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MAGNETIC SUSCEPTIBILITY OF SEDIMENTARY STRATA IN THE LATE DEVONIAN ANTRIM FORMATION OF THE MICHIGAN BASIN

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INTRODUCTION

This study utilizes the magnetic susceptibility (MS) of sedimentary strata to correlate the Late Devonian Antrim Formation black shale and calcareous mudstone across the Michigan Basin as well as with a previously published MS profile from contemporaneous, shale-dominated strata from the Illinois Basin. MS can be used as a proxy for changes in material composition, which is linked to paleoclimate-controlled sediment fluxes and depositional environments.

The Devonian Period of Earth's history contains many geological events of environmental instability, often tied to sea-level fluctuations (Becker at al., 2020). The cores interpreted in this study include strata from the Middle-Upper Devonian, specifically the Givetian, Frasnian, and Famennian stages.The studies of Gutschick and Sandberg (1991a,b) provide the basis for much of our understanding of the biostratigraphy and depositional history of the Middle-Late Devonian succession in the Michigan Basin, including repeated transgressive-regressive cycles.

The Acadian Orogeny is a major Devonian mountain-building event in eastern North America, resulting from the collision of the eastern margin of Laurentia with a series of landmasses (Fig. 1; Ver Straeten, 2010). In the Appalachian Basin, the alternating sediment types (carbonate versus siliciclastic) record a cyclic series of sedimentary basin responses to tectonic events (tectophases) in the Acadian Orogeny (Ver Straeten, 2010). Subsidence during the Acadian Orogeny created a deep anoxic sea floor depositional environment within the Appalachian Basin; anoxic

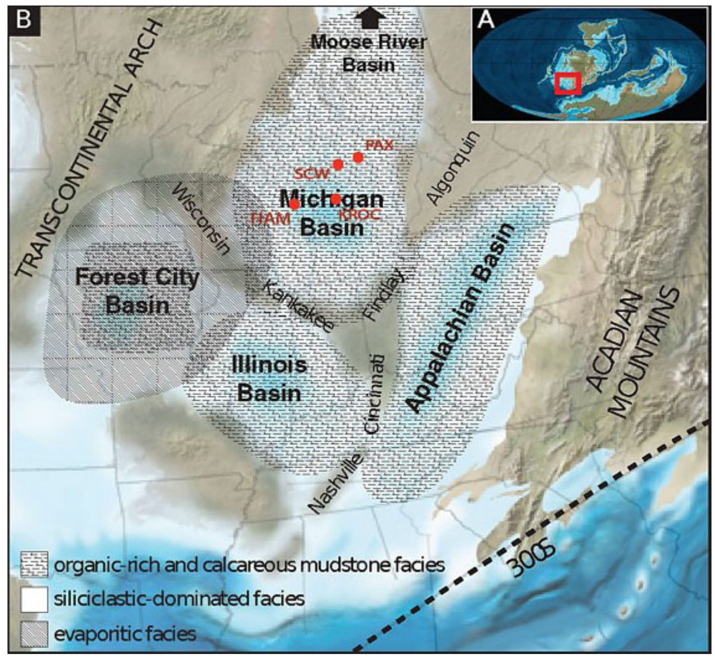

Figure 1. A) Global paleogeographic map for the Devonian (red box is location of panel B). Paleogeographic map of a portion of North America. Location of four rock cores analyzed in this study, the Krocker (KROC), Paxton Quarry (PAX), State Chester Welsch (SCW), and State Hamlin (HAM). Paleogeographic maps are adapted from Blakey (2013) and Zambito and Voice (this volume)

deposits (black shale) are also seen in the Michigan Basin at this time, though Michigan Basin subsidence was not necessarily tectonic (Zambito and Voice, this volume). These periods of black shale deposition align with major global events and can be used to create an event stratigraphic framework (Becker et al., 2020). Paleoclimate-controlled sediment fluxes and depositional environments are influenced by sea level changes (local and those related to global events) and therefore have the potential to record global events. For more information on the geological setting of the study area, see Zambito and Voice (this volume).

METHODS

Data Collection

The magnetic susceptibility of sediment is related to the concentration of detrital-dominated paramagnetic and ferrimagnetic minerals and is therefore a proxy for detrital influx (Ellwood et al. 2011). Significant magnetic minerals are either in the iron-titanium-oxygen (FeTiO) group or the iron-sulfur (FeS) group; each mineral or rock has a different average susceptibility (SI) value based on its composition. There are two basic sources of magnetic minerals in carbonates, authigenic and detrital minerals. Authigenic magnetic minerals are commonly magnetite, hematite, siderite, etc. The occurrence and concentrations of these minerals are related to the local sedimentary setting (Zhang et al., 2000). Detrital magnetic minerals come from the erosion and accumulation of rock fragments, sediment, or other materials. The occurrence and concentration of these minerals is therefore related to the sediment already present within the sedimentary environment.

The Terraplus KT-10R v2 Magnetic Susceptibility Meter was used to collect data approximately every foot along a flat surface of the cores. The measurement sequence is as follows; a free air measurement followed by a sample measurement then the final free air measurement. The sample measurement involves placing the oscillator coil directly on to the surface of the core being measured. The complete sequence takes 7 seconds to complete after which the SI unit appears on the screen. Excel was used to plot the data collected with the Terraplus MS Meter, as the device maintains an excel file with the values recorded.

Converting MS Data

The Terraplus KT-10R v2 Magnetic Susceptibility Meter outputs magnetic susceptibility as volume susceptibility based on the diameter of core input into the instrument. Ellwood et al (2011) suggest presenting magnetic susceptibility data as δMS, which is dimensionless and allows direct comparison to other datasets. To convert volume susceptibility (k) data to mass susceptibility (χρ) data for conversion to δMS, the following formula is used: $\chi\rho = k/\rho$, where ρ = density (g/cm^3). The following density values were used when converting MS values, based on the average density for the strata studied from previously collected density values from drill plug analysis: lower, calcareous Squaw Bay (ρ = 2.734, n = 10); upper Squaw Bay (ρ = 2.605, n = 9); Norwood (ρ = 2.458, n = 12); Paxton (ρ = 2.654, n = 19); Lachine (ρ = 2.479, n = 32); and Ellsworth (ρ = 2.689, n = 15).

RESULTS

The magnetic susceptibility data was collected from rock cores taken from three different areas within the Michigan Basin; in this paper, only the data from the Krocker 1-17 core is presented (Fig. 2). The stratigraphic succession studied in the Krocker (KROC) core is 280 ft thick. In ascending order, there are the Traverse Group, the "Squaw Bay Formation", the Antrim Shale (which includes the Norwood, Paxton, and Lachine Members), and the lower Ellsworth Formation. As seen in Figure 3, the "Squaw

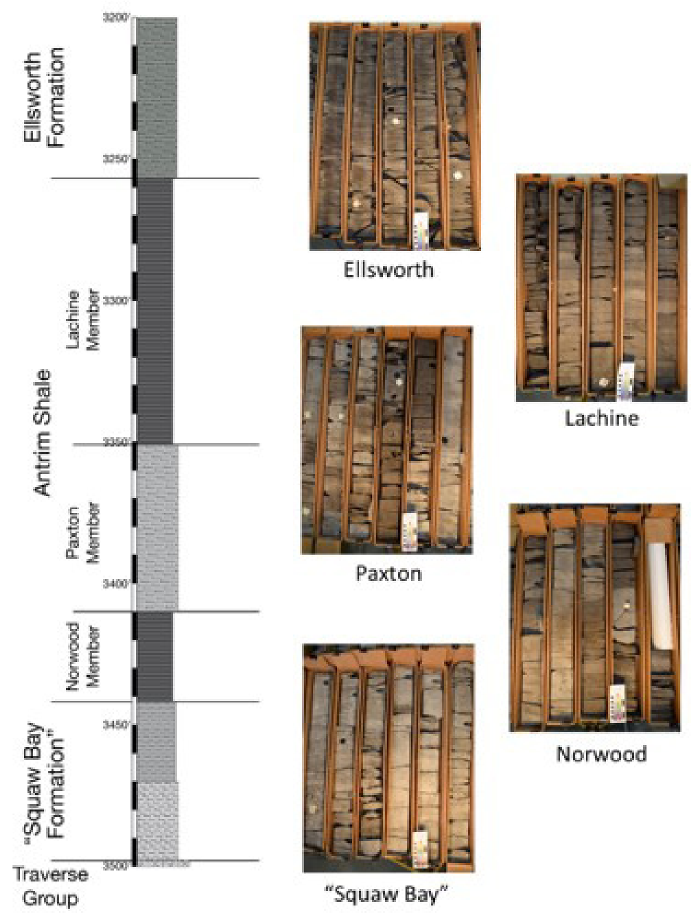

Figure 2. Stratigraphic section of the Krocker Core showing unit thicknesses, changes in lithology, and stratigraphic units. Pictures of the rock core were taken at the Michigan Geological Repository for Research and Education.

Bay Formation" and Norwood have δMS values which occur in the -0.4 to 0.4 range. The Paxton has δMS values which are slightly higher than the Norwood and around 0.0 to 0.6. The Lachine typically has δMS values in the 0.0 to 0.4 range. The Ellsworth has δMS values which occur in the 0.4 to 0.8 range.

DISCUSSION

Visual characteristics of rock cores can also be analyzed to understand the history of each formation (Fig. 2). Gray shales are typically more fossiliferous and have intense bioturbation, consistent with rock found within the "Squaw Bay Formation", Paxton Member of the Antrim Shale, and the Ellsworth Formation. During these times, relatively more clastic sediment was deposited into the basin. These units tend to have higher MS values indicating a decrease in sea level during time of deposition and increased detrital influx (Fig. 3). Darker shales present in the Norwood and Lachine members illustrate times of sea level rise and typically display lower MS values (Fig. 3). During these times there was an increase in organic matter preservation and less detrital clastic input. Shifts seen along the magnetic susceptibility profiles align with boundaries of lithostratigraphic units, suggesting abrupt changes in detrital influx at unit boundaries.

Using the converted MS data makes comparison of the Michigan Basin Krocker 1-17 core with previously published data from the "Bullitt County Core" from Kentucky (Over et al., 2019) in the southern Illinois Basin possible. The magnetic susceptibility basinal profiles of the Michigan and Illinois basin cores appear to show similar MS patterns within biostratigraphically correlated stratigraphic intervals. Both basins likely received sediment input from the Acadian Orogeny but have a slight difference in proximity to the source (Fig. 1).

CONCLUSION

In the Michigan Basin, a MS profile through the basinal Krocker 1-17 core shows that MS patterns correspond to lithostratigraphic units. For some of these units the MS patterns are similar among the cores, though not for all units. Preliminary

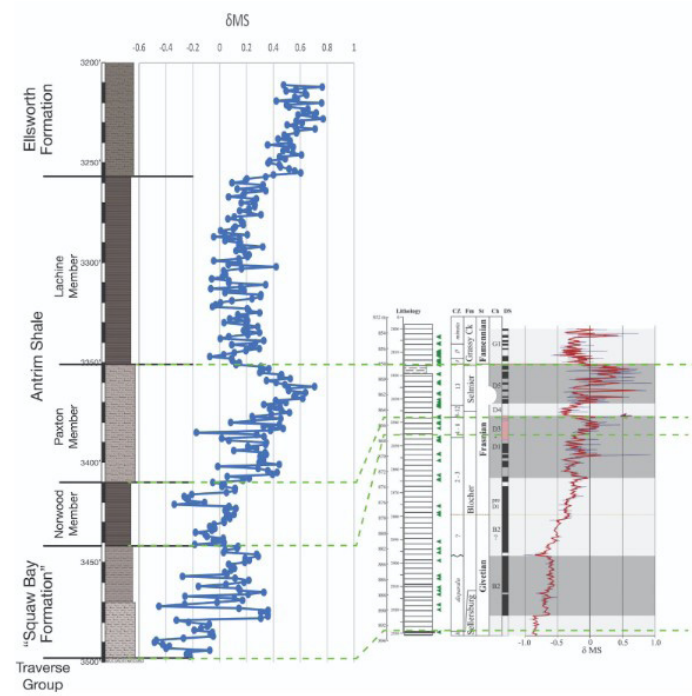

Figure 3. Location of the State Chester Welch 18 drill core used in this study.The converted MS data of the Krocker 1-17 core plotted next to MS data from the Bullitt County Core located in the Illinois Basin (Over, et al., 2019). Corresponding biostratigraphic intervals are denoted with green dashed lines.

interpretation is that MS patterns are a result of proximity to sediment source (Acadian Orogeny versus Transcontinental Arch) as well as intrabasinal early diagenetic processes (pyrite mineralization). Furthermore, the lithostratigraphic units in these cores may not be chronostratigraphically equivalent.

This study also compares the Michigan Basin MS basinal profile (Krocker 1-17 core) with previously published data from the "Bullitt County Core" from Kentucky, in the southern Illinois Basin (Over et al., 2019). Within a biostratigraphic framework, the Michigan and Illinois Basin cores express similar MS patterns. This is possibly because sediment input to these two locations is primarily sourced from the Acadian Orogeny, and the depositional environment and therefore early diagenetic processes, are similar. Future work could combine mineralogical analysis with the MS profiles to decipher the source of magnetic susceptibility, currently hypothesized to be driven by ilmenite concentration.

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REFERENCES

Becker, R.T., Marshall, J.E.A., Da Silva, A.-C., Agterberg, F.P., Gradstein, F.M., and Ogg, J.G., 2020, The Devonian Period, in Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M. eds., Geologic Time Scale 2020, Elsevier, p. 733–810, doi:10.1016/B978-0-12-824360-2.00022-X.

Blakey, R.C., 2013, Deep Time MapsTM – Maps of Ancient Earth, https://deeptimemaps.com/ (accessed April 2022).

Ellwood, B., Tomkin, J., El Hassani, A., Bultynck, P., Brett, C., Schindler, E.& Feist, R., and Bartholomew, A., 2011, A climate-driven model and development of a floating-point time scale for the entire Middle Devonian Givetian Stage: A test using magnetostratigraphy susceptibility as a climate proxy. Palaeogeography Palaeoclimatology Palaeoecology. 304. 85-95. doi:10.1016/j.palaeo.2010.10.014.

Gutschick, R. and Sandberg, C. 1991a, Late Devonian history of Michigan Basin. Early Sedimentary Evolution of the Michigan Basin. GSA Special Papers. doi:10.1130/SPE256-p181.

Gutschick, R. and Sandberg, C. 1991b, Upper Devonian biostratigraphy of Michigan Basin. Early Sedimentary Evolution of the Michigan Basin. GSA Special Papers. doi:/10.1130/SPE256-p155

Over, D., Hauf, E., Wallace, J., Chiarello, J., Gilleaudeau, G., and Song, Y., 2019, Conodont biostratigraphy and magnetic susceptibility of Upper Devonian Chattanooga Shale, eastern United States: Evidence for episodic deposition and disconformities. Palaeogeography, Palaeoclimatology, Palaeoecology. 524. doi:10.1016/j.palaeo.2019.03.017.

Ver Straeten, C.A., 2010, Lessons from the foreland basin: Northern Appalachian basin perspectives on the Acadian orogeny, From Rodinia to Pangea: The Lithotectonic Record of the Appalachian Region, Richard P. Tollo, Mervin J. Bartholomew, James P. Hibbard, Paul M. Karabinos (251-282) doi: 10.1130/2010.1206(12).

Zambito IV, J.J., and Voice, P.J., this volume, Integrated stratigraphic and paleoenvironmental study of the Middle-Late Devonian carbonate to black shale transition in the Michigan Basin.

Zhang, S., Wang, X., and Zhu, H., 2000, Magnetic Susceptibility Variations of Carbonate Controlled by Sea-Level Changes. Sci. China Ser. D-Earth Sci. 43, 266–276. doi.org/10.1007/BF02906822.