RECONSTRUCTION OF A PALEOCENE MEANDER BEND IN SOUTH-EASTERN MONTANA

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Introduction:

A computer-simulation model was used to compare two meander bends of the Lebo Member of the Fort Union Formation (Paleocene) in south-eastern Montana. The paleo-river channels are exposed in roughly one-quarter square mile of badlands in the Buck Mountain Quadrangle. The Lebo Member is composed dominantly of light gray fine and very fine sand that is believed to represent various depositional facies of meandering river systems. Full stratigraphic sections in three dimensions were exposed by gully erosion and became the basis of my field work.

My original intention was to construct a paleo-geographic map of the a number of small channels that traversed across this small section of the quadrangle. However, discontinuous exposures made correlations of key units from butte to butte virtually impossible. Field work by Ed Belt last summer suggests that a major channelbelt existed in strata directly underlying those I studied. The relationship of this larger meander belt to the smaller multistoreyed/multistepped channels studied by me remains unclear. Because of the correlation problem, I opted instead to attempt a paleo-hydraulic reconstruction of two meander bends from individual cross-sectional exposures. The computer simulation model generated the reconstructions.

Sediment description and interpretation:

The sediment in the two exposures is primarily fine and very fine sand with a clay matrix. The clay matrix is a smectite clay believed by Belt and others (1985) to have entered the basin detritally and to have remained unaltered since. Connie Hayden (see article, this volume) is presently studying these clays. The sand units, which are each several meters thick, are sporadically parted by thin (less than 1 m) carbonaceous shale layers and discontinuous nodular horizons. Interpretation of the deposits is based upon their depositional geometries, their grain size, and a variety of sedimentary structures.

Evidence that the sediment in the two chosen sections represents river channel deposits is fairly conclusive. At both sites, the asymmetrical shape of the cross section and dipping beds that extend horizontally away from it were clearly visible and lay above an eroded base of the deposit. The dipping beds are interpreted to be lateral accretion units whose lower portions contain trough cross beds. In each of the channel cross sections, a classic fining-up abandonment sequence was observed, and is thought to represent channel avulsion after a long period of migration. Rip-up clasts and mud breccia appear at the base of the sequence in one thick massively-bedded sand unit. This unit grades into thinner horizontally-bedded layers of alternating fine and coarse sediment and finally into massively-bedded mud that weathers like popcorn.

After identifying the complete cross sections of two channels, field measurements of channel geometry were taken and later used in the computer model. Bankfull depths were measured vertically from the base of the point bar to its top. Bankfull widths (for the purposes of the model) were taken as the horizontal flow-parallel distance from the top of the point bar to the thalweg. This distance is roughly .6 times actual full channel width (Bridge, and Jarvis, 1982; Bridge and Diemer, 1983). Flow directions were estimated from trough cross beds at the bases of the lateral accretion units. Mean grain size was qualitatively estimated (optical comparator) at regular intervals along the point bar surfaces. In both sections average grain size was found to fine upward from fine to very fine sand; mud units overlay these channels where not amalgamated with an overlying channel deposit. The final measurement that was necessary for use in the model was the maximum dip of lateral accretion bedding. Paleoflow directions on lateral accretion beds paralleled the strike of these beds and down the axis of the channel.

Channel reconstruction using the Bridge model:

Assumptions:

The results of this study are based on a number of important assumptions. First, in order for the model to be applicable to data from individual channel cross sections, it is assumed that the cross sections are located near meander bend apexes. This assumption is reasonable in both cases for two reasons. First, the fining-up sequence of sediment along the point bar surface is consistent with bar deposition down-flow from the bend apex (Thompson, 1985). Second, although quantitative sediment size analyses were not conducted, grain sizes coarser than those sampled at each of the cross sections were not observed elsewhere in the field. This fining-up sequence of the coarsest sediment is expected at meander bend apexes.

Two assumptions regarding the paleo-environment must be made as well. In measuring channel depth, I have assumed that there has been no sediment compaction. This is not unrealistic, since sands have been observed to have compaction factors close to 1.0 (Gardner, 1983). Finally, I assumed that modern stream relationships are applicable to the paleo-environment. This also seems reasonable, because the sediments are only Paleocene in age.

Reconstruction methodology:

The computer simulation model used was developed on the basis of observed relationships between flow, sediment transport, and bed topography (Bridge and Jarvis, 1982). In a study of a meander bend of the River South Esk, Scotland, the model closely reproduced the observed flow and sediment patterns. In the simplest of terms, the model combines the field data with standard empirically-derived input parameters to reproduce depth, velocity, grain size, and bed shear stress for ten equally-spaced cross sections from the inner bank to the thalweg. The empirical equations from which the reconstructions were produced are thoroughly derived in Bridge and Jarvis (1982). The output is plotted as an idealized, sine-generated, planform reconstruction of a segment of a meander bend (Figures 1 and 2). In addition, the program also estimates sinuousity and paleo-discharge.

Discussion:

The flow and sedimentation patterns that are shown on the planform diagrams are very similar to the simulations produced by Bridge and Jarvis (1982) and are consistent with the current understanding of helical flow. According to the accepted model for helical flow, two spirals of water converge and promote scouring and undercutting of the outer bank at the meander bend of a stream (Thompson, 1985). Bridge and Jarvis (1982), in their study of the River Esk, found that a single spiral exists over the entire point bar (i.e. inner bank to thalweg), and that a minor second spiral coverges with it between the thalweg and the outer bank. Since the planform diagrams contour output data from inner bank to thalweg, the information reflects only flow and depositional patterns produced by the major helix.

In simulating the pattern of flow velocity around the meander bend, Bridge and Jarvis (1982) observed that the pattern of secondary flow causes maximum mean velocity to shift from close to the inner bank in the upstream part of the bend to the thalweg in the downstream cross sections. The greatest depth is found at the apex of the meander bend channels (Figures 1A and 2A). The maximum velocity does indeed shift from the inner bank to the deepest parts of the channels (Figures 1B and 2B). Similarly, bed shear stress is also controlled by helical flow, and the crossover of maximum bed shear occurs at the same locations around the bend apexes as the velocity (Figures 1C and 2C). The behavior of these two flow characteristics is what governs the pattern of sedimentation around the meander bend. It is therefore not surprising that the patterns of grain size distribution are analogous to the ones for velocity and bed shear stress (Figures 1D and 2D).

In comparing the simulated data for each of the two cross sections, it has been noted that the same basic flow and sedimentation patterns have been produced according to our understanding of helical flow. However, the diagrams for the two channels are not identical (Figures 1 and 2). Differences in cross-section area and dip of lateral accretion bedding produced a greater discharge for channel 1 (134.78 cubic meters/second compared with 93.65 cubic meters/second for channel 2). In their study of the River Esk, Bridge and Jarvis (1982) noted that helical flow patterns are influenced by discharge. It is for this reason that the crossovers from inner bank to thalweg take place farther down stream on the meander bend in channel 1 than they do in channel 2.

Conclusion:

In criticizing my own results, I admittedly have reservations concerning the value of the output. First, the necessary assumptiion that the cross sections were meander-bend apexes may be somewhat suspect, because grain size analyses were entirely qualitative. However, in an area where channel systems are not laterally traceable, it may not be possible to determine precisely the location of the bend apex, and the Bridge model may be of limited applicability.

Second, it should not be overlooked that the relationship between flow and the sedimentary processes is still incompletely understood. The empiricial equations on which the model is based were developed from studies of modern stream patterns, but the applicability of this model to the myriad of river environments that exist has yet to be proved. Lastly, while the two reconstructions have produced idealized flow and sedimentation patterns, which may be of some value in understanding Paleocene river systems in southeastern Montana, in general, they contribute little to furthering our understanding of the regional geologic history of the area.

In summation, the goal of my research has been to reconstruct two paleo-river meander bends from data obtained at two channel cross sections, using empirical observations derived from modern stream systems. In as much as the idealized output uses the given field data to reproduce the flow and sedimentation patterns that have been observed in modern rivers, the project can be considered a success.

References:

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Figure captions:

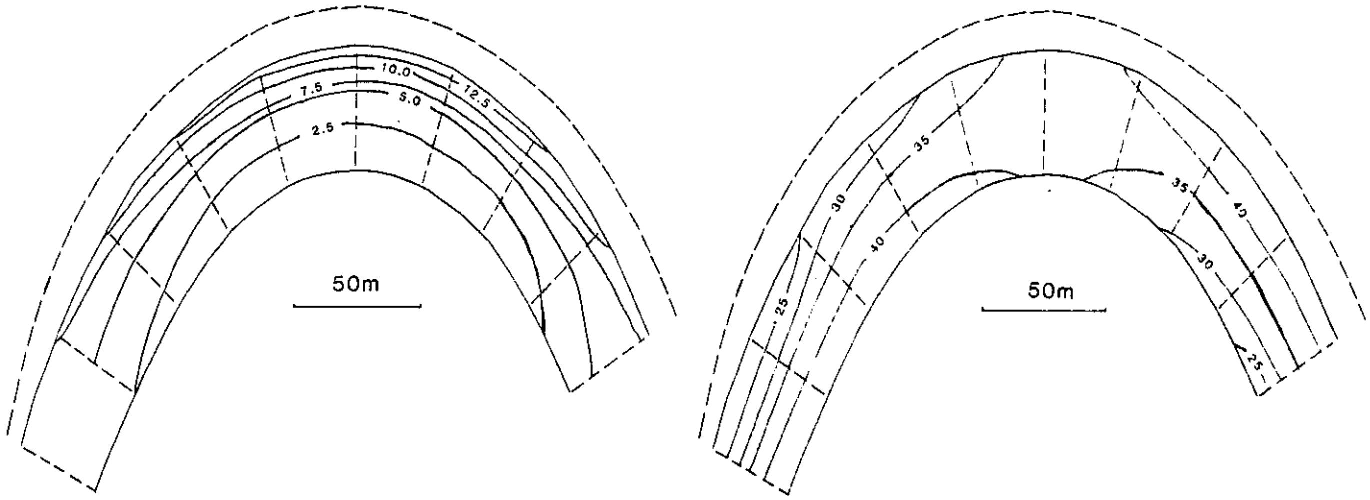
Figure 1. Channel 1: depth contours (A), velocity contours (B), bed shear stress contours (C) and grain size distribution (D).

Figure 2. Channel 2: depth contours (A), velocity contours (B), bed shear stress contours (C) and grain size distribution (D).

Figure 1

A. CHANNEL 1 DEPTH CONTOURS (m)

B. CHANNEL 1 VELOCITY CONTOURS (cm/s)



C. CHANNEL 1 BED SHEAR STRESS CONTOURS (dyn/cmsq.)

D. CHANNEL 1 GRAIN SIZE DISTRIBUTION (mm)

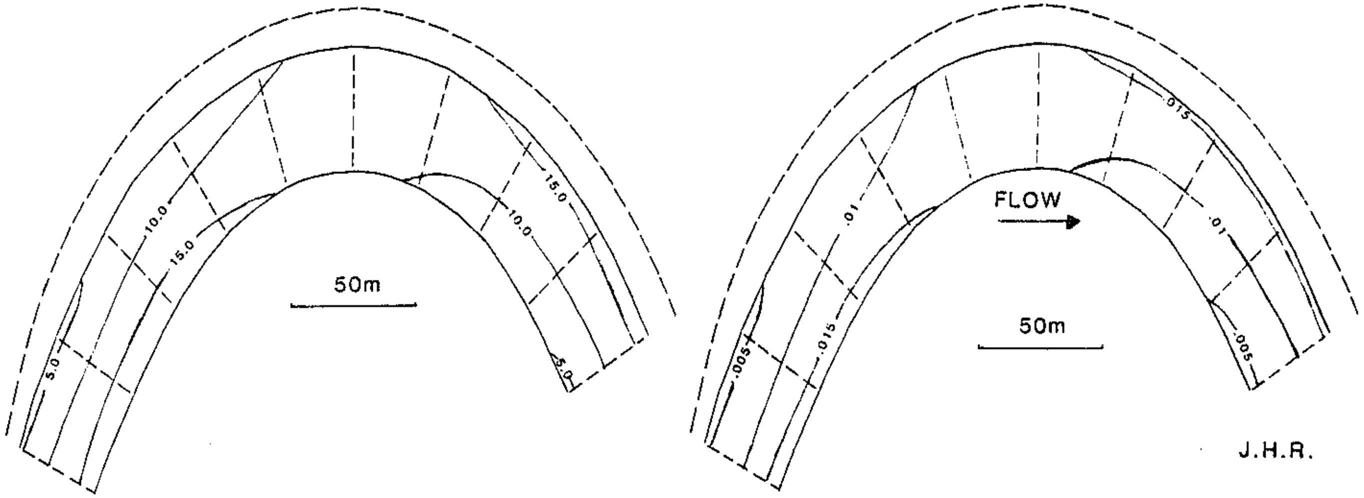
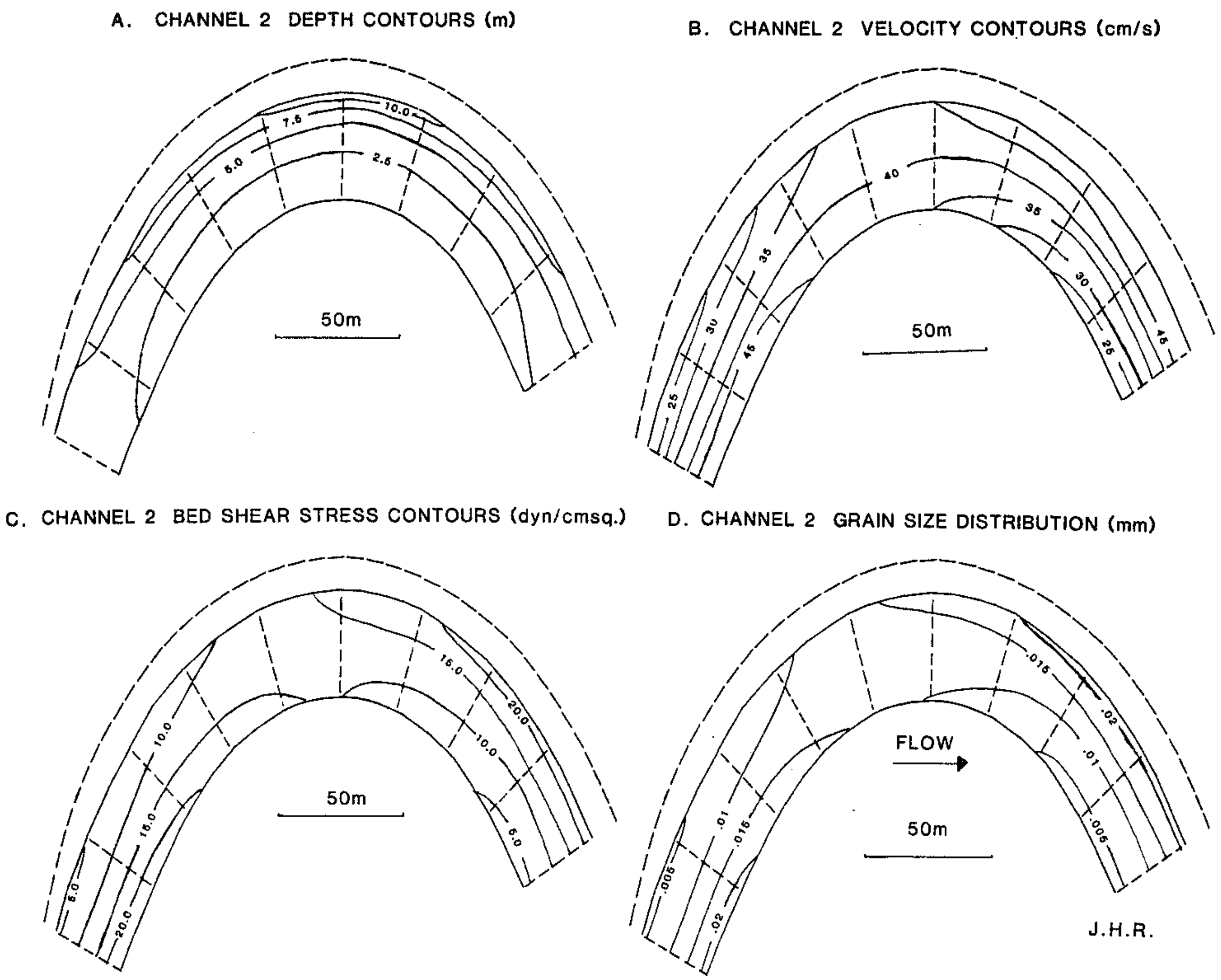


Figure 2



A. CHANNEL 2 DEPTH CONTOURS (m)

B. CHANNEL 2 VELOCITY CONTOURS (cm/s)

C. CHANNEL 2 BED SHEAR STRESS CONTOURS (dyn/cmsq.)

D. CHANNEL 2 GRAIN SIZE DISTRIBUTION (mm)

A STUDY OF THE FOSSIL FLORA PRESENT IN A PALEOCENE RIVER SYSTEM, SOUTHEASTERN MONTANA

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Three localities, from a field area 30 mi east of Miles City, MT, were chosen for the study of fossil leaves. More than four hundred individual specimens were collected from specially selected stratigraphic units within the Lebo Member of the Fort Union Formation in southwestern Williston Basin. The purpose of the project was to determine the depositional environments of the unconsolidated sediments and to relate the leaf assemblages to those environments, noting differences in species percentages from one environment to another.

The age of the Lebo is Torrejonian (Early Paleocene). This age is based on turtle bones collected by John Diemer and the leaf fossils collected by myself. J. H. Hutchison (Museum of Paleontology, Berkeley, August, 1987) and L. J. Hickey (Peabody Museum of Natural History, New Haven, February, 1988) independently dated the strata by examining the bone and leaf fossils, respectively. This is the first time Lebo strata in eastern Montana have been dated. In the past the Lebo was assumed to be Torrejonian age. This assumption was based on the age of Ludlow strata 200 miles to the east in North Dakota.

The lithologies of the Lebo units included fine-grained quartz-rich sands, silts, silty muds, clays, carbonaceous shaly mud, and lignitic coal. The clay minerals include smectite, kaolinite, illite, and chlorite (see Hayden report, this volume). Where smectite dominates (in any of the above lithologies except carbonaceous shale and coal), the sediment weathers to a concrete-hard unit, when sandy. It shows popcorn textures, when muddy. Lithification is usually limited to non-extensive nodular layers and clinker. Clinker results from the underground burning of coal that fused the surrounding sediment.

Twenty-two stratigraphic sections were measured and correlated by means of facies associations that define the depositional environments. The scheme for identifying the various environments was developed for Lebo strata in the area by Belt and Rockwell (in press). These depositional environments consist of meandering river systems that carried sediments from a source area located in the vicinity of either the Bighorn Mountains (Wyoming) or the Black Hills (South Dakota) (see Wong report, this volume).

The channel deposits are composed of fine- to medium-grained cross-bedded sand. These deposits are lenticular in sections perpendicular to the flow direction. They are characterized by ripples and cross beds, lateral accretion bedding, and fining-up sequences which are typical of meandering rivers (see Metcalf report, this volume).

The flood basin adjacent to the river channels is characterized by extensive fine-grained sediment, often rich in organic material, including fossil leaves and roots. These sediments are deposited during flood situations when the river has left its banks and carries fine to very fine clastics in suspension. These become deposited when the flood recedes. Vegetation is drowned by this sediment influx, thus allowing their widespread preservation. Levees along the margins of the river channels form and grow during floods. The river overtops its banks and drops sand and sandy mud at the channel edge, and progressively finer material away from that edge. The sands on the levee are current rippled and commonly penetrated by roots and tree stumps. Levees are only recognizable in the strata where the outcrop exposure will allow observations perpendicular from the channel margin outward into the flood basin, and the above characteristics are noted.

The final facies associated with the meandering river system is the crevasse splay deposit. Whenever the river makes a major breach in the levee, water funnels through the hole and fans out onto the flood plain. These splays form lobes that coarsen-upwards from the fine-grained deposits of the flood plain as they prograde outward from the main channelbelt. Each lobe has one or more channelways that bring the sediment from the breached region to the surface of the lobe. These crevasse channels thus are rippled and cross bedded sands that later become root bioturbated when the lobe is abandoned. The surface of the lobe has ripple-bedded fine-grained sand and mud. The lobe surface can form a region where vegetation can grow.

Leaf fossils can be preserved in all of the environments of deposition (Figure 1), but the best preser-