The breccia layer of the Heart Mountain fault and related clastic dikes

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Introduction

The Heart Mountain allochthon moved along the nearly horizontal Heart Mountain fault as a continuously extending upper plate driven by the gravitational collapse of an unstable volcanic pile (Hauge, 1993). The allochthon is composed of carbonate and volcanic rock. Beutner and Craven (1996) studied the fault at White Mountain and proposed that the upper plate was buoyed up by a lateral injection of volcanic fluid from a volcanic center at Hurricane Mesa. A breccia layer exists along much of the fault and varies in thickness from 0-2 m. In numerous places this breccia was injected upward into the upper plate as clastic dikes. This study characterizes the breccia layer and clastic dikes along the length of the fault and try examines evidence for the cause of friction reduction along the fault plane.

Petrography

The breccia layer and clastic dikes are similar in composition and texture and are composed of a very fine grained (3-20 μm) carbonate matrix with mm and larger clasts of carbonate and volcanic rocks. Carbonate clasts are subangular to subrounded and are derived from the dolomites and limestones on both sides of the Heart Mountain fault. Volcanic clasts fall into three categories: 1) broken or unbroken single crystals, usually plagioclase, but occasionally amphibole and pyroxene; 2) yellow glass, with or without plagioclase and pyroxene microphenocrysts; 3) volcanic rock fragments, which are rare and found only in a few samples. Many volcanic clasts have been partially to nearly completely altered to calcite.

Clasts make up about 40% of the breccia; the rest is a matrix of fine grained carbonate with minor amounts of fine volcanic material and some clays. The breccia is usually massive but occasionally shows slight horizontal banding parallel to the fault. Imbrication is not present. The breccia sometimes armors clasts.

In one location, clasts of a distinct, earlier breccia are found within the breccia matrix. At least one of these breccia clasts contains a fragment of potassium feldspar. The presence of two distinct microbreccias suggests that there were at least two phases of faulting and that enough time elapsed between the two for the first breccia to lithify.

"Glass" clasts contain a yellow to opaque brown matrix of partially to completely devitrified volcanic glass, and commonly contain >50% plagioclase and pyroxene crystals. The shapes of the glass fragments vary considerably from rounded and equant to shards which are flattened parallel to the Heart Mountain fault. In some samples the glass has partially engulfed carbonate clasts.

The proportion of both volcanic and glass clasts decreases with distance from Hurricane Mesa, a known volcanic center (figure 1).

Volcanic glass compositions

The compositions of the glass fragments vary considerably (figure 2). When compared to the Wapiti volcanics and the allochthonous plutons in the upper plate of the Heart Mountain fault (see Stone, this volume) the glass compositions are typically higher in SiO_2, Na_2O, K_2O, and lower in CaO, Al_2O_3, and MgO. Some of this variation may be the result of devitrification or metasomatic alteration of the glass. However, even the analyses of the least altered glass do not match the analyses of surrounding igneous rocks. The chemical analyses of the Wapiti formation and the plutons are whole-rock analyses, including crystallized components that came up with the magma. The glass analyses represent compositions of the *interstitial magma* between those phenocrysts. By adding the compositions of possible phenocrysts to the glass we can create glass plus crystal compositions similar to those of the other igneous rocks.

plane would follow the same rules as sill injection. This argument requires that stresses in the Clarks Fork region were aligned vertically and horizontally, and that σx was in the horizontal direction, possibly related to Laramide age deformation, and that sill injection and the injection of volcanic gas are mechanically analagous. The occurrence of the detachment horizon fits this model perfectly: it is above a lithologically weak unit, the Snowy Range Formation, and at the base of a lithologically strong unit, the Bighorn Dolomite. Thus, assuming that the volcanic fluidization model is correct, then the most likely location for an injection of fluidized material is exactly where the Heart Mountain detachment occurs.

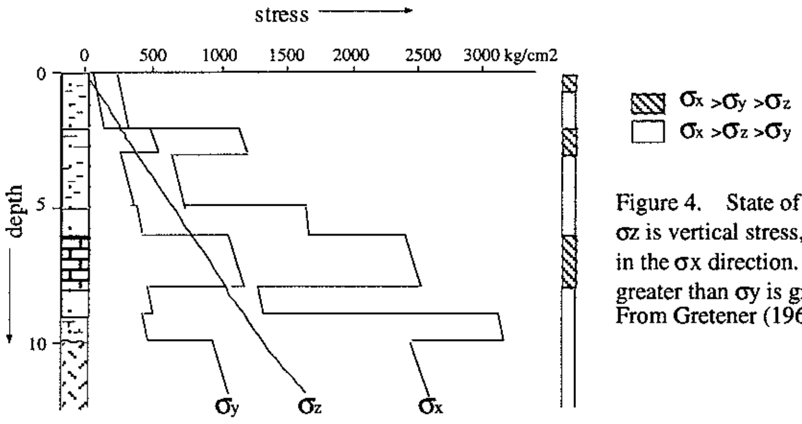

Figure 4. State of stress in the basement and sedimentary sequence. σz is vertical stress, and σx and σy are horizontal with compression in the σx direction. Stress varies with lithologic unit. When σx is greater than σy is greater than σz, then sill injection can occur. From Gretener (1969).

CONCLUSION

The purpose of this project was to collect for the first time a description of footwall deformation in the bedding-parallel portion of the Heart Mountain detachment. My study supports a model for catastrophic faulting, provides evidence against a slow-faulting mode, and indicates the presence of fluidized material along the fault plane. Therefore, observed footwall deformation most strongly supports the volcanic fluidization model of Beutner and Craven (1996). The model for sill injection of Gretener (1969) provides an explanation for the occurrence of the detachment along a bedding plane of the Bighorn dolomite rather than Cambrian shales below. A combination of the volcanic fluidization model (Beutner and Craven, 1996) and the model for sill injection (Gretener, 1969), provides the most comprehensive model yet for the formation and movement of the Heart Mountain fault.

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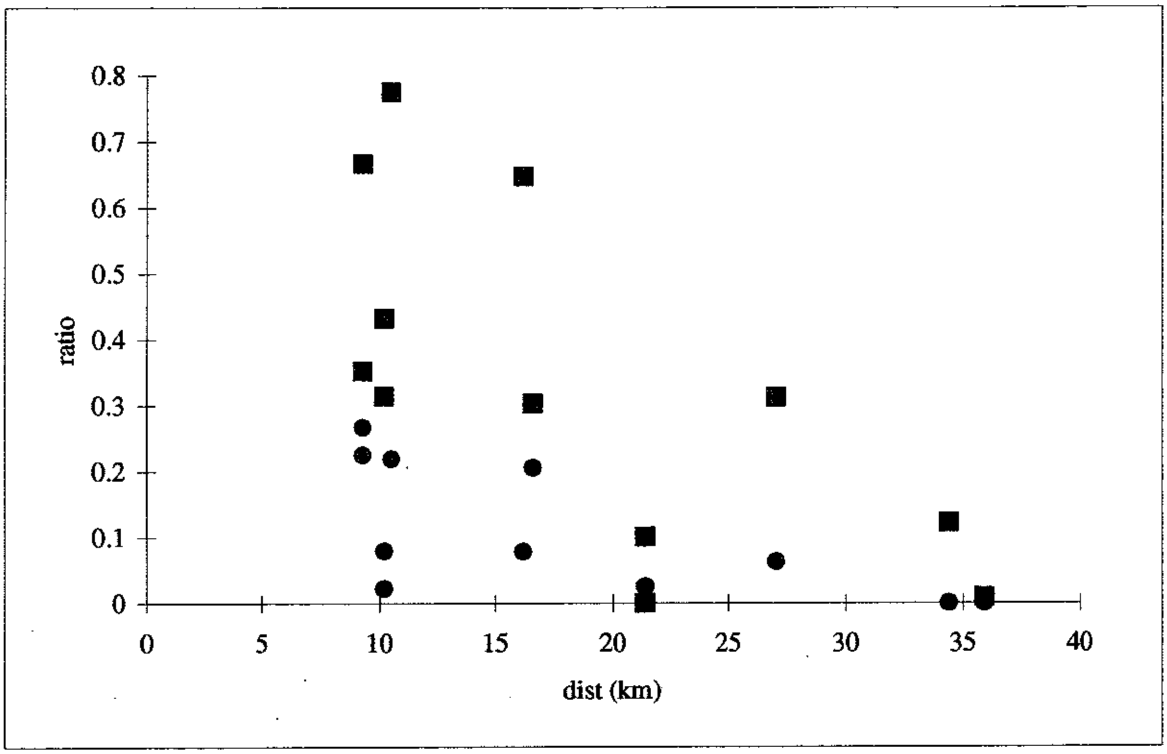

Figure 1. Proportions of glass clasts and volcanic clasts decrease with increasing distance from Hurricane Mesa. Squares--volcanic clasts/total clasts. Circles--glass clasts/total clasts

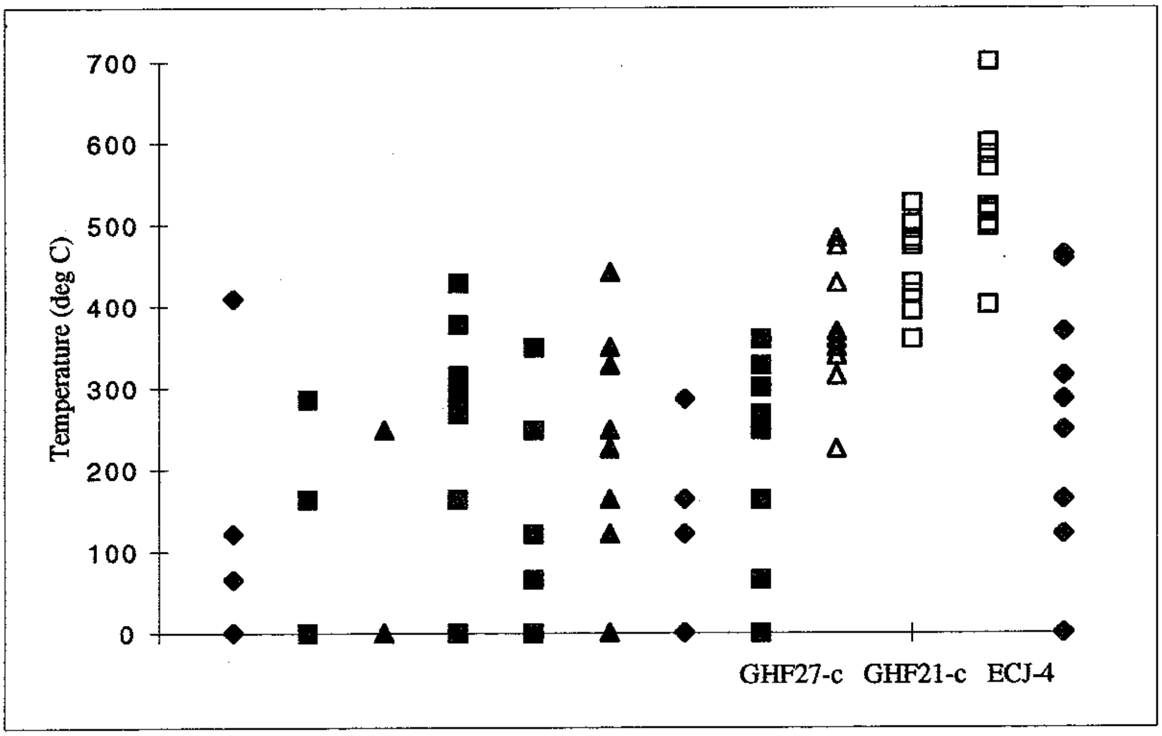

Figure 3. Three samples show consistently higher carbonate equilibration temperatures than other samples. Square--breccia. Diamond--clastic dike. Triangle--Footwall.

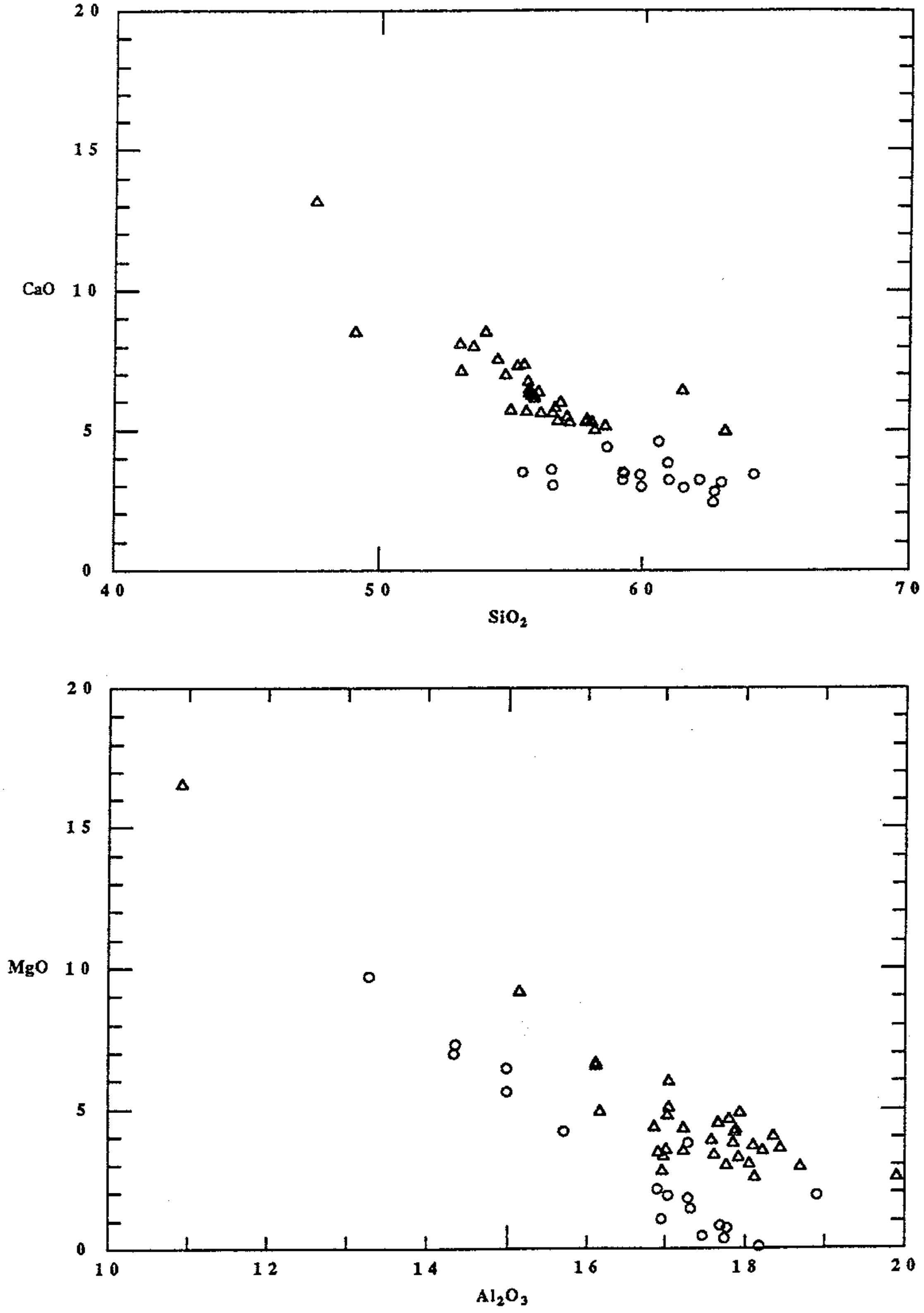

Figure 2. Glasses in the Heart Mountain fault contain more SiO_2 and less CaO, MgO, and Al_2O_3 than Wapiti volcanics (Nelson and Pierce, 1968) and allochthonous plutons (Stone, personal communication). Circles--glass. Triangles--Wapiti and plutons.

Temperature

Carbonate thermometry was performed on the breccia samples following the method of Anovitz and Essene (1987). Calcite grains in the matrix of the breccia, clastic dikes, and footwall were analyzed for magnesium and equilibrium temperatures were calculated for each analysis. Analyzed grains were small, approximately 5 µm, commonly with gently curved grain boundaries suggestive of equilibration. Most, but not all, grains were in contact with dolomite. Calculated temperatures range from 0-700°C. The lowest temperatures probably represent calcite grains that were not in equilibrium with surrounding dolomite, while the highest temperatures may be a product of mixed calcite-dolomite analyses from very fine grains, or high-magnesium calcite. All the samples showed considerable variation in temperature (figure 3), but a weak trend exists. Most samples likely equilibrated at low temperatures, probably <100°C, and certainly <200°C Three samples, however, GHF27-C, GHF21-C, and ECJ-4, contain carbonate that may have equilibrated at higher temperatures. These samples come from beneath rootless plutons which were formed over the volcanic source at Hurricane Mesa and subsequently displaced during faulting (Beutner and Craven, 1996; see Stone, this volume). The fact that the carbonate beneath the plutons equilibrated at higher temperatures than elsewhere along the fault suggests that the plutons were still relatively hot during emplacement. With such variability in the data it is impossible to say how hot the plutons were. The breccia sample taken from near a pluton at White Mountain (ECJ-4) shows even higher temperatures than the other two "hot" samples. Marble is present in the upper plate of the Heart Mountain fault at White Mountain, and it is likely that the high temperatures in the White Mountain breccia are a result of the carbonate fragments being derived from that marble. Study of the clay minerals in the breccia may be helpful in determining temperatures at the time of faulting.

Conclusions

The breccia which formed during Heart Mountain faulting is composed of fragments of lower plate carbonate rocks and upper plate carbonate and volcanic rocks, and devitrified volcanic glass. The proportions of both glass and volcanic clasts decreases with increasing distance from Hurricane Mesa. Compositions and morphologies of the devitrified glass clasts are consistent with hot volcanic fluid having been injected laterally along the fault plane from a source at Hurricane Mesa. Allochthonous plutons truncated by the fault may have been hot during emplacement.

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Petrochemistry of plutons in the Heart Mountain Allochthon

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INTRODUCTION

Although large-scale landslides at the earth's surface are not common occurrences, their effects can be very significant. Movement along the Heart Mountain Fault, a low angle detachment fault in northwestern Wyoming, was one such event. A sheet of rock approximately 1300 km^2 (similar in size to New York City) and >2 km thick detached and spread to cover an area greater than 3400 km^2. This had a profound impact upon the stratigraphy and geomorphology of the nearby region.

The area affected by faulting contains a series of 14 small plutons of shoshonite and diorite located along a 28 km long linear array trending N 65° W (Fig. 1). These plutons have been interpreted as a "hot spot" trace, formed during movement along the fault (Beutner and Craven, 1996). The term hot spot refers to the method of emplacement (injection from one fixed source into the moving hanging wall) and is not meant to indicate that the magma is mantle-derived. Beutner and Craven (1996) suggest that the source for the plutons is currently beneath the Crandall intrusive complex. The allochthon slid downhill catastrophically when magmas injected into the allochthon degassed, injecting fluids and gases along the fault, thereby reducing friction to zero.

There have been many hypotheses to explain how a sheet of rock as large as New York City slid down a surface that dips only 1-2°. One of the major differences between hypotheses is the question of time scale which varies from hours (Beutner and Craven, 1996) to millions of years (Hauge, 1985). The goal of this project is to use petrochemical analyses to test the Beutner and Craven hypothesis. The major questions that will be explored are: 1) were the magmas wet enough to provide the vapor lubrication of the fault surface through degassing?; 2) are the rocks which comprise the plutons similar in composition to those of the Crandall complex?; and 3) are the plutons comagmatic?

METHODS

Field observations were made and samples were collected from 12 plutons. Twenty-one samples were analyzed using X-ray fluorescence spectrometer at Franklin and Marshall College for major and trace elements. Ten samples were analyzed for trace elements using INAA data obtained through Oregon State University. Thirty-five thin sections were prepared and examined.

PETROGRAPHIC DESCRIPTION

The plutons are composed of two dominant rock types: diorite and shoshonite. Both rock types are present in almost all the plutons. The only exceptions were the three small plutons from which sample sets 6, 7, and 9 were taken. These plutons were poorly exposed and only contained diorites; there was no evidence for the presence of the fine-grained rock in outcrop or float.

The diorite is coarse-grained, hypidiomorphic massive to porphyritic, and contains phenocrysts of plagioclase (An_{44-58}), orthopyroxene, clinopyroxene, and less commonly, biotite and alkali feldspar. The alkali feldspar grains were usually poikilitic with inclusions of plagioclase and pyroxene. Modal mineralogy of the diorites type varied widely and included plagioclase, clinopyroxene, alkali feldspar, orthopyroxene, biotite, opaque oxides, olivine and amphibole. Some samples contained enough alkali feldspar to be considered monzonitic. Acicular apatite was prevalent as an accessory mineral. During a routine examination of a thin section of diorite using backscattered electron imaging (BSE), deeply embayed xenocrysts of monazite were observed.

The shoshonite is porphyritic to aphyric and contains phenocrysts of plagioclase (An_{44-58}), orthopyroxene, clinopyroxene, and, less commonly, olivine and alkali feldspar. The modal mineralogy includes plagioclase, clinopyroxene, orthopyroxene, alkali feldspar, opaque oxides, biotite, and olivine. These rocks have holocrystalline, intergranular and usually trachytic texture. Acicular apatite was also common as an accessory mineral in the shoshonite.

SPECIFIC PETROGRAPHIC OBSERVATIONS

Despite having largely anhydrous phenocryst phases, there is ample evidence that these magmas are wet. Most samples contain a small amount of magmatic biotite and there are indications of deuteric alteration of the