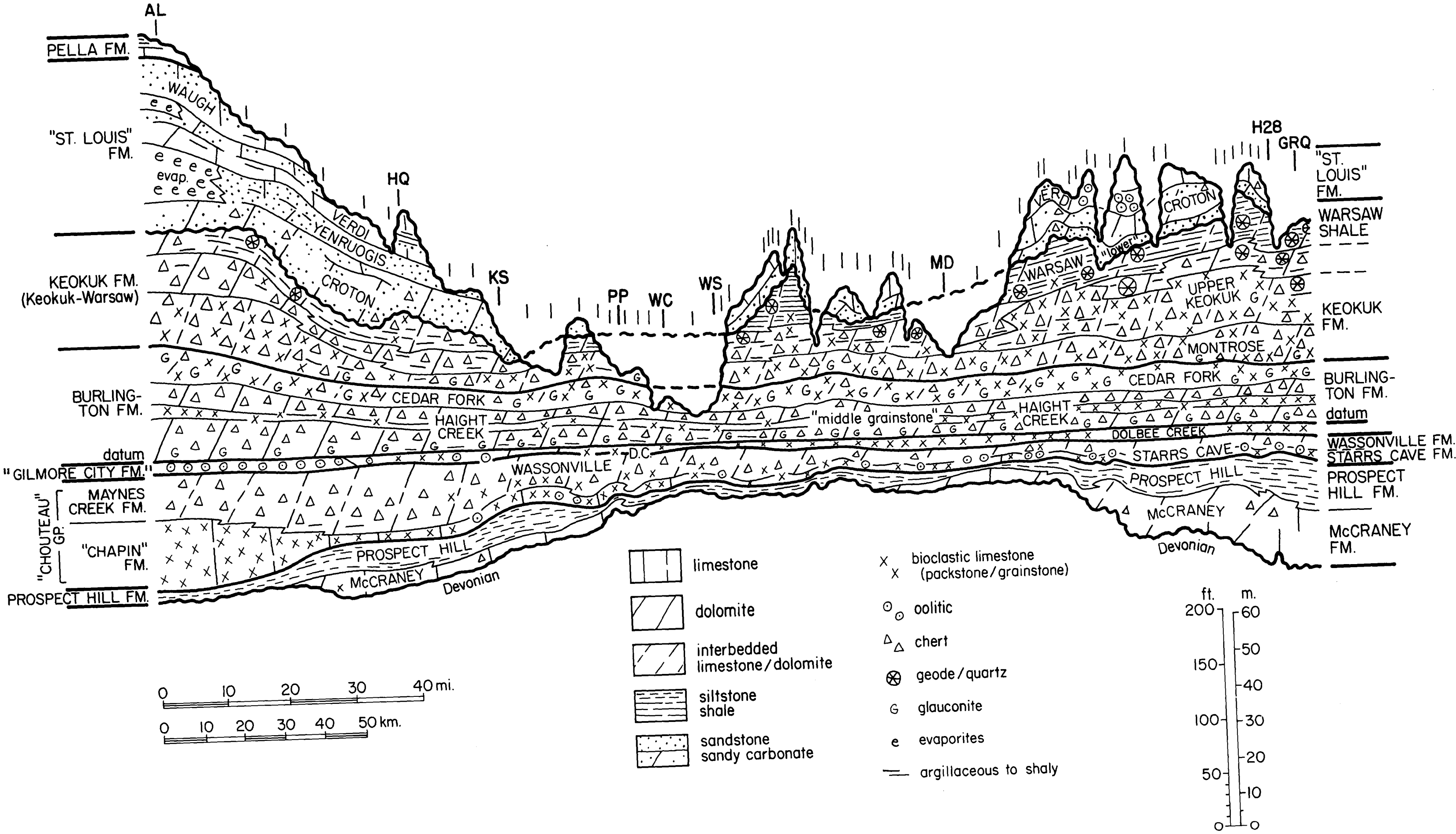

Figure 3. Mississippian stratigraphic cross-section across southeast Iowa; cross-section line indicated on Figure 1. Datum is base of Haight Creek Member (basal glauconitic horizon). Water well cuttings (5 ft sample interval) provide primarily control, but important quarry and core locations are designated by letters along the top edge. Note erosional unconformity at base of "St. Louis."

of the Starrs Cave interbed with basal Wassonville dolomitic strata at many localities (e.g., Fig. 5), suggesting that the Starrs Cave-Wassonville sequence is gradational. The contact between the two stratigraphic units is arbitrarily selected at the base of the lowest dolomite in the sequence. In areas where the lower Wassonville is dominated by limestone, contact relations with the Starrs Cave are further obscured.

The gradational character of Starrs Cave and Wassonville strata at many localities suggests that the two units should be naturally grouped. Although the thin Starrs Cave interval has been accorded formational status and separated from overlying Wassonville strata in most previous reports, it may be desirable at some point to re-assign the Starrs Cave as a member of the Wassonville Formation pending further regional study. Collinson (1961) favored including the Wassonville with the Starrs Cave in an expanded "North Hill Group." The Starrs Cave interval typically ranges in thickness between 0.5 and 1.5 m (1.5-5 ft) in much of the southeast Iowa outcrop belt. It thickens westward in the field trip area, ranging between 1.5 and 4.5 m (5-15 ft). Thicker sections of skeletal packstone-grainstone, varying between 6 and 18 m (20-60 ft), occupy the same stratigraphic position in the subsurface west of the field trip area in southern Iowa (Fig. 3). It is unclear at present whether these thicker sections should be assigned to the Starrs Cave or "Chapin" (a northern Iowa unit), or included within the "Chouteau Group" as in adjacent Missouri.

The Starrs Cave is very fossiliferous in most sections, and a diversity of brachiopods (chonetids, productids, *Schellwienella*, spiriferids, others) and molluscs (bivalves, gastropods, rostroconchs, nautiloids) have been noted (Weller, 1900; Van Tuyl, 1925; Laudon, 1931). Crinoid debris is extremely abundant at many localities, and solitary corals, bryozoans, ostracodes, and trilobites also occur (Person, 1976). The Starrs Cave fauna recovered in the field trip area is virtually identical to that seen in overlying beds of the lower Wassonville Formation, and is discussed more fully in the next section.

WASSONVILLE FORMATION

The "Wassonville limestone" was named by Bain (1896) for Kinderhookian cherty dolomite strata at Wassonville Mill along the English River in Washington County. At its type locality (Fig. 4) it overlies Prospect Hill siltstones, but, at most localities in southeast Iowa, limestones of the Starrs Cave underlie the Wassonville. The Wassonville is characterized by dolomite, slightly argillaceous and faintly laminated in part. However, dolomitic limestone and limestone occur within the formation, especially in the lower part, at most localities. Nodular chert bands are a common and characteristic feature of Wassonville strata in the field trip area and throughout most of its subsurface extent, although chert is more sporadic in occurrence and locally absent in Lee and Des Moines counties. Limestones in the Wassonville Formation are most commonly seen as thin skeletal packstone and grainstone beds, but skeletal wackestones and sparse mudstones also occur. Upper Wassonville strata generally lack limestone beds and are characterized by common large calcite-filled vugs. At some localities (e.g., STOP 1) the upper Wassonville has a mottled to banded "zebra-stone" appearance, somewhat like that of the McCraney Formation.

Recognition of sedimentary structures at many Wassonville sections has been hampered by extensive dolomitization and diagenetic modification, although original sedimentary fabrics are remarkably well preserved at some localities. Faint laminations are commonly preserved in dolomitic strata, characterized by horizontal to parallel laminae with low-angle truncation surfaces and small-scale hummocky cross-stratification in some units. Laminated and hummocky units commonly display thin graded skeletal limestones or chonetid shell coquinas at their bases. The basal skeletal limestones are typically lensatic and irregularly discontinuous, but some skeletal grainstones appear to be laterally persistent at some localities. These basal limestones are commonly silicified, forming fossiliferous nodular chert bands. The occurrence of flat laminae and hummocky stratification, with basal graded lags, through much of the Wassonville suggests the dominance of storm sedimentation (Dott and Bourgeois, 1982). The preservation of articulated crinoids within some basal laminated intervals further supports rapid burial during episodic sedimentation events. Burrowing fabrics are present in some beds, but are absent or only sparsely developed in the laminated intervals.

The Wassonville fauna is abundant and diverse, although extensive dolomitization, as at the type

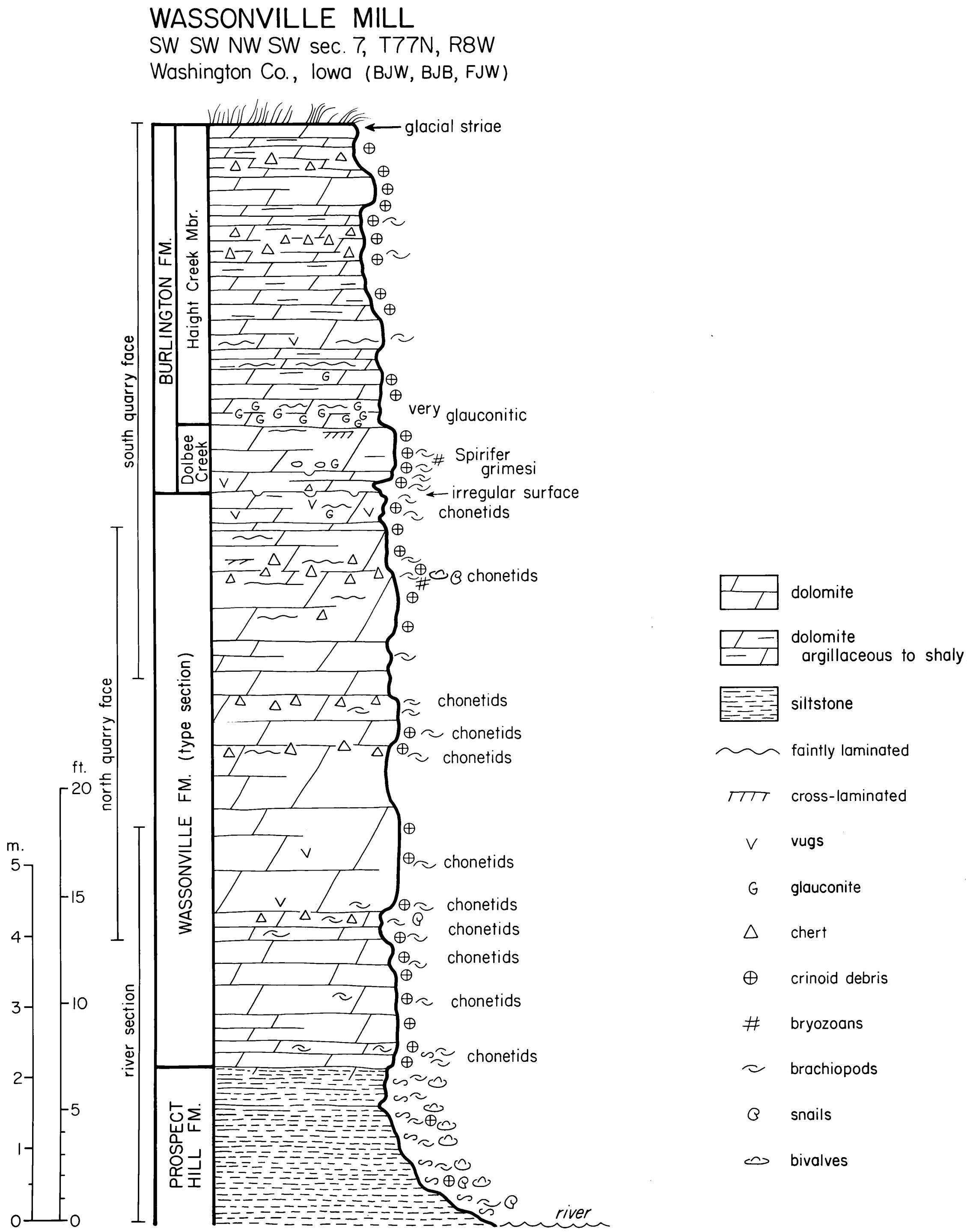

Figure 4. Stratigraphic section at Wassonville Mill, Washington County, Iowa, type locality of Wassonville Formation. Composite sequence based on exposures along the English River and adjacent quarry area.

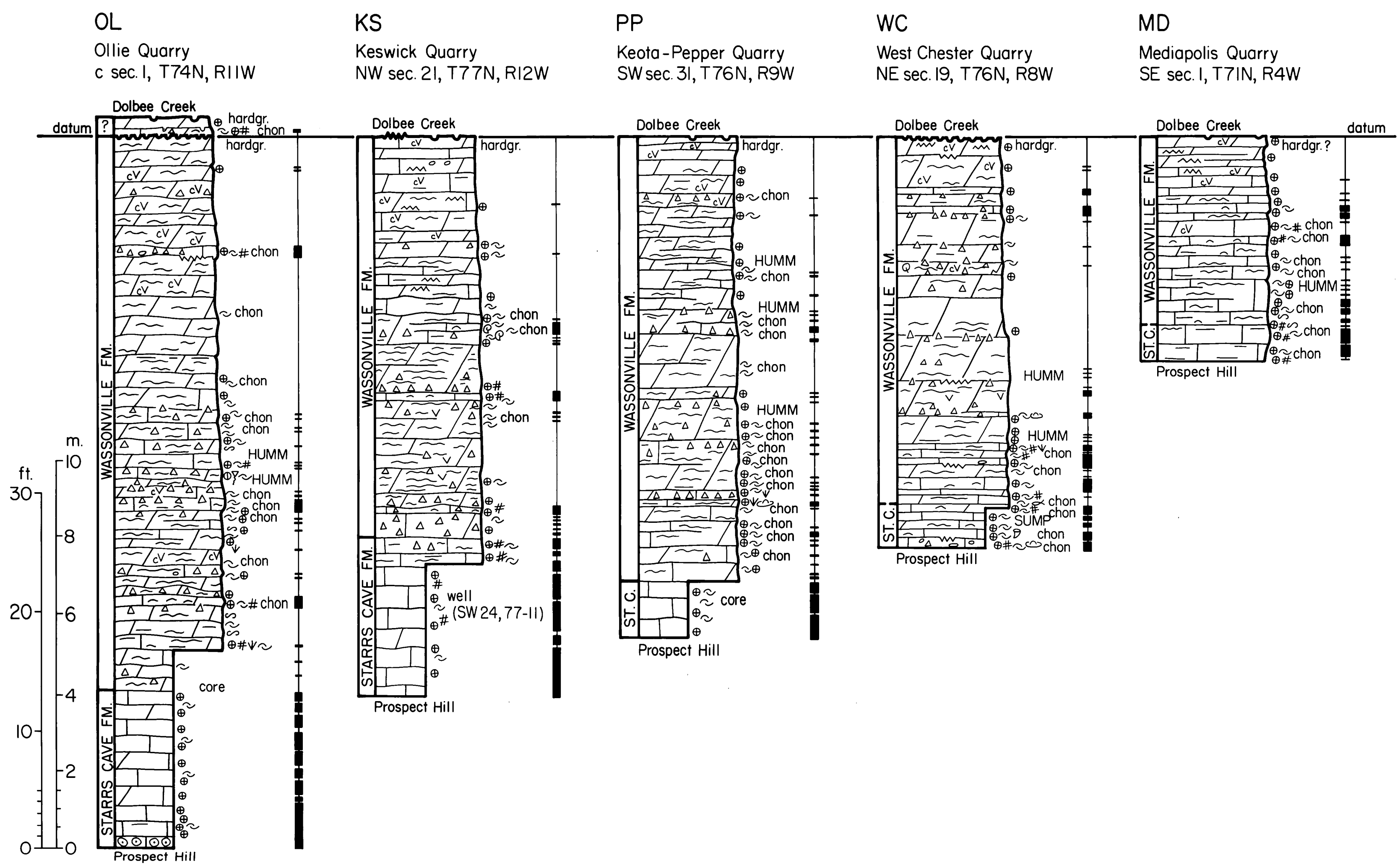

Figure 5. Representative sections of Starrs Cave and Wassonville strata in southeast Iowa (locations shown on Fig. 1); datum is base of Burlington Formation (upper Wassonville hardground discontinuity). Position of packstone-grainstone beds indicated by black bars. See legend (in Appendix) for symbols.

locality, has hampered fossil recognition through much of the sequence. Silicified intervals have been more notably fossiliferous in previous studies. Skeletal limestone lenses and fossiliferous cherts have produced the bulk of the fauna collected by the authors in Washington and Keokuk counties, but silicified brachiopods, especially chonetids, are abundant in some dolomite beds. Our collections from lower and middle Wassonville strata at Keota (STOP 1) are summarized here to supplement the faunal lists of Weller (1900), Van Tuyl (1925), Moore (1928), and Laudon (1931). Chonetid-dominated shelly horizons are common in the lower to middle Wassonville (primarily *Rugosochonetes multicostus*; some *Caenanoplia logani*, *Plicochonetes* sp.). Additional brachiopod taxa are present, particularly in crinoidal packstone and grainstone beds in the lower part of the formation, including spiriferids (*Unispirifer platynotus*, *Brachythyris* cf. *burlingtonensis*, *Punctospirifer* sp., *Eumetria* sp., ?*Calvustrigus* sp.), productids (*Spinocarinifera arcuatus*, *Piloricilla sedaliensis*, *Ovatia laevicosta*), and others (*Schellwienella* sp., *Rhipidomella* sp., *Macropotamorhynchus tuta*, *Beecheria chouteauensis*). Trilobites are moderately common in some lower Wassonville beds (*Proetides insignis*, *Breviphillipsia* sp.), and additional fauna include bryozoans (fenestellid and branching forms), solitary corals, sponge spicules, fish bones/teeth, and conodonts (Straka, 1968). Articulated crinoids are known from at least two localities in the field trip area, and preliminary identifications include camerates (*Rhodocrinites* spp., *Platycrinites* sp., *Dichocrinus* sp.), inadunates (*Scytalocrinus* sp., *Gilmocrinus* sp.) and flexibles (taxocrinid). Wassonville strata in Washington and Keokuk counties appear to provide exceptional opportunities for the recovery of an otherwise undescribed echinoderm fauna. Mollusc molds are sparse to absent in most beds, but some mollusc-dominated chert lenses that preserve shell ornamentation are present in the formation. A diverse silicified gastropod fauna (28 species) was described from the type Wassonville section by Rollins (1975). Bivalves are abundant in some chert lenses (*Nuculopsis*, nuculanids, *Schizodus*, *Edmondia*, *Aviculopecten*, *Pernopecten*, *Lepotodesma*, *Myalina*, *Mytilarca*, others). Additional molluscs include scaphopods, rostroconchs (*Conocardium*), and small nautiloids. *Tubisalebra*, a calcareous microfossil of uncertain biologic affinity (see Bogush and Brenckle, 1982) occurs approximately 3 m (10 ft) below the top of the Wassonville at the Ollie Quarry.

The Wassonville faunas of southeast Iowa most closely resemble those from portions of the Chouteau Group of Missouri, and a Kinderhookian age is clearly indicated. The Wassonville Formation grades southwestward into strata assigned to the upper Chouteau Group in northern Missouri. To the north and west, the Wassonville Formation is laterally equivalent to at least part of the Maynes Creek Formation, a similar cherty dolomite interval. It may be desirable to unify stratigraphic nomenclature across Iowa pending further study of Wassonville-Maynes Creek lithostratigraphic relationships. As presently used, the Wassonville is restricted to southeast Iowa, where it ranges between about 1.5 and 15 m (5-50 ft) in thickness; it is thinnest in Des Moines and Lee counties (1.5-6 m; 5-20 ft). Wassonville strata apparently are bevelled to the southeast beneath the Burlington Formation; the Wassonville Formation is absent across most of western Illinois, where the Burlington overlies older Kinderhookian units (Workman and Gillette, 1956). The top of the Wassonville is marked by a prominent irregular hardground surface in the field trip area. Previous studies in the type Wassonville area failed to recognize this surface and did not distinguish the bounding strata (e.g., Laudon, 1937; Harris and Parker, 1964; Straka, 1966). As a result, dolomitized lower Burlington strata (Dolbee Creek Member) went unrecognized, being mistakenly included within the Wassonville Formation. As presently recognized, the Dolbee Creek Member overlies the Wassonville Formation at all known localities in southeast Iowa.

STRATIGRAPHY OF THE OSAGEAN AND MERAMECIAN SERIES

The "Osage group" was proposed in a list of names by Williams (1891) to include the Burlington and Keokuk formations (see next sections for descriptions of these formations). The name derives from the Osage River in west-central Missouri, although no rocks of Keokuk age are apparently represented in the type area (Keyes, 1893; Lane and Brenckle, 1981). Subsequent usage modified the rock term to become a chronostratigraphic concept, the Osagean Series. The top of the Osagean Series in the Mississippi Valley has been variably drawn above, within, or below the Warsaw Shale (see later discussion), each position having been used to mark the base of the overlying Meramecian Series by different workers. This confusing agglomeration of time- and rock-stratigraphic nomenclature has created unnecessary semantic problems. As will be discussed in the chapter on cyclic deposition, the Burlington, Keokuk, and Warsaw formations should be grouped together to simplify and unify rock-stratigraphy, particularly in areas where facies changes make standard formational distinctions difficult or impractical. However, these rock strata cannot be consistently grouped under the chronostratigraphic label, "Osagean Series."

Keyes (1893) introduced the "Augusta limestone" as a term that grouped together the Burlington, Keokuk, and Warsaw formations; he named it after characteristic exposures at Augusta in Des Moines County, Iowa. The Augusta was never adopted for general use in Iowa or the Mississippi Valley; Van Tuyl (1925) rejected the Augusta as a valid term, stating, ". . . as Weller [1898] has pointed out the term Osage clearly has priority." Nevertheless, the Augusta apparently is the only historic term available for what we consider to be a logical lithostratigraphic grouping; if lithostratigraphic utility is regionally applicable, it is suggested here that the "Augusta Group" as a term may be worthy of resurrection.

The "Meramec group," named after Meramec Highlands in St. Louis County, Missouri, was introduced by Ulrich (1904) for the interval encompassing the Warsaw through St. Louis formations. As with the Osage, the term quickly evolved into a chronostratigraphic concept, the Meramecian Series. The upper and lower boundaries of the Meramecian Series have been placed at different positions by different workers, and regional consistency in definitions has not yet been achieved. Meramecian stratigraphic concepts are discussed later in this report.

BURLINGTON FORMATION

Owen (1852) recognized the "encrinital group of Burlington," and the term "Burlington limestone" was introduced by Hall (1857) and Hall and Whitney (1858) for crinoidal limestones exposed in the Mississippi River bluffs at Burlington, Iowa. The Burlington is presently used as a formational term over a broad area of the Midcontinent, from Iowa to Arkansas and from Illinois to Kansas. The Burlington Formation encompasses the lower part of the Osagean Series in southeast Iowa, where it unconformably to disconformably overlies the Wassonville Formation. The Burlington Formation, where capped by the Keokuk Formation, varies between about 16 and 24 m (55-80 ft) in thickness in the outcrop belt of southeast Iowa, but it thickens westward in the subsurface (Fig. 3). Although crinoidal limestones (packstones and grainstones) characterize much of the Burlington Formation across its extent, cherty, dolomitic, and glauconitic intervals are also recognized. These lithic variations were used by Harris and Parker (1964) to subdivide the Burlington Formation in southeast Iowa into three members, in ascending order, the Dolbee Creek, Haight Creek, and Cedar Fork.

Various biostratigraphic studies constrain the age of the Burlington Formation in its type area to the early Osagean. Crinoids and brachiopods have proven to be of biostratigraphic interest, but it is the conodonts that have apparently provided the major focus for inter-regional correlation of the Burlington. The reader is referred to various publications that pertain to the conodont biostratigraphy of the Burlington in southeast Iowa (Youngquist et al., 1950; Collinson et al., 1971; Lane, 1978; Lane et al., 1980; Chauff, 1978, 1981; S. Baxter, 1988, 1990). The fortuitous discovery of calcareous foraminifera in the upper Burlington of the field trip area now provides some independent biostratigraphic control (see later discussion).

DOLBEE CREEK MEMBER. Crinoidal packstones and grainstones characterize lower Burlington strata across most of southeast Iowa and adjacent areas of Missouri and Illinois. Originally termed the "*Cactocrinus* zone" (Laudon, 1937), these strata were named the Dolbee Creek Member by Harris and Parker (1964), after a locality in Des Moines County, Iowa (see map, Fig. 1). Some beds are dolomitic to varying degrees, minor wackestones are present, and stylolites are common; chert nodules are scattered but locally absent. Low-angle cross-laminae are noted in some beds. The presence of pervasively dolomitized facies of the Dolbee Creek Member in Washington and Keokuk counties apparently went unrecognized until this study; previous workers in this area interpreted the succeeding member of the Burlington, the Haight Creek, to directly overlie the Wassonville Formation, with no Dolbee Creek present (e.g. Laudon, 1937; Harris and Parker, 1964; Harris, 1982). A relatively thin interval of dolomitized crinoidal packstones and wackestones, variably included in the Wassonville or Haight Creek by previous workers, is noted in areas of Washington and Keokuk counties. It occurs above a prominent hardground (top of Wassonville) and below basal Haight Creek glauconitic strata. These dolomitic strata are included without reservation in the Dolbee Creek Member because: 1) sedimentary fabrics (coarse crinoidal debris, some low-angle cross-laminae) resemble those seen in Dolbee Creek limestones and not underlying Wassonville strata; 2) they contain Osagean conodont faunas characteristic of the lower Burlington (including *Pseudopolygnathus multistriatus* and *Hindeodus regularis*); and 3) recovered macrofauna is of Dolbee Creek aspect (including large brachiopods of the *Spirifer grimesi* group). Of interest, however, is the presence of multiple hardground surfaces or irregular discontinuities within dolomitized Dolbee Creek facies at localities in Washington and Keokuk counties, particularly in the lower part of the member. The Dolbee Creek Member ranges between about 1.5 and 5 m (5-17 ft) in thickness across most of southeast Iowa, but locally thins to as little as 0.5 to 1.0 m (1.5-3 ft) in areas of Washington and Keokuk counties (e.g., locations WC and KS, Fig. 6; location WM, Fig. 4).

HAIGHT CREEK MEMBER. An interval dominated by dolomite and cherty dolomite characterizes the middle part of the Burlington Formation. Originally termed the "*Physetocrinus* zone," Harris and Parker (1964) named these strata the Haight Creek Member after a locality in Des Moines County, Iowa (see map; Fig. 1). The member sharply overlies the Dolbee Creek Member with apparent conformity. Haight Creek dolomites are slightly argillaceous, in part, and thin shales are locally present, especially in the lower part. Some intervals display sparse skeletal-moldic (small crinoid debris) wackestone or burrowed fabrics. Faint laminations, reminiscent of Wassonville strata, are developed in some dolomite and chert beds. Cherts typically occur as nodular bands, but bedded cherts are prominently developed at many localities, especially in the middle to upper parts of the member. The lower interval of the Haight Creek Member is consistently glauconitic in southeast Iowa, and abundant glauconite grains are interlaminated with dolomite at or near the base of the member. "This glauconitic zone at the base of the Haight Creek is the most important horizon marker in the entire Osage Series, because it is as outstanding in well cuttings as it is in surface exposures" (Harris and Parker, 1964, p. 15). We have used this horizon as a stratigraphic datum for construction of various cross-sections and structure contour maps (Figs. 2,3).

Van Tuyl (1925, p. 121) locally identified "a layer of crinoidal limestone near the middle" of what is now termed the Haight Creek Member, and Harris and Parker (1964) also recognized resistant cherty crinoidal limestones in the middle of the member at various localities. However, these limestones, which lithically resemble many limestones seen in the overlying Cedar Fork Member, apparently were a source of considerable stratigraphic confusion. Van Tuyl (1925) variably assigned them to either his "Lower" or "Upper Burlington" intervals, thereby failing to recognize their stratigraphic continuity. We presently recognize the widespread geographic extent of crinoidal packstones and grainstones in the middle Haight Creek Member across much of southeast Iowa, and we informally term this interval the "middle grainstone" (Figs. 3,6). It is typically displayed at Locality MD, Des Moines County (Fig. 6). Crinoidal limestones are locally absent in the middle Haight Creek in areas of Washington and Keokuk counties, but equivalent dolomite strata in those areas display common to abundant crinoid debris molds (Fig. 6). Strata apparently equivalent to the "middle grainstone" interval of the Haight Creek Member, therefore, can also be identified in dolomitized facies.

Most of the Haight Creek Member is typified by sparsely fossiliferous dolomites (with scattered crinoid debris and rare brachiopods, corals, bryozoans, conularids, and sponge spicules), but the "middle grainstone" unit is abundantly fossiliferous with diverse assemblages of crinoid cups, brachiopods (including large *Spirifer*), and other fossils (see lists in Van Tuyl, 1925; Laudon, 1929). The contact of the Haight Creek with the overlying Cedar Fork is generally sharp, but interfingering of crinoidal grainstones and dolomite over a thin interval (0-20 cm) indicates a more gradational contact at some localities. The Haight Creek Member ranges between about 8.5 and 14 m (28-45 ft) in thickness across most of southeast Iowa, but it thickens westward in the subsurface (Fig. 3).

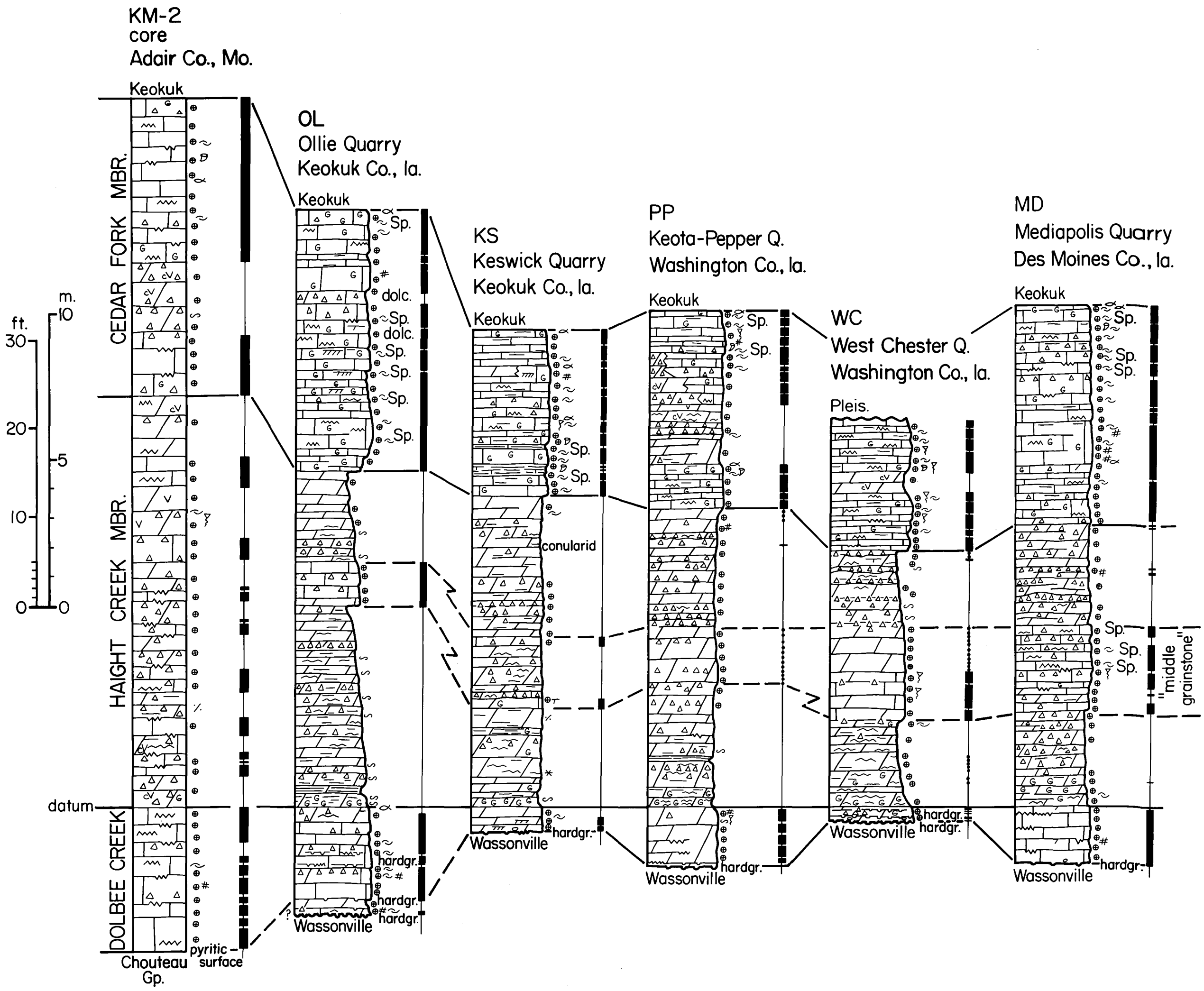

Figure 6. Representative sections of the Burlington Formation in Washington and Keokuk counties, Iowa; sections in Des Moines Co., Iowa, and Adair Co., Missouri, are included for comparison (Iowa locations shown on Fig. 1). Datum is base of Haight Creek Member (glauconitic horizon). Position of packstone-grainstone beds indicated by black bars. See legend (in Appendix) for symbols.

CEDAR FORK MEMBER. Crinoidal packstones and grainstones, commonly glauconitic, dominate the upper one-third of the Burlington Formation across southeast Iowa. This interval was distinguished as "Upper Burlington" by the pioneering geologists (e.g., Niles and Wachsmuth, 1866; Van Tuyl, 1925), although they did not consistently identify this unit at all localities. The "*Dizygocrinus*" and "*Pentremites*" zones of Laudon (1937) encompass these strata in southeast Iowa. This interval was subsequently termed the Cedar Fork Member by Harris and Parker (1964); they designated the type locality in Des Moines County (Loc. MD, Figs. 1,6). Crinoidal limestones of the Cedar Fork grossly resemble those seen in the Dolbee Creek Member and the "middle grainstone" interval of the Haight Creek. However, Cedar Fork limestones are typically glauconitic to varying degrees, unlike most underlying Burlington limestones. Some beds in the Cedar Fork contain abundant glauconite grains and display a greenish color on outcrop. Crinoidal packstone-grainstone beds in the Cedar Fork Member are commonly separated by thin argillaceous or shaly partings or stylolitic bedding surfaces. Calcareous shales with skeletal packstone lenses are seen at some sections (e.g., location KS, Fig. 6). Some grainstones display parallel stratification or low-angle cross-stratification. Graded bedding occurs in some wackestone-packstone beds.

Although the Cedar Fork Member is limestone-dominated, dolomites and dolomitic limestones also occur at most sections. Cedar Fork limestones typically display grain-supported fabrics, but most dolomites in the Cedar Fork of the field trip area are characterized by sparse skeletal wackestone fabrics (moldic skeletal debris), in part with faint laminations. These dolomites are largely indistinguishable from those of the Haight Creek Member. Dolomitic strata are most commonly developed in the middle part of the Cedar Fork Member. Dolomites are known to interfinger with and laterally replace limestones within the span of single quarries (e.g., STOP 1), indicating that individual packstone-grainstone beds are locally discontinuous over distances of 0.5 km (0.3 mi) or less. Nodular cherts are observed in most Cedar Fork sections, but chert abundance varies significantly between localities. Chert nodules are absent or rare in some sections, while nodular to bedded cherts are prominent at other localities. Skeletal grain silicification (crinoid, brachiopod) is common in many limestone beds.

The Cedar Fork Member is sharply overlain by the Keokuk Formation, but no evidence of erosional relief is seen at the contact. However, at many localities an interesting bed of glauconitic limestone occurs in the top 10 to 20 cm (4-8 in) of the Burlington that contains noteworthy concentrations of fish bones, spines, and teeth. Remains of cladodont, ctenacanth, and bradyodont sharks are most common. This interval has been referred to as the upper Burlington "bone bed" or "fish bed" (e.g., Van Tuyl, 1925), and is commonly overlain by a thin green-gray shale. The widespread distribution of the "bone bed" was recognized by the pioneering paleontologists Wachsmuth and Springer (1878), who noted that "it is one of the best stratigraphic landmarks that we know in this formation, as it is found over a wide area in localities over a hundred miles apart and always in the same position." Additional bone-rich horizons are seen at other stratigraphic positions within the Cedar Fork Member, but none are as persistent as the one at the top of the member.

The Cedar Fork Member ranges between about 4.5 and 9 m (15-30 ft) in thickness in the southeast Iowa outcrop, but the member thickens slightly westward in the subsurface. The member extends into adjacent Missouri and Illinois. The Cedar Fork is dominated by limestone through most of southeast Iowa. However, dolomite content increases progressively to the north and west, and the member is dolomite-dominated across central Iowa, where dolomitized crinoidal packstones are recognized (Harris and Parker, 1964). Laudon (1937) interpreted a progressive northward overlap of Burlington units in Iowa, with the "*Dizygocrinus* zone" [i.e., Cedar Fork Member] overlying Wassonville strata in part of Washington County. However, as recognized in this report, Cedar Fork strata consistently overlie the Haight Creek Member in southeast Iowa.

The Cedar Fork Member contains an abundant and diverse benthic fauna. Van Tuyl (1925) and Laudon (1929) list numerous taxa from Cedar Fork strata in Des Moines and Louisa counties, including crinoids (35 species), blastoids (4 species), brachiopods (24 species), bryozoans (8 species), corals (9 species), gastropods (10 species), bivalves (2 species), and trilobites (2 species). However, published information on the Cedar Fork faunas of Washington and Keokuk counties is unavailable, and a listing of taxa we recovered from Cedar Fork strata in the field trip area (especially locations WC and PP, Fig. 6) is included here. Crinoid debris is ubiquitous, with some large columnals up to 2 cm diameter. Articulated camerate crinoid cups occur in some beds; *Dizygocrinus rotundus* is the most common, but additional taxa occur (*Macrocrinus verneulianus*, *Platycrinites* sp., *Actinocrinites* sp.). Blastoids are scattered in the Cedar Fork grainstones, including *Orbitremites norwoodi* and *Pentremites elongatus*; the latter species was constrained to upper Cedar Fork strata in southeast Iowa ("*Pentremites* zone") by Laudon (1929, 1937), although we also recognize it in the lower Cedar Fork of Washington County. Brachiopods are scattered to abundant in the field trip area. Large spiriferids are conspicuous in some beds, and their valves occasionally display borings and corroded pits. Brachiopods of the Order Spiriferida include *Spirifer grimesi*, *Unispirifer forbesi*, *Imbrexia incerta*, *Syringothyris typa*, *Verkhotomia plana*, *Brachythyris* sp., and *Cleiothyridina incrassata*. Additional brachiopods from the field trip area include productids (*Marginatia burlingtonensis*, *Echinoconchus alternata*, *Setigerites viminalis*), strophomenids (*Schellwienella* sp.), chonetids (*Rugosochonetes illinoisensis*), orthids (*Rhipidomella burlingtonensis*, *Schizophoria swallovi*), terebratulids (*Dielasma* sp.), and undetermined rhynchonellids. Solitary corals (not studied) and gastropods (*Platyceras* sp., *Orthonychia* sp., *Serpulospira paradoxus*) are also noted.

BURLINGTON CALCAREOUS FORAMINIFERA. Reconnaissance sampling by Woodson of the Starrs Cave-Burlington interval in southeast Iowa has, to date, produced identifiable multilocular Foraminifera only from the Cedar Fork Member of the Burlington Limestone.

Calcareous Foraminifera occur sparingly in the Cedar Fork Member in Keokuk and Washington counties. Endothyrids and *Earlandia* spp. occur in abraded bryozoan echinoderm packstones to grainstones containing common glauconite and phosphatic material. Although some lithologies appear "oolitic" in hand sample, no coated grains are noted in thin-section. Rather, the "ooids" are small pelmatozoan columnals and comminuted bryozoan debris representing the winnowed fines of the Cedar Fork. This fine-grained facies occurs sporadically, both vertically and laterally, in the Cedar Fork and is the source for most of the Foraminifera recovered. Medium to coarse-grained Cedar Fork calcarenites typically yield no endothyrid taxa.

At Keswick Quarry (STOP 2), where there is good stratigraphic control (about 50 thin-sections from 10 samples within a 5.7 m [18.7 ft] interval of Cedar Fork), multilocular Foraminifera are present throughout most of the unit. However, the Cedar Fork depositional environment was clearly unfavorable for the production of abundant, taxonomically diverse assemblages such as are found in inner shelf environments. Lane and Brenckle (1981) noted that the Burlington of the type Osage and of the Mississippi River Valley exhibit both a paucity and a low diversity of calcareous microfossils. Although deposited on a shallow-water carbonate shelf, the Burlington assemblage appears to represent a slightly deeper water, more basinward foraminiferal biofacies.

Although the fauna is not diverse, it is of biostratigraphic interest. *Earlandia* spp., "*Priscella*" of the group "*P. prisca*," *Endothyra* spp., and *Endothyra* of the group *E. obsoleta* are present in the Cedar Fork Member. All of these taxa are long-ranging. The genus "*Priscella*" (Mamet, 1974) first occurs in the Late Tournaisian (Tn3), at the base of or within Mamet zone 9 (Sando et al., 1969; Mamet, 1976; Armstrong and Mamet, 1977; Mamet and Bamber, 1979; Beauchamp and Mamet, 1985; Mamet et al., 1986). Similarly, *Endothyra* sensu stricto first occurs at the base of or within zone 9 (Mamet, 1977; Armstrong and Mamet, 1976, p.19; Armstrong and Mamet, 1977; Beauchamp and Mamet, 1985). Thus, the presence of "*Priscella*" and *Endothyra* s.s. in Cedar Fork strata at Keswick and nearby quarries indicates that the unit is largely, probably entirely, of Late Tournaisian (zone 9) *or younger* (Visean) age. The total range of *Endothyra* of the group *E. obsoleta* is uncertain in North America, but in Western Europe it apparently first occurs in the Visean (see Brenckle et al., 1974). The occurrence of "*Priscella*" and *Endothyra* in the Cedar Fork Member is congruous with the interpretations of Brenckle et al. (1974, 1982), Baxter and Brenckle (1982), and Brenckle and Groves (1987). It clearly contradicts, however, the assertion of Mamet (Sando et al., 1969; Mamet and Skipp, 1970a, 1970b; Petryk et al., 1970; Macqueen et al., 1972; Armstrong and Mamet, 1974, 1975; Bamber and Mamet, 1978) that the upper Burlington is of Middle Tournaisian (Tn2, zone 7) age.

In summary, the Cedar Fork Member of the Burlington Limestone contains no foraminiferal taxa that *restrict* its age to the Late Tournaisian (zone 9). The Cedar Fork can be *no older* than Late Tournaisian, but, as suggested by the presence of *Endothyra* of the group *E. obsoleta*, it may be younger (Visean).

BURLINGTON PETROGRAPHY AND DIAGENESIS. The Burlington Formation in southeast Iowa and adjacent areas of Missouri and Illinois has been the subject of numerous petrographic, sedimentologic, and geochemical studies over the past decade. These studies have provided insights into depositional and diagenetic processes that affected Burlington strata, but various studies have also created unresolved interpretive problems. Carozzi and Gerber (1984) recognized two general suites of carbonate microfacies in the Burlington, an "arenite suite" (packstones and grainstones) and a "wacke suite" (wackestones). They interpreted the arenite suite to represent shallow, subtidal crinoidal bank facies deposited at or near fair-weather wave base, with graded strata of the wacke suite deposited as "inertia flows" off the banks. In contrast, Harris (1982) suggested that Burlington sediments were deposited below fair-weather wave base, but above storm wave base. The presence of fish bone horizons and abundant glauconite in the Cedar Fork grainstones suggests periods of slow sedimentation (Cander et al., 1988, p. 131), which is generally inconsistent with a shoaling carbonate bank model. We suggest, instead, that episodic storm currents adequately account for the winnowed grainstones, graded bedding, low-angle cross-stratification to parallel laminations, preservation of articulated echinoderms, and discontinuous tabular to starved lensatic bedforms seen in the Burlington Formation.

Carbonate constituents in the Burlington Formation were analyzed for trace elements and stable carbon and oxygen isotopes by Brand and Veizer (1980, 1981). They indicated that the Burlington carbonates were "stabilized in an open diagenetic phreatic meteoric system" and subjected to "intense diagenetic equilibration with meteoric water" (Brand and Veizer, 1981, p. 987, 995). Subsequent petrographic, cathodoluminescent, and isotopic studies of the Burlington Formation in Iowa and Missouri by researchers at the State University of New York at Stony Brook, further supported a freshwater phreatic origin for *all* calcite cements in the formation (Harris, 1982; Harris and Meyers, 1987; Kaufman et al., 1988; Cander et al., 1988; Kohrt et al., 1988). The Burlington crinoidal grainstones are typically cemented by inclusion-poor syntaxial calcites that display a constructive cathodoluminescent (CL) crystal growth zonation. The Stony Brook research group further supported a view that meteoric calcite cementation occurred no earlier than the pre-St. Louis unconformity (some is younger), as marine waters did not withdraw from the region until after Keokuk-Warsaw deposition. In this interpretation, intergrain porosity would have had to remain open during submarine burial, and was not cemented until after the full sequence of Osagean and lower Meramecian strata had been deposited. In the case of the Dolbee Creek grainstones, which are buried beneath 60 m (200 ft) of sub-"St. Louis" strata, an open framework would need to be preserved during several million years of burial history with no apparent cementation. Although the analytical data are compelling, the resulting burial scenario raises intriguing questions.

Why aren't marine cements obvious in the Burlington grainstones? Although the bulk of the calcite cements are syntaxial to echinoderm grains, additional cements are noted that deserve additional study, including "fringing prismatic calcites" (Harris, 1982; Kaufman et al., 1988). We have observed prominent bladed and acicular cements in some Cedar Fork grainstones with CL signatures that are highly suggestive of a marine origin with subsequent diagenetic modification. Although the Stony Brook research group has reasonably interpreted the syntaxial calcites to be of meteoric origin, is it possible that some syntaxial cements were of marine origin but diagenetically overprinted or replaced during later meteoric events?

Dolomite and silica diagenesis of Burlington rocks has also been evaluated in several recent studies, and a complex diagenetic history is indicated (Harris, 1982; Harris and Meyers, 1987; Seigley, 1987; Seigley et al., 1988; Banner et al., 1988; Cander et al., 1988). The Stony Brook research group recognized that most lime mud was regionally dolomitized, and they interpreted an early and dominant phase of dolomitization that predates *all* calcite cementation (Harris and Meyers, 1987; Cander et al., 1988). Later-stage dolomitization was minor and largely replacive of earlier dolomite rhombs (ibid.). A differing view of the paragenetic sequence was presented by Seigley (1987), who found petrographic evidence to suggest that the earliest stages of syntaxial calcite cementation and microquartz (chert) replacement pre-date dolomitization. Banner et al. (1988) supported a marine/meteoric-mixing model for the early and dominant stages of dolomitization, and we concur. However, if some syntaxial calcite pre-dates dolomitization, then a marine origin may be indicated for some syntaxial cements. Although the past decade has seen considerable advancement in our understanding of the diagenesis of Burlington rocks, further studies may help to unravel additional aspects of the diagenetic history.

KEOKUK FORMATION

The Keokuk limestone was named by Owen (1852) for bluff exposures of cherty carbonate at Keokuk, Lee County, Iowa. Hall (1857; Hall and Whitney, 1858) defined the Keokuk Formation to include a lower cherty limestone interval, a middle crinoidal limestone unit, and upper geode-bearing strata. Keyes (1895) designated these lower beds the "Montrose cherts," named for exposures at Montrose, Lee County, but he included these strata in an expanded Burlington Formation. Van Tuyl (1925) returned the Montrose interval to the Keokuk Formation, but assigned the geode-bearing strata to the overlying Warsaw Formation. Subsequent usage in Iowa has followed Van Tuyl's definition of the Keokuk (see Harris and Parker, 1964). We currently divide the Keokuk Formation in southeast Iowa into two units, a lower Montrose Member and an informal "upper Keokuk" interval (Fig. 7). Regional biostratigraphic relations of Keokuk strata are discussed by Collinson et al. (1971) and Baxter and Brenckle (1982). Faunal lists from Keokuk strata in Iowa are given by Van Tuyl (1925).

The Montrose Member in southeast Iowa is an interbedded sequence of skeletal limestone, dolomite, and nodular to bedded chert. The Montrose Member is significantly more cherty than underlying Cedar Fork strata. "Upper Keokuk" lithologies are similar to those of the Montrose, but limestones are commonly more abundant, chert is notably less abundant, and interbedded shales become significant in the "Upper Keokuk." The contact between these two intervals is apparently a facies transition, and can usually be drawn for convenience at the position where a prominent decrease in chert content is observed. Changes in chert content are less abrupt at some localities, where the contact is arbitrarily drawn below the first prominent shale in the sequence. Keokuk limestones (primarily crinoidal packstones) are similar to those of the Burlington but commonly display brownish colors unlike those of the Burlington. Glauconitic limestones occur in the Keokuk, but these apparently do not have the lateral persistence of the Burlington glauconitic horizons. "Bone bed" horizons are also noted in the "Upper Keokuk." Keokuk dolomites characteristically contain only sparse macrofauna, although scattered small crinoid debris molds are usually present. Keokuk dolomites are argillaceous to varying degrees, and differ from most Burlington dolomites by the common presence of interstitial siliceous material or sponge spicule molds (as seen under hand lens). Keokuk cherts commonly contain abundant sponge spicule fragments, and quartz crystals and chalcedony are common in some siliceous intervals.

The Keokuk Formaton in southeast Iowa ranges in thickness between about 14 and 27 m (45-90 ft), and averages about 20 m (65 ft) in the type area. The Keokuk is conformably overlain by the Warsaw Formation at most localities in southeast Iowa, but "St. Louis" strata unconformably overlie the Keokuk at some localities in Washington and Keokuk counties. The Montrose Member is directly overlain by the Croton Member of the "St. Louis" at the Keswick Quarry in Keokuk County (STOP 2), where the Keokuk Formation thins to as little as 7 m (23 ft). The Keokuk Formation becomes more dolomitic and incorporates significantly thicker shale intervals westward in the subsurface (Harris and Parker, 1964), and distinctions between Keokuk and Warsaw strata become increasingly more difficult to recognize in that direction (undifferentiated "Keokuk-Warsaw" interval on Fig. 3). Harris and Parker (1964, p. 6) "emphasize[d] the gradational relationship of the Warsaw and the Keokuk"; they (ibid., p. 31) recognized regionally that the Warsaw-Keokuk boundary is "nebulous and arbitrarily placed for uniformity at the top of the gray calcarenites in the southeastern district and at the top of the brown dolomites and brown cherts in the western [subsurface] district."

WARSAW FORMATION

We will not see strata of the Warsaw Formation on the field trip because of local sub-"St. Louis" erosional truncation, but a brief description of the formation is included here for completeness. The Warsaw Formation was named by Hall (1857; Hall and Whitney, 1858) for a sequence of interbedded shale and carbonate found above the so-called "geode beds" at Warsaw, Illinois, about 5 km (3 mi) down the Mississippi Valley from Keokuk, Iowa. Because of lithic and faunal similarities, Van Tuyl (1925) expanded the Warsaw to include the "geode beds."

The Warsaw Formation in the Keokuk, Iowa, area can be simplistically subdivided into two intervals (Fig. 7): 1) a lower interval of argillaceous dolomite and shale containing quartz geodes (the "geode beds" of Hall, 1857), and 2) an upper shale-dominated interval with interbeds of shaly to argillaceous dolomite. Bryozoans (including the distinctive *Archimedes* "corkscrews") and brachiopods are common in some beds in the formation, and faunal lists have been compiled (Van Tuyl, 1925). The absence or scarcity of undolomitized carbonate beds contrasts Warsaw and Keokuk strata in areas of southeast Iowa, but

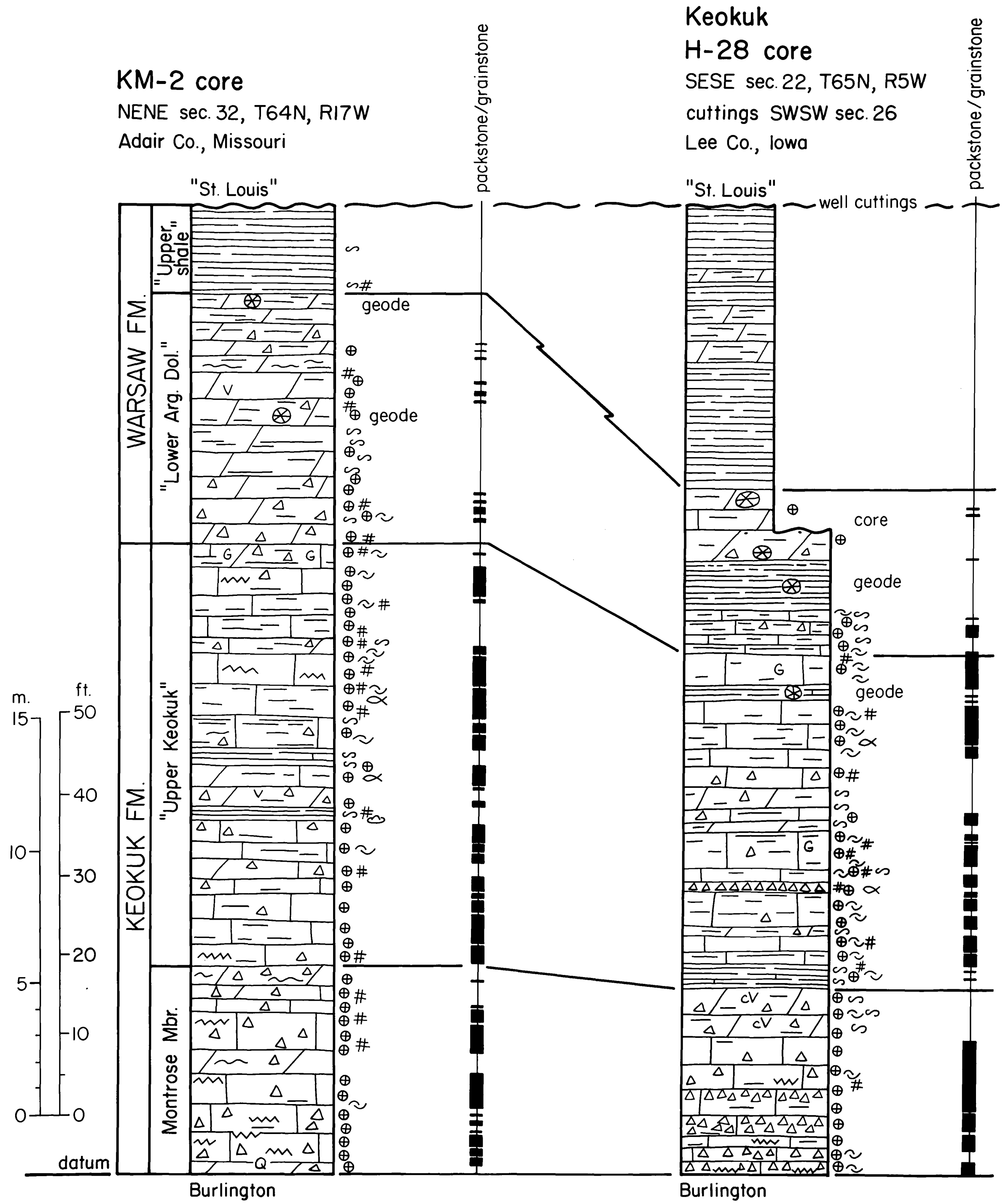

Figure 7. Stratigraphic section of Keokuk and Warsaw formations at Keokuk, southeast Iowa (core and well cuttings; Loc. H28, Fig. 1). Cored sequence in Adair Co., north-central Missouri, included for comparison (core on loan from Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla). See legend (in Appendix) for symbols.

distinctions between the two formations are less obvious regionally. The "lower argillaceous dolomite" interval of the Warsaw seemingly displays lateral relationships with both shale-dominated Warsaw facies and "Upper Keokuk" strata (Fig. 7). A prominent erosional unconformity marks the top of the Warsaw Formation in southeast Iowa, and "St. Louis" strata overlie this unconformity. Because of erosional truncation, the thickness of the Warsaw Formation varies significantly; it is commonly about 15 m (50 ft) thick, but is known to range between 0 and 26 m (0-85 ft) in southeast Iowa (Harris and Parker, 1964).

"ST. LOUIS" FORMATION

NOMENCLATURAL PROBLEMS. The interval in Iowa which has been termed "St. Louis" Formation has been little studied since the work of Van Tuyl (1925). This interval was first recognized in Iowa by Owen (1852) near the mouth of the Des Moines river, who referred to these exposures as the "concretionary limestone". In 1858 Hall and Whitney correlated the concretionary limestone with the St. Louis Limestone, a unit first named by Engelmann (1847) for extensive exposures near St. Louis, Missouri. Part of the basis for his correlation was the occurrence of the colonial rugose coral "*Lithostrotion*", which at the time was considered a guide fossil of the St. Louis. White (1870) continued the usage of the term St. Louis and Gordon (1895) subdivided the formation in Van Buren County into informal member divisions which were assigned formal member status by Bain (1896) based upon his work in Keokuk and Washington counties. The "Pella beds", the uppermost of Bain's three member divisions, were subsequently correlated with the Ste. Genevieve Formation and raised to formational rank (see summary in Johnson, 1967, and Johnson and Vondra, 1969). Bain's other member divisions, Verdi and Springvale, were modified by Weller and Van Tuyl (1915) who simply divided the formation into "Upper" and "Lower" St. Louis. Van Tuyl (1925) discarded the term Springvale, demonstrating that this interval was equivalent to the Keokuk Limestone, and proposed a new member name, Croton, for a lower "St. Louis" division, while retaining the name Verdi for an upper member. Although Van Tuyl (1925) formalized the member names Verdi and Croton, he frequently synonymized them with "Upper" and "Lower" St. Louis in his section descriptions, and the names fell into disuse by subsequent geologists during the last 60 years. Hence, most geologists working in Iowa presently use the name "St. Louis" Formation referring to upper or lower "St. Louis" as needed. The Geological Survey Bureau presently and tentatively subdivides the "St. Louis" Formation in Iowa into four members which are in ascending include order the Croton, Yenruogis, Verdi, and Waugh.

Re-examination of these Mississippian strata was initiated as part of the Geological Survey Bureau's stratigraphic studies, and subsequent study has sought to clarify the stratigraphic position, age, and depositional conditions of a unique occurrence of abundant tetrapod fossils in Keokuk County discovered in 1985 (McKay et al., 1986; McKay et al., 1987; and Bolt et al., 1988). In this report, portions of the Iowa "St. Louis" interval are regarded as distinct from type St. Louis strata for three reasons: 1) biostratigraphic correlations between the Iowa sections and the St. Louis, Missouri type area suggest that the "Upper St. Louis" in Iowa is younger than any St. Louis strata from the type area (Woodson, 1987), 2) a significant portion of the Iowa "St. Louis" interval is composed of siliciclastic deposits that are strikingly dissimilar to the carbonate-dominated sections of the St. Louis Formation in the type area, and 3) lithostratigraphic based transgressive-regressive (T-R) cycle correlations suggest that the "Upper St. Louis" of Iowa is correlative with portions of the Ste. Genevieve Formation of eastern Missouri and western Illinois. Therefore, the Iowa "St. Louis" is placed in quotes in order to emphazise: 1) that the Iowa "St. Louis", as currently understood, is only in part a time correlative of the type St. Louis, and 2) that correlational and nomenclatural problems are associated with use of the term in Iowa. Additional stratigraphic study of the "St. Louis" in southeast and north-central Iowa is needed, and pending a more complete study of the interval in the outcrop and subsurface, use of the term in quotes seems appropriate.

SUB-"ST. LOUIS" UNCONFORMITY. The "St. Louis" Formation unconformably overlies the Keokuk, Warsaw, Salem, and Sonora formations in southeast Iowa. In Iowa, both the Salem and Sonora formations were previously referred to as the Spergen Formation (Ulrich, 1904) by Van Tuyl (1912 and 1925). However, current practice by the Geological Survey Bureau refers these strata to the

Salem or Sonora formations (Keyes, 1893; Wills, 1971; Willman et al., 1975) and restricts their distribution to that originally proposed by Van Tuyl (1925) for the Spergen. The Salem and Sonora formations are only sporadically preserved between the Warsaw and "St. Louis" formations in several southeast Iowa counties (Lee, Henry, Des Moines, Van Buren, and Jefferson). The magnitude of the sub-"St. Louis" unconformity increases from extreme southeast Iowa towards the northwest (Figs. 3 and 8). In southern Lee County the basal Croton Member lies upon either the Salem, Sonora, or Warsaw formations. To the northwest, in Washington and Keokuk counties, the Croton member rests unconformably on the Warsaw and Keokuk formations. Approximately 30 m (100 ft) of regional relief is present on the unconformity.

CROTON MEMBER. The "Lower St. Louis", as defined by Van Tuyl (1925), is synonymous with the Croton Member. The Croton derives its name from the town of Croton along the Des Moines River in western Lee County. No type section was specifically designated by Van Tuyl (1925), but he stated that the member is typically developed in the vicinity of Croton where the unit attains a thickness of about 9 m (30 ft). According to Van Tuyl the Croton is a massive, dense, variably cherty, dolomitic limestone which frequently grades laterally over short distances into dense, fine grained, gray, non-dolomitic limestone. Both lithologies may also be interbedded. Fossils, although apparently not abundant, include brachiopods, bryozoans, trilobites, bivalves, solitary rugose corals, tabulate corals, and the colonial rugosan *"Lithostrotion"* (now *Acrocyathus*, Sando, 1983). At many localities in Lee, Van Buren, Des Moines, and Henry counties the Croton is highly brecciated and consists of megabreccia to megaconglomerate. Megabreccias at a similar stratigraphic horizon occur in the St. Louis Formation in several west-central Illinois counties (Adams, Brown, Fulton, Hancock, Madison, McDonough and Schuyler; Collinson, 1964; Harvey, 1964; Baxter, 1965; Goodwin and Harvey, 1980), and in at least two counties (Clark and Lewis) in northeastern Missouri (Krey, 1924; Noble, 1957). Collinson (1964) interpreted these deposits as solution collapse breccias resulting from the dissolution of bedded gypsum/anhydrite, either by fresh or marine waters that transgressed the region during deposition of the upper St. Louis Formation. The limestone breccias of the Illinois outcrop belt appear to correlate with extensive middle and lower St. Louis sulfate evaporites in the subsurface of the Illinois Basin (Saxby and Lamar, 1957; McGregor, 1954; McGrain and Helton, 1964; Jorgenson and Carr, 1972; De Witt et al., 1979). Gypsum and anhydrite also occur in what is regarded as the lower "St. Louis" in the subsurface of south-central and southeast Iowa (Fig. 3). Previous workers (Tester, 1936; Dorheim and Campbell, 1958; Lemish and Sendlein, 1968) suggested that these evaporites occur within the Warsaw Shale, but more recent interpretations, including ours, consider them as belonging within the lower "St. Louis" (Dorheim, 1966; Perry, 1971; McKay, 1985). We concur with Collinson (1964) and interpret the megabreccias as resulting from dissolution of sulfate evaporites leading to collapse of overlying strata.

Although the Croton is brecciated at many localities in southeast Iowa, it also exists in what Van Tuyl (1925) referred to as its "undisturbed phase." The "undisturbed phase" was described (ibid.) as a regularly bedded facies consisting of medium to thick beds of variably fossiliferous and cherty, slightly sandy, dolomitic limestone, and minor interbedded sandstone. *"Lithostrotion"* is often present within the upper part of this normally bedded, marine facies.

Recent study of reconnaissance samples (lime wackestones to packstones) from the non-brecciated *"Lithostrotion"*-bearing interval in eastern Jefferson County (Fig. 8, Wesley core) has revealed the presence of biostratigraphically useful calcareous microfossils. Representatives of the foraminiferal genus *Eoendothyranopsis* occur abundantly as do fragments of the problematic alga *Koninckopora*. These microfossils occur in direct association with *Acrocyathus floriformis* (*"Lithostrotion"*). *Eoendothyranopsis* and *Koninckopora sp.* range no higher than the St. Louis Limestone in the Illinois Basin (Pohl, 1970; Baxter and Brenckle, 1982; Woodson, 1982; Brenckle et al., 1988).

This recently acquired biostratigraphic evidence supports Van Tuyl's (1925) and previous workers' traditional faunal and lithic based correlation of the Croton Member with the St. Louis Formation of the St. Louis type area. This traditional correlation was rejected by Campbell and Dorheim (Tri-State, 1957), and by Campbell (1966). These workers considered much of Van Tuyl's "Lower St. Louis"

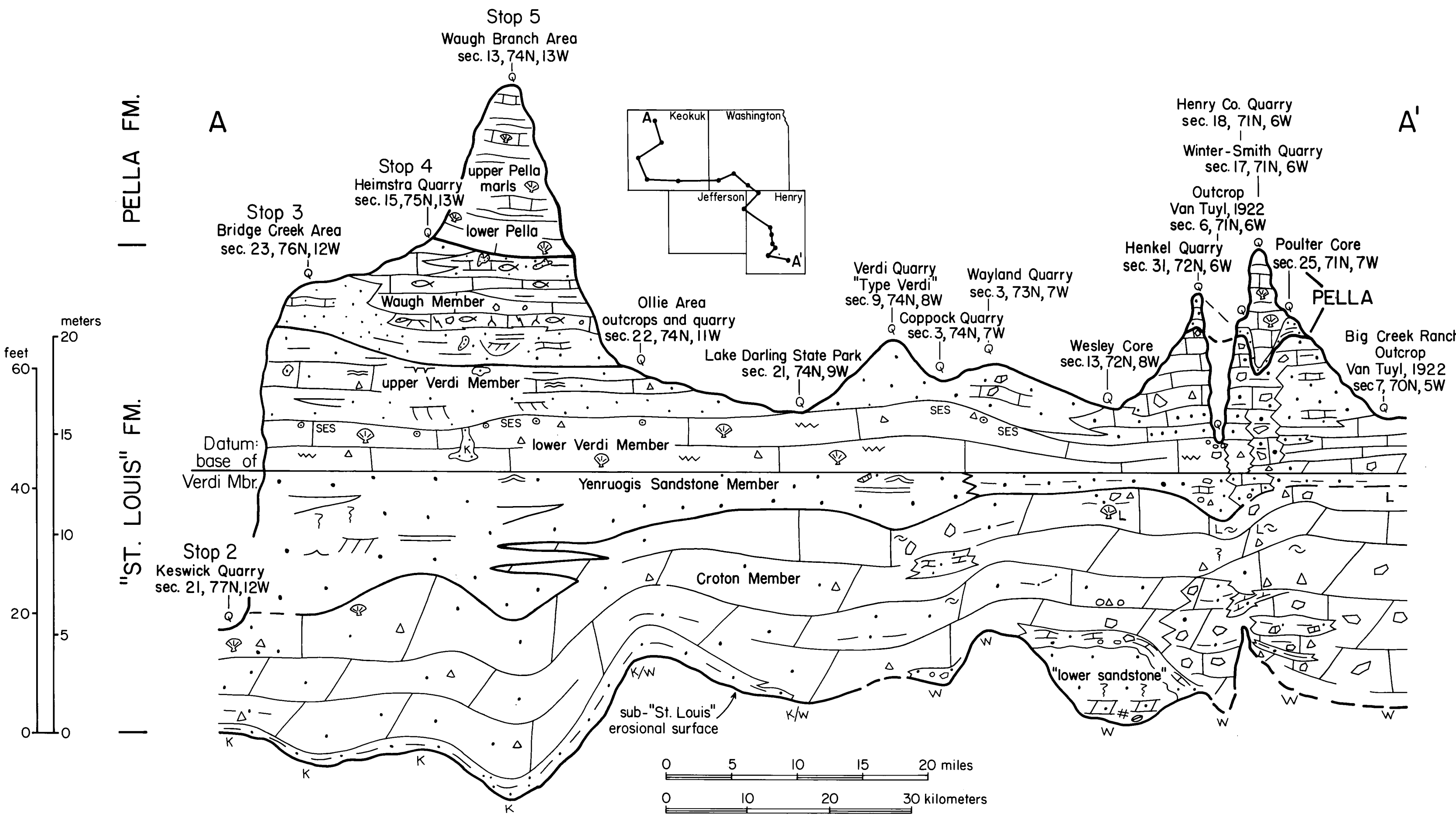

Figure 8. Stratigraphic cross-section of the "St. Louis" and Pella formations through a portion of their outcrop belt in Keokuk, Washington, Jefferson and Henry counties, Iowa. See legend (in Appendix) for symbols.

(Croton Member) to be equivalent to the Salem or Spergen formations and apparently promoted use of the term Spergen Formation in Iowa for the previously recognized "Lower St. Louis" (Croton Member). It appears that their use of the term Spergen for this interval strongly influenced most local geologists working in the Mississippian in southern Iowa, for it became common practice to refer to this interval as the Spergen (Iowa Geological Survey, cuttings, core, and outcrop logs; Iowa Department of Transportation, core and quarry logs; and Milne, 1978).

The Croton Member is readily traced from its type area in Lee County northwestward to Washington and Keokuk counties, primarily through the use of corehole and drillhole data and quarry exposures (Figs. 3 and 8). Natural outcrops of the Croton in the field trip area are rare and usually poorly exposed. The basal few feet of the Croton frequently consists of green to brown unfossiliferous siltstone to silty dolomite which often contains angular clasts of chert and limestone or dolostone. Locally, this basal siliciclastic interval is sandstone dominated. Where adequately exposed, as at Keswick Quarry, the basal siltstone is observed to infiltrate and fill fractures and voids in the irregular surface of the underlying Keokuk Formation. Locally, the lower portion displays a thickly laminated to blocky fabric which grades upward to a thinly, well-laminated fabric.

In several sections, the basal siltstone interval grades upward into a well-laminated, silty to argillaceous, very finely crystalline, unfossiliferous, cherty dolomite (STOP 2). The chert is typically distributed in thin elongate layers and lenses 2 mm to 2 cm thick. Chert color varies from brown to white, and chert fabric is well-laminated. In the Ollie area (southeast Keokuk County), similar cherts at this stratigraphic horizon display well developed desiccation crack patterns.

The middle and upper portions of the Croton Member in the field trip area are best exposed at the Keswick Quarry (STOP 2), hence much of the lithic description for this interval is derived from that section. The middle part of the Croton is a mixed siliciclastic-carbonate interval, approximately twenty-five percent of which is comprised of siliciclastic units. Most of the carbonate is dolomite but locally dolomitic limestones are present. The dolostones are brown to brownish gray, fine to very fine crystalline, variably argillaceous to sandy, moderately porous, and slightly to moderately cherty; fossils are not noted. Dolomite fabric is generally massive or faintly laminated, and argillaceous partings are moderately common. A few dolostone beds are brecciated to conglomeratic; these usually contain angular to subangular chert and limestone clasts in a sandy dolomite matrix.

Siliciclastic material within the middle Croton are present as argillaceous to sandy and pebbly components of the dolostones, and as discrete beds of shale, siltstone, or sandstone. Within the dolostones, clay, silt and sand are both disseminated and concentrated in horizontal, planar to wavy partings and laminae. The sand is quartz or chert, and very fine- to coarse-grained. Coarse-grained quartz sand is often rounded and frosted. Discrete beds of siltstone and sandstone dominate over shale. Siltstone and sandstone beds generally are less than 0.5 m (1.6 ft) thick. Siltstone is calcareous to dolomitic, variably sandy to argillaceous, and usually massive, but some beds display faint horizontal planar lamination. Sandstones range from poor to moderately sorted, and dominant sand grain size ranges from very fine to coarse. At Keswick Quarry (STOP 2), the least sorted sandstone unit occurs above laminated dolomite and chert of the lower Croton. The sandstone contains large (up to 7 cm) angular clasts of these laminated cherts in a medium to coarse-grained quartz sand matrix. Siltstone and sandstone also sporadically contain detrital clay flakes and clasts. Fossils have not been recovered from any siliciclastic unit of the middle Croton. Sandstones are usually calcareous or dolomitic, and some sandstone units contain lenses of very fine crystalline dolomite.

Lateral Relationships. Detailed lateral facies relationships of the lower and middle Croton in the field trip area are poorly known because of the scarcity of quality outcrop and subsurface data. Generalized facies patterns, however, are reasonably established (Figs. 3 and 8). Most of the sections available in Keokuk and Washington counties appear to be analagous to Van Tuyl's (1925) "undisturbed phase" in that they are dominantly well bedded and lack extensive brecciation. However, to the southeast in Henry County and further south into Des Moines and Lee counties, this interval contains sections which are highly brecciated. The lithology of the clasts within these brecciated sections is similar to the lithology of the undisturbed sections to the northwest, and the breccia matrix is often dominated by a siliciclastic component of clay, silt and sand. Subordinate matrix components include dolomite and calcite spar, calcium sulfate spars and trace amounts of iron and zinc sulfides. Westward in the subsurface of Mahaska and Marion counties and southwestward into Monroe and Appanoose counties, the lower and middle Croton grades laterally into a mixed dolostone, siliciclastic, and sulfate evaporite facies. The evaporites (gypsum and anhydrite) are currently mined at the Kaser Corporation Durham Underground Mine in Marion County, and were mined for a brief time during the 1920's at Centerville in Appanoose County (McKay, 1985).

The upper Croton is distinctly different from the lower and middle portions in that it contains sparsely to moderately fossiliferous dolostones and limestones; siliciclastic content is also lower. Carbonate fabrics include skeletal mudstones, nonskeletal, laminated desiccation-cracked mudstones, and skeletal wackestones through grainstones. Dolomitic equivalents of these rock types locally are dominant. Skeletal grains are dominated by brachiopods, echinoderms, and foraminifera; subordinate faunal elements include gastropods, solitary rugose corals, bryozoans, tabulate corals, ostracodes, and colonial rugose corals; limited search for conodonts has been unsuccessful to date. Nonskeletal carbonate grains include peloids and mudstone lithoclasts. Quartz silt and sand is present in variable amounts in the fossiliferous carbonates, but is most abundant in the laminated and desiccation-cracked intervals. Skeletal carbonate beds within the upper Croton are generally medium to thick bedded, and frequently are stylolitic. Some carbonate beds display a bioturbated fabric or discrete burrows. Cross-stratification within the carbonates has not been noted. Minor amounts of white and black chert in the form of nodules to thin lenses are also present.

Systematic collection and identification of fauna from the the Croton Member in southeast Iowa has never been fully completed. Van Tuyl (1925) listed the fauna from several sections, and it is apparent from his descriptions of relatively sparse collections that the Croton is more fossiliferous towards the southeast (e.g. Lee, Van Buren, and Henry counties). *Lithostrotion* (now *Acrocyathus*, Sando, 1983), a colonial rugose coral, is perhaps the best known macroinvertebrate of the Croton. It has been widely reported from the upper Croton, and is preserved as a calcitic to silicified skeleton. However, *Acrocyathus* has not been reported northwest of eastern Jefferson County, and has not been found in the Croton from the field trip area. *Eoendothyranopsis*, a calcareous foraminiferan, has recently been recovered from the *Acrocyathus* horizon of the upper Croton in Jefferson County. This occurrence bolsters the long-held correlation of the Croton with the St. Louis of the type area, since *Eoendothyranopsis* ranges no higher than the St. Louis (Baxter and Brenckle, 1982).

In the field trip area, the upper Croton is best exposed at the Keswick Quarry (STOP 2), however the upper contact with the overlying Yenruogis Member is not present. It is dominated by lime mudstones to grainstones and contains subordinate amounts of dolostone and siliciclastics (STOP 2). Although slightly truncated, the interval is less than 2.0 m thick. The least faunally restricted marine unit (lower part of Unit 45) occurs immediately above desiccation-cracked, laminated lime mudstones, and is only 22 cm thick. Above this is 90 cm of medium-bedded, sparsely skeletal lime mudstone which contains several 1 to 2 cm thick layers of whole-valve brachiopods including *Composita* and *Brachythyris altonensis* (personal communication, B.F. Glenister, 1989). *Brachythyris altonensis* has been noted to occur in the Croton further to the southeast in Iowa (Van Tuyl, 1925), and also in the St. Louis Formation at Alton, Illinois (Weller, 1914).

In the field trip area the upper contact of the Croton with the overlying Yenruogis Member is poorly exposed, and has not yet been studied in outcrop or core. However, to the southeast in Jefferson and Henry counties, the uppermost Croton consists of sandy, laminated dolostone overlain locally by a sandy and dolomitic, brecciated to conglomeratic interval (Fig. 8). This clastic interval, at least locally, characterizes uppermost Croton strata.

Depositional Interpretation. The Croton Member is interpreted to represent renewed marine incursion into southeast Iowa following a period of substantial erosion which partially truncated portions of the Keokuk, Warsaw and Salem formations. The hiatus beneath the Croton represents the largest and most significant unconformity within the Mississippian System in Iowa.

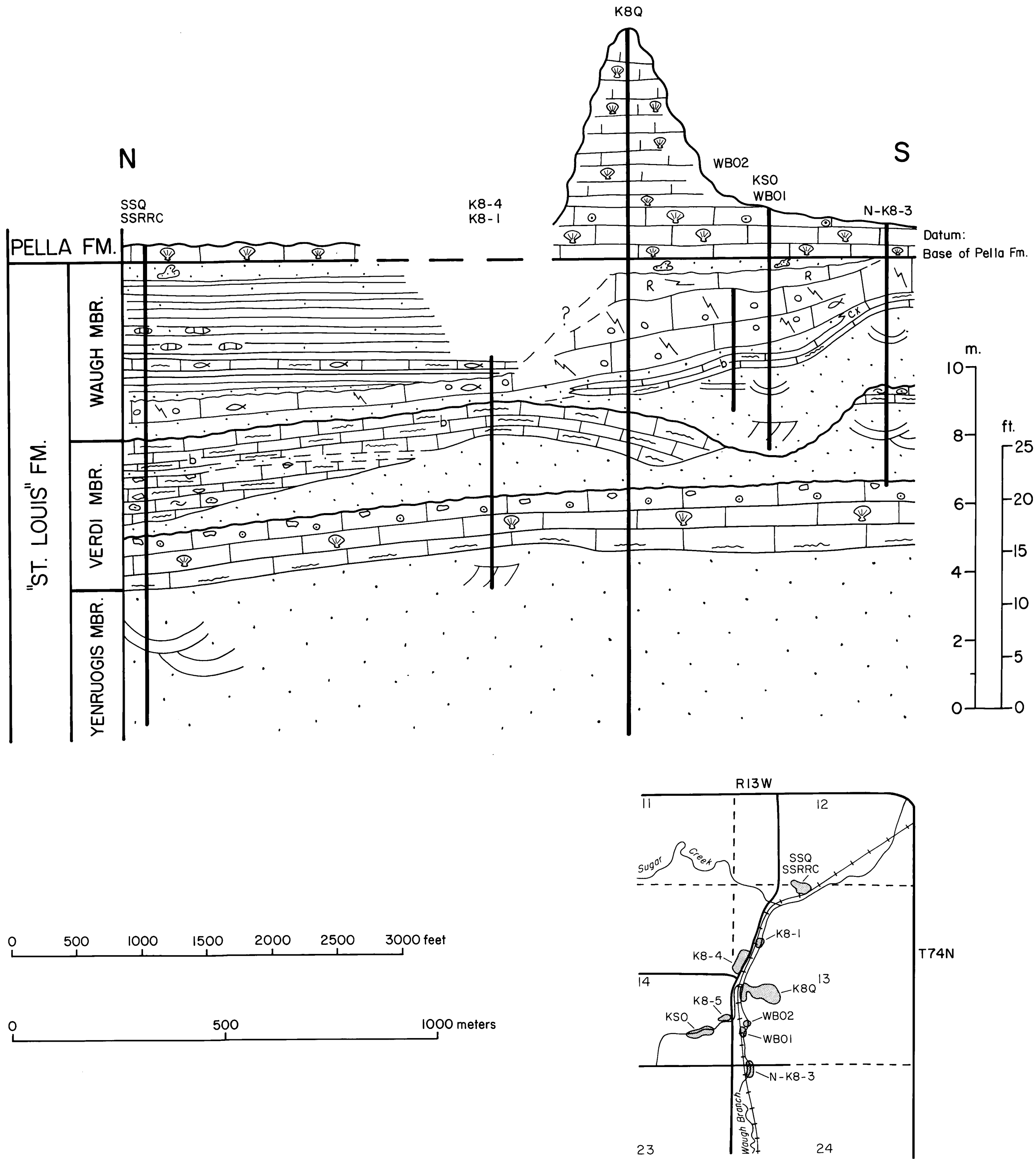

Figure 9. Stratigraphic cross-section along the Waugh Branch, Keokuk County, illustrating relations of the Verdi and Waugh members, and the overlying Pella Formation. See legend (in Appendix) for symbols.

The lower and middle portions of the Croton have received little regional study, and detailed study of multiple sections is lacking. However, available data suggest that these portions of the member were deposited under highly to moderately restrictive marine conditions. The laminated fabrics and unfossiliferous nature of the lower and middle Croton at Keswick Quarry, and their inferred lateral relationship to sulfate evaporites and solution collapse breccias indicate deposition within a highly restricted to evaporitic marine realm. These facies are similar to those of the lower St. Louis Formation in the Illinois Basin.

The upper Croton, is the most fossiliferous portion of the member, represents continued marine transgression across the region and introduction of more normal-marine water. The moderately diverse fauna of the upper Croton contains elements common to the St. Louis Formation of Illinois and Missouri (*Acrocyathus* and *Eoendothyranopsis*). The contact of the Croton with the overlying Yenruogis sandstone is poorly studied, but declining faunal diversity and occurences of conglomerate and breccias in the uppermost meter or so suggest shallowing to possible subaerial exposure at the close of Croton deposition.

YENRUOGIS MEMBER. The Yenruogis Member is, herein, proposed as a newly named member of the "St. Louis" Formation in Iowa. The Yenruogis Member is a mappable sandstone unit that contains minor carbonate interbeds. The type section (STOP 3) is located along the south valley wall of Bridge Creek in the SE NE NE sec. 22, T76N, R12W (Van Buren Township), Keokuk County. The member is particularly well exposed in natural outcrop along Bridge Creek in Keokuk County, and for this reason the type section was selected from this area. Additional reference sections occur along the south and north valley walls of Bridge Creek in sections 22 and 23, T76N, R12W. Unfortunately, neither the upper nor lower contacts of the Yenruogis are exposed in the type area. However, at least the upper bounding contact is exposed in sections north of Hedrick, Keokuk County (Figs. 9 and 10A). The name Yenruogis is taken from nearby Lake Yenruogis, an abandoned, water-filled quarry, which is now part of Lake Yenruogis County Park. The park is operated by the Keokuk County Conservation Board, and is located in the NE sec. 23 T76N, R12W. Both the park and the type section locations are found on the USGS Keswick 7.5 minute quadrangle topographic map.

The Yenruogis Member occupies a stratigraphic position above the Croton Member and below the Verdi Member (Fig. 8). Sandstone in this position was previously considered by Bain (1895) and Van Tuyl (1925) to be part of the Verdi Member. However, our recent investigations recognize this sandstone to be a widespread, distinct lithic unit of mappable dimensions that warrants member status. Outcrop, quarry, and subsurface data indicate that sandstone of the Yenruogis Member varies in thickness from 1 m (3 ft) to approximately 14 m (45 ft) over at least a six county area in south-central and south-east Iowa. Sandstone at this stratigraphic position has been recognized in the following counties: Keokuk, Mahaska, Marion, Poweshiek, Wapello and Washington.

The type Yenruogis section, (STOP 3), consists of 5.5 m (18 ft) of well-stratified, very fine- to fine-grained, quartzose sandstone. The sandstone is weakly calcite-cemented, friable, porous and lightly case-hardened. The dominant sedimentary structures include large-scale horizontal to low-angle planar stratification, and pronounced large-scale low-angle major truncation surfaces. The truncation surfaces cut into 0.6 to 1.5 m (2 to 5 ft) thick sets of horizontal to low-angle strata at shallow angles of ten to fifteen degrees. Truncation surfaces extend laterally up to 8 m (26 ft) across the section and dip to the southeast (133^o and 145^o dip azimuth). Horizontal and low-angle strata comprise the bulk of the outcrop. Sandstone texture is uniform and this characteristic complicates determination of the thickness of individual laminae or layers, but most appear to range between 1 and 10 mm. Laminae do not appear to exhibit significant size-sorting, grading, or concentrations of heavy minerals. A minor number of laminae display low-amplitude (2.5 cm) wavy (30 cm wavelength) structure. Small-scale symmetrical ripple cross-strata with silt-drapes are present along the lower truncation planes. Symmetrical ripple amplitudes are 0.5 to 1.0 cm, and wavelength is 10 to 12 cm. Skeletal or moldic faunal remains have not been observed in the sandstone, but trace fossils in the form of burrows are present at several positions. Burrow forms include simple vertical tubes (*Skolithos*), bilobed to branched vertical tubes, and vertical to diagonal j-shaped tubes. Burrow tubes are sand-filled, and are slightly differentially cemented from the enclosing sandstone; this attribute renders them visible on weathered outcrop. The average burrow width is 0.5 cm, and burrow lengths range between 1.5 and 4.5 cm.

Similar textural properties and physical and biogenic sedimentary structures are found in other outcrops of the Yenruogis in the type area along Bridge Creek, but several outcrops exhibit some facies variation. Large-scale tabular cross-strata, in sets up to 70 cm thick overlain by horizontally-stratified sandstone, are locally present. Sand-size within these tabular sets is slightly coarser and ranges into the medium-grained size range. Maximum foreset dip azimuths of tabular set laminae average 343 degrees (n = 2). Additional bedform configurations include minor development of hummocky to swaley cross-stratification.

Outside of the type area the Yenruogis is usually poorly exposed, however texture and sedimentary structures appear to be similar. At Bain's (1896) type Verdi section in Washington County, grain-size is comparable and stratification is dominated by horizontal laminae. Exposures in the southern portion of Keokuk County (Fig. 10A) also display similar lithic characteristics.

Figure 8 displays the generalized lateral relationships of the Yenruogis to the south and east of the type area. South of the type area the member contains some sandy dolostone interbeds. To the east the member thins to approximately one meter and appears to grade to a mixed siltstone to sandstone-dominated interval. To the west, in the subsurface of Mahaska and Marion counties, the Yenruogis sandstone thickens locally up to 14 m (45 ft), and overlies both carbonate and gypsum/anhydrite facies of the Croton.

Where adequately exposed, bed configuration in the uppermost meter of the Yenruogis sandstone is observed to be dominated by small-scale ripple bed forms. Such well-exposed ripple fields have only been observed on the floors of quarries near Verdi, Washington County, and in the Waugh Branch area, southern Keokuk County. Ripple shape is dominantly symmetrical, but some ripples display a weakly developed asymmetrical profile. Ripple heights range from 0.5 to 1.5 cm and spacing ranges from 6 to 10 cm. Ripple lengths range from 7 to 100 cm, and crest patterns are primarily sinuous and three-dimensional. Crest axis orientations are rather unimodal, varying between 336^{o} and 53^{o} (n = 16). Some ripples are draped by thin laminae of sandy lime mudstone, and locally, thin lime mudstone intraclasts are enclosed in sandstone matrix.

The contact of the Yenruogis sandstone with the overlying Verdi Member is sharp, but appears to be conformable. As previously noted, uppermost Yenruogis sandstone beds contain intercalated sandy lime mudstone as ripple-drapes and thin layers. These are typically overlain by 10 to 20 cm of sandy, faintly laminated, peloidal lime mudstone to overpacked packstone that contains birdseye-like calcite spar. Desiccation cracks or other evidence of a subaerial disconformity appear to be absent.

Depositional Interpretation. The Yenruogis Member is interpreted to record progradation of siliciclastic sediments across the study area following the termination of carbonate dominated sedimentation of the Croton. The Croton-Yenruogis contact and the lower Yenruogis are poorly exposed and poorly studied, and it is not known if the lower Yenruogis contains evidence of nonmarine deposition. The presence, at least locally, of sandy dolostone breccia to conglomerate at the top of the Croton suggests the presence of an erosional surface at the contact, hence lower Yenruogis deposits may possibly record nonmarine sedimentation, but further study is needed.

The middle to upper Yenruogis interval is better studied and is interpreted to record nearshore marine siliciclastic sedimentation. Primary evidence for a marine origin is derived from the physical and biogenic sedimentary structures. The only ichnofossils known from the interval are the well-preserved burrow tubes. The burrows are typical marine forms. The well-stratified nature of the unit, in conjunction with only intermittent zones of bioturbation, indicate frequent agitation of bottom sediment. The sporadic occurrence of small-scale symmetrical ripples indicates deposition by wave-generated oscillatory flow. Silt and mud drapes over the ripples represent fallout from suspension in calmer water. If wave-generated oscillatory flow is assumed to be at least partially responsible for formation of stratification, the dominant horizontal to low-angle bedding of the fine-grained sandstone can be interpreted to have been deposited by flows having minimum orbital velocities of 0.4 m/sec (Harms et al., 1982, fig. 2-14). The prominent low-angle planes of truncation are assumed to have formed from flows with orbital

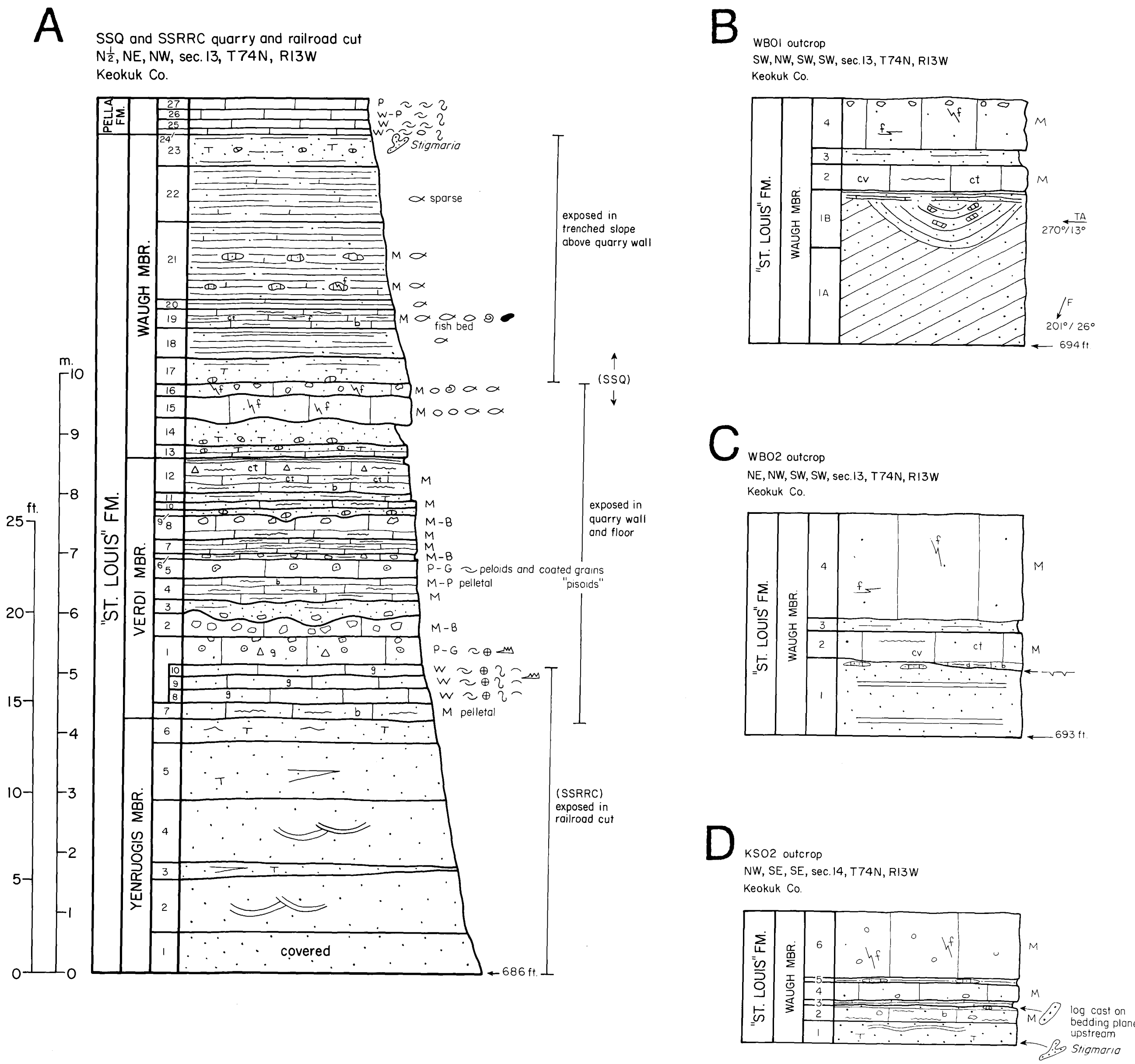

Figure 10. Measured sections of "St. Louis" and Pella exposures in the Waugh Branch, Keokuk County, area. Locations noted on map inset Figure 9. Written descriptions contained in McKay et al. (1987). See legend (in Appendix) for symbols.

velocities in excess of 0.4 m/sec. The presence of hummocky to swaley stratification also supports the interpretation that much of the flow was oscillatory and wave induced (Harms et al., 1982).

The presence of tabular sets of cross-strata is evidence of sporadic unidirectional to combined flow. The slightly coarser grain size within the tabular cross-strata suggests that flow conditions were more energetic than those that deposited the horizontal strata. The occurrence of three-dimensional symmetrical ripple fields at the top of the Yenruogis also supports the interpretation of wave-induced flow. Paleocurrent data from all structures, when considered with known paleogeography, suggests that wave propagation was primarily from the east and southeast, and more unidirectional flows were from the south to southeast. Wave-dominated siliciclastic sedimentation of the Yenruogis ceased as sea-level rose and drowned siliciclastic sediment sources, initiating carbonate-dominated deposition of the lower Verdi Member.

VERDI MEMBER. The Verdi Member was informally named the "Verdi beds" by Bain (1895) and formally named the Verdi Member the following year (Bain, 1896). The Verdi derives its name from the abandoned Verdi railway station in western Washington County (SW SE NE sec. 9, T74N, R8W). Bain (1896) described the type section from an old railway quarry near Verdi station. Van Tuyl (1925) maintained this locality as the type section and included a written description of the old quarry exposure. The Verdi was Bain's middle division of the "St. Louis" and encompassed essentially all strata that Van Tuyl (1925) and later workers would consider as the entire "St. Louis" in Iowa. Bain sometimes characterized the Verdi as the brecciated division of the "St. Louis", but also noted that the descriptor "brecciated" did not seem applicable because brecciated beds were only one phase of the unit. He noted that "in the counties lying farther west of Washington, the outcrops are more frequently of alternating layers of sandstone and limestone, as seen at Atwood (Keokuk County) and many other points in Keokuk and Mahaska counties (Bain, 1896)." Van Tuyl (1925) considered the term Verdi to be synonymous with upper "St. Louis" and characterized the unit as dense, fine-grained, sporadically oolitic limestones, locally interbedded with or passing laterally into sandstones. He noted a maximum thickness of 10.5 m (35 ft) for the unit and characterized the marine fauna as varied but not overly abundant.

The Verdi Member is a laterally persistent unit that is well exposed at numerous localities in southeast Iowa and in the field trip area (STOP 4, and Figs. 10A and 11A). In Keokuk, and Washington counties the Verdi averages 6 m (20 ft) in thickness; it sharply but conformably overlies sandstone of the Yenruogis Member and is overlain by sandstone or shale of the recently named Waugh Member (Fig. 8; McKay et al., 1987). The Verdi in this area is now considered to represent a middle, mixed carbonate-siliciclastic member of "St. Louis." Although Van Tuyl (1925) clearly included underlying sandstones within the Verdi Member, this sandstone interval, which occurs below the prominent marine limestones of the Verdi, is now regarded as the Yenruogis Member. As presently used, the base of the Verdi is a convenient stratigraphic datum, marked in Keokuk, Washington and adjacent counties by the contact between massive Yenruogis sandstone below and fossiliferous marine limestones above. Uppermost "St. Louis" strata of probable nonmarine origin, which formerly were included in the Verdi, are now assigned to a new member, the Waugh. The upper contact of the Verdi, which is locally disconformable, is marked at the highest occurence of peloidal, coated-grain, or marine skeletal limestone, and below lime mudstone, shale or sandstone that lack typical marine fabric and fauna.

Lower Verdi. The Verdi, in Washington and Keokuk counties, is readily divisible into a lower marine limestone interval and an upper interbedded limestone and sandstone interval (Fig. 8). The lower Verdi averages 2 m (6.5 ft) in thickness and is composed primarily of medium to thick bedded, bioturbated, peloidal and skeletal, lime wackestones to packstones that contain a relatively diverse marine macrofauna (Table 1). Marine microfauna in the form of conodonts, foraminifera, ostracodes, and miscellaneous calcareous microfossils are also common skeletal constituents (Witzke and McKay, 1987). The abundant, diverse, and biostratigraphically significant calcareous microfauna of the Verdi at Heimstra Quarry (STOP 4; Table 1) was described by Woodson (1987). Reconnaissance thin sections from the type Verdi of Van Tuyl (1925; Figs. 1 and 8) contain a foraminiferal assemblage similar to that at Heimstra Quarry. Foraminifera from these

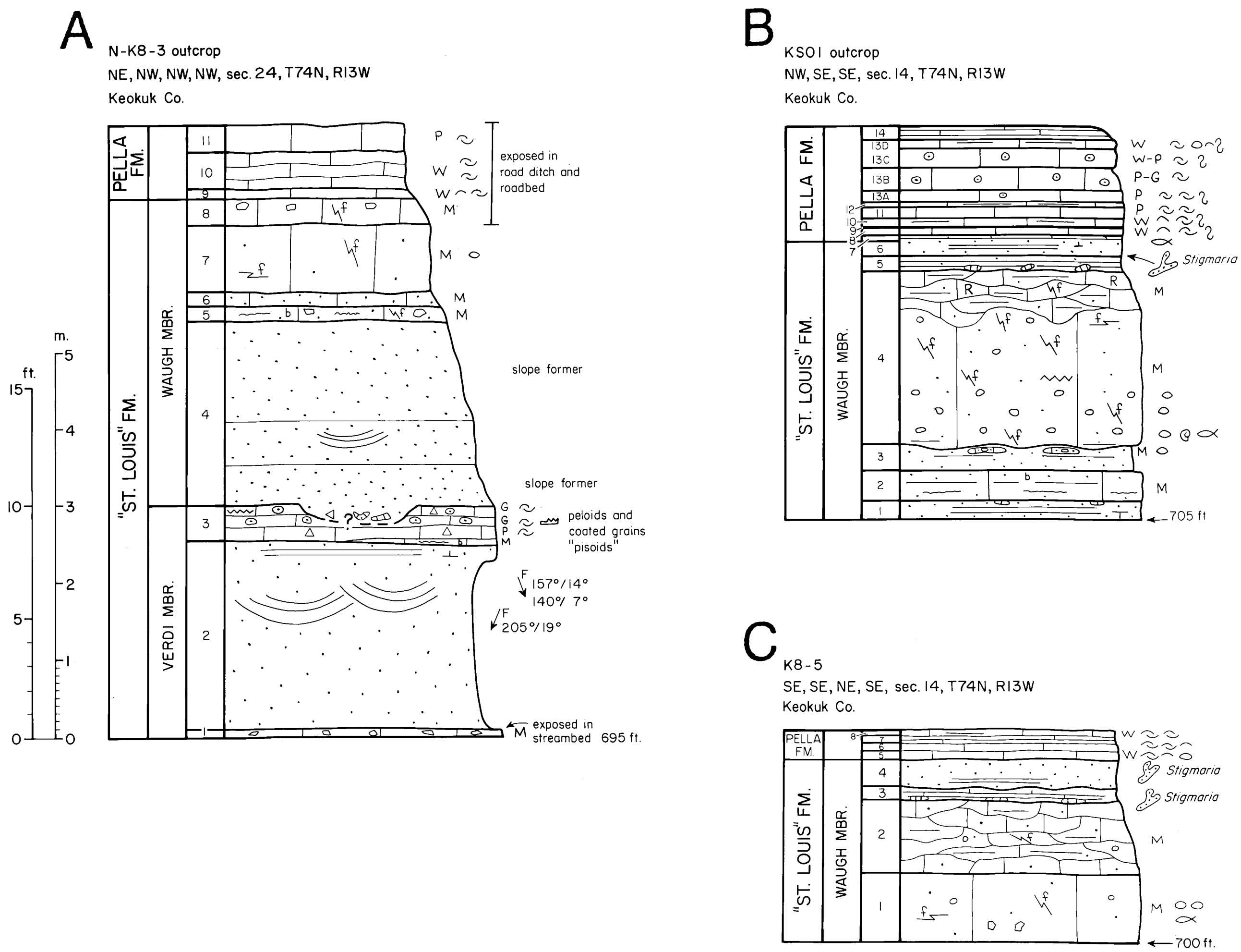

Figure 11. Measured sections of "St. Louis" and Pella exposures in the Waugh Branch, Keokuk County, area. Locations noted on map inset Figure 9. Written descriptions contained in McKay et al. (1987). See legend (in Appendix) for symbols.

Table 1. Macrofauna, Lower Verdi Member, "St. Louis" Formation, Keokuk County, Iowa.

Brachiopods
- -strophomenids
  - *Echinoconchus* sp.
  - *Ovatia ovata* (Hall)
  - *Setigerites* sp.
  - *Streptorhynchus* sp.
  - *Orthotetes* sp.
- -spiriferids
  - *Composita trinuclea* (Hall)
  - *Cleiothyridina* sp.
  - indet. small spiriferid
- -terebratulids
  - *Girtyella* sp.

Molluscs
- -bivalves
  - *Spathella* sp.
  - *Clinopistha* sp.
  - *Aviculopecten* sp.
  - *Cypricardella* sp.
  - *Schizodus* sp. *
  - *Modiomorpha* sp. *
- -scaphopods
  - *Laevidentalium* sp. *
- -gastropods
  - *Bellerophon* sp. *
  - *Bucanopsis* sp. *
  - *Straparollus* sp. *
  - indet. gastropods

Arthropods
- -ostracodes--indet. ostracodes
- -trilobites--*Kaskia* sp.

Echinoderms
- -indet. crinoid debris

Bryozoans
- -indet. bryozoans
  - *Fenestella* sp.

Corals
- -rugosans
  - *Neozaphrentis* sp.
- -tabulates
  - *Syringopora* sp.

Foraminifera and calcareous microfossils
- archaediscids, indeterminate
- *Asphaltinella* sp.
- *Calcisphaera laevis* Williamson 1880
- dasyclads, indeterminate
- *Diplosphaerina inaequalis* (Derville, 1931)
- *Earlandia* sp.
- encrusting foraminifers (e.g., calcivertellids, calcitornellids)
- *Endostaffella discoidea* (Girty, 1915) ["*Eostaffella*," *Eostaffella*?, *Zellerina* Mamet in Mamet and Skipp, 1970]
- *Endostaffella* spp.
- *Endothyra* of the group *bowmani* Phillips 1846 emend. Brady 1876 emend. ICZN 1965
- *Endothyra* of the group *obsoleta*? Rauzer-Chernousova 1948
- *Endothyra* spp.
- *Fourstonella* sp.
- "*Priscella*" spp.
- *Pseudoammodiscus* sp.
- *Pseudoglomospira* sp.
- *Tubisalebra* sp.

(* = listed by Van Tuyl, 1925, but not indentified in this study)

collections indicate that the Verdi is younger than the St. Louis Limestone in the Illinois Basin. The Verdi conodont fauna is also consistent with a post-St. Louis age assignment.

The Verdi marine macrofauna is similar in a general sense to that found in the Pella Formation, and several taxa are shared between the two units. However, some key brachiopods of the Pella (*Protoniella, Pugnoides*) are not known in the Iowa "St. Louis," and tabulate corals occur in the "St. Louis" but are absent in the Pella. The listed macrofauna (Table 1) represents fossils identified from the Heimstra (STOP 4) and Showman Station (Fig. 10A) quarries, but also includes molluscs listed by Van Tuyl (1925) from other Keokuk County locations. The marine fauna is regarded as stenohaline shallow marine, and suggests deposition under normal-marine salinities.

The medium to thick limestone beds of the lower Verdi are locally separated by thin 0.5 to 4.0 cm thick green to dark gray calcareous shale layers. The limestones contain minor amounts of chert, and spherical "cannonball" chert nodules locally replace tabulate corals. Trace amounts of glauconite and quartz sand are scattered throughout the wackestones to packstones. The upper one-half meter of many lower Verdi exposures grades upward to cherty, oolitic packstones to grainstones that are capped by laminated to brecciated intraclastic lime mudstones. This upper zone of mudstone displays features characteristic of subaerial exposure surfaces; it includes desiccation cracks and probable caliche and paleosol fabrics. Locally, the lower Verdi carbonates also host paleokarst that is infilled with sandstone that derived from the immediately overlying upper Verdi sandstone.

Upper Verdi. The upper Verdi averages 2.5 to 3.5 m (8 to 12 ft) in thickness. It consists of interbedded limestones and sandstones and locally displays numerous minor disconformities. Thin bedded, laminated, pelletal lime mudstones to packstones containing sparse birdseye dominate the sequence. These often grade upward into brecciated lime mudstones overlain by thin sandstones containing lime mudstone lithoclasts at their bases (Fig. 10A). Peloidal to coated-grain (pisoids to oncoids) packstones to grainstones, and laminated pelletal wackestones containing a low diversity marine fauna are also present. Minor white to gray chert lenses are noted locally. The fauna shows a marked decline in diversity compared to the lower Verdi. Calcareous foraminifera, ostracodes, molluscan debris, sparse conodonts (*Cavusgnathus*), and brachiopods (*Composita*) are present. Brachiopods are common locally, but occurrences represent monospecific brachiopod associations characteristic of so-called "stressed" environments.

Sandstone units, while thin at some localities (Fig. 10A), are notably thicker at sections JHQ (STOP 4) and N-K8-3 (Fig. 11A). At these locations the sandstones average 2.5 m (8 ft) in thickness and comprise 70-80 percent of the upper Verdi. To the southeast in Henry County, sandstone also locally dominates the unit (Fig. 8). The sandstones are quartzose, friable to slightly calcareous, and usually cross-stratified. Cross-stratification generally varies from large-scale tabular to large-scale trough sets, but horizontal and low-angle planar stratification are noted from other exposures. Limited paleocurrent direction data indicate that sand transport was predominantly to the south and southwest.

Depositional Interpretation. The lower Verdi interval is interpreted to represent a rapid, moderate-scale marine transgression over nearshore sands of the Yenruogis Member, and subsequent shallowing upward carbonate deposition of a single marine cycle. The low siliciclastic content indicates clear-water sedimentation removed from the clastic influx that characterized the underlying Yenruogis Member. The bioturbated, faunally diverse limestones indicate deposition under relatively calm bottom-current conditions within an aerobic normal-marine shelf or lagoonal setting. The ooid grainstones of the upper portion of the lower Verdi record shallowing, leading to increased bottom agitation. The overlying laminated mudstones record mudflat conditions, and the cycle cap, composed of mudstone breccia, caliche, and paleosol, indicates subaerial exposure. Localized paleokarst, filled with sandstone sourced from the overlying upper Verdi, indicates meteoric groundwater conditions prevailed until onset of upper Verdi sedimentation.

The upper Verdi interval is interpreted to have been deposited in very shallow restricted marine and nearshore to shoreface environments. Laminated birdseye mudstones which grade upward to brecciated mudstones suggest intertidal to supratidal conditions. Coated grain (pisoid to oncoid) fabrics were generated in periodically agitated settings under conditions of increased salinity, probably in shallow lagoonal environments. The low diversity faunas, are characteristic of "stressed" environments, probably related to increased salinity and temperature. The thick cross-stratified sandstone units may have been deposited as shallow nearshore subtidal bars. Thinner sandstone units which overlie brecciated mudstones and have mudstone lithoclasts incorporated at their bases may represent storm deposits during which subtidal sands were transported onshore into supratidal environments. Alternatively, they may record a thin distribution of fluvially-derived sands which were deposited during a flood interval of a nearby seaward-draining stream. In terms of overall "St. Louis" depositional patterns, upper Verdi strata record restricted marginal marine deposition which represents the final offlap of the "St. Louis" seaway from the area. The upper Verdi interval is overlain by the recently named Waugh Member, which was deposited in a variety of nonmarine settings. Marine onlap and deposition in this area apparently did not resume for an extended period of time until the Pella marine transgression.

WAUGH MEMBER. The Waugh is a recently recognized and named member of the "St. Louis" Formation in the Keokuk County area (McKay, 1987); it is now considered the uppermost member of the "St. Louis" in the area. The Waugh Member derives its name from the Waugh Branch, a small north-flowing tributary to the South Skunk River north of the town of Hedrick, southwestern Keokuk County. The Waugh is characterized by lateral lithofacies variability (Figs. 8 and 9), and because of this variability, designation of one locality as a type section was considered insufficient for member definition. Instead, a type area was proposed (McKay, 1987). The type area of the Waugh is within sections 13 and 14, T74N, Rl3W (Benton Township), Keokuk County (Hedrick Quadrangle, 7.5 minute series). Reference sections are at STOPS 4 and 5, and additional sections in the field trip area are shown in figures 10 and 11. Within the study area, Waugh Member thickness varies from 4.5 to 6.0 m (15 to 20 ft). Five major lithofacies are recognized within the Waugh Member. In ascending stratigraphic sequence they are: 1) planar to cross-stratified sandstones with thin laminated lime mudstones in the upper part, 2) sandy shales, 3) massive, fractured to brecciated, and intraclastic to conglomeratic, ostracode- and fish-bearing lime mudstones, 4) thin-to thick-bedded, partly laminated, ostracode- and fish-bearing lime mudstones interbedded with shale, and 5) scale tree root-bearing sandstone and associated paleosol. Two aerially restricted, but very significant, minor lithofacies also occur within the Waugh Member: 1) tetrapod-bearing limestone conglomerate and laminated shale, and 2) tetrapod-bearing boulder conglomerate. Both of these lithofacies are known only from the collapse structures at the Heimstra Quarry (STOP 4).

The strata of the Waugh Member in Keokuk County lack evidence of marine or restricted-marine deposition, and the contained fauna lacks all elements that are definitive for such settings (e.g., foraminifera, conodonts, echinoderms, bryozoans, brachiopods, trilobites, corals). Instead, the interval is dominated by a variety of fish, one species of small "spirorbid" snail, and one or two species of ostracodes. Tetrapods have been found only at the Heimstra Quarry (STOP 4). Table 2 is a listing of the fossils found in the Waugh Member and the following sections discuss the aforementioned lithofacies and their contained fauna.

Planar to Cross-Stratified Sandstone and Sandy Shale Facies. Planar- to cross-stratified sandstones occupy the basal portion of the Waugh in Keokuk County. These sandstones rest disconformably upon upper Verdi limestones and locally appear to truncate portions of the upper Verdi (Fig. 9). The planar-stratified subfacies is the most widespread sandstone type in the area. This sandstone is quartzose, very fine- to fine-grained, and slightly calcareous to friable. Planar-stratified sandstone is in part a lateral facies of large-scale cross-stratified sandstone, (Figs. 9, 10B and 10C). In general, planar sandstone is unfossiliferous, but scale tree log and root casts (*Stigmaria*) are present locally (Fig. 10D). At the top of the basal sandstone sequence, planar sandstone is interbedded with sandy, laminated lime mudstone. These mudstones contain birdseye-like structures, calcite-spar filled voids and small calcite spar-filled anastomosing tubules. Desiccation cracks as well as breccia clasts are present locally.

Locally, the basal portion of the Waugh is dominated by large-scale tabular and trough cross-stratified sandstone. This sandstone subfacies is well developed at section WBO1 (Fig. 10B) and is present, but less visible, at section N-K8-3 (Fig. 11A). The sandstone is quartzose, very fine- to fine-grained with some medium grains, and friable to slightly calcareous. Large-scale tabular cross-stratification is dominant and maximum foreset dip directions are toward the southwest. At section WBO1 (Fig. 10B) a large-scale trough cross-stratified channel fill overlies and truncates a portion of a large tabular set. Angular lime mudstone lithoclasts are present within some of the trough shaped foreset laminae. Trough foreset laminae display a relatively shallow inclination (13°), and the trough axis azimuth is due west. This channel is overlain by thinner, argillaceous planar-stratified sandstone and lime mudstone. Sandy shales locally occupy positions stratigraphically equivalent to planar and cross-stratified sandstones. At STOP 4 sandy shales overlie thin-bedded peloidal lime mudstones of the upper Verdi. Shales are generally light

Table 2. Fossils of the Waugh Member, "St. Louis" Formation, Keokuk County, Iowa

-Plants
- -*Stigmaria* roots and woody impressions
- -indet. carbonaceous fragments (bed a, main fill)
- -molds of branching three-pronged elements of uncertain affinities.
- -root molds

-Arthropods
- -indet, ostracod molds
- -myriapods

-Molluscs--small snail molds ("spirorbids")

-Vertebrates (sharks, fish, tetrapods)
- -Chondrichthyans (sharks)
  - -xenacanths--teeth; cartilaginous cranial bones; large skull (crushed)
  - -petalodonts--teeth
  - -ctenacanths--spines?
  - -indet. shark scales--numerous simple placoid and complex forms (probably xenacanths)
- -Acanthodians (fish)--scales; dermal tesserae; teeth and jaw fragments; spines and pinnal plates; partial body fossil ("*Gyracanthus*")
- -Palaeoniscoid Actinopterygians (fish)--numerous scales; jaw and maxillary fragments; post-cranial bones; partial articulated fish (several spp.)
- -Crossopterygians (lobe-finned fish)
  - -rhipidistians---nearly complete skeleton with scales; indet. scales
  - -rhizodonts--numerous large scales, dermal girdle bones (some in articulation); fins; jaws; cranial bones; partial skulls
- -Dipnoans (lungfish)--toothplate; nearly complete skeleton (aff. *Ctenodus*)
- -Labyrinthodont Amphibians--isolated bones (ribs, vertebrae, limb bones, pectoral and pelvic girdles, cranial bones, jaws, teeth), semi articulated material (vertebral columns, limbs, skulls), partial and nearly complete skeletons
  - -colosteid temnospondyls--at least one genus (new)
  - -proterogyrinid anthracoaurs--at least one genus (new) {now interpreted as proto-anthracosaur}
- -?Lepospondyl Amphibians
  - -possible microsaur material from micro-residues--jaw and maxillary fragments; limb bone

green, often oxidized to tan and orange hues, calcareous in part, laminated in part, and sandy to very sandy. Ostracodes, "spirorbid" snails, and fish scale debris are common to abundant. Dense, slightly argillaceous lime mudstone interbeds containing sparse fish debris may occur within the sandy shales. Locally these display desiccation cracks.

Depositional Interpretation. The planar- to cross-stratified sandstone facies and the sandy shale facies are interpreted to have been deposited in fluvial to marginal marine deltaic deposystems following regression of the Verdi seaway, in which restricted marine carbonates of the upper Verdi were deposited. Fluvial incision into upper Verdi carbonates is documented by large-scale tabular and trough cross-stratified sandstone sets which exhibit south and west flowing transport directions. A maximum of 2 m (6.5 ft) of fluvial incision into underlying upper Verdi carbonates is suggested by exposures along the Waugh Branch (Fig. 9). Documented truncation of upper Verdi carbonates by fluvial incision is limited to the Waugh Branch area. Planar-stratified sandstones and sandy shales which dominate the upper portion of basal Waugh strata may represent dispersal of sands and finer-grained siliciclastic sediments into overbank and shallow flood basin environments during stream floodstages. Scale tree logs were deposited locally during these events. In places, as at section KSO2 (Fig. 10D) scale tree growth was established as evinced by the presence of *Stigmaria* root casts. Shallow ponds or lakes probably existed in portions of the flood basin at certain times. These served as habitats for low-diversity ostracode and "spirorbid" snail populations, as well as fish. Laminated lime mudstones displaying calcite spar-filled voids and anastomosing tubules, and desiccation cracks with birdseye-like structures may record early stages of carbonate-dominated lacustrine sedimentation, or alternatively, may represent a brief period of restricted marine incursion. Overall, basal Waugh strata represent initiation of dominantly nonmarine depositional conditions which persisted throughout the remainder of Waugh Member deposition.

Massive, Fractured, and Conglomeratic Ostracode Lime Mudstone Facies. Massive, fractured to brecciated, and intraclastic to conglomeratic, ostracode- and fish-bearing lime mudstones are perhaps the most unusual and striking lithofacies of the Waugh Member when viewed on outcrop. Single, massive beds display thicknesses of 2 m (6.5 ft) in some outcrops. This lithofacies is present at numerous localities always overlying the basal sandstone-shale lithofacies. The massive lime mudstone lithofacies appears to have a wide lateral distribution extending at least as far west as eastern Mahaska County, and possibly extending into Marion County. Its eastern extent is not known. Overall thickness of this facies varies from 0.6 to 2.3 m (2 to 7 ft) within the field trip area.

In most outcrops, calcite spar-filled microfractures course through the rock. Locally, fractures are larger (up to 1 cm wide by several cm long); these are often filled with a combination of calcite spar and internal sediment of angular to subrounded lime mudstone intraclasts. Fracture-filling calcite varies in crystal size from micritic to coarse equant spar. High-density fracture portions of the rock exhibit a brecciated fabric. Some calcite spar and internal sediment-filled vertical voids may be related to filling of plant root void space (STOP 4).

Massive lime mudstones are variably intraclastic to conglomeratic throughout the study area. Subangular to subrounded lime mud clasts ranging in size from sand and granules to occasional pebbles are present in almost all outcrops. Intraclasts are usually enclosed within a mud matrix, but locally they may be concentrated to the extent that the rock becomes a clast to matrix-supported conglomerate. Conglomeratic horizons are present at sections KSOl (Fig. 11B), K8Q (STOP 5), and JHQ (STOP 4). At the Heimstra Quarry (STOP 4) conglomerate is noted at the top of Unit 11. Limestone conglomerate is also one of the two lithologies which comprise the tetrapod-bearing bone bed at the Heimstra Quarry.

Laminated fabrics are rarely present within massive mudstones. Quartz sand is present in all mudstones in minor amounts and mudstones may in places be slightly argillaceous. Thin calcareous shales locally interbed with massive mudstones.

The fauna of the massive mudstones lacks elements characteristic of marine or restricted-marine environments. Instead, the interval is dominated by "spirorbid" snails, ostracodes, and a variety of fish remains from several groups (acanthodians, elasmobranchs [sharks], crossopterygians, palaeoniscoids). Scant tetrapod bone has also been found in this facies. Witzke and McKay (1987) refer to this fauna as the nonmarine fish-tetrapod association.

Massive lime mudstones may be overlain by sandstone, shale, or laminated lime mudstone. Alternatively, as at many sections along the Waugh Branch (Figs. 11B and 11C), they may grade upward through a rubbly, rooted horizon overlain by a paleosol and a sandstone unit containing scale tree root casts (*Stigmaria*). Where overlain by *Stigmaria*-bearing sandstone and paleosol, the massive limestones are rubbly and lenticular. Anastomosing shaly and argillaceous seams course through the rubbly zone and fossil rootlet fabrics are noted. Acid residues from rubbly zone mudstones contain large amounts of clay and sand. At one locality (Fig. 11A) massive mudstones displaying a conglomeratic to brecciated upper surface are overlain by basal transgressive marine limestones of the Pella Formation, and the *Stigmaria*-bearing sandstone unit appears to be absent.

The transition from massive mudstones to overlying units appears to be separated by a local disconformity. Upper parts of mudstones at Showman Station (Fig. 10A) are, in places highly brecciated and recemented. Conglomerates occur at a similar horizon at the Heimstra Quarry (STOP 4). It is probable that the conglomerates of the Heimstra Quarry amphibian bone bed were generated during the time interval during which this disconformity surface was being formed. Figure 9 illustrates the stratigraphic relations between massive mudstones and overlying units in the Waugh Branch area. Although a disconformity is evident along the northern end of the transect, relations are less clear in the area of present-day valley of the Waugh Branch. For this reason, the lateral relationships are uncertain.

Depositional Interpretation. The massive lime mudstones of the Waugh Member are interpreted to represent deposition in a fresh to possibly brackish water lake or lagoon which lacked tidal exchange with the nearby seaway. Possible connections with the sea cannot be totally excluded. The fauna, as discussed by Witzke and McKay (1987), is characteristic of other Carboniferous lacustrine deposits. Fractured and brecciated fabrics were probably generated during periodic desiccation of the lake, and conglomeratic horizons formed when rainstorm-generated surface flow reworked fractured and desiccated semilithified sediment. The calcite spar and internal sediment which fills large vertical voids probably represent filling of root cavities. Periodic fluvially-sourced clastic influx supplied minor quantities of sand and clay into the lake basin. The lake basin apparently extended at least as far west as eastern Mahaska County and possibly into Marion County. Its eastern extent is not known. Lake levels fluctuated, and periodically the lake was desiccated, as evinced by the fractured and conglomeratic sediments. Although only scant tetrapod bone fragments have been found in these massive lacustrine limestones, it appears that ecologic conditions would have been suitable for them to inhabit the area.

Laminated Ostracode- and Fish-Bearing Lime Mudstone and Shale Facies. Thin- to thick-bedded, variably laminated, ostracode- and fish-bearing lime mudstones and interbedded shales overlie massive lime mudstones in portions of the study area. This interval varies in thickness from 0 to 3.5 m (0 to 12 ft). Limestones dominate this lithofacies at the Heimstra Quarry (STOP 4) where they attain a total thickness of 3 m (10 ft). Sandy shale is more prominent in the Waugh Branch area where 70 to 80 percent of the interval is shale (Figs. 9 and 10A). The limestones are variably laminated. Laminae are mostly discontinuous and may be disturbed and/or bioturbated. Rare lime mudstone intraclasts are present. Calcite spar-filled vertical voids, similar to those of the underlying massive mudstones, are locally common. Acid residues of the limestones have produced a fauna very similar to that of the underlying massive mudstones. In addition, large rhizodont crossopterygian fish scales have been found been found at three localities within this facies.

Excavation of bedded lime mudstones and minor shale at the Heimstra Quarry (STOP 4, Units b-i) yielded fish, shark, and tetrapod fossils including xenacanth teeth and cartilaginous cranial material, petalodont teeth, shark and acanthodian spines, large rhizodont scales and cranial and post-cranial bones (especially Unit d), a nearly complete lungfish skeleton (Unit c), and scattered tetrapod bone, including a beautiful colosteid skull associated with five jaws (base Unit d). The laminated shale (Unit a) which overlies and grades downward into the main bone bed produced a variety of interesting fish, plant, myriapod, and tetrapod material. This shale was processed for palynomorphs, but none were recovered (R. Baker, personal communication, 1986). The shale contains an abundance of phosphatized coprolites (1-15 cm), some of which incorporate scales and bone fragments (obviously from predatory fish and/or tetrapods), and thin phosphatic films, possibly shark ejecta. This shale also yielded a variety of tetrapod bone, mostly disarticulated, and an abundance of fish scales, primarily palaeoniscoid and rhizodont. A few articulated partial specimens of palaeoniscoids and a nearly complete rhipidistian crossopterygian with scales were collected from the shale. A large crushed skull of a xenacanth shark, nearly 75 cm in diameter, was collected in the central area of the collapse structure near the contact of the shale with the underlying boulders of the main bone bed. A few specimens of poorly preserved plant and myriapod fossils were also recovered from this shale.

Shales comprise the bulk of this facies in the Waugh Branch area. The shales are generally nonlaminated, and contain moderate quantities of quartz sand and sparse amounts of fish debris. The shale sequence at SSQ (Fig. 10A) becomes sandier upward and sand to granule-size lime mudstone clasts are common in the upper half. A 30 to 40 cm laminated lime mudstone bed occurs in the lower part of the shale sequence at SSQ. It contains abundant fish scales, ostracodes, and some "spirorbid" snails. Coprolites, rich in palaeoniscoid fish scales, are also present in this bed. This limestone contains minor birdseye-like structures and small calcite spar-filled tubules. Shales

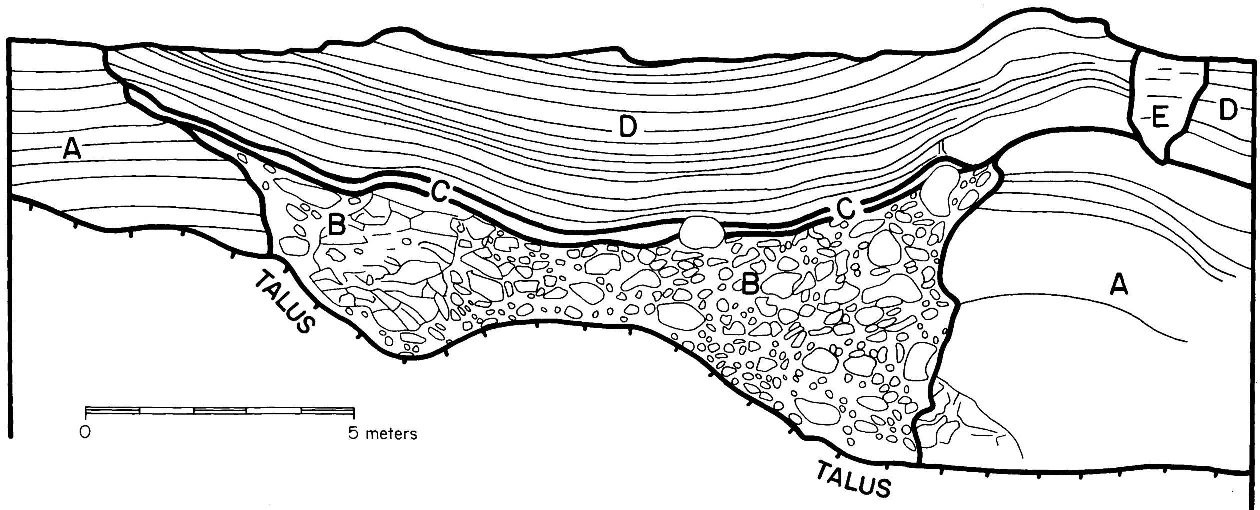

Figure 12. Stratigraphic relations at the Heimstra Quarry (photo tracing of main collapse structure, east quarry wall, prior to excavation). Lettered units discussed in text.

immediately above and below this limestone bed are more laminated and much less sandy than other shales in the sequence. Lime mudstone lenses to nodules occur at two horizons within the sandy shale subfacies at SSQ. These argillaceous limestones lack lamination, and contain sparse fish debris.

Depositional Interpretation. The laminated lime mudstone and shale facies of the Waugh Member is considered to represent renewed and continued lacustrine sedimentation in the area. Lake level fluctuations appear to have been less frequent as suggested by the laminated fabrics within some of the limestones. Desiccation of portions of the lake apparently did occur, perhaps for short time intervals, and brecciated and conglomeratic fabrics were not commonly formed. Calcite-spar filled rootlets may indicate that aquatic vegetation was locally rooted in the lake bottom sediments. The fauna is aquatic, although the tetrapods (colosteid) certainly were capable of locomotion in terrestrial environments as well. The absence of characteristic marine fauna in these strata suggests that the aquatic environments were nonmarine, probably including fresh to brackish waters. However, the vertebrate fauna, by itself, remains equivocal as to whether or not the aquatic environments were marine or nonmarine. Palaeoniscoids, xenacanths, ctenacanths, acanthodians, and rhipidistians are known from both marine and nonmarine deposits in the Paleozoic (Schultze, 1985; Zangerl, 1981). However, xenacanths are particularly common in many freshwater deposits of the Late Paleozoic (Zangerl, 1981). Lungfish are characteristically freshwater forms, although lungfish burrows are noted in some marginal marine settings (Schultze, 1985). Rhizodonts generally are regarded as fresh to brackish water predators, and their distinctive large scales are common at many Late Paleozoic tetrapod localities. In general, tetrapods presumably were adapted for life in terrestrial and nonmarine aquatic environments, although the possibility that some tetrapods were salt-water tolerant cannot be excluded (Schultze, 1985). On the whole, the vertebrate fauna of the Waugh Member, and this facies, particularly the common association of xenacanths, lungfish, rhizodonts, and tetrapods, is generally consistent with a nonmarine aquatic setting. The only possible exception may be the occurrence of petalodonts in the fauna; petalodonts are "almost entirely marine" (Zangerl, 1981, p. 94). Small petalodont teeth from the Heimstra Quarry apparently represent an undescribed taxon; serrated spatulate teeth display an extremely long and thin tooth base. Since this new petalodont apparently is not known from confirmed marine deposits elsewhere, it conceivably may represent an unusual nonmarine form.

Fluvial clastic influx, perhaps in the form of small deltas or overbank deposits, overwhelmed carbonate sedimentation in parts of the lake basin where sandy shale was deposited. Deposition of the laminated mudstone facies slowed and finally ceased as fluvial-deltaic clastic influx shut-off carbonate production and infilled the basin. The presence of the overlying scale tree root-bearing sandstone and paleosol marks the end of lacustrine sedimentation and the establishment of a relatively widespread swamp environment near the end of Waugh Member deposition.

Scale Tree Root-Bearing Sandstone and Paleosol Facies. Sandstones and claystones containing *Stigmaria* root casts and other rooting structures form the uppermost facies of the Waugh Member (Figs. 10A, 11B, 11C, and STOP 5). Excellent examples of branching and attached radiating rootlets are present at the base of the sandstone. The top of this unit marks the top of the "St. Louis" Formation across most of the study area. To the west, in Mahaska and Marion counties, carbonaceous shales up to 30 cm (1 ft) thick occur at this horizon (Johnson, 1967). The shales contain thin 1 to 2 mm thick laminae of coal and overlie rooted sandstones. This sandstone and shale interval has always been included within the basal Pella Formation in this area and in southeastern Iowa (Van Tuyl, 1925; Johnson, 1967; Johnson and Vondra, 1969). However, we prefer to exclude this interval from the Pella and to include it in the Waugh Member of the "St. Louis." This revision of the "St. Louis"/Pella formational boundary allows the contact to be consistently and easily drawn at the base of marine limestones of the Pella, and above sandstones and carbonaceous shales of the "St. Louis." This definition makes the base of the Pella coincident with Pella marine onlap. Drawing the "St. Louis"/Pella contact in this manner is similar to the placement of formational contacts in Pennsylvanian cyclothems where transgressive deposits overlie coal-bearing nonmarine strata. The carbonaceous shales and root-bearing sandstones of the upper Waugh are the earliest known Carboniferous coals and plant fossils from Iowa, and may represent the very early stages of the cyclothemic deposition that would later dominate the Chesterian (Late Mississippian) and Pennsylvanian.

Depositional Interpretation. The widespread occurrence of coaly to carbonaceous shale and extensively rooted sandstone indicates that widespread swampy conditions with locally dense populations of scale trees were developed prior to the Pella marine transgression. Observations by Schabilion (1987) suggest that the distinctive texture found on the lower surface of the sandstone represents an impression or imprint of the swamp surface. Fluvial influx of sand eventually buried the scale tree swamp and filled in the decayed rhizophores and rootlets. The existence of widespread nonmarine environments of the Waugh Member ceased as transgression initiated faunally-restricted marine sedimentation in the area.

Tetrapod-Bearing Limestone Conglomerate, Shale, and Boulder Conglomerate Facies. Perhaps the most significant facies within the Waugh Member, and the entire "St. Louis" Formation is the tetrapod-bone-rich limestone conglomerates and shales which fill paleocollapse-structures at the Heimstra Quarry, near Delta, Iowa (STOP 4, and Figs. 12 and 13; McKay et al., 1986; McKay et al., 1987; and Bolt et al., 1988). Abundant and well preserved tetrapod bone is concentrated within two collapse-structures (7 and 16 m wide) developed in the Verdi and lower Waugh members. The bone bed has been the object of three excavations (fall, 1985, and summers, 1986 and 1988) headed by John Bolt of the Field Museum of Natural History, Chicago.

The discovery of abundant Mississippian tetrapod material at the Heimstra Quarry rates as one of the great paleontological discoveries in the United States, and, depending on your personal bias, may be the most important fossil site ever found in Iowa. The fossil record of early tetrapods (Late Devonian-Early Carboniferous) is scant, being known only from scattered localities around the world. Tetrapods evolved from crossopterygian (or dipnoan) fish precursors in the Late Devonian by modification of lobed fins to limbs. Devonian tetrapods (ichthyostegids) are known primarily from East Greenland, but specimens also have been identified from Australia and the USSR. Subsequent tetrapod evolution remains poorly known, primarily because Tournaisian-early Visean fossils are virtually unknown. Late Visean tetrapod localities, which include the Delta site, are few in number, but are known from several localities in

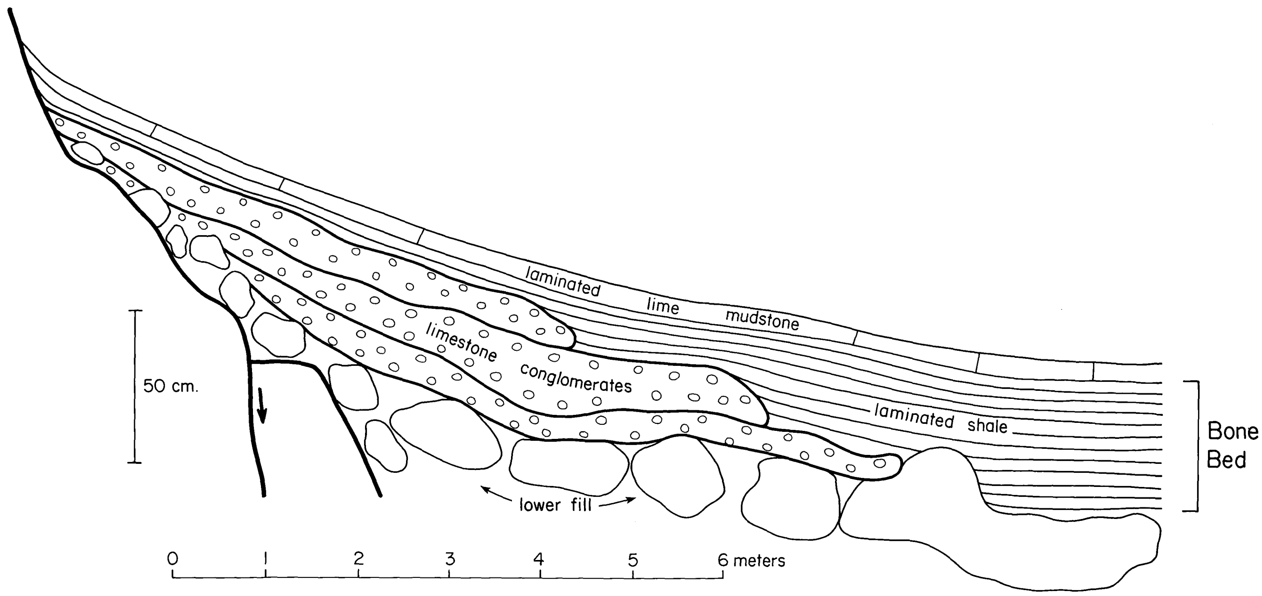

Figure 13. Stratigraphic relations of the bone bed, main collapse structure, Heimstra Quarry.

Scotland (Wood et al., 1985; and Milner et al., 1986) and from Greer, West Virginia (Smithson, 1982). Recent discoveries by Brian Foreman in the Chesterian (latest Visean and/or early Namurian) of southern Illinois will add to our knowledge of early tetrapods (see note in News Bull., Soc. Vert. Paleon., no. 139, p. 56, 1987). The Delta, Iowa, discovery is of Genevievian (early Chesterian) age and marks the oldest well-preserved tetrapod fauna known from North America.

Rocks at the Heimstra Quarry can be divided into five units (Fig. 12) for discussion purposes. Unit A represents Verdi through lower Waugh strata; these are truncated by the paleocollapse structures. Development of both collapse structures display collapse of surrounding strata, and may relate to dissolution of bedded gypsum at depth in the lower Croton Member, although their origin is still uncertain. The walls of the depression are solutionally pitted, suggesting subaerial exposure.

The lower portion of the fills in both collapse-structures (Unit B) are composed of clast to matrix-supported boulder conglomerate. Boulders range up to 1.5 m (5 ft) in length and have solutionally-pitted surfaces. Matrix material ranges in size from clay to cobbles; scattered tetrapod bone is present. Large slump blocks of Unit A are also present in Unit B. The boulders and cobbles and much of the finer matrix material were derived from Unit A strata. The base of Unit B is not visible and has not been excavated so its total thickness and the composition of basal strata is not known.

Unit C is the main bone bed; it overlies the very uneven upper surface of the boulder conglomerate of Unit B. Figures 14 and 15 portray the irregular topography of the upper surface of the boulder conglomerate on which the bone bed rests. The bone bed ranges from 0 to 60 cm thick and locally overlaps parts of Unit A at the fill margins (Figs. 12 and 13). The bone bed is composed of lobate layers and lenses of limestone conglomerate and an area of thick laminated shale. Both rock types contain abundant tetrapod bone. The limestone conglomerates are poorly sorted, clast to matrix-supported, and crudely stratified. Clasts are subangular to rounded sand- to pebble-sized fragments of Unit A limestone; occasional cobble size limestone clasts are also present. Tetrapod bone within the conglomerates is mostly disarticulated into individual bones which are variably broken (especially long thin bones such as ribs); however most of the bone material is unabraded. The conglomerates are restricted to the outer portion of the fill and they attain

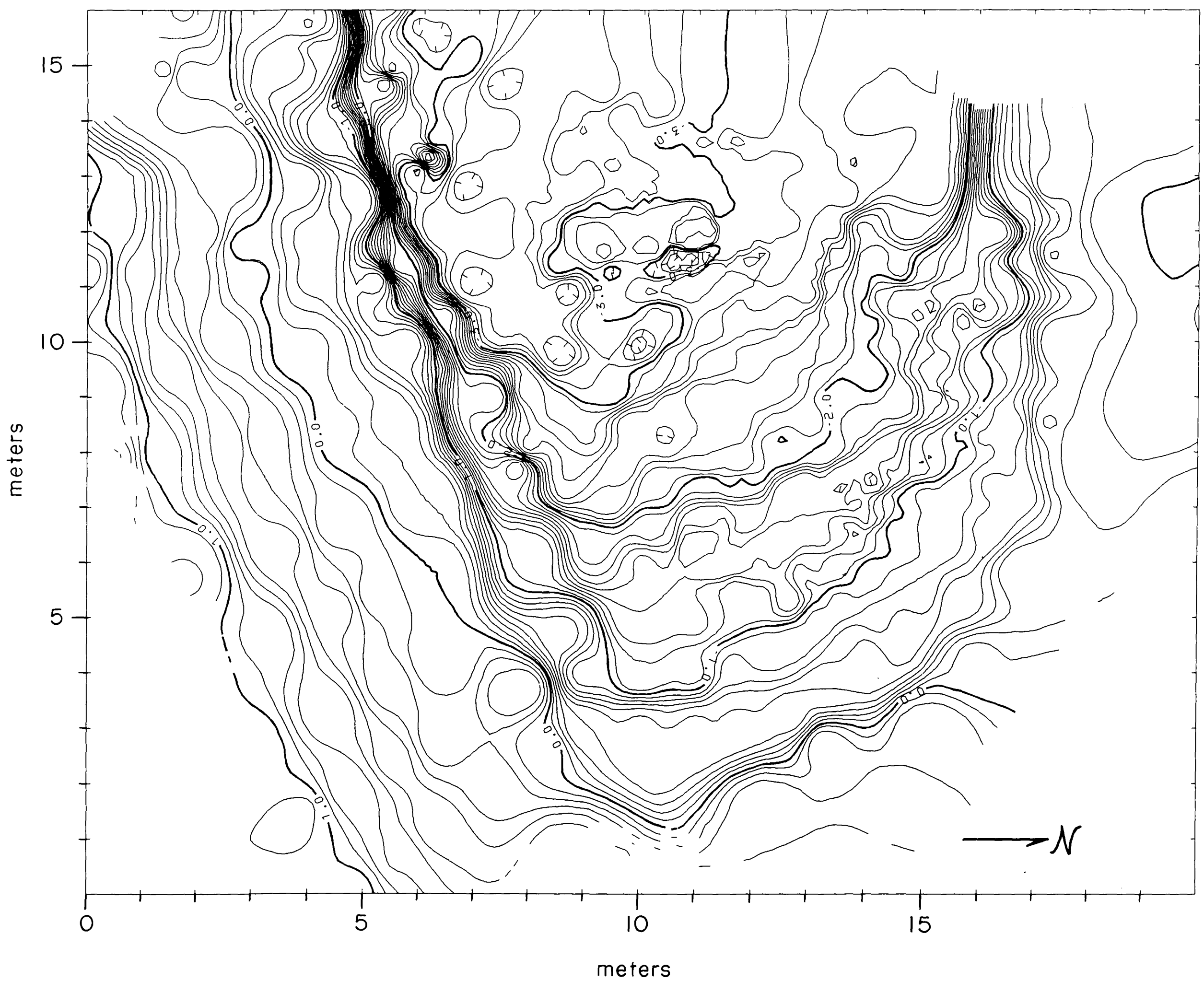

Figure 14. Topography of the irregular surface underlying the bone bed at Heimstra Quarry which was exposed during the 1986 and 1988 excavations. High wall on south side marks southerly limit of excavation. Arbitrary datum of 0 meters lies immediately above and outside of excavation pit. Contour interval is 10 centimeters.

maximum thickness near the fill margins. Conglomerates are not continuous across the fill, and they pinch out in lobate fashion before reaching the fill center. Conglomerate layers are in part separated by thin shale partings which contain slightly more articulated bone. The conglomerates grade laterally and abruptly into laminated brownish-green shale that is the dominant rock type in the central area of the fill. The shale attains a maximum thickness of sixty centimeters within closed depressions situated between large boulders of Unit B (Fig. 12). It thins to only a few centimeters over the tops of the largest boulders. Tetrapod bone is most abundant in the lower portion of both the conglomerate and the shale, however the most highly articulated tetrapod material occurs in the lower third of the shale in the central area of the fill. In the central shale-dominated area the upper half of the shale lacks significant tetrapod material, and instead is dominated by fish material (previously discussed). This upper shale (STOP 4, Unit a) overlaps the conglomerates throughout the main fill and extends out of the main fill into the undisturbed rock section.

The main bone bed was the target of joint Field Museum - Geological Survey Bureau excavations during the summers of 1986 and 1988. Partial

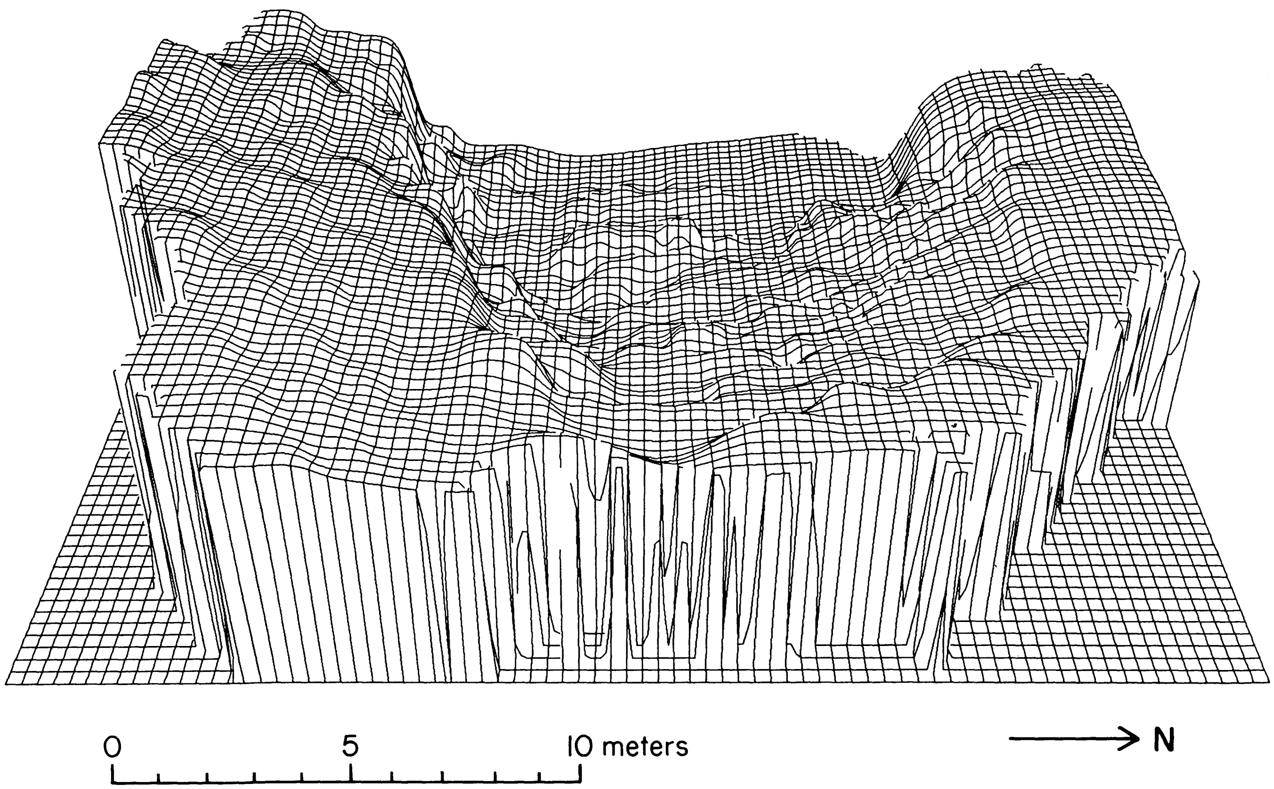

Figure 15. Fishnet diagram of the topography shown in Figure 14.

funding for the excavations was provided by the National Geographic Society, Washington, D.C. The majority of the fossil material collected (which includes hundreds of individual specimens) is reposited at the Field Museum and lesser amounts are reposited at the Department of Geology, University of Iowa. The bulk of the material collected during 1986 was collected from the conglomerates and for the most part consists of individual bones. However, the last month of the 1986 collecting period and the entire 1988 season was spent excavating within the shale-dominated central area; these collections are dominated by moderately to highly articulated cranial and post-cranial tetrapod material, including several nearly complete skeletons and numerous skulls (see guidebook cover). This material is presently under preparation and study by John Bolt and colleagues at the Field Museum.

Although colosteid tetrapod material has been recovered from the limestones above the main bone bed, the bulk of the tetrapod bone from the bone bed appears to belong to a primitive anthracosaur-like amphibian form which Bolt et al. (1988) informally referred to as a "proto-anthracosaur". The colosteid, probably a new species, is the earliest temnospondyl known from North America, and one of the oldest in the world. The proto-anthracosaur is approximately coeval with the earliest reported anthracosaurs, which are undescribed specimens from the Scottish Brigantian (Bolt et al., 1988).

Depositional Interpretation. The accumulation and concentration of tetrapod bone at the Heimstra Quarry is directly related to two factors: 1) existence of a suitable habitat for tetrapods, and 2) generation of collapse structures which served as natural depressions for the accumulation and preservation of bone as well as whole to partial skeletons. Although the origin of the collapse structures is uncertain, they may have resulted from dissolution of underlying gypsum beds in the underlying Croton. Karstification of underlying carbonates cannot be ruled out however. In either case, the influx of meteoric water into the groundwater system would facilitate dissolution of rock and the opening of subsurface voids into which overlying strata could collapse.

The timing of collapse structure generation is constrained by stratigraphic relations at the Heimstra Quarry. Collapse structures formed midway through the deposition of the massive lime mudstone facies, because only the lower portion of these mudstones are truncated by the collapse structures at the quarry. The massive mudstones have been interpreted as the product of fresh to brackish water lacustrine sedimentation that exhibit features indicative of intermittent drying and desiccation. The presence of numerous calcite-filled root-like voids within these mudstones may indicate the presence of aquatic (probably shallow water) vegetation in the lake. During times of desiccation in the lake basin, portions of the lime mudstones were fractured and broken into clasts which were subsequently reworked into limestone conglomerate accumulations. Conglomerates at both the Heimstra Quarry and the Waugh Branch area are conjectured to have formed in this manner.

At Heimstra Quarry, the limestone conglomerates of the collapse structures accumulated when debris from the surrounding terrain was transported periodically into the depression. This debris included disarticulated amphibian bone and articulated amphibians. Conglomerate layer geometries, documented during the 1986 excavation, are lobe-like. This lobate shape and the clast-to matrix-supported fabric suggest that deposition of these layers occurred as viscous subaqueous sediment flows into a water filled depression. The laminated brownish-green shales towards the center of the depression are interpreted to have been deposited subaqueously in quiet water. The absence of benthic fauna and burrows, as well as the laminated nature of the shale, suggest that bone accumulation occurred within a stratified body of water with low oxygen or anoxic bottom conditions. The absence of rooting structure in the shale may suggest that water depth was great enough to preclude rooted aquatic vegetation in the depression. The quiet environment of the shale-dominated portion of the depression provided an ideal setting in which to bury and preserve partial to whole amphibians that were transported into the depression.

The shales and limestone conglomerates of Unit C were subsequently covered by ostracode, fish and tetrapod-bearing lime mudstones of Unit D (Fig. 12) which were deposited as lake levels rose and carbonate sedimentation resumed.

In summary, stratigraphic relations within the Waugh Member indicate that a variety of nonmarine depositional environments characterized the Keokuk county area following retreat of the "St. Louis" sea. The various rock types of the Waugh, their fabric and their contained fauna are interpreted to indicate deposition in a mosaic of lacustrine, fluvial, and swamp environments in a coastal lowland setting. The absence of definitive marine fauna in the Waugh, and the similarity of the its fauna to that of other Carboniferous lake and swamp deposits at Linton, Ohio (Hook and Ferm, 1985; and Hook and Baird, 1986), Nyrany, Czechoslovakia (Milner, 1980), and Foulden, Scotland (Anderton, 1985) suggest that deposition occurred within a fresh to brackish water setting which lacked significant fluid exchange with marine water.

PELLA FORMATION

Geologists first recognized fossiliferous calcareous shale and limestone (marls) at the top of the Mississippian sequence in southeast Iowa in the mid to late 1800s, which Bain (1895) termed the "Pella beds" of the St. Louis Formation. (Summary in Johnson, 1967). Subsequent workers elevated the Pella beds to formational rank. Pella strata reach thicknesses to 15 m (50 ft) in the Iowa subsurface, and fossiliferous marine limestones and marls of the Pella reach thicknesses in excess of 9 m (30 ft) in the outcrop belt of Washington, Keokuk and Mahaska counties.

A degree of confusion has existed in previous studies as to where the base of the Pella should be drawn. Some have included nonmarine limestones, sandstones, and carbonaceous shales within the Pella (e.g., Van Tuyl, 1925; Rexroad and Furnish, 1964; Johnson, 1967). We now exclude these strata from the Pella and mark the base of the Pella at the lowest brachiopod-and/or bivalve-bearing limestone above the sandstone and carbonaceous shale interval, which we now include in the Waugh Member of the upper "St. Louis." Using this definition, the Pella is marked by a significant marine transgression at its base, and it disconformably overlies an upper "St. Louis" surface regionally. This definition allows the Pella-"St. Louis" contact to be drawn at a consistently recognizable boundary, as underlying

Table 3. Fauna of the Pella Formation in Keokuk and Mahaska counties, Iowa.

Brachiopods
- -strophomenids
  - *Ovatia ovata* (Hall)
  - *Protoniella parva* (Meek and Worthen)
  - *Orthotetes kaskaskiensis* McChesney
- -spiriferids
  - *Anthracospirifer pellaensis* (Weller)
  - *Composita trinuclea* (Hall)
  - *Cleiothyridina sublamellosa* (Hall) (not illustrated)
- -terebratulids
  - *Girtyella indianse* (Girty)
  - *Dielasma formosum* (Hall)
- -rhynchonellids
  - *Pugnoides ottumwa* (White)

Molluscs
- -bivalves
  - *Clinopistha* sp.
  - nuculanid sp.
  - crassatellacean sp.
  - "*Edmondia*" sp.
  - *Glossites* sp.
  - *Schizodus* sp.
  - *Spathella* sp.
- -gastropods
  - *Straparollus* sp.
  - *Rhineoderma* sp.
  - *Anematina* sp.
  - *Bellerophon* sp.
  - *Euphemites* sp.

Bryozoans
- *Anisotrypa* sp.
- *Batostomella* sp.
- *Fenestella* sp.
- others

Corals
- *Neozaphrentis pellaensis* (Worthen)

Annelids
- *Spirorbis* sp.

Arthropods
- -trilobites
  - *Paladin wilsoni* (Walter)
- -ostracodes
  - *Polytylites wilsoni* (Croneis and Gutke)
  - *Ectodemites primus* Cooper
  - *Bairdia* sp.
  - others

Echinoderms
- -blastoids
  - *Pentremites pulchellus*
  - *Diploblastus glaber*
- -crinoid debris and cups
- -echinoid and other echinoderm debris

Foraminifera
- *Earlandia*
- *Pseudoglomospira*
- calcivertellids
- *Endothyranella*
- *Endothyra*
- *Endostaffella*

Conodonts (see Rexroad and Furnish, 1964)

Vertebrates
- bradyodontid teeth

nonmarine sandstones and shales display complex facies patterns which include one or more erosional surfaces locally. Carbonaceous shales or shaly coals locally underlie the Pella in a situation similar to many cyclothemic formational boundaries of the Pennsylvanian.

Our investigations in Keokuk and Mahaska counties have consistently identified fossiliferous limestones in the basal Pella which contain low-diversity brachiopod faunas (*Composita, Pugnoides*), commonly with abundant bivalve molds. These display mudstone to packstone fabrics and are interbedded with thin shales. Johnson (1967) identified ostracode biomicrites as a major facies at this stratigraphic position, and we have recognized this facies in the Keokuk-Mahaska county area. Ostracode biomicrites are also common in underlying upper "St. Louis" strata. Basal Pella fossiliferous limestones (which average about 70 cm thick) are overlain in the Keokuk-Mahaska county area by oolitic packstones with scattered lime mudstone intraclasts (average about 40 cm thick). This oolitic facies also occurs in Lee, Davis, Wapello, Monroe, and Marion counties, reaching maximum thicknesses (1.3 m) in the Ottumwa area (Johnson, 1967). Macrofossils are sparse in the oolitic beds, although brachiopods (*Composita*) and molluscs occur. The upper 40 cm of the lower Pella limestone sequence is characterized by skeletal wackestones, in part argillaceous, with a diverse fauna. This interval records deposition under open-marine conditions and displays a marked increase in echinoderm content and brachiopod diversity over underlying strata. In addition, trilobites, bryozoans, and solitary corals become noteworthy, and foraminifera and ostracodes also occur in these upper beds (ibid.).

The upper Pella marls (shaly, very calcareous) are highly fossiliferous, and are characterized by bioturbated, poorly-indurated skeletal wackestone to packstone fabrics. They contain a diverse marine fauna throughout, and weathered slopes in this interval provide excellent fossil collecting. A faunal list of taxa identified in the Keokuk-Mahaska county area is included (Table 3). (Note: productid taxonomy follows Muir-Wood and Cooper, 1960, for *Ovatia* and *Protoniella*.) Dense, nodular to platy argillaceous limestones are interbedded with the marls, and include skeletal wackestone to abraded packstone fabrics. Dense, elongate limestones (to 60 cm or more long) with ovoid cross-sections (5-10 cm) occur within the marl sequence and apparently represent large horizontal burrow fills formed by an unknown organism. In addition to the conspicuous macrofauna, the marls and interbedded limestones in this interval contain an abundant microfauna, primarily foraminifera and ostracodes. Some beds are termed foraminiferal limestones by Johnson (1967), who noted an abundance of endothyrids.

The presence of abundant *Pugnoides ottumwa* and the absence of *Talarocrinus* (T. Frest, personal communication, 1987) strongly suggest a Genevievian age (see Witzke, 1987 for further discussion).

REGIONAL MISSISSIPPIAN SEDIMENTATION AND SEQUENCE STRATIGRAPHY

FACIES MODELS AND RELATIVE SEA-LEVEL CHANGES

Mississippian strata in Iowa are interpreted to display evidence of bathymetric deepening and shallowing during deposition, and inferred changes in relative water depth apparently are regionally synchronous across the Iowa area. Although local tectonic movements undoubtedly influenced local bathymetric trends, it is the inter-regional synchroneity of relative changes in water depth that may constrain possible eustatic changes, that is, absolute changes in global sea level. Eustatic sea-level events, whether deepening or shallowing, should produce recognizable changes in the patterns of regional sedimentation. Boundaries separating shallowing (regressive) from deepening (transgressive) trends should be definable based on sedimentary criteria. Because eustatic sea-level changes are regionally synchronous, by definition, they provide a means independent of paleontology for evaluating regional chronostratigraphic relations. The recognition that many changes in regional sedimentation patterns are a response to eustatic change forms the conceptual basis for the newly emerging discipline of "sequence stratigraphy." Basic chronologic units are constrained within identifiable "transgressive-regressive" (T-R) sedimentary increments which are used to define a sequence of "T-R" units. Sequence stratigraphy, when coupled with accurate biostratigraphic control within a regional lithostratigraphic framework, provides the most powerful technique presently available for constraining regional sedimentation patterns in a temporal framework.

The identification of depth-related carbonate facies in the British Lower Carboniferous (Mississippian) sequence led to the regional establishment of "major T-R cycles" in a pioneering paper by Ramsbottom (1973). Ramsbottom (1973) delineated a basic onshore-offshore facies pattern, from shallowest to deepest: 1) carbonate mudstones, in part stromatolitic or with desiccation features (supratidal to intertidal); 2) oolitic limestone; 3) bioclastic limestones; 4) argillaceous skeletal limestones; and 5) offshore shales. Smith (1972) and Wilson (1975) also recognized a general onshore-to-offshore trend in Mississippian carbonate facies of Montana, which formed the basis for defining a series of depositional cycles: 1) sabkha mudstones; 2) pelleted to skeletal limestones (back-shoal); 3) oolite grainstone (shoals); 4) crinoidal grainstones; 5) skeletal to peloidal wackestones; 6) interbedded shales and dark skeletal to spiculitic limestones; and 7) offshore shales.

The facies patterns recognized by Ramsbottom (1973), Smith (1972), and Wilson (1975) directly parallel our interpretations of onshore-to-offshore trends in the Mississippian sequence of southeast

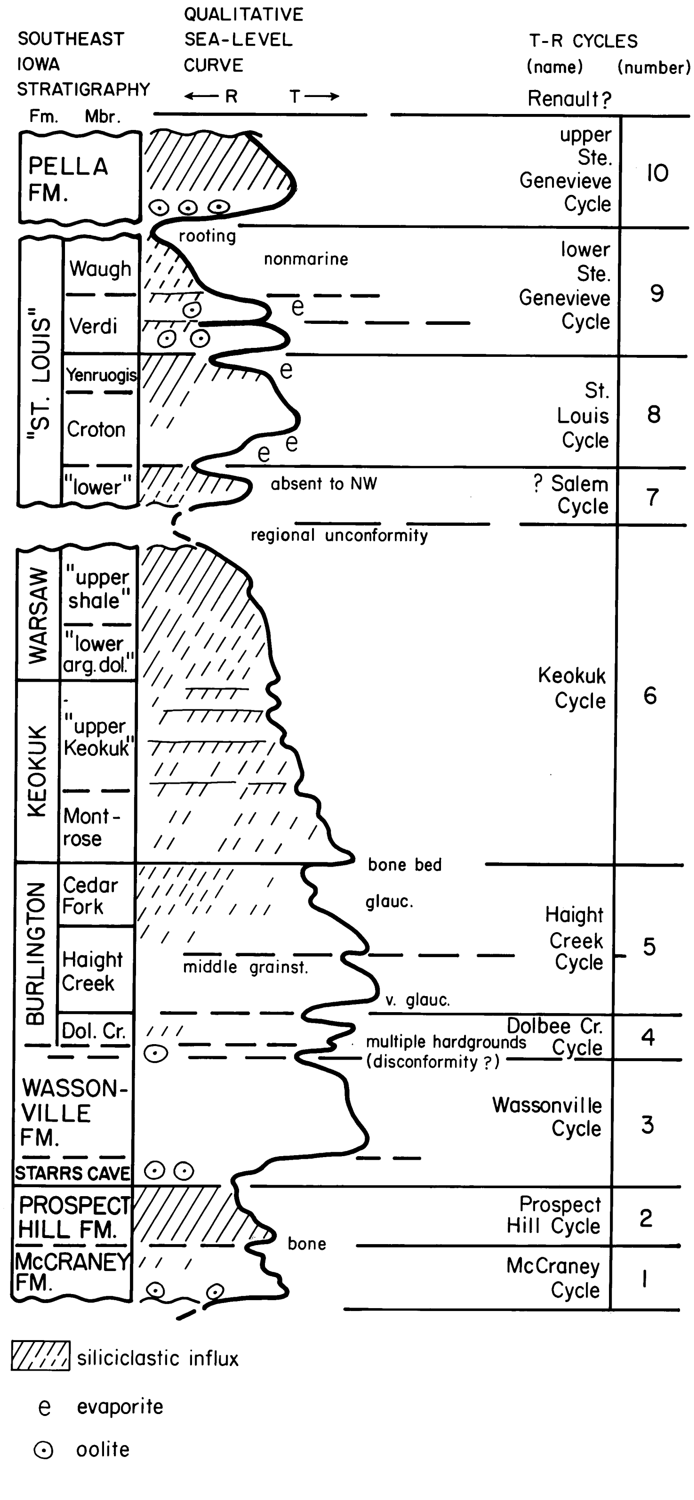

Figure 16. Qualitative sea-level curve interpreted for the Mississippian sequence of southeast Iowa (T = transgressive or deepening trends; R = regressive or shallowing trends). Interpreted T-R cycles are named and numbered at the right.

Iowa. The idealized progression of onshore-offshore carbonate facies interpreted for the Iowa Mississippian includes: 1) nonmarine lacustrine carbonates, associated fluvial and paludal facies and rooted horizons; 2) pelleted and "sublithographic" mudstones, in part with stromatolites, "birdseye," desiccation features, or evaporites (supratidal and sabkha facies); 3) peloidal to skeletal (low diversity faunas) wackestones and mudstones, oolitic in part (back-shoal facies); 4) oolitic grainstones (oolite shoals); 5) skeletal packstones-grainstones, abraded grain in part (near fair-weather wave base); 6) discontinuous skeletal packstones-grainstones (especially crinoidal) interbedded with skeletal wackstones-mudstones; low-angle to hummocky crossbedded in part, graded beds and planar laminations present; moderately diverse faunas (above storm wave base); and 7) skeletal mudstones-wackestones, with packstones notably absent; benthic faunas may show decrease in diversity (oxygen stresses?) (below storm wave base). An eighth facies belt, characterized by dysoxic offshore shales or starved basinward sedimentation is developed during some Mississippian T-R cycles in central and southern Illinois (e.g., Lane, 1978; Lineback, 1981) and around the continental shelf edge, but is not present in southeast Iowa. Siliciclastic sediments (sandstones, siltstones, shales) prograde in an offshore direction during some Iowa depositional cycles, and the progradation of these sediments is interpreted to suggest regressive phases of particular sedimentary cycles.

The Mississippian sedimentary sequence in southeast Iowa has been interpreted to display evidence of ten major T-R cycles. Although no hierarchical ordering of these cycles has been attempted, some of these cycles can be logically grouped together to form larger-scale units, and many of the cycles display evidence internally for smaller-scale transgressive-regressive (T-R) events or "subcycles." A generalized and qualitative graphic presentation of interpreted T-R cycles in southeast Iowa is given in Figure 16. It is acknowledged that many sedimentary details remain to be worked out, and that problems in interpreting events that bound some cycles are apparent. Some aspects will undoubtedly need revision, and it is hoped that the interpretations shown in Figure 16 will provide an impetus for further study by other researchers. Nevertheless, much of the regional stratigraphy can be reasonably integrated into a sedimentologic framework consistent with the proposed T-R cycles. Woodson and Bunker (1989) interpreted Mississippian T-R cycles in northern Iowa, which, with some variation, closely parallel those interpreted for southeast Iowa. In both areas, the depositional cycles are typically asymmetric, with thin basal transgressive deposits capped by a thicker regressive package (ibid.).

KINDERHOOKIAN CYCLES AND SEDIMENTATION

McCRANEY AND PROSPECT HILL SEDIMENTATION

Mississippian sedimentation was initiated in southeast Iowa with deposition of the McCraney Formation unconformably above Devonian shales and siltstones. The McCraney transgression must have been relatively rapid, as skeletal to oolitic limestone, interpreted to have been deposited in an open-marine setting (Person, 1976), lies above the unconformity with no basal siliciclastic shoreface facies preserved. Faunas are sparse to absent through the remainder of the McCraney, suggesting probable shallowing conditions, and a shallow restricted subtidal to nearshore setting has been proposed (ibid.). The presence of probable gypsum pseudomorphs (ibid.) further supports environmental restriction. Straka (1968) reported an irregular upper McCraney surface in some sections, capped by a lag concentrate of fish bone in the basal Prospect Hill Formation. This surface was interpreted to mark an erosional unconformity (ibid.), although it remains to be seen whether it was produced by subaerial or submarine processes. The pronounced sedimentologic change at the top of the McCraney is interpreted to mark the boundary between successive sedimentary cycles. The various paleontologic and sedimentologic criteria cited above serve to constrain the first Mississippian T-R cycle in Iowa (Cycle 1; Fig. 16).

The base of the Prospect Hill Formation marks an abrupt change in sedimentation, from carbonate-dominated to siliciclastic-dominated, reflecting appreciable influx of terrigenous clastic material into the area. The lag concentrate of fish bone at the base of the formation is interpreted to mark an episode of starved sedimentation, possibly above a transgressive discontinuity. The Prospect

Hill displays an increase in faunal diversity over that seen in the McCraney (Laudon, 1931; Glenister et al., 1987), further supporting relative bathymetric deepening during Prospect Hill deposition. Shallow open-marine conditions are indicated (ibid.). In addition, the Prospect Hill as a lithostratigraphic unit oversteps the McCraney edge to the north and west in Iowa, supporting the idea of possible transgressive expansion of the seaway. Nevertheless, further resolution of biostratigraphic correlations between northern and southern sections in Iowa may modify this interpretation, especially if the northern Iowa Prospect Hill sections are older than the McCraney of southeast Iowa as proposed by Glenister et al. (1987). Although shales are known to interbed with siltstones at various positions within the Prospect Hill sequence, shales are best developed in the lower part of the interval. As such, the Prospect Hill sequence forms a general coarsening-upward sequence consistent with a regressive phase of sedimentation following initial transgression.

The Prospect Hill Formation is herein tentatively interpreted as a discrete T-R Cycle (Cycle 2, Fig. 16). The progradation of a siliciclastic interval above the McCraney carbonate sequence could alternatively be interpreted to represent continued shallowing within the same general T-R cycle. Complementary thickness variations between the McCraney and Prospect Hill at some southeast Iowa locations may suggest a depositional relationship, although the abrupt lithologic change and bone lag separating the two formations suggest a depositional discontinuity at that position. Woodson and Bunker (1989) considered the northern Iowa Prospect Hill sequence to mark the basal transgression of a T-R cycle that includes the overlying "Chapin" oolite. However, the "Chapin"-Maynes Creek contact is notably abrupt, whereas the Starrs Cave-Wassonville contact, which is presumably correlative, appears gradational. Hence, the Starrs Cave interval of southeast Iowa is lithologically similar to the "Chapin," but is not included within the Prospect Hill Cycle in this report.

THE WASSONVILLE CYCLE

Skeletal to oolitic limestones of the Starrs Cave Formation abruptly overlie Prospect Hill siltstones at many southeast Iowa localities, and the absence of lithologic gradation between the two units suggests that the contact may mark a T-R boundary. The Starrs Cave-Wassonville contact "is lithologically gradational" (Person, 1976, p. 53), and the Starrs Cave is tentatively included with the Wassonville within the same major T-R cycle (Cycle 3 = Wassonville Cycle, Fig. 16). Likewise, the fauna of the Starrs Cave "continues into the overlying beds with little or no break" (Laudon, 1931). In the type Wassonville area, Starrs Cave limestones are absent and Wassonville dolomites directly overlie Prospect Hill siltstones. However, an "oolitic zone" has been recognized locally in the basal dolomites of that area by Straka (1968), indicating that the lowermost Wassonville and Starrs Cave may be,in part, lateral facies. Laudon (1931, p.376) noted that strata of the Wassonville Cycle overlie an irregular surface along the English River, with concentrates of fish bone and reworked siltstone and shale at the base of the cycle. As with other Mississippian cycles in southeast Iowa, the contact between adjacent T-R cycles is often marked by "bone bed" concentrations.

The Starrs Cave is presently interpreted to mark the initial phases of transgression of the Wassonville Cycle. The distribution of its oolitic facies is geographically discontinuous in southeast Iowa (Lawler, 1981). The oolitic grainstone facies of the Starrs Cave is interpreted to record initial but localized oolite shoaling during early transgression of the Wassonville Cycle. The upward intergradation of skeletal grainstones of Starrs Cave aspect with dolomitized skeletal wackestones in the lower Wassonville suggests progressive environmental deepening in the sequence. The presence of graded skeletal packstone and grainstone lenses within intervals of horizontally laminated to hummocky cross-stratified carbonate mudstones-wackestones and calcisiltites in the lower to middle Wassonville sequence indicates deposition below fair-weather wave base but above storm wave base. Therefore, the lower part of the Wassonville Cycle records upward deepening, from above fairweather wave base (Starrs Cave oolite shoaling) to below normal wave base (storm-generated sedimentary structures in the Wassonville). Deposition of the upper Wassonville sequence is more difficult to interpret because of more pervasive dolomitization and secondary vugular porosity. However, a marked decrease in skeletal grain abundance (fewer skeletal packstones) and overall faunal diversity in the upper Wassonville, the presence of prominent hardgrounds at the top of the formation, and sub-Burlington truncation of Kinderhookian strata in western Illinois are consistent with upward-shallowing (regression) during deposition of the upper Wassonville sequence.

The Wassonville Cycle of southeast Iowa shares overall similarities with the lower part of the Maynes Creek Cycle of northern Iowa (Woodson and Bunker, 1989), and the rocks in both areas are dominated by similar cherty dolomites, in part with storm-generated sedimentary features. The Wassonville Cycle is interpreted to be partially, or perhaps wholly, equivalent to the Maynes Creek Cycle of northern Iowa. However, differences are apparent. A middle oolitic unit (possibly the type Chapin) within the Maynes Creek Cycle of northern Iowa (ibid.) marks depositional shallowing, but this regressive subcycle has not been clearly identified in southeast Iowa. The Maynes Creek Cycle is capped by supratidal mudflat facies in northern Iowa, but similar facies are absent in southeast Iowa. Additionally, strata of the Maynes Creek Cycle reach thicknesses to about 40 m (130 ft) in northern Iowa, whereas strata of the Wassonville Cycle in southeast Iowa are as thin as 3.3 m (11 ft) [more commonly 5 to 20 m; 15-65 ft]. Is the apparent southeastward thinning and the absence of upper mudflat facies to the south evidence for sub-Burlington erosional bevelling in the southeastern sections, as many previous studies have suggested? Or alternatively, is the thinning of depositional origin, with slower rates of sediment accumulation in more offshore settings in southeast Iowa? Or is it a combination of both factors? Clear-cut answers to these questions have proven frustratingly elusive.

Stratigraphic thinning and geographic facies variations between northern and southeast Iowa, similar to those of the Mississippian, are seen within T-R cycles of the Devonian Cedar Valley Group (Witzke et al., 1989). Evidence strongly favors southeastward depositional thinning in the Devonian cycles, not erosional bevelling. The Devonian cycles are capped by submarine hardgrounds or discontinuity surfaces in southeast Iowa, but are capped by supratidal mudflat and sabkha facies in northern Iowa. Similar facies relations are seen between Maynes Creek and Wassonville strata.

Further biostratigraphic studies in uppermost Wassonville and Maynes Creek strata are needed to more accurately resolve chronostratigraphic relations. In most cases, all strata above the lowest hardground at the top of the Wassonville contain Osagean (Burlington) conodont faunas. However, at the Ollie Quarry, Keokuk County (Figs. 5,6), strata above the prominent hardground at or near the top of the Wassonville contain probable late Kinderhookian faunas (including abundant chonetids and the conodont *Siphonodella*). This raises the possibility that an additional T-R subunit occurs in the upper Wassonville Cycle in southeast Iowa, where it is represented by a starved interval bounded by hardgrounds or, in most cases, by a non-sequence. Alternatively, the interval in question may represent the basal transgressive interval of the Dolbee Creek Cycle (Cycle 4; Fig. 16).

Evidence for subaerial erosion is absent at the top of the Wassonville in the field trip area, but the presence of prominent hardgrounds at or near the top of the sequence indicates depositional hiatuses. The absence of a weathering horizon and vadose features in the upper Wassonville, the low-relief sculpted hardground surfaces, and the presence of marine faunas, increased conodont abundances, and bored hardground clasts above the these surfaces are most consistent with a submarine origin for the hardground discontinuities in Washington and Keokuk counties. Multiple hardground surfaces separate the main body of the Wassonville Formation from the overlying Dolbee Creek Member. The duration of the depositional hiatuses or erosional episodes represented by the hardgrounds is not yet known with certainty. To further complicate interpretations, the Burlington Formation is known to overlie Upper Devonian strata, as well as the McCraney, Prospect Hill, and Starrs Cave formations in areas of western and central Illinois (Workman and Gillette, 1956), indicating that a pre-Burlington erosional episode occurred in the area, possibly reflecting local structural upwarping coincident with regression of the Wassonville Cycle. Sub-Burlington erosional bevelling apparently extends into southeast Iowa, as the Dolbee Creek Member is known to overlie Starrs Cave limestone in portions of Des Moines County (Harris and Parker, 1964). No matter how the discontinuities at or near the top of the Wassonville are interpreted, they serve to mark a distinctive boundary zone separating the Wassonville Cycle from subsequent Osagean cycles.

OSAGEAN-EARLY MERAMECIAN CYCLES AND SEDIMENTATION

DOLBEE CREEK DEPOSITION

The base of the Osagean in southeast Iowa is drawn at the base of the Dolbee Creek Member, a distinctive and widespread crinoidal packstone and grainstone interval interpreted to have been deposited in subtidal open-marine shelf settings. Lateral intergradation of grainstones with dolomitized wackstones indicates that depositional environments were not pervasively agitated (i.e., not a shoal facies); N.G. Lane (1971) inferred relatively low-energy conditions and slow sedimentation for the Burlington crinoidal limestones. Occurrences of graded beds and low-angle cross-stratification are consistent with storm sedimentation events on the shelf (Harris, 1982, p. 31).

Many specific questions remain concerning the initial phase of Burlington sedimentation in southeast Iowa, here termed the Dolbee Creek Cycle (Cycle 4; Fig 16), and much work remains to be done. Why are Dolbee Creek strata, which mark the base of the Burlington sequence, dominated by crinoidal packstones and grainstones in southeast Iowa, whereas younger Burlington crinoidal grainstones mark the regressive or shallowing portions of specific cycles and subcycles? In other words, why does the initial cycle of Burlington sedimentation resemble only the upper regressive phase of the subsequent sedimentary cycle? Why does the Dolbee Creek seemingly lack the skeletal wackstones and mudstones that record transgressive deepening in the subsequent Haight Creek Cycle (Cycle 5; Fig. 16)? The presence of low-relief hardground surfaces within the Dolbee Creek, especially in the lower part, indicates periods of non-deposition, probably in a submarine setting. How much time is represented by such discontinuities?

The answer to this latter question may be the key to unravelling regional sedimentation patterns within the Dolbee Creek Cycle. Deeper depositional facies (dolomitized skeletal wackestones and mudstones) of the lower Burlington occur beneath typical Dolbee Creek grainstones farther south in northeast Missouri and adjacent Illinois (Burlington "Unit 1" of Baxter, 1988, 1990). We interpret the Dolbee Creek Cycle to be more completely represented in that area (e.g., Woodson measured 13 m [43 ft] of Dolbee Creek Cycle strata near Kinderhook, Illinois). Continuing southward in Missouri, transgressive phases of the Dolbee Creek Cycle are interpreted to include even farther offshore facies of the Meppen-Fern Glen (nodular fossiliferous carbonates, shaly to cherty) and Pierson formations. The Dolbee Creek Cycle in southeast Iowa is seemingly missing the transgressive phases of sedimentation, which may be represented within the condensed interval of basal hardgrounds or by non-deposition above the basal discontinuity (a transgressive discontinuity surface). Conodont biostratigraphic studies indicate that one or two conodont zones are missing between the Wassonville and the base of the Dolbee Creek (Collinson et al., 1971; Thompson and Fellows, 1970; Lane 1978; Chauff, 1981), and a diastemic discontinuity is indicated. Complications resulting from biofacies and their influence on the ranges of key taxa need to be considered in all biostratigraphic schemes.

Certain stratigraphic misinterpretations in previous studies have excluded Dolbee Creek strata from portions of southeast Iowa and placed Haight Creek strata directly above the upper Wassonville discontinuity (e.g., Laudon, 1937; Harris and Parker, 1964; Straka, 1966; Harris, 1982), primarily in Washington County. These ideas promoted an interpretation of progressive onlap of Burlington units in southeast Iowa. Nevertheless, we have consistently recognized the presence of Dolbee Creek strata at all localities in southeast Iowa, even though they are commonly represented by thin dolomitized facies that superficially resemble the Wassonville in portions of Washington and Keokuk counties. In the field trip area the Dolbee Creek is notably thinned and typically includes one or more hardground surfaces, suggesting a condensed sequence. Although dolomitized crinoidal packstones are present in this area, the coarse crinoidal grainstones typical of the Dolbee Creek elsewhere are locally absent. The presence of structural highs may help explain the thinning and facies variations of the Dolbee Creek in Washington and Keokuk counties. Episodic storm events may have periodically removed skeletal grains and other sediment from submarine highs, producing apparent thinning and punctuating the interval with discontinuities.

The Dolbee Creek Cycle has proven to be difficult to recognize north and west of southeast Iowa, although its relation southward to include

Fern Glen-Meppen and Pierson strata seems clearer (see cross-sections in Lane, 1978). In northern Iowa, the Maynes Creek Cycle, a likely correlate of the Wassonville Cycle, is overlain by the next depositional cycle represented by the type sequence of the Gilmore City Formation (Cycle IIIa of Woodson and Bunker, 1989). The type Gilmore City is overlain by lower Osagean strata of the upper Gilmore City (the "Humboldt oolite"; Cycle IIIb, ibid.), indicating that at least part of the Gilmore City sequence is a Burlington correlate (Brenckle and Groves, 1987). It is tempting to equate the Dolbee Creek and lower Gilmore City cycles because of stratigraphic position. The Dolbee Creek interval occupies the same relative position as oolitic strata in the subsurface of south-central and central Iowa that have traditionally been included in the Gilmore City Formation, and the two units seemingly intergrade in Mahaska County (see cross-section, Fig. 3). Nevertheless, the Dolbee Creek contains Osagean faunas, whereas the type Gilmore City has traditionally been included in the late Kinderhookian (Laudon, 1933), suggesting non-equivalence. In particular, the presence of the conodont *Siphonodella* in the basal Gilmore City at its type locality has suggested a Kinderhookian age that would preclude its correlation with the Burlington.

However, lower Pierson strata of Oklahoma and basal Fern Glen strata in Illinois, both considered to be the basal transgressive interval of the complete Dolbee Creek Cycle, contain late representatives of *Siphonodella* (Thompson and Fellows, 1970; Lane, 1978). It is possible that the basal type Gilmore City represents the initial transgressive phase of the Dolbee Creek Cycle, but, as discussed earlier, this initial transgressive phase left no direct evidence in the type Dolbee Creek area, possibly obscured as a transgressive non-sequence. However, the upper regressive part of the type Gilmore City section may correlate with part of the Dolbee Creek Cycle. Further studies are needed to more clearly delineate stratigraphic and chronologic relations in the basal Burlington, particularly with respect to hardground development and the regional character of the basal discontinuity. Sequence stratigraphy should be an integral part of such analyses.

THE HAIGHT CREEK CYCLE

The Dolbee Creek Member is sharply but concordantly overlain by strata of the Haight Creek Member in southeast Iowa. The contact between the Dolbee Creek grainstones and dolomitized mudstones and wackestones, highly glauconitic and argillaceous in part, of the Haight Creek is abrupt, and marks the base of the next depositional cycle, the Haight Creek Cycle (Cycle 5, Fig. 16). The significant concentration of glauconite in the basal Haight Creek, a characteristic of regional extent, is interpreted as a relatively condensed basal transgressive zone. The preponderance of carbonate mud and the paucity of skeletal grainstones through most of the Haight Creek sequence suggest relative depositional deepening, in part below storm wave base, compared to Dolbee Creek environments. The widespread lithic and faunal continuity in the Haight Creek indicates widespread depositional uniformity, and a subtidal position is clearly indicated. The development of the "middle grainstone" unit of the Haight Creek across southeast Iowa is interpreted to record a shallowing episode (regressive subcycle) of regional extent. Like other Burlington grainstones, it probably formed through storm winnowing as benthic environments shallowed above storm wave base. The return to skeletal mudstone and wackestone deposition in the upper Haight Creek is interpreted to record a second phase of relative deepening (upper Haight Creek transgressive subcycle). The more common occurrence of grainstones within the Haight Creek of north-central Missouri (see Fig. 6) suggests more frequent winnowing events in that area.

The overlying Cedar Fork Member, dominated by crinoidal packstones and grainstones, is interpreted as the major regressive sedimentary phase of the Haight Creek Cycle. The Cedar Fork was clearly subjected to more frequent winnowing events than the underlying Haight Creek, indicating a depositional position generally above storm wave base. Cedar Fork grainstones interbed and intergrade with dolomitized wackestones and shales, suggesting that winnowing was not laterally pervasive. In addition, the common occurrence of glauconite within the Cedar Fork grainstones and the presence of multiple "bone bed" horizons within some sections are interpreted as evidence for relatively slow sedimentation through much of the sequence. The most regionally persistent "bone bed" horizon, characteristically very glauconitic, occurs at the top of the Cedar Fork, and this horizon has been used to mark the top of the Burlington Formation in southeast Iowa and adjacent regions. It apparently represents a depositional discontinuity.

The magnitude and origin of the Burlington-Keokuk discontinuity has been disputed by various workers. Some conodont biostratigraphers propose that a zone (*G. bulbosus* Zone) is missing between the Burlington and Keokuk formations, although this supposed "zone" may represent a biofacies variation endemic to southern Missouri and of "little biostratigraphic significance" (see Collinson et al., 1971, p. 381). Ross and Ross (1987) interpreted a subaerial exposure surface between the Burlington and Keokuk formations, but we agree with D. Harris (1982, p. 39) that in southeast Iowa "absolutely no evidence was seen to suggest a subaerial unconformity" between the two formations. Instead, the uppermost Burlington "bone bed" is interpreted to be a submarine discontinuity, coinciding with a significant slowdown in sedimentation rates (ibid.). This discontinuity is interpreted to mark the boundary between the Haight Creek and succeeding Keokuk cycles. It also occurs at a noteworthy lithic and faunal boundary (Collinson et al., 1971), that possibly corresponds to the end of Cycle 1 in the British Dinantian (Ramsbottom, 1973). Van Tuyl (1925, p. 144) apparently was the first to interpret the upper Burlington as a regressive sequence, and suggested "shallowing of the sea in the region at the close of Burlington time." S. Baxter (1988, 1990) apparently included dolomite and limestone strata above typical Cedar Fork grainstones between Hannibal, Missouri, and Hamilton, Illinois, within an expanded Burlington Formation (informally labelled "Unit 5"). Faunas, stratigraphic position, and lithologies are more consistent with inclusion of these strata within the Keokuk Formation.

The Haight Creek Cycle of southeast Iowa is reasonably correlated with the upper Gilmore City sequence ("Humboldt oolite") of northern Iowa (Cycle IIIb of Woodson and Bunker, 1989), which is of Early Osagean age (Baxter and Brenckle, 1982; Brenckle and Groves, 1987). This northern sequence occurs entirely within shallower depositional facies than are seen in southeast Iowa. The shallowing-upward Humboldt sequence is characterized by skeletal to peloidal wackestones to grainstones (coated grain) of shallow subtidal origin in the basal portions, and by supratidal and evaporitic sabkha facies at the top of the cycle (Sixt, 1983). Significant differences, therefore, are apparent in gross facies and biofacies patterns of lower Osagean strata between northern and southeast Iowa, which include: 1) the occurrence of lagoonal, supratidal, and sabkha facies in the north and their absence to the southeast, which is characterized exclusively by subtidal facies; 2) the development of oolite shoals and back-shoal facies in northern Iowa, but not to the southeast; 3) significant differences in the echinoderm, brachiopod, and coral faunas between the two areas; and 4) the common occurrence of calcareous foraminifera in the northern sections, but their virtual absence in the type Burlington area. The presence of calcareous foraminifera in some fine grainstones of the Cedar Fork in Washington and Keokuk counties presently represents the southernmost known occurrence of biostratigraphyically useful forams in the Burlington Formation. The apparent regional differences in depositional facies and biofacies are integrated into a generalized paleogeographic model that encompasses the expansive Early Osagean cratonic and marginal shelf seas of North America (Fig. 17).

REGIONAL EARLY OSAGEAN PALEOGEOGRAPHY

Figure 17 is a schematic representation of gross facies patterns developed during the interval of Burlington deposition (Early Osagean) on the Tournaisian paleogeographic base map of Witzke (1990). This represents an expanded version of the depositional paleogeography that Lane (1978), Lane and DeKeyser (1980), Gutschick et al. (1980), and Gutschick and Sandberg (1983) presented for the same time interval. Lane and DeKeyser (1980) recognized several broad regional depofacies: 1) "inner shelf" facies characterized by dolomites and grain-supported skeletal limestones (e.g. type Burlington area); 2) "main shelf" facies characterized by largely undolomitized skeletal limestones, primarily with packstone and wackestone fabrics (Harris, 1982, p. 39); 3) a narrow "shelf margin" biofacies of argillaceous to cherty lime wackestones and mudstones; 4) a "starved magnafacies" characterized by deeper water environments with submarine surfaces of nondeposition which extends to the continental

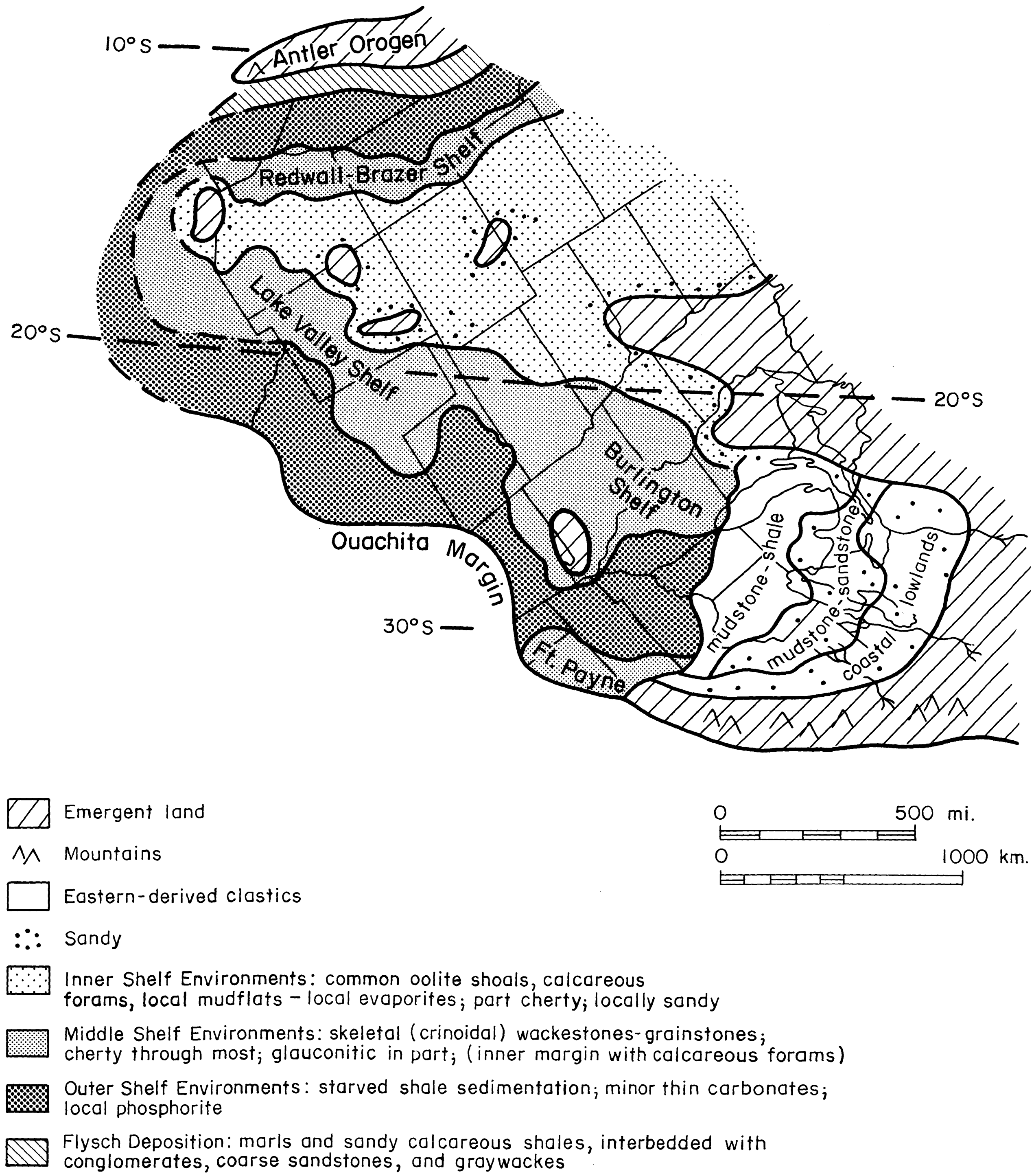

Figure 17. Early Osagean (late Tournaisian) paleogeography of western Euramerica (United States area) during deposition of the Burlington Formation and coeval stratigraphic units. General distribution of Inner, Middle, and Outer Shelf environments are delineated. Base map and paleolatitudes after Witzke (1990); adapted in part from facies and paleogeographic maps of Lane (1978), Lane and DeKeyser (1980), Gutschick et al. (1980), Gutschick and Sandberg (1983), and Craig and Connor (1979).

margin; 5) a "novaculitic magnafacies" of radiolarian-rich siliceous rocks deposited along the contintal slope; and 6) a "clastic magnafacies" of eastern-derived terrigenous clastic rocks that prograded toward to the carbonate shelf margin. These interpretations of large-scale facies patterns are extremely useful for placing much of Burlington deposition in a broad paleogeographic context.

However, Lane and DeKeyser (1980) did not recognize additional facies shoreward from the type Burlington area, and our revised paleogeography (Fig. 17) attempts to incorporate an additional broad facies belt in that position. Three large-scale facies tracts are delineated: 1) A broad, shallow "inner shelf" belt (*not* the "inner shelf" of ibid.) roughly parallels the Transcontinental Arch (e.g., Gilmore City Fm.); it includes a mosaic of shallow subtidal, restricted nearshore, oolite shoals, supratidal, and evaporitic facies; calcareous foraminifera commonly occur. 2) An intermediate "middle shelf" facies tract is recognized that includes the "inner" and "main" shelf facies of Lane and DeKeyser (1980); it is characterized by subtidal open-marine facies, especially grain-supported limestones deposited above storm wave base and skeletal wackestones deposited in slightly deeper environments (e.g., Burlington Fm.); this facies tract commonly displays a narrow shelf margin facies on its seaward side that separates the "middle" and "outer" shelf facies tracts. 3) An "outer shelf" facies belt runs from the "middle shelf" margin to the edge of the continental shelf. The "outer shelf" tract includes large areas of starved deeper-water sedimentation; prodeltaic muds prograded onto the "outer shelf" from eastern sources, and flysch facies occur marginal to the Antler highlands to the west.

KEOKUK CYCLE

The abrupt shift from packstone-grainstone textures of the upper Cedar Fork Member to dolomitized and unwinnowed sparse skeletal wackestone-mudstone fabrics at the base of the overlying Keokuk Formation is interpreted to record a depositional deepening, the transgressive phase of the Keokuk Cycle (Cycle 6; Fig. 16). The "bone bed" at the top of the Burlington represents a slowdown in sedimentation that coincides with the boundary between successive T-R cycles. The abundant occurrence of sponge spicule molds in the skeletal wackestones of the lower Keokuk suggests a likely biogenic silica source for the abundant cherts of the lower Keokuk (Montrose Member). The crinoidal and spicular wackestones and mudstones of the Keokuk are argillaceous to varying degrees, and a quiet-water subtidal environment below fair-weather wave base is likely for these intervals. Interbedded crinoid-bryozoan packstone intervals are interpreted to record episodic bottom agitation during storm events in the "middle shelf" environments.

The influx of clay, which generally increases upward through the Keokuk sequence, records the influx of distal terrigenous clastics during probable regression. Van Tuyl (1925, p. 143) recognized the general upward increase in argillaceous content in the Keokuk, and interpreted it to record "a slow contraction of the sea during Keokuk time"; as such, he was the first to propose that the Keokuk is an upward-shallowing sequence. The influx of siliciclastic sediments, including siltstone and sandstone, becomes more significant in the overlying Warsaw Formation, which is interpreted to record continued progradation during later regression of the Keokuk Cycle. Presently, there appears to be no obvious physical evidence for significant breaks in sedimentation within the Keokuk-Warsaw interval in southeast Iowa, and gradational boundaries, both laterally and vertically, between major lithic packages are most simply interpreted to reflect progressive upward-shallowing in the sequence. Nevertheless, small-scale changes in relative water depth may coincide with the progradation of discrete and laterally persistent shale units sandwiched within the Keokuk-Warsaw carbonate sequence. The presence of such minor "subcycles" in the larger Keokuk Cycle are schematically represented on the qualitative sea-level curve (Fig. 16). Further, glauconitic and bone-bed horizons within the "upper Keokuk" sequence (e.g., Fig. 7) may mark positions of additional T-R subunit boundaries. The "Foram Bed" described by Brenckle et al. (1982) clearly represents a regressive episode in the middle Keokuk of the St. Louis area. The significant erosional unconformity developed regionally on the Keokuk and Warsaw formations records withdrawal of the sea from the Midcontinent at the end of the Keokuk Cycle. This may reflect structural uplift and/or a eustatic drop in sea level.

Historic placement of the Osagean-Meramecian boundary in the classic Mississippian sections between Keokuk, Iowa, and Chester, Illinois, has varied considerably depending on lithostratigraphic groupings or definitions of Warsaw and Keokuk strata and on paleontologic preferences. For some, the differentiation of Osagean and Meramecian proved elusive and impractical, and the two series have been joined together to form a single series, the Valmeyeran, in some areas. As summarized by Thompson (1986, p. 99): "Because a clearly defined faunal break between the Osagean and Meramecian Series is lacking, the Illinois and Indiana Geological Surveys, among others, have adopted . . . the Valmeyeran Series." In Iowa, the Meramecian has been drawn *above* the Warsaw Formation (Avcin and Koch, 1979). Kammer et al. (1989) proposed that the first occurrences of a distinctive brachiopod (*Warsawia lateralis*) and blastoid (*Pentremites conoideus*) mark the base of the Meramecian, which they correlated near the historic base of the Warsaw of Hall and Whitney (1858), that is, the shales above the "Geode Beds." If these taxa can be shown to have widespread distribution in both shale and carbonate lithofacies, they may have demonstrable regional biostratigraphic utility.

Lithostratigraphic concepts of the Warsaw have been historically significant for defining the base of the Meramecian Series, although modern practice requires a clear biostratigraphic definition permitting chronostratigraphic resolution. The Warsaw Formation displays significant regional facies variations, from siliciclastic to carbonate dominated, across Illinois, Missouri, and Iowa, and a clear-cut separation between the Keokuk and Warsaw formations has proven extremely difficult in many areas. Westward across Iowa, and into Nebraska, Kansas, and western Missouri, the Warsaw loses much of its argillaceous and shaly character to become, as Thompson (1986, p. 102) noted in Missouri, ". . . a 'typical' middle Mississippian carbonate, lithologically similar to the underlying Keokuk." The lateral and vertical similarity of Warsaw and Keokuk strata over broad areas indicates that no major T-R cycle boundary separates the formations in southeast Iowa. Placement of Keokuk and Warsaw strata in one large-scale cycle reflects both difficulties in interpretation and the need for additional study. In areas of Missouri and Illinois, presumed upper Warsaw strata intergrade with Salem-like lithologies, suggesting a possible gradational boundary with the succeeding cycle in some areas.

Ross and Ross (1987) divided the Keokuk-Warsaw sequence into three major T-R cycles, with an exposure surface separating the Keokuk and Warsaw formations. We have been unable to recognize any significant sedimentologic or biostratigraphic breaks in Iowa that allow us to differentiate these additional cycles. Ramsbottom (1973) recognized two major cycles (Cycles 2 and 3) in the British Dinantian for the interval that correlates with the Keokuk-Warsaw sequence in Iowa. The presence of oolitic shoal facies in the upper Keokuk Formation in parts of Missouri (Thompson, 1979; 1987) and Illinois (Brenckle et al., 1982) records a regressive phase developed within the larger Keokuk Cycle. The upper and lower boundaries of our Keokuk Cycle apparently correspond to eustatic sequence boundaries recognized by Ross and Ross (1987) and Ramsbottom (1973). Our inability to delineate additional T-R units in Iowa may reflect the need for greater study and for further evaluation of eustatic versus structural controls of regional T-R units.

MERAMECIAN AND GENEVIEVIAN CYCLES

Following an erosional hiatus in Iowa, the Keokuk Cycle was succeeded by several major T-R cycles represented by strata variably assigned to the "Spergen," "St. Louis," "Ste. Genevieve," and Pella formations. The need for an independent lithostratigraphic nomenclature in southeast Iowa is underscored by the recognition of long-term miscorrelation and lithologic dissimilarities with classic St. Louis, Ste. Genevieve, and Salem strata to the south and east. Strata informally grouped as "St. Louis" are subdivided into a series of members herein, although new formational nomenclature will be proposed in future studies. Improved lithostratigraphic and biostratigraphic control and the recognition of major T-R cycles through this interval have allowed a clearer picture of regional relationships to emerge. However, the post-Warsaw sequence remains an inadequately understood Mississippian interval in southeast Iowa, and additional study is needed.

SALEM AND ST. LOUIS CYCLES

Van Tuyl (1925) recognized a thin interval, the "Spergen" Formation or "Belfast beds," of sandy to fossiliferous carbonate, shale, and sandstone disconformably above the Warsaw in portions of southeast Iowa. The interval was observed to pinch out to the northwest. The "Spergen" is now assigned to the Salem Formation across the midwestern U.S. Van Tuyl (1925) correlated the Iowa interval with more typical Salem strata in Indiana based on faunal similarities, although there have been no subsequent faunal studies in Iowa to confirm his correlations. Subsequent use of the "Spergen" in Iowa by well loggers at the Iowa Geological Survey and others (e.g. Milne, 1978) was inexplicably modified from Van Tuyl's intent to include strata assignable to portions of the overlying Croton Member. As presently recognized, shoreward equivalents of the Salem Formation are not recognized north or west of Jefferson County, Iowa, being overstepped by the Croton Member. The relationship of the Iowa "Spergen" (Salem) with similar lithologies of the Sonora Formation in Illinois is not clear, although the Sonora is reported to grade laterally into the Salem, in part (Atherton et al., 1975). The Salem Formation in Illinois and Indiana is characterized by shallow-water packstones and grainstones, oolitic in part, with common calcareous foraminifera; minor evaporites are present (ibid.).

Probable Salem equivalents in southeast Iowa are presently considered to form an independent T-R cycle (Cycle 7, ?Salem Cycle; Fig. 16), separated from adjacent cycles by disconformities. The geographic distribution and sandy lithofacies suggest that the Cycle 7 marine transgression was of lesser magnitude than other Iowa Mississippian T-R cycles. Salem strata in the Mississippi Valley (Baxter and Brenckle, 1982; V2b age) may correlate with Cycle 4 of the British Dinantian (Ramsbottom, 1973; V2b age), suggesting eustatic controls. Ross and Ross (1987) also recognize a Salem cycle, with a significant sea-level drop proposed for the upper Salem. Reported intergradation of Salem grainstone lithologies with underlying "Warsaw" and overlying St. Louis strata in areas of Illinois and Missouri possibly suggest gradational boundaries with preceding and succeeding T-R cycles in areas outside of Iowa.

The Croton Member of the "St. Louis" Formation in Iowa unconformably overlies an eroded surface developed on the Warsaw and Keokuk formations across much of the state. Erosional relief on this surface approximates 30 m (100 ft) in southeast Iowa (see Fig. 3), forming one of the most easily recognizable boundaries in the area. The sequence of environments during Croton deposition has not been worked out in detail, but it is interpreted to form a general transgressive-regressive interval (T-R Cycle 8; Fig. 16). Evaporites, collapse breccias, or limestone "conglomerates" occur in the lower part of the sequence in many sections, overlain by dolomitized crinoidal wackestones or sparse mudstones, arenaceous in part. Upper Croton strata are fossiliferous in areas of southeast Iowa, with "*Lithostrotion*" corals (*Acrocyathus*) of particular note (Van Tuyl, 1925; Sando, 1983). As described in this guidebook, the Croton is capped by the Yenruogis Sandstone in the field trip area, interpreted to represent progradation of siliciclastics during regression of Iowa Cycle 8. To the west in the Iowa subsurface, the cycle is locally capped by an evaporite unit (Fig. 3). The upper boundary of Iowa Cycle 8 is drawn at a regional disconformity marking a "short interval of erosion," as interpreted by Van Tuyl (1925, p. 231).

Croton strata in Iowa have been traditionally correlated with the St. Louis Formation to the south, and lithostratigraphic and biostratigraphic evidence supports this. Accordingly, Iowa Cycle 8 is provisionally labelled the "St. Louis Cycle" (Fig. 16). The upper contact of the St. Louis has been the source of consternation to many workers and, consequently, its stratigraphic position varies appreciably throughout the Illinois Basin. These inconsistencies in stratigraphic placement have had the unfortunate effect of blurring faunal distinctions between the two formations. The contact endorsed here is that of Pohl (1970), Woodson (1982), and Rexroad et al. (1990). Pohl (1970) proposed that stratigraphic terminology for sequences of thick carbonates should be based on T-R cycles. He clearly considered the St. Louis (Horse Cave Member)-Ste. Genevieve (Fredonia Member) contact to be a cycle boundary. Rexroad et al. (1990) suggested that a hiatus occurs between the St. Louis and Ste. Genevieve formations. Cycle 8 is recognized in Iowa and adjacent Missouri and Illinois, and the St. Louis interval is also shown as a single major T-R cycle by Ross and Ross (1987). Ramsbottom's (1973) Cycles 5 and 6 of the British Dinantian have not been observed as discrete cycles in correlative strata of the Mississippian sequence in the Iowa area. Ramsbottom (1973) grouped strata of V3b age within British Cycle 6, although age equivalent rocks in the Mississippi Valley include strata of both the upper St. Louis and lower

Ste. Genevieve (Baxter and Brenckle, 1983), which we separate into portions of two cycles. Interestingly, the T-R boundary separating upper from lower Ste. Genevieve cycles in southeast Iowa seems to have greater physical magnitude than that which separates the St. Louis and Ste. Genevieve.

The Genevievian Stage, named for the Ste. Genevieve-Aux Vases-lower Renault sequence, was proposed by Swann (1963) to occupy the upper Valmeyeran Series. Different workers have variably assigned the Genevievian stage to the Meramecian or Chesterian Series, and the most recent proposal includes the Genevievian with the Chesterian (Maples and Waters, 1987). Regardless of its series placement, the Genevievian interval in Iowa is subdivided into two T-R units separated by a subaerial unconformity (Cycles 9 and 10; Fig. 16). The Verdi and Waugh members of the upper "St. Louis" interval in Iowa are now correlated with the lower Ste. Genevieve sequence in Illinois (see earlier suggestions of Woodson, 1987; "case B" of Witzke, 1987). The Verdi records a widespread, albeit thin, marine transgression in the Iowa area, where it forms a general shallowing-upward sequence, overlain by non-marine strata of the Waugh. The rooted horizon and coaly strata at the top of the Waugh mark the upper boundary of the first Genevievian T-R cycle in Iowa (Iowa Cycle 9). Additional subaerial exposure surfaces and two or more prograding sandstone bodies in the Verdi Member (see earlier discussion) mark additional T-R subcycles in the sequence.

The lower Ste. Genevieve interval over areas of Illinois, Indiana, Kentucky, and Missouri also forms an apparent shallowing-upward sequence; marine limestones occupy the lower part (Fredonia Limestone), and sandstone and sandy carbonate strata (Spar Mountain Sandstone) mark the final regressive phase of prograding siliciclastic sediments in the upper part. Swann (1963, p. 16) was the first to identify the lower Ste. Genevieve interval (Fredonia-Spar Mountain) as a transgressive-regressive sequence. We propose to correlate Iowa T-R Cycle 9 with the lower Ste. Genevieve sequence, and have accordingly labelled it the "lower Ste. Genevieve Cycle" on Figure 16).

The youngest Mississippian T-R cycle in Iowa corresponds to the Pella Formation (Cycle 10; Fig. 16). The lower Pella is characterized by oolitic to skeletal limestone, locally with sandstone at the base; this lower interval forms a deepening-upward depositional sequence recording marine transgression. The overlying Pella interval (calcareous shale, interbedded nodular to thin-bedded limestone) contains a diverse marine fauna. This interval is interpreted to record maximum transgression in subtidal settings, followed by gradual regression. The skeletal packstone lenses, some with abraded grains, are interpreted to have been generated by periodic storm currents. Progradation of terrigenous clastic sediment (primarily clay) characterized Pella deposition above the basal limestone beds, recording the regressive phase of the T-R cycle. A general upward decline in faunal diversity through the Pella sequence is consistent with a shallowing-upward interpretation. Although sub-Pennsylvanian erosion has truncated the final regressive phases of sedimentation in most Pella sections, unfossiliferous red shales and sandstones, possibly upper Pella strata, locally occur above fossiliferous Pella beds in some areas (Van Tuyl, 1925). Van Tuyl (1925, p. 289) recognized that "at the close of Pella time the sea withdrew from the Upper Mississippi Valley" area.

The Pella Formation in Iowa has been correlated, virtually from its inception, with Ste. Genevieve strata in Illinois and Missouri, and we agree that the most reasonable correlation of the Pella is with some part of the Ste. Genevieve sequence. The Pella clearly represents an independent T-R cycle, which we tentatively equate with upper Ste. Genevieve strata of the Karnak and Joppa members of the Illinois Basin ("upper Ste. Genevieve Cycle" of Fig. 16). Swann (1963, p. 16) Cycle" of Fig. 16). Swann (1963, p. 16) interpreted the Karnak-Joppa interval in Illinois as a transgressive-regressive sequence; this interval is both capped and replaced laterally by the Aux Vases Sandstone, marking the progradation of sands during regression of the upper Ste. Genevieve T-R sequence. The final regressive phases of sedimentation of Iowa Cycle 10 have been erosionally bevelled across the state, and it is unknown if any later Chesterian marine transgressions encroached into Iowa.

PART II.

Stop Discussions and Descriptions

The field trip will visit operating and inoperative quarries and other exposures in Washington and Keokuk counties, Iowa. The stops will provide access to a nearly complete sequence of Mississippian strata in the area. *Quarries are potentially dangerous places, and participants are asked to exercise caution and display courtesy at all times. Hard hats are required in the operating quarries, and some quarry faces and high walls must be avoided as designated by the field trip leaders.* A map of the field trip route is found on the back cover of the guidebook.

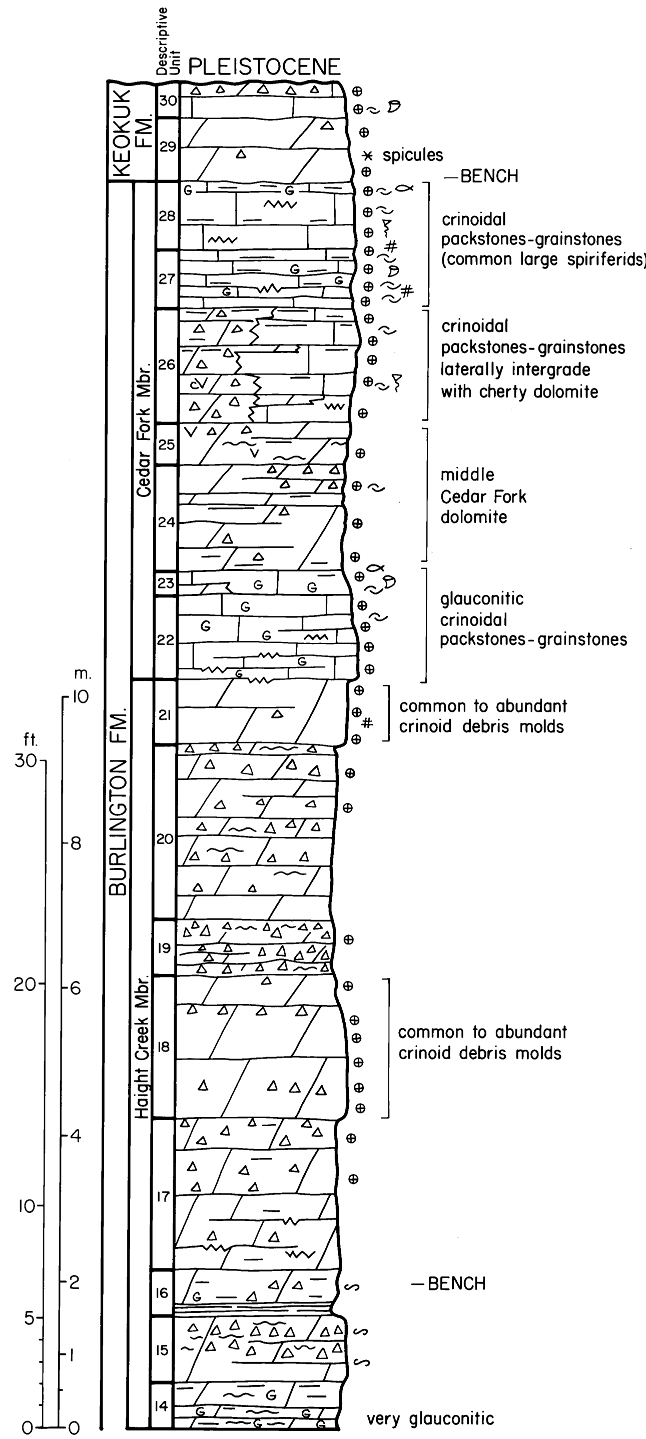

Figure 18. Stratigraphic section of Burlington (Haight Creek and Cedar Fork members) and Keokuk strata at STOP 1, Keota-Pepper Quarry, Washington County, Iowa. See legend (in Appendix) for symbols.

STOP 1. KEOTA-PEPPER QUARRY;

Wassonville and Burlington stratigraphy and paleontology

(River Products Company, owner)

DISCUSSION. The Pepper Quarry exposes an exceptionally instructive sequence of Wassonville and Burlington strata (Figs. 18-19), most of which can be safely accessed along the quarry ramp. Depending on the progress of quarrying activities and time constraints, upper Burlington and basal Keokuk strata can be seen in the upper bench area. Unlike the type Wassonville section, 19 km (12 mi) to the northeast, the Wassonville sequence in the Pepper Quarry contains beds of undolomitized skeletal limestone. Well-preserved fossils are abundant in the lower and middle parts of the Wassonville, not only in the limestone beds, but as silicified faunas within the dolomites and cherts. Chonetid brachiopods are conspicuous along some bedding surfaces (especially *Rugosochonetes multicostus*), and numerous other brachiopods are found in the skeletal limestones (see earlier discussion). Some packstones are highly crinoidal, and articulated crinoids (with arms and stems attached) have been collected from laminated dolomitic rocks in the quarry. Trilobites are not uncommon in the lower Wassonville, and an interesting molluscan fauna can be found in some nodular cherts.

Wassonville strata in the Pepper Quarry display interesting sedimentary structures interpreted to have formed by storm-current activity, including graded skeletal limestone lenses, planar laminated and low-angle cross-laminated beds, and small-scale hummocky stratification. These structures are displayed not only in the quarry walls, but are clearly seen in the large blocks that border the quarry ramp. The top of the Wassonville is marked by an abrupt change in dolomite lithology along a slightly irregular hardground surface.

Lower Burlington strata of the Dolbee Creek Member are dolomitized, but the massive bedding and crinoidal packstone fabrics resemble that seen in undolomitized Dolbee Creek sections elsewhere in southeast Iowa. Dolbee Creek strata in this quarry were included in the Haight Creek Member in a previous study (Harris, 1982, p. 275). The basal Dolbee Creek includes two closely-spaced hardgrounds, locally forming stylolitic surfaces. The Haight Creek Member is dominated by sparsely fossiliferous dolomite, faintly laminated in part. An interval of common crinoid debris molds in the middle part (Unit 18, Fig. 18) probably correlates with the "middle grainstone" unit to the southeast. Nodular cherts are common in the member, and bedded cherts are prominent in some intervals (especially Unit 19, Fig. 18). The basal Haight Creek is highly glauconitic, with abundant glauconite grains along dolomite laminae. Shaly and argillaceous strata are noteworthy in the lower Haight Creek.

The upper Burlington Cedar Fork Member in the Pepper Quarry is dominated by limestone (crinoidal packstone and grainstone), but significant dolomite occurs in the middle part of the member. Some limestone strata are seen to be replaced laterally by cherty dolomite within the quarry (Unit 26, Fig. 18). The Cedar Fork limestones are glauconitic to varying degrees, with glauconite most abundant in the lower part and at the top of the member. Large spiriferid and productid brachiopods (*Spirifer grimesi*, *Syringothyris typa*, *Echinoconchus alternata*, others) are prominent in some beds, particularly in the upper Cedar Fork. Overlying Keokuk strata are preserved in the east quarry area, where basal Keokuk dolomites sharply overlie bone-bearing crinoidal grainstones. An excellent Pleistocene section of pre-Illinoian tills caps the upper bench.

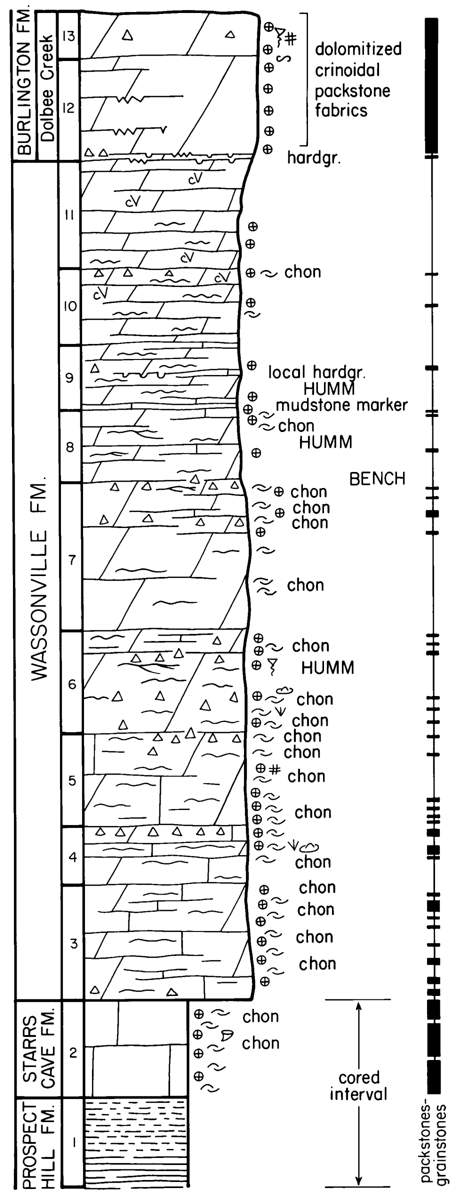

Figure 19. Stratigraphic section of lower Burlington (Dolbee Creek Member) and Wassonville strata exposed at STOP 1, Keota-Pepper Quarry. Prospect Hill-Starrs Cave sequence based on Iowa Department of Transportation core log. Same vertical scale as in Figure 18. See legend (in Appendix) for symbols.

KEOTA-PEPPER QUARRY DESCRIPITION

LOCATION: NE NW SW sec. 31, T76N, R9W, Washington Co., Iowa; measured 5/16/90 by B.J. Witzke, B.J. Bunker, F.J. Woodson; Units 28-30 exposed only along upper bench in east quarry area.

MISSISSIPPIAN--OSAGEAN
KEOKUK FORMATION

UNIT 30
Limestone, brown, fine skeletal packstone; large *Spirifer*, cup coral, indet. brachiopods; interbedded with thin dolomite near base; upper 20 cm very cherty dolomite; brown skeletal packstone at top; 50 cm.

UNIT 29
Dolomite, light brown, xf-vf xlln, some poikilotopic calcite cement; in one or two beds, sharp basal contact; scattered chert (especially near top); fine skeletal molds, sponge spicules, crinoid debris; 90 cm.

BURLINGTON FORMATION
CEDAR FORK MEMBER

UNIT 28
Limestone, very light brown to light gray, fine to coarse crinoidal packstone-grainstone, medium bedded, stylolitic; top 10 cm very glauconitic, fish bone scattered; 1-2 cm shale parting 35 cm above base; some crinoid debris and brachiopods are silicified in top 20 cm; scattered to common *Spirifer grimesi* and other large spiriferids, especially in upper part, some shells are pitted and bored; crinoid cups scattered in grainstones (*Dizygocrinus*), *Platycrinites* columnals; 90 cm.

UNIT 27
Limestone, fine to medium crinoidal packstone to grainstone, coarse near top and bottom; slightly glauconitic, in beds 5-15 cm thick, separated by thin shale partings; scattered stylolites, scattered chert near base; scattered to common large spiriferids (*Spirifer grimesi*, *Imbrexia*, *Unispirifer*, *Syringothyris*), some valves bored and pitted; other brachiopods (*Marginatia*, *Echinoconchus*, etc.); bryozoans, solitary corals and fish debris noted; 80-85 cm.

UNIT 26
Limestone, fine to coarse crinoidal packstone-grainstone, scattered brachiopods, crinoid cups, slightly glauconitic; limestone-dominated along north wall, cherty dolomite at base; limestone section interbeds with skeletal-moldic dolomite beds 5-30 cm thick in northeast quarry area; west quarry face includes grainstone in basal 35 cm, overlain by skeletal-moldic dolomite and dolomitic packstones, upper dolomite interval is cherty with scattered glauconite; south quarry face is dominated by dolomite, scattered fine crinoid debris molds, calcite-filled vugs, slightly argillaceous in upper part, shale partings (3-6 cm) at top and 70 cm below top, nodular chert bands (noted 60, 75, 105, 130, 145, 165 cm above base); 1.65-1.75 m.

UNIT 25
Dolomite, xf-vf xlln, scattered to common fine crinoid debris molds, faintly laminated in part; scattered vugs, poikilotopic calcite; scattered chert nodules in upper part, laterally variable; argillaceous to shaly parting at top; 62 cm.

UNIT 24
Dolomite and calcitic dolomite, xf-f xlln, medium to thick bedded, slightly argillaceous near base; argillaceous to shaly partings at top and 55 cm below top; nodular to bedded chert laterally variable, most prominent in upper part (chert in beds to 20 cm thick along north wall); scattered fine crinoid debris, small brachiopods, medium-grained calcitic crinoid debris in lower 40 cm; sharp basal contact; 1.45 m.

UNIT 23
Limestone, fine to coarse crinoidal packstone-grainstone, glauconitic, in one or two beds; common brachiopods (*Spirifer grimesi*, others), large crinoid stems; scattered cup corals; scattered fish bone at top; argillaceous parting at top; minor dolomite in northeast corner area; 35 cm.

UNIT 22

Limestone, fine crinoidal packstone-grainstone, slightly glauconitic, stylolitic; in beds 10-20 cm, separated by argillaceous surfaces, shale parting 47 cm above base; 1.1 m.

HAIGHT CREEK MEMBER

UNIT 21

Dolomite and calcitic dolomite, very light brown gray, xf-vf xlln, in two beds (lower bed 50 cm, upper bed 37 cm); lower bed has common to abundant (upwards) fine crinoid debris molds, fenestellids in middle; upper bed with common small crinoid debris molds; unit contains scattered chert nodules, laterally discontinuous and locally absent in quarry; 87 cm.

UNIT 20

Dolomite, xf-vf xlln, medium bedded, recessive, scattered fine crinoid debris molds; lower 1.4 m and upper 15 cm is faintly to finely laminated in part; nodular chert bands developed at 0.4, 0.8, 1.25-1.4 (locally single chert bed), 1.5-1.65, 2.0 (silic. lensoidal crinoidal packstone), 2.1, and 2.25-2.4 m (locally single chert bed) above base; 2.4 m.

UNIT 19

Dolomite, very light brown gray to light gray, xf-vf xlln, scattered fine crinoid debris molds, very cherty; chert is light gray, smooth, faintly laminated, interbedded with light gray dolomite; 15-30 cm thick chert bed at top; lower 35 cm with two to three prominent chert beds merging to single bed laterally; 60-70 cm.

UNIT 18

Dolomite, very light orange brown, slightly calcitic, common to abundant fine to medium crinoid debris molds, scattered silicified crinoid columnals; in 3 to 5 beds, unit forms resistant ledge former; silicified lensoidal crinoidal packstone 43 cm above base, laterally forms chert nodules to 7 cm thick; laminated and crinoidal chert nodules 1.5 m above base; *Platycrinites* stem 1.1 m above base; 1.95 m.

UNIT 17

Dolomite, very light brown gray, xf-vf xlln, slightly argillaceous, scattered stylolites, recessive; nodular cherts, smooth, chalcedonic in lower part; scattered chert nodules 0.3-0.4, 1.1, 1.35 (prominent band with crinoid debris), 1.7, 1.9, and 2.0 above base; 2.07 m.

UNIT 16

Dolomite, very light brown gray, slightly argillaceous, xf-vf xlln, some m-c xlln, fine disseminated glauconite; faint argillaceous partings scattered; lower 15 cm is recessive gray dolomitic shale, soft, laminated, grading upward to shaly dolomite; laterally discontinuous nodular cherts noted 17 cm and 25-35 cm (light gray, faintly burrowed) above base; 65 cm.

UNIT 15

Dolomite, xf xlln, ledge former, single bed, faint argillaceous laminations, scattered burrow mottling, poikilotopic calcite; prominent chert nodules 30-85 above base, light gray, smooth, finely laminated to wavy laminated, agate void fills, laterally includes discontinuous chert beds to 20 cm thick; 95 cm.

UNIT 14

Dolomite, very light gray to pale brown gray, xf (vf) xlln, faintly laminated, slightly argillaceous to argillaceous; very glauconitic laminae in lower 10 cm, less glauconitic upward; scattered chalcedony void fill in upper half; sharp contact at base, overlies slightly irregular surface; 60 cm.

DOLBEE CREEK MEMBER

UNIT 13

Dolomite and calcitic dolomite, light gray, single bed, common to abundant crinoid debris molds (fine to coarse) and dolomitized to silicified crinoid stems and columnals, less crinoidal in lower part; moldic to replaced crinoidal wackestone to packstone fabrics throughout; scattered chert nodules 30 cm above base, smooth to chalky (replaced fine packstone); crinoid cups and fenestellids noted; subvertical burrows scattered in lower part; sharp and irregular upper contact; 60 cm.

UNIT 12

Dolomite and calcitic dolomite, light gray to light brown, in 1 to 3 beds, stylolitic bedding surfaces; dolomitized fine to coarse crinoidal packstone and crinoid-moldic wackestone fabrics throughout, silicified crinoid debris in upper part; horizontal laminae or low-angle cross-laminae present; irregular hardground surface at base; prominent and irregular hardground surface 10-14 cm above base, pockets of crinoidal packstone fabrics below this surface; 1.3-1.4 m.

MISSISSIPPIAN--KINDERHOOKIAN
WASSONVILLE FORMATION

UNIT 11
Dolomite, slightly calcitic, pale orange brown to light gray, xf-vf xlln, slightly argillaceous, faint wavy to irregular laminations; irregularly to rubbly bedded, nodular in part; scattered large calcite-filled vugs; sparsely fossiliferous, scattered crinoid debris molds near top; prominent lithologic change at irregular upper hardground-like surface; 1.45 m.

UNIT 10
Dolomite and calcitic dolomite, light gray to light orange brown, xf-f xlln, wavy argillaceous laminae, wavy and irregular bedding, sparsely fossiliferous (brachiopod molds 45 cm above base); calcite-filled vugs in upper half; thin limestone (crinoidal packstone) 55 cm above base, possibly ripple laminated; top 5-10 cm with chert nodules, smooth to chalky, laterally includes dolomite with silicified skeletal material (crinoid debris, rhynchonellids, chonetids); 1.05 m.

UNIT 9
Dolomite, calcitic, light gray, slightly argillaceous, irregularly and rubbly to wavy bedded; irregular wavy laminations, small-scale hummocky cross-stratification in part, scattered crinoid debris along some bedding surfaces (locally packed at 60 cm above base); probable hardground surface developed near middle; thin limestones (sparse skeletal mudstone), pale gray, in basal 2-10 cm, 50 cm above base, and near top; scattered crinoid debris, brachiopods; 90 cm.

UNIT 8
Dolomite and calcitic dolomite, slightly argillaceous, in two or more beds, nodular bedforms present; laminated to low-angle cross-laminated, small-scale hummocky cross-stratification; sparsely fossiliferous; thin limestones (lensatic crinoidal packstones) noted 40 cm above base, two in top 10 cm (with chonetids); 1.0 m.

UNIT 7
Dolomite, calcitic, light gray, in 1 to 3 beds, finely laminated through most, sparsely fossiliferous (scattered chonetids and productids 50-75 cm above base); upper 55 cm displays low-angle cross-laminae, interbedded thin limestone lenses (crinoidal packstones), most prominent limestones at top and 20 cm below; sharp bedding break at top; chert nodules 1.5 m (with chonetids) above base and at top; 2.05 m.

UNIT 6
Dolomite, calcitic, xf-vf xlln, faintly to finely laminated (mm-scale); middle part displays low-angle cross-laminae and small-scale hummocky cross-stratification; lower 55 cm with scattered thin chonetid-rich laminae, scattered crinoid debris in upper 80 cm; upper 30 cm with 2 thin bands of dolomitic limestone (skeletal packstone); scattered chert nodules near base and 35 cm and 1.25 m above base; prominent nodular chert bands (0-12 cm thick) developed 45 cm and 1.0-1.1 m above base, including skeletal lenses laterally; prominent bedding surface at top; 1.4 m.

UNIT 5
Dolomitic limestone and calcitic dolomite, xf-vf xlln, in 1 to 2 beds, fine argillaceous laminae (mm-scale); thin crinoidal packstone lenses (with chonetids) scattered in lower 40 cm; scattered chonetid-rich layers, chonetid packstones 30-40 cm and 1.0 m above base; large chert nodules (to 12 cm thick) at top, smooth to chalky, laminated in part, with chonetids; scattered chert nodules 25-30 cm below top; 1.3 m.

UNIT 4
Dolomitic limestone and calcitic dolomite, dark wavy argillaceous laminae; in 3 beds; chonetid packstone 40-50 cm above base, with crinoid debris, brachiopods, trilobites, bivalves; prominent chert bed at top (0-15 cm thick), light to medium gray, smooth, encloses discontinuous chonetid packstone; 80 cm.

UNIT 3
Dolomitic limestone and calcitic dolomite, light brown gray, argillaceous laminae and scattered argillaceous partings; interbedded thin lensatic chonetid and crinoidal packstone and grainstone layers scattered through; poor accessibility in lower half (scattered chert noted near base); prominent

argillaceous bedding surface at top; very fossiliferous in part, brachiopods include chonetids, productids, spiriferids, others; 1.6 m.

STARRS CAVE FORMATION

UNIT 2 (from DOT core log; not exposed in quarry)
Limestone, biofragmental (i.e., packstone-grainstone), crinoid debris, brachiopods (chonetids, others), solitary corals; 1.3 m.

PROSPECT HILL FORMATION

UNIT 1 (from DOT core log; not exposed in quarry)
Siltstone, dolomitic, dark gray, and shale, dark gray; sharp upper contact; 1.25 m cored (probably not full).

STOP 2. KESWICK QUARRY;

Kinderhookian through Meramecian stratigraphy and the sub-"St. Louis" unconformity

(Kaser Corporation, owner)

DISCUSSION. The Keswick Quarry exposes the most complete section of Mississippian strata known in the field trip area, with five formations represented (Figs. 20-22). Much of the Keswick sequence is similar to that seen at STOP 1, but the upper portions of the quarry provide access to additional stratigraphic intervals. Recent quarry activities have modified accessibility of some strata, and portions of the Wassonville and Burlington formations may not be easily accessed. Skeletal limestones of the Starrs Cave are overlain by dolomitic strata of the Wassonville Formation at the base of the quarry. Finely laminated dolomites, nodular cherts, chonetid-rich horizons, and interbedded skeletal limestones similar to those seen at STOP 1 also characterize the Wassonville Formation at the Keswick Quarry. The top of the Wassonville is drawn at a slightly irregular hardground surface. The thin overlying Dolbee Creek interval is dolomitized, and displays distinctive crinoidal packstone fabrics, in part with low-angle cross stratification. The Dolbee Creek at Keswick is notably thinner than at Keota, but retains its lithic distinction.

The Haight Creek Member of the Burlington Formation is dominated by sparse skeletal-moldic to faintly laminated dolomite with horizons of nodular chert bands and chert beds. As at STOP 1, the lower beds are highly glauconitic and argillaceous to shaly. Unlike STOP 1, middle Haight Creek strata include dolomitic limestone beds with crinoidal packstone or grainstone textures (units 14 and 16, Fig. 21). The upper Burlington Cedar Fork Member is characterized by glauconitic crinoidal packstone and grainstone beds separated by thin argillaceous or shale partings. Unlike STOP 1, Cedar Fork strata at Keswick Quarry contain only minor dolomite, but shale beds are well displayed in the lower part. Fish bone is common in several horizons within the Cedar Fork interval, including the topmost bed. Fine grainstones in the Cedar Fork at the Keswick Quarry contain calcareous foraminifera, a noteworthy addition to the Burlington fauna (see earlier discussion).

The Keokuk Formation sharply overlies the Burlington, and a prominent thick bed of dolomite marks its base. Crinoidal packstones interbed with dolomite in the lower interval, but most of the Keokuk sequence at the Keswick Quarry is characterized by slightly argillaceous spicular dolomite with prominent bands of nodular to bedded chert. The stratigraphic position and abundance of chert indicate assignment to the Montrose Member. Keokuk strata in the Keswick Quarry have been the primary source for local rockhounds and lapidarists of so-called "Keswick agate" or "benderite" (the former name of this quarry was the Bender Quarry). Attractive red-and-white banded agate locally occurs as void fillings within the bedded cherts. The top of the Keokuk Formation is marked by a prominent erosional surface with up to 1.4 m (4.5 ft) of relief in the Keswick Quarry. The upper beds of the Keokuk are fractured and highly weathered and display prominent reddish colors. The Keswick Quarry contains the thinnest section of the Keokuk Formation, where capped by younger Mississippian strata, known in the state of Iowa.

The Mississippian sequence is capped by an interval of carbonate and siliciclastic rock assigned to the Croton Member of the "St. Louis" Formation. These strata are displayed in the upper bench area, but quarrying activity may have limited accessibility. The lower Croton interval is characterized by siltstone and sandstone with interbedded dolomite, laminated in part. This interval was probably deposited in restricted or marginal settings, and fossils have not been recovered. Upper Croton strata at Keswick include limestone beds, in part with marine fauna. These beds provide evidence of more open-marine conditions during later Croton deposition. Pennsylvanian sandstone locally fills a small channel cut into Croton strata, and Quaternary sediments (pre-Illinoian tills, loess) cap the quarry.

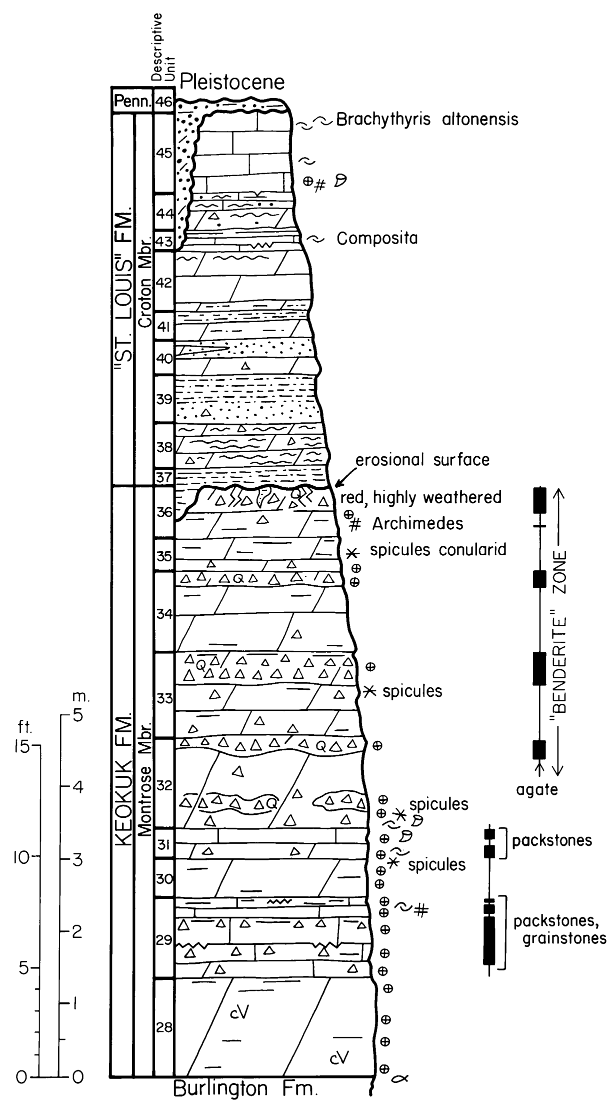

Figure 20. Upper quarry section, Keokuk and "St. Louis" formations, STOP 2, Keswick Quarry, Keokuk County, Iowa. See legend (in Appendix) for symbols.

KESWICK QUARRY DESCRIPTION

LOCATION: NW sec. 21, T77N, R12W, Keokuk Co., Iowa; measured 9/27/89 by B.J.Witzke, B.J.Bunker, F.J.Woodson; with R.M.McKay in Keokuk Fm.; McKay's St. Louis description.

PENNSYLVANIAN
CHEROKEE GROUP undifferentiated

UNIT 46
Sandstone, vf-m, channel fill, common carbonaceous plant material on bedding planes; thin-bedded to laminated, bedding is concordant with channel shape; cuts across top 2 m of St. Louis section into Unit 42.

MISSISSIPPIAN--MERAMECIAN
"ST. LOUIS" FORMATION
CROTON MEMBER

UNIT 45
Limestone, brown, mudstone, slightly dolc, conchoidal fracture; upper 90 cm in 3 beds with 1-2 cm layers of whole-shell brachiopods (*Brachythyris altonensis*); basal 22 cm is skeletal wackestone-packstone with auloporid and solitary rugose corals, crinoid debris, bryozoans; 1.12 m.

UNIT 44
Upper 22 cm is Limestone, mudstone, laminated, with thin 1-2 mm sandstone lenses and laminae, mudcracked upper surface; basal 28-32 cm is Dolomite, tan, porous, slightly calcitic, fine xlln, m-c quartz sand, laminated in upper part with thin black to white discoidal chert, undulose base with 2 cm relief; 50-54 cm.

UNIT 43
Limestone, sublithographic mudstone at base, dense, stylolitic; limestone, vf skeletal grainstone, dense, brachiopods (*Composita*), possible foraminifera; upper 5 cm is shale, slightly calcareous, light brown-tan, laminated; 14-26 cm.

UNIT 42
Dolomite, tan, vf xlln, calc. to very calc., arg. to slightly silty, silty in basal 15 cm (soft); clay vug fills to 3 m; thin 1 mm-thick horizontal calcite laminae spaced 2-10 cm apart in upper 35 cm; 85 cm.

UNIT 41
Basal 25 cm is Dolomite, tan, porous, vf xlln, silty to arg., calcitic, massive, soft; upper 16 cm is siltstone, tan, blocky to massive, soft, calcareous; 1 cm-thick sandstone, vf, 6 cm from base with green clay flakes; 41 cm.

UNIT 40
Lower half is Dolomite, tan with red stain, soft, porous, calcitic, vf xlln, angular chert clasts up to 1 cm; upper half is Sandstone, vf-m, tan, calcareous, interbed of vf xlln dolomite (0-10 cm thick) pinches out laterally; 55 cm.

UNIT 39
Sandstone to siltstone; lower 24 cm is Sandstone, m-c, tan, quartzose, rounded grains, chert clasts derived from underlying unit to 7 cm diameter; upper 41 cm is Siltstone, tan, massive, calcareous, porous, scattered faint laminae, thin 3 cm thick sandy zone at base of siltstone; 65 cm.

UNIT 38
Dolomite, tan with reddish oxidized stains, calcitic, porous, vf xlln, in 3 beds, laminated (laminae 1-10 mm); laminated chert layers, cherts are white to brown with white margins (5 in lower 10 cm, one at 17 cm up, thin cherts at 30, 34, 45 above base); 62 cm.

UNIT 37
Siltstone, light brown, non-calc., thickly laminated and blocky fabric in lower part, laminated in upper 15 cm; irregular basal contact, siltstones infiltrated into fractures and voids in underlying unit; 18-44 cm (locally thicker, basal St. Louis siltstone observed to overlie strata as low as upper Unit 34).

MISSISSIPPIAN--OSAGEAN
KEOKUK FORMATION

UNIT 36

Dolomite, xf xlln, slightly arg., light brown with oxidized mottles in lower part, middle part, fossils preserved as molds or in chert nodules near middle of unit (including *Archimedes*, fenestellid, crinoid debris); upper half is highly weathered, fractured and broken, red-brown, part silty; prominent red to white chert residuum in upper 15-45 cm, fractured with chalcedony, quartz druse and agate (Keswick agate or "benderite") void fills; 75 cm (variable thickness).

UNIT 35

Dolomite, light brown-gray, xf-vf xlln, slightly argillaceous to silty, becomes more arg. upward, shaley parting at top; faintly laminated in part, scattered chert nodules in lower 17 cm (cherts include crinoidal skeletal debris, some Keswick agate and quartz druse); sponge spicules abundant 17-22 cm above base, conularid found near middle of unit; 47 cm.

UNIT 34

Dolomite, light brown-gray with oxidized mottles, slightly argillaceous; top 18 cm is nodular to bedded chert (smooth chert), light gray to light brown, scattered indeterminate brachiopods, chert locally with Keswick agate and quartz druse void fill; 1.1 m (lower portion is covered in part).

UNIT 33

Dolomite, light brown to brown-gray, oxidized mottles, xf-vf xlln, scattered to common sponge spicule molds, scattered crinoid debris molds; scattered to common smooth chert nodules (light brown); upper 45 cm is massive to nodular chert (part red to white), banded with skeletal wackestone and packstone replacements (crinoidal) and molds, moldic dolomite inclusions, locally with Keswick agate and quartz druse void fills; shale parting at top; 1.2 m (middle part covered beneath upper bench).

UNIT 32

Dolomite, light to medium brown, xf-f xlln, part with dark mottles, scattered sponge spicule molds; smooth chert band 8-12 cm above base (wackestone to packstone fabrics, brachiopod, solitary coral); thick smooth chert nodules 23-55 cm above base, moldic to replaced crinoid debris, silicified crinoidal packstone in part; top 10-20 cm is a prominent chert bed, smooth to chalky, part porous, with quartz druse and Keswick agate-lined voids; 1.23 m.

UNIT 31

Dolomite, in 2 beds; lower 22 cm chalcedonic dolomite, coarse to fine crinoidal packstone, fining upward, scattered silicified brachiopods, chert nodules (silicified packstone) at base; upper 20 cm is dolomite grading into dolomitic limestone, basal 2 cm is mudstone, remainder is crinoidal packstone, fining upward, includes silicified solitary coral (3 cm diameter); 40-42 cm.

UNIT 30

Dolomite, v. light brown-gray, red-brown mottles, xf xlln, slightly arg., scattered fine skeletal molds, sponge spicules, single bed; 52-55 cm.

UNIT 29

Limestone, dominantly crinoidal packstone; basal 20-22 cm in one bed with 6 cm shale at top, calcitic dolomite upward to dolc limestone, scattered to common skeletal debris (including crinoid columnals to 1.5 cm), scattered smooth chert nocules (skeletal wackestone fabrics, 4-6 cm); middle 79 cm is limestone, primarily fine to coarse crinoidal packstone, includes coarse packstone-grainstone in upper 35 cm, 1-3 cm thick arg. mudstone 14 cm below top, shale parting 18 cm below top, prominent stylolite 25 cm above base, scattered large brachiopods (part silicified), bryozoans, smooth to chalky chert nodules (wackestone-mudstone fabrics) 12-27 cm above base and 16-30 cm below top (includes large nodules to 2.0 m diameter); uppermost 8 cm is limestone, fine crinoidal packstone, stylolitic, shale partings at top, sharp lithologic break at top; 1.07-1.09 m.

UNIT 28

Dolomite, v. light orange-brown to red-brown at base, xf xlln, slightly arg., scattered crinoid debris molds (most abundant near base and top), large calcite-filled vugs scattered through (to 35 cm diameter); 2-3 cm shale parting at top; sharp lithologic break at base; single massive bed; 1.35 m.

BURLINGTON FORMATION
CEDAR FORK MEMBER

UNIT 27

Limestone, dominantly fine skeletal (crinoidal) packstone and grainstone, scattered large spiriferids (some with borings); irregular beds 2-15 cm thick each separated by thin shale partings; large brachiopods and fish debris (bone bed) in coarse grainstone at base; fish debris (bone bed), large brachiopods, solitary corals in coarse packstone to grainstone near top, abundant glauconite; shale parting at top, green-gray, glauconitic; 1.25 m.

UNIT 26

Limestone, fine crinoidal packstone to grainstone in lower half (scattered brachiopods, stylolites); upper half is coarse crinoidal packstone to grainstone, scattered brachiopods, displays low-angle crossbeds, this interval grades to xf xlln dolomite in northwest quarry area, light gray, with common to abundant crinoid debris molds; shale partings at 10, 30 and 50 cm above base and at top; unit is in part slightly glauconitic; 1.1 m.

UNIT 25

Limestone, crinoidal packstone to grainstone, coarsening upward, scattered brachiopods (including spiriferids); nodular chert band (smooth chert) 10-15 cm above base, scattered chert nodules at top; thin shale parting at top; 38 cm.

UNIT 24

Limestone, fine skeletal (crinoidal) packstone to grainstone, interfingers with very coarse crinoidal and brachiopodal lithologies in mid portion (includes crinoid cups, fish debris); slightly glauconitic through most; stylolites scattered through; shale partings at 17, 47, 64 cm above base and at top; small chert nodules 13 cm below top; 95 cm.

UNIT 23

Limestone, fine to coarse crinoidal packstone to grainstone, slightly glauconitic, solitary corals near middle; scattered smooth to chalky chert nodules in middle part; 1-4 cm green-gray shale at top; irregular top and bottom; 26-30 cm.

UNIT 22

Limestone, dominantly fine to very coarse crinoidal packstone to grainstone, probable crossbeds, scattered brachiopods (spiriferids, chonetids), very glauconitic; basal 8 cm is fine crinoidal packstone, glauconitic, scattered brachiopods, large horizontal burrows, capped by thin shale parting; upper 11-14 cm is shale, light gray to green-gray, calcareous, with thin skeletal packstone lenses; 66-69 cm.

UNIT 21

Limestone and calcareous shale; lower 70 cm is limestone, very light brown, crinoidal packstone to grainstone (upper part mostly packstone), scattered brachipods (including large spiriferids), fish debris, glauconitic; shale partings at 30, 47, 62 cm above base; upper 35 cm is shale, green-gray, calcareous, with lenses of fine skeletal packstone (1 to 5 cm thick), solitary coral noted, glauconitic; 1.05 m.

HAIGHT CREEK MEMBER

UNIT 20

Dolomite, light gray, xf xlln, scattered fine crinoid debris molds and small indeterminate brachiopods; in 1 or 2 beds, forms slight overhang; light gray shale parting at top; 86 cm.

UNIT 19

Dolomite, argillaceous, recessive, xf xlln, siliceous, small chert nodules scattered, bedded chert bands at top and 45 cm down; shaley parting 84 cm above base; conularid collected 1.0 m above base; 1.94 m.

UNIT 18

Dolomite, slightly argillaceous, xf xlln, scattered fine crinoid debris molds; two chert bands in upper half, 3-6 cm thick, chert bands diverge laterally; 87 cm.

UNIT 17

Dolomite, light gray, slightly arg., scattered to common fine crinoid debris molds; scattered nodular chert

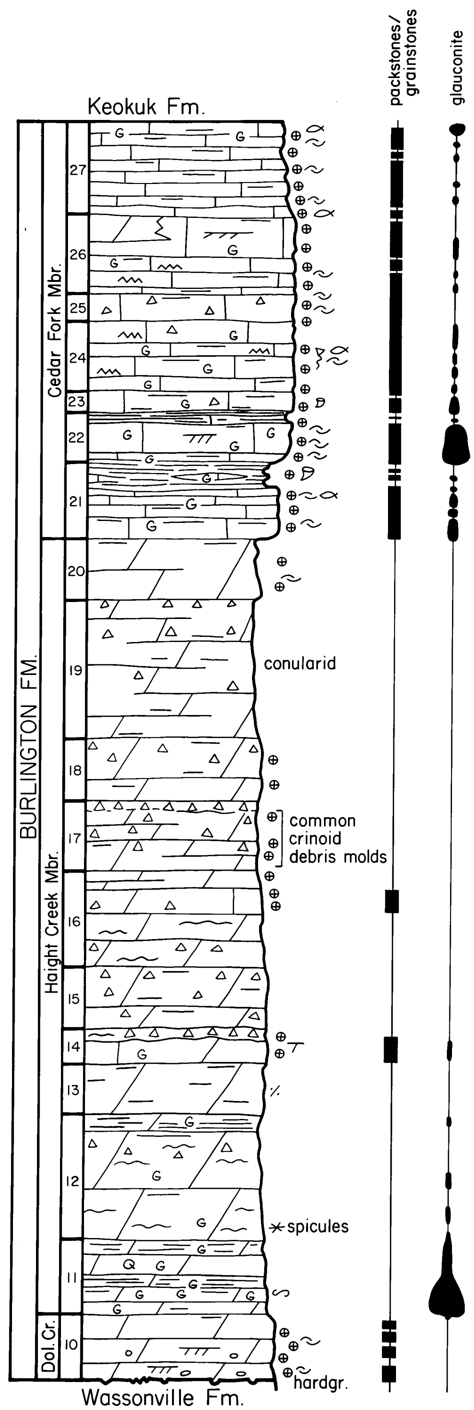

Figure 21. Burlington Formation sequence exposed at STOP 2, Keswick Quarry. Packstone-grainstone beds and glauconitic intervals indicated. Same scale as in Figure 20. See legend (in Appendix) for symbols.

bands (smooth chert, light gray, faintly laminated, unfossiliferous) noted 36, 51, 59, 66 cm above base; bedded chert bed at top, 5-15 cm thick; 96 cm.

UNIT 16

Dolomite, irregularly bedded, top 25 cm is rubbly and recessive with scattered fine crinoid debris molds; nodular chert bands, light gray, faintly laminated, unfossiliferous, noted at 20-25 and 29 cm above base; chert nodule preserving crinoidal packstone fabrics 85 cm above base; 80-105 cm above base is limestone, dolomitic, light brown, crinoidal packstone; 1.35 m.

UNIT 15

Dolomite, slightly arg., xf xlln, medium gray mottles as unit 13; argillaceous parting 28 cm above base; scattered chert nodules at 23 and 47 cm above base; top 15 cm with common smooth chert nodules (to 15 cm); 85 cm.

UNIT 14

Calcitic dolomite to dolomitic limestone, f-m crinoidal packstone, slightly glauconitic, one bed, colonial coral noted; chert bed at top (10-20 cm thick), smooth chert, light gray, laminated, unfossiliferous with some skeletal debris near base; 49 cm.

UNIT 13

Dolomite, light gray, xf xlln, slightly arg., possible fine skeletal molds; arg. partings 20 cm above base and at top; irregular medium gray mottles 1-10 cm diameter scattered through; sharp contact at top; one bed; 72 cm.

UNIT 12

Dolomite, light gray, xf xlln, slightly arg., in 2 to 3 beds, faintly laminated in lower half, arg. laminae 1.0-1.5 m above base; irregular green mottles, part glauconitic; scattered nodular chert bands (smooth chert, medium gray) 1.12, 1.21, 1.3 m above base; upper 22 is dolc. shale grading upward to arg. dolomite, glaucontic at top surface; 1.72 m.

UNIT 11

Dolomite, light gray, arg. to shaley (middle to upper parts), xf-vf xlln, faintly laminated, irregular burrow mottling; glauconitic to very glauconitic, glauconite pellets concentrated in subvertical burrows or along laminae and arg. partings, less glauconitic in upper half; green-gray dolc. shale parting at top (to 5 cm thick), glauc., shaley partings in upper 15 to 40 cm; light gray dolc. shale, slightly glauc., locally present 37-50 cm above base; rare agate-filled voids in upper half (1 cm diameter); sharp basal contact, base locally displays an irregular surface with 2 cm relief; 0.88-1.03 m.

DOLBEE CREEK MEMBER

UNIT 10

Dolomite, light brown to light medium gray, f-c xlln lower 22 cm, xf-f xlln with f-m xlln calcitic dolomite mottlings in upper 65 cm; lower 22 cm is dolomitized crinoidal packstone with scattered brachiopods, low-angle crossbeds; upper 65 cm is skeletal wackestone to crinoidal packstone, crinoid debris molds, scattered brachiopods, irregular mottled aspect (may include intraclasts in middle to upper part), low-angle crossbeds in lower 10-15 cm, slightly arg. at top, upper contact sharp (glauconitic on top surface); basal contact sharp, locally stylolitic, irregularly sculpted medium gray lithoclasts (1-2 cm) scattered in basal 0-13 cm (derived from basal hardground), hardground surface locally present at base (with 0-10 cm relief); 87 cm.

MISSISSIPPIAN--KINDERHOOKIAN
WASSONVILLE FORMATION

UNIT 9

Limestone, pale gray, peloidal?, displays irregular fracture patterns along bedding surfaces; sculpted hardground clasts (to 6 cm) locally at top; porous burrow fills at top; 55 cm.

UNIT 8

Limestone and dolomitic limestone, alternating light gray and light brown-gray, dense, slightly arg., irregularly bedded and mottled through, generally featureless; scattered arg. stylolitic streaks; scattered calcite-filled voids to 10 cm; 10 cm below top with pockets of small intraclasts (1-5 mm); 91 cm.

UNIT 7

Dolomite and dolomitic limestone, slightly arg., irregularly mottled light brown and light medium gray (contrasting dol. and dolc. limest.), faintly laminated in part; lower 93 cm includes dolomite, dolc. limestone, and limestone interswirled in a mottled to nodular fashion, limestone is dense, pale brown, most common in basal 50 cm; scattered stylolites in lower and upper parts; scattered smooth chert nodules 1.75 m above base; scattered calcite-filled vugs in upper 1.6 m; basal 30 cm with rhynchonellids, crinoid columnals; 1.5 m above base with crinoid and brachiopod debris, packed in part; 1.75 m above base with crinoid, bryozoan, and brachiopod debris (including productids, rhynchonellids); thin band of crinoidal packstone 30 cm below top; 3.06 m.

UNIT 6

Dolomite, dolomitic limestone, and limestone, in 1 to 3 beds; basal 35 cm bed is dolc. limestone, light gray, slightly arg., skeletal wackestone with packstone lenses (especially 5-15 cm above base), small chert nodules locally replace wackestones and packstones in upper 20 cm of lower bed, brachiopod-rich (part silicified) including chonetids and productids, crinoid debris, gastropods; middle 20-25 cm bed is pale brown limestone and dolc. limestone, wackestone to packstone, lower part with abundant gastropods, crinoid debris, scattered to common chonetids (and chonetid packstone); upper 20-30 cm bed is arg. dolomite interswirled with nodular or lensatic limestones (limestones 1-12 cm thick), skeletal wackestones include chonetids, productids, sparse crinoid debris; 80 cm.

UNIT 5

Dolomite, light to light medium gray, xf-vf xlln, in 1 to 2 beds, finely laminated through most, marked color changes at top and bottom; basal 20 cm is prominent smooth chert bed, faintly laminated in part, skeletal in upper 6 cm (small crinoid debris, fenestellids), dolomite inclusions in chert bed; nodular chert band 47 cm above base; 1.3 m.

UNIT 4

Dolomite, light gray, pale brown bands 1.65-1.8 m above base, xf-vf xlln, some m xlln, massive to irregularly bedded unit; scattered crinoid debris molds and whole-shell brachiopods in upper part; top 19-25 cm is limestone, medium to coarse crinoidal packstone to grainstone, bryozoans (fenestellids, others); 2.05 m.

UNIT 3

Dolomite, light gray, xf-vf xlln, faintly and finely laminated in part, in 2 beds (lower bed 37 cm); sparsely fossiliferous, crinoid and brachiopod molds 57-77 cm above base, small vugs scattered in upper bed; chert nodules (smooth chert with chalky rinds), laminated, common near base, scattered in lower bed (with sparse crinoid debris), 55 cm above base, near top; 1.05 m.

UNIT 2

Dolomitic limestone, medium gray, slightly arg., laminated, alternating with laterally discontinuous bands of limestone, pale brown, crinoidal packstone-grainstone (some with common branching and fenestellid bryozoans, brachiopods); 10 medium gray bands range 0.5-6 cm thick (thickest at base), distort around chert nodules; most of unit forms single bed; top 15 cm is crinoidal packstone (with scattered to common bryozoans, brachiopods), thins laterally (lensatic, resembles megaripple bedform); 50-60 cm above base are prominent large smooth chert nodules (to 90 cm wide), silicified crinoidal packstone; top 15 cm with scattered chert nodules (to 60 cm wide), silicified packstone and wackestone; 80-82 cm.

STARRS CAVE (?) FORMATION

UNIT 1

Limestone, light gray, slightly arg., very fossiliferous, in 2 beds; lower 65 cm dominantly a skeletal wackestone (crinoid debris, fenestellids, brachiopods) with arg. laminae; top 25-30 cm is a pale gray medium-grained crinoidal packstone (with bryozoans, brachiopods); 40 cm above base are prominent smooth to chalky chert nodules (up to 50 cm wide), light gray, silicified crinoid and bryozoans grains, arg. laminae distort around nodules; 65 cm.

NOTE: *section measured to water level, limestones continue lower in sump.*

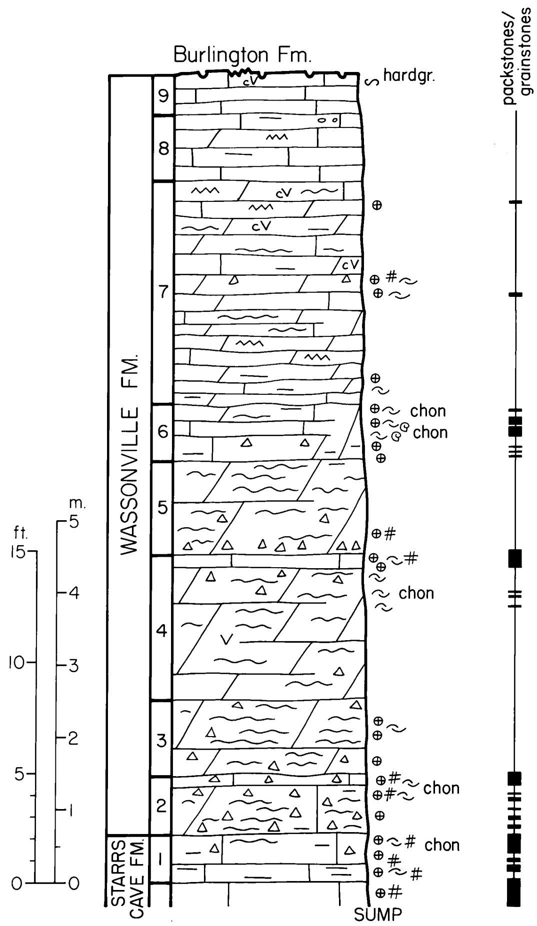

Figure 22. Starrs Cave-Wassonville interval exposed at STOP 2, Keswick Quarry. Packstone-grainstone beds indicated. Same scale as in Figure 20. See legend (in Appendix) for symbols.

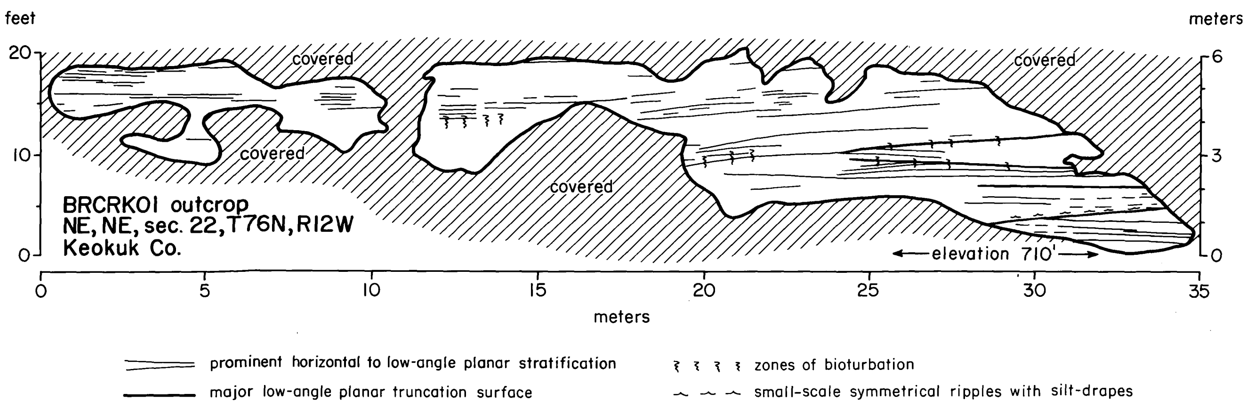

Figure 23. Outcrop sketch of Yenruogis Member sandstone at its type locality (locality BRCRKO1) along Bridge Creek (STOP 3). See legend (in Appendix) for symbols.

STOP 3.

Type Section of the Yenruogis Member sandstone, "St. Louis" Formation

(Ray Osweiler, owner)

DISCUSSION. This is the type section of the newly-proposed Yenruogis Member of the "St. Louis" Formation. The Yenruogis is a widespread sandstone interval which occurs between the underlying Croton and overlying Verdi members over at least a six county area in southeast and south-central Iowa. Sandstone in this position was previously assigned to the Verdi Member by Van Tuyl (1925), but the interval is now considered to be of sufficient thickness and lateral extent to warrant member status.

This section (Fig. 23) exposes 5.5 meters (18 feet) of sandstone. Maximum thickness of the member is 14 m (45 ft). Much of the Yenruogis is characterized by the texture and sedimentary structures which are displayed in this outcrop. Sandstone at this locality is rather uniform in texture and structure. It is very fine- to fine-grained and friable. The sedimentary structures are dominated by tabular to wedge shaped sets of large-scale horizontal to low-angle planar strata that are cut by major low-angle planar truncation surfaces. Minor zones of wavy lamination and small-scale symmetrical ripples are present in the lower half. Body fossils or molds have not been found in this or other Yenruogis sections, however thin zones of bioturbation and distinct individual burrows are moderately common. Burrow forms include simple vertical tubes (*Skolithos*), vertical bilobed depressions, j-shaped tubes and some horizontal to diagonal traces. Lateral facies in the area include large-scale sets of tabular cross-strata, and minor developement of hummocky to swaley stratification. To the south, in the Waugh Branch area, the top of the Yenruogis contains well-developed fields of small-scale symmetrical to slightly asymmetric ripples.

The Yenruogis Member records progradation of siliciclastics across the study area. This outcrop is interpreted to record nearshore marine deposition. Primary evidence for a marine origin is derived from the physical and biogenic sedimentary structures. The burrows are typical marine forms. The well stratified nature of the unit in conjunction with only intermittent zones of bioturbation indicate frequent agitation of bottom sediment. The sporadic occurence of small-scale symmetrical ripples indicate deposition from wave-generated oscillatory flow. If wave-generated oscillatory flow is assumed to be at least partially responsible for stratification formation, the dominant horizontal to low angle bedding of the fine-grained sandstone can be interpreted to have been deposited by flows having minimum orbital velocities of 0.4 m/sec (Harms et al., 1982, fig. 2-14). The prominent low-angle planes of truncation are assumed to have formed from flows with orbital velocities in excess of 0.4 m/sec. The presence of minor hummocky to swaley stratification in nearby exposures also supports the interpretation that much of the flow was oscillatory and wave induced (Harms et al., 1982).

Paleocurrent data from all current-formed structures, when considered with known paleogeography, suggests that wave propagation was primarily from the east and southeast, and more unidirectional flows were from the south to southeast. Wave-dominated siliciclastic sedimentation of the Yenruogis drew to a close with transgression, which drowned siliciclastic sources and initiated carbonate-dominated deposition of the lower Verdi Member.

LOCATION: SE NE NE sec. 22 T76N, R12W, Keokuk Co., Iowa. Measured 9/13/88 by R.M.McKay and M.P.McAdams. Section exposed as natural outcrop along south valley wall of Bridge Creek next to county highway V45. Elevation at base of section is approximately 710'.

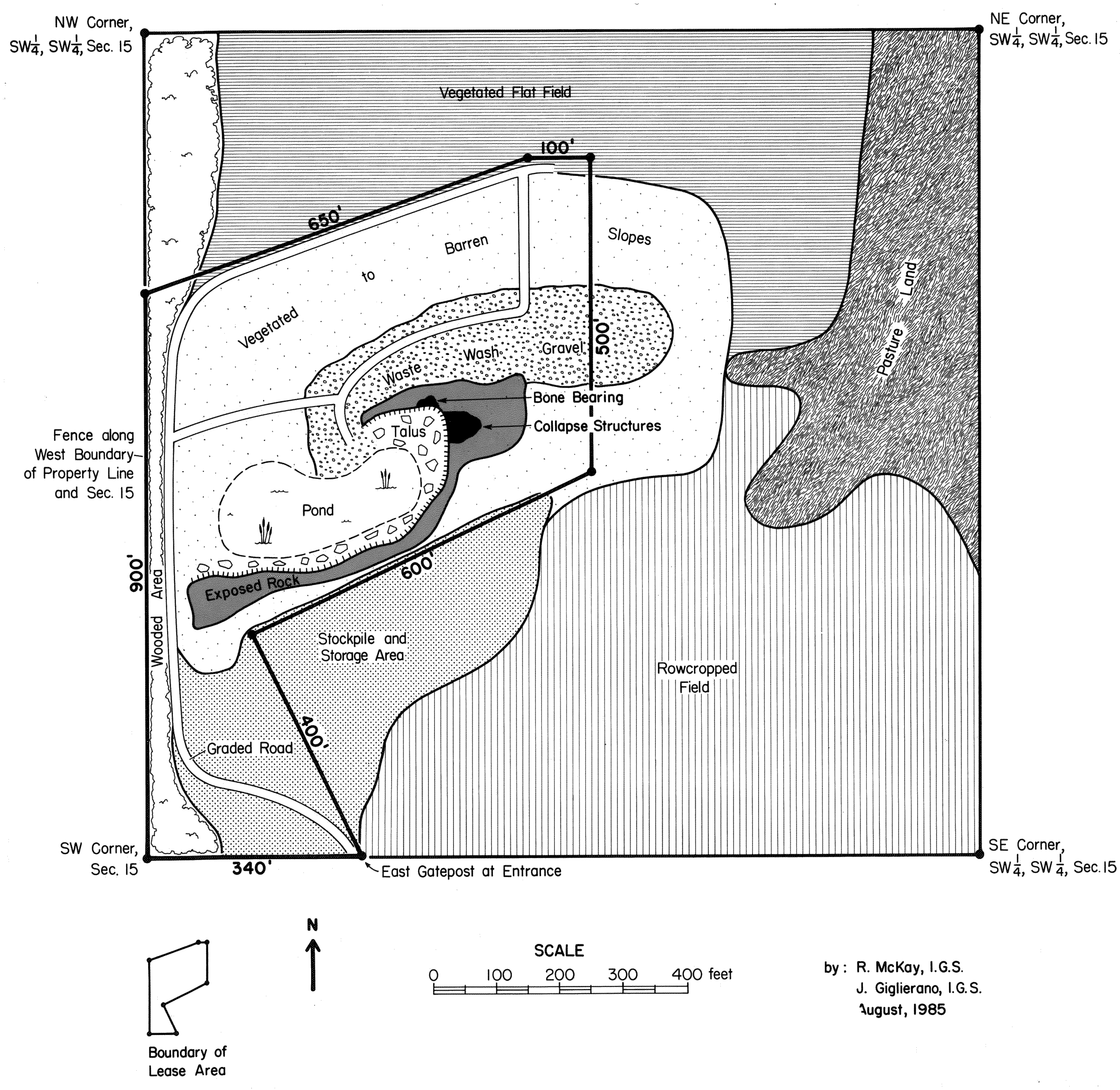

Figure 24. Map of the Heimstra Quarry (STOP 4) showing location of bone-bearing collapse structures and the boundary of land leased by the State of Iowa in 1985-1989.

STOP 4. HEIMSTRA QUARRY;

The Verdi and Waugh members of the "St. Louis" Formation, and the Delta Fossil Amphibian Site

(Jasper Heimstra, owner)

DISCUSSION. The Heimstra Quarry is the locality of the Delta Fossil Amphibian Site (named after the nearby town of Delta). In 1985 abundant and well-preserved Mississippian tetrapod fossils (fossil amphibians, e.g., guidebook cover) were discovered within a thin 60 cm thick layer of limestone conglomerate and shale along the east quarry wall (McKay et al., 1986; and Bolt et al., 1988). The main bone bed is located within the middle part of the dish-shaped depression along that wall (see Figure 12 for sketch of the east quarry face prior to recent excavations). The fossil record of early tetrapods (Late Devonian-Early Carboniferous) is scant. Early tetrapods are known from only a few Upper Devonian localities, none of which are in North America. Mississippian tetrapods, while more common than Devonian ones, are known from only 20 localities worldwide. The majority of these sites are in Scotland and the remainder (approximately six) are in North America. The Delta Site, which is middle late Visean (V3b) in age, contains the oldest well-preserved tetrapod fauna known from North America, and is considered as one of the most important Mississippian tetrapod sites ever found. During the summers of 1986 and 1988 the Field Museum of Natural History, Chicago, and the Geological Survey Bureau excavated approximately two-thirds of the Heimstra Quarry bone bed. The large collection of specimens (hundreds) which were collected are presently under preparation and study by John Bolt at the Field Museum. Fossil tetrapod material includes an abundance of disarticulated bone (primarily recovered from the limestone conglomerates during 1986), numerous skulls and partially articulated post-cranial sections, and several nearly complete articulated skeletons (recovered from the laminated shale). The bulk of the tetrapod bone from the bone bed appears to belong to a primitive anthracosaur-like form which Bolt et al., (1988) referred to as a "proto-anthracosaur". The proto-anthracosaur is approximately coeval with the earliest reported anthracosaurs.

Two bone beds are known from Heimstra Quarry. They both occur within the fills of two dish-shaped depressions or collapse structures developed in the upper part of the "St. Louis" Formation (Fig. 24). The smaller of the two is 7 m wide and is present along the north wall of the quarry. The large fill is 16 m wide and was partially excavated during the summers of 1986 and 1988. Strata exposed at the quarry can be divided into five units for discussion purposes (see photo-tracing sketch of the large fill, east quarry face, Fig. 12). Unit A is composed of interbedded limestone, sandstone and shale that records a shallowing-upward sequence associated with the regional offlap of the "St. Louis" sea. Units 1 and 2 (measured section description, Fig. 25) are the lower Verdi; Units 3-6 are the upper Verdi; Units 7-21 are Waugh Member strata. Lower Verdi strata contain a shallow-marine fauna; upper Verdi strata contain a restricted-marine fauna. The Verdi sequence represents a shallowing and offlap of the seaway. Lower Waugh strata (Units 7-10) record nonmarine deposition within clastic-dominated fluvial-deltaic systems. These were succeeded by lacustrine environments in which massive lime mudstones having an ostracode-snail-fish fauna were deposited (Units 11-13). Waugh strata lack fauna diagnostic of marine conditions. Common calcite spar-filled tubes in the massive mudstones are interpreted to represent the infilled root molds of aquatic vegetation.

The collapse structure truncates Unit A (Fig. 12). It may have formed as a result of dissolution of lower "St. Louis" bedded gypsum which led to collapse of overlying strata. The walls of the depression are solutionally pitted, suggesting subaerial exposure. A conglomeratic horizon, locally present at the top of unit 11 and containing sparse tetrapod bone, suggests desiccation of the lake and formation of a disconformity coeval with collapse structure generation.

Unit B (Fig. 12) is the lower portion of the main fill. It is composed of solutionally-pitted pebble to boulder-sized clasts derived from Unit A. Green shale with scattered tetrapod bone comprises the matrix. The upper surface of this boulder conglomerate is well exposed in the excavation pit, but much of the remainder has been covered by the talus pile generated during excavation. Figures 14 and 15 in the text illustrate the irregular upper surface of unit B upon which the bone bed was deposited.

Unit C (Fig. 12) is the main bone bed. Almost all of the bone bed that was uncovered during the excavation was removed. Thin in-place bone bed is still present in the east portion of the pit. The talus pile below the excavation contains pieces of bone bed limestone conglomerate. Bone bed shale is also present on the talus pile. Tetrapod bone can be found in both. The bone bed is dominated by layers and lenses of limestone conglomerate which grade laterally within the depression into tetrapod and fish-rich brownish-green laminated shales. The conglomerates accumulated when debris from the surrounding "St. Louis" surface was transported periodically into the depression. The lobate geometry of the conglomerate layers, and their clast to matrix-supported fabric suggest that they were deposited as viscous debris flows. Bones of dead, disarticulated tetrapods, as well as more intact carcasses were transported in the flows. At the time of conglomerate deposition the depression was water filled. This is documented by the tetrapod-bearing laminated shales which occur lateral to the conglomerates. These shales were deposited under quiet subaqueous and probably low-oxygen conditions. Evidence of rooting or bottom infauna (bioturbation etc.) is absent. Tetrapods present are labyrinthodont amphibians of the anthracosaur group. Virtually all skeletal elements (cranial and post-cranial) have been found as abundant disarticulated or articulated material. Abundant fish material was recovered from the upper part of the shales.

Unit D (Units a-j and 12-21 in Fig. 25) is dominated by well bedded, laminated to massive ostracode lime mudstones with minor thin shales. A basal shale contains abundant fish scales with some tetrapod bone. These lime mudstones contain a fauna similar to that of uppermost Unit A; fish (elasmobranch and palaeoniscoid scales), ostracodes, and "spirorbid" snails are common. Large rhizodont crossopterygian scales are present and especially abundant near the base. A colosteid amphibian skull and a lungfish skeleton were collected at the base of Unit d. Calcite spar-filled rooting structures are present in these limestones outside of the main collapse structure. This suggests that the water may have been shallower away from the collapse depression, thus allowing establishment of aquatically-rooted vegetation. Unit D is interpreted to have been deposited in a lacustrine environment as base levels rose, resulting in complete flooding of the depressions and surrounding areas and resumption of carbonate sedimentation.

In summary, stratigraphic relations within the Waugh Member indicate that a variety of depositional environments characterized the Keokuk County area following retreat of the "St. Louis" sea. The various rock types of the Waugh, their fabric and their contained fauna are interpreted to indicate that the Waugh was deposited in a complex mosaic of lacustrine, fluvial, and swamp environments in a coastal lowland setting. The absence of definitive marine fauna in the Waugh, and the similarity of the Waugh's fauna to that of other Carboniferous lake and swamp deposits suggest that deposition occurred within a fresh to brackish water setting which lacked significant fluid exchange with marine water.

Unit E (Fig. 12) is a sandstone of probable Pennsylvanian age.

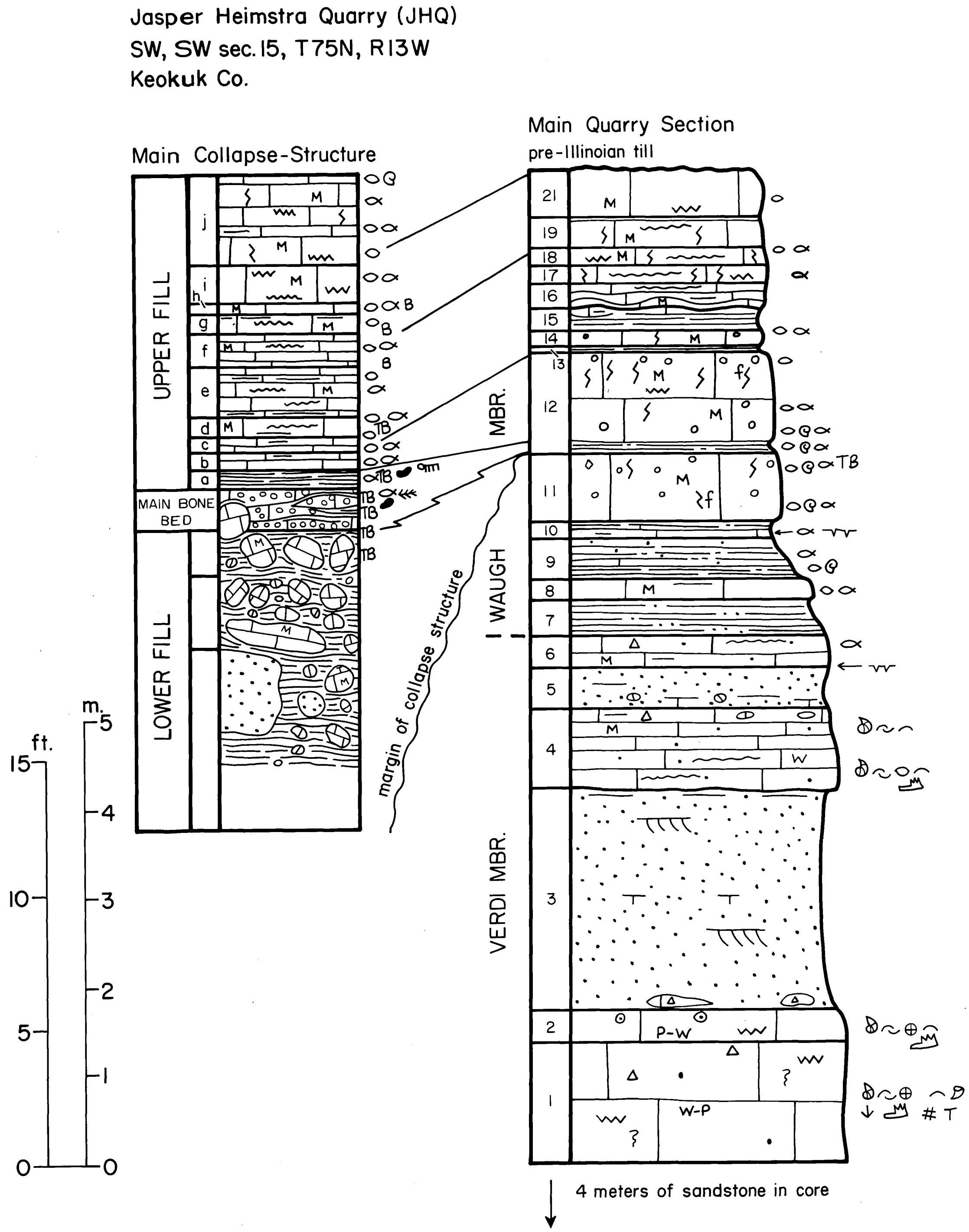

Figure 25. Measured sections of rocks at the Heimstra Quarry (STOP 4). See legend (in Appendix) for symbols.

JASPER HEIMSTRA QUARRY DESCRIPTION

LOCATION - SW, Section 15, T75N, R13W, Keokuk County. Main portion of the St. Louis is exposed along north, east and south quarry walls. The main fill within the bone-bearing paleocollapse is confined to the northeast corner of the quarry. Elevation at base of section is approximately 745'; section measured by R.M. McKay, B.J. Witzke, and P. McAdams, 1985-1986; with updates in 1988 by R.M. McKay.

"ST. LOUIS" FORMATION (MAIN QUARRY SECTION)
WAUGH MEMBER

UNIT 21
Limestone, light gray brown, dense, mudstone, ostracodes, minor styolites; 55 cm.

UNIT 20
Shale, thin, brown gray, pinches out locally; 0-4 cm.

UNIT 19
Limestone, dense, mudstone, laminated in part, styolitic in part, scattered vertical calcite void and fracture fills, relief on upper surface; 22-29 cm.

UNIT 18
Limestone, light gray, dense, mudstone, laminated, styolitic, ostracodes, fish debris, common vertical calcite spar and lithoclast filled voids and fractures, some kaolinite filling voids; 14-18 cm.

UNIT 17
Limestone, light gray, dense, mudstone, laminated, styolitic, rare Rhizodont fish scales, common vertical calcite spar and lithoclast filled voids and fractures, some kaolinite filling voids; 18 cm.

UNIT 16
Limestone, light gray, dense, mudstone, thin wavy bedded to nodular with shaley partings, slightly argillaceous, upper part laminated with vertical calcite spar filled voids and fractures, some kaolinite filling voids; 7-26 cm.

UNIT 15
Shale, light green brown to brown-gray, variable thickness; 4-24 cm.

UNIT 14
Limestone, light gray, dense, mudstone, conglomeratic in part, calcite spar void and fracture fills, most relief at base of bed; 8-16 cm.

UNIT 13
Shale, green gray, oxidized in part, calcareous, undulatory upper contact, thin limestone lenses at top along south quarry wall; 6-11 cm.

UNIT 12
Limestone, light gray, dense, mudstone, massive in one bed, ostracodes, fish scales, "spirorbid" snails, conglomeratic to intraclastic, styolitic in part, common vertical calcite spar and lithoclast filled voids and fractures; lower 9 cm shale, light green to orange brown (oxidized), laminated; 1.07 m.

UNIT 11
Limestone, light gray, dense, mudstone, massive, abundant rounded intraclasts to conglomeratic in part especially at top, ostracodes, "spirorbid" snails, abundant fish scales, teeth, dermal denticles, and fragments, common "3-prong" plant? material, rare tetrapod bone (ribs) at top, common vertical to anastomosing calcite spar and lithoclast filled voids fractures and microfractures; 75 cm.

UNIT 10

Limestone, light gray, two beds separated by thin 1 cm shale with thin shale at top, mudstone, faintly laminated, quartz sandy, peloidal to possibly intraclastic, calcite spar fracture and intergranular cements, mudcracked in part, sparse fish scales; 17-23 cm.

UNIT 9

Shale, tan green, calcareous, sandy to very sandy in upper part, weathers blocky, ostracodes, "spirorbid" snails, fish scales; 45 cm.

UNIT 8

Limestone, light gray to light tan, dense, mudstone, slightly argillaceous, fish debris; 3 cm.

UNIT 7

Shale, light green, oxidized to tan and orange, sandy, laminated, weathers blocky; 40 cm.

VERDI MEMBER

UNIT 6

Limestone, light gray, dense, mudstone, thin wavy bedded with argillaceous partings, slightly sandy, peloidal in part, white chert nodules in upper part, prominent mudcracks at base; 37 cm.

UNIT 5

Sandstone, very fine-medium, calcareous, argillaceous, limestone pebbles up to 2 cm in diameter in lower 5 cm; 43 cm.

UNIT 4

Limestone, medium brown gray, dense, skeletal wackestone, pelletal-peloidal, brachiopod, bivalve, ostracodes, conodonts, forams, laminated in part, quartz sandy in part, thin wavy bedded, drapes over sandstone unit below, styolitic bedding contacts with dark gray argillaceous partings, skeletal mudstone in upper 25 cm; very sandy; large chert nodules (0-15 cm thick by 97 cm wide) 26-37 cm below top, chert parallel to bedding, white-light gray, dense, contains silicified to non-silicified lime mudstone clasts (1-7 cm long); 87 cm.

UNIT 3

Sandstone, white to tan, very fine to medium quartzose, large scale tabular cross-strata, direction of foreset inclination south to southwest; mostly friable, calcareous in part, argillaceous and planar laminated in upper 15 cm, silicified limestone lenses at base; 2.45-2.5 cm.

UNIT 2

Limestone, light gray, skeletal packstone to wackestone, pelletal to peloidal, ooids locally at top, forams, brachiopods, echinoderms, bivalves, conodonts, styolitic, trace quartz sand, bioturbated; 35 cm.

UNIT 1

Limestone, light gray, skeletal wackestone to packstone, pelletal to peloidal, forams, brachiopods, echinoderms, bivalves, trilobites, conodonts, bryozoans, corals, bioturbated, styolitic, rare gray to white rounded chert nodules some with silicified corals (*Syringopora*); 98 cm.

NOTE: 4 meters of Yenruogis Member sandstone below quarry floor. Concrete Materials Co. test core. Core received and described by Iowa Department of Transportation, 11/05/71.

MAIN COLLAPSE-STRUCTURE SECTION (northeast part of quarry)

"ST. LOUIS" FORMATION
WAUGH MEMBER
UPPER FILL

UNIT j
Limestone, light gray, mudstone, dense, in 4-5 beds, bioturbated, slightly intraclastic, sparse fish scales, ostracode and gastropod, kaolinite clay fills some small voids, styolitic; middle bed, wavy, argillaceous-shaley, common shark dermal denticles in thin 1 cm thick green clay; calcite spar void fills common in upper 40 cm; 1.0 m.

UNIT i
Limestone, light gray, dense, mudstone, massive bed, styolitic, discontinuous laminae near base, bioturbated, ostracodes, sparse fish material; 29-40 cm.

UNIT h
Limestone, light gray, dense, mudstone, ostracode, snails, fish debris, 3 prong plant? material; 7-10 cm.

UNIT g
Limestone, light gray, dense, mudstone, shaley parting at top and bottom, styolitic, ostracode, snails, bone debris, 3-prong plant? material, laminated in part; 17-20 cm.

UNIT f
Limestone, light brown gray, dense, mudstone, discontinuous laminae, sparse ostracodes, "spirorbid" snails, crossopterygian and other fish scales in upper part, shale parting at base, laminated 2 cm thick green shale part at top, unit divided by styolitic parting near middle; 29-38 cm.

UNIT e
Limestone, light gray, dense, in 4 beds, brown shale partings, separate beds, sparse ostracode mudstones, "spirorbid" snails, fish bone and scale, discontinuously laminated in part, argillaceous in upper part; 27-58 cm (thickens toward fill center).

UNIT d
Limestone, light gray, dense, mudstone, massive, discontinuously laminated, ostracodes common, tetrapod bone and fish scales at base, kaolinite void fills; overlaps unit 12 of main quarry section; 10-26 cm (thickens toward fill center).

UNIT c
Limestone, light gray, dense, mudstone, sparse ostracodes, in 3 beds separated by brown shale partings, faint laminations in upper part, beds thin towards south margin and become lensatic, top bed overlaps unit 12 of main quarry section, fish scale and bone common; 13-19 cm.

UNIT b
Limestone, light gray, dense, mudstone, ostracodes, fish bones and scales, "spirorbid" snail, faint discontinuous laminae, calcite spar filled vertical fractures, trace quartz silt; 17 cm (appears to abruptly end at southern fill margin).

UNIT a
Shale, light-medium brown green, laminated, abundant fossil fish material (scale, bone, skeletons) and coprolites in upper 20 cm, minor myriapod and plant fossils in upper 20 cm, calcareous; thickens in central and south portions of fill and becomes lateral to bone bearing conglomerate, contains abundant articulated tetrapod bone in basal 10-20 cm, may have very thin lenses to laminae of fine grained limestone conglomerate, highly irregular thickness due to draping and filling over underlying boulder conglomerate surface in central fill area; 5-60 cm.

MAIN BONE BED

Limestone Conglomerate, light to medium gray, poorly sorted, clast to matrix supported, grain size ranges from silt and very fine sand to pebbles with some cobbles, grains are angular to subrounded, abundant tetrapod bone throughout, mostly as disarticulated elements ranging from small broken pieces to complete rib, limb, pelvic, and shoulder bones, some articulated vertebral columns, some complete to partial skulls; 1 to 4 layers within main fill, layers to lenses of conglomerate mostly sourced from the north side of fill as debris lobes, layers separated by and grade laterally into tetrapod-rich laminated shale, very uneven lower contact over boulders of lower fill. Shale is concentrated and thickest towards center of fill, brownish-green; lower 10 to 20 cm contains abundant articulated tetrapod bone including several nearly complete skeletons and numerous skulls; 0-60 cm.

LOWER FILL

Boulder Conglomerate, poorly sorted, clast supported, clasts range in size from cobble to large boulders up to 1.5 meters in diameter, clasts are mostly limestone with lesser amounts of sandstone derived from the main quarry section; includes slump blocks of main quarry section; matrix consists of tetrapod.

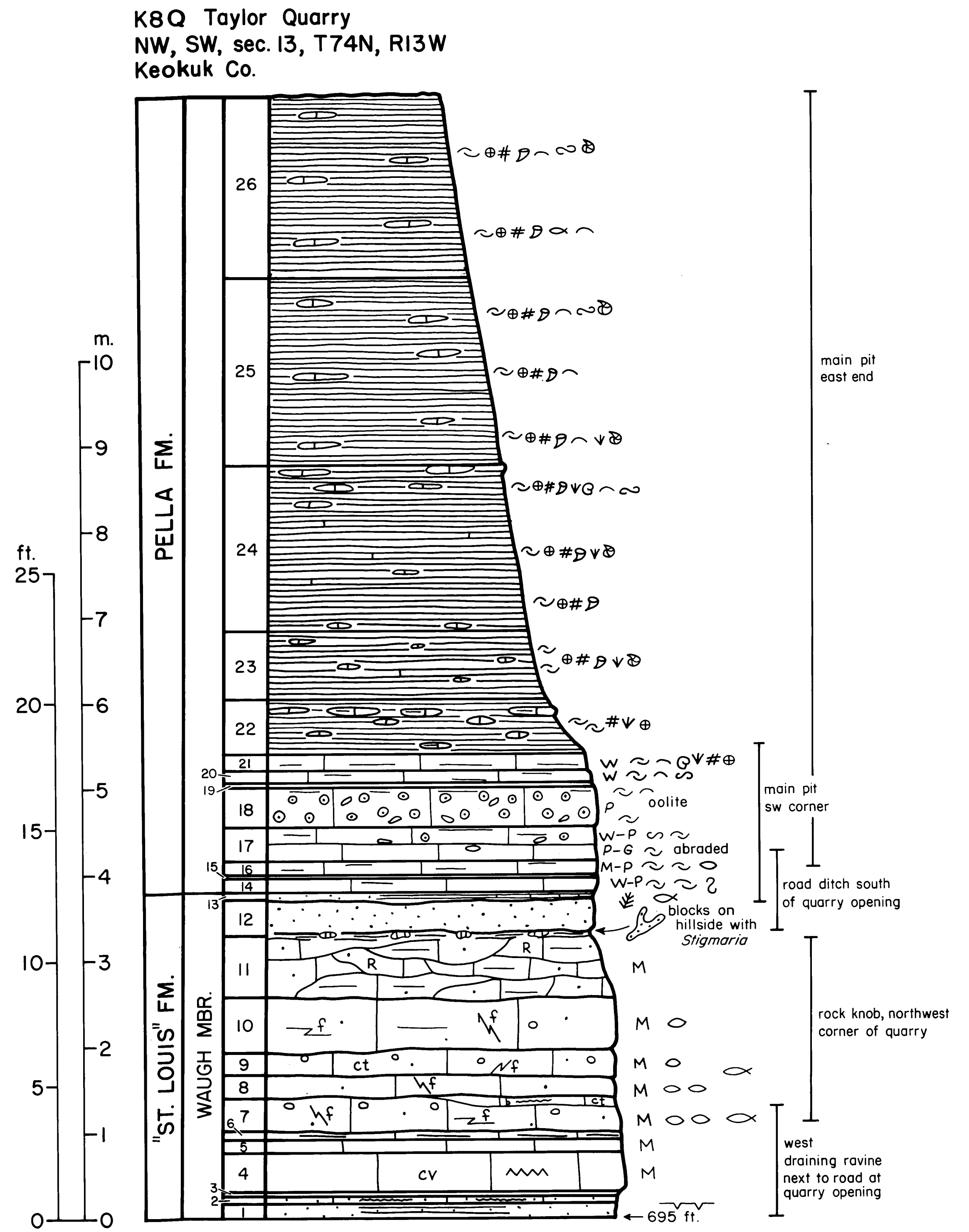

Figure 26. Measured section of rocks at the Taylor Quarry (STOP 5). See legend (in Appendix) for symbols.

STOP 5. TAYLOR QUARRY;

Waugh Member and Pella Formation

(Marjorie Gambell, owner)

DISCUSSION. This stop is an abandoned and water-filled Pella-"St. Louis" quarry. The Pella (Units 14-26) is exposed in the main part of the quarry, and the upper portion of the "St. Louis" Waugh Member (Units 1-13) is exposed on the west side of the quarry area and in streamcuts slightly upstream. The lower portion of the section exposes Waugh Member massive lime mudstones and overlying sandstones with *Stigmaria* roots casts. A brecciated to conglomeratic horizon within the massive lime mudstones is visible on bedding plane exposures in the west-draining ravine next to the road at the quarry opening. Blocks of *Stigmaria*-bearing sandstone are present on the hillside next to the road ditch exposures at the quarry opening.

The medium- to thick-bedded lime mudstones of the upper Waugh and the overlying Pella units can be considered within the stratigraphic relations portrayed in Figure 9 of the text discussion. The basal Waugh in the Waugh Branch area consists of fluvial sandstones which display both channel and overbank facies. Massive lime mudstones of variable thickness overlie the sandstones. The mudstones are fractured to microfractured and fractures are filled with combinations of mudstone clasts, calcite spar, and micrite. Locally the mudstones are brecciated or conglomeratic. Ostracodes and minor fish scale material is present. At STOP 5 the mudstones are about 3 meters thick, and the upper meter displays a rubbly texture. The rubbly zone (Unit 11) also displays rooting and pedogenic structure. The mudstones are interpreted to record lacustrine deposition roughly coeval with similar mudstones and collapse structure generation at the Heimstra Quarry. The presence of fractures and lime mudstone clasts is interpreted to indicate periods of intermittent desiccation and sediment reworking in the lake basin. Towards the north end of the transect (Fig. 9) the mudstones are distinctly thinner and are overlain by fish and ostracode-bearing shales and laminated lime mudstones. The cause of the lateral transition from thick mudstones on the south end to shale and limestone at the north end is not totally clear but is probably a combination of lateral facies variation and erosion of the massive mudstones . Both facies along the entire length of the transect are overlain by the rooted sandstone of Unit 12, which contains casts of *Stigmaria.* As discussed in the text, this rooted sandstone horizon records establishment of a widespread scale tree swamp environment across the area once occupied by the lake. The scale tree swamp environment was relatively short-lived and only locally led to the accumulation of enough peat to form thin millimeter-thick coal laminae. Swamp environments were terminated by transgression of the Pella sea across the area.

The main quarry section exposes the Pella Formation. Shallow-marine transgressive limestones containing a low-diversity fauna dominate the lower Pella. These are succeeded by ooid packstones containing scattered lime mudstone intraclasts. Ooid packstones are overlain by skeletal wackestones containing a diverse fauna. This interval records deposition under open-marine conditions. Above the wackestones at the east end of the quarry pit are extensive exposures of upper Pella marls. These shaly, very calcareous strata are highly fossiliferous and contain a diverse marine fauna. The weathered marl slopes at this exposure provide excellent fossil collecting. A faunal list of the Pella fauna can be found in the text discussion (Table 3).

STOP 5 - TAYLOR QUARRY DESCRIPTION

LOCATION - NW, SW, Section 13, T74N, R13W, Keokuk County. Section exposed in several areas of quarry as noted on section illustration. Elevation at base of section is approximately 695'; section measured by B.J. Witzke and R.M. McKay, 1987.

PELLA FORMATION

UNIT 26
Shale, light gray, very calcareous (marl), scattered lime packstone lenses to nodules, possible large burrow fills up to 61 cm long by 6 cm wide, very fossiliferous with brachiopods, echinoderms, bryozoans, rugose corals, bivalves, fish teeth; section partly disturbed; 2.1 m.

UNIT 25
Shale, light gray, very calcareous (marl), very fossiliferous with similar fossils as unit above plus trilobites in lower part, scattered thin lime packstone lenses to nodules, oxidized pyrite common, large burrows; 2.2 m.

UNIT 24
Shale, light gray, very calcareous (marl), very fossiliferous with brachiopods, echinoderms, bryozoans, corals, trilobites, bivalves, gastropods; lime packstone-wackestone lenses and thin beds scattered throughout but more common towards top, some large horizontal burrows, many brachiopods are larger than noted below; 1.9 m.

UNIT 23
Shale, light gray, very calcareous (marl), very fossiliferous with brachiopods, echinoderms, bryozoans, corals, trilobites, scattered thin platy lenses to nodules of lime wackestone-packstone; 80 cm.

UNIT 22
Shale, light gray, very calcareous (marl), very fossiliferous with brachiopods, bryozoans, trilobites, and echinoderms; scattered thin limestone lenses to nodules throughout; 53 cm.

UNIT 21
Limestone, light gray, shaly partings, argillaceous, skeletal wackestone, common brachiopods, bryozoans, trilobites, snails, bivalves; 22 cm.

UNIT 20
Limestone, light gray, shaley partings at top and bottom, argillaceous, skeletal wackestone, abundant brachiopods, clam molds; 18 cm.

UNIT 19
Shale, light greenish gray, calcareous; 5 cm.

UNIT 18
Limestone, light gray, massive, dense, ooid packstone, calcite spar cement in part, pyritic, scattered rounded lime mudstone intraclasts, brachiopods in lower and upper part, clams near top where unit becomes argillaceous; 41 cm.

UNIT 17
Limestone, light brown gray, in one or two beds, upper part skeletal wackestone-packstone, fine skeletal debris, brachiopods, some flat pebble intraclasts near base, minor ooids, faint horizontal to subhorizontal burrow mottling, argillaceous in part, thin shaley partings at top; lower part abraded grain ostracode-brachiopod packstone-grainstone, dense, argillaceous parting near top; 40 cm.

UNIT 16
Limestone, light brown gray, dense, ostracode-brachiopod mudstone-packstone, brachiopods spar filled, shaley partings at top, argillaceous; 16 cm.

UNIT 15

Shale, light brown gray, calcareous; 2 cm.

UNIT 14

Limestone, light brown gray, brachiopod wackestone-packstone in upper part, whole and broken brachiopods, thin bedded, argillaceous in part; 16-20 cm.

"ST. LOUIS" FORMATION
WAUGH MEMBER

UNIT 13

Sandstone, very light gray, very fine to fine grained, quartzose, calcareous, horizontally laminated, fish scale and teeth debris, and coaly plant debris on lamination planes; upper 2-3 cm may be shale with fish scales and coaly plant debris; 6 cm.

UNIT 12

Sandstone, light tan, calcareous, well cemented, very fine-medium grained, quartzose, Stigmaria root casts on base (exposed on blocks of sandstone on rubble pile immediately east of road ditch exposure); 30-40 cm.

UNIT 11

Limestone, light brown gray, mudstone, dense, argillaceous, very fine-coarse quartz sandy, irregularly bedded with argillaceous partings, rubbly appearing, abundant 1 mm to 1 cm very fine crystalline calcite spar fills throughout some with faint laminated linings (possible rootlet structures), pyrite and iron oxides, shaley at top with mudstone lenses; 70 cm.

UNIT 10

Limestone, light gray, dense, mudstone, mottled texture, minor subhorizontal microfractures some filled with micrite-very fine crystalline-coarser calcite spar, very fine-medium quartz sandy, slightly argillaceous, conglomeratic to intraclastic in part, sparse ostracodes, trace fish debris; 63 cm.

UNIT 9

Limestone, light gray, dense, mudstone, moderately abundant ostracodes, microfractured in lower part, conglomeratic to intraclastic in upper part, lithoclasts to 1 cm, very fine-medium grained quartz sandy, pyrite and iron oxides, some calcite spar filled tubules lined with iron oxides and micritic to very fine crystalline spar with partial fillings of particles of cement and lithoclasts, trace amount phosphatic fish? debris; 25 cm.

UNIT 8

Limestone, light gray, dense, mudstone, massive to 3 beds, basal beds wedge out and contain faint discontinuous laminae with birdseye and calcite spar filled tubules 1 mm wide by 3-4 mm long in all orientations; upper part is very fine-medium quartz sandy mudstone, moderately abundant ostracodes, minor calcite spar filled microfractures; 25-35 cm.

UNIT 7

Limestone, light gray, dense, mudstone, ostracodes abundant, moderately abundant fish scale, bone, shark denticles, extensively microfractured, fractures filled with calcite spar and combinations of spar and lithoclasts, micritic to very fine crystalline spar line sides of some fractures, very conglomeratic in upper 10-20 cm, clasts to 2 cm, 5-10 cm relief on top; 35-40 cm.

UNIT 6

Limestone, light brown gray, very shaley; 8 cm.

UNIT 5

Limestone, light gray, dense, mudstone, barren; 16 cm.

UNIT 4

Limestone, light gray, dense, mudstone, minor calcite spar fills, stylolitic; 48 cm.

UNIT 3

Shale, brown, discontinuous; 0-2 cm.

UNIT 2

Limestone, light gray, sandy-very sandy, horizontally laminated, mudcracks at base; 10 cm.

UNIT 1

Sandstone, light gray, fine-medium, calcareous, friable in part, horizontal laminae, mudcracks at top; 20 cm.

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APPENDIX.

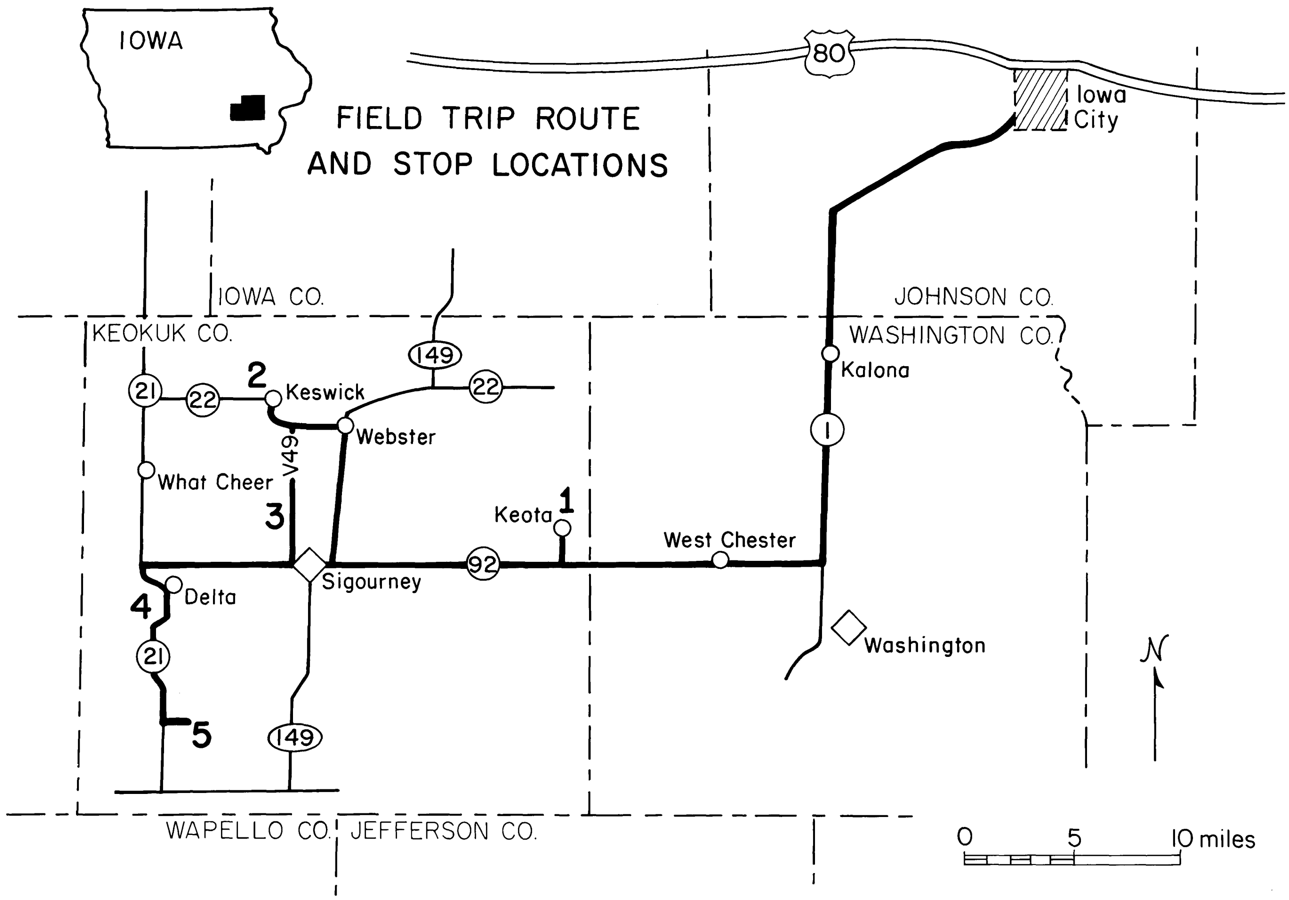
Legend for Stratigraphic Sections

	limestone
Gr	grainstone
P	packstone
W	wackestone
M	mudstone
	dolomite (dolostone)
	dolomitic limestone
	sandstone
	siltstone
	shale
	argillaceous or shaly
	silty
. . . .	sandy
or dolc.	dolomitic
or	calcareous
	chert
	conglomerate
	brecciated
	angular limestone clast
	shale clast
	ooids
	pisoids - oncoids
	stylolite - stylolitic
	dessication cracks
	faintly laminated
or	cross-laminated
	large-scale tabular cross-stratification
	horizontally stratified

	large-scale low-angle cross-stratification
	large-scale trough cross-stratification
	trough-shaped channel
hardgr.	hardground
R	rubbly, possible rooting
	nodules
G or g	glauconite
	fractures and microfractures, calcite spar and sediment-filled
	paleokarst
SES	subaerial exposure surface
	intervals of crinoidal packstone or grainstone
	common crinoid debris molds
	small-scale symmetrical ripples
	small-scale symmetrical ripples with silt or carbonate mud drape
V	vugs
cV	calcite spar-filled vugs
HUMM	hummocky cross-stratification
	geodes
ct	calcite spar-filled tubules
270° TA/26°	trough axis azimuth and foreset inclination
180° F/26°	azimuth of maximum foreset dip direction and inclination
	shelly marine fauna

⊕	crinoid debris
	crinoid cups
	brachiopods
#	bryozoans
	solitary rugose corals
T	tabulate coral
L	*Lithostrotion* colonial rugose coral
or	bivalves
	trilobite
✳	sponge spicules
	snails (gastropods)
	ostracodes
	foraminifera
	coprolites
	indeterminate skeletal debris
or	fish teeth, scale, or bone
	conodonts
B	bone
or TB	tetrapod bone
	scale-tree log
	Stigmaria root casts
	plant fossils
	myriapods
Sp.	*Spirifer grimesi* group
chon.	chonetids
or	bioturbated

λ	rooting
	burrows
K	Keokuk Fm.
K/W	Keokuk-Warsaw fms. undiff.
W	Warsaw Fm.
Q	Quaternary



Iowa Department of Natural Resources
Energy and Geological Resources Division
123 North Capitol Street
Iowa City, Iowa 52242
(319) 335-1575