

DEFORMATIONAL STYLE AND STRUCTURAL RELATIONSHIPS ASSOCIATED WITH A WELL-EXPOSED SLUMP BLOCK WITHIN THE TONGUE RIVER FORMATION OF THE FORT UNION GROUP, CARTER COUNTY, SOUTHEASTERN MONTANA

Cheryl Kallweit
 Department of Geology, Trinity University
 San Antonio, TX 78212

INTRODUCTION

Carter County, Montana (figure 1) contains an unusual zone of deformation within the typically flat lying rocks of the region. The units are of Paleocene age and belong to the Tongue River and Ludlow Members of the Fort Union Formation (Garrett, 1963) (figure 2). Rocks in the deformed interval are folded, faulted, and tilted. The geographically and stratigraphically isolated nature of these features suggests that a local deforming mechanism was responsible. A single, well exposed, and laterally continuous outcrop located in the northeast quadrant of Section 8, T2N, R59E, Carter County, establishes that the deformation was most likely the result of a slumping event. This outcrop, 320 feet long and 60 feet high, documents the deformational relationship between a slumped block and the enclosing rock units. The flat lying Ludlow sands, muds, and coals immediately below the block have been deformed by the slumping, whereas an unconformable overlying Tongue River channel sandstone is flat-lying and locally downcuts into, and truncates the slumped and deformed units (figure 3). This single outcrop is a microcosm for the structural style of the region, providing information on the deformed zone contacts, macro and micro-scale structures produced during the event, and the kinematics of the slumping.

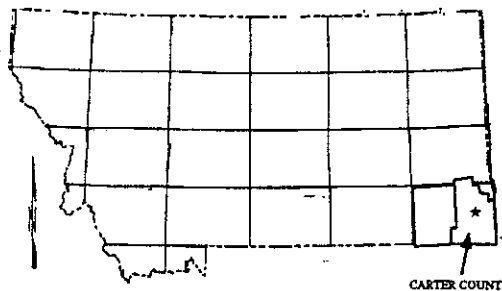


Figure 1. Location map of Carter County, Montana. Star indicates study location.

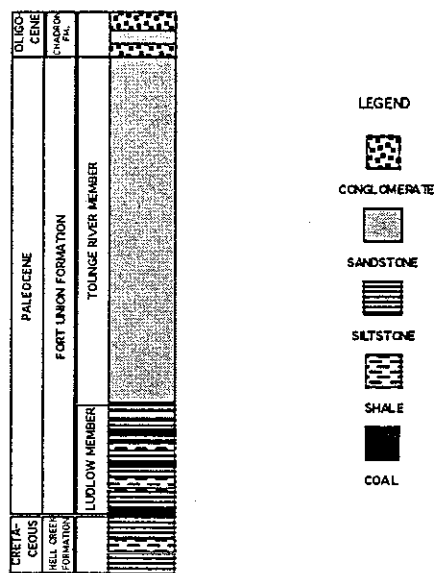


Figure 2. Generalized stratigraphic column of Southeastern Montana and Western South Dakota, modified after Dane (1978).

METHODS OF DATA COLLECTING

The outcrop was sketched and photographed. To aid in this task, a horizontal datum was established and subdivided into ten foot horizontal increments. A Brunton compass was used to determine the attitudes of bedding planes, fault planes, and hinge lines of folds. Orientation data were plotted with a Macintosh computer using *Stereo* to illustrate various structural trends. In addition to structural measurements, representative samples of each lithology and oriented samples, including fault surfaces,

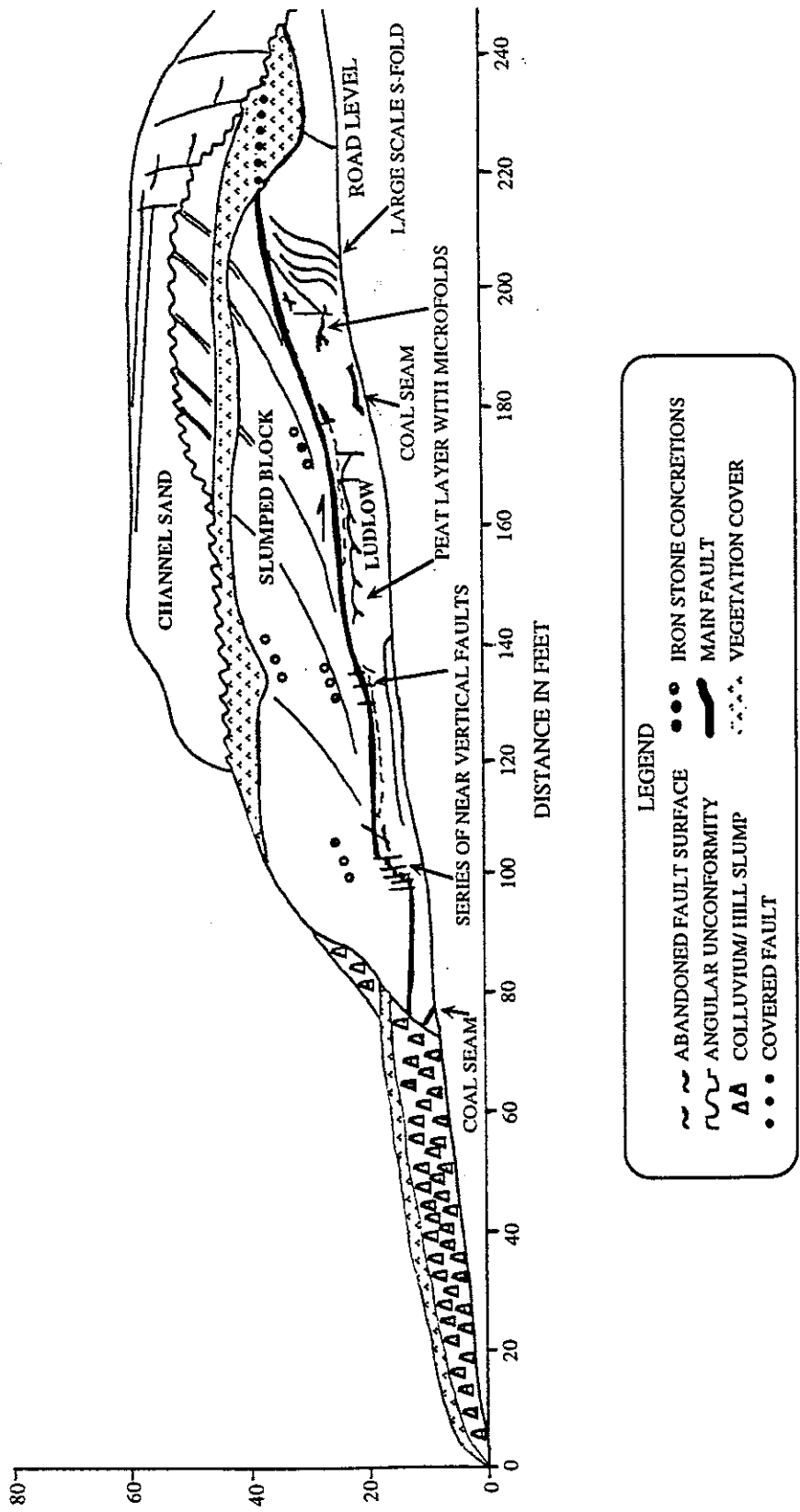


Figure 3. Line representation of the outcrop depicting deformation and the slump block.

were collected. Due to the poorly consolidated nature of the samples, a few required impregnation with epoxy during collection. Thin sections were made and analyzed to determine lithologies, microstructure, and microfabric orientations.

DISCUSSION

The outcrop includes four units comprising varying lithologies. The lowest unit is a gray, silty sandstone of the Ludlow Member. Within this unit are discontinuous lenses of buff-colored, very fine-grained sandstone. These lenses are commonly located above discontinuous slip surfaces, which appear to be earlier faults. These surfaces developed early during the slumping event and were abandoned for relatively younger, more favorably oriented fault surfaces. Two peat layers, now discontinuous and found throughout this unit, are greatly deformed and act as marker beds. In addition, a faulted lignite layer is present. In response to stresses generated by the slumping event, these layers behaved both plastically and brittly by folding and faulting. Ten small folds and fold couples, all showing clockwise rotation sense, are present within exposures of the upper peat layer. Their mean hinge line orientation is approximately $5^{\circ}\text{S}60^{\circ}\text{W}$ (figure 4a). In addition to small scale folding, the peat layers have been stretched and thinned laterally. In some locations peat layers have been displaced by near vertical faults that do not cut through the contact with the overlying slump block.

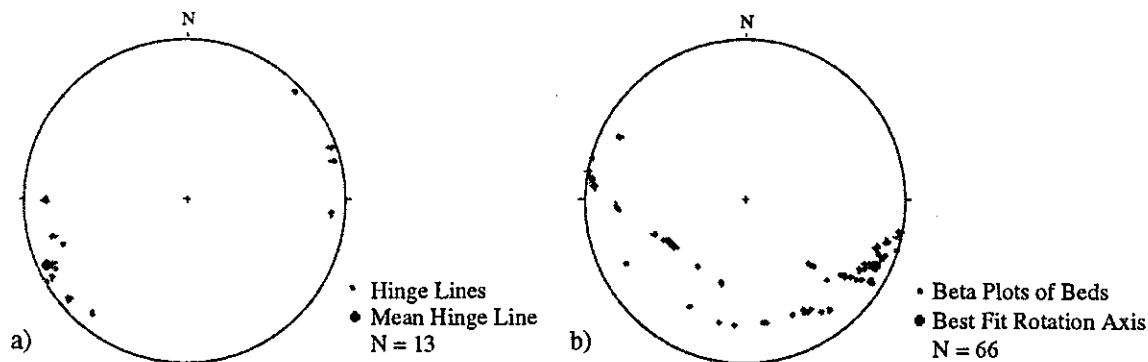


Figure 4. Schmidt Equal Area Projection of a) the mean hinge line of the small scale folds in the Ludlow Member and b) the best fit rotation axis of the slumped block using Beta intersections.

A fault surface separates the gray silty sandstone of the Ludlow Member from the slump block. An abrupt change in lithology marking the location of a generally planar contact defines this fault. The lack of slickensides and other displaced lines and features across the fault plane hinders the precise measurement of slip. The fault dips about 15° to the southwest across much of the exposure. The microfabric of the rocks immediately under the fault appears to have been affected by the faulting.

The slump block, with an average thickness of 20 feet, is composed of a very fine-grained, tan Tongue River sandstone, with ironstone concretions along some bedding planes. This unit is thickly bedded with dips that vary in orientation from slightly tilted near the basal fault plane to nearly vertical near the eroded and truncated top of the block. The best fit rotation axis for the slump block bedding is approximately $10^{\circ}\text{S}60^{\circ}\text{E}$ (figure 4b). This outcrop exposes the rotated and eroded leading edge of the slump block, as indicated by low dipping beds at the base and near vertical dips at the top of the block.

Below the main detachment at the base of the slump block and toward the north margin of the outcrop, is a large S-fold, with a height and width of about 15 feet, comprising the same lithology as the slump block. The rotation of the fold is counter-clockwise, indicating a different principal stress direction than that of the small scale folds within the lignite. The S-shape could have resulted from the effects of two separate slumping events (figure 5). Before the main slump block evolved, a smaller slump block slid down into the channel actively being cut on the north side of the exposure. The leading edge of the slump block was eroded away by the channel, leaving a remnant of the block containing steeply dipping beds. When the second, larger block slumped, it dragged the top of the first block with it, forcing the first block to bend in the slip direction forming the S-shape, now preserved in outcrop.

The slumping in this outcrop was apparently influenced by the downcutting of a channel which created a free face, and by instability in the tan sandstone which permitted failure of the channel margin and evolution of the slump block. Slumping could have been triggered by a local seismic event. A younger Tongue River channel sandstone crosscuts both the slumped tan sandstone and the silty Ludlow sandstone,

and lies unconformably over the slump block. A thickly bedded medium to coarse grained, tan Tongue River sandstone filled the channel at a time after both slumping events occurred. Trough crossbeds persist throughout the channel fill and rippled beds are present at the top of the unit. The outcrop is blanketed by recent colluvium, creep, and hillwash material, which is exposed for almost 80 feet at the southern margin of the cut. The filling and compaction of the channel caused loading, resulting in late stage, local, small-scale displacement of the fault plane bounding the base of the slump block. The slump block and the underlying gray silty Ludlow sandstone were offset as much as two feet along several near-vertical faults.

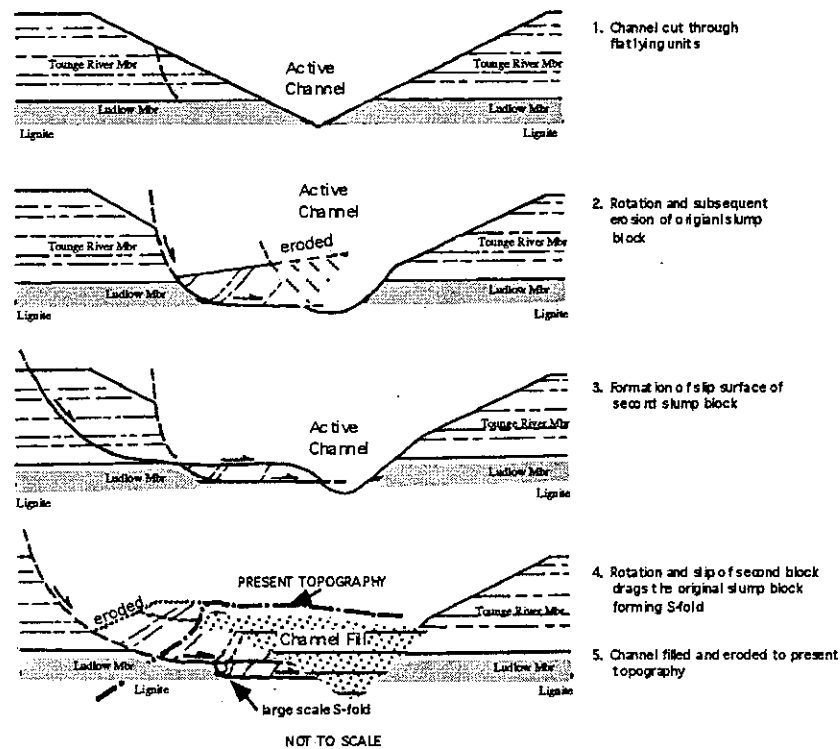


Figure 5. Sequential diagram of dual slumping events forming a large scale S-fold.

CONCLUSIONS

- Multiple slump events (at least 2) are documented in this exposure.
- A channel downcut through this region causing instability of the preexisting rock units. This downcutting and possibly a seismic event triggered the slumping. The channel was later filled by the massive, tan Tongue River sandstone.
- The tan Tongue River sandstone, with bedding planes ranging in orientation from slightly tilted to nearly vertical about an axis $10^{\circ}S60^{\circ}E$, comprises the major slump block.
- The severe deformation within the gray, silty Ludlow sandstone resulted directly from the stresses produced by the slumping of the overlying tan Tongue River sandstone block.
- A large scale S-fold formed due to a pair of slumping events in which the vertical beds resulting from the first slumping event were subsequently truncated and deformed by the second event.
- Loading caused by the deposition of the massive channel-fill sand produced the small scale vertical faults that displace the lower two units.

REFERENCES CITED

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- Garrett, H. L., 1963, Fossil slump features of the Tertiary Paleocene Fort Union: Billings Geological Society, 17p.