Postglacial mass wasting: large-scale slump blocks and earthflows, Clay Butte, Absaroka Wilderness, Wyoming

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INTRODUCTION

Clay Butte, located at the edge of the Absaroka Wilderness of northwestern Wyoming, covers approximately $8km^2$ and has an average elevation of 3050m (10,000ft). The butte is composed of approximately 300 meters of alternating shales and limestones dipping 8 degrees to the southwest (Pierce and Nelson, 1971). The Paleozoic rocks of Clay Butte rest uconformably on the Precambrian granites of the Beartooth Plateau. It is one of the only areas on the plateau where sedimentary rocks still remain.

The purposes of this study are to characterize the various features of mass wasting occurring on the west side of Clay Butte; determine their extent; estimate timing of specific events; and assess the controls and causes of failure. Features of slope instability include large-scale slump blocks of the Pilgrim Limestone, sag ponds within the depressions behind the rotated slump blocks, and numerous earthflows within the unconsolidated surface sediments.

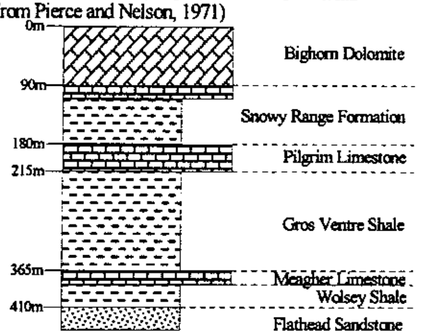
METHODS

Field Methods. Fieldwork was conducted between July 21 and August 11, 1997. Morphologic features were mapped and slope profiles were constructed using air photos, 7½' topographic maps (Beartooth Butte and Muddy Creek Quadrangles), Global Positioning System receiver (GPS), Brunton compass, inclinometer, barometric altimeter, a 50 meter tape, and field observations.

Unconsolidated clay-rich surface sediments were sampled from areas near shale outcrops. Bottom sediments from one of the smaller sag ponds were sampled with a 3-inch diameter bucket auger. The pond's sediments were cored to refusal at a depth of 2.4 meters by extracting incremental sections, each approximately 12.5 cm in length. Samples of clay-rich sediments, peat and an old log were also taken from a cutbank along Muddy Creek.

Lab Methods. Four organic samples were sent to Geochron Laboratories in Cambridge Massachusetts for radiocarbon dating: twigs and root hairs extracted from the lowest sag pond core, wood chips extracted from a middle core, the old log from the stream cutbank, and the peat from the stream cutbank. All samples were dated by the standard beta decay counting method, except for the twigs and root hairs, which were dated by accelerator mass spectrometry.

Figure 1: Stratigraphy of Clay Butte
(From Pierce and Nelson, 1971)



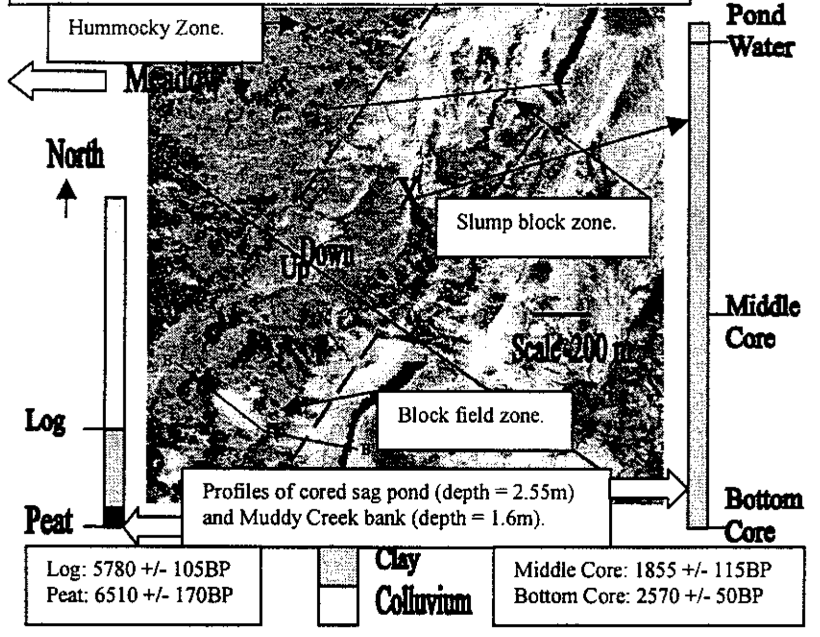
Clay mineral identification of the colluvial surface sediments, sag pond sediments, and stream cut bank sediments was conducted using x-ray diffraction techniques (Moore and Reynolds, 1997). Each sample was x-rayed after the following treatments: air dried, 24 hours in an ethylene glycol atmosphere, and heated at 350 °C for one hour. Oriented samples were prepared using the vacuum filter method (Velde, 1992) and x-rayed with a Scintag XDS-2000 X-ray Diffraction System, using copper Kα radiation.

RESULTS

Slope Characteristics. The Pilgrim Limestone forms a dominant cliff trending northeast (see stratigraphy on Fig. 1) and is cut by a vertical fault with approximately 50 meters of displacement (Pierce and Nelson, 1971). Landslide morphologies differ on either side of the fault, as well as below the Meagher Limestone, allowing the area to be divided into three distinct morphologic zones (Fig. 2).

Block Field Zone. Within the block field zone, numerous rock falls of the Pilgrim Limestone have built an extensive talus slope. Along the relatively flat top of the cliff, joint controlled lateral spreading has produced some impressive elongated fractures. Their lengths vary from 12 to 60 meters and their widths from 0.5 to 5 meters. Spacings between individual fractures range from 2 to 24 meters and they occur as far as 30 meters back from the cliff's edge.

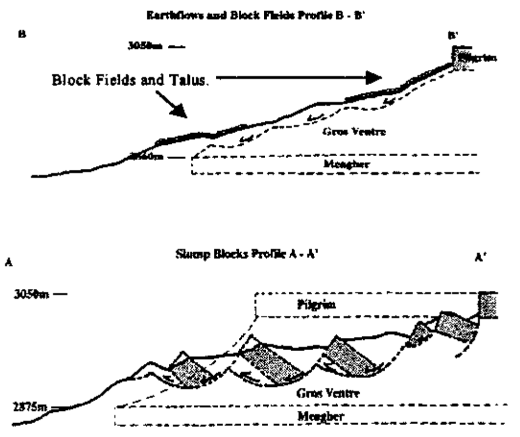
Figure 2: Airphoto of study area. (Dashed lines show steep ridges of clay-rich surface sediments built up on underlying Meagher Limestone. "X" marks location of cored sag pond)



A steep ridge of clay-rich earthflow material, with a westward slope of about 30 degrees, runs parallel to cliff just below the talus. Its steep slope is in part due to the shear strength of the underlying Meagher Limestone (Fig. 2). Below the ridge are four isolated block fields ranging from 1,000m^2 to 15,000m^2 in area. These features originated as talus from above and are now riding passively down the slope on earthflows. Slope profile B-B' depicts the undulating flow-like topography and inferred failure surface (Fig. 3).

Slump Block Zone. Within the slump block zone the stratigraphic units have been displaced downward approximately 50 meters. In the area closest to the fault, remnants of the overlying Snowy Range Formation and Bighorn Dolomite cap the Pilgrim Limestone cliff. Slumping of Pilgrim Limestone on Gros Ventre Shale has produced a series of five back-rotated blocks spread over an east-west distance of approximately 0.5 km (Fig. 2). The dips of the rotated blocks vary from 6 to 52 degrees eastward, with most between 20 to 30 degrees. Blocks furthest from the cliff are more broken up and in some cases partially buried by earthflow lobes, suggesting that the furthest slumps formed first with progressively younger slumps occurring closer to the cliff. While small-scale earthflows remain active throughout the area, the slumps appear relatively inactive. All slump blocks are highly eroded and undercut from long periods of exposure, and many depressions behind the rotated blocks have been partially filled. Slump block displacement does not extend below the top of the Meagher Limestone. Clay-rich material, squeezed out by compression from the limestone slump blocks, has built up a steep ridge on the underlying Meagher Limestone (Fig. 2). A slope profile A – A' depicts the interpreted failure surface (Fig. 3). Restoration to prefailure positions indicates 80 meters of cliff retreat (dashed lines in Fig. 3).

Figure 3: Slope Profiles.



Hummocky Zone. A hummocky topography of older earthflows occurs below the Meagher Limestone. Much of this older material has been funneled down a narrow channel (approx. 300 meters wide at its narrowest point) between granite outcrops and terminates in a meadow approximately 0.5 km^2 in area. The meadow appears to be an old lake that has filled from the rapid influx of mass wasting material. A cutbank along Muddy Creek, a stream that runs through the meadows sediments, reveals 122cm of colluvium underlain by lacustrine clay-rich sediments (Fig. 2). An old log was found imbedded within the sediments between the colluvium and underlying lake beds, and a 5cm thick layer of peat was found 33cm below the top of the lake beds (Fig. 2).

Lab Results. Radiocarbon dates show the sediments from the meadow (5780 and 6510 BP) to be older than those of the sag pond in the slump block zone (1855 and 2570 BP) (Fig. 2).

Table 1: Clay Mineralogy of sampled sediments.

Sample	*Kaolinite*	*Chlorite*	*Illite*	*Smectite*
Gros Ventre	D	L	D	M
Snowy Range	M	L	D	M
Wolsey	D	M	M	L
Top Core	M	L	D	M
Bottom Core	M	L	D	M
Old Lake Bed	D	L	D	M

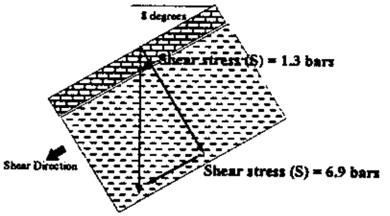
(Relative amts: D=dominant, M=moderate, L=little)

X-ray diffraction shows variable amounts of kaolinite, chlorite, illite , and smectite (Table 1). Relative abundances were interpreted by the intensity of the diffraction peaks. The mineralogy of the cored sag pond sediments is similar to the Snowy Range shale, while the mineralogy of the lake beds is similar to the Gros Ventre Shale. Since slump block failure occurred within the Gros Ventre Shale, the overlying Snowy Range Formation would provide most of the pond's sediments. The old lake beds are expected to be dominantly Gros Ventre since this area occurs well below all formations and the Gros Ventre is the thickest shale unit (Fig. 1).

DISCUSSION

Slope failure. The sequence of events leading to slope failure likely began approximately 13,000 years ago during Pinedale deglaciation (Pierce, 1979; Oliver, 1997). With the removal of the lateral support of the ice, the glacially eroded steep slopes of Clay Butte were susceptible to shear stresses induced by gravitational forces. The slight dip of the strata to the southwest likely explains why the west side of the butte is more susceptible to mass wasting than the east side. A shear stress of 1.3 to 6.9 bars results, depending on whether the shear plane is located at the top or bottom of the Gros Ventre Shale (Fig. 4). Shearing within the Gros Ventre Shale likely results in the lateral spreading of the overlying Pilgrim Limestone and the development of the open fractures observed on top of the butte. These fractures likely contribute to slump block failure by isolating large coherent blocks from the main unit. Although such fractures were not observed on top of the butte directly above the slump block area, one should not conclude that fracture formation did not contribute to their failure. The fractures may lie hidden beneath the overlying Snowy Range Formation and Bighorn Dolomite, or current fracture development may be inhibited by a lateral support of the already failed slumps. Once separated from the main limestone unit, the extra weight of the overlying Snowy Range Formation and Bighorn Dolomite may have been an important slump block triggering mechanism, and which might explain the absence of large-scale slump blocks to the immediate south and north.

Figure 4: Shear Stress Analysis.



S = Sin(8) x [density x thickess x gravitational acceleration]

Water saturated clay will significantly reduce shale shear strengths (Ritter et al., 1995). All slump block and earthflow failures at Clay Butte occur within the Gros Ventre and Snowy Range shales, suggesting that water saturated clay may be a fundamental triggering mechanism. As noted by Borchardt (1977), smectites and other expandable clays have a high plasticity and water adsorbance which, when water saturated, can greatly reduce shear strengths. Moderate amounts of smectites were found in both the Gros Ventre and Snowy Range shales (Table 1).

Timing. All slump blocks are highly eroded and undercut from long periods of exposure, and many depressions behind the rotated blocks have been partially filled, suggesting that the slumping process is relatively inactive. This leads one to suggest they formed under different climatic conditions. Though studies of similar inactive slump blocks have been attributed to wetter climates immediately following the Pleistocene (Reiche, 1937; Strahler, 1940) or during the Pleistocene (Watson and Wright, 1963), radiocarbon dating suggests that the slumps of Clay Butte are much younger (Fig. 2). Assuming sag pond formation occurs immediately after failure and that the bottom core is representative of the date of pond formation, radiocarbon dating suggests that slumping was occurring at 2,570 BP. This date, however, may not represent initial slumping. Instead, each successive slumping may push earlier slumps forward, away from the main cliff. If this is the case, the sag pond is not stationary, its present position is determined by the last block to slump off the main cliff, and its sediments only date back to this most recent movement. At least three main slump blocks occur up slope of the sampled pond, and each of them would have displaced the sag pond a little further from the main cliff. Initial slumping, therefore, could have begun at 13,000 BP, with removal of ice lateral support, and continued until approximately 2,570 BP. The present relative inactivity of the slump blocks may have more of a structural control than a climatic control. Since slump block displacement is confined to the top of the Meagher Limestone, the slump blocks may be supporting the main cliff and inhibiting further slumping.

Using the two dates obtained from the bottom (2570 BP) and middle cores (1855 BP), we calculate a sag pond sedimentation rate of 1.6 ± 0.3 mm/yr., which is relatively low. Though highly variable, typical lake sedimentation rates can be anywhere between 2.5 to 50 mm/yr. (Hakanson and Jansson, 1983).

Radiocarbon dates from the meadow (Fig. 2) suggest that the lake which once existed here filled with sediment about 5,780 BP. Using this date for the top of the lake beds with the date for the peat 33 cm below (6510 BP), we obtain a sedimentation rate of 0.45 ± 0.16 mm/yr., which is extremely low. The low sedimentation rates of the old lake and the sag pond suggest that sedimentation may be episodic instead of continuous. The higher sedimentation rate of the sag pond likely results from its closer location to the sediment source.

Holocene climatic studies show a warmer/drier period, known as the Altithermal Period, occurring between 10,000 to 5,000 BP (Baker, 1976; Whitlock, 1993), with a cooler/moister period beginning 5,000 BP and continuing until today. Perhaps the increased precipitation following the Altithermal Period initiated large scale movements on the west side of Clay Butte, including both debris flows, which eventually filled in the lake, and the large-scale block slumping. It is possible that mass wasting features which developed immediately following Pinedale deglaciation 13,000 years ago have eroded away and that the present features are representative of approximately the past 5,000 years.

CONCLUSION

In summary, the principal factors contributing to the unstable slopes of Clay Butte are thick sequences of shales and the gentle dip to the southwest. These factors have resulted in the lateral spreading of the Pilgrim limestone with subsequent slumping. Water saturated clay is likely the dominant triggering mechanism for both slump block and earthflow failures. Another important triggering mechanism may include periodic earthquakes, such as the Hebgen Lake earthquake (7.1 Richter scale) in 1959 (seismicity of area is summarized in Pierce and Morgan, 1992). A cooler/wetter period following the end of the Altithermal Period (5,000 BP) may have triggered faster rates of movement. However, the present relative inactivity of the slump blocks is most likely due the strength of the underlying Meagher Limestone and not to a change in climate.

Further details of Holocene climatic variations may be found from a pollen/diatom analysis of the old lake sediments. Also, an understanding of failure mechanics may be obtained from quantitative measurements of the physical properties of the clay-rich material, such as plasticity, permeability and shear strengths.

REFERENCES CITED

Baker R. G., 1976, Late Quaternary vegetation history of the Yellowstone Lake Basin, Wyoming: U.S. Geol. Survey Prof. Paper 729-E, 48 p.

Borchardt, G. A., 1977, Clay mineralogy and slope stability: California Division of Mines and Geology, Special Report 133, 15 p.

Hakanson, L. and Jansson, M., 1983, Principles of lake sedimentology: Berlin, Springer-Verlag, 316 p.

Pierce, K.L., 1979, History and dynamics of glaciation in the northern Yellowstone National Park area: U.S. Geol. Survey Prof. Paper 729-F, 90 p.

Moore, D. M. and Reynolds, R. C. Jr., 1997, X-ray diffraction and the identification and analysis of clay minerals: New York, Oxford University Press, 378 p.

Oliver, George, 1997, Debris flow's effect on Holocene alluvial fan formation and record of environmental instability, Corral Creek, Park County, Wyoming: The Tenth Keck Research Symposium In Geology, The College of Wooster, Wooster, Ohio, p. 166-169.

Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot: volcanism, faulting, and uplift, *in* Link, P.D., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geol. Society of America, Memoir 179, p. 1-53.

Pierce, W.G. and Nelson, W.H., 1971, Geologic map of the Beartooth Butte quadrangle, Park County, Wyoming: U.S. Geol. Survey Geol. Quad. Map GQ-935, scale 1:62,500

Reiche, Parry, 1937, The Toreva-Block - A distinctive landslide type: Journal of Geology, v. 45, p. 538-548.

Ritter, D. F., Kochel, R. C., and Miller, J. R., 1995, Process geomorphology (3rd Ed.): Iowa, Wm. C. Brown Publishers, 546 p.

Strahler, A. N., 1940, Landslides of the Vermilion and Echo Cliffs, northern Arizona: Journal of Geomorphology, v. 3, p. 285-301.

Velde, B., 1992, Introduction to clay minerals: London, Chapman and Hall, 198 p.

Watson, R.A. and Wright, H.E. Jr., 1963, Landslides on the east flank of the Chuska Mountains, northwestern New Mexico: American Journal of Science, v. 261, p. 525-548.

Whitlock, Cathy and Bartlein, Patrick J., 1993, Spatial variations of Holocene climatic change in the Yellowstone region: Quaternary Research, v. 39, p. 231-238.