DEPOSITIONAL ENVIRONMENTS AND PALEOHYDRAULIC RECONSTRUCTIONS OF THE LEBO MEMBER, FORT UNION FORMATION (PALEOCENE), SOUTHEASTERN MONTANA

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Introduction:

The Fort Union Formation is widespread in Montana, Wyoming and North Dakota. It is the lowermost Tertiary unit and immediately overlies the Cretaceous Hell Creek Formation. The contact between the two is taken at the lowest persistent bed of lignite above the highest in-place dinosaur remains (Fastovsky, 1987). As this lowermost lignite is a time-transgressive unit (Johnson, 1987; Hickey, personal communication, 1988), the Hell Creek-Fort Union contact only approximates the Cretaceous-Tertiary boundary.

The Fort Union Formation comprises the Tullock, Lebo and Tongue River Members. The Tullock Member consists of "buckskin" brown, gray and drab yellow very fine- to medium-grained sands, silts, and muds of fluvial and ponded-water origin. The Lebo Member is composed of gray and minor yellow, very fine- to fine-grained sands, silts, muds, carbonaceous shales and lignitic coals of fluvial and ponded-water origin. Most units containing clay are dominated by smectite (Belt and Rockwell, in press; see report of Connie Hayden). The base of the Lebo is gradational and is taken at the base of the C coal (Luft et al., 1984) which approximates the upper limit of the drab-yellow colors of the Tullock Member. The Tongue River Formation is composed of light yellow, light brown and gray, muddy sands interbedded with gray to brown muds and coal (Luft et al., 1984). Most units containing clay are dominated by kaolinite and illite (Belt and Rockwell, in press). The base of the Tongue River is taken at the base of a dominantly sandy sequence above the last appearance of smectite muds.

The study area is located on the Boatwright ranch in the Hogan Creek Quadrangle, Custer County, Montana, 10 miles east of the Powder River. Within the field area, only the Lebo and Tongue River Members are exposed.

The purpose of this project is to describe the physical geometry of the channelbelt facies so that the ancient hydraulic parameters can be estimated. The project concentrates on the description of the various facies and the interpretation of the depositional environments. The channel deposits are interpreted first qualitatively and then quantitatively using a computer model. The field work for this project was done during the summer of 1987.

Data collection:

Numerous outcrops of the Lebo Member were examined in the badlands characteristic of the field area. The unconsolidated nature of the outcrops permitted trenching so that continuous sections could be observed. The data was recorded in the form of graphical logs showing the vertical distribution of grain size (using a grain size comparator), composition, sedimentary structures, fauna and flora (Figure 1). Field sites were further documented with sketches and photomosaics. Special care was taken to identify channel deposits, to measure grain size variation at one meter intervals, and to document dimensions of channel fills and lateral accretion surfaces using a stadia rod and transit. The sedimentological logs were then correlated with the aid of photomosaics and used to construct cross section panel diagrams (e.g. Figure 1).

Facies:

There are four major lithologies present in the Lebo Member: sand bodies, sand-mud interbeds, carbonaceous shales to coals, and sheet sands. The sand bodies are meters thick, fine upward and comprise cross-stratified, horizontally-stratified, and cross-laminated sands. Bedsets are typically arranged into erosively-based storeys with lateral accretion bedding. Erosion surfaces are typically laterally extensive and sub-horizontal with only a few decimeters of relief. However, steeply dipping erosion surfaces (interpreted as cutbank and channnel incision surfaces) with relief on the order of sand-body thicknesses, occur locally. Breccias composed of mud clasts and vertebrate fragments occur locally above both kinds of erosion surfaces. Most sand bodies are laterally extensive and either single- or multi-storeyed.

Laterally restricted sand bodies bounded entirely by incision surfaces also occur. They lack well-developed lateral accrretion bedding, and are either single storey or tgruncated lower storeys of multi-storey sand bodies. They are composed of vertically accreted sets of trough cross-stratified sand. The sand bodies typically form resistant buttes of light gray color as they contain cohesive smectite muds. Sand bodies contain locally developed ironstone bands with commonly delineate lateral accretion surfaces The sand bodies also contain abundant plant debris in the form of branching material and leaves, particularly in the upper parts of storeys. In places, rootlets have disturbed sedimentary structures (de-watering structures?) in the upper parts of storeys.

The sand-mud interbeds comprise layers decimeters to meters thick. Each interbed is rarely as much as a meter thick. Bedding is generally horizontal but may exhibit low-angle dips locally. The relative proportion of sand and mud varies, producing both fining-up and coarsening-up sequences. In most cases, the muds predominate. The muds range in color from gray to brown, many containing yellow-orange iron stains. The muds in the Lebo are dominantly smectite (although kaolinite and illite horizons also occur) and exhibit a popcorn weathering surface. The muds are commonly massive but may locally be laminated on a millimeter scale. Laminated muds contain semi-lithified shaley partings where dark brown organic material is interlaminated with the mud. Fossil roots are abundant and disturb the laminations in some units. Sands are commonly erosively-based, range from fine to very fine sand, and are cross-laminated, planar stratified or massive. Colors vary from tan to yellow with orange iron stains. The cohesiveness of the sands varies spatially, possibly due to variation in clay-mineral content.

The coal and carbonaceous shales occur in interbedded units decimeters to meters thick. Many of the coal-carbonaceous shale interbeds can be traced laterally for hundreds of meters. The coals are lignite grade and vary in thickness from 5 centimeters to 2 meters (rare). The carbonaceous shales consist of dark brown, organic-rich muds that exhibit fissility. They contain abundant plant fragments, including well-preserved leaf fossils (see the report of Beth Williams) and rootlets. Thicknesses of the carbonaceous shales range from 5 centimetrs to 3 meters.

The sheet sands are tabular, decimeters to a meter or so thick, laterally extensive for hundreds of meters, and tan to yellow in color. The sheet sands are commonly carbonate-cemented and form resistant benches within and on top of the buttes. These are the only truly lithified beds (in contrast to nodules) in the Fort Union Formation, but locally they may be unlithified. They contain cross beds, cross lamination and horizontally-bedded fine to very fine sand and silt. Cross-bedded units within them are erosively based.

Massive muds centimeters to decimeters thick occur locally at the tops of sheet sands. Asymmetrical and symmetrical ripples are common on bedding-plane surfaces. Individual depositional units fine upward, but stacks of depositional units both fine and coarsen upward. In some cases, the cross laminations are disturbed by soft-sediment deformation. Drifted leaf and stem fossil are abundant on bedding-plane exposures. *In situ* roots and tree trunks are also present in the sands; trunks are upright, 6-9 cm in diameter, and occupy local depressions in the bedding (where the bedding dips toward the trunks). Burrows of *Planolites* occur locally.

Qualitative Interpretation:

The laterally extensive sand bodies are interpreted as point bar deposits of laterally migrating and aggrading single-channel rivers. Single storey sand bodies record deposition from single lateral-migration events. Multistorey sand bodies record downvalley migration of meander bends within a channel belt between avulsion events. The laterally restricted sand bodies are interpreted as the coarse-grained fill of no migrating channels. These may record the down-cutting of a straight channel accompanying an avulsion or crevasse event followed by vertical aggradation. The common juxtaposition of sand bodies with lateral accretion surfaces suggests that straight channels developed meandering patterns with time and net aggradation. The mudstone breccias and skeletal debris covering the erosion surfaces are likely reworked floodplain (cutbank) material. The presence of rootlets and leaves in the upper portions of storeys suggests that tops of point bars were vegetated.

The sand-mud interbeds are interpreted as overbank deposits. The differences in thickness and composition are probably a function of magnitude and frequency of flood events. The deposits dominated by mud represent distal levee and flood basin facies where the thin sands resulted from large flood events th had the power to transport sand-sized sediment to distal localities. Sand-dominated deposits likely forme closer to the channel where flood-current velocities were greater.

The coals and carbonaceous shales are interpreted as swamp deposits from the flood basin of the river. The coals and organic-rich shales indicate a vegetation-rich, low-oxygen to anoxic environment of deposition. The carbaonaceous shales may have been deposited in a part of the swamp that was close enough to the channel to receive fine-grained clastics.

The sheet sands are interpreted as crevasse-splay deposits shed into bodies of ponded water on the floodplain. The fining-up depositional units represent individual flood events whwere the gradation to finer grain sizes and smaller-scale structures resulted from waning flow. The overlying massive mudstones were likely deposited in the ponded water between flood events; they became thoroughly bioturbated. Leaf and stem fragments from trees and plants on the floodplain adjacent to the ponds are preserved on bedding planes. The stacks of depositional units were produced by multiple crevasse-splay events into the ponded water. Coarsening-up stacks may represent the approach of a source channel with time.

Quantitative Interpretation:

Paleohydraulic reconstructions of the rivers responsible for the sand bodies were made using a computer simulation model (Bridge, 1977, 1978, Bridge and Diemer, 1983). Field data such as mean grain size in fining-up units, thickness of sand bodies, and dimensions and orientations of lateral accretion surfaces were inputs used in the simulations. The model simulates flow around meander bends responsible for the channel deposits as constrained by the input variables. The output includes stream velocity, bed shear stress, grain size, slope and bed topography at various positions around the meander bends (Figure 2).

Paleohydraulic reconstruction of point bar deposits suggests two distinct channel sizes. Larger channels flowed eastward and had sinuousities, discharges and slopes of about 1.22, 480 cubic meters per second, and .000026, respectively. Outcrop relationships suggest the smaller channels were tributaries or distributaries of larger channels.

East-flowing larger channels were reporeted earlier by Belt and Rockwell (in press) 10 miles southwest of the study area, but their smaller channels flowed consistently northeast. One northeastward-flowing anastomosed channel system was also found. In the summer of 1987, a third east-flowing wide meanderbelt was found by Belt and Wong just below the Lebo - Tongue River contact in Wong's thesis area.

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Figure captions:

Figure 1. Vertically exaggerated overlay drawing of outcrop photomosaic. Heavy vertical lines are the position of measured sections. Each section is reproduced. Butte H, Boatwright ranch, Hogan Creek Quadrangle, Montana. Cross section is exaggerated two times. Lateral accretion bedding in the single storey sand body dips to the left. Coal and carbonaceous shales are indicated by solid black pattern in the cross section.

Figure 2. Results of computer simulation of paleohydraulic conditions. The distributioin of depth (top diagram), grain size (middle diagram), and velocity (lower diagram) are shown around the reconstructed meander bend responsible for the major sand body in Figure 1. Current direction shown by arrow.

Figure 1

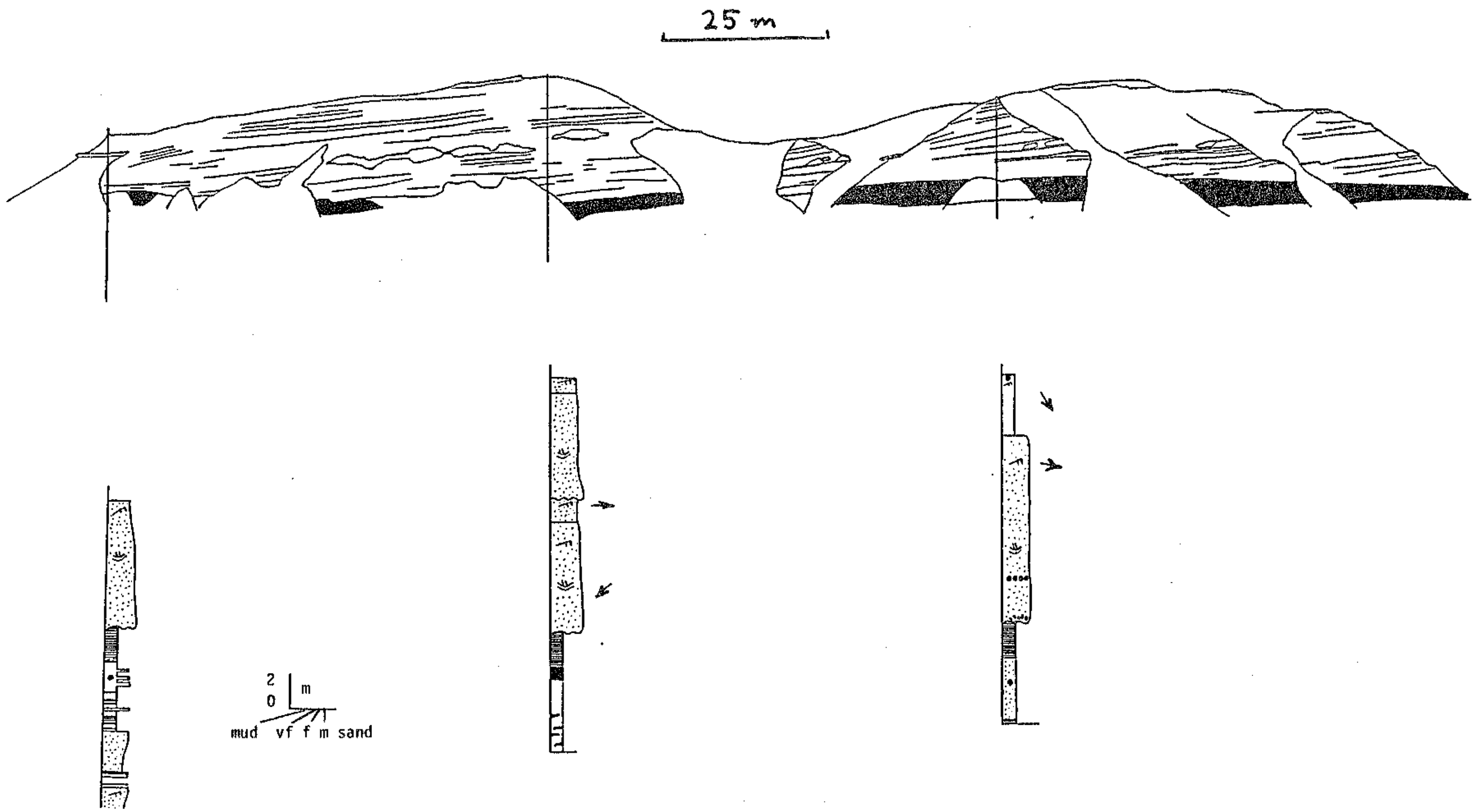
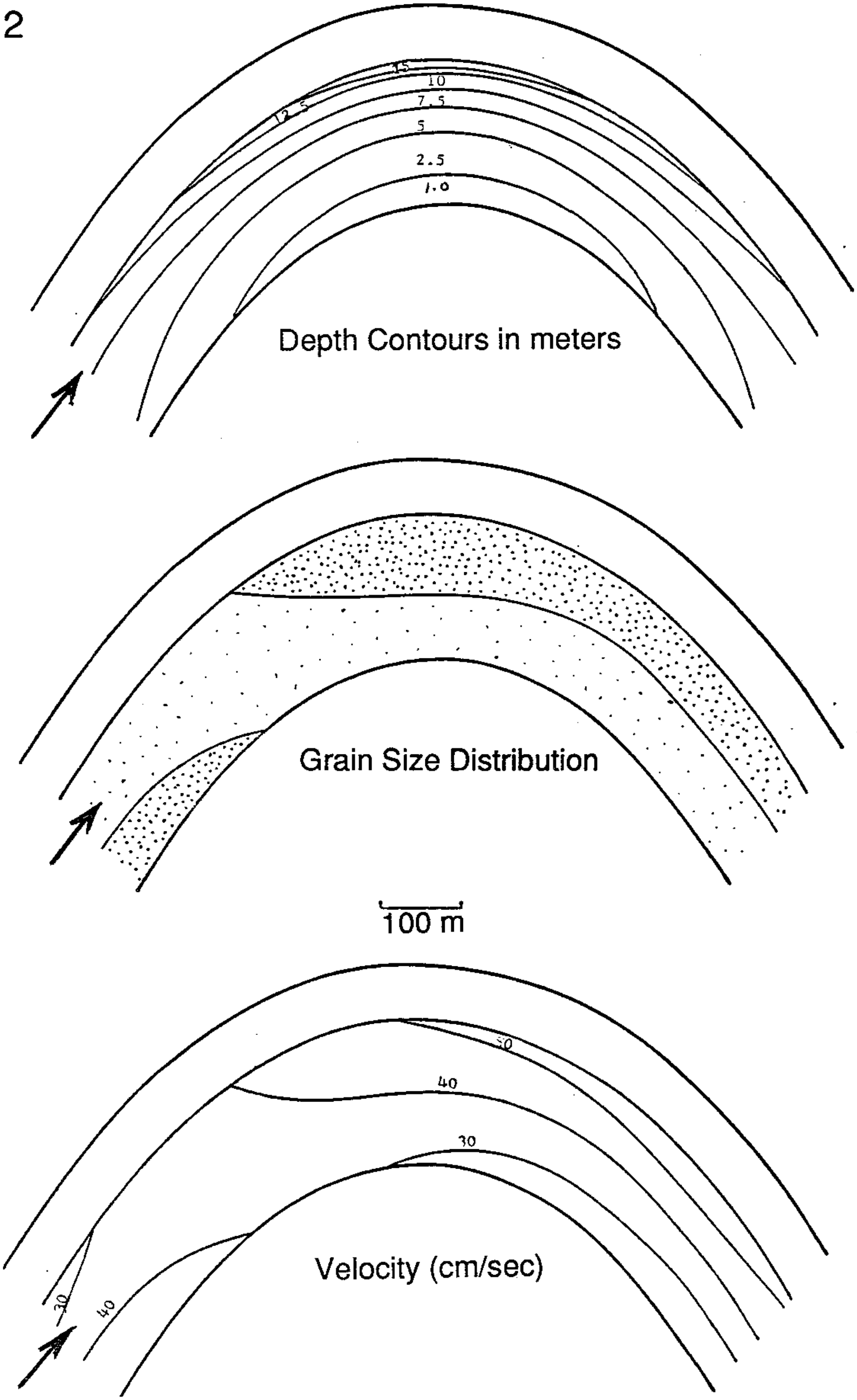


Figure 2


15
10
12.5
7.5
5
2.5
1.0
Depth Contours in meters
Grain Size Distribution
100 m
50
40
30
Velocity (cm/sec)
30
40

PALEOMAGNETIC STUDY OF THE LOWER FORT UNION FORMATION (EARLY PALEOCENE), EASTERN MONTANA

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The technique of magnetostratigraphy makes use of the fact that the Earth's magnetic field has reversed polarity many times in the past and that these reversals are recorded in strata. My study presents the results of reconnaissance work in a sedimentary sequence from the Lebo and Tongue River Members of the Fort Union Formation.

Results now emerging from the studies by Wong and Hayden (this volume) and earlier by Belt and Rockwell (in press) and Belt and others (1984) indicate that a major change in composition (both sand and clay mineralogy) and depositional style occcurred across the Lebo - Tongue River boundary. This boundary can be seen as a profound color change visible at great disances from outcrops. That color change can be traced across the entire western Williston Basin through parts of four western states. The boundary has been widely assumed (e.g. Bluemle et al., 1981) to be synchronous over this entire region. Whether the boundary is time-transgressive or synchronous effects the conclusions on the timing of the earliest uplift of the ancestral rockies and the periods of quiescence that followed. It is now believed the boundary records the transition from uplift (Lebo Member) followed by a period of quiescence (Tongue River Member) (see Wong report, this volume).

This project set out to establish a type section based on magnetostratigraphy from eastern Montana area so that in subsequent summers additional type sections could be made in western North Dakota and in northeastern Wyoming. Because of the difficulties encountered in sample preparation and measurement, not all of the objectives were achieved. The results reported here deal with the sources of magnetism in the sediment and the techniques by which future work will have to be conducted. Emphasis is on methodology, as results are just now appearing.

Sedimentary rocks acquire a natural remanent magnetization, NRM, during deposition, while igneous rocks acquire a NRM during cooling of constituent minerals through their respective Curie temperatures. It would be expected that the NRM of the rocks in my field area would be a DRM, detrital remanent magnetization, caused primarily by the orientation of remanence-bearing minerals in the Earth's magnetic field at the time of deposition or soon thereafter. Subsequently, such rocks may acquire secondary magnetizations, CRM (chemical remanent magnetization) from iron oxides which formed during diagenesis or as products of weathering, and VRM (viscous remanent magnetization) from the effects of subsequent and present magnetic fields. Most serious is the potential for secondary chemical changes that destroy preexisting magnetic particles and result in the growth of the new ones, thereby producing a CRM more resistant to demagnetization procedures than the primary remanence. Critical, therefore, to all paleomagnetic studies is an identification of the minerals carrying the remanence as this can provide direct evidence of the likely age of the magnetization and also the mechanism by which such magnetization was acquired. For additional information see Tarling (1983).

Two stratigraphic sections sampled for this study are located 25 miles east of Miles City, Custer County Montana. Three to five samples were taken from each of thirty-four sites along sections which traverse the boundary between the Lebo and Tongue River Members of the Early Paleocene Fort Union Formation. Sediments are unconsolidated and poorly lithified, and the coarsest clastic material in the sections is fine-grained sand. This range of grain sizes is ideal for paleomagnetic study, as sediments undergo major chemical changes during lithification. Fine sediments are the most magnetically stable and are more likely to reflect accurately the geomagnetic field direction, while larger grains may demonstrate a depositional anisotropy. Lithologies sampled were therefore silt size or finer, and ranged from well-consolidated, but friable, carbonaceous shales to less well-consolidated clays, silty clays, clayey silts. Muddy fine sands were avoided whenever possible.

Rocks exhibiting several features thought to indicate a greater potential for secondary magnetism or from analytical problems were avoided whenever possible. In carbonaceous shales, these features included extremely friable nature, and high organic content (leaf fossils) which can provide a source for secondary sulfide minerals. Iron-stained sands and silts, interpreted as recent pyritic or hematitic weathering, was