Heart Mountain Faulting and the emplacement of intrusive rocks at Painter Gulch, near White Mountain, northwest Wyoming.

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INTRODUCTION

The Heart Mountain Fault in northwest Wyoming was discovered and mapped for the first time almost a century ago, but for the last hundred years it has remained one of the enduring puzzles of structural geology. About 48 million years ago, a 1300km2 sheet of rock about 2km thick slid southeast down a detachment that dipped a mere 1-2°, expanding to cover some 3400km2 before coming to rest (Hauge 1993). Beutner and Craven (1996) suggest that this was accomplished by the injection of magmatic fluids along the detachment, which effectively reduced friction to zero and allowed gravity to mobilize the upper-plate in a single event of, at most, a few hours duration. The allochthon contains 14 small plutons, which form a 28km linear array trending N 65°W between Hurricane Mesa and White Mountain (Fig. 1). Noting the similarity between the trend of the pluton array and the direction of fault motion (S60°E), Beutner and Craven (1996) interpreted the string of plutons as a "hot spot" trace formed as the upper plate moved over the vent complex at Hurricane Mesa. They envisioned the plutons being injected one by one into the moving allochthon, like volcanos created as a crustal plate moves over a hot spot. In Beutner and Craven's scenario the vent under Hurricane Mesa, site of the Crandall Intrusive Complex (CIC), is the most likely source of the volcanic fluids that mobilized the fault as well as the source of the material in the plutons.

The goal of this project is to determine if the observed composition and deformation of the Painter Gulch pluton is consistent with the "hot spot trace" hypothesis of Beutner and Craven's model for Heart Mountain Faulting. With that goal in mind, this study addresses the following questions:

1) Are the rocks at Painter Gulch comagmatic with the other plutons and the CIC?
2) Were the rocks at Painter Gulch emplaced during Heart Mountain faulting or prior to the faulting event?
3) Is the observed deformation of the Painter Gulch intrusion consistent with catastrophic motion of the allochthon?

FIELD RELATIONSHIPS AND PETROGRAPHIC DESCRIPTION

The Painter Gulch intrusive rocks are located along the east flank of the mouth of Painter Gulch, which extends northward from the Sunlight Basin (Fig. 2). Fieldwork consisted of identifying and mapping intrusive units, measuring structural data, and collecting samples. Knowing the number of different intrusive units and the order in which they intruded is important in evaluating Beutner and Craven's "hot spot" hypothesis. It does not allow sufficient time for multiple episodes of intrusion, nor time for the rocks to cool between intrusions.

There are three main intrusive units at Painter Gulch: shoshonite, diorite, and andesite. The shoshonite is porphyritic and contains large phenocrysts of plagioclase, clinopyroxene, and orthopyroxene, in a fine-grained, commonly trachytic, groundmass of plagioclase, pyroxene, and very small Fe-Ti oxode grains. Modal mineralogy includes plagioclase, clinopyroxene, orthopyroxene, Fe-Ti oxides, biotite, and olivine.

The diorite is fine to coarse-grained, with a holocrystalline, intergranular texture. Modal mineralogy includes plagioclase, clinopyroxene, orthopyroxene, biotite, potassium feldspar, and Fe-Ti oxides. One sample contained enough potassium feldspar to be considered monzodiorite, and some are sufficiently mafic to be considered gabbro. Apatite is a common accessory mineral.

The andesite is porphyritic and contains small phenocrysts of plagioclase and pyroxenes. The groundmass is aphanitic to fine-grained, and sometimes opaque. Modal mineralogy includes plagioclase, clinopyroxene, orthopyroxene, and Fe-Ti oxides.

The intrusive rocks were emplaced into Eocene volcanic rocks, which consist of lava flows and volcanoclastics. The shoshonite was present first, and it was cool when intruded by the diorite. The diorite sent numerous small dikes into the shoshonite and surrounding rocks, and then cooled before it was intruded by the andesite. The time necessary for these rocks to cool between each intrusive event is several orders of magnitude greater than the several hours allowed by Beutner and Craven's "hot spot" model, suggesting that they were fully in place prior to the onset of Heart Mountain faulting. The andesite forced its way along the contact between the diorite and the shoshonite, and incorporated numerous diorite xenoliths while sending numerous dikes into the diorite. Because it is fine-grained and present only as numerous large and small dikes, it is possible that the andesite was intruded during the faulting event, but the other units clearlt predate faulting, which argues against "hot spot" style emplacement.

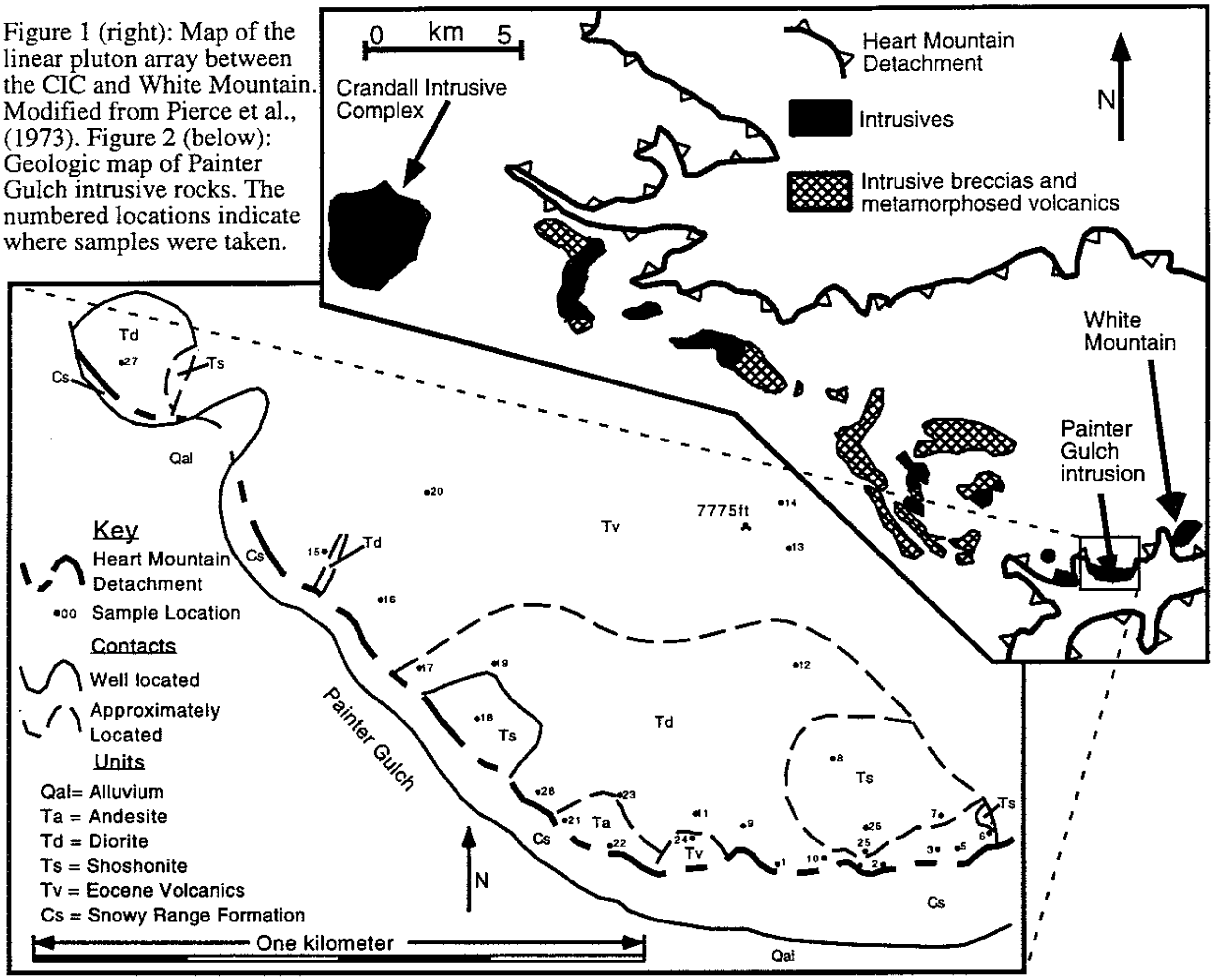

Figure 1 (right): Map of the linear pluton array between the CIC and White Mountain. Modified from Pierce et al., (1973). Figure 2 (below): Geologic map of Painter Gulch intrusive rocks. The numbered locations indicate where samples were taken.

FAULTING AND DEFORMATION

The intrusive rocks are cut by a number of small faults. These faults are observed to crosscut both andesite and diorite where they intrude shoshonite, indicating that the faults were formed after the intrusion of the andesite. Although there are very few striations and no sense of slip indicators on these faults, the plot is consistent with "a family of conjugate normal or normal-oblique slip faults with approximately north-south extension" (Beutner, personal communication, 1998). Some faults contain well developed, planar, aphanitic veins about 1-3cm thick. From these veins, small veinlets, 1-2cm wide and up to 6 cm long, can be seen to intrude the surrounding rock at right angles to the fault surface (Fig. 5). The veins contain a brown, aphanitic material, and the surrounding rock appears deformed immediately adjacent to the veins. In thin section, the vein material is brown, opaque, and contains small, angular mineral and lithic grains. Some of these grains are deeply embayed, and others have a very definite orientation parallel to the sides of the vein (Fig. 6).

Collectively these features suggest a pseudotachylyte origin for the material in the veins. Pseudotachylytes are formed by frictional melting along faults, which requires very rapid, brittle faulting. Pseudotachylytes are characterized by "dark, aphanitic veins showing intrusive relations, sharp boundaries, included clasts and crystals of the host rock, and, critically, an association with fault or shear zones" (Magloughlin and Spray, 1992). Pseudotachylyte veins may contain glass, spherulites, vesicles, microlites, amygdules, and embayed lithic fragments, and may show chilled margins. The veins are typically thin and planar along the fault or "surface of generation," but frequently small, irregular veinlets called "injection veins" can be seen to intrude the host rock from the surface of generation.

The characteristics of pseudotachylyte are consistent with the observed characteristics of the veins along the faults, but they could also occurr in an ultracataclasite, which is a fault rock that has been crushed to the size of flour rather than melted. The best indicator for melting, and thus for pseudotachylyte, would be the presence of glass along the fault, but any glass has long since devitrified and turned to clay minerals. Pseudotachylytes form under conditions that are unfavorable for glass preservation, and furthermore "the presence or absence of glass is not a test of a melt origin for pseudotachylyte" (Magloughlin and Spray, 1992).

Without the presence of glass or other features indicative of a melt, such as crystallites or vesicles, it is impossible to "prove" that the vein material is friction melt rather than ultracataclasite. However, the observed features of the veins better fit those described for pseudotachylytes, especially the embayed grains, which indicate a very hot matrix material.

Further evidence for catastrophic movement is the presence of microstructures associated with varying degrees of brittle deformation. In thin section, some samples show different degrees of fracturing and crushing in the plagioclase grains, which range from undeformed to completely crushed. Dr. Jan Tullis at Brown University examined extra-thin, doubly-polished sections of several samples. In two of these samples, small features were observed at high magnification (500x) which suggest that melting occurred during deformation. These include embayments in the edges of opaque mineral grains, tiny rounded forms in the plagioclase grains, and reactions at the edges of pyroxene clasts (Tullis, personal communication 1998).

Deformation of this type, called "cataclastic flow," has been studied in experimentally deformed feldspar aggregates. It appears ductile when viewed macroscopically, but actually occurs by micro-scale brittle deformation which is characterized by distributed cracking, primarily on cleavages, and the formation of "micro-crush" zones (Tullis and Yund, 1992). This deformation, especially the incipient melting, is consistent with emplacement of the rocks at Painter Gulch in a single catastrophic event, although it could also be produced by a number of smaller movements along the detachment.

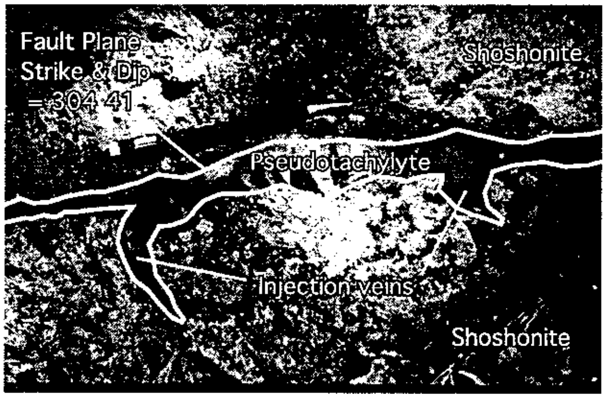

Figure 5 (left). Photograph and interpretation of fault on west side of field area (#18 in Fig. 2), pencil for scale. Fault cuts shoshonite and is filled with brown, aphanitic material interpreted as pseudotachylyte. Note injection veins intruding host rock from the fault plane.

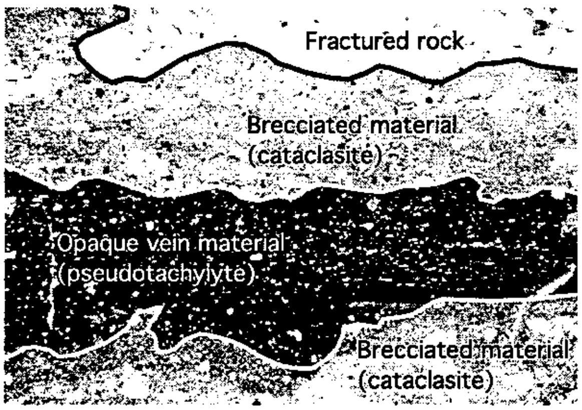

Figure 6 (right). Photomicrograph and interpretation of vein material from fault in Fig. 5. Field of view is 11mm (1X magnification), plane polarized light. Material adjacent to vein contains abundant angular lithic fragments in fine grained matrix. Material in vein is opaque and contians angular lithic fragments. Note oriented fragments on right side of photo.

WHOLE ROCK GEOCHEMISTRY

Twenty-four samples were analyzed for major and trace elements by XRF. Major element data were used to compare the different rocks within Painter Gulch and to compare the Painter Gulch rocks to the CIC and the other plutons in the allochthon. The diorites, shoshonites, andesites, and assorted other rocks from Painter Gulch show almost complete overlap with each other in major element chemistry. The data scatter too much to make conclusions about the evolution of the magma over time, but it can still be used to compare the rocks from Painter Gulch to those from the CIC and the other plutons in the allochthon.

The major element chemistry of the Painter Gulch intrusive rocks is consistently similar to the plutons from the allochthon, although the Painter Gulch rocks display a wider range of $SiO2$ values (Fig. 3). The major element chemistry of the Painter Gulch rocks also overlaps with the CIC, although less than it does with the other plutons (Fig. 4). In both cases, the samples appear to plot along a common trend, although the data from all three site scatters too much to talk about evolution along the trend. The overlap of the values along a common trend is not proof of a common magmatic origin, but it is consistent with it. This would be expected if the plutons were all generated by the same feeder pipe that later generated the CIC, which is required by the Beutner and Craven (1996) "hot spot" model for pluton emplacement.

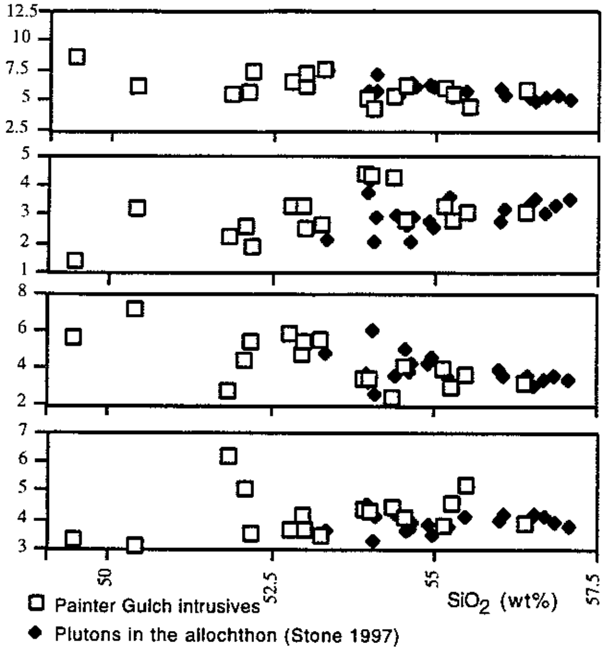

Figure 3. Plots of selected major elements vs. silica for the Painter Gulch intrusives and the other plutons in the allochthon. The data overlaps almost completely for all elements.

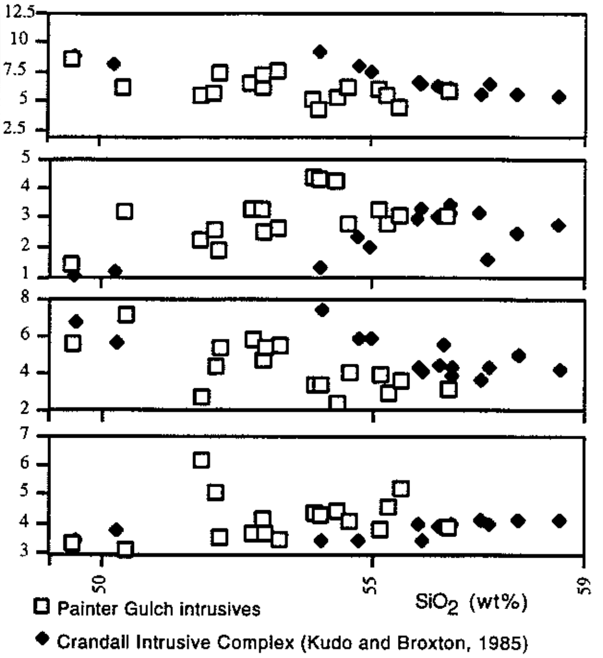

Figure 4. Plots of selected major elements vs. silica for the Painter Gulch intrusives and rocks from the CIC. There is significant overlap among all elements, but the Painter Gulch ocks generally dispaly lower silica content

CONCLUSION

The observed deformation is consistent with catastrophic motion of the allochthon, which does not allow time for the multiple intrusive events indicated by the field relationships, nor for the coarser intrusive rocks to cool enough for brittle faulting to occur. This argues against the emplacement of the Painter Gulch pluton in the manner suggested by Beutner and Craven (1996). The other plutons and the CIC are chemically very similar to the Painter Gulch rocks, which is consistent with a common magamtic origin for all three. The Painter Gulch pluton probably represents a piece of the pre-fault "cap" of the feeder pipe beneath Hurricane Mesa. When faulting occurred, the old volcano was truncated by the fault and transported southeast, coming to rest at what is now Painter Gulch.

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