Microfossil fauna from the Blue Earth Siltstone of the Lower Ordovician Prairie du Chien Group, Minnesota, USA

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Senior Integrative Exercise
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ABSTRACT

The white to green, thinly laminated, argillaceous, feldspathic siltstone known as the "Blue Earth Siltstone bed," can be found at the base of and within solution cavities of certain exposures of the Oneota Dolomite, part of the Lower Ordovician Prairie du Chien Group. This siltstone, present in outcrops near Mankato, Minnesota, is of undetermined origin and contains a poorly understood fossil fauna. Two localities of the Blue Earth Siltstone were sampled for microfossil analysis, one featuring the shaley fill of solution cavities in the lowermost Oneota and the other featuring a flat lying, laminated siltstone bed located between the Oneota and the underlying Jordan Sandstone. Fossil groups present include conodonts, sponges, brachiopods, gastropods, crinoids, and trace fossils. Most identified conodont species correspond with those described in previous studies (Furnish, 1938; Ray and Ethington, 1983) and are within the Rossodus manitouensis conodont biozone from the Skullrockian Stage of the Ibexian Series (Lower Ordovician). Characteristics of the fossil fauna of the Blue Earth Siltstone provide evidence that the siltstone was deposited as a primary sedimentary unit prior to the deposition of the surrounding Oneota Dolomite.

Keywords: Prairie du Chien, microfossils, Blue Earth Siltstone, Minnesota, Lower Ordovician, conodont, sponge

INTRODUCTION

Portions of the Lower Ordovician Prairie du Chien Group Dolomite near Mankato, Minnesota contain solution features filled by a white to green, argillaceous, feldspathic siltstone known as the “Blue Earth Siltstone.” The name “Blue Earth Siltstone” is also used to refer to a seemingly in-place layer of similar white to green laminated siltstone situated between the Late Cambrian Jordan Sandstone and the Oneota Dolomite in the Ottawa-St. Peter-Mankato area (Stauffer and Thiel, 1941). An unconformity marks the top of the Jordan Sandstone. The Oneota Dolomite above was deposited during a period of transgression (Smith et al., 1993). The role which the Blue Earth Siltstone played during these environmental changes is inconclusive, and it is unclear whether the siltstone is a primary or secondary deposit.

The presence of conodont elements in the Blue Earth Siltstone has been noted by Furnish (1938) and Repetski and Ethington (1983). The conodont species identified are within the *Rossodus manitoensis* conodont biozone from the Skullrockian Stage of the Ibexian Series, within the Lower Ordovician (Repetski and Ethington, 1983). Few macrofossils have been described in the karst feature fill, the most notable being linguloid brachiopods of undetermined genera (Stauffer and Thiel, 1941). This report focuses primarily on the microfossil content of the Blue Earth Siltstone. This is a qualitative microfossil survey whose main purpose is to expand the known fossil faunal assemblage of the Blue Earth Siltstone, and by doing so provide some insight into the siltstone’s origin.

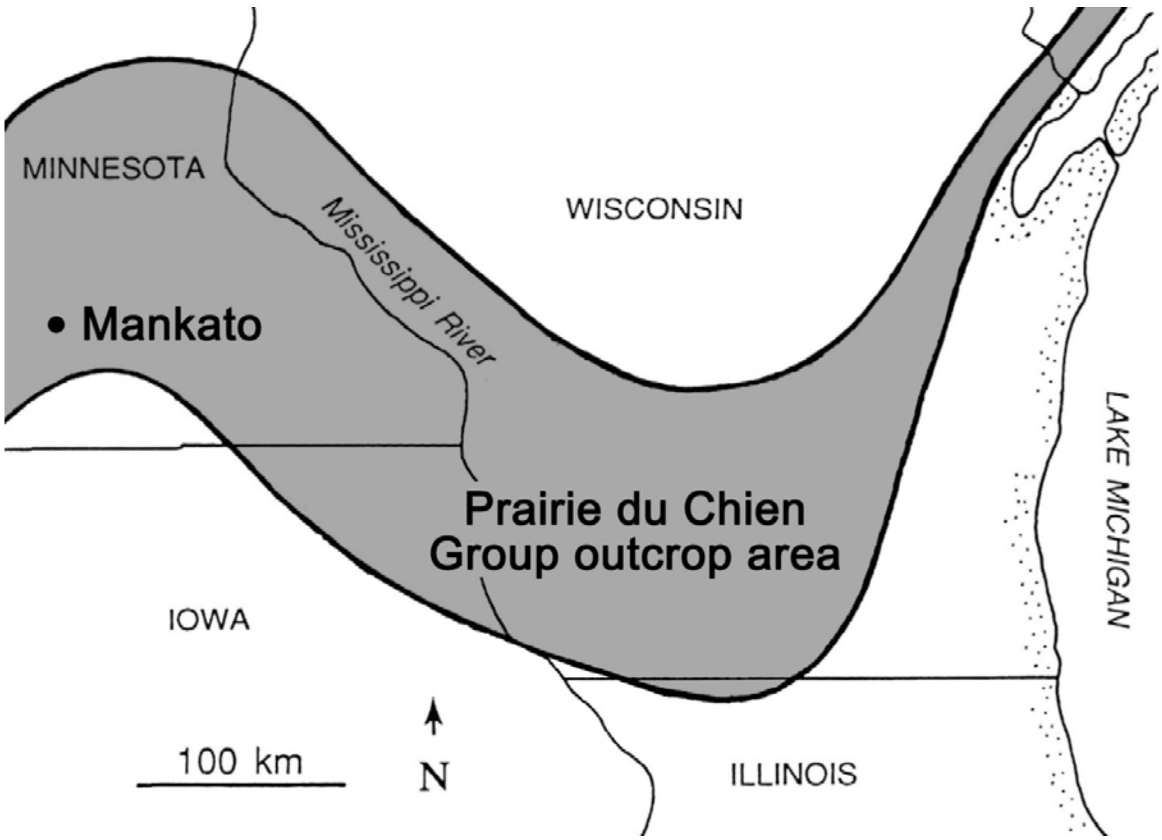

Figure 1. Map showing much of the extent of the Prairie du Chien Group outcrop area (shaded). The location of the samples in Mankato, Minnesota, is marked. Modified from Smith and Clark (1996).

GEOLOGIC SETTING

The Prairie du Chien Group is a collection of carbonates and siliclastic sediments deposited during early Ordovician time (488.3 ± 1.7 to 471.8 ± 1.6 Ma; Gradstein et al., 2004) in a shallow marine environment within the Hollandale embayment, a structural basin bordered by the Transcontinental Arch to the north and west and by the Wisconsin Arch to the north and east (Smith et al., 1993). The Prairie du Chien group is bounded unconformably by the Upper Cambrian Jordan Sandstone below and the Middle Ordovician St. Peter Sandstone above. In the Mankato area, the Prairie du Chien is about 70 to 76 meters thick, except in places where its upper bedrock has been eroded (Mossler, 2008). The Prairie du Chien is exposed in Minnesota, Wisconsin, Iowa, northern Illinois, and northern Michigan (Fig. 1; Smith and Clark, 1996).

The Prairie du Chien is divided into two formations: the lower Oneota Dolomite and the upper Shakopee Formation (Fig. 2). The Oneota Dolomite is mainly composed of thick beds of very fine grained dolostone with some siliciclastic interbeds in its lower layers, and is about 15 meters thick in the Mankato area (Mossler, 2008). The Oneota is made up of the Hager City and Coon Valley members. The Hager City member is a thickly bedded, finely crystalline dolostone, while the lower Coon Valley member consists of The Blue Earth Siltstone and a light gray, medium to coarse grained quartz sandstone informally known as the “Kasota Sandstone.” The Shakopee Formation is composed of more thinly bedded sandy dolostone, oolitic dolostone, sandstone, shale, and dolomudstone. Thrombolites are common in the Oneota and stromatolites are found throughout the Prairie du Chien Group (Tipping et al., 2006). Fossils are generally rare in the Prairie du Chien, usually only appearing in chert nodules (Howell and Landes, 1936).

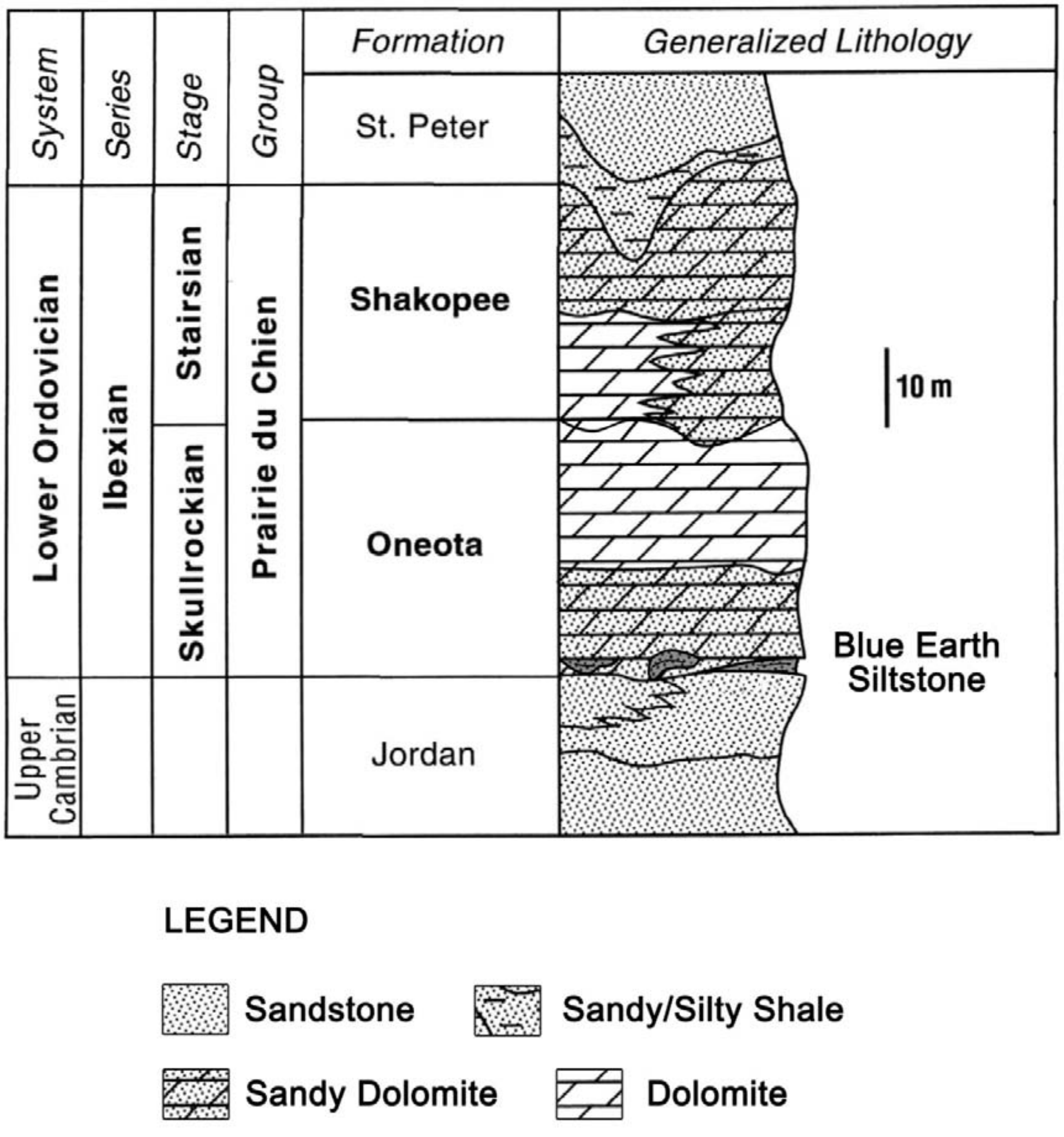

Figure 2. Generalized stratigraphic column showing the Prairie du Chien Group and associated strata. The boundaries between the St. Peter and the Shakopee, the Shakopee and the Oneota, and the Oneota and the Jordan are all unconformities. The Blue Earth Siltstone beds are shaded in dark gray. Modified from Smith and Clark (1996).

Abundant fossil fauna may have once existed in these sediments, but most fossil material could have been destroyed by extensive dolomitization (Smith et al., 1993).

Karst Features

Two episodes of major karst dissolution took place in southern Minnesota during the Ordovician Period, each affecting the Prairie du Chien. These karst processes occurred at or near the water table and saltwater interface and under relatively stable geologic conditions (Tipping et al., 2006). The first major dissolution episode occurred before deposition of the Shakopee Formation. Subareal exposure of the Oneota Dolomite caused extensive weathering and dissolution for approximately five million years (Smith et al., 1996; Tipping et al., 2006). Later, during the end of Shakopee Formation deposition, the area underwent roughly fifteen million years of subareal exposure. This second period of subareal exposure likely reactivated and expanded many of the karst features formed earlier. (Tipping et al., 2006) In some areas, the cavities created by Ordovician karst dissolution in the Oneota Dolomite have been partly or entirely filled with sediment.

Blue Earth Siltstone

Winchell (1874) described the fill of karst features in the lowermost Oneota along the Minnesota River as a silty shale. He thought the sediment to be Cretaceous silt that had descended down through cracks in the dolostone to fill the solution cavities. Stauffer and Thiel (1941), when observing the same features, suggested that the fine silty shale of the fill might have originated as parts of the floors of the solution cavities, and referred to it as a siltstone. Later this material was squeezed into cracks and joints in the Oneota Dolostone as the cavities collapsed and the bulk of the rock settled downward. Stauffer and Thiel reasoned that if the silt had been deposited in the Cretaceous and flowed down, as it would most likely have continued down into the Jordan Sandstone and not stopped to follow the contact between the Jordan and the Oneota. They also observed that the siltstone immediately below the Oneota was flat lying and undisturbed whenever the Oneota itself was flat lying and undisturbed, and concluded that "the shale shows every evidence of a deposit in place between the sandstone and the dolomite." The siltstone cavity fill and the flat lying shale previously mentioned have both been referred to as the Blue Earth Siltstone. Stauffer and Thiel (1941) described the siltstone as rarely exceeding a thickness of two feet (~60 cm) and "usually thinner, except as a filling in cavities or nearly vertical fissures."

Conodont elements found within the Blue Earth Siltstone have been correlated to the *Rossodus manitouensis* conodont biozone (Repetski and Ethington, 1983), also known as the *Loxodus bassleri* interval (Smith and Clark, 1996). This places the bed within the middle to upper part of the Skullrockian Stage of the Ibexian Series, which is in the earliest part of the Ordovician (Repetski and Ethington, 1983; Smith and Clark, 1996; Gradstein et. al, 2004). Joe Beer (2003) also reported conodonts from the *R. manitouensis* biozone within the Blue Earth Siltstone in an unpublished undergraduate thesis. Beer also noted the presence of sponge spicules and gastropods. The youngest conodonts in the Jordan Sandstone below the Oneota in the Mankato area are from the *Fryxellodontus inornatus* conodont biozone, which is lower in the Skullrockian Stage than the *R. manitoensis* zone (Runkel et al., 1999).

METHODS

A total of seven sediment samples were collected for microfossil analysis from two well exposed localities just outside of Mankato, Minnesota. Six samples were taken from sediment-filled solution features in the lowermost Oneota at a site along the Minnesota River. One sample was taken from the second locality, a laminated siltstone bed along Highway 169, which appears to be in place between the Jordan Sandstone and the Oneota.

Sediment in each sample was broken into small chunks by hand (a couple of centimeters in diameter each) and soaked in a combination of water and Dawn dish soap for a few days. Once the siltstone was completely disaggregated, the resulting mud was washed through a series of nested sieves in three size fractions (210µm, 105µm, 63µm) in order to separate different sized fossils. Sediments from each sieve were allowed to dry overnight, and then placed in dishes for identification. For this study, only the largest size fraction (210µm) was used for microfossil analysis, as this fraction had the least fragmented and most identifiable material. Individual microfossil specimens were picked using a small round paintbrush under a binocular microscope and placed on carbon plates for identification using the Carleton College Hitachi S-3000N Scanning Electron Microscope. Additional microfossil specimens from the solution feature fill of the locality along the Minnesota River were provided by Tony Runkel of the Minnesota Geological Survey. Due to the size fraction for individual specimens and the overall small sample size, quantitative and systematic microfossil analysis was abandoned as it lies outside the scope of the present study.

MICROFOSSIL SURVEY RESULTS

The microfossil survey of the Blue Earth Siltstone yielded numerous fossil specimens, many of which were not easily identifiable. Most specimens are fragmented and nearly all of the non-conodont microfossils are chalky and weathered in appearance. Conodont elements and sponge spicules make up the vast majority of identifiable microfossils. Poorly preserved crinoid ossicles and fragments of gastropods and brachiopods were also identified, as well as one some indistinct burrows. Several fossils of unclear phylogenic association are also present.

Conodonts

Numerous conodont elements were found at both sites within the Blue Earth Siltstone. Conodont elements are tooth-like structures interpreted as part of the feeding apparatuses of conodonts, small, eel-shaped animals generally associated with vertebrates (Sweet and Donoghue, 2001). Nearly all of the conodont elements identified in survey were coniform, while only one was ramiform (Fig. 3). Similar to the conodonts reported by Smith and Clark (1996) in the Oneota and the Shakopee, the conodonts present in the Blue Earth Siltstone are well preserved and have an alteration index (CAI) of 1 (Epstein et al., 1977; Harris, 1981). Conodont species identified within the Blue Earth Siltstone during this study include *"Acanthodus" lineatus* Furnish (The taxonomy for *"Acanthodus"* in this instance is unsettled and is therefore referred to in quotation marks within this report), *Acanthodus uncinatus* Furnish, *Colaptoconus quadraplicatutus* Branson and Mehl, *Eucharodus parallelus* Branson and Mehl, *Loxodus bransoni* Furnish,

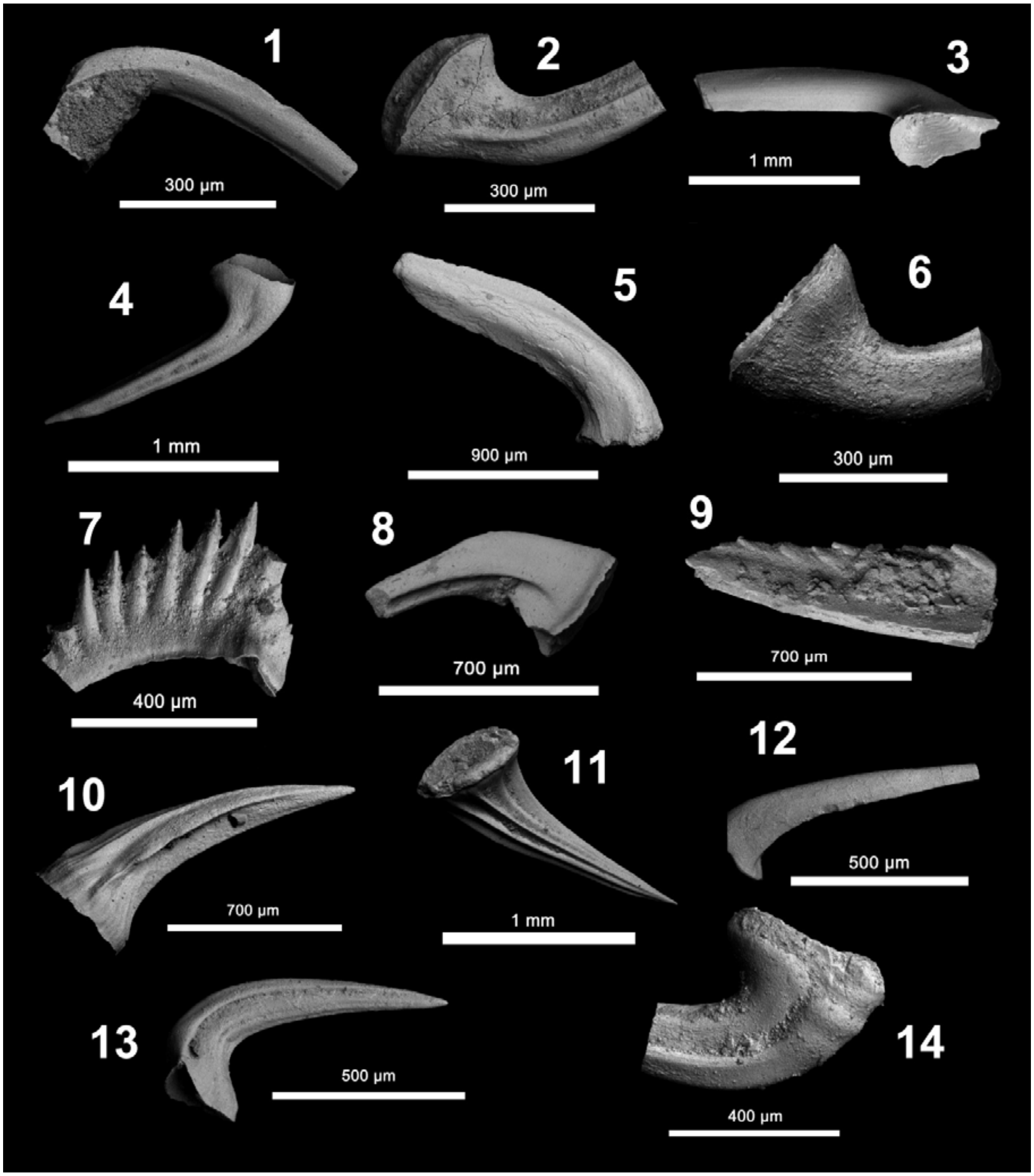

Figure 3. Conodont species identified in the Blue Earth Siltstone during this study: *"Acanthodus" lineatus* (1, 2), *Acanthodus uncinatus* (3), *Colaptoconus quadraplicatutus* (4), *Eucharodus parallelus* (5), ?*Laurentoscandodus triangularis* (6), *Iapetognathus landingi* (7, 8), *Loxodus bransoni* (9), *Polycostatus sulcatus* (10), ?*Polycostatus sulcatus* (11), ?*Utahconus longipineatus* (12), and *Variabiloconus bassleri* (13, 14). The specimen ?*Polycostatus sulcatus* (11) is not entirely clear, and is therefore listed with a question mark. Most conodont elements found are coniform, except for one specimen of *Iapetognathus landingi* (7), which is ramiform.

Iapetognathus landingi Nicoli, Miller, Nowlan, Repetski, and Ethington, ?*Laurentoscandodus triangularis* Furnish, *Polycostatus sulcatus* Furnish, ?*Utahconus longipineatus* Ji and Barnes, and *Variabiloconus bassleri* Furnish (Fig. 3; Ethington, 2010, personal communication). Specimens of *"Acanthodus" lineatus*, *V. bassleri*, and *P. sulcatus* were found at both sample sites. The specimens of ?*Laurentoscandodus triangularis* and ?*Utahconus longipineatus* are not entirely clear, and are therefore listed with a question mark. Overall, the conodont elements were the best preserved group of fossils, though some elements were still fragmented.

Sponges

Siliceous sponge spicules were the most commonly found fossils in the Blue Earth Siltstone. Nearly all of the spicules found were hexactine, meaning they possess six rays that are all at ninety degree angles with one another (Boardman, 1987; Laubenfels, 1955). Some of the spicules are acanthose (spiny), some are not (Fig. 4). Hexactine sponge spicules were abundant in the field site along the Minnesota River, but were completely absent from the site off of Highway 169.

Other Fossil Taxa

Both crinoid ossicles and fragments of gastropod shells were found within the Blue Earth Siltstone. Specimens of each were chalky and distorted, and therefore difficult to identify. The clearest fragments of gastropods were found within samples JBR-4 and JBR-6, while the clearest examples of crinoid ossicles were found in sample 169-7. Crinoid ossicles were much more common in sediments from the field site off of

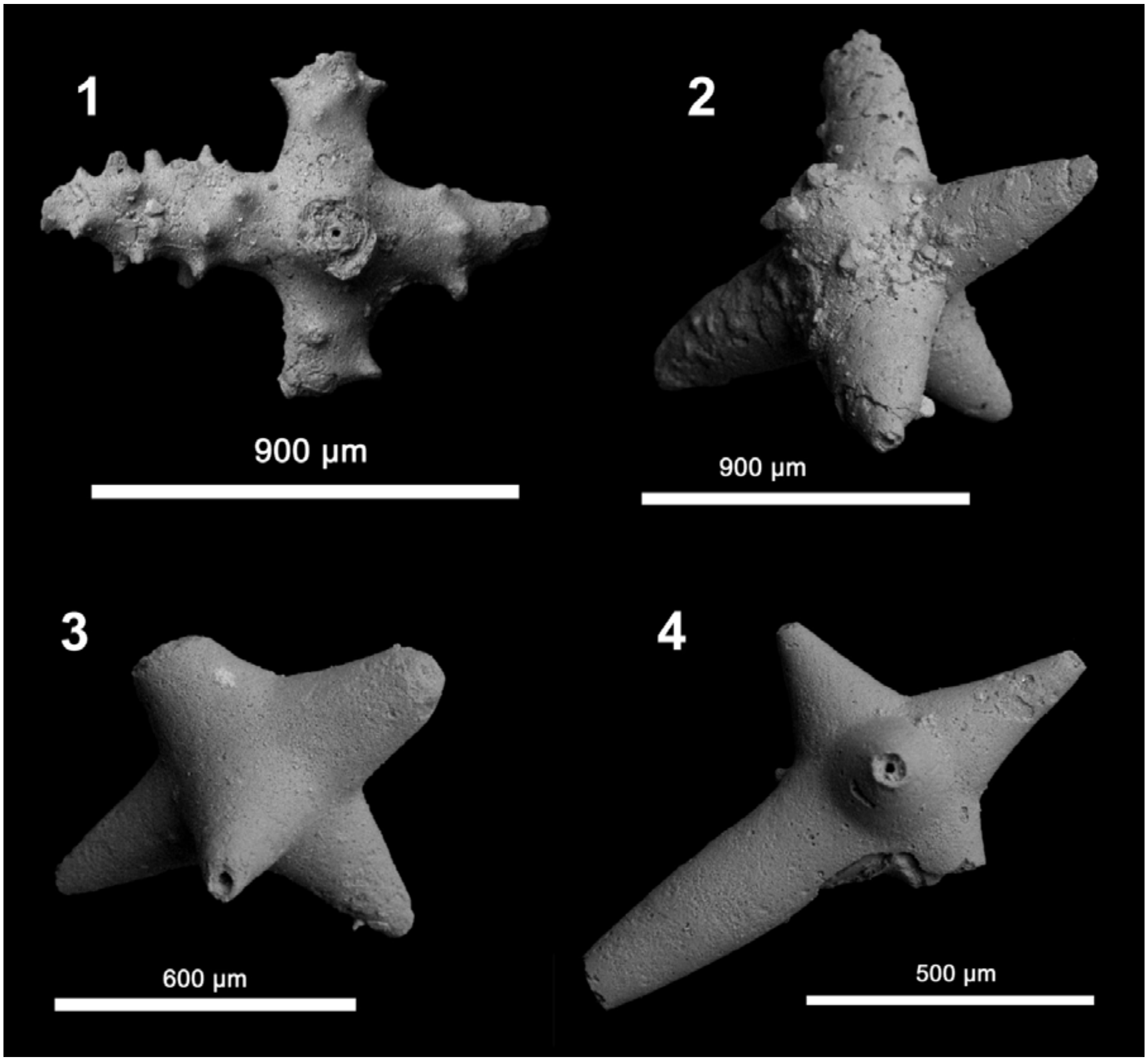

Figure 4. Sponge spicules found in the Blue Earth Siltstone. Acanthose, or spiny, (1) and non-acanthose (3, 4) spicules were both common. Many of the spicules found in the Blue Earth Siltstone are fragmented or weathered and battered in appearance (2).

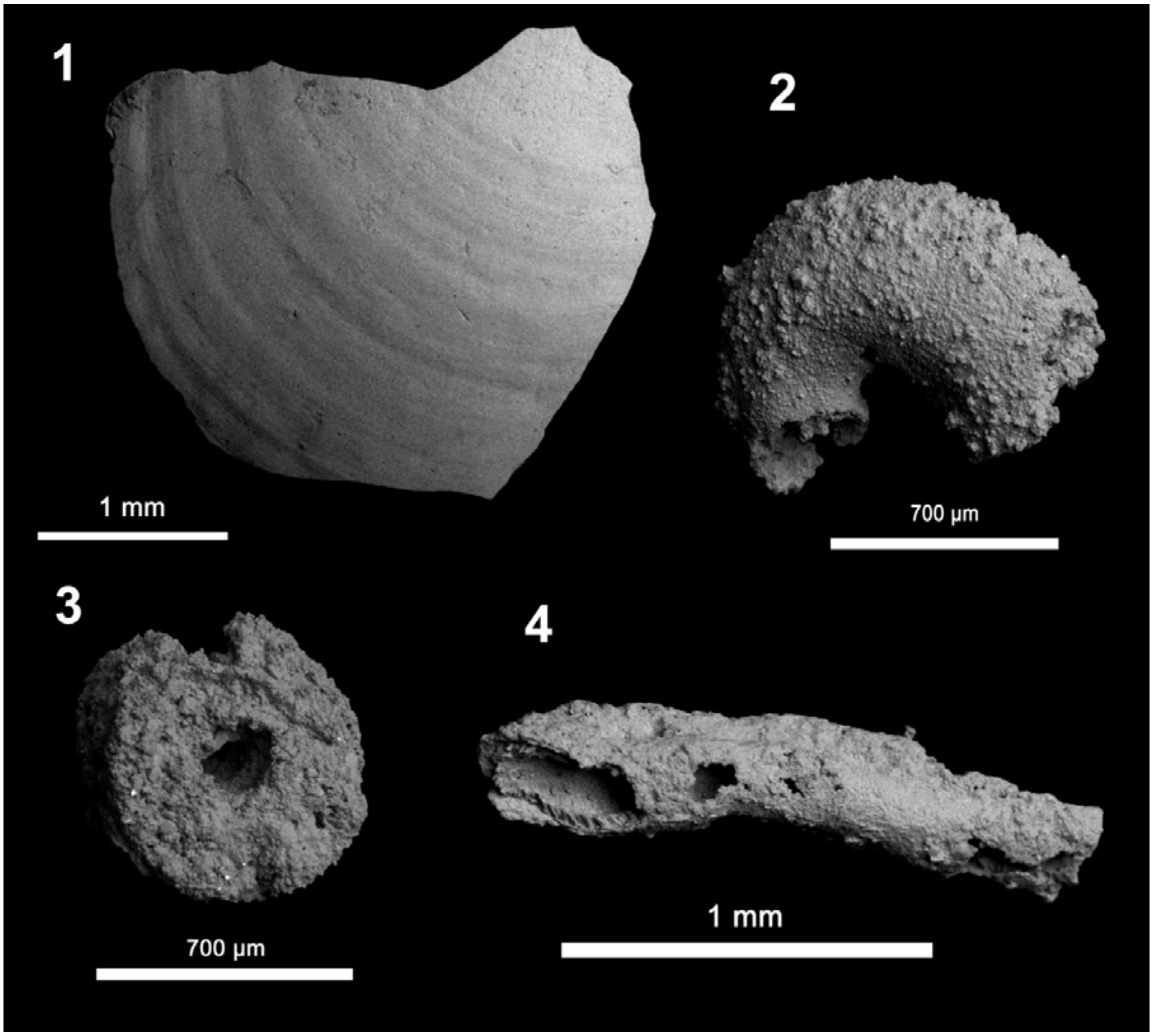

Figure 5. Among the macrofossils present within the Blue Earth Siltstone are (1) brachiopod fragments, (2) gastropod fragments, and (3) crinoid ossicles, all of which are poorly preserved and very weathered. Unidentified burrows such as depicted above (4) were also found within the sediment.

Highway 169 than in the solution cavity fill by the Minnesota River. Fragments of brachiopods were found to be present within the Blue Earth Siltstone as well. Burrows were also found during the course of the microfossil survey, though, as they are too small to be noticeable in the field, their orientation in the Blue Earth Siltstone *in situ* was not recorded (Fig. 5).

DISCUSSION

This survey of microfossils reveals the presence of conodonts, sponges, brachiopods, crinoids, and gastropods within the Blue Earth Siltstone. The fossil fauna uncovered in this survey is consistent with Early Ordovician deposition. The conodont species *L. bransoni*, *V. bassleri*, *P. sulcatus*, *A. uncinatus*, and *L. triangularis* are common representatives of the *Rossodus manitouensis* conodont zone. This places the Blue Earth Siltstone within the middle to upper part of the Skullrockian Stage of the Ibexian Series, during the earliest Ordovician (Repetski and Ethington, 1983).

Conodonts

All of the conodont species listed above have previously been noted in the Blue Earth Siltstone by Repetski and Ethington (1983) and by Furnish (1938). *Utahconus longipinnatus* has also previously been found in the Blue Earth Siltstone by Ethington (2010, personal communication). *Iapetognathus landingi* has been found associated with conodont species in the *R. manitouensis* zone, but has never been found in the Blue Earth Siltstone before. Previously this species was only known from the lower Ibexian Manitou Formation of Colorado (Ethington, 2010, personal communication).

Colaptoconus quadraplicatutus is typical of an assemblage of conodonts that are commonly found in the Shakopee, and is not included in other occurrences of the *R. manitouensis* zone (Ethington, 2010, personal communication). Furnish (1938) found *C. quadraplicatutus* in the Oneota Dolomite, but it has not been previously described in the Blue Earth Siltstone. *Eucharodus parallelus* is another species more common in younger materials than those found in the *R. manitouensis* zone. However, this species has been reported in the Blue Earth Siltstone by Furnish before, though it was referred to as *Drepanodus subarcuatus* (Furnish, 1938; Ethington, 2010, personal communication).

Conodonts appear to be more abundant in the Blue Earth Siltstone than in the dolomites of the Prairie du Chien Group overall. Conodonts have been described in the Prairie du Chien in numerous studies (Furnish, 1938; Guldenzopf, 1967; Miller and Melby, 1971; Clark and Babcock, 1971; Grether and Clark, 1980; Smith and Clark, 1996), but are generally only sparsely abundant within the formation. Smith and Clark (1996), for example, reported an average of less than one conodont element per kilogram of Prairie du Chien material studied. While qualitative analysis is out of the scope of this present survey of the Blue Earth Siltstone, it is noteworthy that most of the samples in this study yielded a much higher concentration of conodont elements than one per kilogram. Samples JBR-3, JBR-4, and JBR-6, from the solution cavity fill along the Minnesota River averaged five conodont elements per 200g, while 20 conodont elements were found in 200g of the Blue Earth Siltstone sediments off of Highway 169 (Sample 169-7). Considering the nature of this survey, it is possible that the prevalence of conodont elements in these sediments is even greater than the numbers reported here.

Sponges

It seems most likely that the sponge spicules represented in the Blue Earth Siltstone are from the class Hexactinellida, formerly Hyalospongea, whose members are sometimes known as “glass sponges” (Boardman et al., 1987; Laubenfels, 1955). Sponge spicules are abundant in the solution fill site, but notably missing from the flat lying siltstone bed. This suggests that sponges, if not outright absent from the Blue Earth Siltstone sediments off of Highway 169, were at least not nearly as common as they were in the paleoenvironment recorded by the solution feature fill by the Minnesota River. Very few sponges have been reported in the Oneota Dolomite as a whole. The only other sponges described in the Oneota outside of the Blue Earth Siltstone are Monactinellids (single ray spicules) from near Springfield Corners, Wisconsin (Howell and Landes, 1936; Needham, 1933).

Unidentified Material

Due to their poor preservation and fragmentation, some fossils found in the course of this survey were extremely difficult to identify properly. Among these was one possible specimen of a chitinozoan. Chitinozoans are flask-shaped microorganisms of uncertain phylogenetic association, common in rocks deposited in the Ordovician through the Devonian (Brasier, 1980; Paris and Novak, 1999). A possible Conulariid was also found, though its identification as such is dubious at best, and classification of it as a brachiopod fragment or sponge wall is also plausible. Conulariids are an extinct type of sessile Cnidarian with a box-like structure (Moore and Harrington, 1956). Another

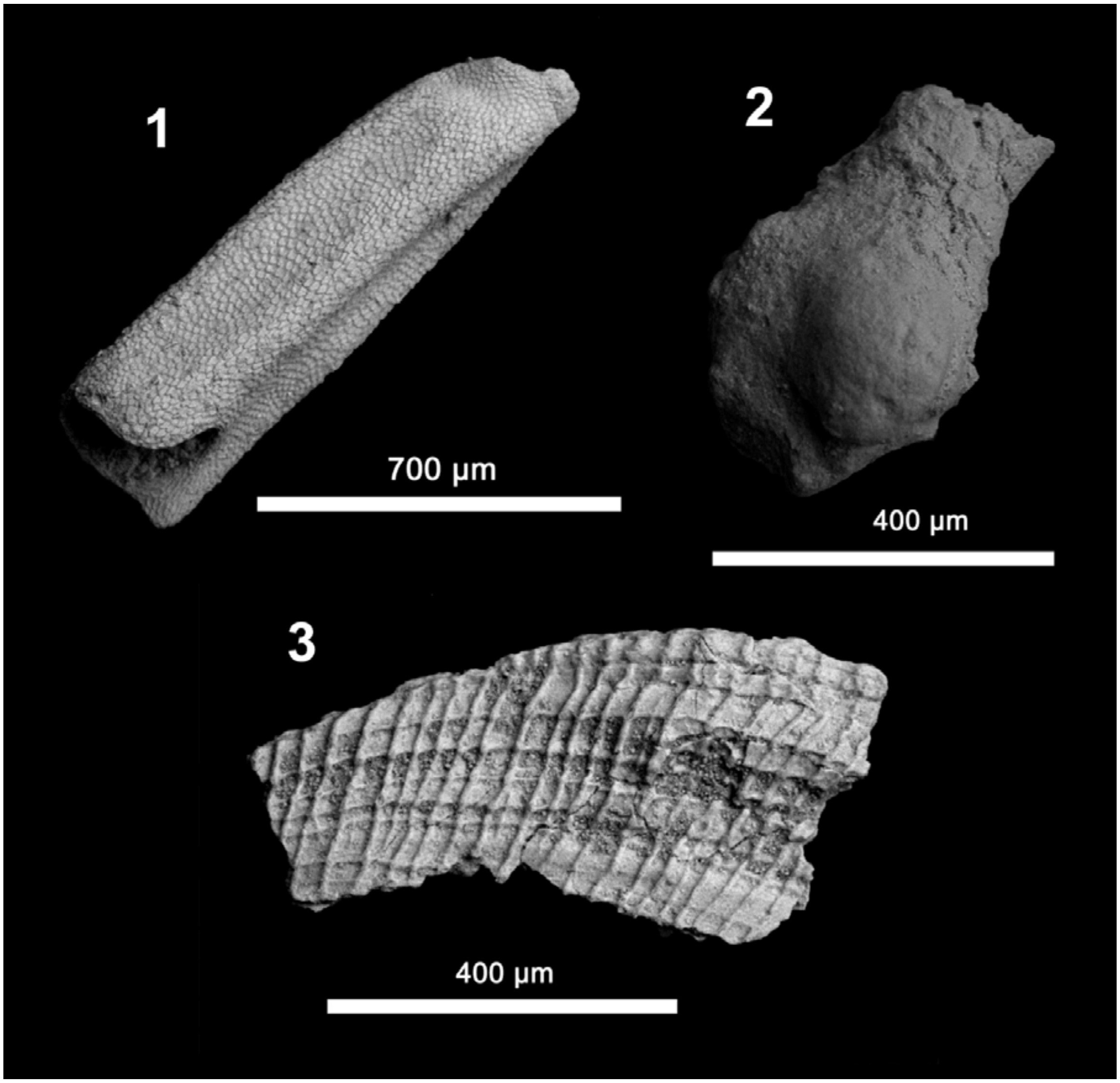

Figure 6. Unidentified fossils from the Blue Earth Siltstone include a tube shaped specimen with a scale-like texture (1), a possible chitinozoan (2), and a possible conulariid (3).

specimen of uncertain phylogenetic affinity is a tube like fossil with a texture resembling scales (Fig. 6).

Conclusions

There is some evidence that the sediments from the flat lying Blue Earth Siltstone off of Highway 169 and the solution cavity fill along the Minnesota River may record different paleoenvironments. Sediment from the Highway 169 locality yielded a much higher concentration of conodont elements and crinoid ossicles than the solution feature fill samples. Sponge spicules are common throughout the solution feature fill samples, but appear to be absent from the Highway 169 sediment (Fig. 7). It is possible that the two localities record the same paleoenvironment, but deformation of the material currently in the solution cavities of the Oneota affected fossil preservation. Differences also exist between the two sample sites in the character of their sediments; for example, glauconite was more prevalent in the Highway 169 siltstone than in the solution fill. The existence of macrofossil fragments could be considered evidence of episodic storm action in both locations.

Fossils are generally rare in the rest of the Prairie du Chien, usually only appearing in chert nodules (Howell and Landes, 1936). The relatively high concentration of fossils in the Blue Earth siltstone could be a result of the siltstone being a residue of Oneota material. Many of the conodont species identified in the Blue Earth Siltstone are found elsewhere in the Prairie du Chien (Furnish, 1938; Smith and Clark, 1996). However, some of the fossil material found in the Blue Earth Siltstone is absent from the rest of the Oneota Dolomite, like conodont species *I. landingi* (Ethington, 2010, personal

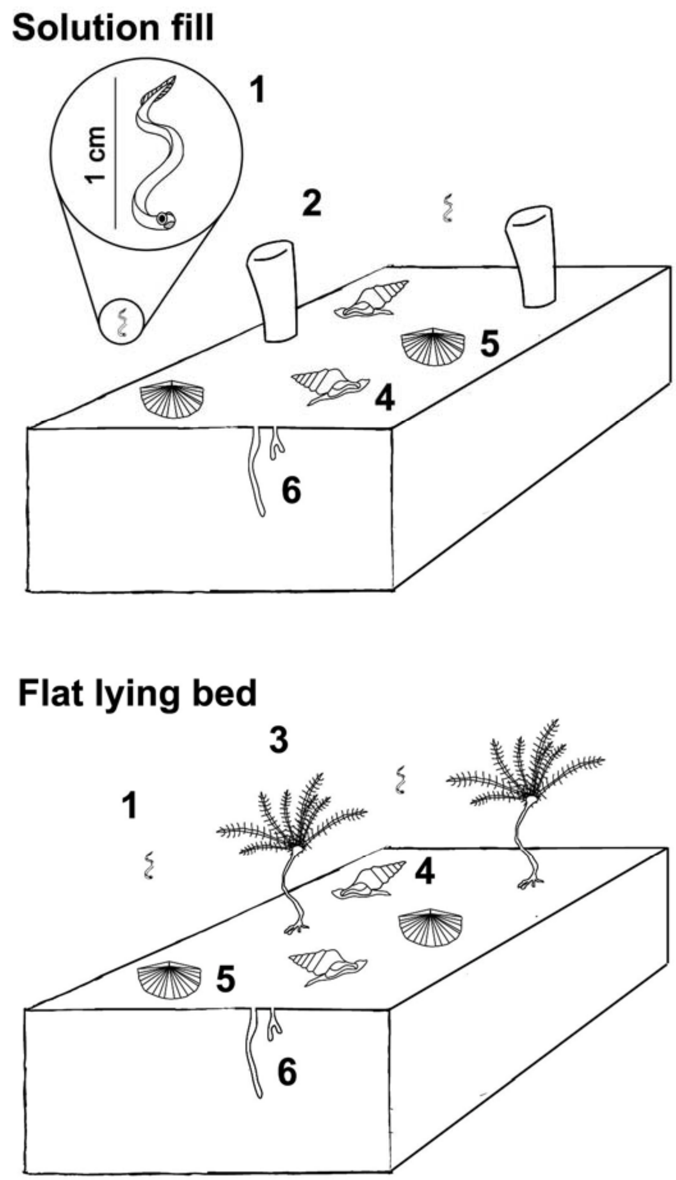

Figure 7. Paleoenvironmental reconstructions of the Blue Earth Siltstone beds sampled for microfossil analysis. The reconstruction of the environment recorded by the solution feature fill is pictured on the top, while the reconstruction of the environment recorded by the Highway 169 bed is pictured below. Fossil groups present include conodonts (1), sponges (2), crinoids (3), gastropods (4), brachiopods (5), and burrows (6). Representations of animals generalized and not to scale with each other. Modified from Aldridge et al. (1995) and Varela (2009).

communication) and hexactine sponge spicules (Howell and Landes, 1936; Needham, 1933).

The conodont assemblage present in the Blue Earth Siltstone is closer in age to Oneota than to the Jordan. The Blue Earth Siltstone may have its origin as residue from dissolved portions of the Oneota Dolomite. However, the differences between the faunal assemblages of the Blue Earth Siltstone and the rest of the Oneota, as well as the placement of the Highway 169 Blue Earth bed, support the notion that the Blue Earth Siltstone was deposited before the rest of the Oneota Dolomite. If this is true, the Blue Earth sediment in the solution features near the Minnesota River could have been squeezed upward into collapsing karst features of the Oneota as Stauffer and Thiel (1941) proposed.

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