# EARLY TETRAPODS, STRATIGRAPHY AND PALEOENVIRONMENTS OF THE UPPER ST. LOUIS FORMATION • WESTERN KEOKUK COUNTY, IOWA

Robert M. McKay • Brian J. Witzke • M. Patrick McAdams

and

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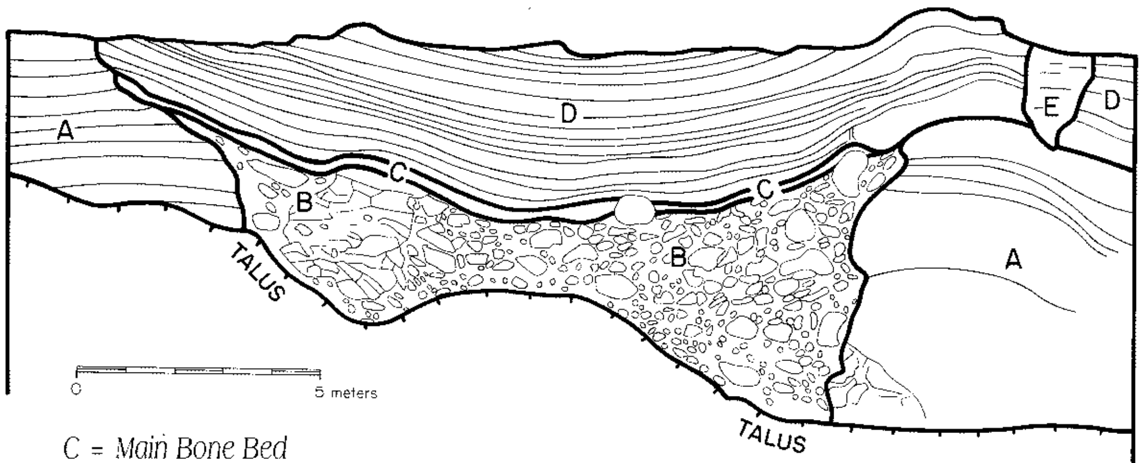
*Heimstra Quarry, Delta, Iowa*




C = *Main Bone Bed*

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GEOLOGICAL SOCIETY OF IOWA

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by

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# INTRODUCTION

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In May, 1985, during preliminary field studies of Mississippian strata in Keokuk County, Iowa, a thin 50 cm thick layer of rock rich in fossil amphibian bone was discovered (McKay et al., 1986). This rock layer, now referred to as the Heimstra Quarry bone bed, was found in an inactive limestone quarry (sec. 15, T.75N., R.13W.) near the town of Delta in west-central Keokuk County. Since the discovery, extensive study of the bone bed, its fossils and the host St. Louis Formation has been accomplished. These efforts have documented the Delta Site as a very rare and unique deposit which contains the oldest well-preserved tetrapod fauna in North America, and one of the oldest in the world. In view of the paleontological significance of the Delta Site the following chronicle documents the discovery and subsequent excavation of the bone bed, and the concomitant stratigraphic, paleontologic and sedimentologic studies which have been completed.

### Discovery of the Delta Amphibian Site

Much of the credit for the discovery must go to Pat McAdams. Having worked as a coal exploration geologist in Keokuk and neighboring counties, Pat theorized that some of the mineable Pennsylvanian coal seams in the area were localized within paleotopographic lows on the pre-Pennsylvanian erosional surface developed on Mississippian strata. In particular he was interested in a Pennsylvanian outlier with a mineable coal seam in section 14, T.75N., R.13W., one mile northeast of the Heimstra Quarry. During the summer of 1984 in an effort to improve his understanding of this paleotopographic surface, the lithologies of the rocks in which it was developed, and the occurrence of coal seams, Pat began to locate and visit outcrops and quarries in this area. Pat's first visit to the Heimstra Quarry occurred in the summer or fall of 1984. This visit was uneventful except that Jasper Heimstra, a local farmer and owner of the quarry, expressed curious amazement that anyone would want to look at the rocks in his quarry. Late in 1984 Pat and Matt Culp, a friend and fellow geologist, returned to Heimstra Quarry. They discussed the unusual dish shaped rock layers visible in the quarry wall, their stratigraphic position relative to the St. Louis, and its mode of origin. At this time they also recognized the presence of phosphatic material in the shales of what has since become known as the "main fill." They have recounted the events of that day several times, and neither of them is able to say with certainty whether they recognized the phosphatic material as bone. In Pat's words: "It was after all, a concept totally alien to Paleozoic Iowa geology. It was clear however, that the fill was unique."

In January, 1985, Pat returned to Heimstra Quarry and video-taped the walls of the quarry from a distance and closeup. This video, which has become known as "The Pink Floyd Quarry," was shown to members of the stratigraphy group of the Iowa Geological Survey Bureau (IGSB) later that winter. By that time Pat realized that the phosphatic material was bone and mentioned this fact to Brian Witzke at the video showing, but Pat did not comprehend its unusual occurrence in the St. Louis Fm.

At about the same time (fall of 1984), Bob McKay, IGSB geologist, expressed an interest to Pat in visiting the area to examine exposures of the St. Louis Fm. Bob had just completed an article on gypsum occurrences in Iowa, and wanted to initiate a field study of the St. Louis in order to better understand Mississippian evaporite occurrences in the subsurface. On May 17, 1985 Bob met with Pat near Delta to examine a few of the local St. Louis Fm. exposures and on this day stopped at Heimstra Quarry.

While examining the quarry section Bob saw a small digit bone in a limestone conglomerate talus block. Cracking open this block and other similar conglomerate blocks revealed numerous vertebrate bones (shoulder girdle elements, and ribs). At this point they located the conglomerate bed in the quarry wall and dislodged a large block. Cracking open this block revealed a large jaw with teeth. Together they noted the lateral extent of the limestone conglomerate bed and assembled a small collection of bone. Their speculation was that the bones could be reptilian, ranging somewhere in age between Mississippian and Permian.

Upon returning to Iowa City with the small collection, the specimens were shown to Holmes Semken (vertebrate paleontologist, U of I Geology Department) who identified them as Labyrinthodont amphibians based on their labyrinth tooth structure. A quick literature search by Brian Witzke confirmed the uniqueness of the site if indeed it was Mississippian in age. Several survey geologists returned to the Heimstra Quarry later that week and commenced, what has since become, a full scale study of the amphibian site and its stratigraphic occurrence.

## Further Studies

A large amount of work on the amphibian occurrence was conducted between the summer of 1985 and the present. During this time interval Mckay, Witzke, and McAdams measured stratigraphic sections of the Heimstra Quarry and other exposures in western Keokuk and eastern Mahaska counties. Additional bone from the Heimstra Quarry was collected, cleaned and prepared, and invertebrate macro and microfossil collections were assembled for biostratigraphic and paleoenvironmental interpretations.

The possibilities for an excavation of the bone bed were discussed soon after the discovery. Everyone involved in these discussions agreed that a full scale excavation of the bone bed was warranted, but that a specialist in fossil amphibians should be enlisted to lead the project. With that in mind, John Bolt from the Field Museum of Natural History, Chicago, was contacted and asked to participate in the project. After visiting the site and examining the preliminary collections John enthusiastically agreed to organize an excavation of the bone bed.

Simultaneous with discussions with John Bolt, the Geological Survey, working with the State of Iowa's Attorney General's Office, secured a four year lease on the Heimstra Quarry for the purpose of fossil and rock removal. Don Koch and Bernie Hoyer were instrumental in obtaining this lease.

John Bolt took the lead in gaining funding for an excavation. He prepared and submitted a grant proposal to the National Geographic Society, Washington, D.C. which, with minor revision, was accepted and approved in the spring of 1986. The excavation of the bone bed began June 10, 1986 and continued to September 5, 1986. During this period a little less than half of the main bone bed was uncovered and excavated. Field Museum staff (John Bolt, Bill Simpson, Tom Ladshaw) assumed primary responsibility during the excavation and were assisted by Pat McAdams, Bob McKay, Brian Witzke, Jed Day, Amy Nerenhausen, and Dan Hill. Local residents, J. Heimstra, M. Christner, and L. Fowler, offered invaluable logistical support. Hundreds of specimens were collected during the summer; the majority of this collection was transported to the Field Museum for further laboratory preparation. Final preparation of this material will take several years, and paleontologic study of the collection will probably continue for several additional years.

# "ST. LOUIS" FORMATION STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS IN THE KEOKUK COUNTY AREA

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## Historical Nomenclature

The interval which has been termed "St. Louis Formation" in Iowa remains poorly studied, although some earlier reports certainly are noteworthy. 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." Hall (1858) introduced the term "St. Louis Limestone" into Iowa, a unit first named by Englemann (1847) for extensive exposures at St. Louis, Missouri. Hall viewed "St. Louis" strata in several southeastern Iowa counties and noted its "concretionary" aspect and the presence of the rugose coral "*Lithostrotion*," which at the time was considered a guide fossil for the St. Louis. Re-examination of these Mississippian strata was initiated as part of the Iowa Geological Survey Bureau's stratigraphic study, and later study has sought to clarify the stratigraphic position and depositional conditions of a unique occurrence of abundant tetrapod bone in Keokuk County discovered in 1985. In this report, the Iowa "St. Louis" interval presently is regarded as a unit distinct from type St. Louis strata for two reasons: 1) biostratigrapic correlations between the Iowa sections and the St. Louis, Missouri, area are not firmly established, and 2) the Iowa interval, with abundant sandstone and shale, is lithologically dissimilar to type St. Louis strata, which is dominated by carbonate lacking sandstone beds. Therefore, the Iowa "St. Louis" presently is placed in quotes to reflect uncertainty. It may be desirable to give a new formational term to the interval in Iowa to avoid potential regional misunderstandings between the Iowa sequence and Illinois Basin areas. Alternatively, if a St. Louis correlation is confirmed, a series of member names, unique to Iowa, also can serve to distinguish the Iowa lithofacies from dissimilar facies to the southeast.

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 and/or lower Chesterian units and raised to formational rank (summary in Johnson, 1967, 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 (ibid.) formalized the member names Verdi and Croton, he more often than not 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 "St. Louis" or lower "St. Louis" as needed. The Iowa Survey presently divides the "St. Louis" Formation in Iowa into a lower member, the Croton, a middle member, the Verdi, and a newly recognized upper member, the Waugh.

## 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 designated by Van Tuyl (ibid.), but he stated that the member is typically developed in the vicinity of Croton where the unit attains a thickness of about 30 feet. According to Van Tuyl the Croton is a massive, dense, variably cherty, dolomitic limestone which

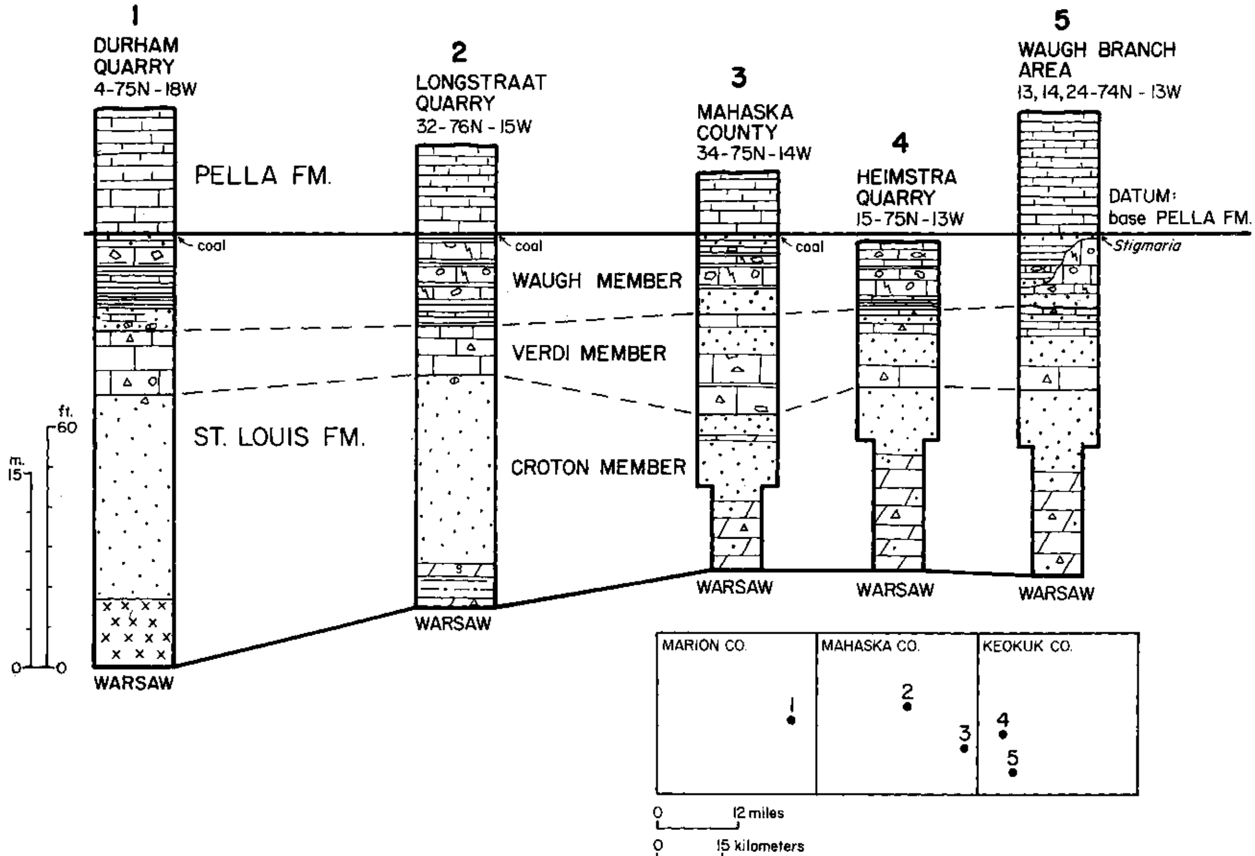


**Figure 1.** Cross-section illustrating the stratigraphic relationships of the three members of the "St. Louis" Formation in Keokuk, Mahaska, and Marion counties. Wide sections from outcrop and core data; narrower sections from well cutting data. Lithologic key in stop description section; XXX are gypsum and anhydrite.

frequently grades laterally over short distances into dense, fine grained, gray, non-dolomitic limestone. Both lithologies may also be interbedded. Fossils, although apparantly not abundant, include brachiopods, bryozoans, trilobites, bivalves, solitary rugose corals, tabulate corals, and the colonial rugosan "*Lithostrotion*" (=*Acrocyathus*). 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 in several west-central Illinois counties (Adams, Brown, Fulton, Hancock, Madison, McDonough and Schuyler; Collison, 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 megabreccias as solution collapse breccias resulting from the dissolution of bedded gypsum/anhydrite by either freshwater or marine waters, which transgressed the region during upper St. Louis deposition. The limestone breccias of the Illinois outcrop belt correlate with extensive middle and lower St. Louis sulfate evaporites in the subsurface of the Illinois Basin (Saxby and Lamar, 1957; Willman et al., 1975). Gypsum and anhydrite also occur in what we regard as the lower "St. Louis" in the subsurface of south-central and southeast Iowa (Fig. 1). 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 and interpret the megabreccias as resulting from solution 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 referred to as its "undisturbed phase." The "undisturbed phase" is 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 facies.

The Croton in the area of this report is present mostly in the subsurface. It varies in thickness between 40 and 70 feet (12-21 m) and is interpreted to rest unconformably upon the Warsaw Shale (Fig. 1). The lower Croton consists of sandy, variably cherty dolomite and sandstone in western Keokuk and eastern Mahaska counties, but grades laterally into sandstones and bedded gypsum-anhydrite in western Mahaska and eastern Marion counties. The upper Croton is dominated by quartzose sandstones throughout the area. Upper Croton sandstones are exposed at the Showman Station Railroad Cut section (Stop 1, SSRRC), and in smaller exposures along the lower reaches of the Waugh Branch of Sugar Creek (locality K8-1, Fig. 2). At the railroad cut section 4 meters of exposed Croton consists of large-scale trough cross-stratified sandstones and low-angle cross-stratified sandstones with wavy bedded to ripple cross-stratified sands near the top. The sandstones are capped by a bed of laminated pelletal lime mudstone containing birdseye. This is overlain by skeletal bioturbated lime wackestones of the Verdi Member. Core logs from the Heimstra Quarry (Stop 4), the Taylor Quarry (Stop 3D, see section K8Q Fig. 2) and other quarries in Mahaska and Marion counties document the presence of thick Croton sandstones beneath marine Verdi strata. Croton sandstones probably reflect shallow marine subtidal reworking of sands transported to the area by fluvial systems. Laminated pelletal lime mudstones with birdseye which cap the Croton sandstones at Showman Station, record a brief period of intertidal to supertidal carbonate sedimentation.

**Sub-Croton Units**

The Croton is known to rest upon several older formations which include: the Salem Limestone (Spergen of Van Tuyl); the Sonora Formation; the Warsaw Shale; and the Warsaw-Keokuk formations undifferentiated. The Salem, in its type area in Indiana, is dominantly cross-bedded skeletal grainstone, but in western Illinois (Madison County), and eastern Missouri (St. Louis County) significant portions of the formation are skeletal argillaceous dolomite and dolomitic skeletal grainstones to packstones (Lane and Brenckle, 1977). The Sonora Formation, named for the extinct village of Sonora, Hancock County, Illinois, consists of about 20 feet of argillaceous and dolomitic, cross-bedded sandstone alternating with sandy shale in its type area. In Hancock County, Illinois, the Sonora grades laterally into the Salem Limestone and the upper part of the Warsaw (Collinson, 1964; Willman et al., 1975).

The Salem was first identified in Iowa by Van Tuyl (1912). In later work (Van Tuyl, 1925) he noted that the Salem (Spergen) was restricted to extreme southeast Iowa, the best exposures being in Lee and Van Buren counties, but also being exposed sporadically in Des Moines, Henry, and Jefferson counties. Van Tuyl assigned a wide range of lithofacies to the Salem: cross-bedded fossiliferous limestone; massive brown dolomitic and fossiliferous limestone; fine grained sandstone; and shale. Assignment of the fossiliferous and dolomitic limestones to the Salem appears correct, based upon lithologic similarity and the presence of typical Salem fossils, such as the brachiopods *Tetracamera subcuneata* and *Brachythyris subcardiiformis*. However, the sandstones, which occur to the north in Jefferson County, if correlative with the Salem, probably should be assigned to the Sonora Formation, while the shales may be assignable to the Warsaw. The Croton overlies Van Tuyl's Salem at many of his localities, but he noted that the Salem appeared to be absent, due to pre-Croton erosion and/or non-deposition, north of eastern Jefferson County. Since Van Tuyl's work, it has been common practice by geologists working in southeastern Iowa to assign most variably cherty, and sandy dolomites and interbedded limestones which rest above Sonora or Warsaw lithologies and below typical Croton lithologies, to the Spergen (Salem). As a result of this practice some geologists have identified Spergen in the subsurface as far west as Keokuk, Mahaska, and Marion counties (Iowa Geological Survey, cuttings logs; Iowa Dept. of Transportation, core and outcrop logs). Few studies have evaluated the validity of these assignments. Milne (1978) found that strata typically assigned to the Spergen in a seven county area of southeastern Iowa consisted predominantly of unfossiliferous variably sandy and cherty dolomites with few interbeds of slighty fossiliferous limestone. Campbell (1966) also noted essentially the same lithologies in strata assigned to the Spergen in Des Moines County.

Although assignment of these faunally restricted carbonates to the Spergen has been almost universal, we feel a great degree of uncertainty over such an assignment, and prefer in most instances to place these strata within the Croton Member of the "St. Louis" (Fig. 1) for the following reasons: 1) The Salem, as identified by Van Tuyl, is almost always fossiliferous to very fossiliferous; even where partially dolomitized, the Salem contains abundant fossil molds, in particular bryozoans. Hence, assignment of unfossiliferous dolomites and limestones to the Spergen (Salem) appears inconsistent. 2) Some dolomitic strata, identified as Spergen (Salem), contain "*Lithostrotion*" corals. These corals have never been identified from strata assigned to the Iowa Salem by other faunal identifications, but they are a characteristic St. Louis guide fossil. 3) Unfossiliferous dolomites at this stratigraphic position appear to be a lateral lithofacies to sandstones and sulfate evaporites in Mahaska and Marion counties (Fig. 1). Interpreting the evaporites as being deposited laterally to restricted unfossiliferous carbonates, rather than limestones containing stenohaline faunas (Salem), appears to be a more acceptable alternative at this time. Further stratigraphic and petrologic study is needed to determine the correct age and stratigraphic placement of these units.

**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 (SE, sec. 4, T74N, R8W). Bain (1896) described the type section from an old railway quarry near Verdi station. Van Tuyl (1925) located the quarry in the eastern part of section 9, Brighton Township (T74N, R8W), one-half mile south of Verdi station. The Verdi was Bain's middle division of the "St. Louis," and it encompassed essentially all strata that Van Tuyl 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." Van Tuyl considered the term Verdi 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 35 feet for the unit and characterized the contained marine fauna as varied but not overly abundant.

The Verdi Member is well exposed at a number of localities in western Keokuk County (Stop 1, SSQ; Stop 3A, N-K8-3; Stop 4, JHQ). In Keokuk, Mahaska and Marion counties the Verdi averages 20 feet (6 m) in thickness; it overlies thick massive sandstones of the Croton Member and is overlain by sandstone or shale of the newly named Waugh Member (Fig. 1). The Verdi in this area is now considered to represent the middle member of "St. Louis." Although Van Tuyl (1925) clearly included within the Verdi Member some sandstones in the middle part of the "St. Louis," we have placed these sandstone, which occur below the prominent marine limestones of the Verdi, within the Croton. As presently used, the base of the Verdi is a convenient stratigraphic datum marked in Keokuk and Mahaska counties by the contact between massive Croton sandstones below and fossiliferous marine limestones above. Uppermost "St. Louis" strata of probable nonmarine orgin, 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 above the highest peloidal, coated-grain, or brachiopod- or foram-bearing limestones and below ostracod mudstones, shales or sandstones which lack characteristic characteristic upper Verdi fabrics and fauna.

The Verdi can be divided informally into a lower limestone interval and an upper interbedded limestone and sandstone interval. The lower Verdi is composed primarily of medium to thick bedded, bioturbated, peloidal and skeletal, lime wackestones to packstones containing a relatively diverse marine macrofauna and microfauna (Shallow-Marine Association of Witzke, this

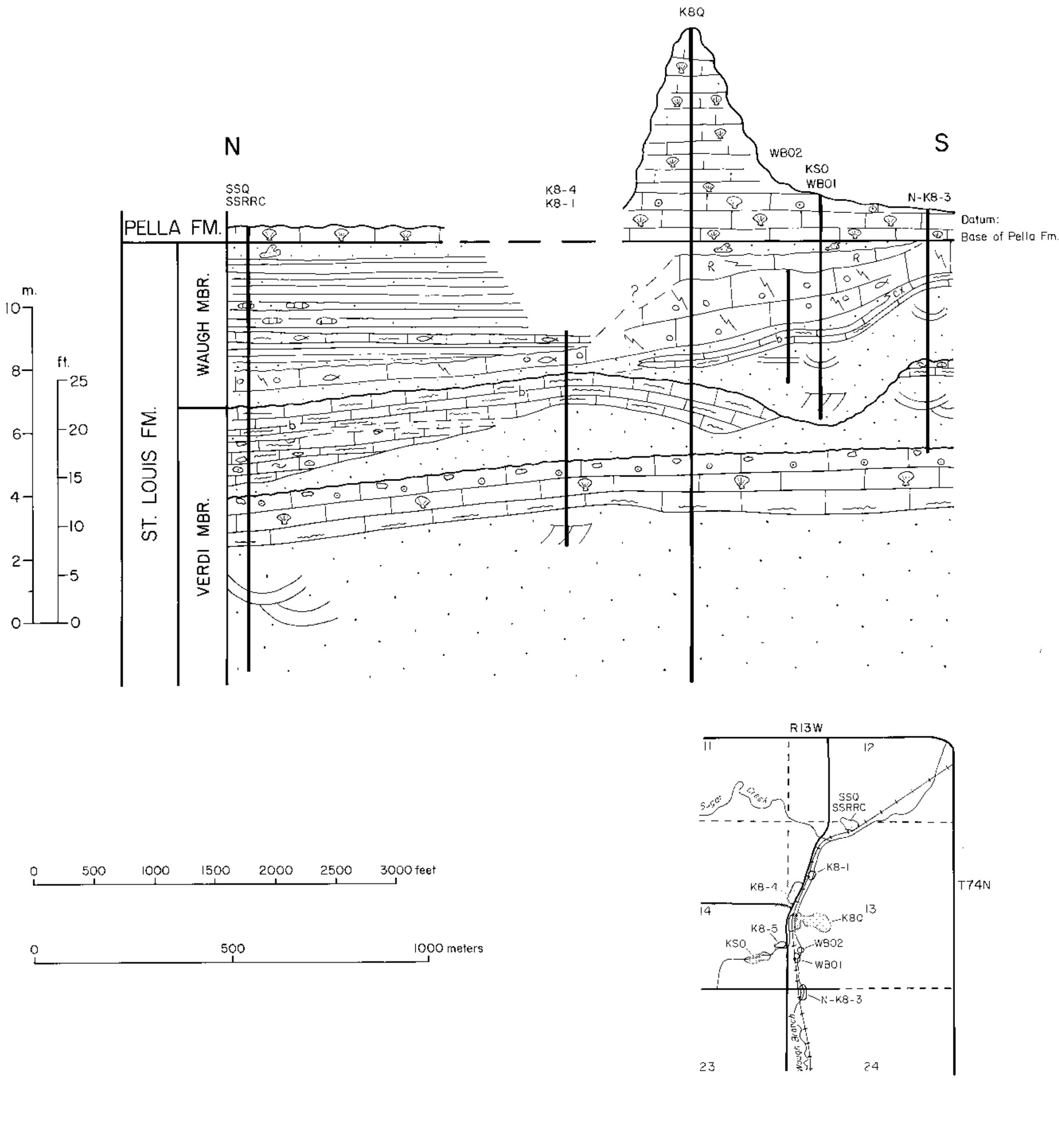


**Figure 2.** Cross-section along the Waugh Branch illustrating stratigraphic relations of the Verdi and Waugh members, and the overlying Pella Formation. Lower Verdi contact should be placed at base of shelly marine limestone; thick sandstones are Croton Member. Lithologic key in stop description section.

guidebook). Large spherical "cannonball" chert nodules are locally present, and they may replace tabulate corals locally. Minor amounts of glauconite and quartz sand are scattered throughout the wackestones to packstones. The upper one-half meter of the lower Verdi grades locally to oolitic packstones to grainstones which are capped by brecciated intraclastic mudstones displaying dessication cracks and possible caliche fabrics. Gray chert lenses locally are present within the ooid facies. This lower Verdi sequence, which averages 1.5 meters in thickness, is interpreted to represent one shallowing-upward marine cycle. Marine transgression and establishment of shallow marine conditions are documented by the fossiliferous wackestones to packstones which sharply overlie massive upper Croton sandstones. Shallowing within the cycle, resulting in increased water agitation and leading to subaerial exposure, is documented by the ooid grainstone-brecciated intraclastic mudstone sequence.

The upper Verdi averages 2.5 to 3.5 meters (8 to 12 feet) in thickness. It consists of interbedded limestones and sandstones and locally displays numerous minor disconformities. Thin bedded, laminated, pelletal lime mudstones to packstones containing birdseye dominate the sequence. These often grade upward into brecciated lime mudstones overlain by thin sandstones containing lime mudstone lithoclasts at their bases (Stop 1, SSQ). Peloidal to irregular, multiple coated grain (pisoidal) packstones to grainstones, and laminated pelletal wackestones containing a low diversity marine fauna (Restricted-Marine Association of Witzke, this guidebook) are also present. Minor white to gray chert lenses are noted locally. Sandstone units, while thin at some localities (SSQ), are notably thicker at section JHQ and N-K8-3. At these places the sandstones average 2.5 meters in thickness and comprise 70-80 percent of the upper Verdi. The sandstones are massive, quartzose, friable to slightly calcareous, and well cross-bedded. Cross-stratification varies from large-scale tabular to large-scale trough sets. Limited paleocurrent direction data indicate sand transport was predominantly to the south and southwest.

The upper Verdi interval is interpreted to have been deposited in shallow restricted marine and nearshore to shoreface environments. Laminated birdseye mudstones which grade upward to brecciated mudstones suggest intertidal to supratidal conditions. Coated grain (pisoidal) fabrics would have been generated in periodically agitated settings under conditions of increased salinity, probably in shallow lagoonal environments. The low diversity faunas, as Witzke notes, are characteristic of "stressed" environments, probably related to increased water salinity and temperature fluctuations. The thick sandstone units may represent shallow subtidal bars and perhaps tidal inlet sand accumulations. 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 or river. 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 Keokuk County area. The upper Verdi interval is overlain by the newly named Waugh Member which appears to represent a variety of nonmarine depositional systems. Marine onlap and deposition in this area apparently did not resume for an extended period of time until Pella marine transgression.

### Waugh Member

The Waugh is a newly recognized and named member of the "St. Louis" Formation in the Keokuk County area; 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 and because of this variability designation of one locality as a type section is not considered sufficient for member definition. Instead, a type area is proposed. The type area of the newly named Waugh Member is within sections 13 and 14, T74N, R13W (Benton Township), Keokuk County (Hedrick Quadrangle, 7.5 minute series). Reference sections are at field trip Stops 1, 2, and 3 (sections SSQ, K8-5, KSO1, KSO2, N-K8-3, WBO1, WBO2, K8Q, and K8-4; see Fig. 2 for location map). An additional and important reference section is at Stop 4 (section JHQ), approximately six miles to the north. Waugh

Member thickness varies within the study area from 15 to 20 feet (4.5 to 6.0 m). Five major lithofacies are recognized within the Waugh Member; in ascending stratigraphic sequence they are (Fig. 2): 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 - fish-bearing lime mudstones, 4) thin- to thick-bedded, partly laminated, ostracode-fish - bearing lime mudstones interbedded with shale, and 5) scale tree root-bearing sandstone and associated underclay. 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 collaspe structures at the Heimstra Quarry.

Planar to Cross-Stratified Sandstones and Sandy Shale. Planar-stratified to cross-stratified sandstones occupy the basal portion of the Waugh in the study area. These sandstones rest disconformably upon upper Verdi Member limestones and locally appear to truncate portions of the upper Verdi (Fig. 2). 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 sands are in part a lateral facies of large-scale cross-stratified sands, as can be seen at Stops 3B and 3C (sections WB01 and WBO2). In general, planar sands are unfossiliferous but scale tree log and root casts (*Stigmaria*) are present locally (Stop 2C, KSO2). At the top of the basal sandstone sequence, planar sands are interbedded with sandy laminated lime mudstones. These mudstones contain birdseye-like structures, calcite spar filled voids and small calcite spar-filled anastomosing tubules; dessication 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 sandstones. This sandstone subfacies is well developed at Stop 3B (section WBO1) and is present, but less visible, at Stop 3A (section N-K8-3). The sandstones are 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 a large-scale trough cross-stratified channel fill lies above 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 ($13^{o}$), and the trough axis azimuth is due west. This channel is overlain by thinner, argillaceous planar-stratified sands and lime mudstones. Sandy shales locally occupy positions stratigraphically equivalent to planar and cross-stratified sandstones. At Stop 4 (section JHQ) sandy shales overlie thin-bedded peloidal lime mudstones of the upper Verdi. Shales are generally light green, often oxidized to tan and orange hues, calcareous in part, laminated in part but weathering blocky, and sandy to very sandy. Ostracodes, "spirorbid" snails, and fish scale debris are common to abundant. Dense, slightly argillaceous lime mudstone interbeds with sparse fish debris may occur within the sandy shales.

The planar-to cross-stratified sandstone facies and the sandy shale facies are interpreted to have been deposited dominantly in fluvial to marginal marine deltaic deposystems following offlap of the St. Louis seaway, in which restricted marine intertidal to supratidal 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 meters of fluvial incision into underlying upper Verdi carbonates is suggested by exposures along the Waugh Branch (Fig. 2). 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 dispersement of sands and finer grained siliciclastics 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, scale tree growth was established as evidenced by the presence of *Stigmaria* root casts. Shallow ponds or lakes probably existed in portions of the floodbasin at certain times. These served as habitat for low-diversity ostacode and "spirorbid" snail populations as well as fish. Laminated lime mudstones displaying calcite spar-filled voids and anastomosing tubules, and dessication 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 sedimentation conditions which persisted with change throughout the remainder of Waugh Member deposition.

Massive, Fractured and Conglomeratic Ostracode Lime Mudstone. Massive, fractured to brecciated, and intraclastic to conglomeratic, ostracode-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 meters in some outcrops. This lithofacies is present at all four field trip stops where it always overlies 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, as noted in Iowa Dept. of Transportation quarry and core log descriptions. Its eastern extent is not known. Overall thickness of this facies varies from .6 to 2.3 meters 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 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.

Massive lime mudstones are variably intraclastic to conglomeratic throughout the study area. Subangular to subrounded lime mud clasts ranging in size between sand and granules to occasional pebbles are present in almost all outcrops. Intraclasts are usually enclosed within the mud matrix but locally they may be concentrated to the extent that the rock becomes a clast to matrix supported conglomerate. Conglomeratic horizons have been noted at sections KSOl, K8Q, and JHQ. At the amphibian site (JHQ) conglomerate is noted at the top of bed 11 (main quarry section). 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). Witzke (this guidebook) refers to this fauna as the nonmarine fish-tetrapod association. Although tetrapods have not yet been found from massive mudstones, small limb bones and jaw material displaying tetrapod affinities have been recovered from acid residues.

Massive lime mudstones may be overlain by sandstone, shale, or laminated lime mudstone. Alternatively, as at many sections along the Waugh Branch (Stops 2 and 3), they may grade upward through a rubbly, rooted horizon and be overlain by a weakly developed underclay and scale tree root cast (*Stigmaria*) sandstone unit. Where overlain by *Stigmaria*-bearing sandstone and underclay the massive limestones are rubbly and lenticular. Anastomosing shaley and argillaceous seams course through the zone and fossil rootlet fabrics are noted. Acid residues from rubbly zone mudstones contain large amounts of clay and sand. At one locality (Stop 3A, section N-K8-3) massive mudstones displaying a conglomeratic to brecciated upper surface are overlain by basal transgressive marine Pella Formation lithologies, and the *Stigmaria*-bearing sandstone unit appears to be absent.

The transition from massive mudstones to overlying shales, laminated lime mudstones or minor sandstones appear to be separated by a local disconformity. Upper parts of mudstones at Showman Station are in places highly brecciated and recemented, and conglomerates occur at a similar horizon at the Heimstra Quarry. It is probable that the conglomerates which comprise the Heimstra Quarry amphibian bone bed were generated during the time interval in which this disconformity surface was being formed. Figure 2 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 along the part where the present day valley of the Waugh Branch is situated. For this reason the lateral relationships are queried.

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 (this quidebook) is characteristic of other Carboniferous lacustrine deposits. Fractured and brecciated fabrics were probably generated during periodic dessication of the lake, and conglomeratic horizons formed when rainstorm generated surface flow reworked fractured and dessicated semilithified sediment. The calcite spar and internal sediment which filled large vertical voids may represent filling of plant and root cavities, or perhaps animal (possibly lungfish or other) burrows. Periodic fluvially sourced clastic influx supplied minor quantities of sand and clay into the lake basin(s). 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 dessicated, as evidenced by the fractured and conglomeratic sediments. Although tetrapods have not been found in these massive lacustrine limestones, it appears that ecologic conditions would have been suitable for them to inhabit the area during this time.

Laminated Ostracode-Fish-Bearing Lime Mudstones and Shales. Thin- to thick-bedded, variably laminated, ostracode-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 meters. Limestones dominate this lithofacies at the Heimstra Quarry (Stop 4, section JHQ) where they attain a total thickness of 3 meters. Sandy shales are more prominant in the Waugh Branch area where 70 to 80 percent of the interval is shale (Stop 1, section SSQ; and Fig. 2). The limestones are variably laminated. Laminae are mostly discontinuous and may be disturbed and/or bioturbated. Rare lime mud intraclasts may be 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 crossopterygian fish scales have been found at three localities within this facies; crossopterygian skull material has been recovered from this facies at the Heimstra Quarry as well as a colosteid tetrapod skull (see Witzke, this guidebook). Thin interbedded laminated calcareous shales are present where the limestones are dominant. At Heimstra Quarry abundant tetrapod and fish remains have been collected from these shales where they form the upper part of the bone bed within the main collapse structure.

Shales comprise the bulk of this facies in the Waugh Branch Area. Here the shales are generally nonlaminated, and contain moderate quantities of quartz sand and sparse amounts of fish debris. The shale sequence at SSQ 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 noted from this bed. This limestone contains minor birdseye-like structures and small calcite spar-filled tubules. One-half mile to the south, at section K8-4, the bed is thinner and contains calcite spar-filled dessication cracks. Shales 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 mudstones lack lamination but are intraclastic and contain sparse fish debris.

The laminated mudstone and shale facies of the Waugh 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. Dessication of portions of the lake apparently did occur, but perhaps for shorter time intervals, thus brecciated and conglomeratic fabrics were not commonly formed. The fauna of this facies is similar to that in the massive mudstone facies except that aquatic tetrapods (colosteids) are present. Fluvial clastic influx, perhaps in the form of small deltas or overbank deposits, overwhelmed carbonate sedimentation in parts of the lake basin where sandy shales were deposited. Deposition of the laminated mudstone facies slowed and finally ceased as fluvial-deltaic clastic influx shut-off

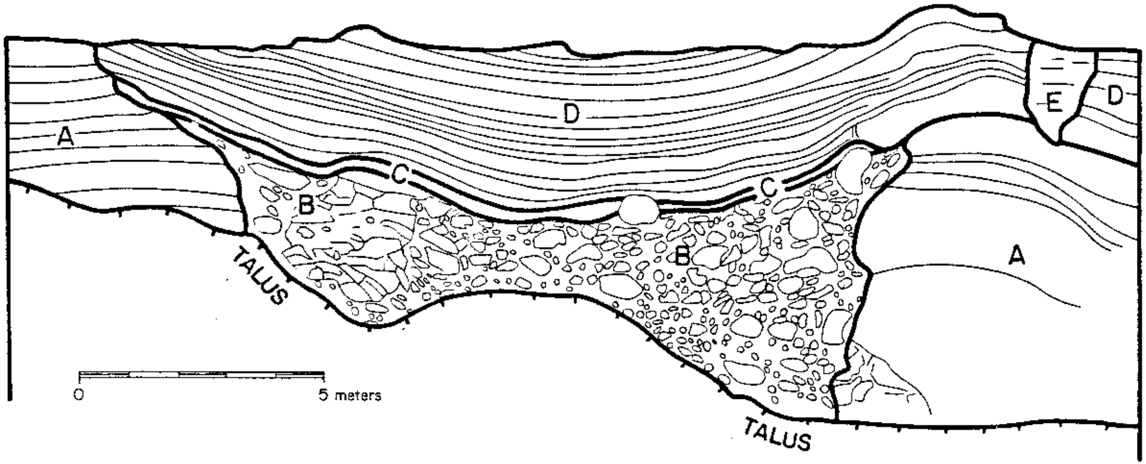


**Figure 3.** Stratigraphic relations of the Heimstra Quarry (photo tracing of main collapse-structure, east quarry wall). Lettered units discussed in text.

carbonate production and infilled the basin. The presence of overlying scale tree root-bearing sandstones and underclays marks the end of lacustrine sedimentation and the establishment of a relatively widespread swamp environment towards the end of Waugh Member deposition.

Scale Tree Root-Bearing Sandstone and Underclay. Sandstones and claystones containing *Stigmaria* root casts and other rooting structures form the uppermost facies of the Waugh Member. 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 1 foot thick occur at this horizon. 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 (Johnson, 1967, 1969; Van Tuyl, 1925). We propose to exclude these strata from the Pella and to include them 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 formational contacts within 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 very early stages of the cyclothemic deposition that would later dominate the Chesterian and Pennsylvanian.

Schabilion and Witzke (this guidebook) both elaborate on environmental interpretations applicable to this upper Waugh Member lithofacies.

Tetrapod-Bearing Limestone and Boulder Conglomerates. Perhaps the most significant facies within the entire 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 (Stop 4; and Fig. 3 and 4). Well preserved tetrapod bone is concentrated within two collapse-structures (7 and 16 m wide) developed in the Verdi and lower Waugh members. Rocks at the Heimstra Quarry can be divided into five units (Fig. 3) for discussion purposes. Unit A represents Verdi through lower Waugh strata; these are truncated by the paleocollapse structure. Development of both features (small one on north quarry wall not illustrated), which display collapse of surrounding strata, may have been caused by dissolution of bedded gypsum at depth in the lower Croton Member. The walls of the depression are solutionally pitted, suggesting subaerial exposure.

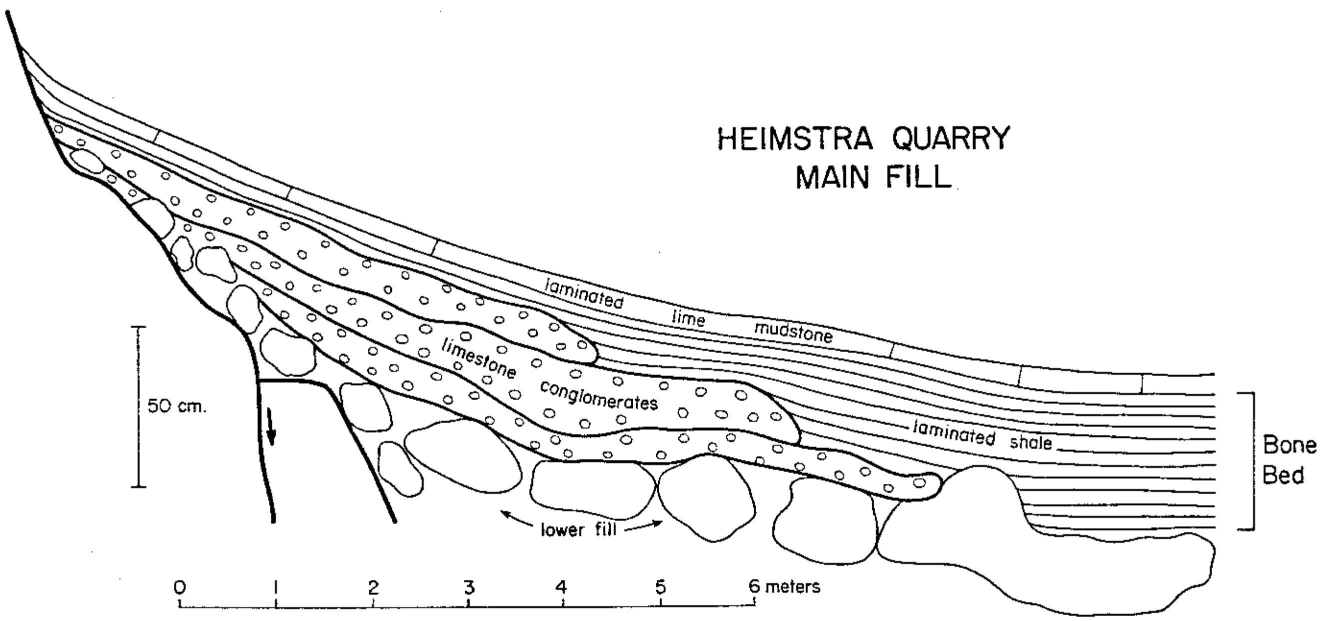


**Figure 4.** Stratigraphic relations of the bone bed, main collapse-structure, Heimstra Quarry.

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 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 was not visible and has not been excavated so its total thickness and deeper level composition is not known. Unit C is the main bone bed; it overlies the very uneven upper surface of the boulder conglomerate of Unit B. The bone bed ranges from 0 to 50 cm thick and locally overlaps parts of Unit A at the fill margins (Figs. 3 and 4). The bone bed is dominated by layers and lenses of limestone conglomerate which contain abundant tetrapod bone. The limestone conglomerates are 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. Conglomerate layers are in part separated by thin shale partings, and the conglomerates grade laterally and abruptly into laminated brownish-green shales. The limestone conglomerates accumulated when debris from the surrounding "St. Louis" surface was transported periodically into the depression. Conglomerate layer geometries, as seen during the 1986 excavation, are lobe-like. This lobate shape and the clast- to matrix-supported fabric suggest that deposition of these layers occured as viscous mudflows which flowed into a water filled depression. Conglomerates do not extend across the entire depression but are concentrated in the north half. They grade laterally into laminated brownish-green shales at the center of the depression. The basal 15 to 20 cm of the shales contain some of the most articulated tetrapod material yet found. Long vertebral columns and a partial skeleton were found within this shale towards the center of the depression. Fish material and coprolites are common in the upper portion of the shale which overlaps the conglomerates throughout the main fill. These laminated shales were deposited subaqueously in quiet water settings. The lack of benthic faunas and bioturbation within this shale, its laminated fabric, and the presence of articulated tetrapods suggest that it was deposited within a stratified body of water with low-oxygen conditions. The shales and limestone conglomerates of Unit C were subsequently covered by fish and tetrapod-bearing lime mudstones of Unit D (Laminated Lime Mudstone Facies) which were deposited as lake levels rose and carbonate sedimentation resumed. Further discussion of the tetrapod and associated bone bed fauna, tetrapod survival strategies and environments of deposition are discussed by Witzke (this guidebook).

# CONODONT BIOSTRATIGRAPHY

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A preliminary conodont study of the marine interval (Verdi) in Keokuk County, which has been assigned generally to the "St. Louis" Fm., was undertaken to constrain age relations of the overlying amphibian-bearing beds. Conodont studies of "St. Louis" strata in Iowa have not been undertaken previously with one noteworthy exception. Rexroad and Furnish (1964) redescribed the conodont fauna of the Pella Formation, following the lead of Youngquist and Miller (1949). However, Rexroad and Furnish's Unit A of the "Pella" in Mahaska County includes the same interval which encompasses the Verdi marine unit and the amphibian-bearing strata of Keokuk County. We have included only their units B and C within the Pella, which disconformably overlies Unit A strata in southern Iowa. The conodont fauna of Unit A listed by Rexroad and Furnish (1964) includes *Cavusgnathus regularis*, *C. unicornis*, *Spathognathodus cristulus*, and "*Ligonodina*" spp.

Conodont collections made by McKay and Witzke during 1986-1987 total 131 specimens in 14 samples from the Heimstra and Showman Station quarries and nearby exposures. Sample sizes ranged from 500 gm to 2 kg. A fauna similar to that noted by Rexroad and Furnish was recovered, which includes the form taxa: *Cavusgnathus regularis* (which may be a synonym of *C. altus*, G. Klapper, pers. comm., 1987), *C. unicornis*, *Spathognathodus cristulus*, *Ozarkodina recta*, *O. curvata*, *Neoprionoidus* sp. (aff. *N. tulensis*), "*Ligonodina*" sp., thin-bladed forms resembling *Magnilaterella* or *Lambdagnathus*, and various S elements. Sweet (in Klapper et al., 1977, p. 209) described the multielement conodont *Hindeodus cristulus* to include a six-member apparatus: *Spathognathodus cristulus* (Pb), *Ozarkodina curvata* (Pa), *Neoprioniodus camurus* (M), and three S elements. All elements of *H. cristulus* are present in our collections except the M element. Additional ozarkodiniform and neoprioniodiform elements in these collections (noted above) may belong to the multielement apparatus of *Cavusgnathus* (G. Klapper, pers. comm., 1987). *C. unicornis*, *C. regularis*, neoprioniodiform, and ozarkodiniform elements were included in the multielement apparatus of *C. unicornis* by Rexroad (1981) and von Bitter and Plint (1987).

Conodonts from the type St. Louis area have been described by Rexroad and Collinson (1963). They recognized an upper St. Louis interval marked by the abundant co-occurrence of *Apatognathus scalenus*, *A. porcatus*, *Cavusgnathus unicornis*, *Neoprioniodus tulensis*, and *Spathognathodus scitulus*. In general, the base of this interval (the *Apatognathus scalenus*-*Cavusgnathus* Zone, Collinson et al., 1971) is marked by the first occurrence of abundant *Cavusgnathus*, and the top is marked by the last occurrences of *Apatognathus* spp., *N. tulensis*, and *S. scitulus*.

The apparent absence of *Apatognathus* and *S. scitulus* in supposed upper "St. Louis" strata in Keokuk County is equivocal, because species of the Iowa conodont fauna are not restricted to the upper St. Louis in the type area. The common occurrence of *Cavusgnathus* in Keokuk and Mahaska counties suggests an upper St. Louis through Chesterian age; the first occurrence of the genus in the Mississippi Valley sections is within the St. Louis Formation. However, *Cavusgnathus* (including *C. unicornis*) ranges into older strata in Britain (Rhodes et al., 1969). The absence of the St. Louis "guide fossil, "*S. scitulus*, in Iowa is perplexing, although this species, *A. scalenus*, and *A. porcatus* span much longer ranges in Britain (ibid.), casting doubt on their utility as inter-regional St. Louis index fossils. Although *S. cristulus* is a common fossil in "St. Louis" strata in Mahaska and Keokuk counties, it has not been noted in the type area of the St. Louis Formation (Rexroad and Collinson, 1963), but is a common Chesterian conodont in the Illinois Basin. Nevertheless, *S. cristulus* is known from St. Louis age equivalents in Britain (Rhodes et al., 1969), and occurrences in the Kansas subsurface (Thompson and Goebel, 1969) indicate that this species ranges through strata equivalent to the St. Louis in that area (which also contains the St. Louis index coral *Acrocyathus proliferus*). *S. cristulus* is noted in Kansas within the range intervals of *A. porcatus*, *A. scalenus*, *S. scitulus*, and *Cavusgnathus*, and co-occurs lower in the sequence with *Taphrognathus varians* below the ranges of *Cavusgnathus* and *S. scitulus* (ibid.). This indicates that *S. cristulus* has a much longer range in areas removed from the type St. Louis Fm., and apparently spans much or all of the Meramecian and Chesterian in midcontinent North America and Britain. The example of *S. cristulus* also points out the disparity between conodont ranges of some taxa in the standard Mississippi Valley sections and adjacent areas (like Kansas, and possibly Iowa).

In summary, the conodont fauna of upper "St. Louis" strata in Keokuk County is not diagnostic of any particular zone, but is consistent with a St. Louis or younger age assignment. However, lithostratigraphic relations, as discussed earlier, and the presence of the coral *Acrocyathus* in the marine interval at other Iowa localities (Van Tuyl, 1925; Sando, 1983), suggest correlation of this interval with more typical St. Louis lithologies in Illinois and Missouri.

The conodont fauna of the overlying Pella Formation (Rexroad and Furnish, 1964) also is equivocal, primarily because the contained species are long-ranging forms through the Ste. Genevieve ("Genevievian Stage") and lower Chesterian in Illinois. The fauna is assigned to the *Gnathodus bilineatus-Cavusgnathus charactus* Zone (Collison et al., 1971) and includes *G. bilineatus*, *S. cristulus*, *C. regularis*, *C. unicornis*, and other forms. Historically, the Pella has been equated with the Ste. Genevieve Formation, primarily on the basis of its macrofauna and stratigraphic position. Further studies are needed.

# UPPER "ST. LOUIS" BIOTIC ASSOCIATIONS AND ENVIRONMENTS IN THE KEOKUK COUNTY AREA

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Four general biotic associations are recognized in stratigraphic sequence in the Verdi and Waugh members of the upper "St. Louis" Formation in the Keokuk County area, in ascending order: 1) shallow-marine brachiopod-echinoderm-mollusc association, 2) restricted-marine brachiopod association, 3) nonmarine fish-tetrapod association, and 4) scale tree association.

### Shallow-Marine Association

Marine transgression is recorded in the lower limestone interval (lower Verdi Member), which overlies sandstones of the middle "St. Louis" in the study area. This interval includes a relatively diverse macrofauna (Table 1), which is regarded as stenohaline shallow marine. In particular, the occurrence of echinoderms and trilobites suggests normal-marine salinities. This marine fauna is similar in a general sense to that noted 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 colonial corals occur in the "St. Louis" but are absent in the Pella. The listed macrofauna (Table 1) represents fossils identified from the Heimstra and Showman Station quarries, but also includes molluscs listed by Van Tuyl (1925) from Keokuk County not identified in this study. Van Tuyl also noted a spiriferid similar to *Anthracospirifer pellaensis*, a common brachiopod of the Pella. In addition to the identified macrofauna, microfauna includes: 1) calcareous foraminifera, 2) conodonts, 3) ostracodes, and 4) rare fish teeth and scales (including acanthodians).

The Verdi marine unit at the field trip stops yielded corals (solitary rugosans, colonial tabulates). The colonial rugosan *Acrocyathus* (="*Lithostrotion*"), which has been considered a guide fossil for the St. Louis Formation. in the upper Mississippi Valley area, has not been found as yet at the Heimstra or Showman Station exposures. However, *Acrocyathus* is found in adjacent Jefferson County to the southeast (Van Tuyl, 1925, p. 269) in strata here considered correlative. Acrocyathid corals with large corallites are known only from St. Louis strata in the Mississippi Valley sections, and they occur only within "St. Louis" strata (upper Croton, Verdi) in southeast Iowa (noted in Lee, Van Buren, Henry, and Jefferson counties; Van Tuyl, 1925).

### Restricted-Marine Association

The upper Verdi in Keokuk County includes limestone, in part laminated to fossiliferous, and sandstone, in part with crossbeds and limestone interbeds. This interval is interpreted to have been deposited in restricted-marine and nearshore to shoreface settings, and the contained fauna shows a marked decline in diversity compared to underlying strata. Foraminifera, ostracodes, molluscan debris, sparse conodonts (*Cavusgnathus*), and brachiopods (*Composita*) are noted. Brachiopods are common locally, but occurrences represent a monospecific brachiopod association characteristic of so-called "stressed" environments. Reduced diversity probably is related to increasingly stressed conditions in a nearshore setting, where salinity fluctuations would be noteworthy.

Sand, derived from fluvial influx, apparently was deposited in shoreface settings and offshore bars. Limestones can be divided into two groups: 1) pelletal, coated-grain, and skeletal mudstones to packstones deposited in nearshore restricted settings, and 2) laminated mudstones, in part brecciated to intraclastic, locally with "birdseye" structures and dessication cracks deposited in tidal flat and supratidal settings. Available faunal and sedimentologic evidence suggests that the "restricted-marine" interval records the final offlap of the "St. Louis" sea from the area. Marine

**TABLE 1.** Macrofauna, Lower Marine Limestone Unit (Verdi), Upper "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**
- -ostrocodes--indet. ostracodes
- -trilobites--*Kaskia* sp.

**Echinoderms**
- -indet. crinoid debris

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

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

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

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deposition did not resume in the area until the Pella marine transgression inundated the area.

### Nonmarine Fish-Tetrapod Assocation

Upper "St. Louis" strata of the Waugh Member in Keokuk County lack evidence of marine or restricted-marine deposition, and the contained fauna lacks all elements definitive for such settings (e.g., foraminifera, conodonts, echinoderms, bryozoans, brachiopods, trilobites, corals). Instead the interval is dominated by a variety of fish (locally with tetrapods), one species of small "spirorbid" snail, and one or two species of ostracodes (Table 2). As previously discussed, Waugh Member strata are laterally variable, but are characterized by dense ostracod-bearing lime mudstones (in part laminated, fractured, brecciated, or conglomeratic), calcareous shale beds, and sandstone. The interval is punctuated by minor subaerial disconformities marked by highly-fractured to conglomeratic horizons in the lime mudstone, by apparent fluvial incision, and locally by collapse structures (as at Heimstra Quarry) which probably relate to dissolution of lower "St. Louis" evaporites at depth.

The fauna (Table 2) contained in the shales and limestones of the Waugh Member is generally of relatively uniform composition, although tetrapods are conspicuous only within collapse structures at the Heimstra Quarry. Acid residues are dominated by aquatic vertebrates and snail and ostracod molds (Figs. 5, 6, 7). Scales, teeth, and bone fragments comprise the phosphatic residue, which is dominated by palaeoniscoid and shark scales (Figs. 5,6). Minor constituents include acanthodian debris, crossopterygian scales, xenacanth and petalodont shark teeth, and miscellaneous bone and dentary fragments. Jaw and maxillary fragments (Fig. 7) have not been studied rigorously, but some are apparently from palaeoniscoids (see examples in Schultze, 1985) and acanthodians (see Denison, 1979, p. 38). However, some jaw and bone

**TABLE 2.** Upper "St. Louis" (Waugh Mbr.) Fossils, 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.

**-Arthropods**
- -indet, ostracod molds
- -poorly preserved segmented form (bed a, main fill), may be myriapod or plant

**-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 skeleton
  - -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

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fragments may be assignable to small lepospondylamphibians (see examples in Thayer, 1985), and a small limb bone (Fig. 7k) is suggestive of possible tetrapod affinities. Further study is needed. In addition to the micro-residues, large scales (1-8 cm in diameter) from rhizodont crossopterygians have been found in lime mudstones from three localities in Keokuk County. Some acid residues have yielded molds of peculiar three-pronged objects (Fig. 5s-u) of uncertain biological affinities; their branching habit suggests a possible plant relationship.

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 includes the Delta site, are few in number but are known from several localities in Scotland (Wood et al., 1985) 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 marks the oldest well-preserved tetrapod fauna known from North America (regardless of whether upper "St. Louis" strata in Iowa correlate with St. Louis or Ste. Genevieve strata in Illinois; see discussion under Pella stratigraphy).

The tetrapod and fish fauna (Table 2) from the Heimstra Quarry is presently under study, and discussions below are based on preliminary observations made during joint Field Museum-Iowa Geological Survey Bureau excavations in 1986 and during subsequent preparation (John Bolt, Field Museum, 1986-1987, pers. comm.). Excavation of bedded limestone and minor shale in the "upper fill" (beds b-i; see earlier discussion) 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 bed d); a nearly complete lungfish skeleton (bed c); and scattered tetrapod bone, including a beautiful colosteid skull associated with five jaws (base bed d). The laminated shale (bed a) which overlies the main bone bed produced a variety of interesting fish and tetrapod material. This shale was processed for palynomorphs, but none were recovered (R. Baker, 1986, pers. comm.). 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), as well as 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 and underlying boulders of the main bone bed.

The "main bone bed," an interbedded sequence of lobate limestone conglomerate beds (with boulders) and shale, was the target of our 1986 excavations at the Heimstra Quarry, both in the main fill and north fill areas. Many hundreds of bones were collected, mostly disarticulated but including articulated skeletal elements and partial skeletons. The bone is well preserved but is highly fractured and crumbly in the shale (preserved primarily with cyanoacrylate, "Krazy Glue"). The fossils in the main bone bed are dominated by tetrapods, but fish (including rhizodonts and acanthodians) and shark material as well as coprolites constitute noteworthy secondary components, especially in the upper part. At least three major groups of tetrapods are included, but most material belongs to two labyrinthodont

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**Figure 5.** Fish, shark, and non-vertebrate microfossils from residues; photo tracings; Heimstra Quarry (bed listed in parentheses). Bar scale 1 mm. a. indet. scale with fenestrae (bone bed); b. indet. scale (bed 11); c. crossopterygian scale fragment (bed 11); d-j. various elasmobranch (shark) dermal scales (bone bed), probably xenacanth; k. partial petalodont shark tooth (bed 11); 1. xenacanth shark tooth (bed 11); m., n. acanthodian scales (bed 11, bed d); 0, p. acanthodian dermal tesserae (bed j, bed d); q. indet. dermal element, aff. acanthodian (bed d); r. indet. serrated tooth, aff. acanthodian (bed 11); s-u. indet. three-pronged element, molds, aff. plants (bed g); v. ostracod mold (bed 11); w. small "spirorbid" snail mold (bed d).

**Figure 6.** Palaeoniscoid scales, Heimstra Quarry, residues from bone bed, bed 11, bed f; photo tracings. Bar scale 1 mm. Includes simple scales (a-d, g, h), ridged scales (e, f, i, j), scales with serrated margin (k-o, q, s, u), prominently serrated scales (p, t, v), spinose scales (r, w - w may be crossopterygian).

**Figure 7.** Various dental elements and bones, including fish and possibly tetrapod material; photo tracings; Heimstra Quarry (bed listed in parentheses). Bar scale 1 mm. a-c. indet. jaw fragments (bone bed and bed 11); d. jaw fragment with curved teeth (bed d); e. jaw fragment similar to a (bone bed); f. jaw fragment (bed j); g. maxillary fragment, occlusal view (bed d); h. jaw fragment bed g); i. maxillary fragment (bed j); j. jaw fragment, aff. acanthodian (bed 11); k. small limb bone, aff. tetrapod (bed 11); l. rib fragment (bed j).

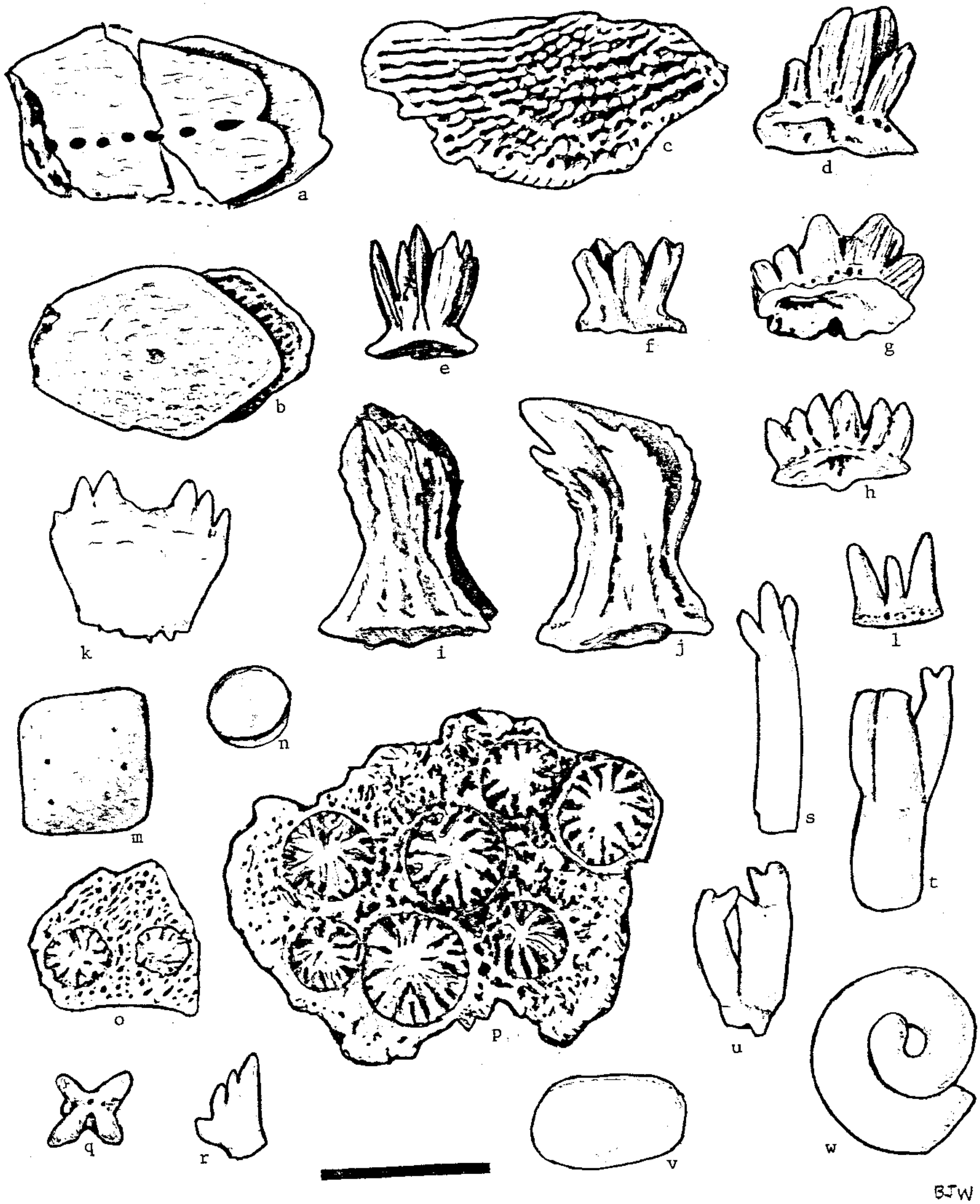


**Figure 5**

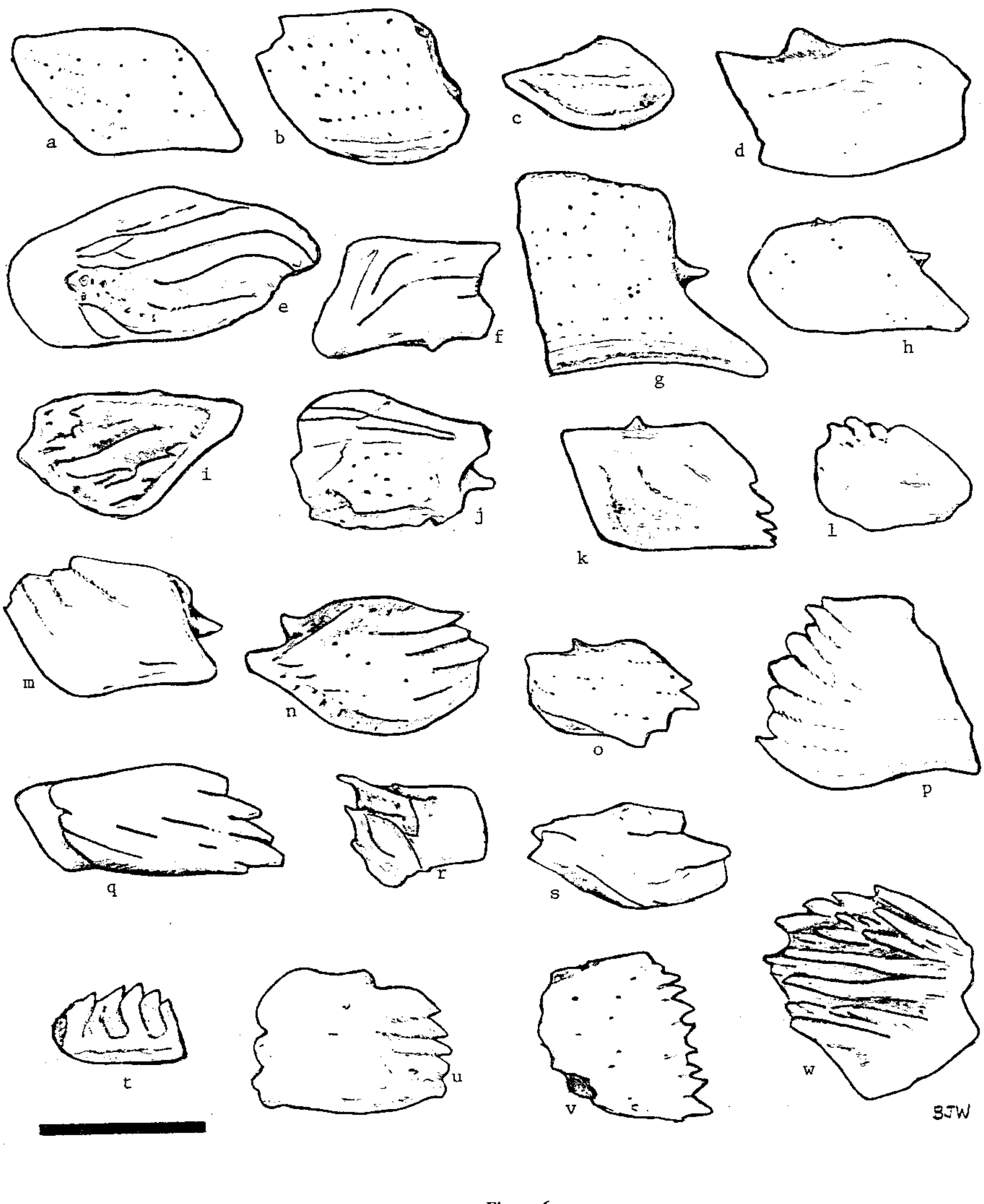


**Figure 6**

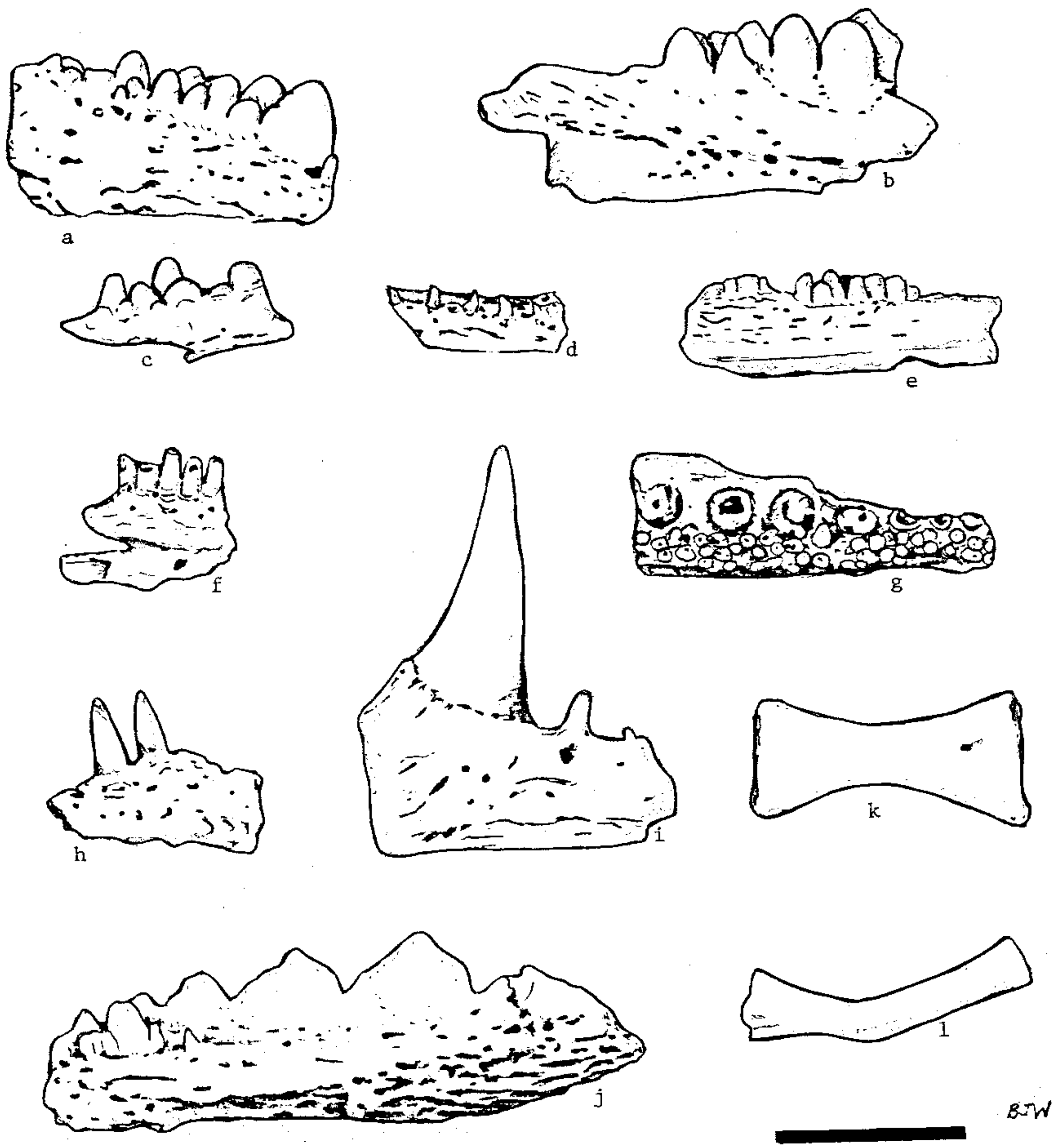


**Figure 7**

amphibian groups, proterogyrinid anthracosaurs (now interpreted as proto-anthracosaurs) and colosteid temnospondyls. The amphibians are represented by a wealth of disarticulated to semi-articulated material incorporating most cranial and post-cranial elements. In life, these tetrapods were relatively large animals, equalled or eclipsed in size only by the contemporary xenacanths and rhizodonts. Articulated material indicates body lengths of about 75 cm to 2 meters (some are smaller), and large isolated pelvic girdles, when compared to other known anthracosaurs, suggest that some individuals may have been 2 to 3 m long. The sharp labyrinthine teeth of these tetrapods were well suited for predatory piscivorous life habits. A third group is represented by a small string of vertebrae exhibiting very reptillian form; this may represent either the oldest known reptile or an as yet undetermined amphibian, possibly a lepospondyl. (Subsequent study assigns this to the proto-anthracosaur.)

Most disarticulated bone in the conglomerates and shales is well preserved and typically is unabraded, suggesting that bone transport processes were not of continuous high energy. In general, the bone-bearing conglomerates form lobate shapes that thicken towards the margin of the collapse structure and interbed with shales within the fill. Conglomerates are not continuous within the structure and are sparsest in the central area where shale dominates. The geometry of the conglomerate beds suggests origin by subaqueous flow of limestone clasts and bone from the surrounding terrain, perhaps during storm events. The dark shales, in part laminated, within the fill were deposited subaqueously in quiet water settings. There is a general increase in the abundance of articulated bone, especially strings of articulated vertebrae, toward the shale-dominated central portion of the main fill. It was in this area that a partial amphibian skeleton was collected (about 1 m long). Nevertheless, articulated material was found at other positions in the fill, including a partial skeleton with an articulated limb and foot in the east side of the fill adjacent to a large boulder. In general, the collapse structures apparently formed natural traps for the subaqueous accumulation of bone as well as whole to partial carcasses. The absence of benthic faunas and burrowers as well as the laminated nature of the sediments within the upper fill suggest that bone accumulation occurred within a stratified body of water with low-oxygen or anoxic bottom conditions.

Representative sketches of the major groups of vertebrates present in Waugh Member strata are shown in Figure 8. The fauna is aquatic, although the tetrapods 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 fresh to brackish water. 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 a common associate 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 is generally consistent with a nonmarine aquatic setting, particularly the common association of xenacanths, lungfish, rhizodonts, and tetrapods. 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.

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. Dominant lithologies in the area include vertebrate-bearing ostracod lime mudstones, in part laminated, which interbed with ostracod-and vertebrate-bearing calcareous shales, in part sandy. These strata are interpreted to have been deposited in a fresh or brackish water stratified lake or lagoon

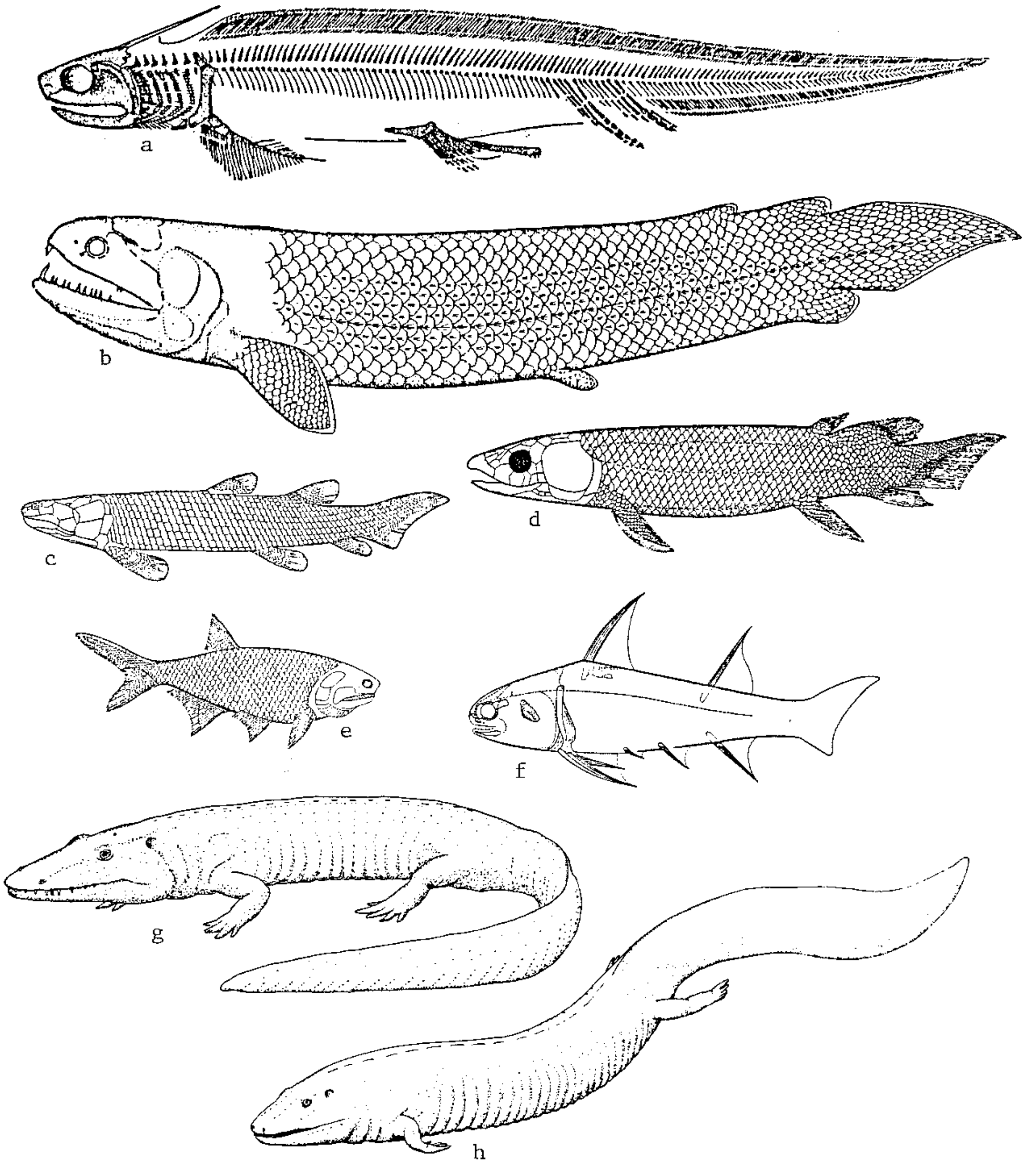


**Figure 8.** Reconstructed examples of major vertebrate groups present at Heimstra Quarry (examples of Devonian-Carboniferous forms from other Euramerican localities; a, c-f. from Moy-Thomas, 1971; b. from Andrews, 1985; g,h. from Milner, 1980). Not to scale; approximate scale of Delta fossils noted. a. xenacanth shark (*Xenacanthus*, Dev.-Trias.), 50 cm to 7 m; b. rhizodont crossopterygian, 50 cm to 5 m; c. rhipidistian crossopterygian (*Osteolepis*, Dev.), about 25 cm; d. lungfish (*Dipterus*, Dev.), about 50 cm; e. palaeoniscoid actinopterygian (*Cryphiolepis*, L. Carb.) 5-20 cm; f. climatiid acanthodian (*Diplacanthus*, Dev.), about 25 cm to 1 m; g. temnospondyl labyrinthodont (*Cochleosaurus* U. Carb), about 75 cm -2 m; g. anthracosaurian labyrinthodont (*Eogyrinus*, L.-U. Carb.), about 75 cm -2 m.

which lacked turnover or tidal exchange with the nearby seaway. Possible quasi-marine connections with these environments cannot be excluded. The contained fauna is similar in a general sense to that noted in Late Carboniferous lake and swamp deposits at Linton, Ohio, and from lacustrine deposits at Nyrany, Czechoslovakia (Milner, 1980). Late Tournaisian brackish water lacustrine sediments at Foulden, Scotland, which were deposited on a coastal plain crossed by rivers (Anderton, 1985), likewise contains a fauna similar to that at Delta (includes ostracodes, "spirorbids," coprolites, palaeoniscoids, acanthodians, sharks, rhizodonts, lungfish, and rare tetrapods). Vertical void spaces with calcite and geopetal fills, so well displayed at the Heimstra Quarry and elsewhere in Keokuk County, were formed in semilithified sediment and are interpreted to represent evidence of rooting or periodic dehydration. Periodic dessication and subaerial exposure also is indicated by the development of conglomeratic to brecciated horizons within these limestones. Therefore, it seems reasonable to suggest that lake levels fluctuated and that lake environments, at least locally, periodically dessicated.

### Scale Tree Association

The influx of clastic material (clay, silt, sand) into the interpreted lake environments was related to fluvial input, which also would tend to freshen the lake waters. Sandstone channels, apparently of fluvial origin, cut across the lacustrine limestones and shales (as at Stop 3-WBO1). Compressed logs and *Stigmaria* roots occur within some of these sandstones, indicating that scale trees grew in the adjacent terrestrial environments. The upper Waugh is marked by widespread development of coaly to carbonaceous shale, and locally the upper sandstone is extensively rooted with *Stigmaria*. This indicates that widespread swampy conditions with scale trees were developed prior to the Pella marine transgression. In general, the Waugh Member was deposited in a complex mosaic of lacustrine, fluvial, and terrestrial environments in a coastal lowland setting. Numerous minor disconformities, locally with fluvial channels and collapse structures, characterize episodes of subaerial exposure and fluvial incision in the varied environments. The contained biota of the Waugh can be interpreted within the context of these environmental interpretations.

### Why Tetrapods?

Because field trip participants will be examining one of the oldest tetrapod localities in the world, it is appropriate to briefly consider some speculations on the adaptive advantages tetrapods would have over other contemporary aquatic predators. In other words, why did tetrapods evolve? It should be pointed out from the start that we probably will never know with certainty which environmental pressures or adaptive mechanisms actually were responsible for the evolution of tetrapods from lobe-finned fish in the Late Devonian. However, the continued success and further adaptive radiation of amphibians in the Early Carboniferous indicate that whatever they were doing, they were doing it well.

The primary feature which distinguishes early tetrapods from closely related fish groups is the development of limbs (legs), an obvious advantage for terrestrial locomotion. But what advantages would increasing the ability for such locomotion provide for the early tetrapods? Because the early tetrapods, including those at Delta, were dependent on the aquatic environment for food (i.e. fish), reproduction, and development, the answer to this question is not immediately apparent. The idea that the earliest tetrapods evolved limbs to utilize terrestrial foood sources is probably incorrect. Plant-eating tetrapods, like the edaphosaurs, did not evolve until the Late Carboniferous, and terrestrial predation was apparently a later adaptation as well (terrestrial prey in the Late Devonian-Early Carboniferous included insects, arachnids, myriapods, and other amphibians). However, three other general factors may have been involved in providing advantages for the first tetrapods, as discussed below.

1) Terrestrial locomotion would enable the early tetrapods to migrate to or from ephemeral or landlocked bodies of water for feeding or reproduction. If a lake environment would dessicate, a tetrapod's advantage over fish would be obvious. Nevertheless, other fish, like lungfish (and possibly some crossopterygians), adapted to ephemeral lacustrine conditions without the benfit of limbs, so the tetrapods' solution is not the only one. If a landscape included a series of unconnected lake and/or fluvial environments,

individual tetrapods would have the potential advantage of utilizing food resources over a broader geographic range than those fish which were restricted to a single body of water. Tetrapods could munch fish in one pond and then migrate to another in their ceaseless search for food. The early tetrapods, like most modern amphibians, were restricted to aquatic environments for reproduction and larval development. Permanent bodies of water may have been poor places for the early tetrapods to lay their eggs, primarily because such places would have been inhabited by a number of predators, like xenacanths and crossopterygians. Larval survival certainly would be enhanced if an organism could lay their eggs in a body of water, probably ephemeral, which lacked large predators. In order to migrate to such a setting, terrestrial locomotion would be necessary. Many modern anurans and urodeles utilize such a reproductive strategy. Terrestrial locomotion also would be necessary when individuals reached a critical size following metamorphosis and needed to migrate to a larger body of water in search of larger prey. Of course, there's a certain circularity in all this reasoning. However, the point remains that once terrestrial locomotion was achieved, even in an ungainly way by the lobe-finned fish ancestors of the first tetrapods, numerous adaptive advantages may have played a role in further evolutionary selection for enhanced limb efficiency.

2) The ability to periodically migrate out of the water would increase the ability for an organism to regulate its body temperature, thereby influencing its metabolic rate and predatory efficiency. Compared with terrestrial environments, aquatic environments display reduced fluctuations in temperature because of the thermal inertia of the water. Basking in the sun enables ectothermic aquatic animals to increase their body temperatures over ambient water temperatures, as practiced by modern turtles and crocodilians. Nevertheless, well developed terrestrial locomotion would not be essential to achieve these goals, and lobe-finned fish which possessed "lungs" presumably were capable of emerging at the water's edge for sun basking as well. It is unclear what sorts of adaptive pressures would influence selection for enhanced limb efficiency in this scenario.

3) Finally, terrestrial locomotion would provide increased opportunity for escaping from aquatic predators. At the time of the early tetrapod radiation, nonmarine aquatic environments were inhabited by several kinds of fearsome predators, especially the xenacanths and rhizodonts. Xenacanths and rhizodonts include the largest predators at the Delta site, although the largest of the tetrapods also were impressive predators. It certainly would be an advantage to leave the water when a xenacanth or rhizodont cruised into the area, and to do so as quickly as possible. Increased limb efficiency would enhance the ability of an organism to move effectively out of the shallows of a lake or river when threatened.

**Comments on Rhizodonts**

As a final sidelight, some comments on rhizodonts seem appropriate, in part because the Delta rhizodont material is among the best preserved anywhere in the world. Rhizodonts are known from the Late Devonian through Late Carboniferous and are among the largest predators of their time. Known primarily from scales and disarticulated bones, some apparently achieved gigantic proportions. Jaws to 1 m and teeth to 20 cm are known (Moy-Thomas, 1971, p. 127), suggesting body lengths to 6 or 8 m! Rhizodonts possessed robust scaled pectoral fins supported on a well developed shoulder girdle (Delta material, also Andrews, 1985), but pelvic and dorsal fins were rudimentary (Fig. 8b). Articulated rhizodont material from Britain (ibid.) as well as the high proportion of rhizodont scales at Delta with lateral line grooves indicate an exceptional development of lateral line organs within the rhizodonts. Lateral line organs in many modern fish discharge electrical impulses and contain acoustic and electroreceptors used for "distant touch sense," that is, for interpreting the movements of water currents and objects and, in some, for electrolocation. The extreme development of lateral line organs in rhizodonts suggests that they may have had well developed electrolocation capabilities enabling them to locate prey even in murky waters (ibid.). This is all pretty wild stuff!

# PELLA STRATIGRAPHY, PALEONTOLOGY, AND CORRELATION PROBLEMS OF THE "ST. LOUIS"-PELLA INTERVAL

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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 50 ft (15 m) in the Iowa subsurface, and fossiliferous marine limestones and marls of the Pella reach thicknesses in excess of 30 ft (9 m) in the outcrop belt of 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 within the Pella non-marine limestones (lacking stenohaline marine faunas), sandstones, and carbonaceous shales below the fossiliferous limestone and marl sequence (e.g., Van Tuyl, 1925; Rexroad and Furnish, 1964; Johnson, 1967). In this report we propose to 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 eroded upper "St. Louis" surface regionally. This definition allows the Pella-"St. Louis" contact to be drawn at a consistently recognizable boundary, as underlying 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 ostracod biomicrites as a major facies at this stratigraphic position, although we have not recognized this facies in the Keokuk-Mahaska county area (contra Johnson, 1967). However, ostracod biomicrites are 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 part (about 40 cm) of the lower Pella limestone sequence, which forms prominent ledges below the marl sequence, is characterized by skeletal wackestones, in part argillaceous, with a diverse Pella 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 ostracods 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 some of the most deluxe fossil collecting to be found anywhere in the Midcontinent. A faunal list of taxa identified in the Keokuk-Mahaska county area during this study is included (Table 3), and the common fossils are sketched to aid the field trip participant in identification (Fig. 9). (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. Further study of the foraminifera are needed to aid in biostratigraphic resolution.

The age of the Pella has long remained a problem, and previous studies have variably correlated the Pella with the Ste. Genevieve (Genevievian) or lower Chesterian strata. Available evidence is reviewed here. The brachiopod fauna, while containing elements of Genevievian to Chesterian affinities (*O. kaskaskiensis, Protoniella parva, Anthracospirifer, C. sublamellosa*), includes *Pugnoides ottumwa*, a form regarded as an "index fossil" to the Ste. Genevieve by Weller (1914) and others. *P. ottumwa* is restricted generally to Ste. Genevieve strata in most Mississippi Valley sections, but it ranges downward into the St. Louis in some areas (F.J. Woodson, pers. comm., 1987). *P. ottumwa* is rare or absent in Chesterian strata, and the few reported occurrences are either misidentified or unconfined (Horowitz, 1984). Conodonts of the Pella belong to the long-ranging *Gnathodus bilineatus-Cavusgnathus charactus* Zone (see later discussion), which spans the Genevievian and early Chesterian, and hence the conodonts do not clarify whether or not the Pella is a Ste. Genevieve correlate.

Additional faunal groups have been used to suggest correlations between the Pella and the standard Mississippian sequence in Illinois-Missouri. Ostracodes of the Pella were studied by Berninghausen (1949), who noted a mixture of known Chesterian species with a number of new species. Comparisons of his fauna with that in the type area of the Ste. Genevieve is not possible at present, as the Ste. Genevieve ostracod fauna remains poorly studied. Relations of the molluscan, coral, and bryozoan faunas in the Pella are not clear, although early workers assigned the Pella bryozoans to the Ste. Genevieve (however, *Anisotrypa* and *Batostomella* are primarily Chesterian genera).

The echinoderm fauna of the Pella is diverse, but is represented primarily by disarticulated debris. Nevertheless, a number of groups are included, and Pella localities in Marion and Mahaska counties have yielded articulated specimens. Crinoid arms and basal plate circlets have been found in Keokuk County. Identified taxa include: machaeridian plates (T. Frest, pers. comm., 1987), starfish (Frest and Strimple, 1977), edrioasteroids (*Lepidodiscus laudoni*, see Bell, 1976), echinoids (*Praepholidocidaris pellaensis*, Frest and Strimple, 1977), microcrinoids (*Passalocrinus* sp., Strimple, 1974), camerate crinoids (*Camptocrinus* sp., *Hyrtanecrinus ornatus, Dichocrinus parvulus*, others; see Broadhead, 1978; Frest and Strimple, 1977; Laudon, 1973), flexible crinoids (*Taxocrinus shumardensis*), and blastoids (*Pentremites pulchellus, Diploblastus glaber*). The common blastoid in the Pella of Marion County was formerly assigned to the Meramecian species *P. conoideus* but now is classified as *P. pulchellus*, which is a late Meramecian and early Chesterian species (Waters et al., 1985). *D. glaber* (s.s.) apparently is a Genevievian species, although a closely related species, previously assigned to *D. glaber* is found in lower Chesterian strata (T. Frest, pers. comm., 1987). The scarcity of blastoids in the Keokuk County sections is noteworthy. Frest and Strimple (1977) noted the presence of the camerate

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**Figure 9.** Common fossils of the Pella Formation in Keokuk and Mahaska counties, Iowa (all approximately x 1.5).

a. *Ovatia ovata*, b. *Protoniella parva*, c. *Anthracospirifer pellaensis*, d. *Girtyella indianense*, e. *Dielasma formosum*, f. *Composita trinuclea*, g. *Pugnoides ottumwa*, h. *Orthotetes kaskaskiensis*, i. nuculanid sp., j. *Clinopistha* sp., k. crassatellacean sp., l. "*Edmondia*" sp., m. *Glossites* sp., n. *Schizodus* sp., o. *Spathella* sp., p. *Straparollus* sp. , q. *Rhineoderma* sp., r. *Anematina* sp., s. *Bellerophon* sp., t. *Euphemites* sp., u. *Neozaphrentis pellaensis*, v. crinoid stem, w. *Anisotrypa* sp., x. *Fenestella* sp., y. *Paladin wilsoni*.

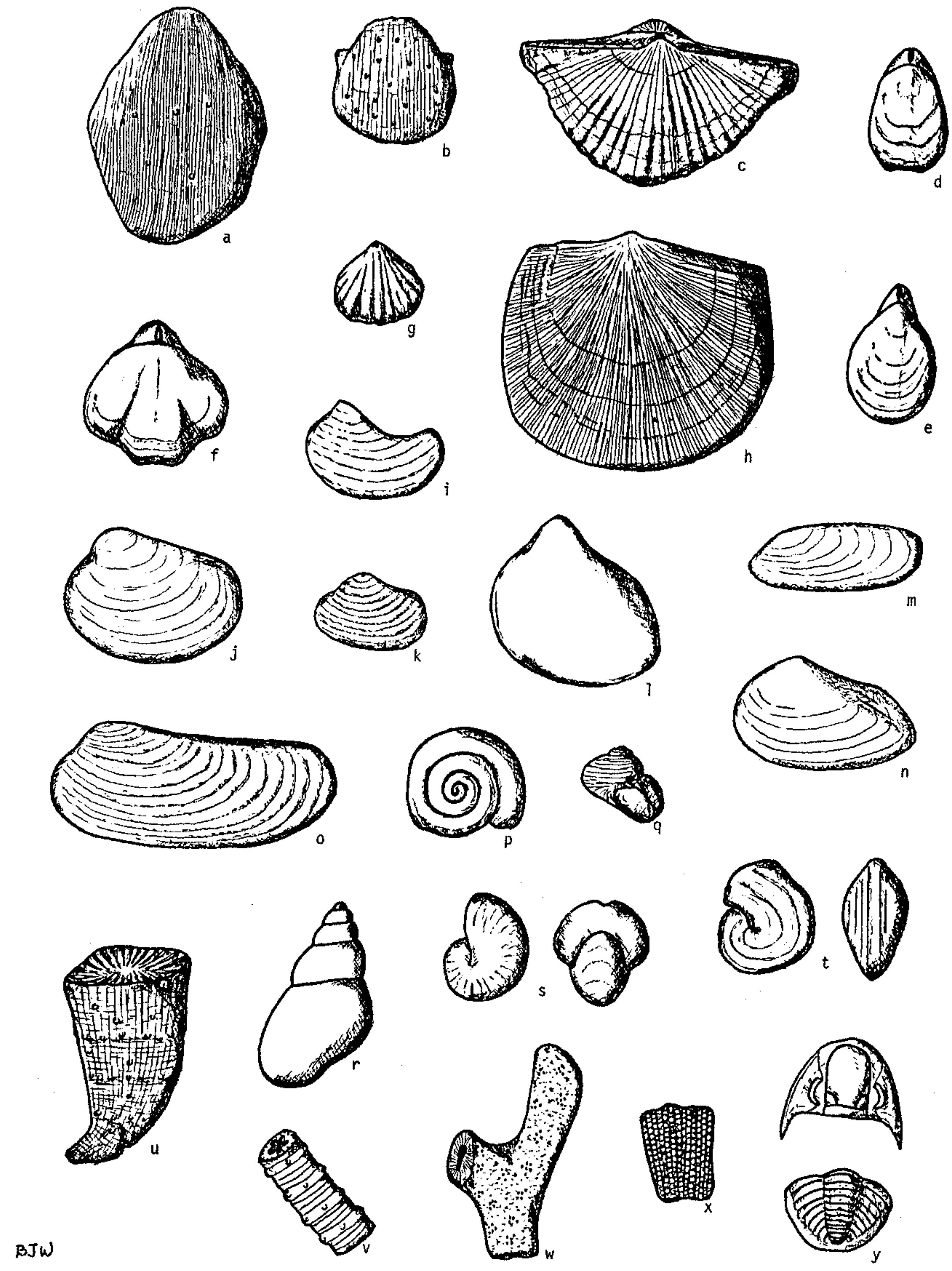
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**TABLE 3.** Fauna of the Pella Formation in Keokuk and Mahaska counties, Iowa.

**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)
- -ostracods
  - *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** (remain unstudied)

**Conodonts** (see Rexroad and Furnish, 1964)

**Vertebrates**
- bradyodontid teeth

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crinoid, *Talarocrinus*, in the Pella, suggesting a Chesterian age (the *Talarocrinus* Zone; see

Horowitz and Strimple, 1974). However, recent study by Frest (pers. comm., 1987) indicates that this crinoid is best considered a transitional form form between *Hyrtanecrinus* and *Talarocrinus* (see also Broadhead, 1978). This suggests a pre-*Talarocrinus* Zone assignment. The Ste. Genevieve of Illinois is included in the *Platycrinites penicillus* Zone, although *Platycrinites* has not been noted in the Pella even by its distinctive stems and columnals.

Available faunal evidence seems to favor a Genevievian correlation for the Pella, but a Genevievian or early Chesterian assignment can neither be confirmed or refuted with present data. Future study of the calcareous foraminifera offers the best hope for further biostratigraphic resolution. Because Pella and upper "St. Louis" correlations are not well established, several possible correlations with the Illinios section will be discussed (Fig. 10). The following possibilities are shown (Fig. 10): A. Pella is early Chesterian, Verdi is Genevievian; B. Pella and Verdi are Genevievian; C. Pella is Genevievian, Verdi is of St. Louis age. Cases A and B require that Croton strata correlate with the St. Louis of Illinois. However, the disconformity between the Ste.

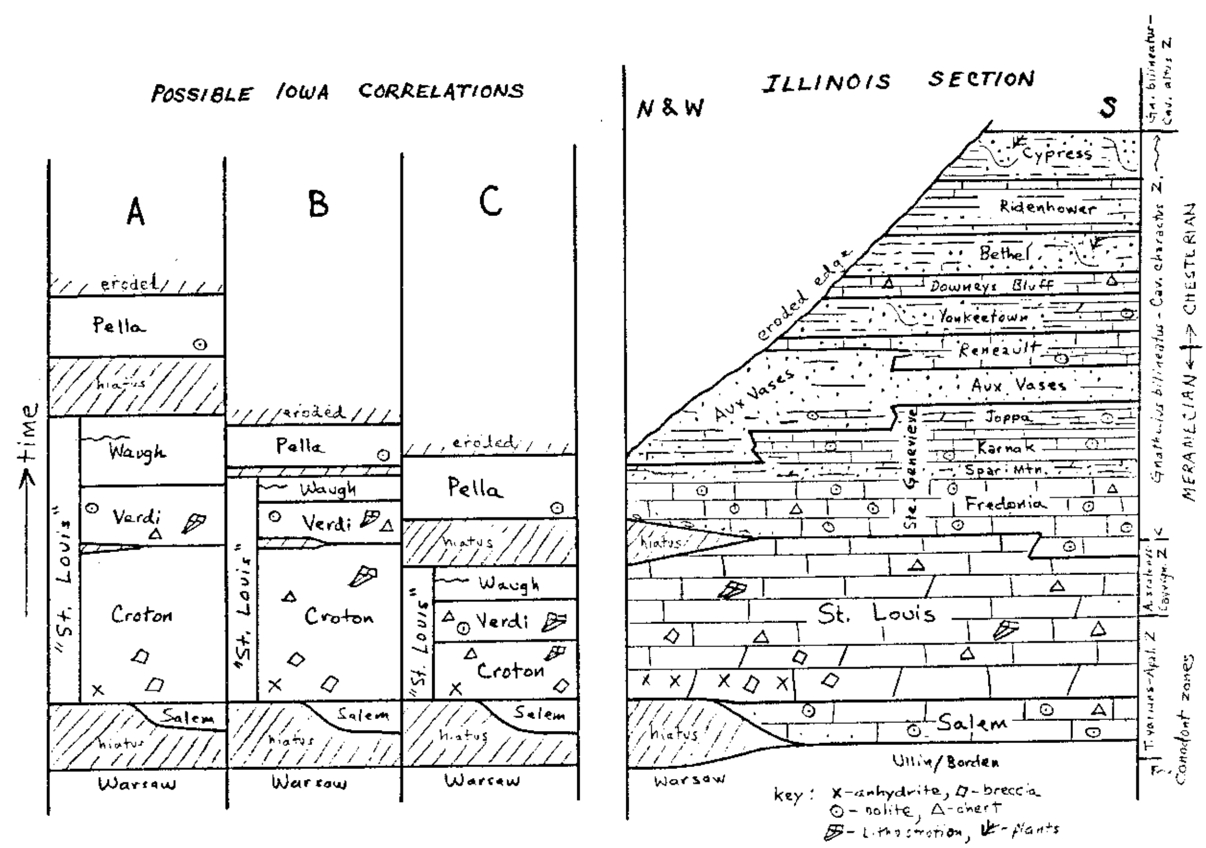


**Figure 10.** Possible correlations of post-Warsaw strata in Iowa with the standard Illinois section.

Genevieve and St. Louis recognized in parts of Illinois, if present at all in Iowa, would need to be placed between the Verdi and Croton in cases A and B, but there is no evidence for an erosional surface at that position. In case C, this disconformity is represented by sub-Pella erosion of the "St. Louis" in Iowa.

If the Pella is Chesterian, as in case A (Fig. 10), then the Pella would presumably correlate to one or more of the cyclothemic Chesterian marine limestone/shale units (upper Reneault, Downeys Bluff, upper and lower Ridenhower) of the *Gnathodus bilineatus-Cavusgnathus character* Zone in the Illinois Basin. These marine units all thin to less than 3 m in thickness at their northern extremity in Illinois (Atherton et al., 1975), whereas truncated Pella marine strata in Iowa are up to 10 to 15 m thick. It is difficult to envision how the Pella, which apparently represents part of a single cycle of marine deposition, could represent a northward thickening of Chesterian marine units from the Illinois Basin. This would run contrary to all known Mississippian isopachous patterns between Illinois and Iowa. However, the northward thinning Ste. Genevieve marine strata in Illinois, from 120 m in the south to less than 25 m thick at its western and northern margin (ibid.), seems most consistent with a correlation of Pella and Ste. Genevieve strata.

The "St. Louis" sequence of Iowa seems to correlate most reasonably with the St. Louis Formation of Illinois-Missouri. The Croton of Iowa and the lower St. Louis of Illinois both include evaporites and solution-collapse breccias. In addition, the colonial rugosans, *Acrocyathus proliferus* and *A. f. floriformis* (*Lithostrotion proliferum* and *L. canadense*, respectively, of earlier workers), which are considered St. Louis index fossils, are noted in the upper Croton and Verdi of Iowa (VanTuyl, 1925; taxonomy after Sando, 1983).

The varied lines of lithostratigraphic and biostratigraphic evidence most strongly support case C (Fig. 10), namely that the Pella is a Ste. Genevieve correlate and the "St. Louis" of Iowa is a distinct formation equivalent to type St. Louis strata. Although we favor case C (Fig. 10), we cannot, as yet, exclude cases A or B or other possible solutions to the correlation problems.

# CALCAREOUS MICROFOSSILS FROM THE "ST. LOUIS" FORMATION, KEOKUK COUNTY, IOWA

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Previous studies of calcareous microfossils (Foraminifera, algae, and organisms of uncertain biologic affinity) from Mississippian strata in Iowa have focused on Kinderhookian and Osagean rock units. In a groundbreaking study, Zeller (1950) illustrated foraminifers from the Kinderhookian Gilmore City Formation at Gilmore City, from the late Osagean Keokuk Limestone near Montrose, and purportedly from the Humboldt Oolite at Humboldt. Additionally he collected, but found barren, samples from the Chapin [Starrs Cave] and a lower oolitic zone [basal McCraney], both Kinderhookian and both at Burlington. Baxter and Brenckle (1982) briefly described assemblages from Gilmore City and Humboldt, Iowa. Brenckle and Groves (1987) illustrated and discussed the diverse, biostratigraphically important early Osagean microfossil assemblage from Humboldt. Johnson (1967) and Johnson and Vondra (1969) incidentally noted the presence of endothyrids in the Pella Formation of southeast Iowa. This report, then, represents the first description of post-Keokuk, pre-Pella calcareous microfossils from Iowa.

The calcareous microbiota reported herein is derived exclusively from the 1.5 m lower marine limestone in the Verdi Member of the "St. Louis" Formation at Heimstra Quarry (SW, SW, Sec. 15, T75N, R13W) and at nearby exposures (K8-4 and K8-1, Fig. 2, this guidebook). Samples collected by R. McKay and B. Witzke represent 5 stratigraphic intervals, including the basal and uppermost portions, within this unit at Heimstra Quarry and 2 intervals from the nearby sections. Sixty-four 1" x 3" thin sections, 47 from Heimstra Quarry, were prepared and studied. Over 150 photomicrographs were taken to document the assemblage.

The following calcareous microfossils were identified:

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.

The microbiota is dominated by abundant *Endothyra, Endostaffella, E. discoidea*, and encrusting foraminifers. Many of the taxa are relatively long ranging. Association of rare archaediscids with abundant calcispheres, encrusting foraminifers, and terrigenous detritus in wackestone to packstone lithologies suggests a slightly restricted, lagoonal marine environment. The absence of *Eoendothyranopsis, Eoforschia, Globoendothyra*, and the dasycladacean alga *Koninckopora*--common taxa in the St. Louis Limestone--might be explained by environmental restriction or, alternatively, by their extinction at or near the St. Louis-Ste. Genevieve contact in the type Mississippian.

Baxter and Brenckle (1982, fig. 3) depict ranges based on collections made in the St. Louis and Ste. Genevieve areas. Encrusting foraminifers (calcitornellids, calcivertellids) first occur in uppermost St. Louis Limestone but begin to proliferate in the overlying Ste. Genevieve, where they occur with *Endostaffella discoidea* (ibid., fig. 3, p. 142-143). Baxter and Brenckle place the first occurrence of *Endostaffella discoidea* (Girty, 1915) within the Ste. Genevieve Limestone but query the lower limit of the range and opine (p. 143) that the taxon "probably originates in the underlying St. Louis." Based on study of a core from north-central Tennessee, Mamet (in Horowitz et al., 1979, p. 224, 226-7), finds *E. discoidea* commencing well above highest *Eoendothyranopsis* and *Koninckopora*--taxa believed to extend no higher than uppermost St. Louis (Pohl, 1970; Baxter, 1977; Baxter and Brenckle, 1982). Rich (1980, Table 1), using outcrop collections mainly from northeast Alabama and south-central Tennessee, places the first occurrence of *E. discoidea* with latest *Koninckopora* in Mamet zone 16i, above *Eoendothyranopsis* in zone 15.

In the North American Cordillera, *E. discoidea* is depicted as occurring with *Eoendothyranopsis* (Mamet and Mason, 1968, fig. 5), with *Koninckopora* (Petryk et al., 1970, fig. 4; Mamet and Gabrielse, 1969, fig. 6), or with both (Mamet, 1970, fig. 3; Mamet *in* Sando et al., 1969, fig. 5). However, in each of these Cordilleran zonal occurrences at least one of the critical taxa is listed as "scarce" or "doubtful." For example, in the Etherington Formation "common" *E. discoidea* occurs in the same zone (16i) with "scarce" *Eoendothyranopsis* and "doubtful" *Koninckopora* (Mamet, 1970, fig. 3). In summary, the first occurrence of *Endostaffella discoidea* in North America is uncertain, but it is apparently no lower than St. Louis and no higher than lower Ste. Genevieve and their temporal equivalents.

The upper age of the lower marine limestone is limited by the last occurrence of *E. discoidea*, which in the Midcontinent is in equivalents of the latest Chesterian Kinkaid Limestone (Baxter and Brenckle, 1982, fig. 6) but in the Cordillera occurs in Atokan (Middle Pennsylvanian) strata (Armstrong and Mament, 1977, pl. 43). However, the absence of Morrowan and Atokan rocks in Iowa (Avcin and Koch, 1979) locally restricts the last occurrence of *E. discoidea* to the Mississippian. Baxter and Brenckle (1982, p. 143) note that "*Millerella*" first occurs in the Glen Dean Limestone, where *Eostaffella* begins to proliferate. The absence of these taxa, which--unlike the archaediscids-- are morphologically similar to *Endostaffella*, is perhaps more plausibly attributed to a pre-Glen Dean age for the fauna than to an inhospitable environment.

Clearly the precise age of the lower marine unit in the Verdi Member of the Iowa "St. Louis" is subject to interpretation. If encrusting foraminifers appeared simultaneously in southeast Iowa and in the vicinity of St. Louis and Ste. Genevieve, then the microbiota of the lower marine limestone can be no older than uppermost St. Louis Limestone (latest Meramecian). An upper age limit is governed by the last occurrence of *E. discoidea*, which in Iowa can be no younger than upper Pella Formation. The presence of abundant endostaffellids (including *E. discoidea*) and abundant encrusting foraminifers, in conjunction with the conspicuous absence of typical St. Louis genera such as *Eoendothyranopsis, Eoforschia, Koninckopora,* and *Globoendothyra*, strongly suggests, but does not prove, that the microbiota is Chesterian in affinity and is correlative with the early Chesterian Ste. Genevieve Limestone or younger strata in the Mississippi River Valley. Future study of calcareous microfossils from the Pella Formation, which overlies the "St. Louis," may further constrain the age of the Heimstra vertebrate deposit.

# STIGMARIAN ROOT FOSSILS FROM THE UPPER ST. LOUIS FORMATION
## With Specific Reference To The Kessel Property Outcrops (STOP 2)

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### Stigmarian Sandstone Unit

Although the *Stigmaria* root fossils found at this sandstone outcrop are not as spectacular as those from the well known "Fossil Grove" in Victoria Park, Glasgow nor as extensive as the stigmarian beds on Cape Breton Island, Nova Scotia, they rank among the oldest and most impressive that have been reported from the North American midcontinent.

### Structure and Taxonomic Assignment

The generic name, *Stigmaria*, has long been applied to the dichotomously branched underground portions of Carboniferous age scale trees. As shown in Figure llA, the scale tree trunk was supported on widely spreading underground branches or rhizophores. These rhizophores branched dichotomously and bore small spirally arranged rootlets. On the older (more proximal) portions of the rhizophores, the rootlets abscised leaving small circular depressions with raised centers. Stigmarian type underground structures are known to have been produced by a variety of different kinds of scale trees including *Lepidodendron, Lepidophloios,* and *Sigillaria*. Most Pennsylvanian age stigmarian fossils have been assigned to *Stigmaria ficoides* (see Fig. llB). Preliminary observation of specimens from this locality suggest that they differ from typical *Stigmaria ficoides* specimens in the following respects:

- they consistently have smaller diameters and exhibit more pronounced tapering
- the dichotomies appear to be more closely spaced
- the rootlet scars have a more pronounced raised central area.

Previous studies of well-preserved petrified *Stigmaria* specimens (Frankenberg and Eggert, 1969) have shown that the rhizophores and rootlets possessed large central cavities or "air chambers." Additional observations by Gastaldo (1986) indicate that further hollowing out of the trunk and stigmarian rhizophores frequently occurred after the death of a scale tree due to the more rapid decay of the softer internal cortical and pith tissues. Internal cavities or "air chambers" are known to have occurred in the underground organs of numerous other coal age plants (i.e. marattialean ferns, seed ferns, calamites, and cordaites) and are presumed to represent adaptations to growth in an extremely wet, swampy environment.

### Paleoecological Interpretation

Numerous *Stigmaria* specimens can be seen by examining the lower surface of the sandstone bed exposed in the overhanging creek bank and on overturned sandstone blocks in the creek bed. Several of the specimens exhibit intact dichotomous branching and attached radiating rootlets. Such examples, along with sand filled specimens in the underclay, strongly suggest an autochthonous, in situ origin. (See Ferguson, 1970, for a thorough discussion of autochthonous versus allochthonous origin of *Stigmaria* specimens.) The abundance of fossil rhizophores at the sandstone-underclay contact suggests that a fairly dense population of scale trees existed at the site. These plants had horizontally oriented stigmarian rhizophores shallowly buried in alluvial clay (paleosol) or in a thin layer of peat. However, it is unlikely that there was much peat at this site as there is no present evidence of a coal or extensive carbonaceous material at the sandstone-underclay contact. The eventual flooding of the area and accompanying rapid influx of sandy sediment buried the scale tree swamp and filled in already dead and hollow rhizophores and rootlets. Preliminary observations

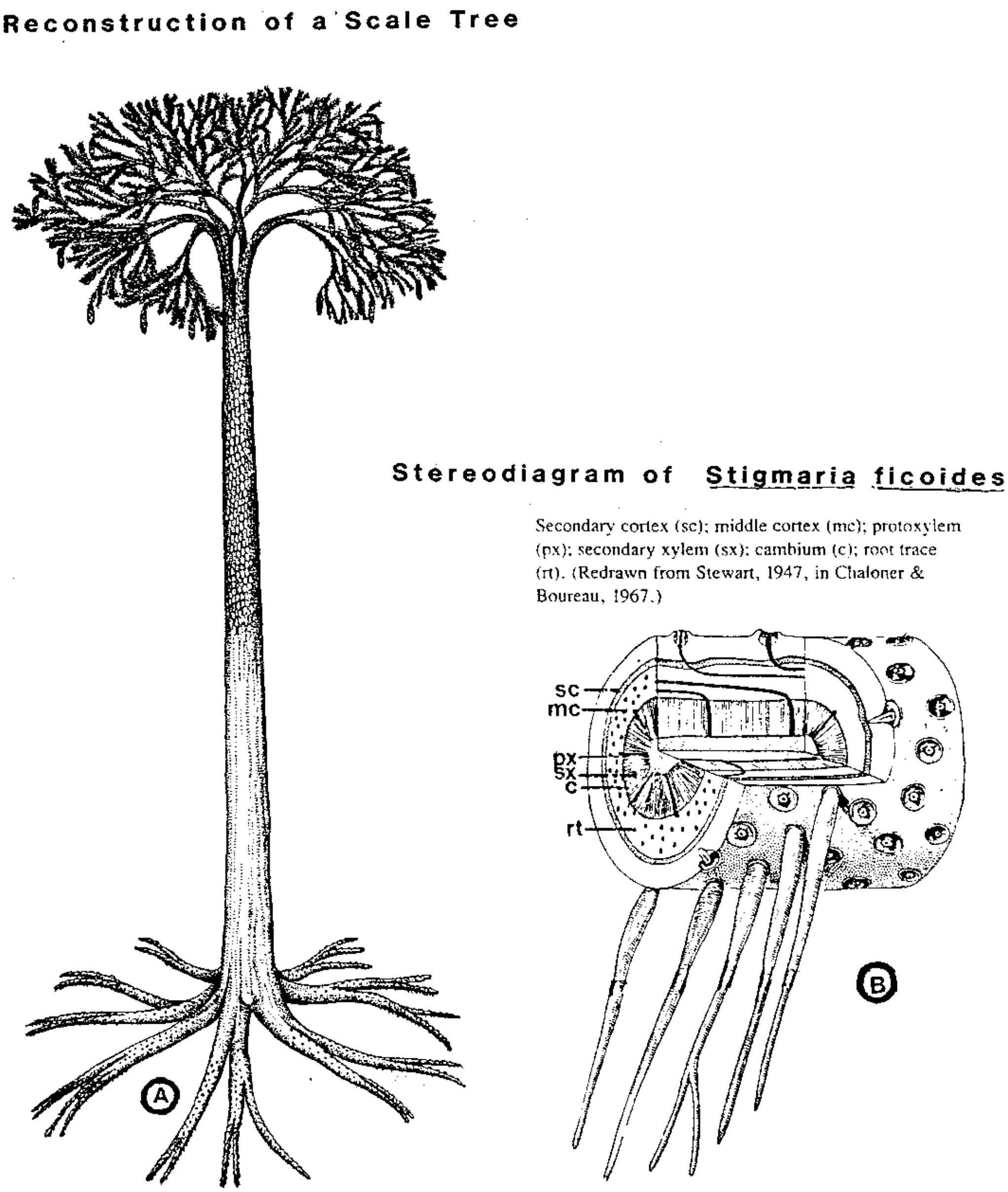


**Figure 11.** A. Reconstruction of a Carboniferous Scale Tree. B. Sterodiagram of *Stigmaria ficoides*.

of the distinctive texture found on the lower surface of the sandstone bed suggests that it represents an impression or imprint of the swamp surface and that the reticulate appearance was due at least in part to the crisscross network of abundant stigmarian rootlets.

# QUATERNARY DEPOSITS EXPOSED AT THE DELTA QUARRY

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The Mississippian-age rocks at the Heimstra Quarry are buried by a relatively thin sequence of Quaternary deposits including Pre-Illinoian till and related sand and gravel, pre-Wisconsinan pedisediment, and Wisconsinan loess. These units are best exposed in rills developed on the southern quarry wall east of the excavation area. The quarry is developed on the northern portion of a tertiary divide and the described section is in the summit position of the modern landscape (Fig. 12). From the bedrock surface upward the section is:

0 - 3.65 m (0 - 12 ft) mottled, jointed, oxidized, unleached loamy Pre-Illinoian glacial till. This unit is yellowish brown (10YR5/4) and exibits common subvertical joints along which secondary iron and manganese accumulation has occurred. Secondary carbonate accumulations are also evident along some of the joints. Discontinuous pockets of iron-cemented medium to fine gravel are present at the till/rock contact. The clay mineral assemblage of this till (56 percent expandables; 16 percent illite; 28 percent kaolinite plus chlorite) indicates that this is one of the Wolf Creek Formation tills documented throughout Iowa and adjacent portions of Illinois (Hallberg, 1980).

3.65 - 4.25 m (12 - 14 ft) mottled, jointed, oxidized and leached loam and sandy loam Pre-Illinoian glacial till. This part of the weathering profile in till is also yellowish brown and contains subvertical joints along which secondary iron and manganese accumulations are present. This part of the section is quite variable and complex mottling patterns are present. Several large sand bodies are present and influence the mottling patterns.

4.25 - 6.04 m (14 - 19.9 ft) Late Sangamon Soil (LSP) developed in Pre-Illinoian glacial till. The paleosol is evident as a reddish brown band across the exposure. The paleosol consists of heavy loam to clay loam texture Bt and Btg soil horizons where soil structure has developed and secondary accumulations of clay, iron, and manganese occur. This soil developed into the Pre-Illinoian till sometime during the long interval between deposition of the till (prior to 500,000 years ago) and burial of the LSP by Wisconsinan deposits (before about 30,000 years ago). The lower boundary of the paleosol is gradual while the upper contact is abrupt and marked by a stone line or lag gravel one to three stones in thickness across the apex of the ridge. The stone line originated as a lag deposit during cutting of an erosion surface on the LSP. Moving off the summit position the LSP decends toward the drainageway on the west side of the quarry. In this area the LSP is thicker than on the summit and is developed in loamy alluvium. The stone line on top of the LSP becomes very diffuse as the paleoslope decends into the drainageway.

6.04 - 6.19 m (19.9 - 20.5 ft) Farmdale Soil developed in Wisconsinan Roxana Formation pedisediment (slope deposits). This deposit and the soil developed in it is dark yellowish brown to yellowish brown and loam texture. The pedisediment was eroded from till up-slope and deposited by slopewash activity. During and following deposition of the pedisediment the deposit was modified by pedogensis and E and EB soil horizons developed. These horizons are ones of net loss of clay and iron compounds by leaching. These compounds accumulated in the Bt horizon of the underlying LSP. Mottles, small manganese nodules, and charcoal flecks are common within the Farmdale Soil. Pedogenic processes associated with the Farmdale Soil, such as leaching and translocation of clay and other compounds, were overprinted onto the underlying LSP during development of the Farmdale Soil.

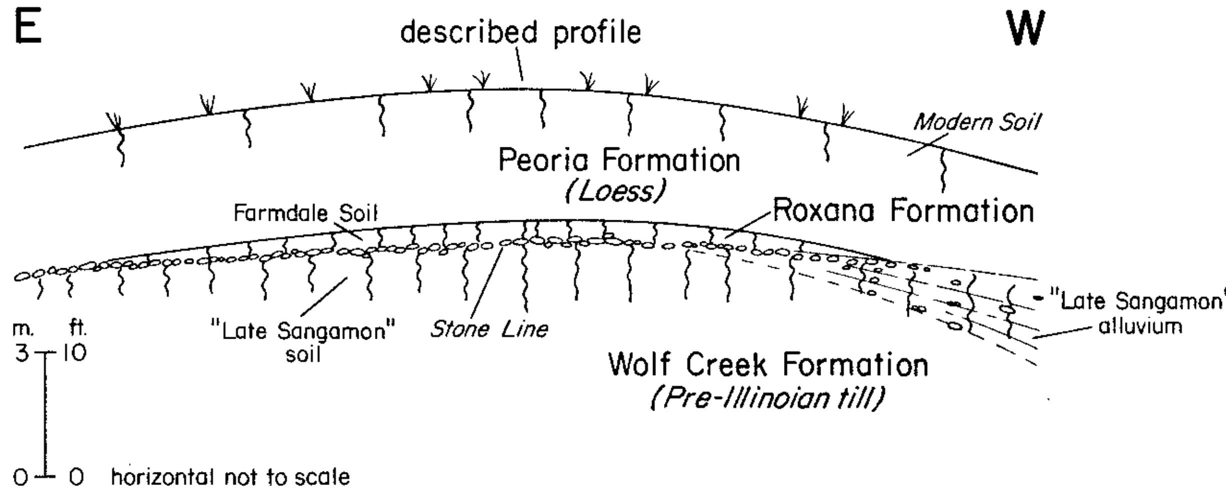


**Figure 12.** Quaternary section at the Heimstra Quarry.

6.19 - 8.02 m (20.5 - 26.5 ft) mottled, deoxidized and leached to mottled oxidized and leached late Wisconsinan Peoria Loess (Peoria Formation in Fig. 12). This unit is grayish brown to brown windblown silt loam. Gray and yellowish brown mottles and streaks indicative of fluctuating water table conditions are present in this unit. Regionally this unit began to accumulate between about 25,000 and 12,500 years ago.

8.02 - 9.23 m (26.5 - 29.5 ft) Modern soil developed in Peoria Loess. This soil is an Afisol which developed under forest vegetation. It has an E horizon from which clay and iron compounds have been leached and an underlying clayey Bt horizon where these compounds have accumulated.

## Discussion

The sequence of Quaternary materials and soils exposed at the Heimstra Quarry are typical for this portion of the Southern Iowa Drift Plain. Several erosional unconformities are present. These unconformities were produced by various combinations of glacial, fluvial, and slope erosion. Slope erosion prior to and during development of the LSP resulted in the accumulation of "Late-Sangamon" alluvium along the drainageway on the quarry's western boarder. Where this old alluvium crops out on the modern landscape the Keswick Soil Series has developed in the old alluvium (Jones and Highland, 1971). The erosion which produced the "Late-Sangamon" alluvium was part of a complex series of stepped erosion surfaces which developed during the last hundred thousand or so years in Iowa. These episodes of erosion produced the stepped landscape typical of southern and eastern Iowa (Bettis et al., 1984). The pre-late Wisconsinan erosion surfaces and the soils developed on the paleolandscape were buried by Peoria Loess between about 25,000 and 12,500 years ago. Since that time, the landscape has continued to evolve and some of these older materials and soils have been exhumed by slope and stream erosion on the present landscape.

## ACKNOWLEDGMENTS

We wish to thank the following landowners in the Delta-Hedrick area for permission to access their properties during this field trip: Mr. Harvey Smith (Showman Station), Mr. Clyde Kessel (Kessel Properties), Mr. Richard Gambell (Waugh Branch, Taylor Quarry), and Mr. Jasper Heimstra (Heimstra Ouarry). We also wish to thank Mary Pat Heitman (IGSB) for typing the guidebook, and Patricia Lohman and Kay Irelan (IDNR) for drafting most of the illustrations. Bill Bunker (IGSB) reviewed the entire guidebook and Paul L. Brenckle (AMOCO Production Co.) assisted in calcareous microfossil identifications. Our thanks are also extended to John Bolt (Field Museum of Natural History) who secured funding for the 1986 excavation. We also wish to thank Gilbert Klapper, University of Iowa, for assistance with conodont identifications.

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# STOP DESCRIPTIONS AND DISCUSSIONS

# KEY

- limestone
- G grainstone
- P packstone
- W wackestone
- M mudstone
- sandstone
- siltstone
- shale
- conglomerate
- conglomeritic
- argillaceous
- sandy
- calcareous
- brecciated
- chert
- ooids
- coated grains
- limestone lithoclasts
- dessication cracks
- R rubbly, possible rooting
- nodules
- g glauconite

- f fractures and microfractures calcite and sediment filled
- vertical calcite void fill
- styolites
- ct calcite spar filled tubules
- cv calcite spar filled vugs
- laminated
- large-scale tabular x-strata
- large-scale trough x-strata
- planar lamination
- low angle x-strata
- 270° ← TA/13° trough axis azimuth and foreset inclination
- 180° ← F/26° azimuth of maximum foreset dip direction and inclination
- shelly marine fauna
- T tabulate corals
- conodonts
- echinoderms
- brachiopods
- bivalves
- ostracodes
- gastropods
- foraminifera
- solitary rugose corals
- trilobites
- bryozoans
- coprolites
- fish teeth, scale or bone
- B bone
- *Stigmaria* root casts
- bioturbated
- plant fossils

## STOP 1 - SHOWMAN STATION QUARRY AND RAILROAD CUT (SSQ & SSRRC);

section measured by R. McKay, B. Witzke, and M.P. McAdams, 1986.

**LOCATION** - N 1/2, NE, NW, Section 13, T74N, R13W, Keokuk County. Basal 5 meters of section exposed in railroad cut along the abandoned Chicago, Milwaukee, St. Paul and Pacific line. Remainder of section exposed in abandoned quarry above railroad cut. Elevation at base of railroad cut section is approximately 686'.

### PELLA FORMATION

#### UNIT 27

Limestone, light brown gray, brachiopod packstone, whole to abraded grains, bioturbated, some whole shells with calcite spar fillings; 20 cm.

#### UNIT 26

Limestone, light brown gray, brachiopod wackestone-packstone, whole and abraded grains, geopetal fills in brachiopods, bioturbated; 17 cm.

#### UNIT 25

Limestone, light brown gray, brachiopod wackestone, whole shells, geopetal spar fills, quartz sandy; 13 cm.

#### UNIT 24

Limestone, light gray brown, skeletal wackestone, whole shells in part, clams, brachiopods, ostracodes, bioturbated, quartz sandy; 8 cm.

### ST. LOUIS FORMATION
### WAUGH MEMBER

#### UNIT 23

Sandstone, quartzose, fine-medium, calcareous, shaley and silty in upper 10 cm, very argillaceous in lower half, limestone lithoclasts to 1 cm scattered throughout, *Stigmaria* root casts; 51 cm.

#### UNIT 22

Shale, light gray green, blocky, non-laminated, fine-coarse quartz sandy, calcareous, limestone lithoclasts with white chalky outer surface to 1.5 cm, slighty pyritic, sparse fish teeth and scales; 94 cm.

#### UNIT 21

Shale, light green, blocky, non-laminated, calcareous in part, silty to very fine to coarse quartz sandy, and sand size limestone lithoclasts; two zones of lime mudstone nodules, one 20 cm thick and near base, other 20 cm thick and near middle; nodules, light gray, mudstone, slightly sandy, argillaceous, brecciated to conglomeratic in part with calcite spar filled microfractures, minor shark dermal denticles, fish teeth and scale; 1.32 m.

#### UNIT 20

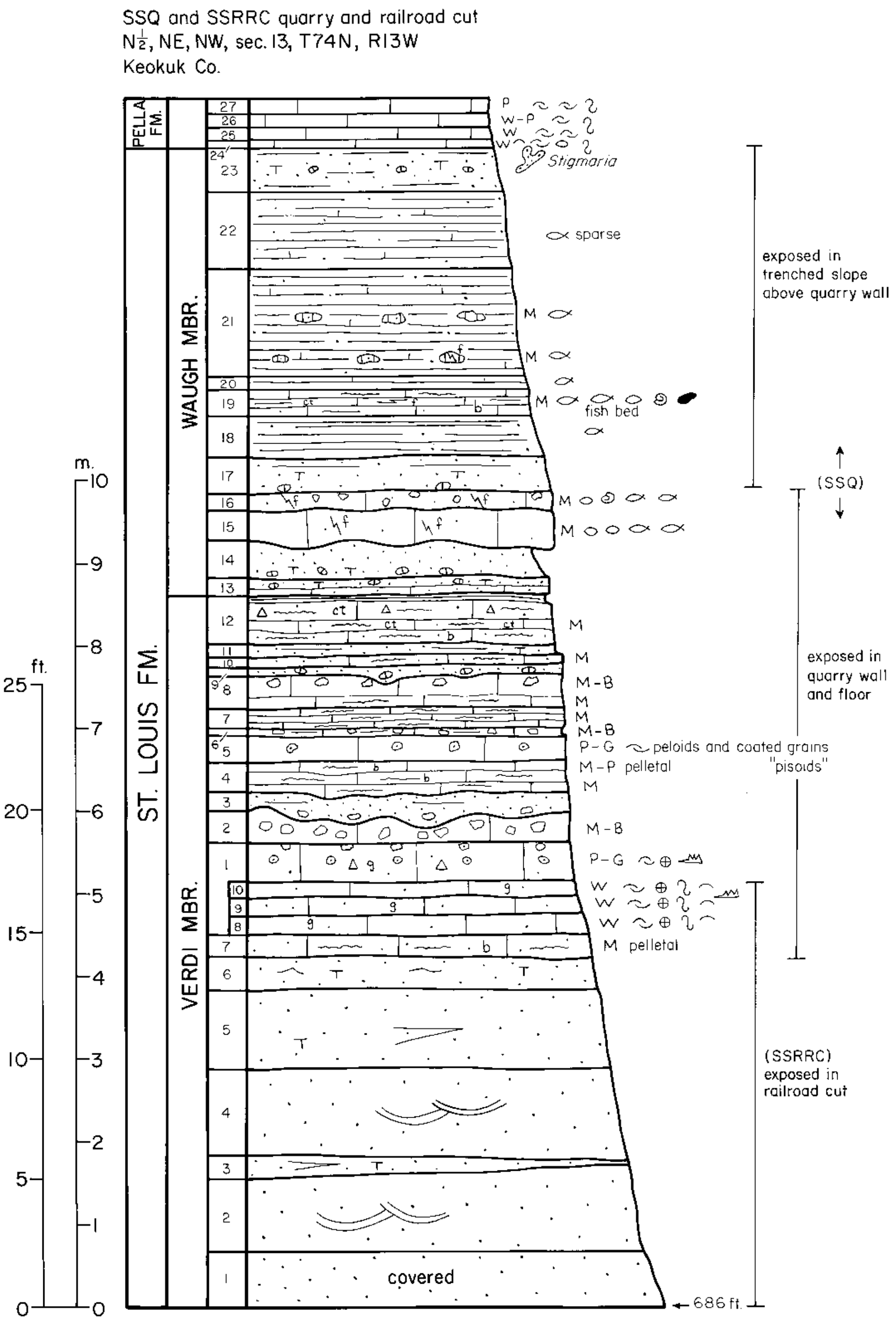
Shale, green gray to orange mottled, well laminated, trace small phosphatic coprolites; 15 cm.

#### UNIT 19

Limestone, light gray, mudstone, laminated, birdseye to calcite spar filled microfractures and tubules abundant, ostracodes, small "spirorbid" snails, abundant fish scales, denticles, and teeth, rare *Rhizodont* scales, scale bearing coprolites; 20-30 cm.

#### UNIT 18

Shale, light green-orange tan, mottled, oxidized, blocky, silty- to very fine-coarse quartz sandy, trace amount fish debris; 50 cm.




**STOP 1.** Showman Station Quarry and Railroad Cut. Base of Verdi should be placed at top of Unit 6. Units 1-6, railroad cut, are Croton Member.

**UNIT 17**
Sandstone, light green, quartzose, very fine-medium, friable to partly calcite cemented, argillaceous especially in upper part, limestone lithoclasts near base; 44 cm.

**UNIT 16**
Limestone, light medium gray, mudstone, conglomeratic to brecciated in upper part, extensively fractured to microfractured with calcite spar fills and clast fills, ostacodes, "spirorbid" snails, common fish scales, teeth, denticles; 22 cm.

**UNIT 15**
Limestone, light gray, mudstone, dense, abundant ostracodes, large calcite spar and kaolin filled voids, voids 1-5 mm wide by 1-5 cm long, calcite spar filled microfractures also common, fish debris common, undulatory knobby basal contact, uneven upper contact; 32-38 cm.

**UNIT 14**
Sandstone, very light gray, fine-medium, quartzose, calcareous, cemented in lower part, friable and argillaceous in upper 15 cm forming reentrant, clay and limstone lithoclasts to 2 cm especially near base; 37-44 cm.

**UNIT 13**
Limestone, in lower bed, very light grey, dense, mudstone, nonlaminated, nonfossiliferous, sandy, brecciated top; overlain by sandstone, fine-medium, with lime mudstone lithoclasts to 2 cm, calcareous; 19 cm.

**VERDI MEMBER**

**UNIT 12**
Limestone, in 4 beds with thin 3-5 cm calcareous shale at top; from base up, bed A, limestone, mudstone, dense, faint laminae, sandy, birdseye (3 cm); B, limestone, light gray, dense, mudstone, sandy-very sandy, upper 1 cm brecciated, possible coated grains, shaley parting at top, laminated, sandy, birdseye (8 cm); C, limestone, very light gray, dense, mudstone, faint horizontal laminations, spar filled calcite tubules 1-2 mm wide by 1 cm long, (13 cm); D, limestone, light gray, dense, mudstone, slightly sandy, laminated, discontinuous white chert nodules up to 2 cm thick and up to .5 m wide, chert occurs 10 cm below top, (24 cm); 51 cm.

**UNIT 11**
Sandstone, light greenish, very fine-fine, argillaceous-shaley, calcareous, forms reentrant; 15 cm.

**UNIT 10**
Limestone, light medium gray, dense, mudstone, sandy, laminated, wavy basal contact; 5-9 cm.

**UNIT 9**
Sandstone, light tan, quartzose, fine-medium, cuts into limestone bed below, contains limestone lithoclasts; 3-10 cm.

**UNIT 8**
Limestone, in two beds, light gray, dense, mudstone, laminated in lower 15 cm, upper part mudstone, brecciated, clasts 1 mm - 3 cm, uneven upper contact, possible small scale karst depression on top filled with overlying sandstone; 42 cm.

**UNIT 7**
Limestone, thin beds in 8 beds, light gray, dense, mudstone, laminated, styolitic contacts; 26 cm.

**UNIT 6**
Limestone, light gray, brecciated mudstone, argillaceous, thin reentrant former; 3 cm.

**UNIT 5**
Limestone, light gray, pelletal to peloidal packstone-grainstone, coated grains "pisoids," abraded brachiopod grains; 24-33 cm.

**UNIT 4**
Limestone, light gray, dense, thin bedded, mudstone at base, laminated, sandy, birdseye; upper part laminated pelletal mudstone-packstone, birdseye to intergranular spar cement; 37-40 cm.

**UNIT 3**
Sandstone, light gray-light tan, very fine-medium, quartzose, calcareous, limestone lithoclasts from underlying bed up to 5 mm concentrated near base, argillaceous in upper few cms, 10-15 cm relief on upper contact, forms slight reentrant; 20-40 cm.

**UNIT 2**
Limestone, light gray, brecciated mudstone, overlying sandstone infiltrated between clasts, clasts 5 mm - 2 cm, light tan interclast clay also present; 15-42 cm.

**UNIT 1**
Limestone, in three subunits; at base A, light gray, dense, medium bedded (21 cm), bioturbated skeletal wackestone, echinoderms, brachiopods, clams, sparse glauconite; B, skeletal wackestone, bioturbated, echinoderms, brachiopods, clams, conodonts, slightly sandy, pelletal in upper 10 cm (19 cm); C, light gray, pelletal/peloidal to ooid packstone-grainstone in basal 40 cm, brachiopods, echinoderms, conodonts, light gray to darker gray chert at 40 cm above base, upper 4-7 cm intraclastic to brecciated and grades to brecciated mudstone of unit 2 (47 cm); 87 cm.

Quarry floor has approximately 1 meter of relief. Floor is composed mainly of skeletal wackestone of lower unit 1 and lessor amount of birdseye mudstone (unit 7 railroad cut section). Sandstone dikes, from unit 6 railroad cut section, intrude up into limestone and are present over part of the quarry floor. Sandstone dikes generally 5 mm -6 cm wide. Central mound of sandstone 7.5 m in diameter intrudes skeletal wackestones. Much of quarry floor covered with network of small v-shaped ridges oriented in several directions. Ridges have about 5 mm-1 cm relief.

## RAILROAD CUT SECTION

### VERDI MEMBER

**UNIT 10**
Limestone, light gray, fine grained skeletal wackestone, bioturbated, brachiopods, echinoderms, clams, pellets-peloids, trace glauconite, slightly sandy; 8 cm.

**UNIT 9**
Limestone, light gray, fine-grained skeletal wackestone, brachiopods, echinoderms, clams, conodonts, fine-coarse quartz sandy, bioturbated, glauconite void fillings; 12 cm.

**UNIT 8**
Limestone, light gray, fine grained skeletal wackestone, echinoderms, brachipods, clams, bioturbated, quartz sandy, pelletal-peloidal; 20 cm.

**UNIT 7**
Limestone, light gray, mudstone, discontinuous laminae, pelletal, sandy, birdseye; 21 cm.

### CROTON MEMBER

**UNIT 6**
Sandstone, quartzose, fine-coarse, calcareous, thin wavy to horizontal laminae, possible small scale ripple lamination; 40 cm.

**UNIT 5**
Sandstone, one thick bed, very fine-medium, case hardened, friable, quartzose, large-scale low angle cross-stratification dipping to north; 97 cm.

**UNIT 4**
Sandstone, quartzose, very fine-fine in lower part, fine-coarse in upper third, case hardened, friable, possible large-scale trough cross-stratification; 1.04 m.

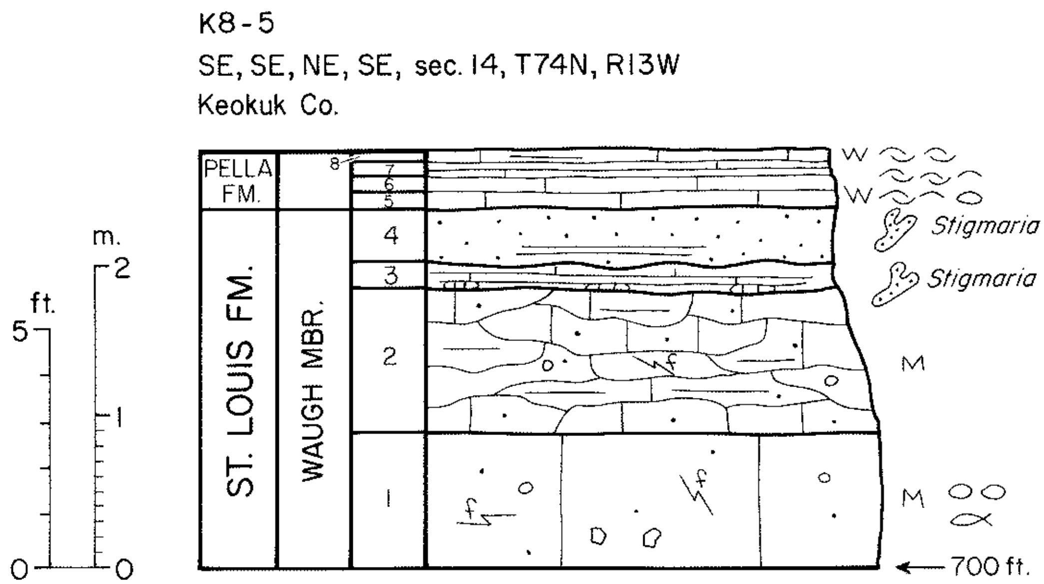
**UNIT 3**
Sandstone, very fine-medium, quartzose, calcareous, thinly laminated, probable large scale low angle cross-stratification; 17 cm.

**UNIT 2**
Sandstone, very fine-medium, calcareous-friable, possible large-scale low angle cross-stratification; 1.07 m.

**UNIT 1**
Sandstone, covered interval; 62 cm.

**STOP 1. DISCUSSION.** Massive sandstone of the upper portion of the Croton Member of the "St. Louis" is exposed in the abandoned railroad cut section as well as a large slump block of Verdi Member strata. The entire Verdi Member and the entire Waugh Member of the "St. Louis" are exposed along the north wall of the quarry. The lower Verdi shallow-marine interval is represented by the thick beds at the base of the section (Units 1 and 2). The upper half meter contains ooid grainstones overlain by brecciated mudstones. This lower Verdi package represents one shallowing upward marine cycle which is present throughout the area. Units 3 through 12 are interbedded sandstones and thin-bedded restricted-marine limestones of the upper Verdi. Upper Verdi laminated pelletal limestones represent deposition in lagoonal through supratidal settings. The upper portions of several units are brecciated, suggesting subaerial exposure. Thin, intervening sandstones of storm surge or fluvial flooding origin contain limestone lithoclasts incorporated in their bases.

The uppermost division of the "St. Louis," the Waugh Member, is exposed at the top of the quarry wall (Units 13-16) and in the overlying slope forming interval (Units 17-23). Massive, fractured to conglomeratic ostracode lime mudstones represent initiation of carbonate lacustrine sedimentation. Fractured and brecciated fabrics indicate periodic lake dessication. These limestones lack any fauna characteristic of marine conditions; the fauna is dominated by ostracodes, "spirorbid" snails and fish material. Laminated ostracode-fish-bearing lime mudstones (Unit 19) also represent lacustrine carbonate deposition. The remainder of the Waugh Member at this locality (Units 17-23) is dominated by sandy shales with sparse fish debris which are interpreted to represent fluvial-deltaic sedimentation into the lake basin. This clastic influx halted carbonate production except during brief intervals (Units 19 and 21). *Stigmaria* root casts of Unit 23 marks the establishment of swamp conditions in which scale trees grew. Brachiopod-clam limestones of the overlying Pella Formation marks renewed marine transgression of the Pella seaway.




**STOP 2A.** Kessel property. Section K8-5.

## STOP 2A - KESSEL PROPERTY OUTCROPS (K8-5)

section measured by R.M. McKay and M.P. McAdams, 1986.

**LOCATION** - SE, SE, NE, SE, Section 14, T74N, R13W, Keokuk County. Section exposed on the north bank of unnamed tributary to Waugh Branch approximately 200' upstream from road crossing. Elevation at base of section is approximately 700'.

**PELLA FORMATION**

**UNIT 8**
Limestone, light brown gray, brachiopod wackestone, argillaceous, geopetal fills in whole brachs; 12 cm.

**UNIT 7**
Shale, light brown gray, calcareous, poorly exposed; 7 cm.

**UNIT 6**
Limestone, light brown gray, brachiopod wackestone, clams at base, geopetal fills, trace fish scales; 10 cm.

**UNIT 5**
Limestone, light brown gray, clam-brachiopod wackestone, quartz sandy, ostracodes; 9 cm.

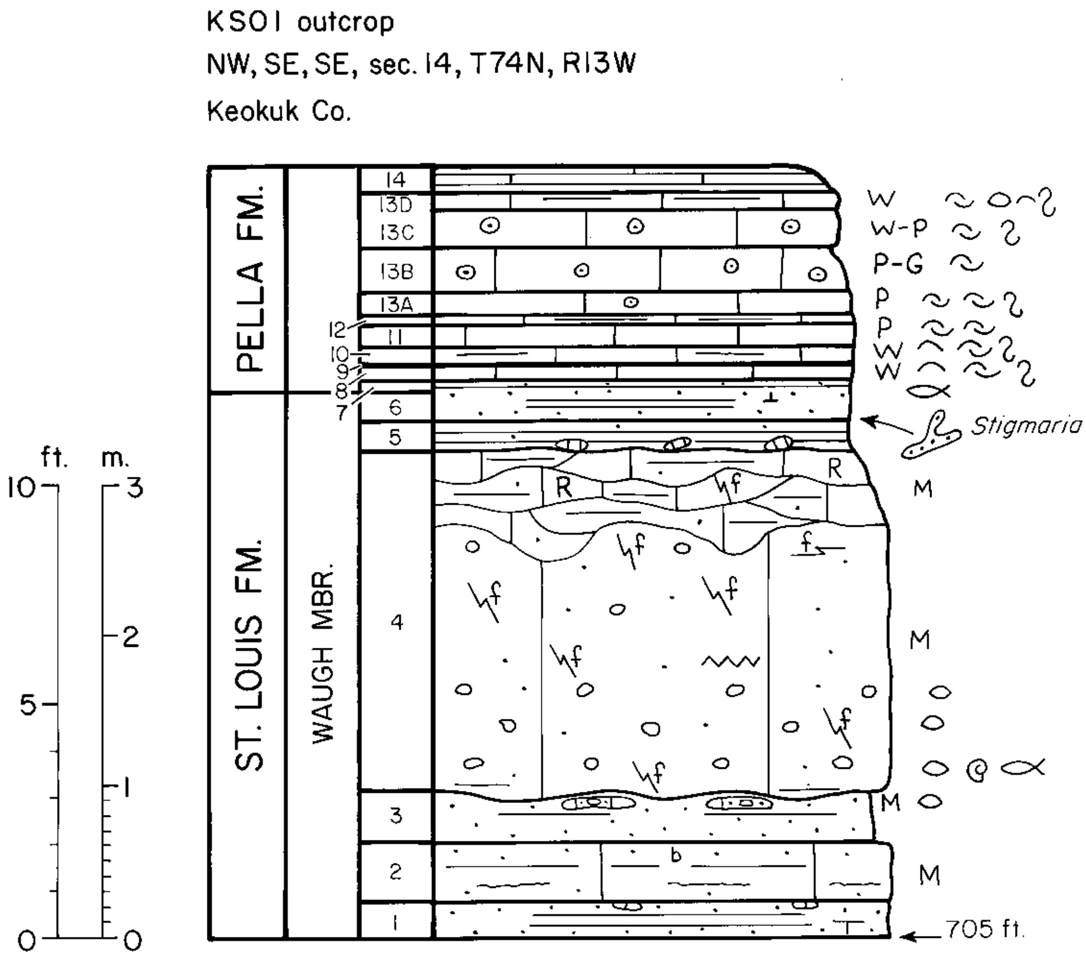
**ST. LOUIS FORMATION**
**WAUGH MEMBER**

**UNIT 4**
Sandstone, white-tan, very fine to medium, slightly calcareous, planar laminated in part, *Stigmaria* root casts on upper and lower surface, undulose base; 15-37 cm.

**UNIT 3**
Shale, light green, calcareous, nonlaminated, slightly sandy, *Stigmaria* root casts, limestone clasts at base; 20 cm.

**UNIT 2**
Limestone, light gray, dense, mudstone, irregularly bedded, argillaceous partings, quartz sandy, calcite spar fills in abundant micro-fractures, conglomeratic to intraclastic in part, slope former; 94 cm.

**UNIT 1**
Limestone, light gray, dense, massive, mudstone, moderately abundant ostracodes, trace fish material, common calcite spar fills of microfractures, slightly conglomeratic to brecciated in places, 88 cm.




**STOP 2B.** Kessel property. Section KSO1.

## STOP 2B - KESSEL PROPERTY OUTCROPS (KSOl )

section measured by R.M. McKay, B.J. Witzke, and M.P. McAdams, 1986 and 1987.

**LOCATION** - NW, SE, SE, Section 14, T74N, Rl3W, Keokuk County. Section exposed in cutbank and streambed along unnamed tributary to Waugh Branch approximately 600' upstream from road crossing. Elevation at base of section is approximately 705'.

### PELLA FORMATION

**UNIT 14**
Shale, slope former, poorly exposed, weathered, contains limestone fragments; 0-23 cm.

**UNIT 13**
Limestone, divided into four subunits. D, light gray, wackestone, brachiopods, clams, ostracodes, bioturbated, argillaceous in upper part; 12 cm. C, light brown gray, coated grain to ooid wackestone to packstone, brachiopods whole and abraded, bioturbated; 25 cm. B, light brown gray, ooid packstone-grainstone, abraded brachiopod grains; 30 cm. A, light brown gray, abraded brachiopod grain packstone, coated grains (peloids and brachiopod), bioturbated; 16 cm.

**UNIT 12**
Limestone, brachiopod packstone to wackestone, argillaceous, very thin bedded; 6 cm.

**UNIT 11**
Limestone, light brown gray, abraded brachiopod grain packstone, some whole valves, *Composita*, planar laminae in part, some spar filled shells; 16 cm.

**UNIT 10**
Limestone, light brown gray, brachiopod wackestone, whole valves, clams, argillaceous, bioturbated, geopetal shell fills; 10 cm.

**UNIT 9**
Shale, light brown, laminated, slightly silty, calcareous; 3 cm.

**UNIT 8**
Limestone, light gray-brown, brachiopod and clam wackestone, bioturbated, slightly sandy at base, kaolinite void fillings; 6-9 cm.

**UNIT 7**
Shale, orange tan, very calcareous, sandy, 4-6 cm.

### ST. LOUIS FORMATION
### WAUGH MEMBER

**UNIT 6**
Sandstone, quartzose, very fine-fine grained, well sorted, slightly calcareous, ledge former, upper part planar to low angle cross-laminated, top few cm with sparse fish scale material, irregular base, some *Stigmaria* root casts along base; 19-26 cm.

**UNIT 5**
Shale, very light green-light orange tan, oxidized, slightly calcareous, basal 2 cm very calcareous with weathered limestone clasts, *Stigmaria* root casts in top 10 cm; 18-26 cm.

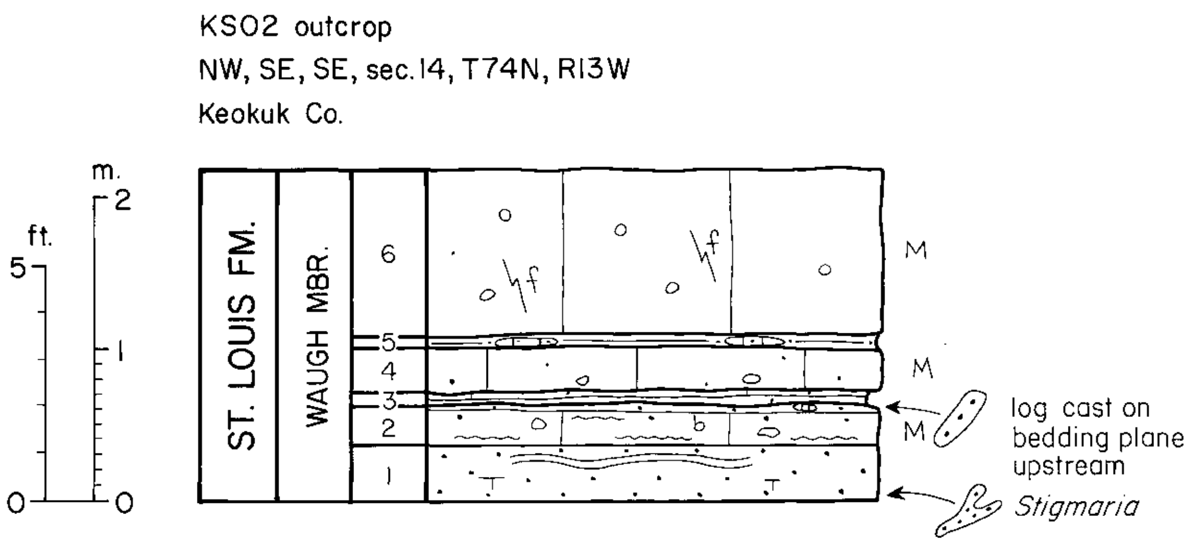
**UNIT 4**
Limestone, in two subunits. Upper, lime mudstone, dense, irregularly bedded, fractured-microfractured, rubbly appearing, argillaceous partings throughout, faint rooting, silty to sandy, microfractures filled with combination of calcite spar, micrite and mudstone clasts, (41-73 cm); Lower, very light gray, dense, lime mudstone, variably intraclastic to conglomeratic to brecciated, silty to sandy throughout, styolitic in part, abundant fractures to

microfractures throughout, fractures filled with combinations of calcite spar, micrite and lime mudstone sediment, ostracodes common in lower part, some microgastropods and fish debris in lower part; (1.5-1.7 m); 1.9-2.4 m.

**UNIT 3**
Sandstone, very light green-gray, very fine-fine grained, argillaceous in upper half, limestone lenses in upper 10 cm; limestone lenses, very light gray, dense, mudstone, conglomeratic to brecciated with clasts fine-granular, styolitic, ostracodes abundant, lenses up to 5 cm by 20 cm long, 26-33 cm.

**UNIT 2**
Limestone, very light gray, dense, mudstone, discontinuous laminae in part, birdseye, silty to sandy, 1 cm calcareous green clay laminae in upper 6 cm, very sandy in upper 2 cm; 39cm

**UNIT 1**
Sandstone, light green gray, very fine-medium, quartzose, calcareous in part, faint planar laminations, minor limestone clasts at top, slightly argillaceous; 23 cm.




**STOP 2C.** Kessel property. Section KSO2.

## STOP 2C - KESSEL PROPERTY OUTCROPS (KSO2)

section measured by R.M. McKay and B.J. Witzke, 1987.

**LOCATION** - NW, SE, SE, Section 14, T74N, R13W, Keokuk County. Section is exposed on bedding planes in streambed 200'-300' upstream of Stop 2B.

**ST. LOUIS FORMATION**
**WAUGH MEMBER**

**UNIT 6**
Limestone, light gray, mudstone, massive, microfractured, intraclastic to conglomeratic, large solutional voids; 1.11 m.

**UNIT 5**
Shale, reentrant, sandy, with sandy lime mudstone lenses 1-5 cm thick by 6-24 cm wide; 6-11 cm.

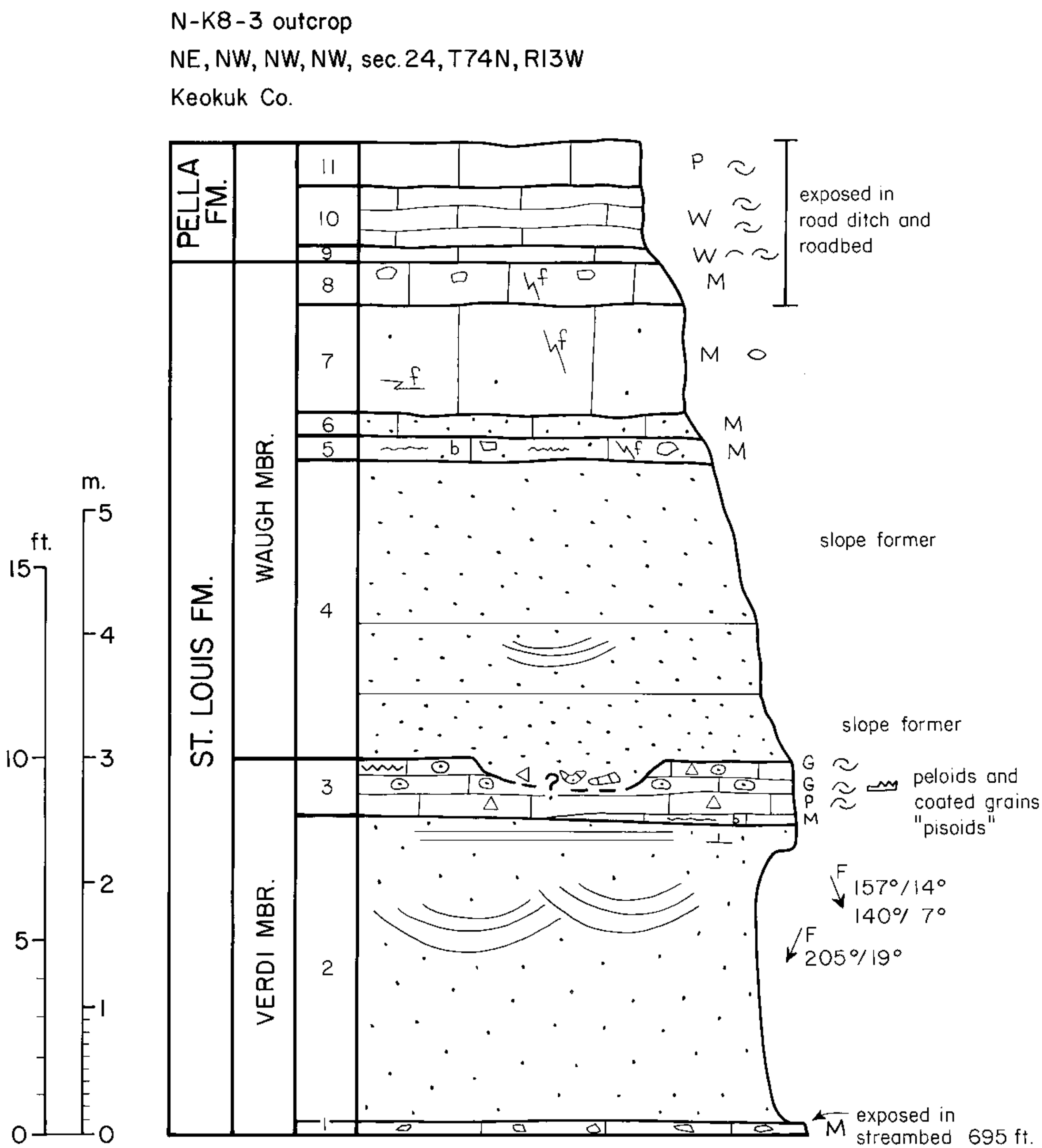
**UNIT 4**
Limestone, light gray, dense, mudstone, conglomeratic at base, fine to pebbly grains in sandy matrix, pyritic; 28 cm.

**UNIT 3**
Shale, reentrant, light green gray, oxidized mottles, calcareous, laminated; 7-8 cm.

**UNIT 2**
Limestone, light gray, dense, mudstone, discontinuous laminae, sparse birdseye, basal part conglomeratic; upper part with pinpoint calcite spar fills and sandstone lenses at top; draped by 1-2 cm thick very fine to medium sandstone with lime mudstone clasts to 2 cm, continues to thicken upstream to 3 cm with large sandstone log cast expressed on bedding plane, 18 cm wide x 1 m long x 3 cm thick; 20-23 cm.

**UNIT 1**
Sandstone, fine to medium, well sorted, calcareous, poorly preserved *Stigmaria* near base, thin wavy bedded, slightly lenticular bedding; 38 cm.

**STOP 2. DISCUSSION.** The upper portion of the Waugh Member and the lower portion of the Pella Formation are exposed at this series of outcrops. The massive lime mudstone facies of the Waugh is well developed at all the sub-stops. Massive lime mudstones lack marine fauna but contain ostracodes, snails, and fish debris which we consider characteristic of lacustrine deposition. Fractured, brecciated, and conglomeratic fabrics are interpreted to have formed during periodic dessication events in the lake basin. Sandstones, below the massive limestones, which contain *Stigmaria* and scale tree log casts, suggest fluvial clastic influx and possible tree growth prior to full fledged carbonate sedimentation. Well developed rubbly and rooted horizons in the upper parts of the massive limestones were developed when swamp conditions, which supported scale tree growth, became widespread. Excellent specimens of *Stigmaria* root casts can be seen on the bases of overturned sandstone blocks at Stop 2A. Pella marine transgression is documented by the presence of brachipod-clam rich limestones which are best exposed at Stop 2B. Ooid packstones to grainstones of the Pella are present near the top of Stop 2B. Excellent bedding plane exposures of brecciated to conglomeratic, massive lime mudstones are exposed upstream of Stop 2C.




**STOP 3A.** Waugh Branch streamcut. Section N-K8-3.

## STOP 3A - WAUGH BRANCH STREAMCUT (N-K8-3)

section measured by R.M. McKay, 1987.

**LOCATION** - NE, NW, NW, NW, Section 24, T74N, R13W, Keokuk County. Elevation at base of section is approximately 697'. Lower part of section exposed along east bank of stream from 50' north of bridge to 150' south of bridge. Uppermost part of section exposed in road and road ditch immediately east of bridge.

### PELLA FORMATION

**UNIT 11**
Limestone, light gray, packstone, abraded brachiopod grains, some coated grains; 36 cm.

**UNIT 10**
Limestone, light gray, brachiopod wackestone, bioturbated, some whole brachs with geopetal-calcite spar fills, thin- to medium-bedded; 48 cm.

**UNIT 9**
Limestone, light brown gray, wackestone with clam molds and brachipods, bioturbated; 11 cm.

### ST. LOUIS FORMATION
### WAUGH MEMBER

**UNIT 8**
Limestone, light gray, dense, mudstone, fractured to brecciated in upper part; 30 cm.

**UNIT 7**
Limestone, light brown gray, dense, massive, mudstone, very sparse, ostracodes, fractured to microfractured with calcite spar fills, quartz sandy,; 85 cm.

**UNIT 6**
Limestone, light gray, mudstone, very quartz sandy, very fine to fine, poorly exposed slope former; 20 cm.

**UNIT 5**
Limestone, light gray, dense, mudstone, discontinuous laminae, birdseye, brecciated in part with quartz sandy lime mud fills, clasts to several cm; 15 cm.

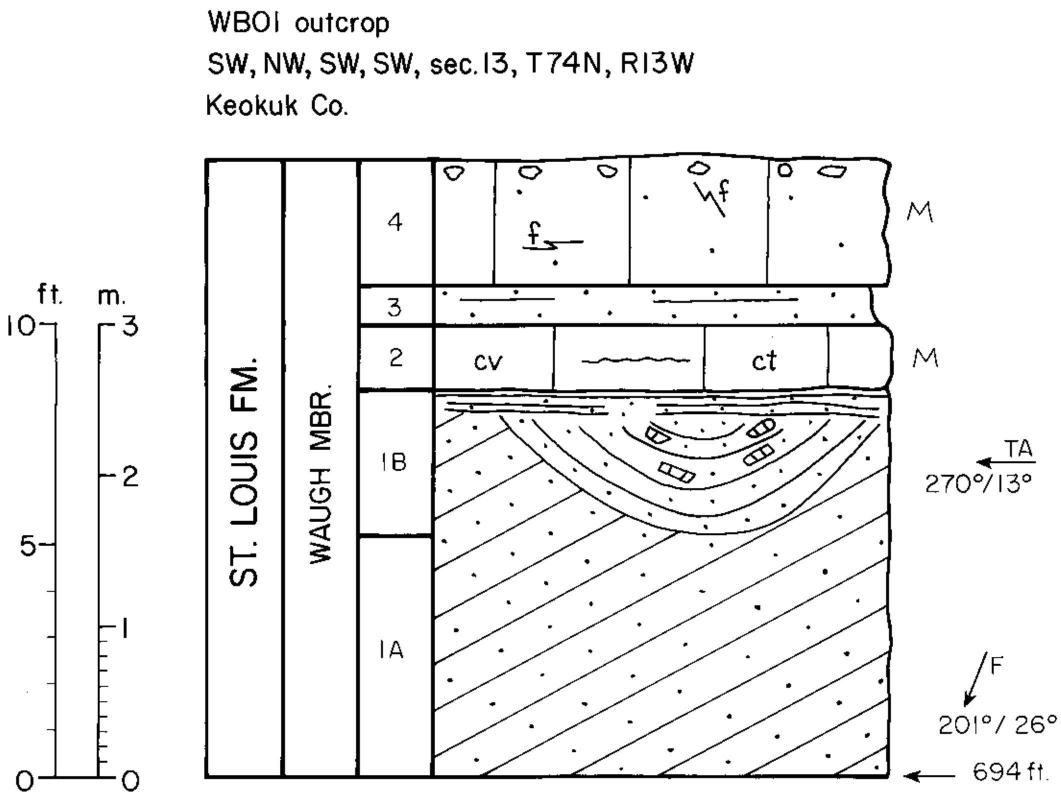
**UNIT 4**
Sandstone, slope former, covered in part; quartzose, very fine to fine, some medium; base of unit appears incised into Unit 3 carbonates with chert and limestone clasts at base; middle part trough cross-stratified, trough axis dips towards west to southwest; upper part poorly exposed slope former; 2.3-2.6 m.

### VERDI MEMBER

**UNIT 3**
Limestone, in five beds; lower bed, dense mudstone with crinkley discontinuous laminae and birdseye, calcite spar filled fracture; next bed, dense, packstone, peloidal, peloids medium to very coarse, brachiopod, quartz sandy, white to dark gray chert lenses 5-6 cm thick by 10-20 cm long, also partially silicified in other parts, bed is normally graded; other beds, dense, grainstone, peloidal and coated grains, peloids and brachipod fragments coated, multiple irregular coatings on some (pisoids), fine to coarse quartz sandy, styolitic bed contacts, minor white dark to gray chert, reversely graded beds coarsen upward, conodonts, and ostracodes also; 42-50 cm.

**UNIT 2**
Sandstone, light tan, very fine-fine, some medium, quartzose; large-scale trough x-strata in middle, trough 1 m thick, foreset dip directions $140^{o}$, $157^{o}$ and $205^{o}$; planar bedded in upper 30 cm, calcite cement; 2.3-2.5 m.

**UNIT 1**
Limestone, light gray, mudstone, brecciated to conglomeratic; exposed in streambed; 10 cm.




**STOP 3B.** Waugh Branch streamcut. Section WBO1.

## STOP 3B - WAUGH BRANCH STREAMCUT (WBOl)

section measured by R.M. McKay, 1987.

**LOCATION** - SW, NW, SW, SW, Section 13, T74N, Rl3W, Keokuk County. Elevation at base of section is approximately 694'. Section on west bank of stream about 950' downstream of bridge.

### ST. LOUIS FORMATION
### WAUGH MEMBER

**UNIT 4**

Limestone, light gray, dense, massive, mudstone, very fine-medium quartz sandy, mottled textured, subhorizontal to vertical fractures and microfractures throughout, fractures filled with calcite spar, micrite, and occasional angular to subangular lithoclasts of mudstone, brecciated in part at top with clasts to 1 cm; 97 cm.

**UNIT 3**

Sandstone, light greenish tan with orange mottling, very fine-fine, argillaceous; forms reentrant, 12 cm.

**UNIT 2**

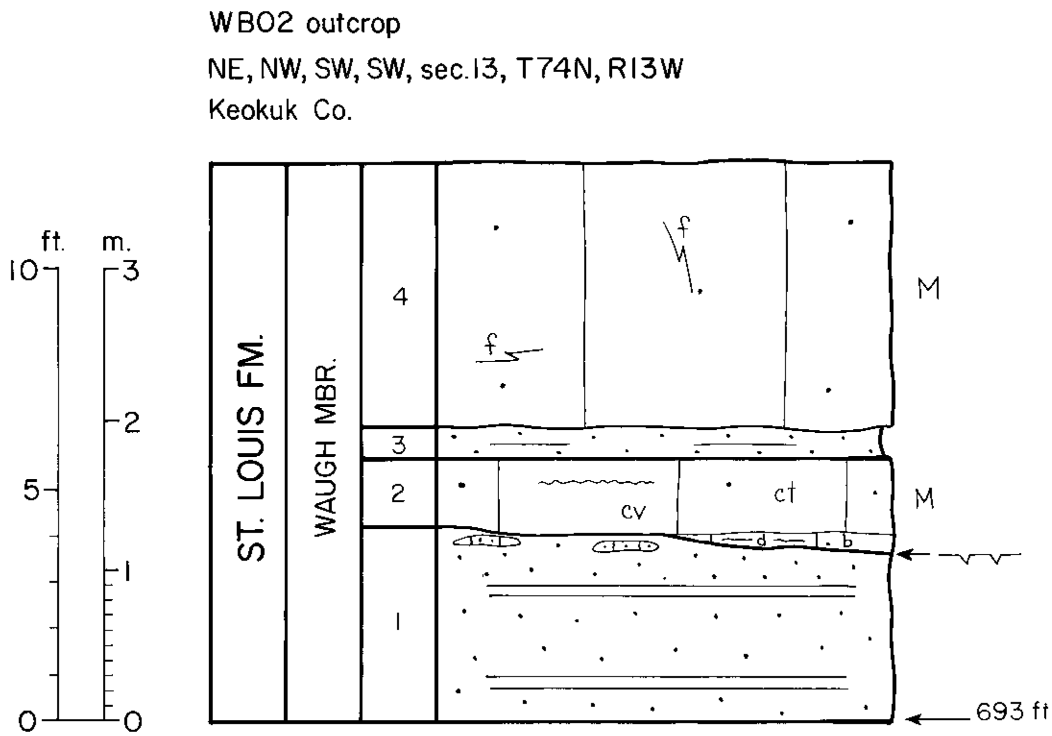
Limestone, light gray, dense, mudstone, discontinuous laminae in middle, prominent calcite spar filled vugs and tubules, tubules form horizontal and vertical network and may have minor sediment fills; minor calcite spar filled microfractures; 36-42 cm.

**UNIT IB**

Sandstone, light tan to light gray, quartzose, very fine-fine, some medium, well sorted, calcareous cement; isolated large-scale trough x-strata truncates Unit IB, angular lime mudstone clasts to several cm in upper foresets, trough 8 m wide by 1.4 m thick, trough axis trends $270^{\circ}$. Overlain by planar to wavy laminated sandstone with thin 1 cm brown shale cap at top; 1.5 m.

**UNIT lA**

Sandstone, light tan to light gray, quartzose, very fine-fine, some medium, well sorted, calcareous cement; large-scale tabular x-strata, foresets 1-20 cm thick, azimuth of foreset maximum dip direction = $201^{\circ}$, foreset inclination = $26^{\circ}$; 1.1 m - 2.5 m.




**STOP 3C.** Waugh Branch streamcut. Section WBO2.

## STOP 3C - WAUGH BRANCH STREAMCUT (WBO2)

section measured by R.M. McKay, 1987.

**LOCATION** - NE, NW, SW, SW, Section 13, T74N, R13W, Keokuk County. Elevation at base of section is approximately 693'. Section on north bank of stream about 200' downstream of Stop 3B.

**ST. LOUIS FORMATION**
**WAUGH MEMBER**

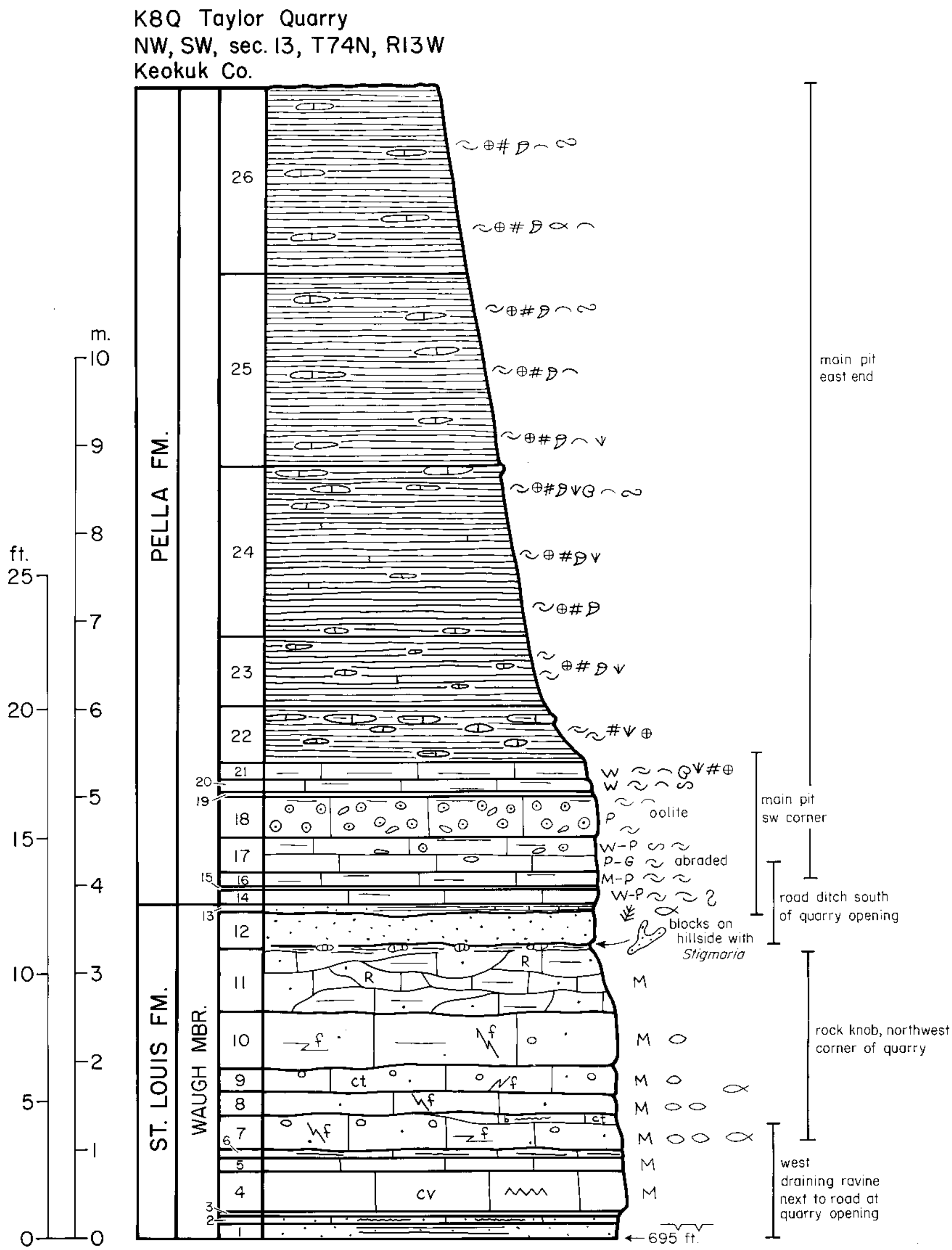
**UNIT 4**
Limestone, light gray, dense, massive, mudstone, very fine-fine quartz sandy, subhorizontal to vertical fractures and microfractures with calcite spar and minor sediment fillings, undulose base; 1.8 m.

**UNIT 3**
Sandstone, very fine-fine, quartzose, argillaceous, forms reentrant; 12 cm.

**UNIT 2**
Limestone, light gray, dense, mudstone, discontinuous laminae in base and upper part, possible spar filled dessication cracks at base of bottom 15 cm which pinches out laterally, fine quartz sandy in part, birdseye in basal part; prominent calcite spar filled vugs and horizontally to vertically oriented network with minor sediment fills; 45-62 cm.

**UNIT 1**
Sandstone, light tan, quartzose, very fine-fine, well sorted, calcareous, planar bedded, beds 2-15 cm thick; 10 cm relief on top, lenses of sandy lime mudstone in upper 10 cm; 1.1 m.

**NOTE** - approximately one meter above the top of this outcrop in the abandoned railroad bed immediately to the west are large surfaces of coated grain brachiopod packstone of the Pella Formation. These appear to be in place which would mean the St. Louis/Pella contact is in the intervening covered interval.




**STOP 3D.** Taylor Quarry. Section K8Q.

## STOP 3D - TAYLOR QUARRY (K8Q)

section measured by B.J. Witzke and R.M. McKay, 1987.

**LOCATION** - NW, SW, Section 13, T74N, Rl3W, Keokuk County. Section exposed in several areas of quarry as noted on section illustration. Elevation at base of section is approximately 695'.

### 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 brachipods, 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 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, brachipods 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, brachipods, 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 brachiopod packstone-grainstone, dense, argillaceous parting near top; 40 cm.

**UNIT 16**
Limestone, light brown gray, dense, brachipod mudstone-packstone, brachipods spar filled, shaley partings at top, argillaceous; 16 cm.

**UNIT 15**
Shale, light brown gray, calcareous; 2 cm.

**UNIT 14**
Limestone, light brown gray, brachipod 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, styolitic; 48 cm.

**UNIT 3**
Shale, brown, discontinuous; 0-2 cm.

**UNIT 2**

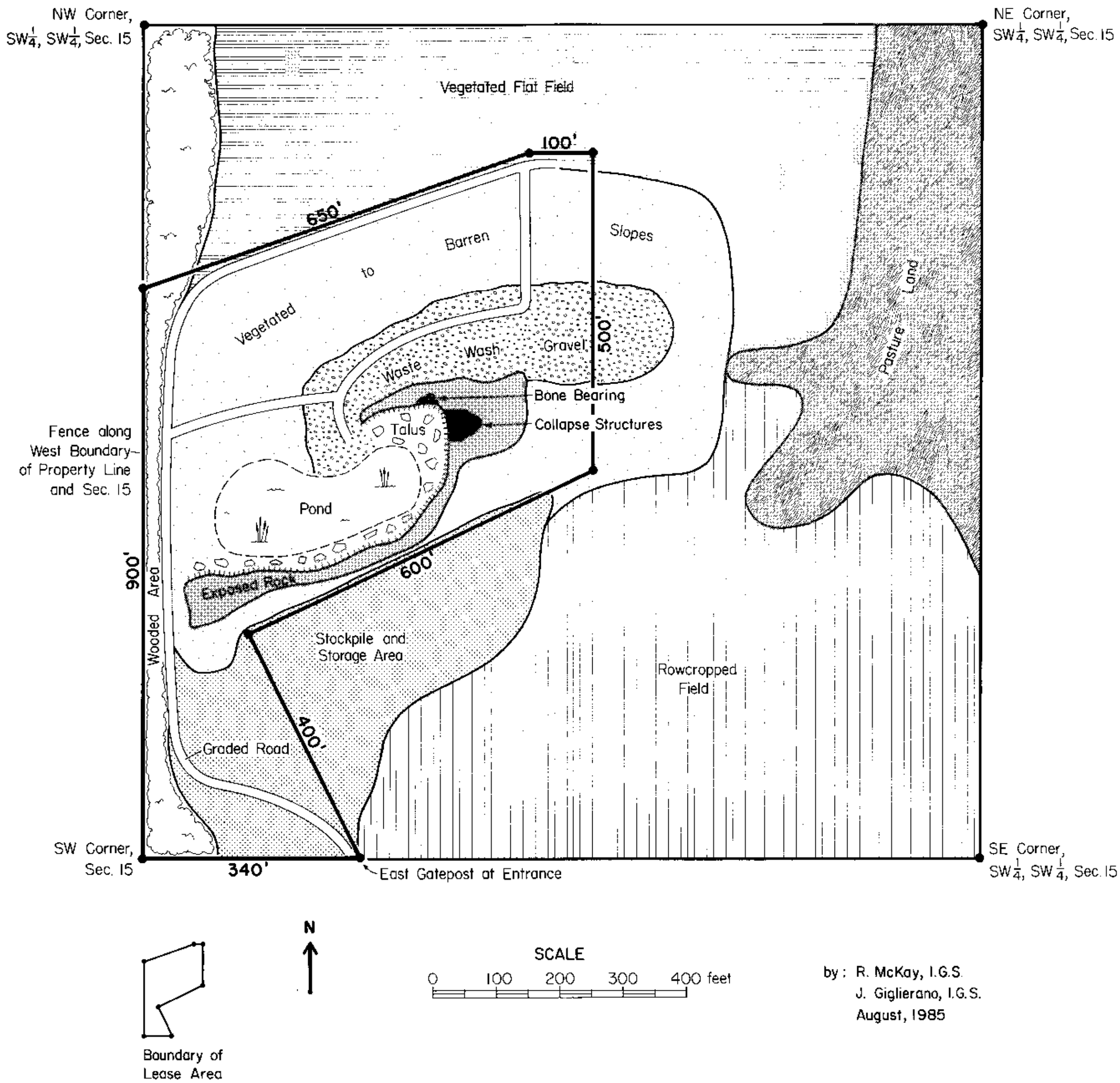
Limestone, light gray, sandy-very sandy, horizontally laminated, mudcracks at base; 10 cm.

**UNIT 1**

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

**STOP 3. DISCUSSION.** The four substops of Stop 3 expose the upper Verdi through Waugh Members of the "St. Louis, " and one of the thickest and most complete sections of the Pella Formation in Iowa. Stop 3A, at the wooden bridge across the Waugh Branch, exposes a thick cross-bedded sandstone of the upper Verdi which is overlain by restricted-marine upper Verdi limestones. These limestones are overlain by poorly exposed cross-bedded sandstones of the lower Waugh which may in part truncate a portion of the limestone interval (queried relationship). Massive lime mudstones are present high on the slope and lower Pella limestones are present in the road ditch and bed. Stops 3B and 3C display the fluvial sandstone facies of the lower Waugh. Large-scale tabular cross-stratified sandstones represent fluvial channel bedforms which were migrating to the southwest. These were later cut by west flowing channels which incorporated lime mudstone lithoclasts within their trough shaped foresets. At Stop 3C, less than 200 feet downstream from Stop 3B, planar-stratified sandstones, which are lateral facies of the cross-bedded sands, can be seen. Both sections are overlain by the distinctive massive lime mudstones of the lacustrine facies. Intervening laminated lime mudstones contain birdseye-like structures and calcite spar filled tubules.

The lower portion of Stop 3D exposes Waugh Member massive lime mudstones and overlying sandstones with *Stigmaria* roots casts. A brecciated to conglomerate 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 main quarry section exposes the Pella Formation. Shallow-marine transgressive limestones containing a low-diversity fauna dominates the lower Pella. These are succeeded by ooid packstones containing scattered lime mudstone intraclasts. Ooid packstones are overlain by skeletal wackestones containing a diverse Pella 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 shaley, very calcareous strata are highly fossiliferous and contain a diverse marine fauna. The weathered marl slopes at this exposure provide some of the best fossil collecting to be found anywhere in the Midcontinent. A faunal list and plate illustrating some of the Pella fauna can be found in Witzke's Pella Stratigraphy section, this guidebook.




**STOP 4.** Map of the Heimstra Quarry showing location of bone-bearing collapse structures and the boundary of land leased by the State of Iowa.

## STOP 4 - JASPER HEIMSTRA QUARRY (JHQ)

section measured by R.M. McKay, B.J. Witzke, and P. McAdams, 1985-1986.

**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'.

### UPPER 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.

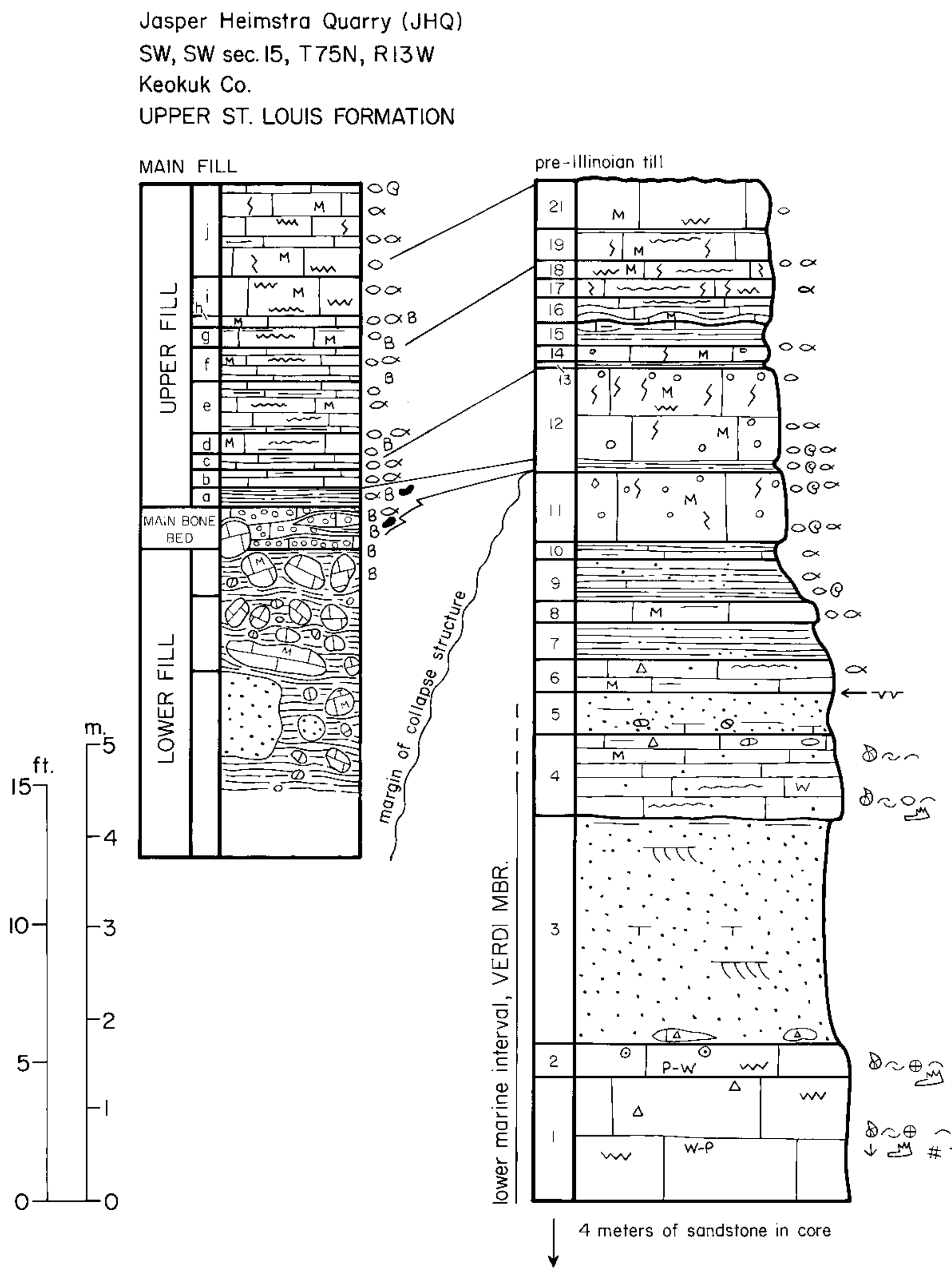
**UNIT 15**
Shale, light green brown to brown-gray, variable thickness; 4-24 cm.

**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, ostracodes, "spirorbid" snails, abundant fish scales, teeth, dermal denticles, and fragments, common "3-prong" plant? material, common vertical to anastomosing calcite spar and lithoclast filled voids fractures and microfractures; 75 cm.




**STOP 4.** Heimstra Quarry. Section JHQ.

**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, 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, 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 Croton Member sandstone below quarry floor. Concrete Materials Co. test core. Core received and described by Iowa Department of Transportation, 11/05/71.

# MAIN FILL SECTION (northeast part of quarry)

## UPPER ST. LOUIS FORMATION
## WAUGH MEMBER

### 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 fish scales and coprolites, 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; 15-45 cm.

**MAIN BONE BED** - Limestone Conglomerate, light to medium gray, polymodal, poorly sorted, clast to matrix supported, grain size ranges from silt and very fine sand to pebbles with some cobbles, grains angular to subrounded, abundant tetrapod bone throughout, bone mostly 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; 0-50 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 lessor amounts of sandstone derived from main quarry section, includes slump blocks of main quarry section; matrix consists of tetrapod bone bearing shale and lesser amounts of limestone conglomerate containing tetrapod bone; 0-5.0 + m.

**STOP 4. 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 were discovered within a thin 50 cm thick layer of limestone conglomerate and shale along the east quarry wall. The bone bed is located within the middle part of the dish-shaped depression along that wall (see guidebook cover or Figure 3 for sketch of the east quarry face). 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 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 summer of 1986 the Field Museum of Natural History, Chicago, and the Iowa Geological Survey excavated approximately half of the Heimstra Quarry bone bed. The large collection of specimens (hundreds) which were recovered are presently under study at the Field Museum.

Detailed discussions of the stratigraphy, paleontology and depositional environments of "St. Louis" Formation strata exposed at Heimstra Quarry are contained in the text sections of this guidebook. This discussion will be as brief as possible.

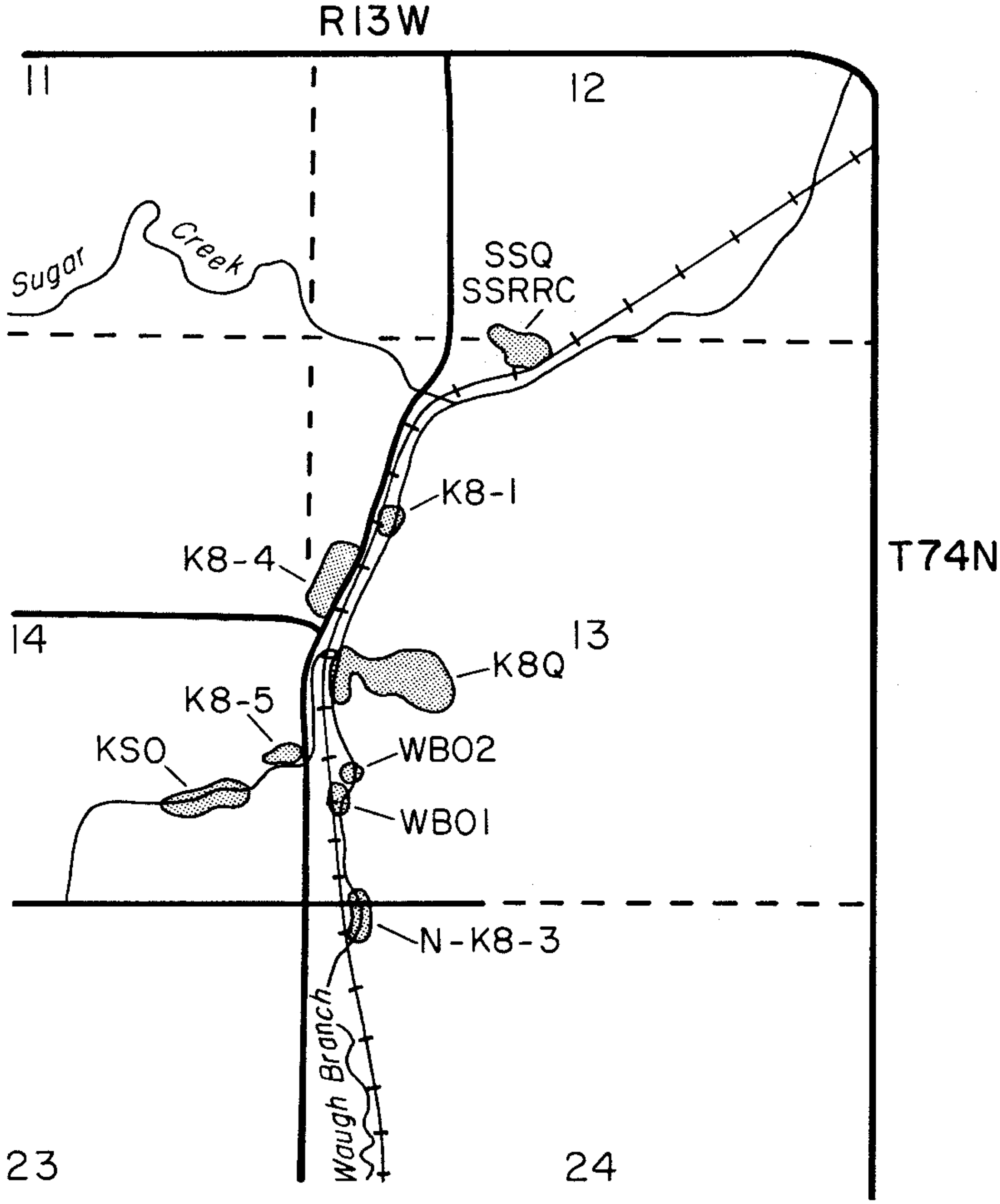
Two bone beds are known from Heimstra Quarry. They both occur within the fills of two dish-shaped depressions or collapse-structures developed in the upper part of the "St. Louis" Formation The smaller of the two is 7 m wide and is present along the north wall of the quarry. It was excavated in October, 1985. The large fill is 16 m wide and was partially excavated during the summer, 1986. Strata exposed at JHQ can be divided into five units for discussion purposes (see photo-tracing sketch of the large fill, east quarry face). 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) 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. This sequence represents a shallowing and offlap of the seaway. Lower Waugh strata (Units 7-11) 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 and lacking fauna characteristic of marine or restricted-marine conditions were deposited. The collapse-structure truncates Unit A. It probably 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 at the top of Unit 11 suggests dessication of the lake and formation of a disconformity at a similar point in time.

Unit B 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.

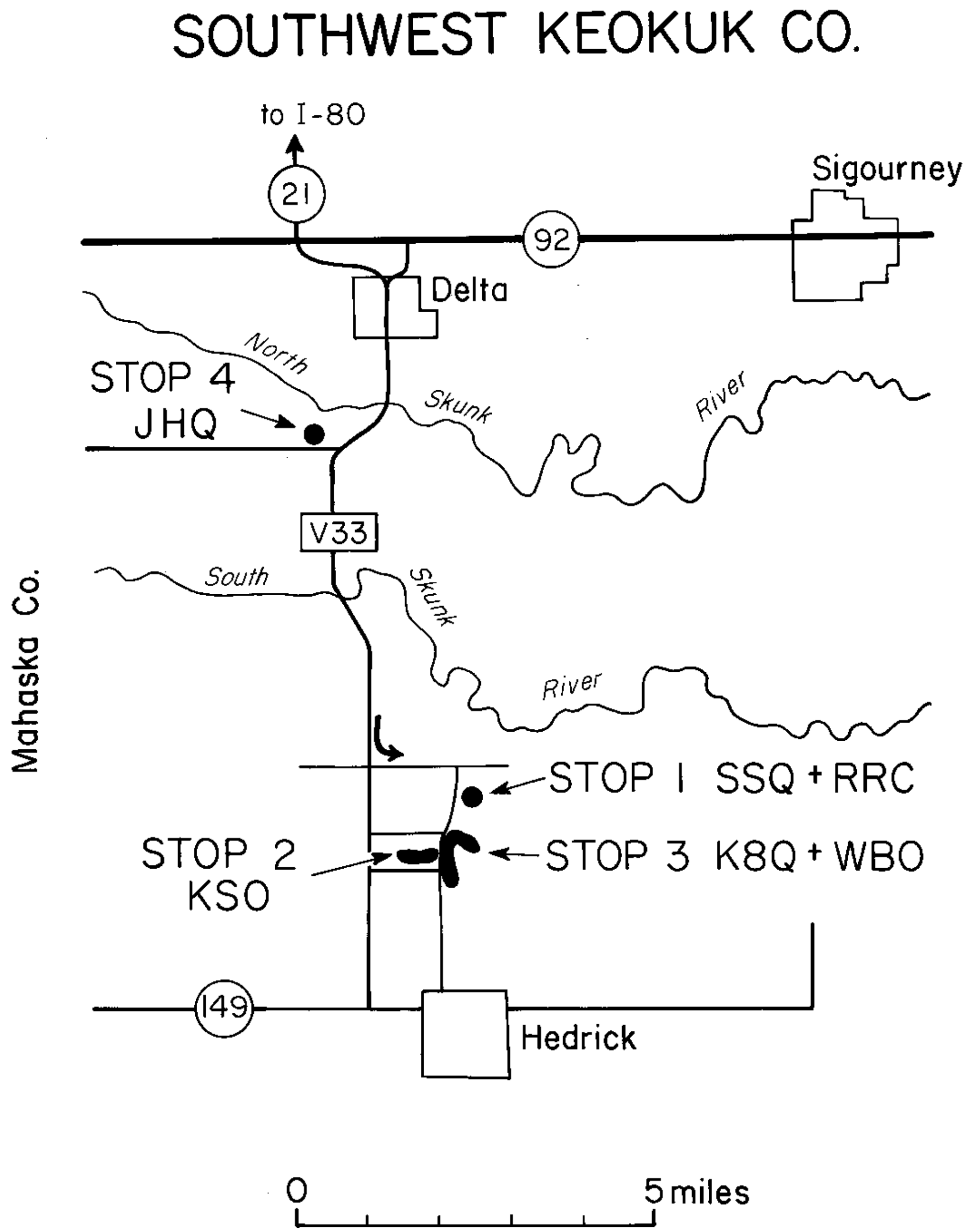
Unit C is the main bone bed. Almost all of the bone bed which was uncovered during the excavation was removed. Thin in-place bone bed is still present in the east portion of the pit. The talus pile below the excavation is loaded with chunks of bone bed limestone conglomerate. Bone bed shale is also present 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 these conglomerate layers, as seen during the excavation, 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. Tetrapods present are labyrinthodont amphibians of the anthracosaur group. Virtually all skeletal elements (cranial and post-cranial) have been found as abundant disarticulated disarticulated to semi-articulated material. Abundant fish material was recovered from the upper part of the shales.

Unit D (Units a-j and 12-21, measured sections) 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" 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 (measured section). Unit D was deposited in a lacustrine environment as base levels rose, resulting in complete flooding of the depressions and surrounding areas.

Unit E is a sandstone of possible Pennsylvanian age. A discussion of the overlying Quaternary section is provided by Art Bettis earlier in this guidebook.




Map showing location of outcrops and quarries in the Waugh Branch area.




**MAP SHOWING FIELD TRIP STOPS AND ROUTE. NO ROAD LOG IS PROVIDED.**