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CHARACTERIZING THE SEDIMENT SOURCE OF THE ELLSWORTH FORMATION OF THE MICHIGAN BASIN USING LITHOSTRATIGRAPHY AND CHEMOSTRATIGRAPHY

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INTRODUCTION

This study aims to litho- and chemostratigraphically characterize the Ellsworth Formation in the Michigan Basin. The stratigraphic relationship between the alternating green-gray silty shale of the Ellsworth Formation and the underlying black shale of the Antrim Formation varies in the literature (Fig. 1; Gutschick and Sandberg, 1991; Catacosinos et al., 2000; Currie, 2016). The differences in proposed relationships are substantial, with implications for chronostratigraphy in the Michigan Basin. This project uses litho- and chemostratigraphy to define the base of the Ellsworth in one core from the north-central Michigan Basin, as well as the amount of lithologic and chemostratigraphic variation within the Ellsworth. These analyses were used to characterize the sediment source in order to better understand and constrain the Ellsworth Formation.

Geologic Setting

This study focuses on the Late Devonian (Fammenian) Ellsworth Formation and upper portion of the Antrim Formation which contains the Lachine and Upper Members, which were deposited approximately 365 mya (Palmer, 1983; Gutschick and Sandberg, 1991). As shown in Figure 1, the green-gray silty shale of the Ellsworth Formation has previously been interpreted as being deposited contemporaneously with the black shale of the upper member of the Antrim Formation (Gutschick and Sandberg, 1991), as a unit that occurs stratigraphically above both the Lachine and the Upper Antrim (Catacosinos, 2000), or as a unit that occurs between the black shales of the Lachine and Upper Antrim and extends into the eastern half of the Lower Peninsula (Currie, 2016). The Antrim Shale Formation of the Michigan Basin is generally known as a period of slow accumulating hemipelagic sediments in an oxygen-starved basin, high in organic material and with no evidence of upwelling (Gutschick and Sandberg, 1991). In the later parts of the Famennian, a shift in sedimentation began, marked by the appearance of the Ellsworth Formation silty shales prograding into the basin. The green-gray silty shale of the Ellsworth Formation deltaic sediments were transported from west to east, originating from the Wisconsin Arch (Ells, 1979; Gutschick and Sandburg, 1991).

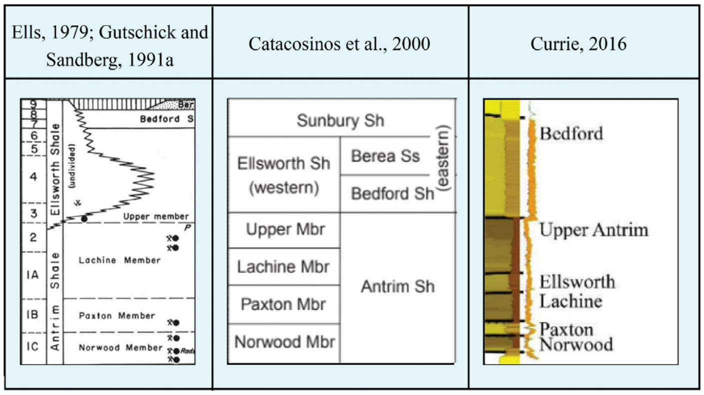

Figure 1. Differing interpretations in the literature of the stratigraphic relationships between the Lachine Member, Ellsworth Formation, and Upper Antrim Member. Modified from Gustchick and Sandberg, (1991), Catacosinos and others (2000), and Currie (2016).

Previous Stratigraphic Studies

Gutschick and Sandberg (1991) describe the Antrim and Ellsworth as deposited contemporaneously and intertonguing at this time (Fig. 1). They describe the Ellsworth being thickest in the west and thinning to the east but not reaching the easternmost side of the

Michigan Basin, as the Antrim Shale is deposited around the Ellsworth wedge (Fig. 1). In the late Famennian, the Ellsworth Delta retreated and the slow accumulation of anoxic, organic-rich clay sediments that make up the Upper Antrim resumed across most of the basin according to Gutschick and Sandberg (1991) as shown in Figure 1.

However, the most recent stratigraphic column produced by the Michigan Geological Survey presents a different stratigraphic interpretation. The chart constructed by Catacosinos et al. (2000) placed the Antrim Shale Formation, including the Upper Antrim Member, to be stratigraphically under the Ellsworth Shale Formation (Fig. 1). This suggests that the Antrim Shale was completely deposited before the Ellsworth Formation prograded into the basin and the Antrim and Ellsworth do not interfinger (Catacosinos et al., 2000) as shown in Figure 1.

More recently, Currie (2016) suggested that the Ellsworth Formation occurs stratigraphically above the Lachine Member, and uniformly thins to the east but reaches the easternmost edge of the basin (Fig. 1). Currie (2016) places the Upper Antrim Member as being deposited on top of the Ellsworth (Fig.1).

METHODS

Johnson (2024) studied two cores from the Michigan Geological Repository for Research and Education (MGRRE). Herein, results are summarized using only one core: St. Chester Welch #18 (see Fig. 3 of Zambito and Voice, this volume). The St. Chester Welch #18 core provides sequences characteristic of shallower depositional systems during the Late Devonian. Using this core allows for the characterization of the sediment that would have been deposited closer to the source that fed the Ellsworth Delta. It should be noted that this core does not show the upper contact of the Ellsworth Formation and overlying units, so the succession in this study reaches an indeterminable portion within the Ellsworth Formation.

For a detailed lithologic analysis, Ellsworth siltstone laminae thicknesses were measured. For elemental and mineralogical analyses of these two cores, pXRF and XRD were used, respectively. For further details and information on methods used in this study, see Johnson (2024).

RESULTS

Lithology

The Lachine Member in the St. Chester Welch #18 core is a dark, black homogenous shale in which laminations were visible with a hand lens (Fig. 2). The transition from the Lachine Member into the Ellsworth becomes highly interbedded with siltstone and shale laminae almost immediately at the contact (Fig. 2). Up section, the siltstone laminae are a light green-gray color and the shale laminae are a dark gray to gray color (Fig. 2). The green-gray siltstone laminations rarely exceeded 1.5 cm. thick, but the thickest observed were 3 cm and 9.1 cm (Fig. 3). The siltstone laminae in this core were thicker near the contact with the Lachine Member, and become thinner upsection (Fig. 3). These thick laminae seemed to occur in intervals, with several feet of thin laminae between the next thick laminae interval (Fig. 3). For detailed laminae thicknesses see Appendix B in Johnson (2024).

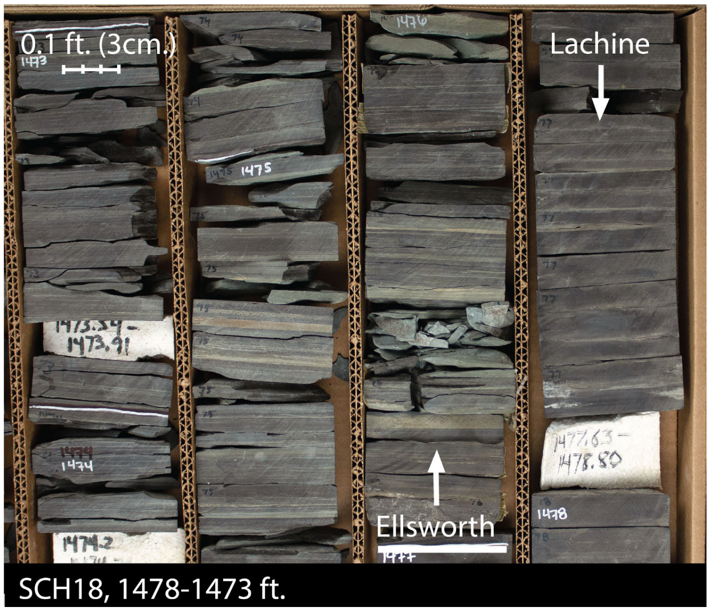

Figure 2. Photograph of the succession of the St. Chester Welch #18 (SCH18) core where the contact between the Lachine Member of the Antrim Formation and the Ellsworth Formation occurs. Photograph shows the St. Chester Welch #18 core from 1478 ft - 1473 ft, and the contact between the Lachine Member and the Ellsworth Formation occurs at 1477 ft (indicated by arrows).

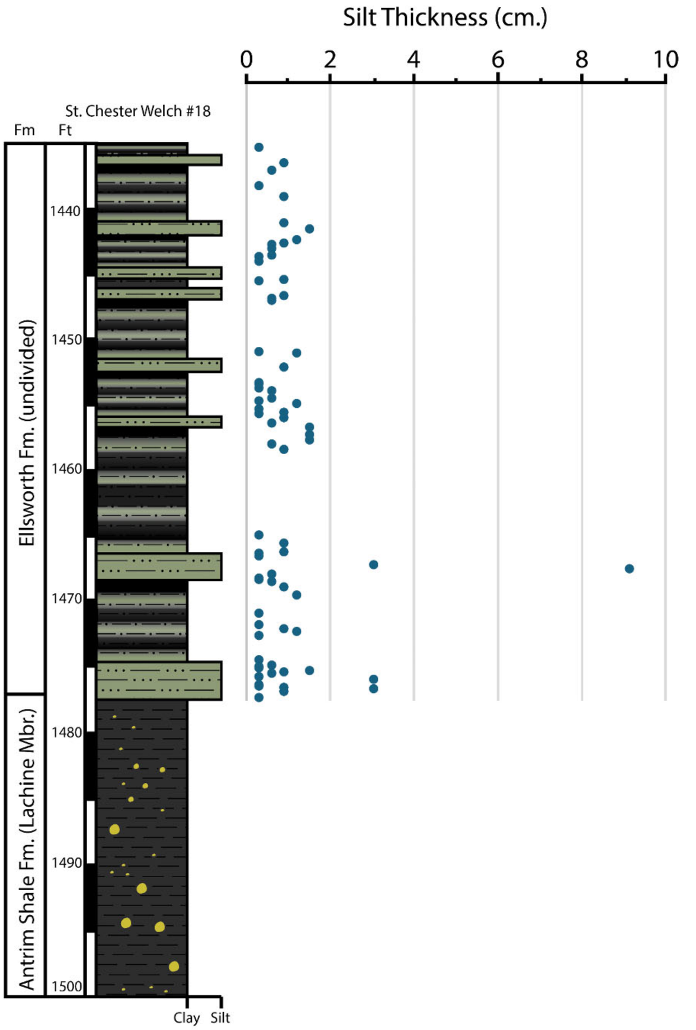

Figure 3. Measured siltstone laminae thickness in the St. Chester Welch #18 core next to a stratigraphic column. It should be noted that only the thickest siltstone laminae were measured, and any laminations less than 0.3 cm (3 mm) are not represented herein.

Elemental and Mineralogical Analysis

In the St. Chester Welch #18 core, K% and Al% covary, with concentrations increasing from the Lachine Member into the Ellsworth Formation (Fig. 4). Si% and Si/Al covary in the Lachine, but Si% maintains elevated concentrations in the Ellsworth and Si/Al shifts to consistently lower values, therefore covariation is difficult to observe visually (Fig. 4). A similar pattern to Si/Al and Si% is seen in Ti% and Ti/Al (Fig. 4). However, Zr/Al and Zr% covary throughout both units, but Zr% exceeds Zr/Al in the Ellsworth (Fig. 4). It should be noted that covariation within the Ellsworth is not consistent (Fig. 4). Additional chemostratigraphic data is available in Johnson (2024).

Minerals detected in this core included quartz, K-feldspar, plagioclase, calcite, dolomite, pyrite, apatite, halite, illite and mica, and other clay minerals (Fig. 4). The Lachine Member contained about 12% clay minerals with a high value of 25% at 1492.5 ft, and the Ellsworth Formation contained 18-25% clay minerals (Fig. 4). Both the Lachine and Ellsworth contained a non-clay mineralogy between 75 and 90%, with the majority being quartz (Fig. 4). The Lachine Member contained 45-70% quartz, with a decrease at the contact with the Ellsworth which contained 30-40% (Fig. 4). K-Feldspar percentages decrease in the Lachine approaching the contact with Ellsworth, and then increase within the Ellsworth Formation (Fig. 4). Additional mineralogic data is available in Johnson (2024).

DISCUSSION

Lithology

The St. Chester Welch #18 core has siltstone-shale interbeds appearing at the contact with the Lachine Member, with the siltstone laminae getting thinner upsection (Figs. 2 and 3). These observations indicate that sedimentation rate and in the St. Chester Welch #18 core was greater near the contact with the Lachine, and gradually decreased through time. This also suggests that the orientation of the delta that sourced Ellsworth Formation sediments likely changed through time (Fig. 5). Initially, due to the thick siltstone laminae at the contact with the Lachine, the Ellsworth Delta reached the St. Chester Welch #18 core in which deposition was high and the core was in the direct trajectory of the delta (Fig. 5). During this time, both hypothesized wind direction and fluvial influx came from the modern day northwest, with the delta prograding into the basin eastward (Fig. 5). However, the gradual rate of laminae becoming thinner upsection suggests that there was a change in sedimentation rate through time, which could be due to the migration of the delta as it prograded into the basin (Fig. 5). However, using just the St. Chester Welch #18 core makes it difficult to determine the lobe migration direction, therefore the area of migration is distinguished by a dashed line herein (Fig. 5).

Sediment Characterization

Si% and Si/Al covary in the Lachine, but Si% exceeds

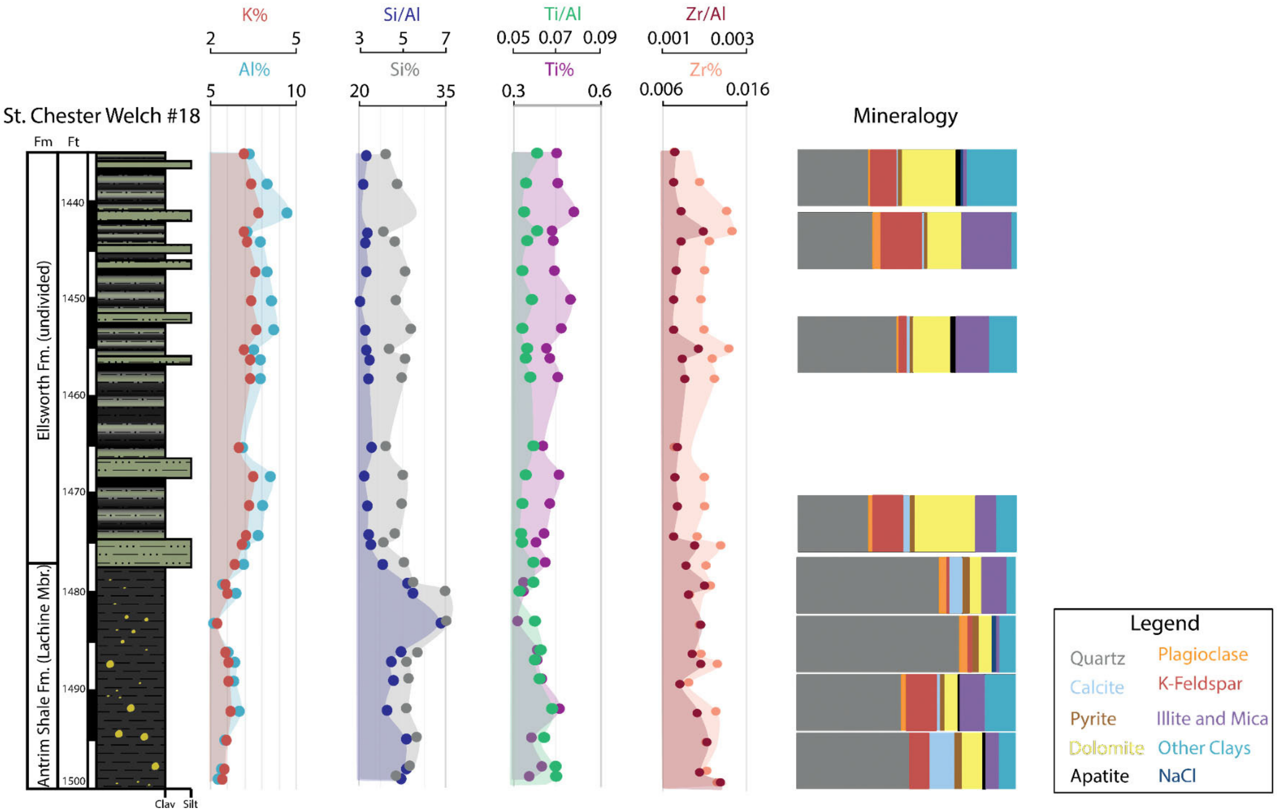

Figure 4. Lithostratigraphy, elemental chemostratigraphy, and mineralogy of the St. Chester Welch #18 core.

Si/Al in the Ellsworth (Fig. 4). This elevation in Si% suggests that clay minerals as well as detrital quartz grains are sourced similarly and coming into the basin together, whereas the Ellsworth delta is receiving more clay minerals and less quartz due to a different siliciclastic source than that which fed the Lachine Member. Non-clay sources of silicon could potentially be sand and silt-sized quartz grains, or silicified microfossils which have been identified in previous studies (Hathon, 1979). The variety of minerals present in the St. Chester Welch #18 core possibly corresponds to the proximity of the core to the Ellsworth Delta, indicating that this core represents an area close to the mouth of the river delta (Figs. 4 and 5).

The Lachine Member of the Antrim Formation also hosts atypical percentages of quartz compared to other black shales (Hathon, 1979). It would be unusual for a black shale to contain such high percentages of quartz sourced from siliciclastic input, so previous studies have speculated that this quartz is authigenic (Hathon, 1979). This authigenic quartz may have precipitated in situ, and may be diagenetic precipitation from pore fluids (Hathon, 1979). Quartz in the Antrim could also be biogenic (Gutchick and Sandberg, 1991). However, the source of the unusual amount of quartz present in the Antrim shale is still debated (Churchman et al., 1976; Hathon, 1979).

Sediment Sources

Because Ti/Al and Zr/Al are proxies for silt-sized grains, and since Ti/Al and Zr/Al are consistently elevated in both cores, the source for some of these silt grains in the Ellsworth could be coming from a combination of fluvial and wind-blown silt as part of the Ellsworth Delta System (Figs. 4 and 5). It is not uncommon for the finest-grained aeolian-sourced loess to be deposited in lakes and seas, and these grains can be transported great distances into these basins (Soreghan et al., 2023 and references therein). Deep-time wind-blown silt deposits show that the lithification of these units can often be preserved as siltstones and mudstones in which the silt-dominated units can have clay components (Soreghan et al., 2023 and references therein). These deep-time aeolian-marine deposits have been observed in Ordovician, Devonian, and Mississippian aged rock (Soreghan et al., 2023 and references therein). In units that occur in these periods, it is likely that if the units being studied were deposited by fluvial systems and contain

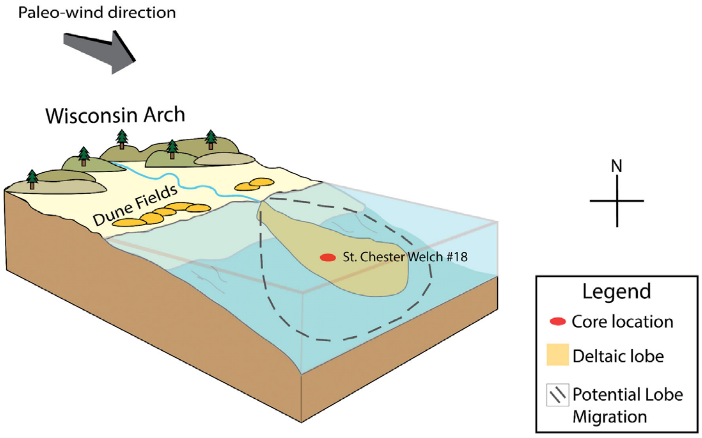

Figure 5. Reconstruction of the progradation of the Ellsworth Delta into the Michigan Basin. The St. Chester Welch #18 core records initial delta deposition, occurring in the center of the deltaic lobe. The dashed outline represents possible directions of migration based on the changes in silt laminae thicknesses recorded throughout the Ellsworth Formation succession. Reconstructions of potential dune fields on the edge of the basin, the river carrying sediment from the Wisconsin Arch, hypothesized paleo-wind direction, and a compass rose pointing to modern-day North are also included. Note that features are not to scale.

silt-sized grains, the silt presence among them could partially be composed of wind-blown silt (Soreghan et al., 2023 and references therein). Since the Ellsworth Formation is prograding into the Michigan Basin as a deltaic lobe fed from fluvial systems (Gutschick and Sandberg, 1991), the siltstone laminae present in the formation could be wind-blown in addition to fluvial sourced. This would indicate that the paleotopographic high of which the loess was sourced had to have been somewhat arid.

However, previous studies have listed the Michigan Basin as being located at a sub-tropical latitude of around 30 degrees south of the equator that receives high rainfall (see Fig. 3 in Zambito and Voice, this volume; Scotese, 1986; Gutschick and Sandberg, 1991). Conversely, 30 degrees north and south latitude are common places to find arid and semi-arid landscapes due to the divergence of the Westerly and Easterly Trade Winds (Walker, 1992). It has been previously suggested that laterally extensive facies of Devonian detrital silt-sized fractions that occur at the subtropical arid belt have a high likelihood of their silt deposits being aeolian-marine (Soreghan et al., 2023 and references therein). So, while the Michigan Basin would have been paleogeographically located in a sub-tropical latitude, it is possible that there could have been a semi-arid transcontinental arch sourcing a combination of fluvial and wind-blown silt-sized grains into the Ellsworth delta system and the basin itself (Fig. 5; Scotese, 1986; Gutchick and Sandberg, 1991). This, combined with the fluvial sediment feeding the delta, could have resulted in the closely interbedded siltstone and shale of the Ellsworth Formation.

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