CLAY MINERAL ORIGIN AND ALTERATION IN FLUVIAL FACIES OF THE LEBO MEMBER, FORT UNION FORMATION (PALEOCENE), CUSTER COUNTY, SOUTHEASTERN MONTANA

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Introduction:

Ancient fluvial architecture and lateral clay mineralogy variations within the fluvial systems of the Lebo Member, Fort Union Formation were studied in southwestern Williston Basin, eastern Montana. The purpose of this project was to see if there was a relationship between the dominance of certain clay minerals and the depositional facies recognized.

The paleogeographic setting is that of a vast alluvial plain 200 miles upstream from deltas that formed at the edge of the Cannonball sea (Belt et al., 1984). The 1987 research concentrated on early Paleocene sediments exposed in badlands along the Powder River, 35 miles east of Miles City, Montana. As the sedimentology had been studied in the badlands to the west of the river (Belt and Rockwell, in press), outcrops east of the river became our focus. My project was on the Boatwright ranch.

Strata within the study area are flat-lying and unlithified. They are well exposed due to the general absence of vegetation on steep slopes, and to the deep gullying by rain wash and stream activity. Buttes in the study area contained sufficiently good marker horizons so that at least part of all twenty-two measured sections could be correlated through all the buttes.

The Lebo Member of the Fort Union Formation has been age dated as Torrejonian (see Williams report, this volume) by fossil bones and leaves collected from the study area. The lithology of the Lebo consists of sand, mud, carbonaceous shale, and lignitic coal. These lithofacies can be organized into the following groups:

(1) Trough cross-bedded very fine- to medium-grained light grey sand. This invariably has an erosion surface at the base, and where not multistories of several amalgamated channels, the top fines upward. These deposits have shoestring geometry.

(2) Current rippled very fine- to medium-grained light grey sand or yellow sand (different clay mineralogy in each). These sand units are interbedded with medium-grey silt and mud. Silt also is light yellow and current rippled. Many horizons contain fossil roots. All these deposits have sheet geometry.

(3) Medium to dark grey clay. These deposits can be laminated, but where bioturbated by roots, the laminae are destroyed. Thin interbeds of fine-grained sand can occur associated with this lithology. Sheet geometry.

(4) Pale reddish-brown to greyish-brown carbonaceous shaley mud. These can be associated with thin impure coal beds. These are important horizons for correlation. Sheet geometry.

(5) Brown to black lignitic coal and brown carbonaceous shale. These vary in thickness from several cm to 1 m and are one of the important marker horizons for correlation. Sheet geometry.

These individual lithofacies were then grouped into channelbelt, flood basin, levee and crevasse splay depositional environments, according to principles laid out by Belt (Belt et al., 1984; Belt and Rockwell, in press). The depositional facies are then correlated from one graphical log to another and the resulting interfingering relationship is shown on a panel cross section. Photographs of the buttes help in this process of correlation.

Channelbelts consist of moderate to well-sorted cross-bedded sand of elongate, scour-based ("shoestring") geometry. Lateral accretion deposits are found within them. These fine upwards from thick beds of sand to interbedded mud and rippled sand. The cutbank side of the channel can often be identified in the field, and was useful in determining flood plain deposits that formed at the same time as the channel deposit. The sand in the channelbelt facies consist contains quartz, feldspar, and sedimentary lithic fragments (see Wong report, this volume). Mud is also found as a matrix in the sand deposit. The largest channelbelt in the field area is 350 m in width and 47 m at its deepest point. It is multistoreyed, so original channel geometry cannot be determined in our area (but see Metcalf report, this volume).

Flood plain facies consist of mud, carbonaceous shale and thin coal beds. The mud can be laminated or massive (root bioturbated). These are far enough from sand deposition so that fine clastics and the organic deposits accumulate readily, although they can be overlain by sand. Clay minerals in this facies were easily collected. Flood plain facies can also contain interbedded mud and thin sand beds that resulted from flood events. As these become rooted, they are difficult to distinguish from levee deposits.

Levee facies consist of interbedded sand and mud that can be shown to lie adjacent to channelbelt facies. Grain size can be shown to decrease away from the channel. Roots are nearly always present. Clay minerals for this study came from the mud and from the matrix in the poorly-sorted sand.

Crevasse splay facies consist of interbedded sand and mud showing sequences that coarsening-up from flood plain facies. These, too, are difficult to distinguish from flood plain flood deposits unless the coarsenin up sequence can be demonstrated, but more importantly, they can be seen as arcuate deposits adjacent to major channelbelt deposits (Belt, et al., 1984). Most of the facies in our field area did not show these relationships, although the unit studied by Kevin Ellingwood (see report, this volume) might have been of this origin.

Clay minerals associated with depositional environments:

Sediment samples were systematically collected below the surface weathering from the various facies of three different fluvial systems and analysed by Robert Stevenson (XRD, University of North Dakota, Grand Forks, ND). The resulting graphs were sent to me where I identified the peaks and calculated the relative percentage of smectite to kaolinite + illite.

Figure 1 shows an example of a transect from a channelbelt, across the channel margin, and into flood plain facies. The data shows a systematic decrease in the percentage of smectite and an increase in the percentage of kaolinite + illite from channel to flood plain.

Discussion:

The question that now arises is: what caused the lateral variation in clay minerals with respect to the depositional facies shown in Figure 1? To answer this, I carefully studied literature suggested by Dr. Richard F. Yuretich, University of Massachusetts, Amherst.

Smectite is a very complex structure composed of units made up of two silica tetrahedra sheets with a central alumina octahedreal sheet. In the stacking of the silica-alumina-silica units, oxygen layers of each unit are adjacent to oxygen layers of the neighboriong units. Consequently, there is a weak van der Waals bond and an excellent cleavage between them. Water and other polar molecules can enter between the unit layers. This causes the lattice to expand. The c-axis dimension of this mineral therefore varies and is dependent upon which molecules enter the structure (Loeffler, 1987). It is this characteristic that causes the mineral to swell, but it also means that smectite is one of the most unstable of all clay minerals, being easily leached of cations. Smectite forms as the clay mineral requiring the least leaching of parent rock material (Keller, 1970), and an adequate supply of Mg++, Ca++, Fe++ and Na+ relative to H+ is needed in the aqueous solution. It is most stable under pH conditions between 7 and 9.

Smectite is smaller in size than kaolinite and varies from 0.12 to 1 mm. As a detrital particle, it can be deposited with clay and silt-sized fragments, staying in suspension when medium-sized (or coarser) sand is being moved.

Kaolinite, on the other hand, has a relatively simple structure. It is composed of a single tetrahedral sheet and a single alumina octahedral sheet combined in a unit so that the tops of the silica tetrahedra and one of the layers of the octahedral shee form a common layer. Composite octahedral-tetrahedral layers are formed, and little substitution occurs within the lattice (Loeffler, 1987). Kaolinite is most stable under pH conditions less than 7. The range of sizes for kaolinite lies between 0.5 and 2 mm. Kaolinite can thus be deposited along with sand-sized fragments.

Any aluminum-rich parent silicate mineral can yield kaolinite, provided that K+, Na+, Ca++, Mg++ and Fe++ are leached away and H+ is added (Keller, 1970). Smectite can also be the source of kaolinite.

Environments of clay minerals:

Where these clay minerals form today is another important factor in determining the cause of the lateral variation in fluvial deposits. The type of clay mineral produced is dependent upon the surface conditions and the chemical composition of the minerals being altered. The main control here is climate, which affects the temperature, availability of water and the extent of plant cover. The plant cover controls the acidity of the soil and the intensity of leaching through its release of organic acids.

Kaolinite is found in well-leached areas high in organic content where peraluminous minerals (e.g. muscovite, microcline) are being weathered under temperate, humid conditions. On the other hand, smectite is found in semi-arid, poorly drained areas low in organic content, and is the result of weathering of a wider variety of minerals than kaolinite. If the conditions of formation of smectite and kaolinite are so different, how can they be found in the same fluvial system in the study area?

Authigenic vs detrital:

In previous studies, Belt and others (1985; also: Belt and Rockwell, in press), concluded that smectite was detrital and kaolinite was authigenic. They based their evidence on the association of smectite with the channel (and adjacent levee) deposits and the kaolinite clays with the flood plain deposits. They also show a TEM photographs of perfect euhedral books of kaolinite crystals from a flood plain environment. They claimed that the smectite was transported into the basin either as discrete clays or as sand-sized shale fragments (shale lithics) eroded from Cretaceous bedrock in the source area. Shale lithics have been found by Bonnie Wong from Lebo sand (see report, this volume), but no x-ray work was done to them.

Figure 1 shows a definite trend from channel to flood plain. While other, more complex explanations are possible, the simplest explanation is that smectite was detrital. Smectite dominates the mud extracted from the channel sands, therefore, it must be a stable clay in those sands today. These sands are surrounded by mud, hence movement of water ought to have been minimal. Smectite is unlikely to form authigenically in those sands because any water moving through those sands would leach, not form smectite. Thin sections studied by me show the presence of what appears to be crystalline smectite in sand-sized shale fragments from those channel sand deposits.

Because kaolinite forms a low percentage of the clays in the channel deposits, its presence on the flood plain must be explained. First of all, if the channel was transporting smectite and kaolinite or just kaolinite, how could the channel rid itself of the larger grains of kaolinite, only to have them hop over the levee and appear in abundance in the flood plain? The flood plain, on the other hand is rich in organic matter, a source of organic acids that would produce lower pH required for smectite leaching and transformtion to kaolinite. According to Singer (1984), kaolinite-dominated sediments can form on a flood plain even though they are being supplied by smectite-dominated main channels. This will happen if the climate is humid enough and the water table is high enough to allow the smectite to be leached in the flood plain. The leaf fossil study of Beth Williams (see report, this volume) indicates that the mean annual temperature during Lebo time was sufficient for the humid conditions required.

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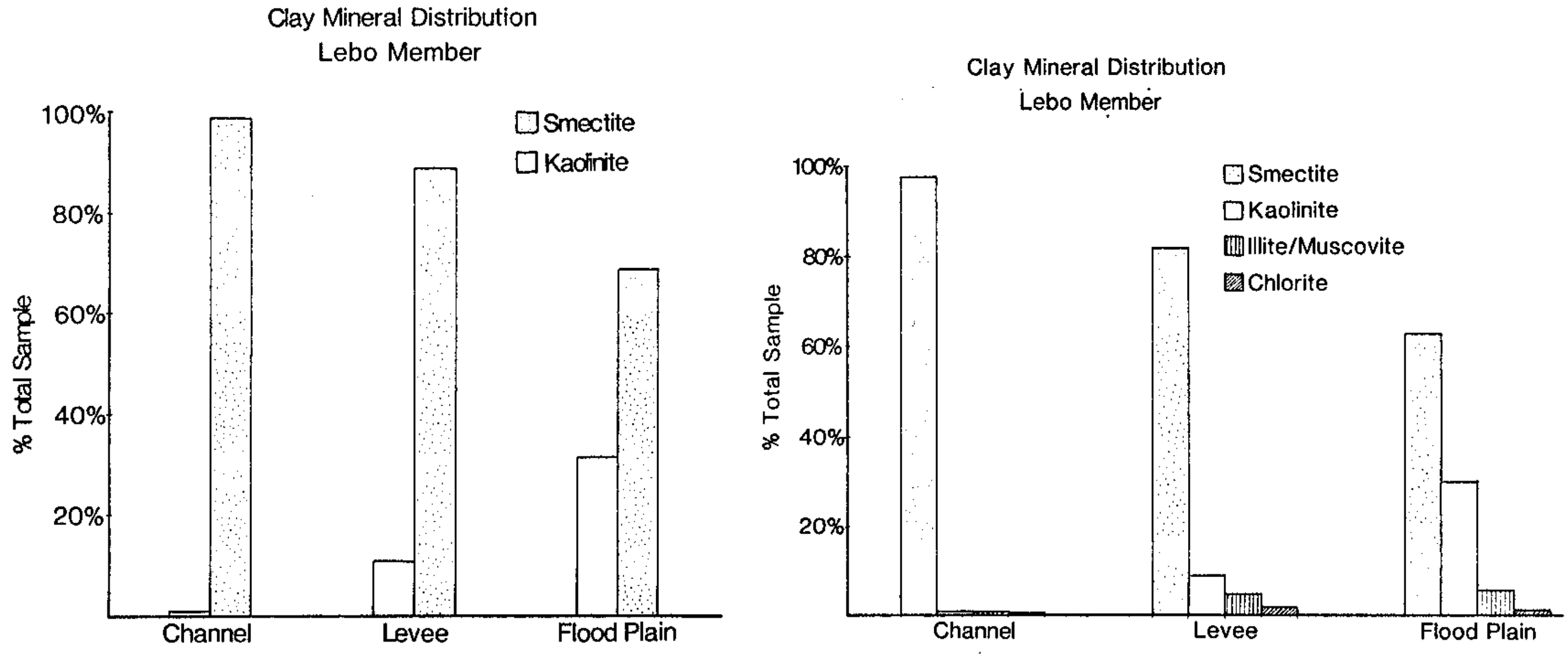
Clay Mineral Distribution
Lebo Member
100%
80%
60%
40%
20%
% Total Sample
Smectite
Kaolinite
Channel
Levee
Flood Plain
Clay Mineral Distribution
Lebo Member
100%
80%
60%
40%
20%
% Total Sample
Smectite
Kaolinite
Illite/Muscovite
Chlorite
Channel
Levee
Flood Plain

Figure 1