A Paleomagnetic Study of Clinkers From the Williston Basin, Southeastern Montana

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The focus of this research is a paleomagnetic study on clinker of the Fort Union Formation in the Williston Basin of southeastern Montana. These clinkers formed from sedimentary rocks above coal beds which caught on fire due to spontaneous combustion, lightning strikes, or range fires soon after being exposed by denudation, baking the sediment above. There are four stratigraphically different clinkers in the area at elevations of approximately 991 m, 939 m, 829 m, and 792 m above sea level. In general, the highest elevation clinkers are older because they were exposed further in the past. What makes the clinker valuable to a paleomagnetic study is the fact that the rocks become remagnetized at the time of burning, acquiring a thermoremanent magnetization (TRM). Fission-track dating in previous studies places the formation of clinkers in the Quaternary period (Herring, 1980; Jones, 1983; and Jones, et al., 1984).

There are several areas of interest in the paleomagnetic study of clinker. The first is the polarity (normal or reversed) of the field at the time of clinker formation. The polarity is important because there have been several polarity changes during the Quaternary. Because samples have been taken from stratigraphically successive clinkers, the possibility exists of finding both normal and reversed sites. Reversed polarities suggest ages of at least 700,000 years before the present, the time of the last magnetic reversal. Mixed polarities could increase dating precision, especially if used in conjunction with radiometric ages.

While there has not been a great deal of work done on clinkers, a good portion of the work done has been in the Williston and Powder River Basins of Montana and Wyoming. Important studies include those by Bastin (1905), Rogers (1917), Herring (1980), Jones (1983), Budai and Cummings (1984), Coates (1984), and Jones et al. (1984). Collectively these papers deal mainly with the formation, dating, temperature of burning, and mineralogy of clinker, as well as describing their paleomagnetic significance.

Field Methods

Standard paleomagnetic techniques were used in both the field and laboratory (Tarling, 1983). While in the field, two criteria were used for choosing sites. First of all, I wanted to cover the four different clinkers present within the stratigraphy of the field area, thus covering a large period of time over which to observe the changing magnetic field. Secondly, I wanted to take samples from one of the clinker units at two separate locations in order to examine the variability of magnetization within a single clinker.

The nature of the clinkers depends on the parent lithology and the temperature and oxidation state during baking. In selecting individual sites, the first goal was to cover all clinker lithologies present at an outcrop. This way, in the lab, it might later be possible to determine the relation between the various lithologies and the magnetization. A second goal was to determine whether folding of the sediments occurred before formation of the clinker or as a result of the formation of the clinker. At one location, samples were taken from five sites along a fold, two on either limb of the fold and one on the fold's hinge point. Then, with both the bedding and magnetic orientations of the five sites, a paleomagnetic fold test could determine at what time the folding occurred.

In taking samples from the clinker, I used a converted chainsaw that had an adapter which allowed for the attachment of both a drill bit and a water tank. The water tank was essential in cooling the bit and flushing out debris. The bits used were 1" in diameter and diamond-tipped, thus permitting the coring of the hard clinker. The cores drilled were approximately 1 1/2" deep, allowing for subsequent cutting of 1" long cores so as to fit in the magnetometer sample holder used in the lab.

After the drilling of between four and ten samples per site, each core was carefully oriented. The plunge of the core was measured with a clinometer, and the azimuth was measured with both a Brunton compass and a sun compass. Use of the sun compass is important if the magnetization of the clinker itself distorts the local magnetic field. Whenever it was not possible to take a sun compass reading (i.e., no direct sunlight was available), the Brunton reading had to suffice.

Lab Methods

The first procedure in the lab was to take the sun compass data and run it through a computer program which produced an azimuth reading. After inputting the sun compass reading and the position of the sun in sky at the time of collection, the program was able to compute the azimuth.

The next procedure involved the measurement of the remanence, for which I used a Molspin spinner magnetometer. After the remanence of all samples were measured, the directions of each was plotted on a stereonet (Figure 1). The next step is then to demagnetize the samples to eliminate any secondary components of magnetization that might have been acquired since the original baking of the clinkers. Successful demagnetization is possible because the secondary components are generally much weaker and less stable than the original thermoremanent magnetization (TRM).

The type of demagnetization used so far is called alternating-field (AF) demagnetization. One pilot specimen from each site was selected for progressive AF demagnetization. These samples were then run through a series of demagnetization steps in order to destroy the secondary magnetization of the samples. The stability of the remanence was examined by the plotting of the demagnetization results on Zijderfeld plots (Figure 2). Plots were also made of the magnetization versus demagnetization step (Figure 3).

A second method of demagnetization that will be used in conjunction with AF demagnetization is thermal demagnetization. Thermal demagnetization will be done on samples with high coercivity. In these samples, AF demagnetization does not destroy much of the remanence. Final AF and/or thermal demagnetization will be carried out for all samples.

Results

Results up to this point have been very encouraging. The samples are strongly magnetized, with the median site NRM being 1.08 A/m. Of the 28 sites analyzed, all but one show good clustering of the NRM directions (Figure 1). The median $\alpha95$ for the NRM site averages is 3.5°.

Alternating-field demagnetization on the pilot samples show high directional stability for 27 of the 28 sites (Figure 2). The median destructive field (MDF), the peak alternating field necessary to destroy 50% of a sample's NRM (Figure 3), has a median value of 29 mT. Samples from 6 sites which are brick-red in color and fine-grained have MDF's greater than 100mT, indicating high coercivity of remanence, presumably due to high hematite content.

The polarities of 26 sites are reversed, one is normal, and only one site seems ambiguous at this time. It is unlikely that additional demagnetization will affect these polarity interpretations. The average NRM direction (normal polarity) for the 27 stable sites is: declination=1°, inclination=64°, $\alpha95$=3.3°, which is not significantly different from the geocentric axial dipole direction for this latitude.

Discussion

An original concern with these clinkers was whether or not they would be good recorders of the magnetic field at the time of burning. One way of testing the fidelity of the clinkers is through the analysis of the demagnetization results on a Zijderveld plot. Once the secondary components have been demagnetized, the points on the diagram should form a straight line headed towards the origin. If a sample has low stability this is demonstrated by a more erratic demagnetization diagram. In all but one of the 27 samples demagnetized, the Zijderfeld plots indicate that the clinkers are good magnetic recorders.

Another result that suggests high fidelity is the calculated average value of direction of magnetization for all sites, which is consistent with the geocentric axial dipole theory. This theory states that the earth's magnetic field will correspond to a geocentric axial dipole once secular variation has been averaged out. If this were the case in southeastern Montana at the time of clinker formation, the expected average direction would be declination=180° (0° for normal polarity sites) and inclination= - 64.5° (64.5° for normal polarity). The $\alpha95$ value is a measure of precision of the calculated magnetic direction, with anything under 4° being considered good. Therefore high fidelity is again suggested.

Of the 28 sites that have been analyzed, 26 have reversed polarity, one has normal polarity, and one is unclear. This suggests that the landscape is at least 700,000 years old, older than would be expected (Mark Sholes, personal communication). This conclusion is important in the reconstruction of the geomorphic evolution of the area (Coates, 1980; Coates and Naeser, 1981; Coates, 1984). There is one additional interesting aspect concerning the placing of the clinkers in the magnetic record. The one normal site is on a promontory of a butte capped by the oldest of the four clinkers. The fact that it is on the promontory probably indicates that it burned prior to the other clinker sites located in more recently eroded stream cuts. Thus this normal site is sandwiched between the reversed sites of the three stratigraphically younger clinkers and the older reversed sites of the same clinker. This therefore suggests the possiblity that the normal site records some short normal polarity epoch within a major reversed epoch. At this time my working hypothesis is that the reversed sites are from the Matuyama epoch, and the normal site represents one of the several minor epochs within the Matuyama (either the Jaramillo, Gilsa, Olduvai, or Reunion). However, because clinker burns are episodic, it is also possible that the sites represent different polarity epochs.

Future Work

Right now my main focus is in completing the demagnetization of all samples. Thus far I have done one pilot sample from each site. The next step is to pick an appropriate demagnetization step from each site and run the samples from that site through at that step. After finishing the demagnetizations, most of the remainder of my research will be in final evaluation of the data.

There is a great deal of further work that needs to be done on these clinkers which extends past the scope of this study. More extensive radiometric dating would probably be the most useful at this time. The first thing it will do is lead to a better knowledge of clinker burn rates. Short-term and regional burn rates will help in determining whether clinkers burn continuously or discontinuously. Radiometric dating of the clinkers will also help to place them in the correct polarity epoch, and increase the precision with which denudation rates can be determined. Petrologic work will also provide more information, including a better understanding of the magnetic mineralogy of clinker.

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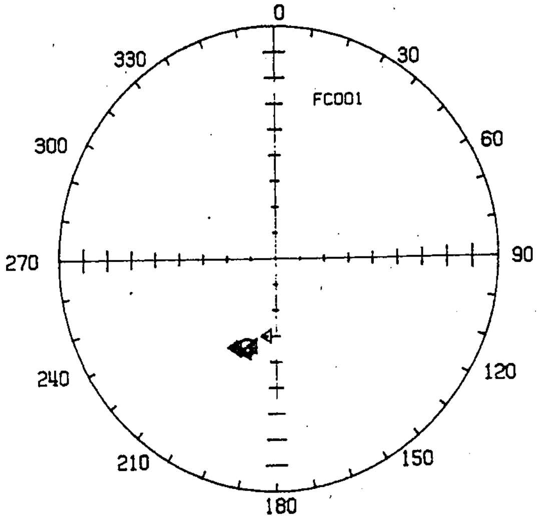

Figure 1. Stereoplot of Sample Directions

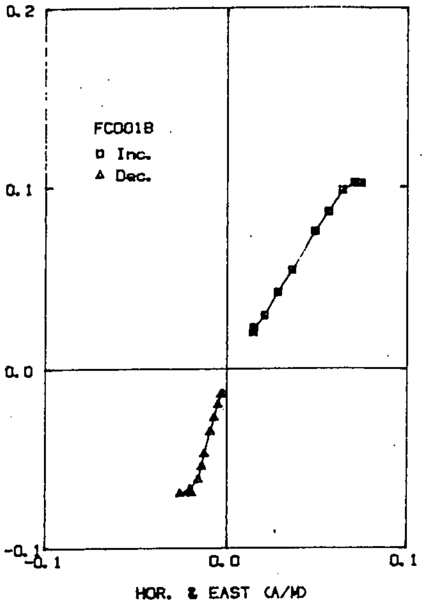

Figure 2. Zijderfeld Plot

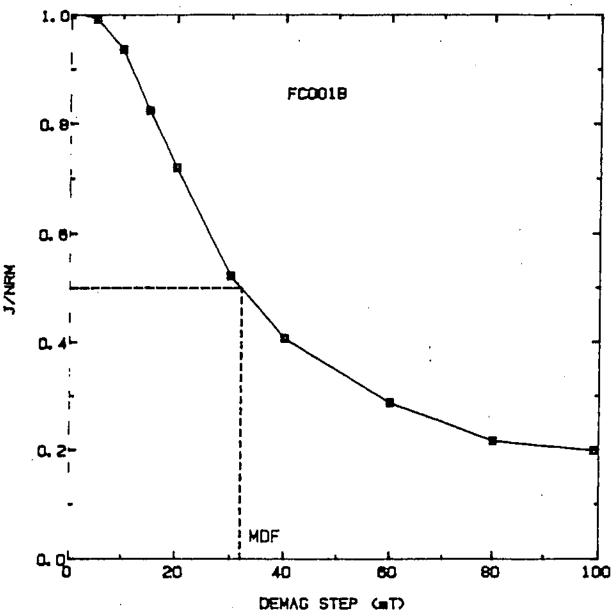

Figure 3. Intensity of Remanence vs. Demagnetization Step