Petrographic and geochemical analysis of Oligocene andesites of the Bonanza volcanic center, northeast San Juan volcanic field, Colorado

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INTRODUCTION

The Bonanza volcanic center is one of several caldera complexes associated with the San Juan volcanic field in southern Colorado. The Bonanza center lies just on the edge of a large gravity anomaly that outlines the majority of the San Juan volcanic field and is thought to represent the inherent shape of a shallow batholith at depth (Steven & Lipman, 1976).

The Bonanza center varies in composition, but is largely composed of 38 Ma intermediate lavas that make up the original volcanic edifice (Varga, 1985). Both a dacite and rhyolite tuff, collectively called the Bonanza Tuff, lie above the intermediate lava, and are then capped by an upper andesite unit. The two andesite units are of interest because they are separated by the Bonanza Tuff, the explosive product of a caldera-forming event. Immediately following the major Oligocene ash-flow eruptions across the San Juan volcanic field, Lipman and others (1970) refer to a change in tectonic setting where the eastern part of the volcanic field was faulted and tilted to the east as a result of the initiation of Rio Grande rift extension. The origin of these continental interior andesites associated with the Bonanza caldera is uncertain, and may be related to regional extension. A petrographic and geochemical analysis of these andesites is used to compare the lower and upper units and to better understand their origin.

METHODS

A representative suite of samples from both the lower and upper andesite units with additional samples from the Poncha Pass area were collected during the field season. Samples were collected from outside of the actual caldera, due to extensive alteration within it. Sampling locations were chosen based on previous mapping of units by Varga and Smith (1985) and their stratigraphic position in relation to the Bonanza Tuff. A stratigraphic sequence from each unit was obtained to account for variation between individual lava flows. Thin sections were made for 34 samples, which were then analyzed for mineralogical characteristics. Twelve of these thin sections were counted for 1000 points. From those 34 samples, 30 were selected for major and trace element analyses via XRF methods at Michigan State University. Twenty-five of those samples were also analyzed for rare earth and other trace elements via ICP-MS techniques (also at Michigan State).

FIELD OCCURRENCE AND PETROGRAPHY

Lower andesite. The lower andesite unit, also referred to as the Rawley Andesite (Varga & Smith, 1985), does not appear in outcrop as frequently as the upper andesite. It is very similar to the upper andesite, and the two units are difficult to distinguish from each other without the presence of the Bonanza Tuff in outcrop. The lower andesite lies below the tuff and is best exposed in road cuts. Where there is more prominent exposure of the lower andesite, weathering patterns suggest that the unit is composed of many flows. Numerous samples were collected from such locations to obtain a complete stratigraphy of the lower andesite. The lower andesite is generally more massive and less flaggy in outcrop than the upper andesite. The lower andesite also contains lahars and autobreccias.

In hand sample, the lower andesite is generally more weathered than the upper andesite. Many of the crystals (most likely pyroxenes) have altered to greenish clays. The weathered surface is dark gray, and the fresh surface is light to dark gray. The rock is fine-grained and relatively crystal-poor. Some samples of the lower andesite are porous, most likely a result of weathering. In thin section, the lower andesite has a fine-grained trachytic plagioclase-rich groundmass. Traces of opaques and clinopyroxene are present in the groundmass as well. The phenocrysts are fine- to coarse-grained and consist of plagioclase, amphibole, clinopyroxene, biotite, and occasional orthopyroxene. The phenocrysts of the lower andesite exhibit similar alteration as those occurring in the upper andesite. The lower andesite is similar to the upper

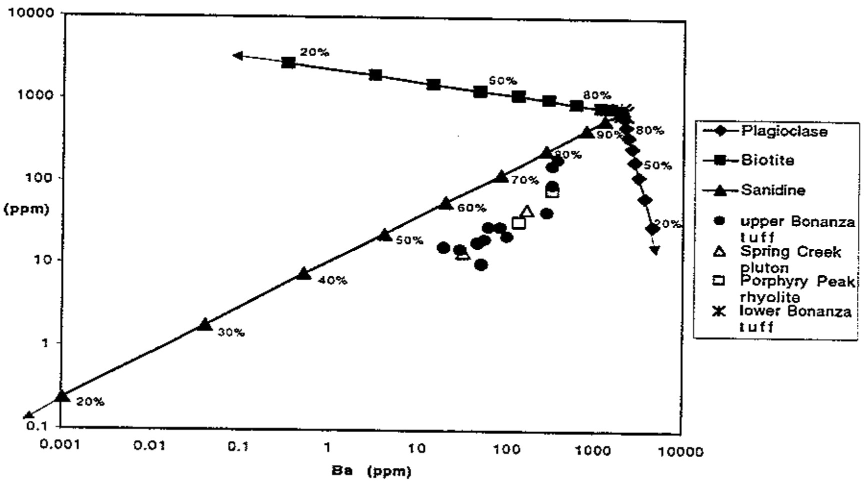

Figure 4. Sr vs. Ba vector plot. Percentages represent amount of remaining liquid (F).

To test the fractionation model further, vectors showing the effects of removal of major phenocrysts are plotted with Sr and Ba data for the UBT and other Bonanza units (Fig. 4). The models assume the lower Bonanza tuff as the parental magma. Figure 4 shows that removal of sanidine appears to be the dominant phase in the fractionating assemblage, which agrees with the petrographic data for the UBT. However, fractionation of assemblages dominated by sanidine does not result in a good match between the major element compositions calculated for liquids that evolve by sanidine fractionation and the observed UBT chemistry. The calculated daughter liquid is too low in SiO_2 whereas most of the other major elements (TiO_2, Al_2O_3, MgO, and FeO_T) are too high compared to the average UBT. A final piece of evidence against the fractionation model is the compositional gap between the UBT major element chemistry and that of the lower Bonanza tuff (cf. Fig. 1) instead of a gradual transition in composition, which could be expected from fractionation processes.

SUMMARY AND CONCLUSIONS

The UBT is petrographically and geochemically distinct from the dacitic lower Bonanza tuff and Bonanza andesites. These distinctions plus petrogenetic modeling support the conclusion that the UBT is not derived by simple fractionation of the lower Bonanza tuff. However, the UBT is geochemically similar to the Spring Creek pluton and the Porphyry Peak rhyolite in both major and trace element compositions, which suggests that these three units may have a common origin. If fractionation did not play a major role in the origin of the UBT, then it may be the result of partial melting of the upper crust.

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andesite in thin section, but there is more variation in phenocryst assemblages and proportions between samples.

Upper andesite. In outcrop, the upper andesite is a well-exposed unit that overlies the Bonanza tuff. It is the uppermost unit on most ridges around the caldera. The unit consists mainly of lava flows, but also includes some lahars and autobreccias. The flows exhibit flaggy weathering, with amphibole crystals aligned on the broken surfaces. At some locations the upper andesite shows flow features and columnar jointing in outcrop. There are zones within the upper andesite that are less flaggy and more massive and contain a greater percentage of phenocrysts, including biotite.

In hand sample, the upper andesite is reddish brown on weathered surfaces, and dark gray on a fresh surface. It is fine-grained and crystal poor in most cases. In some instances, the rocks are altered with crystals being replaced by clays. In thin section, the upper andesite has a fine-grained trachytic plagioclase-rich groundmass. Trace amounts of opaques and clinopyroxene are present in the groundmass as well. The upper andesite is generally phenocryst-poor, and the crystals are fine- to medium-grained. Phenocrysts include plagioclase, amphibole, clinopyroxene, and occasional orthopyroxene and biotite. Most of the plagioclase is resorbed. Most of the amphibole crystals have thick magnetite rims. Many of the pyroxene phenocrysts have altered to clays.

Poncha Pass. The Poncha Pass rocks are assumed to be andesites similar to those of the Bonanza center, but no conclusive petrographic or geochemical work has been done on them. The Poncha Pass rocks crop out along the highway road cuts in large cliffs. Thirteen samples were collected from the Poncha Pass/Marshall Pass area. The rocks along the Poncha Pass road cut exhibit massive weathering features and distinct columnar joints.

In hand sample, the Poncha Pass rocks are heavily altered and friable. They are light to medium-gray on weathered surfaces, and whitish-gray on a fresh surface. They are medium to coarse-grained and crystal-rich.

In thin section, the Poncha Pass rocks are somewhat distinctive from the upper and lower andesites. They are highly altered with many reaction features. They exhibit a fine-grained, plagioclase-rich groundmass. They are phenocryst-rich and the phenocrysts are medium to coarse-grained plagioclase, clinopyroxene, orthopyroxene, and biotite, all significantly altered. The plagioclase crystals are heavily resorbed with spongy cellular texture.

GEOCHEMISTRY

Based on their SiO2 contents, most samples are classified as trachyandesite, although a few are classified as andesite and rhyodacite (Figure 1). All samples are slightly alkaline. In general, the lower andesite is more variable geochemically, including one sample that consistently plots near or within the rhyolite field. In general, all samples show the same trends in major element oxide abundances, with the lower andesite being more variable than the upper andesite. All samples exhibit decreases in TiO2, Fe2O3, MgO, MnO, CaO, and P2O5 with increasing SiO2. All samples cluster on Na2O and K2O vs SiO2 plots, with a slight increase in those oxides with increasing SiO2 content. Rare earth element (Figure 2) and spider diagrams (Figure 3) summarize trends in the trace element data for each unit.

Lower andesite. The lower andesite unit ranges in SiO2 content from 57.13% to 70.29. Light rare earth element (LREE) abundances are enriched about one to three times compared to upper crust. Heavy rare earth element abundances (HREE) show minor depletion and, in one case, minor enrichment. There is a slight positive europium anomaly. Spider diagrams show minor enrichment in Ba and Sr, and a minor depletion in Tb.

Upper andesite. The upper andesite unit ranges in SiO2 content from 61.35% to 66.63%. Light rare earth element (LREE) abundances are enriched about two times compared to upper crust. Heavy rare earth element abundances (HREE) are depleted less than one time compared to upper crust. The upper andesite unit exhibits a slight positive europium anomaly. Spider diagrams show one to three times upper crust enrichment in Sr, and a minor depletion in Tb.

Poncha Pass. The two Poncha Pass samples have SiO2 contents of 59.54% and 62.84%. Light rare earth element (LREE) abundances show two to three times enrichment compared to upper crust, and very little difference in heavy rare earth element (HREE) abundances. Spider diagrams show minor enrichment in all elements for both samples.

DISCUSSION

Petrographic and geochemical analysis of the lower andesite, upper andesite and Poncha Pass andesite show that all three units are strikingly similar. The lower andesite exhibits a more variable geochemical character, while the upper andesite plots in tight clusters within the range of lower andesite samples. The Poncha Pass andesite is geochemically similar to both andesite units of the Bonanza center, but it is petrographically quite different. Incompatible element diagrams suggest that all intermediate rocks from within or near the Bonanza center originated from the same source (Figure 4). When combined with data from the Bonanza Tuff, the andesites are closely related chemically to the lower dacite tuff, but are inherently different from the upper rhyolite tuff.

Processes within the magma chamber are difficult to constrain. There is strong petrographic evidence that all units may have undergone mixing prior to eruption. Several samples from each unit display resorbed plagioclase crystals, and others have spongy cellular textures. This suggests that at some point prior to eruption, these crystals were in disequilibrium with the surrounding melt. Vector diagrams on Ba vs. Sr plots (Figure 5) show that, if the lower dacitic Bonanza Tuff is an evolutionary product of the lower andesite, it underwent little or no fractionation prior to eruption. The upper Bonanza Tuff displays a much different path than the lower Bonanza Tuff, suggesting that it is either not a direct product of the lower andesite, or it underwent significant magmatic differentiation prior to eruption. Since the upper andesite plots directly on top of the lower andesite on many geochemical variation diagrams, it is likely that both andesite units and the lower Bonanza Tuff were derived from similar sources. The upper Bonanza Tuff is significantly different, suggesting that it was derived from a chemically distinct source.

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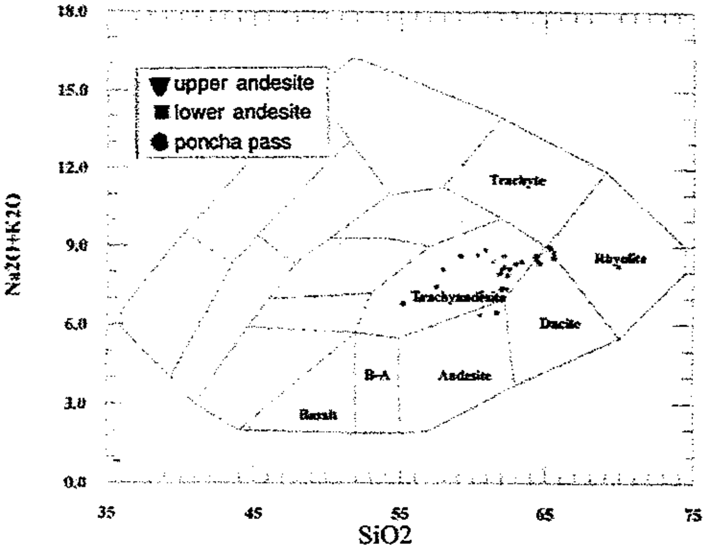

Figure 1: Classification plot of Na2O + K2O vs SiO2

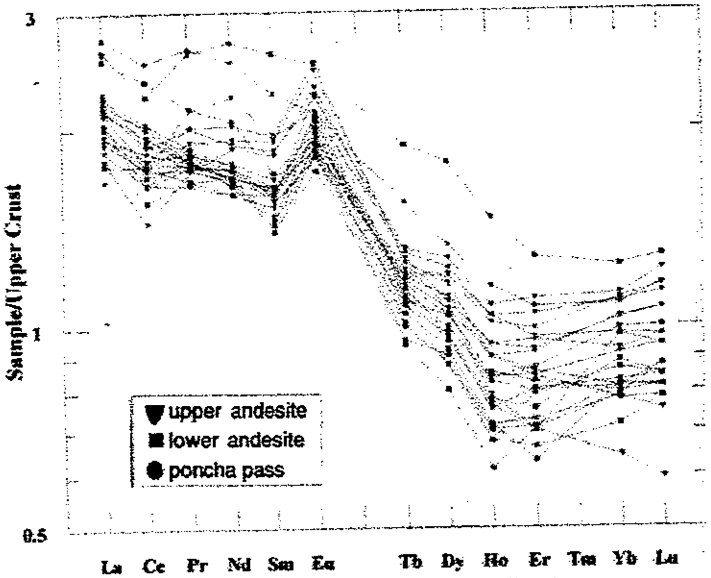

Figure 2: Rare earth element plot normalized to upper crust

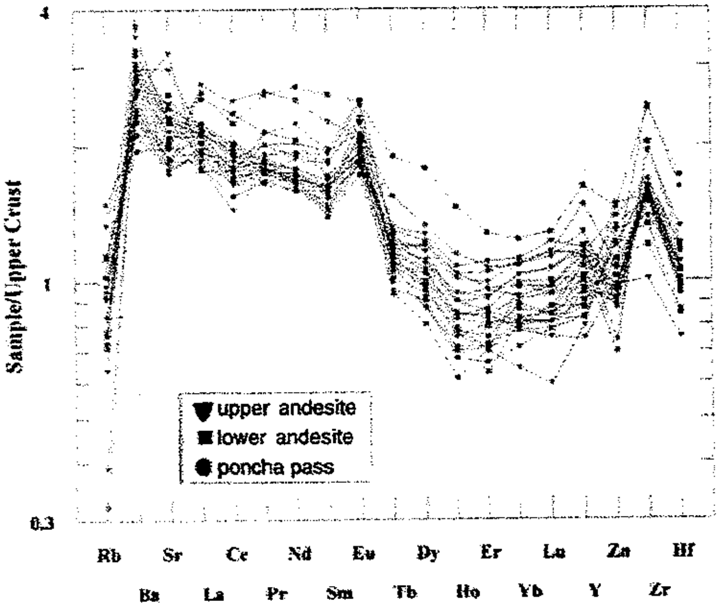

Figure 3: Spider diagram normalized to upper crust

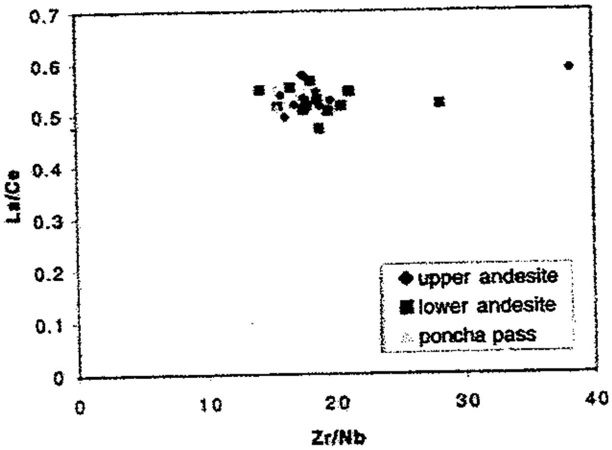

Figure 4: Incompatible element ratio plot of La/Ce vs. Zr/Nb

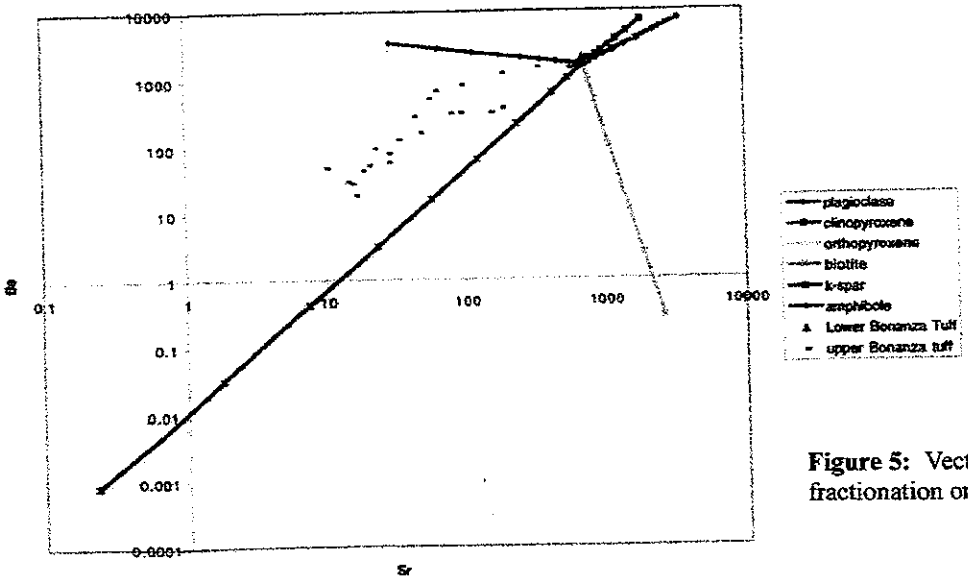

Figure 5: Vector diagram modeling fractionation on a plot of Ba vs. Sr

Folding of rhyolite flows in a series of Exogenous Domes, Porphyry Peak, San Juan Mountains, Colorado

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INTRODUCTION

The Porphyry Peak Rhyolite is named for its exposures on the slopes of Porphyry Peak, one of the topographic highs rimming the Bonanza Caldera in the San Juan Volcanic Field of southern Colorado. Through mapping flow foliations, Varga and Smith (1983) identified three separate extrusive centers in the Porphyry Peak area: Porphyry Peak East, Porphyry Peak West and a flat-topped dome located southwest of Porphyry Peak (Figure 1). The Porphyry Peak rhyolite is exposed on all three of these extrusive domes.

The rhyolite consists of greyish-white to pink rhyolite flows, tuffs, and intrusive rhyolites (Varga and Smith, 1984; Burbank, 1932). There is extensive foliation in the rhyolite, with the exposures on East Porphyry Peak splitting into thin slabs similar to a shale. It is also distinguished by its thin extensive foliations and the intricate and complex folding of these foliations (Figure 2). The rhyolite is especially distinguished by its pronounced lineations which are manifest as small-scale folds.

The relationship between the foliations and the lineations, and consequently the type of deformation which occurred to produce these lineations, is poorly understood. In July and August 1999, I conducted a detailed structural survey of the Porphyry Peak area. I measured the lineations and foliations which occur in the Porphyry Peak Rhyolite. These measurements, when analyzed with stereographic projection, indicated that the lineations show a range of rakes from high to low. Similar types of lineations have been noted in pahoehoe basalt flows in Hawaii (Fink, 1978) and in rhyolitic lava flows (Gregg, Fink, and Griffiths, 1998; Fink, 1980).

RESEARCH METHODS

I used stereonet analysis to determine the preferred orientation of the foliations and lineations within the rhyolite. Porphyry Peak East and West domes show the expected radial distribution of foliation orientations, while in the southwest dome, foliations strike between 0 and 45 degrees and dip to the southeast. However, this result is probably an artifact of the data collection, as no data were collected for the southwestern half of the dome due to a lack of exposure in the area.

Figure 3 shows the relationship between pairs of lineations and foliations which were taken at the same locality. Rakes range from low to high, with the highest distribution being at the extremes of the range .

DISCUSSION AND CONCLUSIONS

Varga and Smith (1983) report seven lineation and foliation pairs from the Porphyry Peak rhyolite that show a range of foliation to lineation relationships from low rake, nearly horizontal, to high rake, steeply plunging lineations. They suggest that the lineations might plunge in the direction of the vent. This study suggests that while some high angle, steeply plunging lineations occur, a number of lineations plunge gently to the ENE on the East Porphyry Peak dome and southeast on the Southwest dome.

Fink (1980), and Gregg and others (1998) have both noted the presence of small scale folds in lava flows. These researchers determined that the folds are the result of compression and viscosity differences between the upper and lower portions of the lava flow. The bottom portion of the lava flow cools less quickly then the top portion which is exposed to the air. This temperature difference results in a viscosity gradient, with the lava on the bottom of the