Petrologic and Structural Evolution of the Bonanza Volcanic Field, Northern Rio Grande Rift, Central Colorado.

FACULTY

Lori Bettison-Varga, The College of Wooster
Robert J. Varga, The College of Wooster
Shelby Boardman, Carleton College
Diane R. Smith, Trinity University

STUDENTS
Rebecca Atkinson, Williams College
Sarah DeWitt, Colorado College
Angela Dudek, Beloit College
Beth Fratesi, Mississippi State University
Jessica Jager, Pomona College
Jen Lenz, Smith College
Miranda Loflin, The College of Wooster
Lela Prashad, Trinity University
Patrick Roehrdanz, Carleton College

VISITING FACULTY
Bruce Panuska, Mississippi State University
Jeffrey Noblett, Colorado College
Reinhard Wobus, Williams College
Cameron Davidson, Beloit College

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Robert J. Varga & Lori Bettison-Varga
Dept. of Geology, The College of Wooster, Wooster, OH 44691

Shelby Boardman
Dept. of Geology, Carleton College, Northfield, MN 55057

Diane R. Smith
Dept. of Geosciences, Trinity University, San Antonio, TX 78212

INTRODUCTION

Funding from the Keck Geology Consortium allowed nine students and associated faculty to pursue research projects centered on the evolution of the Bonanza volcanic center in central Colorado. Students included Rebecca Atkinson (Williams College), Sarah DeWitt (Colorado College), Angela Dudek (Beloit College), Beth Fratesi (Mississippi State University), Jessica Jager (Pomona College), Jen Lenz (Smith College), Miranda Loflin (The College of Wooster), Lela Prashad (Trinity University), and Patrick Roehrdanz (Carleton College). Since its inception, this project shifted somewhat from a more holistic approach to the evolution of the northern Rio Grande rift to a focus on the many unanswered questions surrounding the evolution of the Bonanza volcanic center and its related caldera. Thus, all of the student projects discussed in the following set of papers outline research projects directed toward an understanding of this particular area.

OVERVIEW OF THE BONANZA CALDERA REGION

The >1000 km-long Rio Grande Rift (Fig. 1) extends from central Colorado, where the rift is narrow (~5 km), to a broad (>200 km), diffuse zone of normal faults in northern Mexico and west Texas. The wedge shape of the rift reflects the somewhat older age (~32 Ma.) of rift initiation and greater extension (~50%) in the southern part of the rift as opposed to the northern part (~27 Ma, 8-12% extension) (Chapin et al., 1978; Chapin and Cather, 1994).

In Central Colorado (Fig. 1), the rift narrows considerably at the head of the San Luis Valley where it comes in close proximity to the northeastern part of the Tertiary-age San Juan and Thirtynine-Mile volcanic fields. In an area surrounding the town of Salida, the Rio Grande rift lies close to the Oligocene-age Bonanza caldera and is approximately aligned with several similar-age calderas which lie to the north. This geometry, along with the ages and petrology of these calderas, has led to the suggestion that these volcanic centers might be related to the initiation of extension along the rift (Varga and Smith, 1984). The Bonanza caldera is distinct from other calderas of the San Juan field in having formed at the summit of an andesite-composition stratovolcano as a response to a low-volume eruption of dacite ignimbrite (Varga and Smith, 1984). In addition, this area of the San Juan volcanic field is much less-well studied than regions to the west and has several ignimbrite sheets of unknown age and provenance. Structurally, the Salida region of the Rio Grande rift comprises a region of accommodation wherein the vergence of normal faulting switches. The Villa Grove accommodation zone, as it has been termed by Chapin and Cather (1994), appears to be a classic, but rarely exposed, "synclinal accommodation zone" (Faulds and Varga, 1998).

The San Juan and Thirtynine-Mile volcanic fields have generally been ascribed to an Oligocene-age westward sweep of volcanism related to re-steepening of a previously flattened subduction zone dipping under this part of North America (Lipman, 1983). Volcanism began with eruption of 36-31 Ma, generally hi-K andesites (Conejos sequence) that young to the west (Smith and Varga, 1983), followed by more silicic, caldera-forming eruptions (Steven and Lipman, 1976) between about 31-27 Ma. The character of volcanism changed at about 25 Ma to bimodal basalt and high-silica rhyolite associated with regional crustal extension and evolution of the Rio Grande rift system (Lipman and Mehnert, 1975).

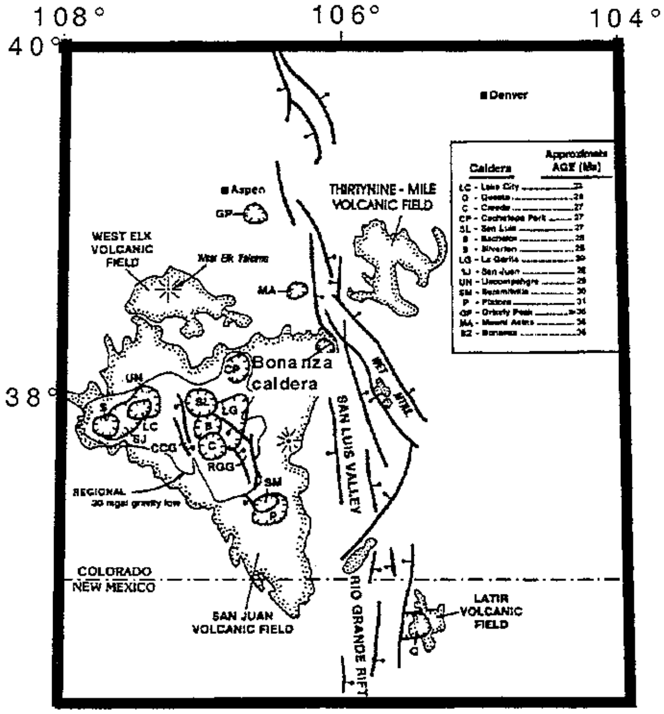

Figure 1. Bonanza caldera in relation to the San Juan volcanic field and the northern Rio Grande rift. After Steven and Lipman (1976).

Several aspects of the above scenario differ in the eastern San Juan Volcanic field near the Rio Grande rift and suggest that the line of calderas that coincide with the western edge of the rift (Bonanza, Mt. Etna, and Grizzly Peak) might be related to very early rift development. Limited dating at Bonanza (Varga and Smith, 1984; Smith and Varga, 1983) suggest that these calderas formed several million years before calderas to the west. Second, while bimodal volcanism is largely Miocene in age in the main San Juan field, mixed intermediate and silicic activity appears to have begun in the Oligocene in the Bonanza region. The evidence for this is, in part, the suggestion of Varga and Smith (1984) that the Upper Bonanza Tuff of rhyolite composition was derived locally. Recently, Chuck Chapin (personal communication, 1997) of the New Mexico Bureau of Mines has suggested that this tuff was derived from a distant source. If not from the Bonanza region, this rhyolite ignimbrite might correlate with ignimbrites in the Thirtynine-Mile field (Fig. 1) or have come from a newly discovered but as yet unstudied caldera located just north of Bonanza (C. Chapin, personal communication, 1997).

STUDENT PROJECTS

The prior and limited research in the Bonanza volcanic field left many unanswered and important questions toward which our student projects were focused. These projects were quite diverse and included the fields of petrology, structural geology, paleomagnetism, geochemistry and fluid inclusion research. Together, these student studies have clarified the evolution of this volcanic center and also highlighted avenues for future research.

Petrologic Studies

Several students took advantage of the excellent exposures of pre-caldera intermediate sequence and caldera-related ignimbrites afforded in the Bonanza region. Unresolved petrologic questions regarding the Bonanza volcanic center concern the petrogenetic relationship(s) among the magma types erupted at Bonanza. Are the petrologic and geochemical characteristics of two sequenes of andesites that occur directly below (Rawley Andesite/Conejos equivalent) and above (the "upper andesites") the Bonanza tuff different? If so, this might reflect a change in the parental magmas and/or magma source regions. Do the andesites represent parental magmas that fractionated to generate the dacitic eruptive products? What is the origin of the rhyolitic upper

Bonanza tuff? Is it a fractionation product of dacitic magmas similar to those erupted as the lower tuff or was it derived by crustal anatexis? Another question is whether the Bonanza volcanic rocks record a transition from an earlier compressional tectonic regime to an extensional one associated with the initiation of the Rio Grande rift.

Sarah Dewitt collected samples from the upper and lower andesite sequences, and Rebecca Atkinson collected the upper Bonanza tuff and other felsic rocks (the Porphyry Peak dome and Spring Creek pluton) associated with Bonanza. Both Sarah and Rebecca utilized petrographic, XRF and ICP-MS analyses to document the mineralogy and major and trace element characteristics of these units, which previously had not been described in much detail. Sarah and Rebecca are using the petrologic and geochemical data to place constraints on the questions posed above.

Geochemical and Fluid Inclusion Studies

The Porphyry Peak rhyolite and its related exogenous domes quickly became a major focus on the project for several students. This series of rhyolite domes was first recognized by Burbank (1932) who also recognized partial alteration of the rhyolite to an assemblage including the mineral alunite. Subsequent studies relating alunite to "acid-sulfate" alteration and related gold mineralization in the Basin and Range led to further study of the Porphyry Peak area, including dating of alunite alteration at ~33 Ma (Varga and Smith, 1984). The extent and origin of the alunite mineralization remain in question, and three students used various techniques to understand the nature of the hydrothermal alteration and the potential for ore-bearing rocks at depth.

Jennifer Lenz, Miranda Loflin and Patrick Roehrdanz mapped the extent of alunite alteration. Together, they sampled across a transect through the most alunitized and silicified zones of the alteration to the least altered rhyolite; their analytical work was performed on this joint set of samples. Using XRF and ICP-MS analyses, Jennifer Lenz investigated the trace element mobility in the system by comparing whole rock geochemistry of altered to unaltered rocks. Jennifer also characterized the mineral chemistry of alunite, and used this as evidence of the hydrothermal system in which the acid-sulfate alteration occurred. The isotopic composition of alunite is used to constrain temperatures and environment of formation of acid-sulfate alteration. Miranda Loflin prepared alunite samples for oxygen, hydrogen and sulfur isotope analyses and acquired those at the USGS analytical lab in Denver under the direction of Dr. Robert Rye. To complete the characterization of the hydrothermal system and to evaluate the potential for ore-bearing rocks at depth, Patrick Roehrdanz used a Fluid Inc. analytical stage to determine homogenization temperatures of fluid inclusions in quartz and alunite. Patrick characterized the fluid inclusions contained in samples from the most altered zones, looking for evidence of boiling in the system. Taken together, the data presented by these students work will thoroughly characterize the hydrothermal system which resulted in acid-sulfate alteration in the Porphyry Peak rhyolite.

Paleomagnetic/Structural Studies

Prior study of the Bonanza caldera by Varga and Smith (1984) suggested that the Bonanza Tuff indeed emanated from the suspected caldera area and that the low volume of this eruption (~50 km^3) resulted in only partial collapse of the foundered magma chamber roof leading to a half-, or "trapdoor" collapse. Inside the caldera, this trapdoor collapse is manifest by moderately west-tilted ignimbrite *and* younger lava flows. The question, of course, is why post-caldera collapse lavas are tilted if the tilting was concurrent with caldera collapse? Is the tilting a later (perhaps Rio Grande Rift) event or were the younger lavas deposited on a slope? Several students employed various paleomagnetic techniques to test both the origin of the Bonanza Tuff and the trapdoor collapse model.

Paleomagnetic techniques are very useful in structural studies of igneous rocks to assess tilting as many such rocks do not contain an unambiguous, originally horizontal marker. To use paleomagnetism in the Bonanza region, we first had to establish "reference directions" for the various volcanic units. Beth Fratesi took on this task as she studied several well-exposed, sub-horizontal stratigraphic sections of the relevant volcanic rocks well outside of the caldera. One of her sections was at Findlay Ridge, the type section of the Bonanza Tuff. Beth's data are critical to assessing the tilt history and magnitudes for volcanic sections inside the caldera where structural and metamorphic histories are complex. Another aspect of Beth's data will be to assess the relative duration of development of the Bonanza volcanic center. Lela Prashad is using Beth's reference data to assess the tilt history of the Bonanza Tuff and later rocks inside of the caldera and to test the "trapdoor" collapse model. Lela is also assessing the timing of formation of well-developed folds within the Bonanza tuff by applying the well-known "fold test" to here data. Jessica Jager collected paleomagnetic samples of the lower Bonanza Tuff to help assess the source region for this ignimbrite. Jessica is employing a technique called anisotropy of magnetic susceptibility to determine flow direction within her ignimbrite samples. The magnetic "lineations" within her samples can then be compared to flow directions determined by analysis of aligned particles in thin sections.

Angela Dudek, in support of the geochemical effort, mapped the internal structural of rhyolite dome/flows of Porphyry Peak. Previous limited study of this area suggested that the rhyolite formed as a series of interconnected exogenous dome, much like the modern analogs at the Glass Mountain or Long Valley volcanic fields. Angela concentrated on the geometry of the rhyolite and its internal structure to assess the exogenous dome model.

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Petrogenesis and correlation of the mid-Tertiary upper Bonanza tuff, central Colorado

Rebecca K. Atkinson
Department of Geosciences, Williams College, Williamstown, MA 01267
Faculty sponsor: Reinhard A. Wobus, Williams College

INTRODUCTION

The Bonanza caldera and the upper Bonanza tuff (UBT) are located between two major mid-Tertiary volcanic fields, the San Juan and the Thirtynine Mile. The San Juan field lies to the west and southwest of the caldera and was active from approximately 35 to 26 Ma (Lipman, 1982). Volcanism began with a period of intermediate composition eruptions which then changed to silicic ash flows from caldera centers at ~30 Ma, shortly after the eruption of the rhyolitic UBT. The Thirtynine Mile volcanic field lies to the northeast of the Bonanza caldera and was active at the same time as the San Juan field, from 37-28 Ma (Shannon, 1988). All the ash flows of this field are suspected to have sources in the Sawatch Range to the west; however, some sources have yet to be discovered. The Wall Mountain tuff, the oldest of the Thirtynine Mile ash flows at 36 Ma, is believed to have been erupted from the Mt. Princeton pluton. The Badger Creek tuff (34 Ma) is believed to be from the Mt. Aetna caldera, which was developed above the Mt. Princeton pluton (Shannon, 1988). The Grizzly Peak caldera lies further to the north but has not yet been correlated with a major ash flow. Varga and Smith (1984) suggested that the Bonanza caldera may be related to these Sawatch calderas to the north, as it is aligned with them along the western edge of the Rio Grande rift. This rift was beginning to form ~30 Ma, just after the eruption of the UBT. This puts the UBT at a time of transition from the earlier compressional tectonic regime to the extensional one that began with the opening of the Rio Grande rift.

The volcanic stratigraphy associated with the Bonanza caldera begins with the Rawley andesite at 37 Ma (Varga and Smith, 1984), composed of andesitic lava flows and lahars. It is overlain by the dacitic lower Bonanza tuff which is itself overlain by the UBT. The latter tuff is lithologically identical to the tuff outside Saguache, dated at ~33 Ma (McIntosh and Chapin, 1994). The sequence is capped by the upper andesite, which is composed of multiple andesitic lava flows and lahars.

The UBT is the only rhyolitic unit associated with the intermediate volcanic rocks of the Bonanza caldera, yet it has not been proven to be outflow from the caldera itself. Therefore, the goals for this project include documenting the petrologic and geochemical characteristics of the UBT and evaluating the petrogenesis of its magma.

FIELD WORK

Most samples of the UBT in this study were collected from a number of drainages located southwest of the caldera and northwest of the town of Saguache, just outside of the Rio Grande National Forest. Samples were gathered here because of the good exposures and because units closer to and within the caldera itself have been hydrothermally altered. Samples of the Spring Creek pluton (a rhyolitic stock east of the caldera) and of the Porphyry Peak rhyolite (an exogenous dome on a ring fracture of the caldera) were also collected for the purpose of comparison.