# THE LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE PELLA FORMATION (MISSISSIPPIAN) IN KEOKUK AND WAPELLO COUNTIES, SOUTHEASTERN IOWA

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## ABSTRACT

The Pella Formation is the uppermost Mississippian rock formation in Iowa, cropping out mainly in the southeastern part of the state. It typically consists of a relatively thin (<2 m) basal limestone that is overlain by thicker (up to 7.5 m), highly fossiliferous marl. The Pella Formation rests unconformably on the "St. Louis Formation," the upper part of which is nonmarine limestone and plant-bearing sandstone. The upper contact of the Pella Formation is a major erosional unconformity corresponding to the Mississippian-Pennsylvanian systemic boundary. Carbonate petrography of the lower part of the Pella Formation enabled identification of distinct brachiopodal and oolitic lithofacies that are locally correlatable. Bioclasts increase in diversity up-section and quartz sand decreases in abundance up-section, suggesting that at least the lower part of the formation is a deepening-upward succession in which restricted marine and then normal marine conditions became established during transgression. The unconformity between the upper Pella Formation and overlying Pennsylvanian rocks is rarely exposed in outcrops because it occurs within relatively nonresistant beds that are eroded and covered by vegetation. The unconformity is well preserved in a core from Wapello County. Uppermost Pella beds in the core are deeply weathered and rubbly, and are interpreted as a coarse residual paleosol.

## INTRODUCTION

The Pella Formation is the uppermost Mississippian rock formation in Iowa. It usually consists of a basal marine limestone and an overlying marine shale (or marl). The basal limestone generally increases in thickness basinward (in a northeastern to southwestern direction), whereas the argillaceous unit has a maximum exposed thickness of about 7.5 meters in one locality, the Taylor Quarry in southwestern Keokuk County. This marl contains abundant fossils, ranging from trilobite fragments to well preserved spirifer brachiopods. Bain (1895) originally named the "Pella beds" for the uppermost Mississippian unit in Iowa, which was discovered near Pella, Iowa. The type section of the Pella Formation is located in the Van Zee New Durham Quarry, 6 miles south of Pella, IA (SW¼, Sec. 4, T.75N., R.18W., Marion County) (Johnson and Vondra, 1969).

This research was initiated to interpret the depositional history of the Pella Formation and to determine if various lithofacies within the Pella are traceable over significant areas. Prior work by Witzke and others (1990), McKay and others (1987), and Johnson and Vondra (1969) showed the unit to be the stratigraphic record of the inundation of the Ste. Genevievian seas into Iowa during late Mississippian time. On the basis of conodont work by Rexroad and Furnish (1964), the Pella was correlated with the Chesterian age Ste. Genevieve Limestone. Johnson and Vondra (1969) assigned a "late Valmeyeran" (late Meramecian) age to the unit. A Ste. Genevievian or early Chesterian age was assigned by McKay and others (1987). Witzke (*in* Anderson, 2004, p. 61–62) later reiterated that the "Pella probably correlates with the upper Ste. Genevieve Formation of Illinois and Missouri," which is now included within the basal Chesterian Series (Lane and Brenckle, 2001). Recent foraminfera work by Groves and Beason (in press) shows that the Pella Formation can be no older than the upper part of the Ste.

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Genevieve Limestone. It may be as young as the mid-Renault Limestone, on the basis of conodonts (Groves and Beason, in press).

# METHODS

## Field Work

The outcrop sites selected for sampling were the Taylor Quarry, locality K8Q (NW¼, SW¼, Sec. 13, T.74N., R.13W., Keokuk County, Iowa) and an exposure along an unnamed tributary of the Waugh Branch on property owned by the Kessel family, locality KSO (NW¼, SE¼, SE¼, Sec. 14, T.74N., R.13W., Keokuk County, Iowa) (Fig. 1). The Taylor Quarry outcrop samples were labeled K8Q-1 through K8Q-10, and the Kessel outcrop samples KSO-1 through KSO-12. At the outcrop localities in Keokuk County, Iowa, stratigraphic sections were measured and described and samples were collected from each bed (Figs. 2.1 and 2.2). The basal limestone of the Pella at these exposures is no more than a few meters thick and allowed for detailed examinations. Both sections were measured and described previously by McKay and others (1987).

The Pella core was from a coal exploration well drilled in October, 1974 (SW¼, SE¼, SE¼, Sec. 36, T.71N., R.13W., Wapello County, Iowa) (Fig. 1). These samples are CP05-1 through CP05-10. It is important to note that the CP05 samples were numbered from the top downward and sample numbers increase with core depth, whereas the KSO and K8Q sample numbers increase up section. The CP05 core includes Pleistocene till, Pennsylvanian shale, and Mississippian limestone, sandstone, dolomite and shale. The Pella Formation is present at depths of 43.46 meters to 48.95 meters (details of this core are available from the Iowa Geological Survey's online GEOSAM database). A stratigraphic section of the core was made (Fig. 2.3), and 12 samples were collected and used for analysis.

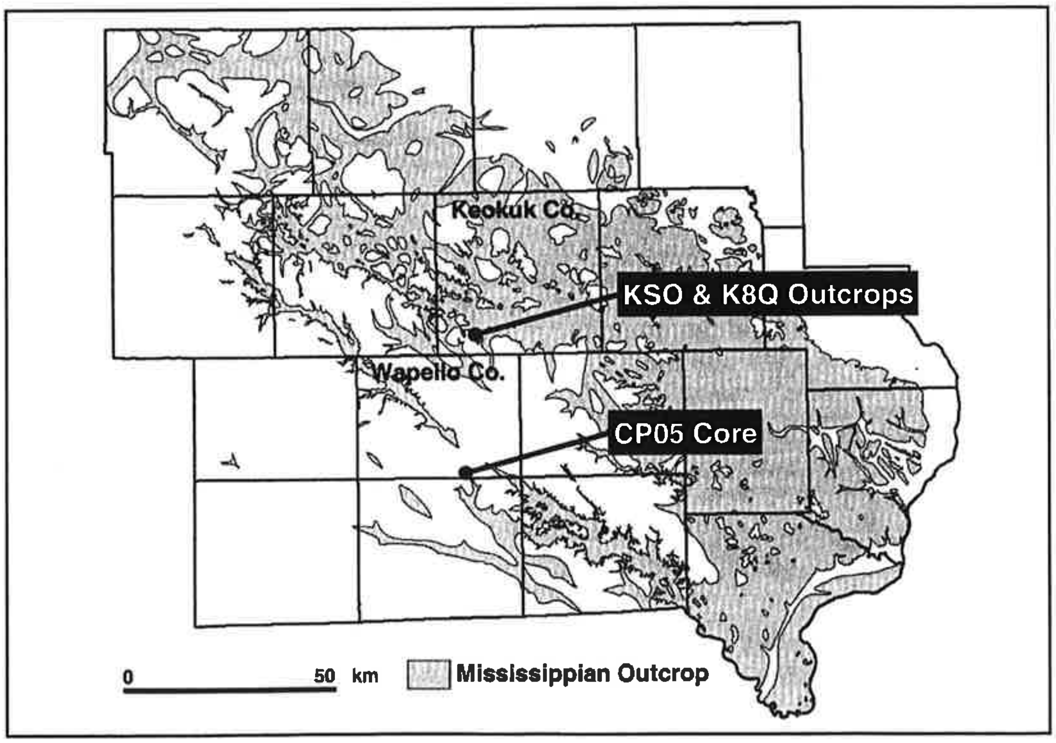



**Figure 1.** Index map to southeastern Iowa with surface distribution of Mississippian units shaded. Localities selected for sampling are highlighted in Keokuk and Wapello Counties. Map provided by B.J. Bunker (Iowa Department of Natural Resources, Geological Survey Bureau).

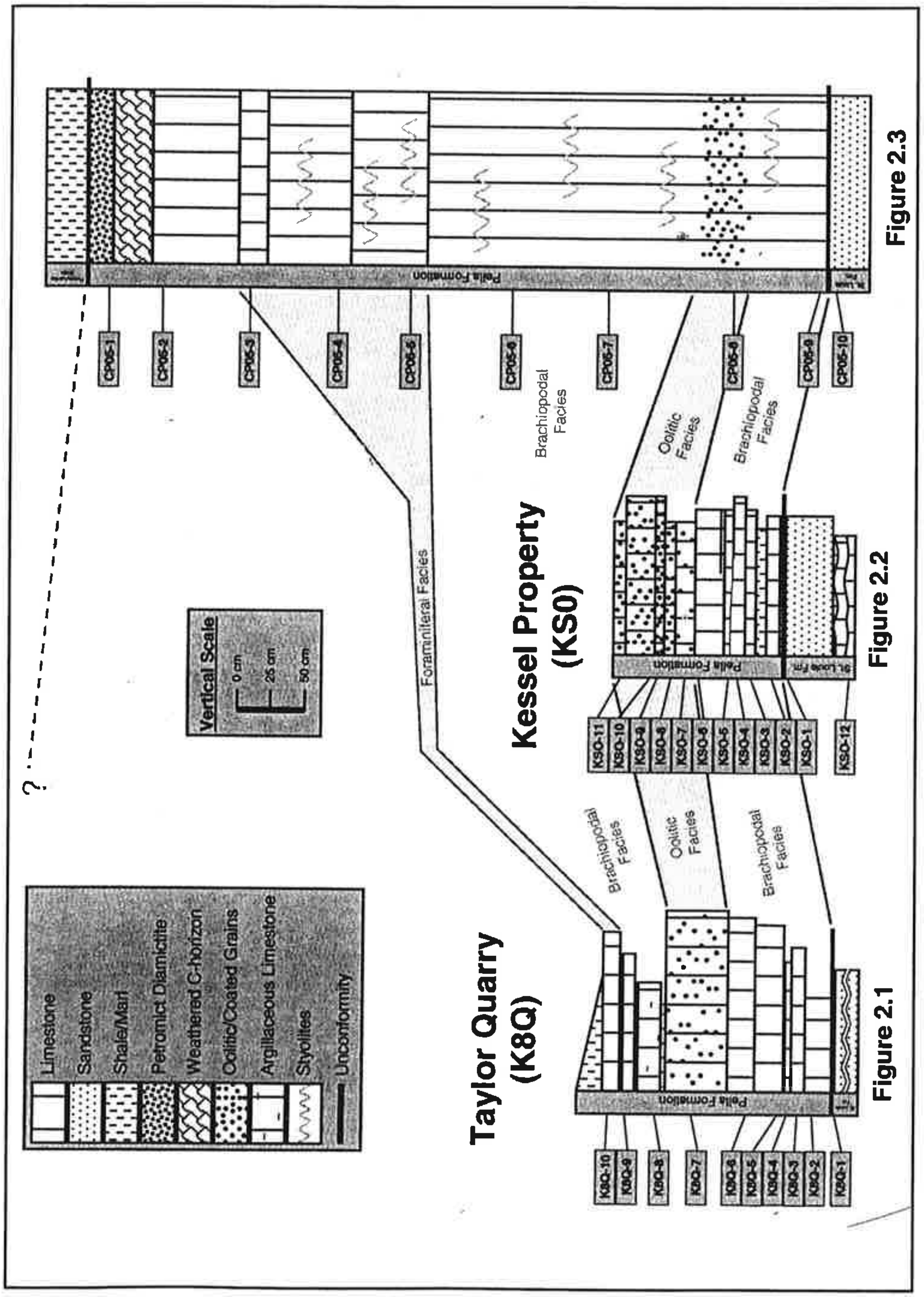



**Figure 2.** Stratigraphic sections and correlation of sampled localities. Samples and stratigraphic section for Taylor Quarry is Figure 2.1, Kessel Property is Figure 2.2 and Wapello County core is Figure 2.3.

## Lab Work

All 32 rock samples were thin sectioned to permit carbonate petrography, which involved identifying calcite cements, micrite matrix, and allochems. Each sample was assigned a rock name according to Robert Folk's classification of carbonate rocks (Folk, 1962). Results of petrographic analyses Table 1 allowed the recognition of several distinct lithofacies within the basal limestone portion of the Pella Formation. Photonegative prints were made of selected thin sections in order to illustrate the lithofacies. The prints were digitally scanned and inverted to result in positive images (Figs. 3.1–3.8).

Relative abundances of allochems, the principal basis for distinguishing lithofaices, were determined by visual estimation rather than systematic point-counting. Some degree of error is inherent in this approach. The lithofacies are sufficiently distinct, however, that observational errors are unlikely to affect the main conclusions of this work.

## OBSERVATIONS

### "St. Louis" Formation

Below the Pella Formation is a unit of quartz arenite sandstone from the Waugh Member of the "St. Louis Formation" (McKay et al., 1987). This unit is a marker bed for identifying the base of the Pella Formation. The sandstone is present beneath the Pella Formation at all localities studied. Below the sandstone is a limestone which is well exposed at the Taylor Quarry (Fig. 2). A sample from this limestone (KSO-12) contained few bioclasts (Table 1). McKay and others (1987) inferred that the "St. Louis Limestone" formed in a lacustrine setting. Additionally, the sandstone beneath the Pella Formation and above the "St. Louis Formation" is a nonmarine plant-bearing bed. The observations noted in the current research indicate that the uppermost "St. Louis Limestone" is compositionally different than the overlying Pella Formation, which is in agreement with prior research. According to McKay and others (1987), the "St. Louis" in Iowa is lithologically distinct from the type St. Louis, and the Iowa unit probably should be given a new name.

### Pella Formation

The Pella Formation contains diverse marine fossils in contrast to the Waugh Member of the "St. Louis Formation" which contains few bioclasts. The bioclasts that are easily recognizable in thin section from the Pella Formation are arthropods (trilobites and ostracodes), bivalves, brachiopods, bryozoans, echinoderms (crinoids and blastoids), foraminifera, gastropods, mollusks, and pellets (Table 1). Two major facies—brachiopodal (Figs. 3.1–3.3) and oolitic (Figs. 3.4–3.6)—were identified in thin section. Other facies are less abundant (foraminiferal [Figs. 3.7 and 3.8] and echniodermal). Each locality exhibits well defined brachiopodal and oolitic facies, yet the transition from brachiopodal to oolitic facies is gradational.

At the Taylor Quarry, about 45 cm of well-cemented quartz sandstone unconformably underlies the Pella Formation (Fig. 2.1). The basal bed of the Pella Formation is an argillaceous, thinly laminated limestone that contains sparse bioclasts (brachiopods and ostracodes). Diversity of brachiopods increases dramatically in the overlying 57 cm of the unit. For the next 41 cm, the brachiopods decrease and ooids increase to a maximum abundance in sample K8Q-7. Above that there is a 19 cm shaley and argillaceous limestone bedset. The next bed of limestone is assigned to the brachiopodal facies. The highest sampled bed, K8Q-10, contains an abundance of foraminifera.

At the Kessel outcrop (site KSO), the "St. Louis Limestone" is partially exposed (Fig. 2.2). Its top contains 36 cm of medium grained quartz sandstone. The lowest limestone bed of the Pella Formation occurs between two rubbly shale and shaley limestone units. As with the Taylor Quarry section, the lowest 10 cm bed contains sparse bioclasts (mostly brachiopods, bryozoa and echinoderms). For the next 58 cm, brachiopod diversity increases up section, reaching a maximum abundance in sample KSO-5. The upper 45 cm of the unit is the oolitic facies. Ooids reach a maximum abundance in the uppermost exposed bed, sample KSO-11.

The Wapello County core locality (CP05) is about 32 kilometers from the KSO and K8Q outcrops. Greenish gray quartz sandstone of the "St. Louis Formation" uncon-

**Table 1.** Allochem abundance percentage and rock names for each sample.

| Sample | Name | N | Fo | By | Br | A | P | E | G | Oo | Ot |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KSO-1 | Quartz Arenite | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| KSO-2 | Brachiopodal Biomicrite | 80 | 0 | 3 | 10 | 1 | 1 | 5 | 0 | 0 | 0 |
| KSO-3 | Brachiopodal Biomicrite | 60 | 0 | 0 | 25 | 1 | 5 | 0 | 5 | 0 | 3 |
| KSO-4 | Brachiopodal Biomicrite | 40 | 1 | 0 | 50 | 0 | 5 | 0 | 1 | 0 | 2 |
| KSO-5 | Brachiopodal Biomicrite | 20 | 2 | 0 | 65 | 1 | 1 | 0 | 5 | 0 | 8 |
| KSO-6 | Brachiopodal Biomicrite | 40 | 0 | 0 | 40 | 1 | 5 | 0 | 10 | 0 | 4 |
| KSO-7 | Brachiopodal Biomicrite | 30 | 0 | 0 | 40 | 0 | 5 | 5 | 5 | 10 | 5 |
| KSO-8 | Oolitic Biomicrite | 30 | 0 | 0 | 25 | 5 | 5 | 10 | 0 | 20 | 5 |
| KSO-9 | Oolitic Biomicrite | 20 | 0 | 5 | 20 | 5 | 1 | 15 | 0 | 30 | 4 |
| KSO-10 | Skeletal Oomicrite | 10 | 0 | 0 | 15 | 8 | 2 | 20 | 0 | 40 | 5 |
| KSO-11 | Skeletal Oomicrite | 15 | 5 | 0 | 10 | 5 | 5 | 5 | 1 | 50 | 4 |
| KSO-12 | Micrite | 95 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 |
| Sample | Name | N | Fo | By | Br | A | P | E | G | Oo | Ot |
| K8Q-1 | Quartz Arenite | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| K8Q-2 | Biomicrite | 90 | 0 | 0 | 5 | 2 | 2 | 0 | 0 | 0 | 1 |
| K8Q-3 | Brachiopodal Biomicrite | 65 | 2 | 0 | 20 | 1 | 2 | 0 | 7 | 0 | 3 |
| K8Q-4 | Fossiliferous Marl | 25 | 0 | 0 | 50 | 2 | 15 | 0 | 4 | 0 | 4 |
| K8Q-5 | Brachiopodal Biodismicrite | 20 | 0 | 0 | 63 | 2 | 1 | 1 | 5 | 0 | 8 |
| K8Q-6 | Brachiopodal Biomicrite | 40 | 0 | 0 | 30 | 5 | 1 | 5 | 1 | 10 | 8 |
| K8Q-7 | Skeletal Oomicrite | 30 | 0 | 0 | 18 | 3 | 2 | 5 | 2 | 35 | 5 |
| K8Q-8 | Brachiopodal Biomicrite | 50 | 2 | 5 | 15 | 10 | 1 | 10 | 0 | 2 | 5 |
| K8Q-9 | Brachiopodal Biomicrite | 45 | 3 | 1 | 20 | 15 | 5 | 5 | 0 | 5 | 1 |
| K8Q-10 | Foraminiferal Biomicrite | 70 | 15 | 0 | 5 | 0 | 2 | 7 | 0 | 0 | 1 |
| Sample | Name | N | Fo | By | Br | A | P | E | G | Oo | Ot |
| CPOS-10 | Quartz Arenite | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CPOS-9 | Brachiopodal Biomicrite | 85 | 0 | 0 | 11 | 1 | 1 | 0 | 1 | 0 | 1 |
| CPOS-8 | Skeletal Oomicrite | 14 | 0 | 0 | 10 | 5 | 1 | 15 | 0 | 45 | 10 |
| CPOS-7 | Brachiopodal Biomicrite | 55 | 1 | 5 | 20 | 5 | 1 | 5 | 0 | 3 | 5 |
| CPOS-6 | Brachiopodal Biomicrite | 71 | 1 | 5 | 6 | 5 | 1 | 5 | 1 | 0 | 5 |
| CPOS-5 | Foraminiferal Biomicrite | 25 | 22 | 0 | 15 | 10 | 3 | 19 | 0 | 1 | 5 |
| CPOS-4 | Foraminiferal Biomicrite | 40 | 15 | 5 | 15 | 7 | 1 | 12 | 0 | 0 | 5 |
| CPOS-3 | Foraminiferal Biomicrite | 20 | 18 | 8 | 12 | 4 | 4 | 15 | 1 | 1 | 17 |
| CPOS-2 | Sparite | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CPOS-1 | Coarse soil residue | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**NOTES:**

1) *Italicized samples* are not part of the Pella Formation, but collected to compare with the Pella Formation.
2) Column name descriptions:
   - **N**…includes micrite and sparry calcite, but mostly quartz sand grains
   - **F**…includes foraminifera
   - **By**…includes branching bryoza
   - **Br**…includes all the variety of brachiopods seen in the formation
   - **A**…includes trilobite and ostracode fragments
   - **P**…includes pellet fragments
   - **E**…includes crinoids and blastoids
   - **G**…includes gastropods
   - **Oo**…includes oolitic and coated grains seen in the formation
   - **Ot**…includes calcareous worm tubes and other features seen in the formation.
3) CP05 sample names start from 10 and go to 1 due to the fact the samples were collected from a core.

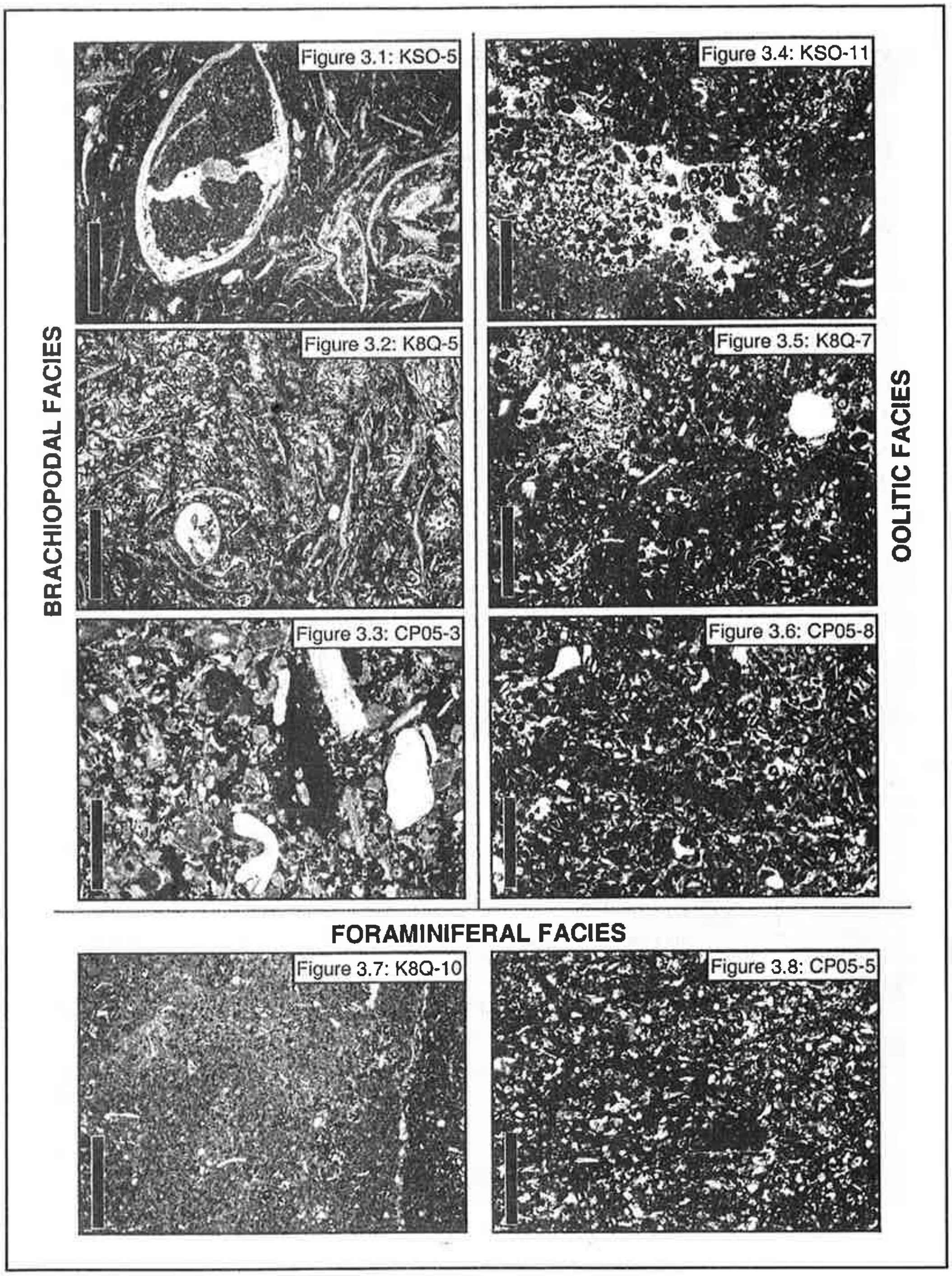



**Figure 3.** Thin section photos for each bio-facies. Scale bar in all photos is 0.3175 cm.

formably underlies the Pella Formation (Fig. 2.3). Individual bedding planes are indistinct within the core, therefore numerous samples were taken from each bed or bedset. The lowest 30 cm of the Pella Formation contain sparse bioclasts, mostly brachiopods. Above that, there is approximately 75 cm of rock dominated by oolitic grains (CP05-8). For the next 185 cm, the brachiopod facies is present, with the abundance of brachiopods decreasing up section. Core samples CP05-3 through CP05-5 display the 138-cm-thick foraminiferal facies that overlies the brachiopod facies. The next unit is a 63-cm-thick allochem-poor fine-grained sparry limestone with greenish shale streaks. Above the limestone, a 46 cm interval consists of orange altered bedrock overlain by what appears to be a coarse paleosol residue. An unconformity separates the paleosol residue from an overlying Pennsylvanian-age black shale.

Table 1 shows the distribution of allochems in samples from the three sections of the Pella Formation. Generally, skeletal allochem diversity and abundance increase up section, whereas the relative abundance of quartz sand grains decreases up section. As quartz abundance decreases, brachiopod diversity increases to a peak, and then diminishes; and oolitic or coated grains appear. In the Wapello County core, foraminifera abundance increases as brachiopod abundance decreases.

Up section in the brachiopodal facies of the Pella Formation, the micritic matrix decreases drastically. This matrix is replaced by more and different allochems. Foraminifera abundance is extremely high in the core, whereas it is significantly lower in the Keokuk County outcrops. As the oolitic facies become dominant in the formation, facies become progressively more micrite-rich up section at all three localities.

The sub-Pella unconformity (McKay et al., 1987) is evident in the core from Wapello County. This basal unconformity is observable in the Taylor Quarry and Kessel outcrops as well. The core from Wapello County additionally contains an upper unconformity. The upper 46 centimeters of the Pella contain two separate units, a lower altered unit and an upper petromict diamictite. The lower bed is a rubbly, orange horizon that is approximately 28-cm-thick. The 18-cm-thick diamictite unit above it contains deeply weathered fragments in a micritic matrix. Above the diamictite is a significant unconformity that corresponds to the Mississippian-Pennsylvanian systemic boundary.

## INTERPRETATION

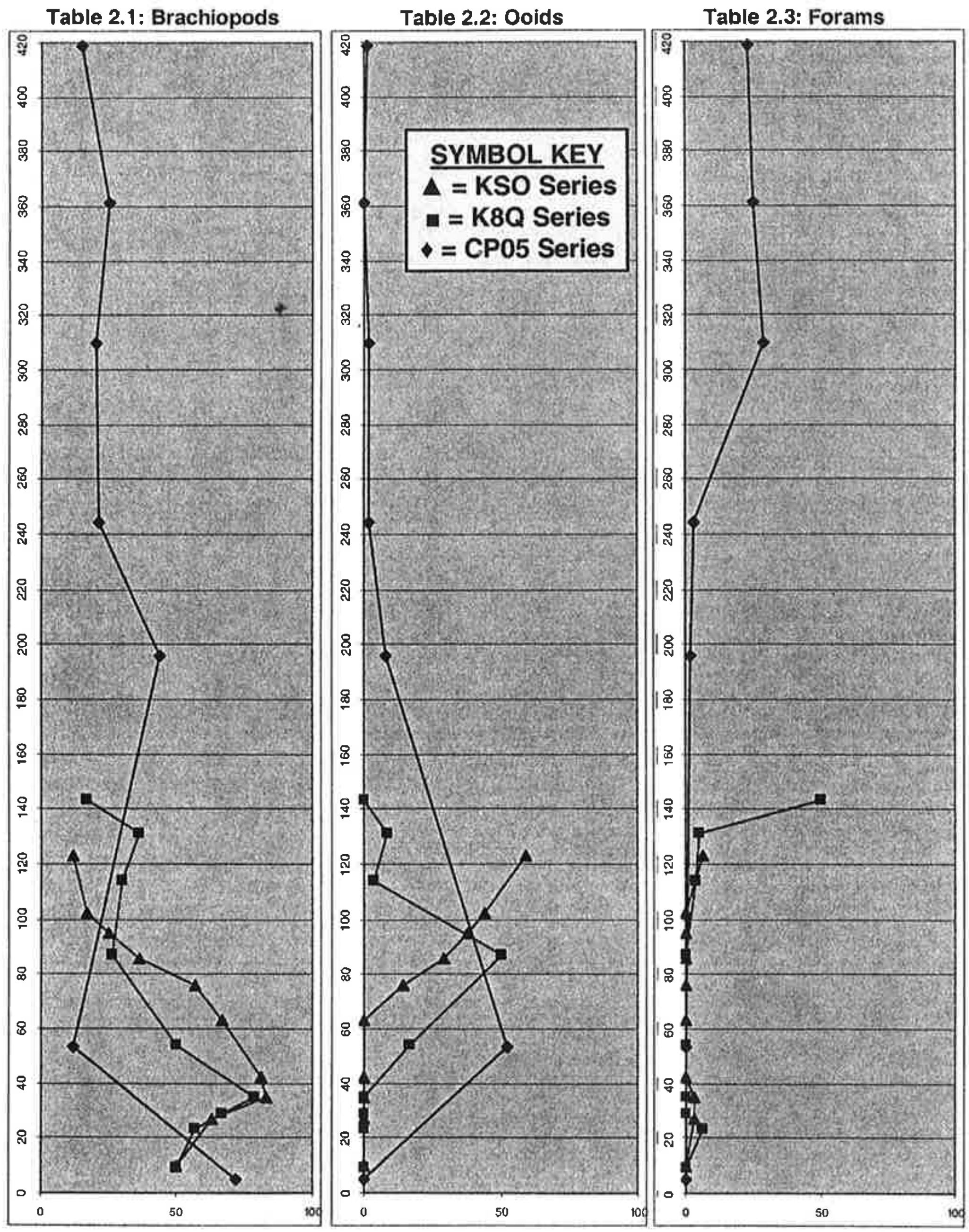
The increase in diversity and quantity of bioclasts and decrease of quartz sand grains up section, the Pella Formation possibly represents a transgression of Ste. Genevievian seas into Iowa. The basal unconformity of the Pella Formation separates nonmarine plant-bearing sandstone of the "St. Louis Formation" and marine brachiopod-bearing limestone of the Pella. McKay and others (1987) wrote that the sandstone contains "Stigmaria root casts on base." One of the thin sections studied in this project contains plant debris in the quartz sandstone.

The unconformity at the top of the Pella Formation records the sub-Pennsylvanian erosional surface. On top of this horizon is a petromict diamictite (conglomerate) with fragments in a fine micritic matrix. These two beds are interpreted as remnants of a soil that developed on the sub-Pennsylvanian surface following the regression of the Ste. Genevievian Sea. A mature soil most likely developed on the Mississippian surface of the Pella Formation, but was partly washed away and reworked when Pennsylvanian seas transgressed.

This project substantiates prior work and indicates that the Pella is the depositional record of a transgressive–regressive cycle. An additional focus of this project was the correlation of Pella Formation lithofacies across different localities. The two Keokuk County exposures occur within a kilometer of each other, whereas the core is located approximately 32 kilometers to the south (Fig. 1). As expected, facies correlation for the Keokuk County exposures is straightforward. Correlation with the Wapello County core is less straightforward. Table 2 shows the relative abundances of allochems versus depth from the base of the Pella Formation.

The basal limestone bed of the Pella Formation is dominated by sparse bioclasts (mostly brachiopods, echinoderms, ostracodes and other grains) in a micritic matrix. The source of the micrite is most likely from calcareous algae. The paucity of allochems in the unit suggests that it formed in either a marginal marine setting or newly marine

**Table 2:** Graphs showing normalized percentages of allochems at all three localities sampled. X-axis is the percentage abundance and Y-axis is depth from base of Pella Formation in centimeters.



environment in which normal marine organisms were not yet fully established. As deposition continued, the micritic matrix became relatively less abundant, and bioclast diversity increased. This increase in biologic remains may represent a trend toward normal marine sedimentation.

Modern foraminifera flourish in salinity settings from 20 to 50 parts per thousand (‰) and brachiopods tolerate only normal marine salinities of 30 to 40‰ (Heckel, 1972). Stratigraphic trends in bioclast type and abundance within the Pella Formation, when compared with modern ecologic data, indicate that establishment of increasingly more normal marine conditions from the base of the formation through at least the upper brachiopodal facies.

Brachiopodal and oolitic abundances exhibit interesting trends. In the lower 100 cm, a similar pattern is seen in both the brachiopods and ooids at all sites. Abundances start low and then increase to 70–80 parts per hundreds (%) for brachiopods and about 50% for ooids at their respective maximum abundances. Foraminiferal abundance trends are not as well defined, but a general increase in the numbers of forams is observed up section. This is especially true at the Kessel locality and in the core samples, but not in the Taylor Quarry samples. The graphs show no obvious trends among other allochems. Thus, the best way to correlate the Pella Formation facies from locality to locality is with brachiopodal and oolitic facies.

Almost all thin sections studied from the upper portion of the lower Pella Formation contain oolitic grains in a micritic matrix. Usually ooids are found in clear water, high energy environments. The oomicritic intervals of the Pella Formation could record storm events, in which water became turbid, mixed a variety of grains and lime mud, and then became quiet again, allowing settling of a poorly sorted range of particles. Oolitic grains form "where strong bottom currents and agitated water conditions exist and where saturation levels of calcium bicarbonate are high" (Boggs, 2001). It has been previously interpreted that the brachiopodal facies of the Pella Formation records a deepening environment (Anderson, 2004). The presence of oolitic grains in the Pella could indicate either a regressive interval (deposition near a shoal) or a series of storm deposits. Witzke *(in* Anderson, 2004, p. 63) noted that at the Lacey–Keosauqua State Park in Van Buren County, "the upper part of the Pella shows an upward loss of brachiopods" and that "the upward increase in mud content and the upward increase in packstones and grain abrasion characterizes a shallowing-upward succession, ranging from subtidal deposition into more turbulent shallow-marine shoals or strongly storm-influenced settings." Increased abrasion of grains up-section in the Pella was noted in samples collected from the three localities for this study and shows a similar pattern for the Pella Formation across southern Iowa.

## CONCLUSION

This study supports previous interpretations of the lower Pella Formation as the record of the transgression of the Ste. Genevievian Sea. This project has identified brachiopodal and oolitic facies that allowed lithostratigraphic correlation of three different localities across the southeastern portion of the state. As water depth increased, a diverse assemblage of life flourished in the shallow waters. Ultimately, the sea regressed and the Pella was exposed to subaerial weathering and pedogenesis. To the author's knowledge, this is the first study to present evidence of an ancient soil at the top of the Pella.

## ACKNOWLEDGMENTS

This study would not have been possible without assistance from Brian Witzke, Bill Bunker, and David Pals from the Iowa Geological Survey in allowing the use of the Pella core from Wapello County. Financial assistance for this project was provided by the Student Opportunities for Academic Research (SOAR) program, provided by the College of Natural Science at the University of Northern Iowa. Dr. James Walters at UNI proofread a manuscript of the research and offered constructive criticism. Dr. John Groves at UNI was a very important advisor for this project, assisting in every aspect and answering the never-ending barrage of questions. Robert F. Diffendal, Sr., and Jack Beuthin critically reviewed the manuscript.

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