A Magnetic Susceptibility Study of the Fort Union Formation, Western Williston Basin, Southeastern Montana

Dan McCarthy
Department of Geology
Franklin and Marshall College
Lancaster, PA. 17604-3003

Introduction

The purpose of this project is to develop an understanding of the magnetic susceptibility of the rocks of the Fort Union Formation, and to investigate the utility of this petrophysical parameter for correlation and/or as an indicator of environment in the sense of Thompson and Oldfield (1986). The project was undertaken in the Western Williston Basin, with the specific field area about 30 miles east of Miles City. A magnetic susceptibility section was also measured at Sunset Butte, near Marmarth, North Dakota. The purpose of this was to determine if there is a distinct difference of magnetic susceptibility across the Cretaceous-Tertiary boundary.

Geologic Setting

The study area is located in a broad alluvial plain produced by aggrading rivers from mountains in Wyoming and central Montana (Belt, 1984). The Fort Union formation is divided into three members, the Tullock, Lebo and Tongue River. The Tullock member is comprised of brown, gray and drab yellow medium to very-fine sands, silts and muds of a fluvial and ponded water nature. The Lebo consists of gray to yellow fine to very-fine grained sands, silts, muds and carbonaceous shales, with dominant lignitic coal horizons. All of these are believed to be fluvially and ponded water-derived. The Tongue River is composed of light yellow, light brown and gray muddy sands interbedded with gray to brown muds and coal. The Lebo is defined by a basal coal unit called the C coal. This is because the Lebo's base is gradational and cannot be easily determined. The base of the Tongue River is in a sandy unit above the last smectite mud appearance. The area is characterized by badland topography, consisting of gently rolling hills and buttes scattered throughout the study area.

Historical Background of Field Methods

Susceptibility or κ is a property of rocks that often indicates the magnetite content. In SI units, κ is a dimensionless quantity and 1 SI unit equals 4π gauss/oersted (cgs)· There has been no previous work done in this area with respect to magnetic susceptibility. Worm and Banerjee (1987) made susceptibility readings of sediments from Petriccio, Italy and DSDP cores in order to look for a magnetic signature due to an abundance of black magnetic microspherules at the Cretaceous-Tertiary boundary. The argument in favor of my study at Marmarth was to determine if the K/T boundary could be tracked at the outcrop level based on magnetic susceptibility data.

In the Fort Union formation, which is principally fluvially derived, the magnetic fraction associated with the sediments will be largely transported although there might be an authigenic component. If the study was extended to a larger section of the area, some sense of source region for the sediments might be determined. In many ways, the study carried out here is similar in principle to gamma-ray logging used for correlation (Chamberlain, 1984). Chamberlain used gamma ray measurements on the outcrop in order to correlate stratigraphic sequences based on their ability to absorb radiation.

Field Methods-Study Area

The instrument used for the susceptibility measurements is a Bartington Instruments Magnetic Susceptibility Meter Model M.S. 2. In general, the probe used for field measurements was the M.S. 2F. This probe has a diameter of 15mm and has an area of sensitivity equal to its diameter projecting in a hemisphere away from the probe end. The study began with detailed vertical sections in the study area. There is some overlap between sections. Sections were offset because a continuous section was not available. As the section was logged, three susceptibility readings was taken at each logged unit. At the same time, field samples were taken for analysis in the laboratory.

As well, detailed measurements were taken from distinct lithologic units. These units include a dominant coal horizon in the area, a channel sand of the Lebo member, a smectite or "popcorn" mud from the Tullock, and a yellow sand in the Tongue River. These units are representative of the different members.

For each lithologic site, ten (10) stations were established laterally along the unit. At these ten sites, three (3) substations were set at three (3) elevations within the unit, one at the top, one approximately halfway through, and one near the base. Three measurements were taken at each substation. At every other station, a trench was dug into the unit to obtain fresher, less weathered surfaces, and three measurements were taken at the intermediate elevation. Following this, at each station, a "big probe" (Model M.S. 2D) measurement was taken three times, with drift corrections. This procedure was repeated at each lithologic unit. The big probe is circular and is 20 cm in diameter, so the susceptibility readings will be integrated over a larger volume than those with the small probe.

At the Marmarth site, a different tactic was used. One long vertical trench was dug, with an arbitrary datum defined by a 2 cm coal seam which corresponds to unit 36 of a vertical section by Kirk Johnson (personal communication). This datum was thought to be the approximate location of the Cretaceous-Tertiary boundary. The section began 64.5 cm above this datum and three readings were taken every 2 cm. This was continued until the end of the section, 70 cm below the datum.

To examine characteristics of instrument drift, an initial drift "set" was taken at the beginning of each day in the field at each lithologic site. The procedure for this was to set the meter on continuous measurement, and to take a reading at 10 second intervals. From this, a drift curve was produced (Figure 1). This figure suggests that it is reasonable to assume that instrument drift is linear over time.

Laboratory Methods

In the laboratory, all of the lithologic data and section data were input into Microsoft Excel for the Apple Macintosh for data analysis. From here an average susceptibility value was determined for each lithologic unit, along with the standard deviation.

As well, hand specimens were measured using probe M.S. 2C and examined for deviation from the in situ measurements.

Results

From the statistical analyses performed on the lithologic sites, the values below were obtained.

	κ	Standard Deviation
Channel Sand		
Sites	4.17	1.05
Trenches	5.50	2.95
Big Probe	6.17	2.29
Hand Specimens	8.1	1.9
Coal		
Sites	-0.29	0.34
Trenches	-0.76	0.56
Big Probe	1.07	0.73
Hand Specimens	-0.2	0.2
Lebo Channel Sand		
Sites	7.60	3.34
Trenches	14.68	3.14
Big Probe	11.85	3.70
Hand Specimens	12.63	1.96
Yellow Sand		
Sites	5.35	1.98
Trenches	5.3	1.18
Big Probe	n/a	
Hand Specimens	5.3	1.7
Smectite Mud		
Sites	7.77	1.11
Trenches	8.14	2.75
Big Probe	8.5	0.9
Hand Specimens	7.9	2.5

The results above were obtained by taking the average of the three drift corrected readings, and averaging that over the 11 sites per lithologic unit. The standard deviation was calculated the same way with respect to each individual station, and then an overall standard deviation was calculated for each unit. The absence of the big probe measurements for the yellow sand was due to a probe malfunction at the site.

The measurements from the hand specimens, the trenches and the sites are all consistent. Further statistical tests will examine in more detail the variability of the data.

From the numbers above, it is evident that the coal lithology has a negative susceptibility, which is a result of the fact that coal is diamagnetic. Otherwise, there are no immediately distinct relationships between a lithology and susceptibility. It appears that the Lebo Channel sand has a significantly different susceptibility value than the other sand units, which may suggest the possibility of correlation based on characteristic units.

A example of the vertical section data is seen in Figure 2. As one moves upsection, an upward trend in susceptibility is also observed. However, further analysis is necessary in order to see if this trend applies to other sections.

The data from the Marmarth site is presented in Figure 3. Initially, there appears to be a trend of increasing susceptibility as one moves upsection, however no distinct "spike" is observed. Further examinations of this data may reveal local differences in susceptibility, but it is too early at this time to tell.

By meeting time, further statistical work will be conducted on both the lithologic section with respect to depth and lateral extent, and the vertical section with respect to the individual member units. The statistical analyses will be done with. Exstatix™ by Select Micro Systems for the Apple Macintosh™.

REFERENCES

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Figure 1

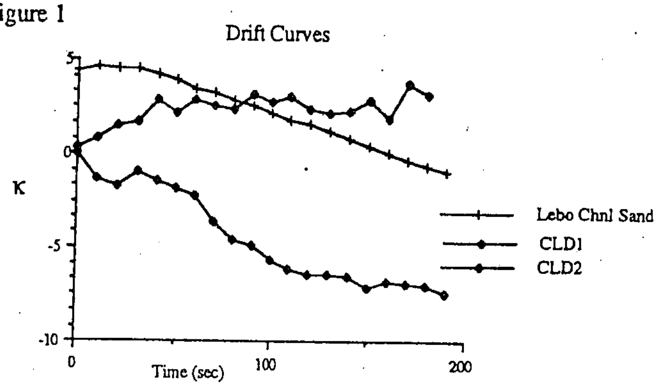

Figure 2

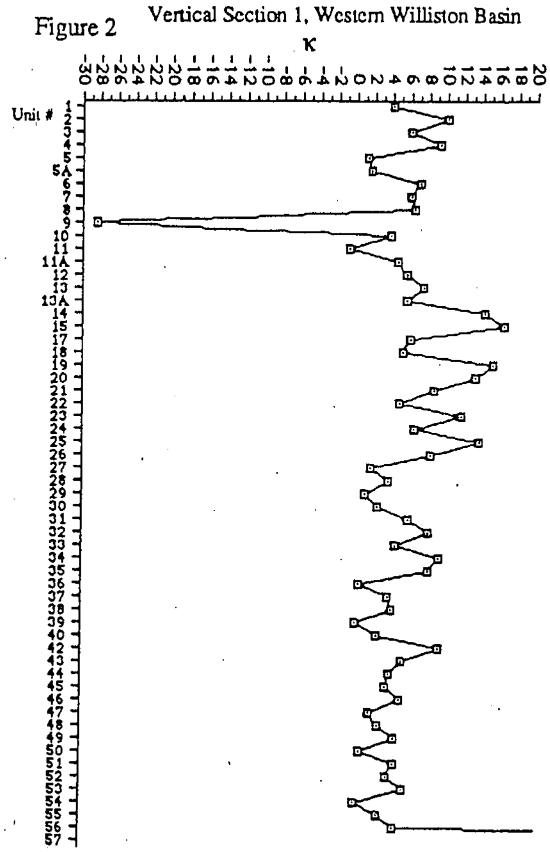

Figure 3