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

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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olivine and pyroxene to biotite, amphibole and opaque oxides. The presence of free water is indicated by additional biotite alteration along veins that cross-cut primary magmatic phases.

Examination of one thin section under back-scattered electrons revealed the presence of monazite. The sample contained several deeply embayed monazite grains interpreted to be xenocrysts probably derived from the Precambrian basement.

GEOCHEMISTRY

In general, all sample types exhibit a high K_2O value (above 2.5-3.25 weight percent) typical of the shoshonitic, high K-series trend for basaltic andesites. Major element data were used for comparison within the trend and also between the plutons and the Crandall complex. Plots of composition versus distance from the Crandall intrusive complex revealed no trends along the pluton trace (Fig. 2), and there was complete overlap in composition between the diorites and shoshonites in all the plutons sampled along the trace. In addition, there was also overlap in composition between the diorites and shoshonites. Data obtained from Kudo and Broxton (1985) indicates that the major elements in the diorites and shoshonites of the Crandall intrusive complex are consistent with those obtained from samples along the pluton trace (Fig. 3).

Spider diagrams constructed for 6 diorites (Fig. 4a) and 4 shoshonites (Fig. 4c) show several similarities. The shape of the diagrams for all the rocks are similar both within the two rock types and also between the rocks types. They are characterized by a depletion in Rb, Nb and Ta and a strongly negative Ti spike. However, the samples also exhibit a range of Th values and Ce/Sr ratios.

Rare earth element patterns have strikingly similar shapes within and between the diorites and shoshonites, including a slightly positive Eu anomaly (Fig. 4b,c). However, several samples have elevated LREE contents. Because there is petrographic evidence for the presence of monazite [(LREE, Th) PO_4], it is possible that this may be controlling the differences in the trace elements. The effect of monazite on the REE patterns can be evaluated on a plot of Th vs. Ce/Sm since monazite contains LREE and Th and Ce/Sm approximates the slope of the LREE pattern. Figure 5 shows a first-order correlation between Th and the LREE. These results indicate that assimilation of monazite influenced the trace element composition of both diorites and shoshonites. The plot also shows that rocks of the Crandall intrusive complex reflect a similar process. This conclusion supports the hybrid origin of the Absaroka Absarokite-Shoshonite-Banakite series suggested on petrographic grounds by Prostka (1973).

DISCUSSION

In summary, several lines of evidence are consistent with the Beutner and Craven (1996) hypothesis. The injection of volcanic fluids and gases along the fault plane suggested as a mechanism for movement of the Heart Mountain allochthon in the Beutner and Craven hypothesis requires the substantial presence of water within the magma, and there is ample petrographic evidence from the plutons to support the idea of a wet magma. The overlap in the major element compositions of all rocks within the plutons, as well as the overall similarity in trace element characteristics, is also compatible with this model. However, preliminary analysis of trace element data suggests that at least some of the trace elements have been effected by contamination due to crustal assimilation. Therefore, the trace element data may not be a reliable evaluation of comagmatism.

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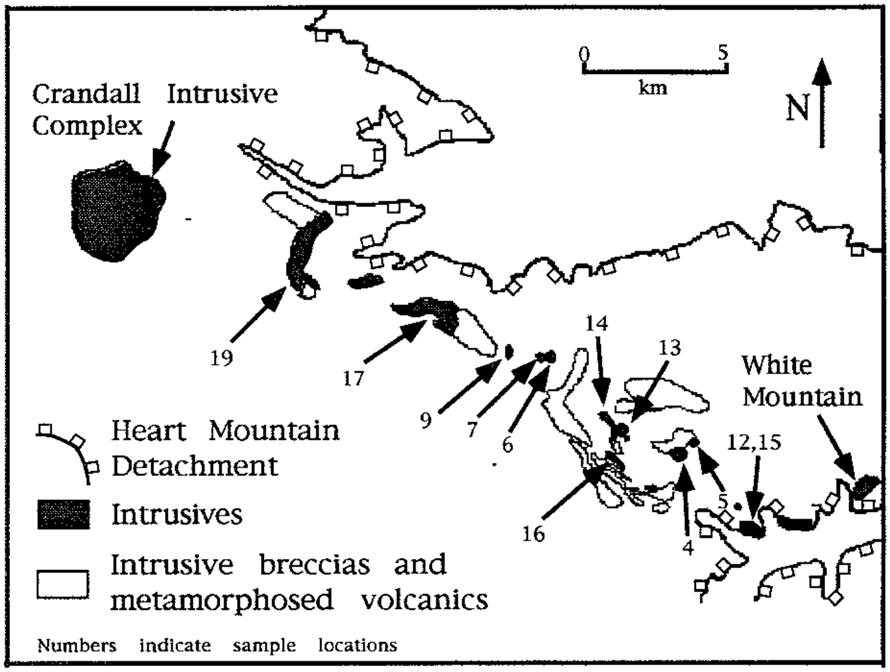
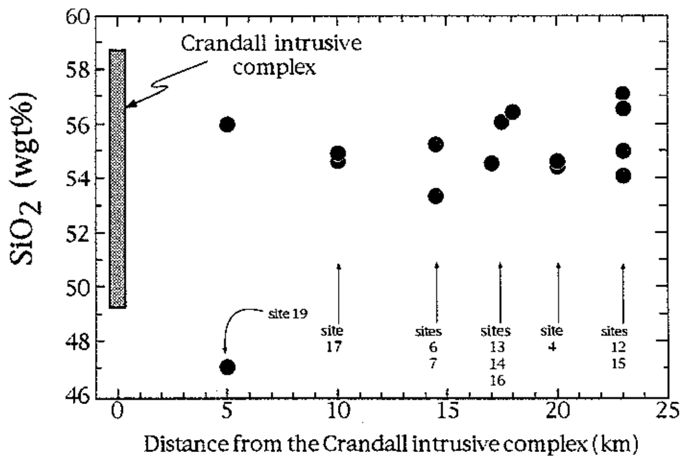


Figure 1. (above) Map of Heart Mountain fault and plutons. Sources: Pierce et al., 1973 and Kudo and Broxton, 1985.

Figure 2. (right) Lack of trend within plutons exhibited by SiO_2 content versus distance.



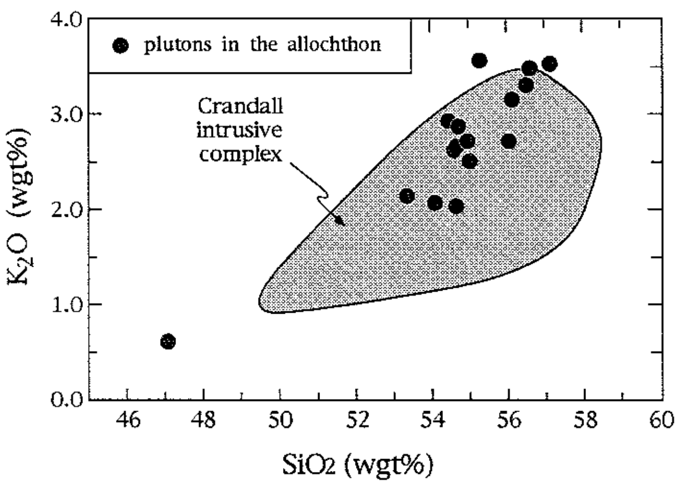


Figure 3. SiO_2 versus K_2O plot illustrates overlap between major element chemistry of the plutons and the Crandall intrusives.

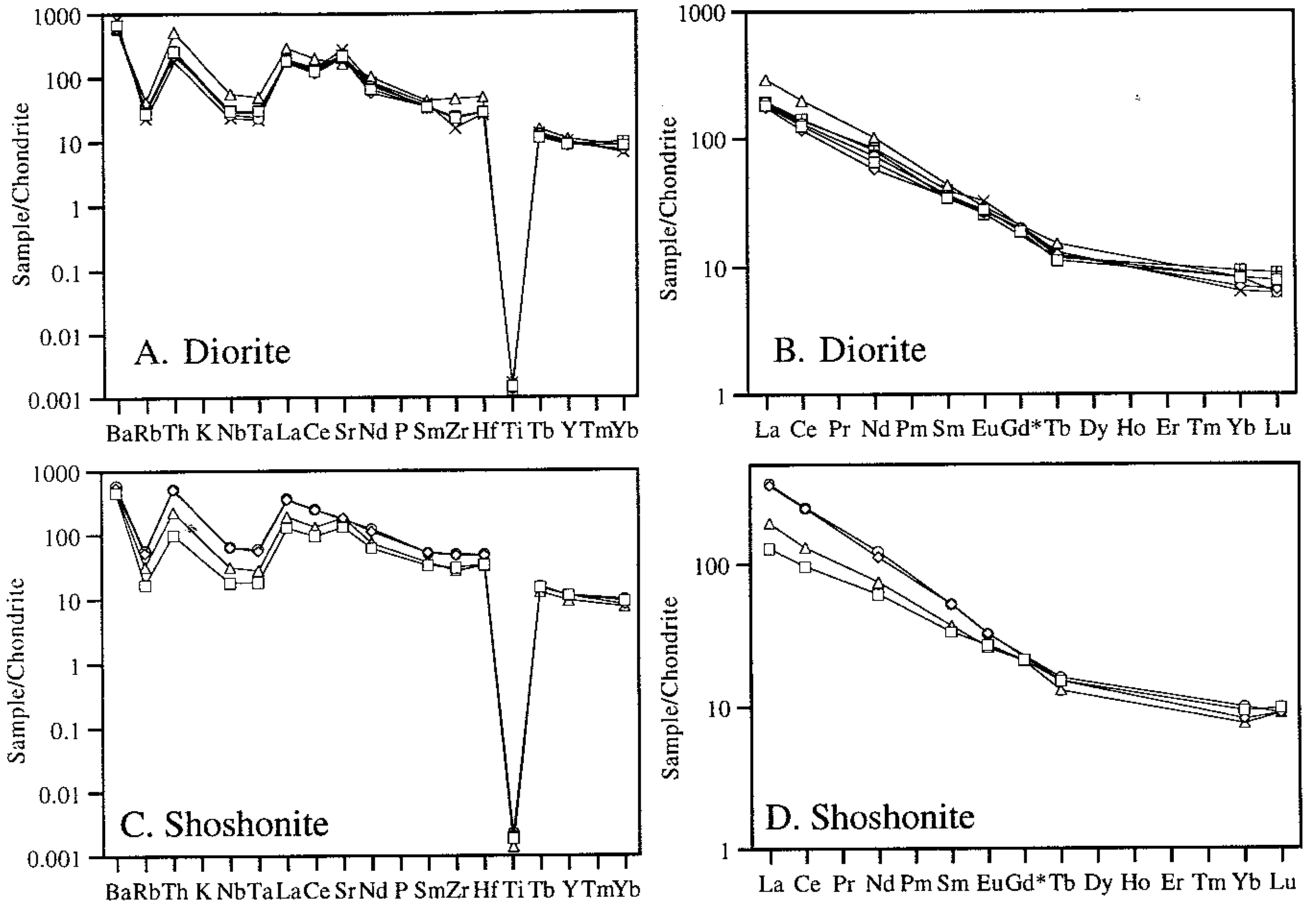


Figure 4. Spider diagram and REE plot for diorites and shoshonites (Gd* values estimated).

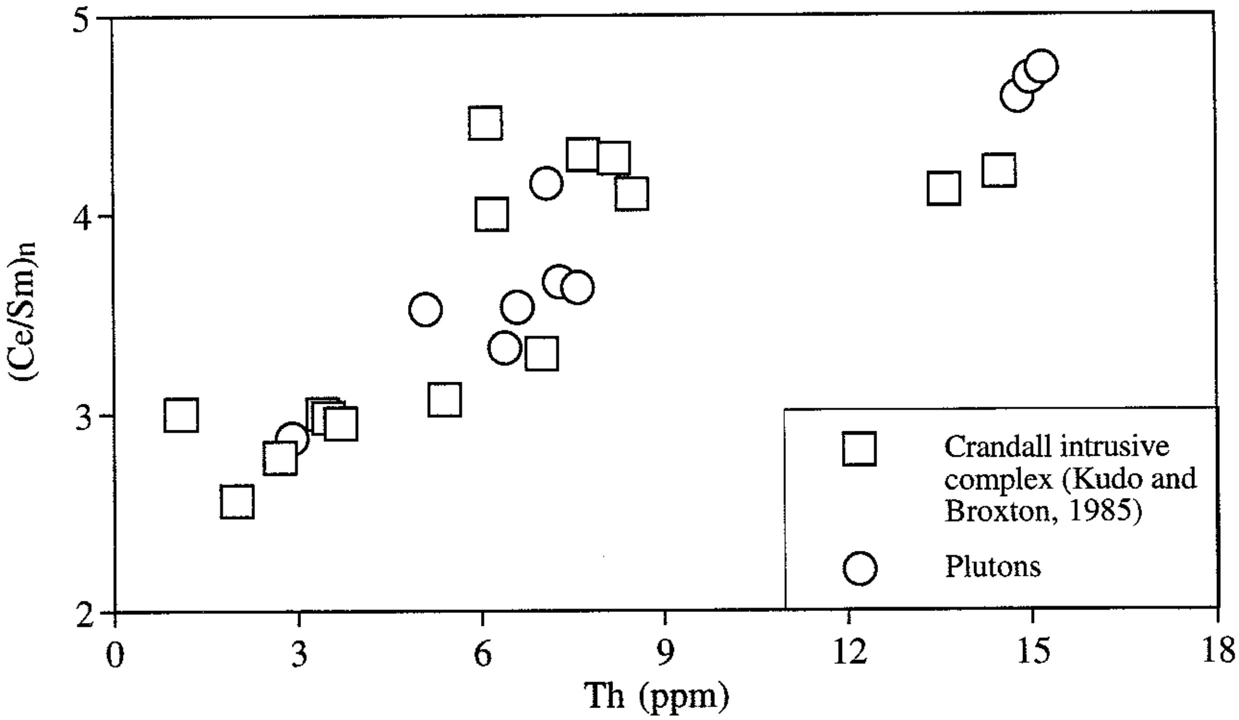


Figure 5. Plot of Th vs. $(Ce/Sm)_n$ illustrates first order relationship of Th and the LREE.

Sackung on Dead Indian Hill, Park County, Wyoming

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INTRODUCTION

The type of alpine gravitational spreading ridge known as a sackung (from the German word for sagging or subsidence) has only appeared in geological literature in the last 70 years. This spreading is commonly characterized by a main trench along the summit ridge as well as associated geomorphic features, including grabens, uphill-facing scarps, double-crested ridges, shallow linear trenches parallel to topographical contours, and in some cases a bulging of lower slopes. Topography seems to be the primary determinant of where such features occur, but joints and faults are also important factors (Varnes et al. 1989). The sackung most commonly cited in the literature are in the Tatra Range of eastern Europe, but other sites include the Swiss Alps, New Zealand's Southern Alps, and the Rocky Mountains.

Gravitational spreading of the ridge top of Dead Indian Hill (elevation, 2643 m) has resulted in a summit trench approximately 100m wide and 400m long as well as uphill-facing scarps and small linear trenches. Dead Indian Hill, a cuesta located just south of the mouth of the Yellowstone River's Clarks Fork Canyon, is part of a monocline of Paleozoic and Mesozoic sedimentary rocks with an east dip ranging from 6 to 15 degrees. Talus mantles both the east and west slopes, and a block slope and block stream extend beyond the talus on the east side. The blocks of these features as well as the bedrock at the sackung are competent Pennsylvanian Tensleep Sandstone. Beneath are the shales and limestones of the incompetent Amsden Formation.

The use of the words "sackung" and "sackungen" has varied in the literature; in this paper, "sackung" denotes the spreading process that creates the geomorphic features noted above, referred to as "sackungen."

METHODS

All field work was performed on foot at Dead Indian Hill, with the help of several assistants. Many qualitative observations were made, and a great deal of quantitative information was recorded as well. In order to map the micro-topography of the main summit trench, eight survey lines were run from the west ridge to the east ridge using an altimeter and a 50m tape. One of these lines was continued down the west talus, the east talus, and across the block field. Eight block surveys were conducted at various sites on the east talus and across the block field. At each site, 50 blocks were measured for strike and dip of the top face, long axis, number of weathering pits if any and their depths, and roundness of edges. The orientation of joints in intact bedrock was measured as well.

DISCUSSION

The main trench trends 015° and has an en echelon appearance when observed in air photos. This is roughly consistent with the vertical joint data recorded at Dead Indian Hill, which show a prominent joint set trending 020-030° and a secondary set at 120-130° (Fig. 1). This data agrees with the local pattern that shows a primary set at 010-020° and a secondary set at 90-120° (Ashley LaForge, written communication, 1997).

The main trench contains several smaller trenches which give clues to the formation of the larger structure. These are visible in the cross-sections derived from survey lines recorded in the field (Fig. 2). Also shown in the cross-sections are the locations and relative sizes of associated scarps and closed depressions. The time of the formation of this structure was of interest as well. Most previous studies on sackungen have cited glacial oversteepening of valley