COLORADO PROJECT

Faculty

R. A. Wobus, Williams
Bruce Loeffler, Colorado
Stan Mertzman, Franklin and Marshall
Shelby Boardman, Carleton

Students

Anne Benjamin, Smith
Elizabeth Eide, Franklin and Marshall
Tamara Filson, Whitman
David Johnson, Colorado
Gordon Keating, Carleton
David Mochel, Williams
Miriam Rothwarf, Franklin and Marshall
Kimberly Sultze, Carleton
Edward Venzke, Beloit

PETROLOGIC AND GEOCHEMICAL STUDIES OF THE MID-TERTIARY GUFFEY VOLCANIC CENTER, THIRTYNINE MILE VOLCANIC FIELD, CENTRAL COLORADO

Reinhard A. Wobus
Professor of Geology
Williams College
Williamstown, MA 01267

The Oligocene Thirtynine Mile volcanic field of central Colorado is second in size in the Southen Rocky Mountains only to the extensive San Juan field (also mid-Tertiary) of southwestern Colorado and northern New Mexico. Even after some 30 million years of erosion, its deposits still cover an area of more than 2000 km^2, flanking the western side of the southern Front Range and forming the southern rim of South Park. These volcanic deposits lie upon an extensive erosion surface, developed mainly on Precambrian rocks, that has been uplifted to elevations averaging 2500 meters and has been segmented by Neogene block faulting. The prevolcanic surface was incised by streams whose valleys locally preserve gravels (Echo Park alluvium) and ash-flow deposits (Wall Mountain Tuff, 35 m.y.), the latter erupted from a source at the southern end of the Sawatch Range several tens of kilometers beyond the western edge of the Thirtynine Mile field.

Volcanism within the Thirtynine Mile field itself probably began with the formation of intermediate to silicic domes, pyroclastics, and localized lava flows of varied composition. These earliest volcanic products emanated from sources at Thirtyone Mile Mountain and at West and East Antelope Mountains, all of which lie a short distance south of the much larger and more complex Guffey center (Epis and Chapin, 1968). Activity then shifted to the Guffey center, where domes, minor flows, and pyroclastics similar to those from the Thirtyone Mile and Antelope Mountains centers were produced both prior to and during the extrusion of thick mafic to intermediate flows, flow breccias, and lahars. The latter group of rocks, poorly stratified and largely fragmental, has been collectively termed the lower member of the Thirtynine Mile Andesite by previous workers. Erupted from vents in several parts of the volcanic field, these flows and lahars reach thicknesses as great as 420 m on Thirtynine Mile Mountain and average more than 150 m through most of the field.

After a second period of formation of domes, shallow intrusives, and vent complexes, the better stratified mafic to intermediate flows of the upper member of the Thirtynine Mile Andesite were deposited, reaching a thickness of 240 m at Black Mountain and 360 m in the upper part of Thirtynine Mile Mountain. Dated at 34.1+1.1 m.y. by K-Ar, the upper member also caps the summits of Cover, Witcher, McIntyre, Castle, and Saddle Mountains. Along with Thirtynine Mile and Black Mountains, these prominences virtually surround the Guffey center, defining an elliptical outline 7 x 13 km that has been interpreted by previous workers as the eroded flanks of a large strato-volcano. The lower country inside this outline has been regarded as a caldera which subsided along ring fractures which may have guided the emplacement of some of the younger domes and shallow intrusives (Epis and Chapin, 1968).

Although volcanic deposits of the Thirtynine Mile field have been known since the late nineteenth century, when they were described by Whitman Cross in the Pikes Peak Folio published by the U.S.G.S. (1894), little has been done to characterize the rocks geochemically. Most of the work of delineating the extent of the field and of establishing the stratigraphy and petrography of its many rock units was carried out during the 1960's by Rudy Epis and his graduate students at the Colorado School of Mines and by Charles Chapin and his students at the New Mexico Institute of Mining and Technology. These studies were subsequently compiled and supplemented by new mapping by members of the U.S. Geological Survey during preparation of the Pueblo 1^{o} x 2^{o} geologic quadrangle map (Scott, Taylor, Epis, and Wobus, 1978). As part of the same USGS project, most of the Thirtynine Mile field was also portrayed at a scale of 1:62,500 on geologic maps of seven

15-minute quadrangles. Many of the rock units of the Thirtynine Mile field were formally named during the 1970's as well, and the very limited amount of chemical data available (major element analyses of only 5 samples from the Guffey center) were published at that time (Epis and Chapin, 1974).

The present study, funded by the Keck Foundation, was undertaken in 1987 specifically to obtain more chemical information about the volcanic and subvolcanic rocks of the Guffey center. We realized that only after the establishment of a sufficient data base including major, minor, and trace element analyses of rocks whose field relations and stratigraphic position are well understood could meaningful comparisons be made with other better-studied Tertiary volcanic fields like the San Juan. And only when the chemistry of the magmas is known can a petrogenetic model be developed for their source and evolution, particularly in terms of the changing tectonic environments of the western United States during the Tertiary.

Of special concern is the relation of the Thirtynine Mile volcanic field to Oligocene plate boundaries. Since the field consists mostly of intermediate volcanics (formerly called andesites), it would appear to resemble most closely the products of volcanic arcs situated above subduction zones. Plate reconstruction for the mid-Tertiary, however, places the Guffey volcanic center nearly 1500 km inland from the western edge of the American plate, beneath which the Farallon plate was being subducted. If the subducted slab were to have any influence on the composition of the magmas that rose into the Guffey center, subduction would have to have occurred at a remarkably low angle, a model which was proposed by Lipman and others to account for the San Juan volcanic activity at about the same time (Lipman, Prostka, and Christiansen, 1971).

Field work for this geochemical study of the Guffey center took place during three weeks in July and August, 1987, using the facilities of the Pikes Peak Research Station south of Florissant as a base. Nine students and three faculty members were involved, representing seven of the ten colleges in the Keck-funded consortium of undergraduate geology departments. The original focus of the field work, as outlined by reconnaissance the previous summer, was to map in detail and sample for chemical analysis a number of volcanic units identified as "domes" in previous studies. It was thought that these structures, whether exogenous domes or subvolcanic intrusives, would be the most homogeneous of all the volcanic units within the center and would thus provide the most representative, least contaminated samples.

It became obvious, however, after only a short time in the field that several of these structures had been misinterpreted by earlier workers, and that problems also existed with some of the previous mapping and stratigraphic interpretation. The group thus elected to study a number of key sites that, when remapped in detail, would help to answer questions about stratigraphy and would also provide the widest possible range of rock compositions for subsequent petrologic and chemical investigation. Each student selected one of these areas (which in some cases are contiguous) for detailed study. Four of these areas are along the eastern edge of the Guffey center (including Saddle, Castle, McIntyre, Witcher, and Cover Mountains) where some of the most mafic rocks of the center are found in lahars and flows of the Thirtynine Mile Andesite (lower and upper members) and the dikes which cut it. Two other project areas are in the interior of the center, extending from north of Guffey west to Chumway Park. This region is characterized by thick intermediate flows and domal lavas and by intermediate to silicic intrusives (as at Rhyolite Hill and Chumway Park), some of which are associated with tuffs and tuff breccias and with vents that contain margins of perlite. The remaining three areas are located along the southwestern and western margins of the Guffey center and include, from south to north: 1) the east-west ridge of Baldy and Hammond Peaks, which is held up by thick dikes of equigranular to porphyritic plutonic rocks of intermediate composition; 2) an area between Thirtyone Mile and Paris Creeks which contains one of the most conspicuous domes, previously mapped as biotite andesite, and a small vent containing rhyolite breccia; 3) an area between Paris and Dicks Creeks underlain primarily by thick flows of intermediate composition which are cut by several prominent dikes.

Following field work and several days of sample preparation and short seminars at Colorado College, participants returned to their respective colleges to undertake, during the ensuing academic year, the analytical and interpretative phases of the project. Petrographic study of 25-30 thin sections for each project area preceded selection of samples for chemical analysis. Major element chemistry and some trace elements were determined by XRF in the geology departments at Carleton, Colorado College, Franklin and Marshall, and the University of Massachusetts. Other trace elements, including rare earths, were obtained by neutron activation at the University of Wisconsin in Madison and through Nuclear Activation Services, Inc., using the Ford reactor at the University of Michigan. More than 200 samples were analyzed chemically, some for up to 44 elements, thus enlarging the previous data base of chemically analyzed rocks from the Guffey center by a factor of 40.

Results from the field and lab study of each project area are presented in the papers which follow, and a complete synthesis of all data is forthcoming. A few significant trends are worth noting here, however. Almost without exception, the rocks analyzed from all parts of the Guffey center are conspicuously enriched in potash for a given silica content, even more so than most of the published values for the San Juan volcanics. Total alkalies are also high, so that rocks previously classified as basalts, basaltic andesites, and andesites are better named trachybasalt, shoshonite, and latite, following the terminology of Le Bas and others (1986). The more silicic rocks are trachytes and rhyolites, and coarser-grained rocks referred to as diorite on published maps of the Guffey center are closer to monzonite and even quartz monzonite, following the IUGS system.

Chondrite-normalized rare earth trends show a nearly linear to slightly concave decrease from light to heavy REE's, with no negative europium anomalies. Rare earth totals are mostly in the range of 200-300 ppm,higher than those reported by Lipman (1987) for San Juan volcanics or for the Spanish Peaks, and there is a pronounced light/heavy fractionation among the rare earths (La_n/Lu_n generally 15 to 25). These data are consistent with the observed trend of increasing K_2O, REE, and light/heavy REE fractionation with increasing distance inland from a subduction type of convergent plate margin. They can also be interpreted as reflecting increased depth, at time of magma genesis, to a subducted oceanic slab (Lipman, 1987).

Models of magma generation to explain these observations will be complex and multi-stage, involving possible contributions from a subducted oceanic slab, partial melting of the overlying mantle wedge, and contamination by the thick continental crust of the American plate. Isotopic data cited by Lipman (1987) indicate a significant input from the continental crust, but similar isotope studies may be necessary to constrain genetic models for the Thirtynine Mile field.

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THE GEOLOGY, PETROLOGY AND GEOCHEMISTRY OF A SILICIOUS DOME AND VENT IN THE THIRTYNINE MILE VOLCANIC FIELD, NEAR GUFFEY, COLORADO

Anne E. Benjamin
Department of Geology
Smith College
Northampton, MA 01063

INTRODUCTION

Located in the southern portion of the Thirtynine Mile volcanic field near Guffey, Colorado, are the remains of a volcanic dome and a volcanic vent. These Oligocene-age features are in sections 13 and 24 of T15S, R74W and section 19 of T15S, R73W of the Thirtyone Mile Mountain and Black Mountain 15' quadrangles. A dome is a steep sided hill that forms when very viscous lava piles up over and around a vent. Domes can form by the piling up of several short flows or by new lava being squeezed from a vent distending the overlying mass. A vent is an opening at the earths surface though which volcanic material is extruded, often forming a mound or hill of interbedded lava flows and tephra.

DOME

The dome, a light-gray, tracyte-trachydacite, is 1.2 km wide and 180 m thick (see western half of map, Fig1). Its sides are very steep and outcrops show numerous joint sets as well as a hint of vertical flow alignment. The dome was extruded up through the Oligocene Wall Mountain Tuff and Eocene Echo Park Alluvium with lava supplied from below. Its relationship to the surrounding laharic breccias is unclear; the dome could have been extruded on top of the lahars or the lahars could have flowed around the dome.

The holocrystalline trachyte-trachydacite contains plagioclase and biotite phenocrysts (5-17 modal %) in a groundmass of plagioclase laths (30-60 modal %), opaques and cryptocrystalline material (20-60 modal %). The plagioclase phenocrysts are subhedral, twinned and zoned, with an average core composition of An_{50} and rim composition of An_{24}. The biotites are also subhedral and have rims of secondary hematite and opaques. Most of the biotites have been slightly resorbed with cryptocrystalline matrix filling the embayments. The groundmass of each sample has a trachytic to orthophyric texture, grading to pilotaxitic to felsophyric where cryptocrystalline material is abundant. The groundmass plagioclase laths are 0.01x0.08 mm to 0.15x0.38 mm, subhedral, twinned and strongly zoned, with core compositions of An_{43} and rim compositions of An_{23}. The rest of the groundmass is composed of cryptocrystalline material with low birefringence, probably plagioclase, quartz and potassium feldspar.

VENT

The vent, a feature 120 m thick and 300 m wide, can be divided into three zones: the eastern zone, the western zone and the central zone (see central hill on map, Fig 1). In the western zone a 6 m thick rhyolitic unit of possible pyroclastic origin overlies a laharic breccia. This rhyolitic unit forms a cliff and contains large, randomly-oriented, banded inclusions of a similar rhyolitic material. In the eastern zone the same cliff-forming rhyolite is found at a lower elevation. It is overlain by slightly banded flows 0.5-1 m thick. Micro-faults with vertical offset disrupt the flow banding and red-pink hydrothermal alteration is concentrated along these faults. In the central zone there is a reddish and blue-gray flow banded rock, which forms an autobreccia at low elevations. This central unit cuts across the rhyolitic unit of the eastern and western zones and spreads out to cover the top of the hill. The thick, possibly pyroclastic rhyolite, the thin flows of the eastern zone, the hydrothermal alteration and the autobreccia suggest that all of these units formed in close proximity to a vent. It appears that the vent opening was located in the central zone and first erupted the rhyolite and flow units of the eastern and western zones, then extruded the flow/autobreccia of the central zone which covered the top of the hill, filled the vent opening and caused the collapse of the eastern zone.

The rhyolitic cliff-forming unit and its inclusions, the flows of the eastern zone and the flow/autobreccia of the central zone are petrographically similar. All are holocrystalline rocks with small amounts of plagioclase and biotite phenocrysts in a fine grained to cryptocrystalline groundmass. The felsophyric to pilotaxitic texture of the groundmass is exhibited by plagioclase laths (0.01x0.05 mm - 0.1x0.2 mm) much smaller than those in the dome. Some of the samples contain up to 15% vesicles and trace amounts of tridymite with a radial habit. The biggest difference seen in the various rocks of the vent area is the percentage of cryptocrystalline matrix, which ranges from