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SIMULTANEOUS PHREATOMAGMATIC AND MAGMATIC RHYOLITIC ERUPTIONS RECORDED IN THE LATE MIOCENE PERALTA TUFF, JEMEZ MOUNTAINS, NEW MEXICO

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Abstract—In the southeastern Jemez Mountains, the Peralta Tuff Member of the Bearhead Rhyolite records the simultaneous deposition of both magmatic and phreatomagmatic eruptive products. The tuff of West Mesa and the tuff of lower Peralta Canyon are two informal eruptive units within the Peralta Tuff. The tuff of West Mesa consists of 19 m of pyroclastic-flow deposits and minor pyroclastic-surge and -fall deposits that were erupted from a vent near present Bearhead Peak. The tuff of lower Peralta Canyon consists of 28 m of massive and crossbedded pyroclastic-surge deposits overlain by 24 m of pumiceous, crossbedded pyroclastic-surge deposits and a 2-m thick pyroclastic-fall deposit. This unit erupted from a dome in lower Peralta Canyon located 7 km southeast of Bearhead Peak. These two eruptive units are interbedded, suggesting that they were simultaneously deposited. Evidence for a primarily magmatic eruptive process for the tuff of West Mesa is indicated by the presence of moderately to highly vesicular pumice lapilli and emplacement temperatures ≤ 600°C. Evidence for a primarily phreatomagmatic eruptive process for the tuff of lower Peralta Canyon is indicated by the presence of accretionary lapilli, contorted bedding, incipiently to moderately vesicular pumice lapilli, and emplacement temperatures up to 300°C. The difference in eruptive style was controlled by the location of each vent. The West Mesa eruption occurred within the dry volcanic rocks of the Keres Group, whereas the lower Peralta Canyon eruption occurred within the wet basin-fill sediments of the Santa Fe Group.

INTRODUCTION

Simultaneous volcanic eruptions from two or more closely spaced, but separate, vents have been observed in modern eruptions (most recently at Rabaul volcano, Papua New Guinea; Global Volcanism Bulletin, 1994) and recognized for a few prehistoric Holocene eruptions (e.g., Fink, 1985; Miller, 1985; Scott, 1987). Radiometric dating of older volcanic fields have yielded eruption dates that overlap (e.g., the Taylor Creek Rhyolite; Duffield and Dalrymple, 1990). While these dates suggest simultaneity of eruptions, conclusive field evidence is lacking. Recent field evidence from the southeastern Jemez Mountains of New Mexico documents the simultaneous eruption of two late Miocene rhyolitic centers located approximately 7 km apart.

Phreatomagmatic eruptions occur when a magma comes in contact with the water in a shallow aquifer (White, 1991; Aranda-Gomez et al., 1992; Godchaux et al., 1992; Brooker et al., 1993), but magmatic eruptions occur when the water-magma interaction is minimal. Phreatomagmatic and magmatic eruptions can occur within the same area if the source of external water is localized (e.g., a lake or river) or the area contains considerable topographic relief (Leat and Thompson, 1988; Heiken et al., 1989). Both phreatomagmatic and magmatic eruptive behaviors were produced during the simultaneous late Miocene eruptions recorded in the southeastern Jemez Mountains because each magma body interacted with a different amount of groundwater.

REGIONAL GEOLOGY

The Jemez Mountains are a large volcanic field located on the western edge of the Rio Grande rift. Volcanism commenced by at least 16 Ma (Gardner and Goff, 1984) and may still be active (Wolff and Gardner, 1995; Reneau et al., 1996). This volcanic field is best known for the cataclysmic, caldera-forming early Pleistocene eruptions that produced the Bandelier Tuff and the Valles caldera (Smith and Bailey, 1966; Smith et al., 1970). Within the Rio Grande rift, Jemez volcanic rocks overlie and are intercalated with upper Tertiary Santa Fe Group basin-fill material consisting of tan to pink siltstone, sandstone, and gravel.

The southern Jemez Mountains are primarily composed of middle and upper Miocene volcanic rocks of the Keres Group. The andesites, basalts and dacites of the Paliza Canyon Formation form the bulk of the Keres Group (Gardner et al., 1986). The 6.96 ± 0.10 to 6.75 ± 0.09 Ma Bearhead Rhyolite (McIntosh and Quade, 1995) consists of numerous small-volume, high-silica rhyolitic domes, plugs and flows that originated as lower crustal melts (Gardner, 1985; Guilbeau, 1982; Guilbeau and Kudo, 1985) and were erupted along faults associated with the Rio Grande rift (Gardner and Goff, 1984). The Peralta Tuff Member of the Bearhead Rhyolite consists of fragmental deposits associated with the dome centers, and forms tuff rings, pyroclastic-flow aprons, and alluvial fans adjacent to these vents (Bailey et al., 1969; Smith et al., 1991). Hanging-wall rotation along rift-related faults produced west-southwest structural dips.

The eruptive history of the Bearhead Rhyolite is well preserved within the Peralta Tuff. The products of at least 35 separate eruptions have been identified in the upper 150 m of the Peralta Tuff, 13 of which produced pyroclastic flows or pyroclastic surges (Smith et al., 1991; Gay and Smith, 1993). The other eruptions are known solely on the basis of preserved fallout tephras. Smith et al. (1991) informally defined six of the eruptive units in the Peralta Canyon-Colle Canyon area, and Gay (1995) defined a seventh eruptive unit (Figs. 1, 2). Each named eruptive unit is separated

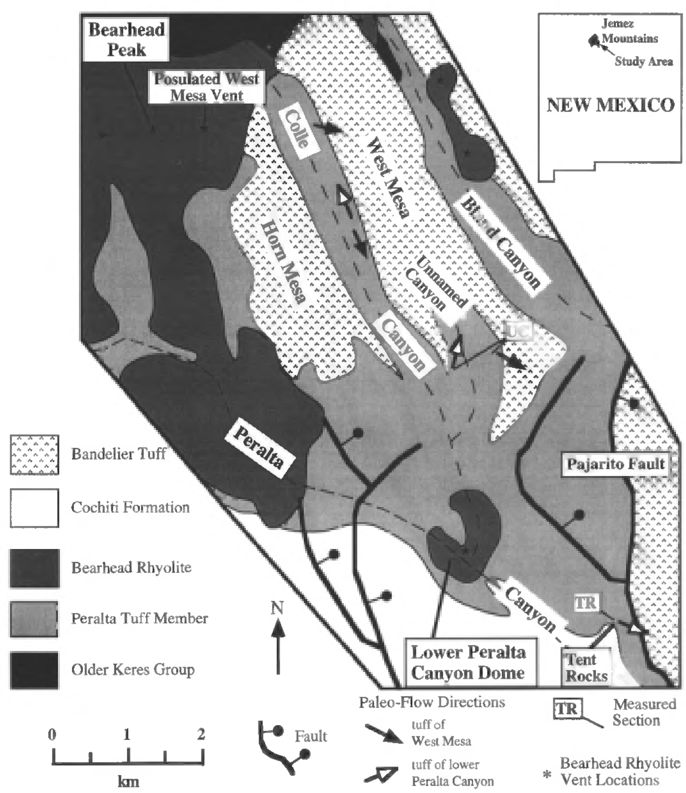


FIGURE 1. Geologic map of the region near the confluence of Colle and Peralta Canyons, showing the locations of the two measured sections (UC and TR) described in the text.

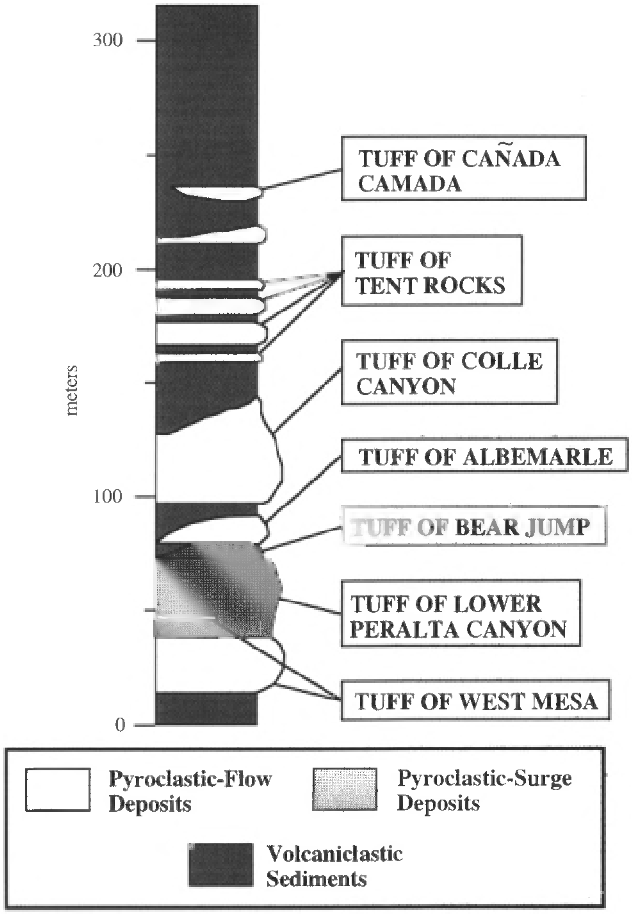


FIGURE 2. Generalized stratigraphic column for the Peralta Tuff, including the informal eruptive units defined by Smith et al. (1991) and Gay (1995).

from adjacent units by paleosols, sedimentary deposits, or contains evidence that stratigraphically adjacent units were erupted from different vents.

The two oldest eruptive units defined by Smith et al. (1991) are the tuff of West Mesa and tuff of lower Peralta Canyon (Fig. 2). The tuff of West Mesa is best exposed in an unnamed canyon (Fig. 2) incised into West Mesa, and the tuff of lower Peralta Canyon is best exposed at Tent Rocks in lower Peralta Canyon. Both units are partially exposed in Colle Canyon. Thermoremanant data from pumice lapilli indicate that the tuff of West Mesa was emplaced at or near 600° C (Smith et al., 1991), and thermoremanant data from lithic clasts within the tuff of lower Peralta Canyon indicate emplacement temperatures of up to 300°C (W. McIntosh and G. Smith, unpubl. data). These two deposits are the focus of this paper, and contain evidence for being simultaneously erupted from different vents under contrasting eruptive conditions.

METHODS

Stratigraphic sections were measured and described based on visual observations and estimates of each component. Depositional facies (Table 1) were defined based on field observations of differing grain size and bedding characteristics. Lapilli compositions were determined in the field and abundances were visually estimated. Samples for grain size and vesicularity analysis were collected from a representative layer within any given bed. For the crossbedded surge deposits of facies 3A, samples were consistently collected from the coarse-grained base of each bed. Two representative stratigraphic sections (sections UC and TR; Figs. 3, 4) illustrate the characteristic features in these eruptive units. Section UC is a composite of two sections from the unnamed canyon (sections UC1 and UC2 from Gay, 1995), and section TR is a composite section from the Tent Rocks (section TR1 from Gay, 1995).

Pumice lapilli vesicularities were measured using the immersion method of Houghton and Wilson (1989). From each bed, pumice lapilli

TABLE 1. Descriptions and interpretations of the depositional facies observed within the tuff of West Mesa and the tuff of lower Peralta Canyon.

Facies	Description	Interpretation
Facies 1A	Tan, fine-grained, well-sorted, crudely crossbedded, thin-bedded tuff containing accretionary lapilli	Wet pyroclastic-surge deposit
Facies 1B	Tan to gray, fine- to medium-grained, well- to moderately-sorted, massive to plane-bedded tuff containing armored lapilli	Wet pyroclastic-surge deposit
Facies 2A	Tan, fine- to coarse-grained, poorly-sorted, massive, thick bedded lapilli tuff containing siltstone and volcanic sand/gravel clasts	High-density pyroclastic-surge deposit
Facies 2B	Tan, fine- to coarse-grained, poorly-sorted, thick, crudely plane-bedded lapilli tuff containing siltstone and volcanic sand/gravel clasts	High density pyroclastic-surge deposit
Facies 3A	White to gray, medium- to fine-grained, moderately-sorted, cross-stratified tuff and lapilli tuff containing abundant pumice clasts	Dry pyroclastic-surge deposit (Increasing Flow Density ↓)
Facies 3B	White, medium- to coarse-grained, moderately-sorted, lapilli tuff containing abundant, imbricated, tabular pumice lapilli	Dry pyroclastic-surge deposit
Facies 3C	White, medium-grained, moderately-sorted, crudely plane-bedded, pumice-rich lapilli tuff	Dry pyroclastic-surge deposit
Facies 3D	Gray, poorly-sorted, massive tuff or lapilli tuff containing pumice and lithic lapilli in an ash matrix. Beds laterally pinch out over a distance of 2-3 m	Dry pyroclastic-surge deposit
Facies 4	Gray to white, medium- to fine-grained, well- to moderately-sorted, plane-bedded tuff or lapilli tuff, typically with abundant pumice clasts	Pyroclastic-fall deposit
Facies 5	Gray, coarse- to fine-grained, poorly-sorted, massive lapilli tuff	Pyroclastic-flow deposit
Facies 6	White to black, coarse-grained, moderately-sorted, massive tuff breccia containing abundant pumice and lithic lapilli	Pyroclastic-flow deposit

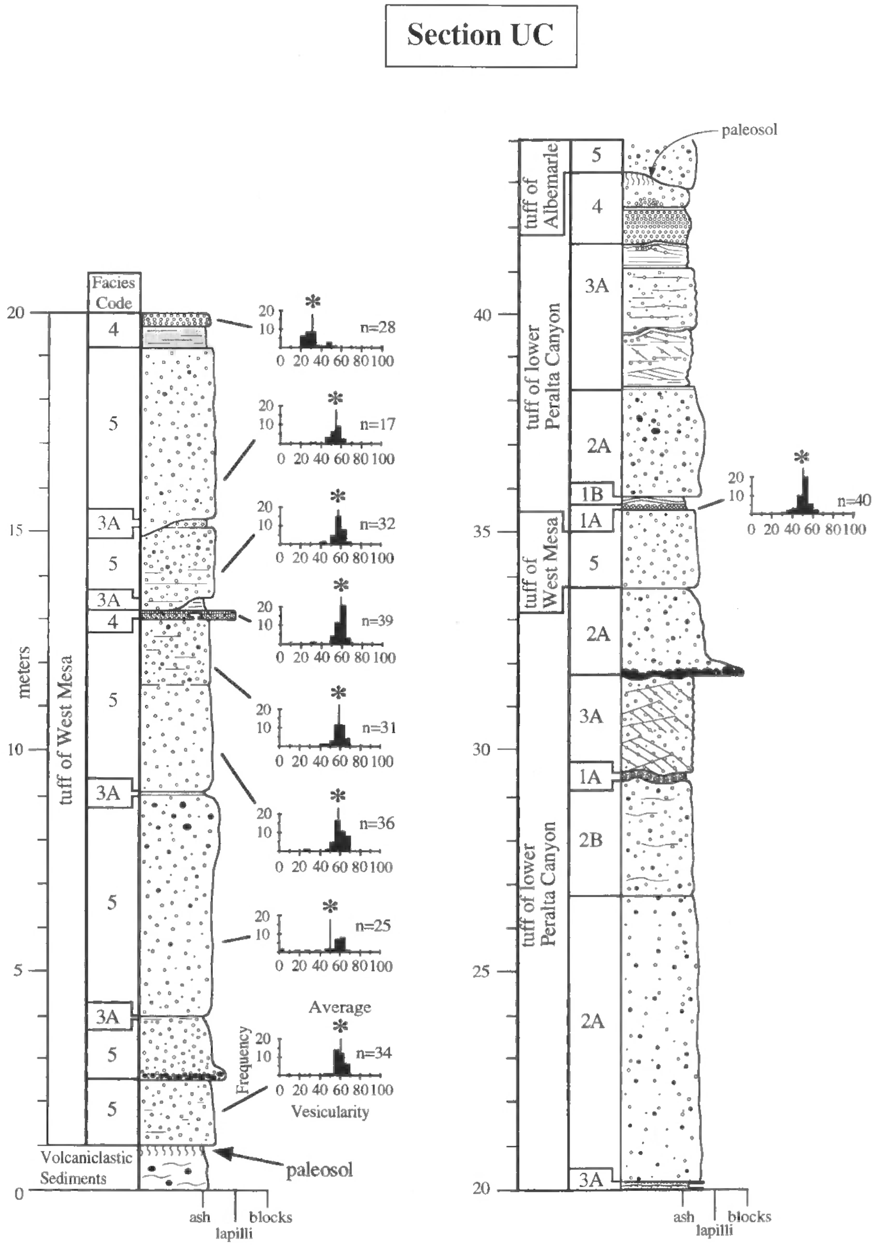


FIGURE 3. Stratigraphic columns (section UC) for the tuff of West Mesa and the tuff of lower Peralta Canyon, including the vesicularity data collected from individual beds within each unit. Histograms represent the data collected from the indicated bed. * = the average vesicularity for that bed, n = the number of samples collected, x-axis = percent vesicular, y-axis = frequency.

were collected from a representative layer. Each lapillus was cleaned and coated with a commercial silicon spray. The mass of each pumice clast was measured in air and water, and the clast vesicularity was calculated using the equations in Houghton and Wilson (1989). The measurement of 30 lapilli per bed yields an accurate vesicularity histogram, though as few as 10 lapilli produce a representative histogram. The average vesicularity is considered to be representative of the entire sample. The model of Houghton and Wilson (1989) asserts that magmatic eruptions produce narrow, unimodal histograms with a high average vesicularity and that phreatomagmatic eruptions produce broad, polymodal histograms with a low average vesicularity. When used in conjunction with additional field evidence, this method provides a valuable tool in interpreting the eruptive conditions that produced a given deposit.

STRATIGRAPHY OF ERUPTIVE UNITS

Tuff of West Mesa

At section UC, the tuff of West Mesa is 19 m thick and is primarily composed of pyroclastic-flow deposits (facies 5) with minor pyroclastic-surge (facies 3A) and -fall (facies 4) deposits. Lithic clasts of rhyolite, basalt, andesite, obsidian, perlite, and extremely rare sandstone are typically less than 3 cm in diameter. Pyroclastic-surge deposits ≤5 cm thick are present between many of the flow units and are interpreted as ash-cloud or ground-surge deposits (sensu Fisher, 1979); however, the field data cannot rule out the possibility that they are genetically unrelated to the adjacent flow units. Crossbedding indicates flow to the southeast away from the area near Bearhead Peak . The top of the tuff of West Mesa contains a 0.8 m-thick, pumice-rich, plane-bedded fall deposit.

The vesicularity data for the tuff of West Mesa contain uniform distributions throughout the eruptive unit except for the upper fall deposit. The average clast vesicularity, for any one bed, ranges from 49% and 60%, and does not vary by facies or by stratigraphic position (Fig. 3). By contrast, the upper fall deposit has an average vesicularity of only 30%. All of the vesicularity distributions are unimodal, and most distributions terminate at a vesicularity of 65%-70%.

In Colle Canyon, the tuff of West Mesa contains two differences from section UC. Near Bearhead Peak, pyroclastic surges (facies 3A) domi-

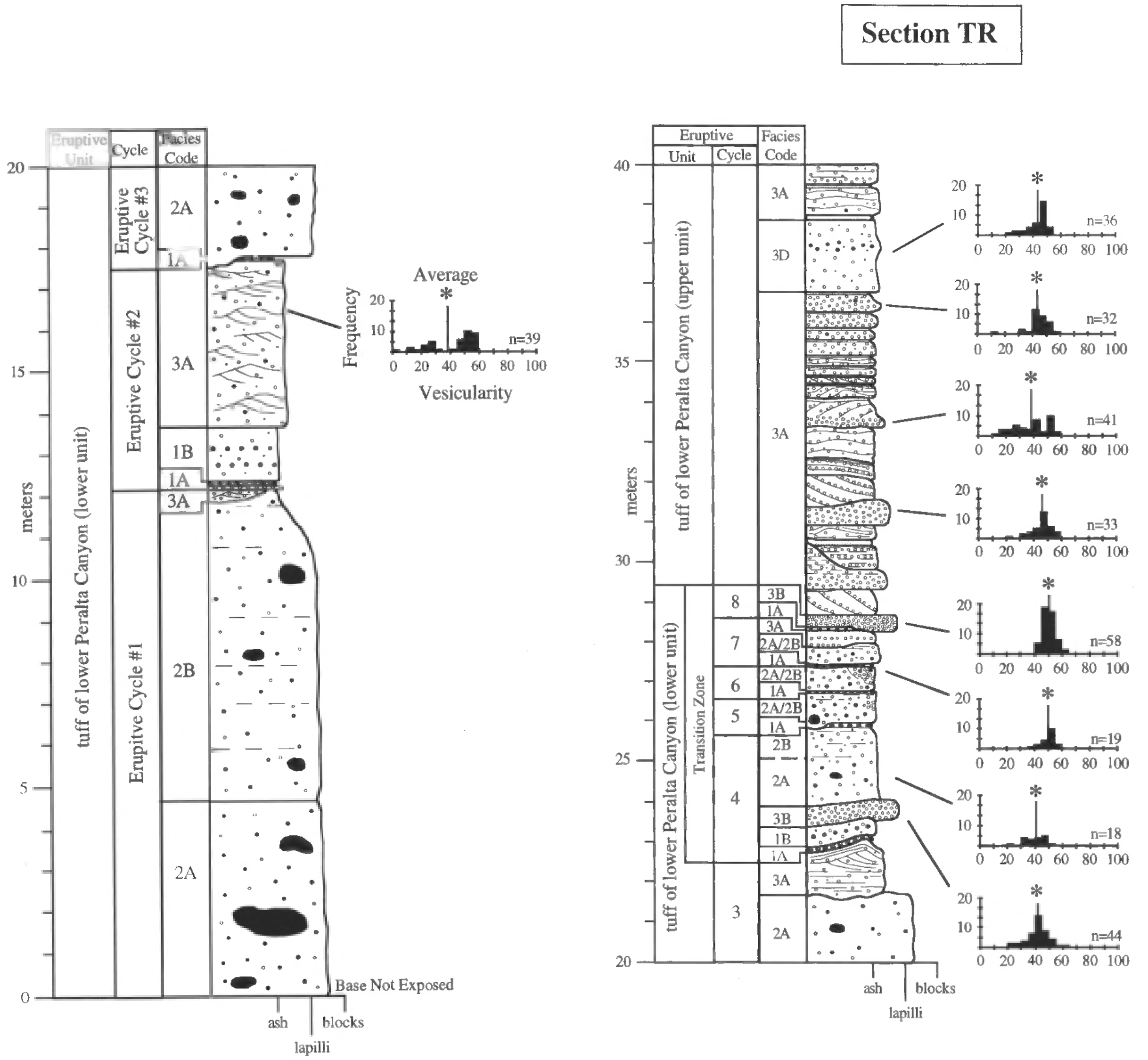


FIGURE 4. Stratigraphic columns (section TR) for the tuff of lower Peralta Canyon; see Figure 3 for explanation and abbreviations.

nate the section, with minor interbedded pyroclastic-flow deposits (facies 5). A coarse-grained tuff breccia (facies 6) is also present in Colle Canyon near Bearhead Peak. Lithic lapilli within this facies include glassy and devitrified rhyolite, basalt and andesite. The deposit was sufficiently indurated to prevent vesicularity calculations using the method of Houghton and Wilson (1989); however, observations of thin sections show that the pumice lapilli are moderately to highly vesicular.

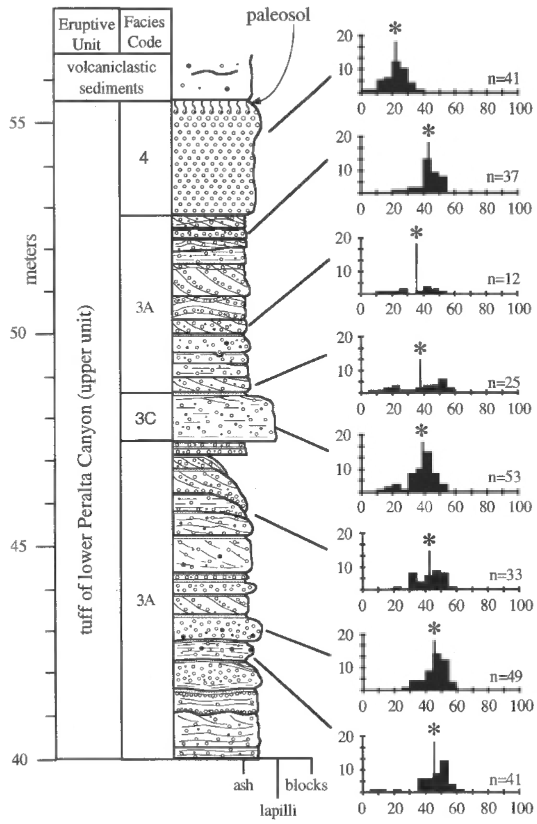
Tuff of lower Peralta Canyon

The ≥ 54 m-thick tuff of lower Peralta Canyon is dramatically exposed in lower Peralta Canyon at Tent Rocks (Fig. 4). Smith et al. (1991) first described the tuff of lower Peralta Canyon and divided it into a lower and upper unit. The base of the tuff of lower Peralta Canyon is not observed at Tent Rocks, but correlation of individual beds to section UC (Fig. 1) indicates that the base of the eruptive unit at Tent Rocks is probably 1-2 m below the surface. Crossbed orientations from pyroclastic-surge deposits form a radial pattern centered on the Bearhead Rhyolite dome in lower Peralta Canyon, 7 km southeast of Bearhead Peak (Fig. 1).

The 28 m-thick lower unit is composed of eight facies sequences that are interpreted as eight repetitive eruptive cycles (Figs. 3, 4). The base of each cycle is defined by the presence of a fine-grained, accretionary lapilli-bearing, wet-surge deposit (facies 1A). In a complete cycle (Fig. 5), this deposit is successively overlain by an armored lapilli-bearing surge deposit (facies 1B), a massive, poorly-sorted deposit (facies 2A), a crudely-bedded, poorly-sorted deposit (facies 2B), and finally a pumiceous, crossbedded surge deposit (facies 3A). The fine-grained wet-surge deposit mantles the underlying bed along a sharp contact, and in places this facies is deformed into flame structures. The poorly-sorted deposits (facies 2A and 2B) compose the majority of each cycle, and may rest upon the underlying stratigraphy along an apparent erosional surface. The poorly sorted facies (2A) typically grades into the crudely-bedded facies (2B), which may grade into a pumiceous, crossbedded surge deposit (facies 3A). The succeeding cycle is marked by the presence of another fine-grained, wet-surge deposit (facies 1A).

The lapilli surge deposits of facies 3B are found twice in the lower unit. This facies contains very little fine ash and abundant, imbricated, tabular pumice lapilli. Smith et al. (1991) incorrectly interpreted these beds as fall deposits.

The cyclic deposits in the upper 4.6 m of the lower unit (Fig. 4) are different from those below. The armored-lapilli surge deposits (facies 1B) are not present, and the fine-grained, wet-surge deposits are thinner than similar beds lower in the section. The poorly-sorted deposits (facies 2A and 2B) are also thinner but more pumiceous, and the crude planar bedding is more pronounced. This increase in the abundance of pumice lapilli and definition of the planar bedding makes this part of section TR transitional between the underlying massive deposits and the overlying surge deposits in the upper unit, and is informally called the transition zone.



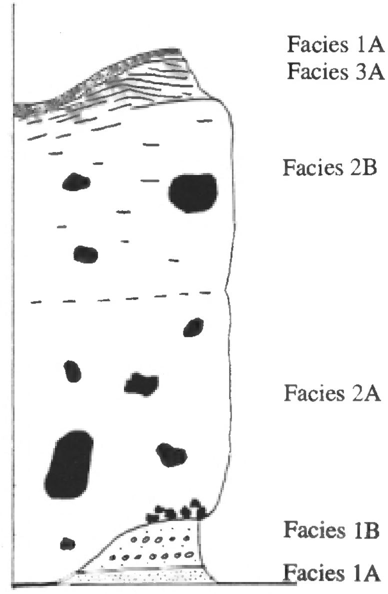


FIGURE 5. Complete depositional cycle from the lower unit of the tuff of lower Peralta Canyon.

The lithic lapilli compositions within the lower unit include pink siltstone, black sandstone and gravel, well-rounded basalt and quartzite, andesite, rhyolite, and very rare arkose. Some of the pink siltstone clasts have been deformed into sinuous ribbons up to 10 cm long. Crystals within these surge deposits include undulose and nonundulose quartz, biotite, sanidine and microcline.

The upper unit of the tuff of lower Peralta Canyon is dominated by a single facies - the pumiceous crossbedded surge deposits of facies 3A which form an impressive 23 m cliff at Tent Rocks. At section TR (Fig. 4) accretionary lapilli were not conclusively observed within the fine-ash surge deposits (facies 1A), but 0.5 km north/northeast of section TR, abundant accretionary lapilli were observed in at least five of the surge deposits. Crossbed orientations suggest flow toward the southeast.

Three additional facies (facies 3C, 3D and 4) are present in the upper unit (Fig. 4). The pumiceous, plane-bedded deposit (facies 3C) is tabular and can be continuously traced for 350 m. The other facies is a massive surge bed (facies 3D) that is present at only one locality, and pinches out laterally against the underlying crossbedded surge deposit. The upper unit of the tuff of lower Peralta Canyon is capped by a 2.5 m-thick pumice fall deposit (facies 4). Reverse-to-normally graded strata up to 5 cm thick are defined by fluctuations in the size of the abundant pumice clasts. Lithic lapilli are very rare. Pumice lapilli are reverse to normally graded. An ashy, orange-colored, bioturbated paleosol is developed in the upper 60 cm of the fall deposit.

The lithic-clasts in the upper unit primarily consist of glassy and devitrified rhyolite, pink siltstone, well-rounded basalt, andesite and quartzite; black sand/gravel clasts are absent or rarely observed.

The data from both the lower and upper units contain similar vesicularity distributions and average vesicularities. In the lower unit, the average clast vesicularity increases with stratigraphic height from 38% to 53%, although only the pumiceous-surge deposits contained enough pumice lapilli to generate a representative distribution. This sampling bias, however, does not invalidate the observed increase in vesicularity. Thin sections of the fine-grained surge deposits and poorly-sorted deposits contain poorly vesicular pumice fragments, which is consistent with the vesicularity trend observed in the pumiceous surge deposits. Pumice lapilli vesicularities from the upper unit surge deposits range from 36% to 46% and exhibit no stratigraphic trend. The upper fall deposit, however, has a vesicularity of only 22%. Many of the surge deposits have polymodal vesicularity distributions and poorly vesicular tails. In contrast, the fallout layer has a nearly a normal, unimodal distribution.

Observations at section UC indicate that the West Mesa and lower Peralta Canyon tuffs are interbedded. At section UC, the lower unit of the tuff of lower Peralta Canyon is present, but most of the upper unit is absent (Fig. 3). In the lower unit, the same cyclic deposits are observed, and can be matched bed-for-bed with the lower unit deposits found at Tent Rocks. Each bed is texturally similar to those found at Tent Rocks. One notable difference is the presence of a pumiceous ignimbrite at section UC (Fig. 3). This deposit is similar in appearance, texture, and composition to the West Mesa ignimbrites. The depression in which it rests is oriented northwest-southeast, colinear with Bearhead Peak. Based on textural and vesicularity similarity to the other West Mesa deposits, and for reasons more fully explained below, this flow deposit is assigned to the tuff of West Mesa rather than the tuff of lower Peralta Canyon. This ignimbrite is not found at Tent Rocks.

ERUPTIVE CONDITIONS

Tuff of West Mesa

The narrow, unimodal vesicularity distributions collected from section UC suggest that the tuff of West Mesa originated from a magmatic eruption. Except for the uppermost fall deposit (with an average vesicularity of 30%), the average vesicularities fall within a narrow range (49% to 60%) (Fig. 3), suggesting that a uniform fragmentation process produced these pyroclasts. These vesicularities are below the ideal 75%-83% of Sparks' (1978) model, which was derived from the regular, geometric, close packing of uniform spheres. Vesiculation, however, is a random process that produces a random packing arrangement, and the maximum void fraction for the random packing of uniform spheres is 60% (Thomas et al., 1994); therefore, the presence of vesicularities below 75%-83% does not preclude a magmatic origin. Vesicularities as low as 50% have been reported for pumice lapilli produced during magmatic eruptions at Mount Vesuvius, Italy (Bertagnini et al., 1991). A high viscosity and/or low volatile diffusivity of the high-silica rhyolitic magma (Sparks, 1978) may have retarded vesicle growth and produced the uniformly low vesicularities for the tuff of West Mesa. The high emplacement temperatures (600°C; Smith et al., 1991) corroborate the magmatic interpretation for the tuff of West Mesa. Significant water-magma interaction would have cooled the magma, resulting in a lower emplacement temperature (Fisher and Schmincke, 1984).

The upper fall deposit is different from the remainder of the tuff of West Mesa, but the vesicularity data do not invalidate a magmatic origin. The vesicularity distribution is bimodal, but two different phases of bubble growth (Hoblitt and Harmon, 1993) or different flight paths while exiting the vent (Thomas et al., 1994), may generate bimodal pumice vesicularities in magmatic deposits. The low average clast vesicularity for the upper fall deposit suggests that these pumice clasts may have come from the volatile-poor interior of the magma body instead of originating in a hydromagmatic eruptive phase.

The water-magma ratio for the initial eruptive phase that produced the tuff breccia (facies 6) and some of the crossbedded surges (facies 3A) exposed in Colle Canyon is uncertain. The erupting magma may have initially interacted with the groundwater system; however, the abundance of moderately to highly vesicular pumice lapilli in the tuff breccia, and its coarse-grained texture, suggest a magmatic origin. If the magma did interact with groundwater, its affect on the eruption was negligible. This initial eruptive phase gave way to a drier magmatic phase during which the bulk of the eruptive unit was produced. The dramatic drop in vesicularity observed in the upper fall deposit resulted when the eruption tapped the volatile-poor interior of the magma body, and without a continual supply of magmatic gases, the explosive eruption could not be sustained.

Tuff of lower Peralta Canyon

The tuff of lower Peralta Canyon contains evidence of abundant water-magma interaction throughout much of the eruption. Data from the lower unit indicate that large quantities of water interacted with the magma. In the upper unit, however, the evidence for water-magma interaction is not as strong and suggests a decreased supply of water during that eruptive phase.

Lower unit

The presence of accretionary and armored lapilli, fine-ash surge deposits, and flame structures all indicate that liquid water was present at the point of deposition (Fisher and Schmincke, 1984; Barberi et al., 1989; Bertagnini et al., 1991). The abundance of sedimentary clasts in the lower unit, and the presence of undulatory quartz, microcline and clay minerals, indicate that the explosions associated with this eruptive phase occurred within the saturated, basin-fill sediments of the Santa Fe Group that underlie this area (Smith et al, 1970; Kelley, 1978).

The presence of poorly vesicular pumice clasts within the fine-grained surge deposits (facies 1A and 1B) and the poorly sorted deposits (facies 2A and 2B) indicate that the magma interacted with a sufficient quantity of water to arrest bubble growth and began to fragment. The broad, polymodal vesicularity distributions indicate a high degree of water-magma interaction (Houghton and Wilson, 1989), whereas deposits with unimodal vesicularity distributions represent drier eruptive conditions. The presence of unimodal vesicularity distributions, coarse-grained texture, and lack of lithic fragments in the imbricated, pumiceous-surge deposits (facies 3B) suggest that these deposits probably represent the driest eruptive phase within the lower unit.

The paleomagnetic data from the tuff of lower Peralta Canyon do not exclude the possibility of high emplacement temperatures (up to 300°C for the tuff of lower Peralta Canyon vs. 600°C for the tuff of West Mesa; Smith et al., 1991; W. McIntosh and G. Smith, unpubl. data). The lower Peralta Canyon data came from lithic clasts within both surge (facies 3A) and massive (facies 2A) deposits, but the West Mesa data came from pumice lapilli within flow deposits; therefore, a direct temperature comparison between the two eruptive units cannot be made. The cooler temperatures for the tuff of lower Peralta Canyon could have resulted from cold accessory lithic fragments transported in a hot pyroclastic current, but given the definite presence of water in the transport system, it seems likely that the tuff of lower Peralta Canyon was emplaced at a cooler temperature than the tuff of West Mesa.

Each depositional cycle in the lower unit contains a sequence that starts with a wet-surge deposit, and ends with a slightly drier pumiceous-surge deposit (Fig. 5). This pattern represents a cyclic eruptive phase where the magma initially encountered a large amount of water, but over time the amount of water in contact with the magma decreased as the water was converted to steam and erupted out of the vent. The magma then encountered more groundwater, and the cycle was repeated. In the transition zone, the increase in the abundance of pumice lapilli, decrease in the abundance of lithic lapilli, and decrease in bedding thickness, suggest that each successive cycle encountered a progressively smaller volume of water.

Upper unit

The lack of accretionary lapilli in most of the upper unit surge deposits may suggest that these surges were deposited at >100°C, yet the one outcrop containing accretionary lapilli indicates that some of these surges were below 100°C. Either these surge beds were deposited from different surges, making the temperature difference temporal, or these beds are from the same surge for which temperature varied laterally. In either case, these upper unit surge deposits probably represent the transition from wet surges containing water to dry surges containing steam (Wohletz and Sheridan, 1983).

Vesicularity distributions from the upper unit indicate that the water-magma ratio fluctuated during this eruptive phase. Surge deposits that possess broad, polymodal vesicularity distributions (Fig. 4) probably represent times of increased water-magma interaction, and those deposits with unimodal vesicularity distributions represent times of decreased water-magma interaction. Even though these latter deposits contain unimodal vesicularity distributions, the low average vesicularities (near 45%) and lack of any clasts with a vesicularity greater than 60%, suggests that the magma was rapidly vesiculating when it encountered the groundwater (e.g., the distributions from Ruamata and Hatepe Ash, New Zealand; Houghton and Wilson, 1989).

The upper fall deposit represents the driest eruptive conditions for the tuff of lower Peralta Canyon. The unimodal vesicularity distribution and narrow range of values indicate dry, magmatic conditions. The low average vesicularity suggests that the eruption was starting to tap the volatile-poor interior of the magma. The abundance of juvenile pumice lapilli and lack of abundant lithic lapilli indicate that the explosions did not significantly excavate the country rock.

Influence of vent location on eruptive style

Differences in water availability at the two vent locations produced eruptions that varied in style and products. The present elevation difference between the two vents is 300–600 m, and the vents lie along the strike of the southwesterly regional dip, so a similar elevation difference probably existed in the late Miocene. The paleotopography consisted of pyroclastic and alluvial aprons gently sloping away from highlands composed of older Keres Group volcanic rocks (Smith et al., 1991). The paucity of sedimentary clasts and presence of volcanic rocks in the tuff of West Mesa suggests that it erupted from within the older Keres Group volcanic rocks. The abundance of sedimentary clasts within the tuff of lower Peralta Canyon suggests that it erupted from within the Santa Fe Group.

The older Keres Group volcanic rocks may have been saturated with water; however, the lower hydraulic conductivities of these rocks would have limited the amount of water that could interact with the magma body. Therefore, the West Mesa magma encountered relatively dry eruptive conditions because the volcanic rocks could not supply enough water to sustain a hydrovolcanic eruption. The uncertain water-magma ratios for the earliest West Mesa deposits (the tuff breccia and surge deposits observed in Colle Canyon) may indicate an early, partially hydromagmatic eruptive phase.

In contrast, the lower elevation of the lower Peralta Canyon vent permitted the magma to erupt within the Santa Fe Group. These basin-fill sediments contain productive aquifers, and presumably were able to transmit sufficient quantities of water to the magma, or were easily ingested and mixed with the magma, to sustain a phreatomagmatic eruption. The inferred decrease in the water-magma ratio with time for the tuff of lower Peralta Canyon suggests that eventually the eruption consumed the water faster than the sediments could transmit it or that chilled magma in the conduit insulated the rising melt from the aquifer. This led to the drier eruptive conditions in the latter phases of the eruption.

Evidence for simultaneous eruptions

Periods of eruptive quiescence within the Peralta Tuff are represented by bioturbated paleosols and poorly sorted, braided-stream deposits. These deposits bound each eruptive unit (Fig. 2) in the Peralta Tuff except for the boundary between the tuff of West Mesa and tuff of lower Peralta Canyon (Smith et al., 1991).

Unlike the other eruptive units, the West Mesa and lower Peralta Canyon tuffs are interbedded. At section UC (Fig. 3), a pumiceous ignimbrite is interbedded with the cyclic, lower-unit deposits of the tuff of lower Peralta Canyon. This flow deposit is texturally similar to the West Mesa flow deposits, and dissimilar to the tuff of lower Peralta Canyon. The vesicularity distribution and average vesicularity are also similar to the West Mesa ignimbrites and dissimilar to most of the lower Peralta Canyon deposits. The few beds from the tuff of lower Peralta Canyon with textures and vesicularity distributions similar to this flow unit are the pumiceous, poorly-sorted deposits (facies 2B) from the stratigraphically higher transition zone. Finally, the channel containing this flow deposit is oriented radial to the Bearhead Peak dome complex and perpendicular to a flowline drawn from the lower Peralta Canyon dome. Based on these arguments, this flow unit is assigned to the tuff of West Mesa.

SUMMARY

During the late Miocene, two small-volume, high-silica rhyolitic magma bodies rose toward the surface, and erupted along rift-related faults. The West Mesa eruption occurred first within the older Keres Group volcanic rocks, and was characterized by relatively dry magmatic eruptive conditions. This eruption produced near-vent tuff breccia and surge deposits and more distal flow deposits. The magma may have interacted with sufficient groundwater to produce initial hydromagmatic eruptions, but if so, this phase was replaced with drier magmatic eruptive conditions. The eruption continued until the volatile-poor interior of the magma was tapped, at which time explosive eruptive activity subsided and dome extrusion probably occurred.

Near the end of the West Mesa eruption, a second high-silica magma body erupted within the saturated, basin-fill sediments of the Santa Fe Group. This lower Peralta Canyon eruption involved several episodes of groundwater mixing with the magma, and produced the depositional cycles of the lower unit. During this eruptive phase, large volumes of the aquifer material were excavated, disaggregated, and erupted onto the surface. During this phase of the lower Peralta Canyon eruption, the continued eruptions at the West Mesa vent produced at least one pyroclastic flow.

Explosive activity at the West Mesa vent apparently ceased and dome extrusion is inferred to have begun. At about this same time, the quantity of water mixing with the lower Peralta Canyon magma steadily decreased, until only dry pyroclastic surges were produced. Eventually, the volatile-poor interior of this magma body was tapped and the upper-fall deposit was generated. Explosive eruptive activity subsided as the lower Peralta Canyon eruption shifted to the extrusion of the lower Peralta Canyon dome.

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