Textural characteristics of the microbreccia layer of the Heart Mountain fault, Wyoming-Montana

Kristin A. Ulstad
Department of Geology, Carleton College, Northfield, MN, 55057
Faculty sponsors: Edward C. Beutner, Franklin and Marshall College; David Bice, Carleton College

INTRODUCTION AND GEOLOGIC SETTING

The Heart Mountain fault in northwestern Wyoming is one of the most enigmatic and controversial geologic features on the North American continent. For more than one hundred years, structural geologists and petrologists have debated the faulting mechanism of this extremely low-angle (1-2°) detachment fault which displaced fault blocks up to 50km to the southeast during the early Eocene, shortly after the onset of Absaroka volcanism. Most recently, Beutner and Craven (1996) have proposed the possibility of a volcanic sill-like injection of volcanic gas along the detachment, triggering fault failure (Figure 1).

A discontinuous fine-grained microbreccia with a carbonate-rich matrix, varying in thickness from 0-3.5m, is found along the fault. This microbreccia includes clasts of carbonate and volcanic rocks as well as amorphous inclusions of devitrified glass. The purpose of this study is to determine if the composition and texture of the microbreccia shed light on the mechanism of fault emplacement and the relationship of the microbreccia to fault movement.

TEXTURAL CHARACTERISTICS

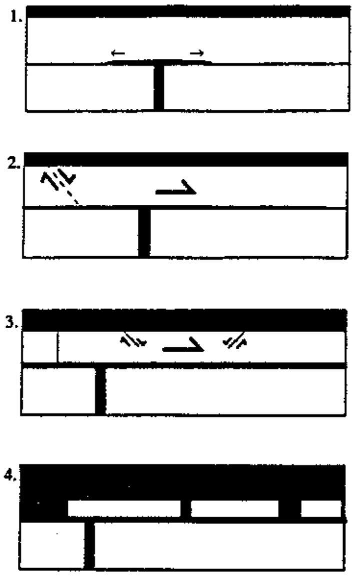
Accreted grains and glass inclusions. Accreted grains similar to accreted lapilli are found distributed throughout the carbonate-rich microbreccia. Amorphous, intact glass inclusions with plagioclase and occasional pyroxene phenocrysts are also present. Gerbi (1997) reported that the percentage of glass grains decreases with distance from the Crandall intrusive complex, the proposed source of volcanic injection. Most glass grains are devitrified; some show a thin carbonate rind, whereas reaction rims are rare on other grains; sometimes glass partially or completely armors grains.

Grain Orientation. A series of fourteen closely spaced (15-20cm) samples were taken from the thick (3.6m) microbreccia outcrop exposed at White Mountain. From these samples, fourteen thin sections were cut vertically, parallel to hanging wall transport direction S60E, and two were cut horizontally, parallel to transport direction (Figure 2). The flow direction was determined by striae and groove casts found on the microbreccia-footwall contact at many locations along the fault. The angle between the apparent long axis of elongate grains and horizontal was determined for all elongate micrograins (usually about 60 grains; N=60) in each of the 14 slides. Rose diagrams of the plunge of apparent long-axes show a consistent near-horizontal to gentle NW plunge, whereas the horizontal slides show little grain alignment (Figure 3).

Wallrock Clasts. Several samples were taken to examine the relationship of the microbreccia to the hanging and footwalls. In the field, the microbreccia-footwall contact is planar and usually horizontal; in thin section this contact is sharp but not perfectly planar, as microbreccia is seen injected into joints and fractures in the footwall. Wallrock clasts are commonly seen in thin section along the footwall. However, no rip-up clasts were observed along the wavy microbreccia-hanging wall contact. Clast orientations along the footwall generally appear subparallel to the horizontal footwall.

Striae and groove marks. Striae and groove casts were observed on some microbreccia/hanging and footwall contacts, as has been reported by others. Recent spring floods have washed out the carbonate footwall at a site just west of Squaw Creek, leaving the resistant microbreccia layer intact, and providing an excellent exposure. Float pieces and new, fresh exposures showed clearly defined groove casts trending S45-60E, reminiscent of those seen on the base of turbidite flows. The grooves are not always parallel, and in one sample a second, faint younger set trend ~15° more easterly than older, deeper grooves.

Microshearing and fracturing. The microbreccia has a remarkably coherent, massive nature. Shearing of grains or matrix in the microbreccia was not observed, and microfaults and fractures are rare. However, a thin section cut from a sample at Republic Mountain reveals a microfault offsetting a carbonate clast and the surrounding matrix 2mm.



1. Magma intrudes into Paleozoic carbonate sediments above the Crandall intrusive complex. Glass and volcanic gas inject along a minor bedding plane in the Bighorn Dolomite. Pulverized carbonate, carbonate pieces, and volcanic clasts are present in the glass and gas layer. Accreted grains form.

2. Friction along the detachment is reduced to near zero. Faulting occurs as gravity causes sliding along the 1-2 degree fault plane. The high-angle normal fault on the left represents the break-away fault.

3. The continuous allochthon moves up to 50 km. Normal faulting in the hanging wall causes thinning and eventually break-up of the block. Volcanic materialoverlying the moving allochthon fills in gaps during thinning.

4. Gas escapes through fractures and gaps in the hangingwall. Fluidized microbreccia layer cools. Movement along the fault stops.

Figure 1. The volcanic fluidization model as proposed by Beutner and Craven (1996).

DISCUSSION

Flow. The hypothesis made at the beginning of this study was that if the microbreccia had been fluidized, evidence of flow structures or textures would be seen either in the field or thin section. Accreted grains, intact glass inclusions, oriented grains and groove casts, and tool marks similar to those seen on the base of a turbidite flow were all observed in this study.

In most turbulent flows, elongate grains entrained in the flow will rotate independently, depending upon the flow mechanism and duration. If at any given time a turbulently flowing material were to "freeze up", the long-axes of entrained grains would not be expected to show alignment (Davis, 1992). Apparent long-axis alignment sub-parallel to the boundaries of the detachment plane is seen in the microbreccia, but the horizontal orientations of grains show no strong alignment. Whether this alignment is due to a morphological flow pattern, or to shearing or compaction of grains previously unaligned during turbulent flow is not yet clear. Instantaneous cooling and compaction of the gas-rich fluidized layer present along the detachment during faulting may have been capable of creating a compaction foliation similar to that seen in ignimbrites (formed as a fast-moving gas-rich cloud of volcanic material cools and collapses under its own weight) (Cas and Wright, 1987). Microfractures present in the microbreccia suggest that slight movement or adjustment of the overriding plates may have continued after the microbreccia layer became "locked" to the surrounding rock.

Gas content of the fluidized layer. Lack of deformation in the footwall seems to require that the upper plate was supported by high fluid pressures which protected the footwall during movement. A bed of liquid or gas could provide this kind of protective cushion. Widespread clastic dikes, primarily in the hanging wall, show evidence of a pressurized carbonate-rich cataclasite along the fault. These dikes, however, give no indication of the phase (liquid, gas, or both) of the fluidized layer.

Various models have been proposed to explain the faulting mechanism. Evidence for flow structure and the presence of accreted grains in the microbreccia have sparked my investigation of "wet" and "dry" fluidization models. Isotope data published by Templeton et al. (1995) indicates that water was present along the detachment during faulting. "Dry" faulting models suggest that faulting was facilitated by an injection of steam or gas (Hughes 1970; Voight 1974; Prostka 1978). The "dry" faulting models seem most compelling to me, given the high pressure environment necessary to buoy up the overlying plate, but the isotope evidence presented by Templeton et al. (1995) requires some kind of water present during faulting. One possibility is that as magma from the Crandall intrusive complex intruded into the carbonate sequence, it encountered groundwater, causing an underground explosion of gas (both volcanic gas and vaporized water) and hot magma. The magma quenched almost immediately, forming the amorphous glass inclusions seen in the microbreccia. These inclusions were transported along the detachment with the gas, protected from fracturing by the cushioning gas matrix. Also in suspension were pulverized particles of carbonate, which now make up the microbreccia matrix, and various lithic and carbonate grains.

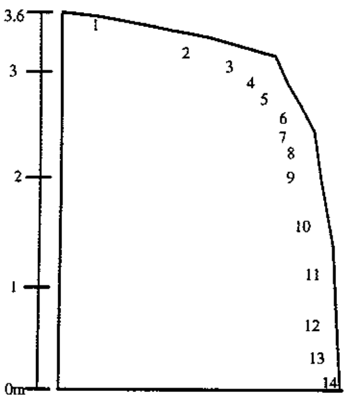


Figure 2A.

Vertical (1-14 in Fig. 3 below)

Horizontal (15 and 16 in Fig. 3 below)

Figure 2B.

Figure 2. Figure 2A shows the sampling pattern at White Mountain. Figure 2B shows the orientation of thin sections cut from the samples.

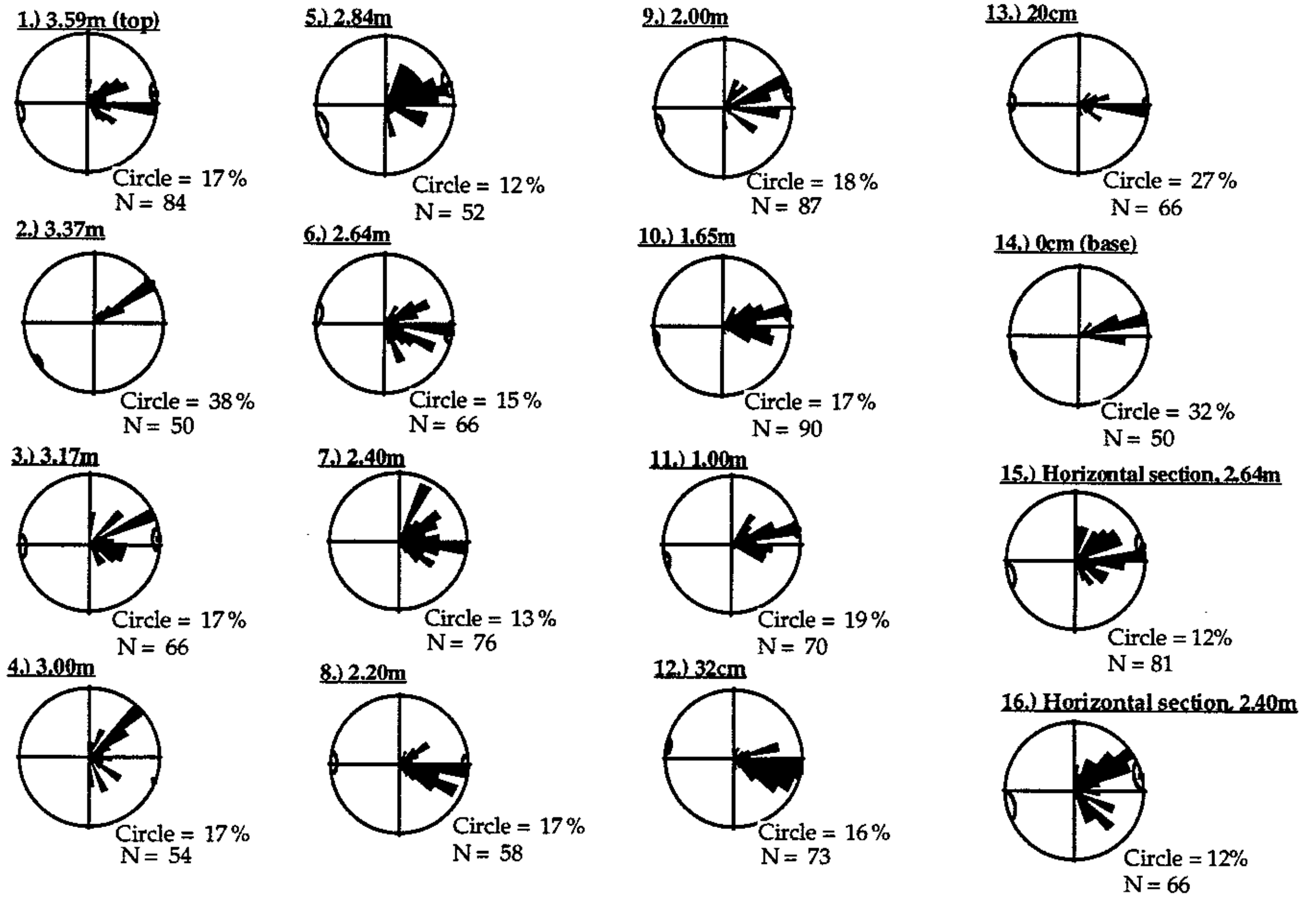


Figure 3. Rose diagrams of micrograin orientations in White Mountain thin sections. Meter numbers indicate height above base of microbreccia-footwall contact. Plots 1-14 present data from thin sections cut vertically, parallel to transport direction S60E. Plots 15 and 16 present data from thin sections cut horizontal to detachment plane, parallel to transport direction. Note the apparent tight grain alignment in most vertical sections and apparent lack of alignment in horizontal sections.

The high gas content volcanic fluidization model may help explain the lack of reaction rims on clasts in the microbreccia and the possible lack of heat alteration in the surrounding carbonate clays (Howse, this volume). Because gas has a lower heat capacity per kilogram than liquid, a high-gas injection would have less thermal energy available to transfer to surrounding rock.

Rate of faulting. Gerbi (1997) suggests that the emplacement of the Heart Mountain allochthon occurred in multiple episodes, a hypothesis based on the presence of one grain in the microbreccia thought to have been an earlier microbreccia. This study does not support that hypothesis; all textural evidence such as intact glass inclusions and a lack of evidence for previously faulted grains in the microbreccia supports a model of single event catastrophic faulting associated with friction reduction due to a volcanic intrusion of gas and glass along the detachment. A high-gas content model demands catastrophic faulting because of the inevitable dissipation of gas through the surrounding rocks as well as leakage through fractures and breaking-up of the overlying expanding plate.

CONCLUSION

The purpose of this study was to conduct a qualitative analysis of the microbreccia layer to further evaluate the viability of the volcanic fluidization model of the Heart Mountain fault as proposed by Beutner and Craven in 1996. Textural evidence observed in the microbreccia such as the presence of armored and accreted grains, vesicles, amorphous glass inclusions, vertical grain alignment, lack of horizontal grain alignment, flow structures, and slight microfaulting support this model of injected volcanic gas and water vapor facilitating detachment and catastrophic faulting by friction reduction along the fault plane. A high-gas content model may account for a lack of reaction rims in the microbreccia and low thermal alteration in the surrounding rock due to the low amount of thermal energy contained in gas.

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