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New Mexico Geological Society Guidebook, 58th Field Conference, Geology of the Jemez Mountains II, 2007, p. 262-267.

INTERPLAY OF MIOCENE RIFT TECTONICS AND RHYOLITIC MAGMATISM IN THE SOUTHERN JEMEZ MOUNTAINS, NEW MEXICO

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Abstract — A reconstruction of the late Miocene structural and volcanic history in the Jemez Mountains, New Mexico, documents the interplay of Rio Grande rift faulting, the eruption of rhyolitic magma, and the basinal preservation of eruptive products. Crustal melting generated a batholith that was incrementally tapped along NNW-striking and NE-striking faults that parallel regional rift faults and reactivated basement structures, respectively. Bearhead Rhyolite (6.5 – 7.1 Ma) was extruded during more than 40 eruptions from more than 20 fault-controlled vents during approximately 0.5 m.y. Simultaneously with this volcanic episode, enhanced rift-basin subsidence (~ 1 km/my) along the NNW- and NE-striking faults above the postulated batholith formed the Bearhead basin, where the best-preserved record of Bearhead Rhyolite pyroclastic deposits and related volcaniclastic sediment basin-fill strata accumulated. Coeval volcanism, faulting, basin subsidence, sedimentation, and hydrothermal alteration document the interplay of extensional deformation, magma generation, and the location of vents and style of volcanism.

INTRODUCTION

Continental extensional faulting and magmatism are closely related. Extensional strain simultaneously thins the upper crust by normal faulting and permits upward migration and decompression melting of underlying mantle as the crust thins. This paper synthesizes volcanological, stratigraphic, geochemical, geochronological, and sedimentological studies within the context of newly completed geologic mapping to show the interplay of extensional-basin development, rhyolitic magmatism, and sedimentation in a part of the Jemez volcanic field of north-central New Mexico. We hypothesize that rift faulting strongly influences the temporal and spatial patterns and the style of volcanism while it also determines basin subsidence that results in spatially restricted preservation of deposits that record the eruptive history.

GEOLOGIC SETTING

The Miocene-Pleistocene Jemez volcanic field covers about 2700 km^2 in the western Española basin of the Rio Grande rift in northern New Mexico (Fig. 1). The volcanic field is best known for the early Pleistocene Valles caldera, source of the Bandelier Tuff. Pleistocene volcanism, however, followed prolonged Neogene magmatism, starting at about 15 Ma, which constructed a broad field of countless vents through which extruded a wide compositional range of lava flows and tuffs (Smith et al., 1970; Gardner et al., 1986; Goff and Gardner, 2004).

The Jemez volcanic field formed at the intersection of the western margin of the Rio Grande rift and the northeast-trending Jemez lineament. The lineament is an 800 km-long alignment of late Cenozoic volcanic features (Lipman, 1980) that coincides with deep-seated structures formed during Paleoproterozoic accretion of crustal blocks (Karlstrom and Humphreys, 1998). Roughly north-south striking normal faults are present across the entire width of the Jemez Mountains. The Pajarito fault is part

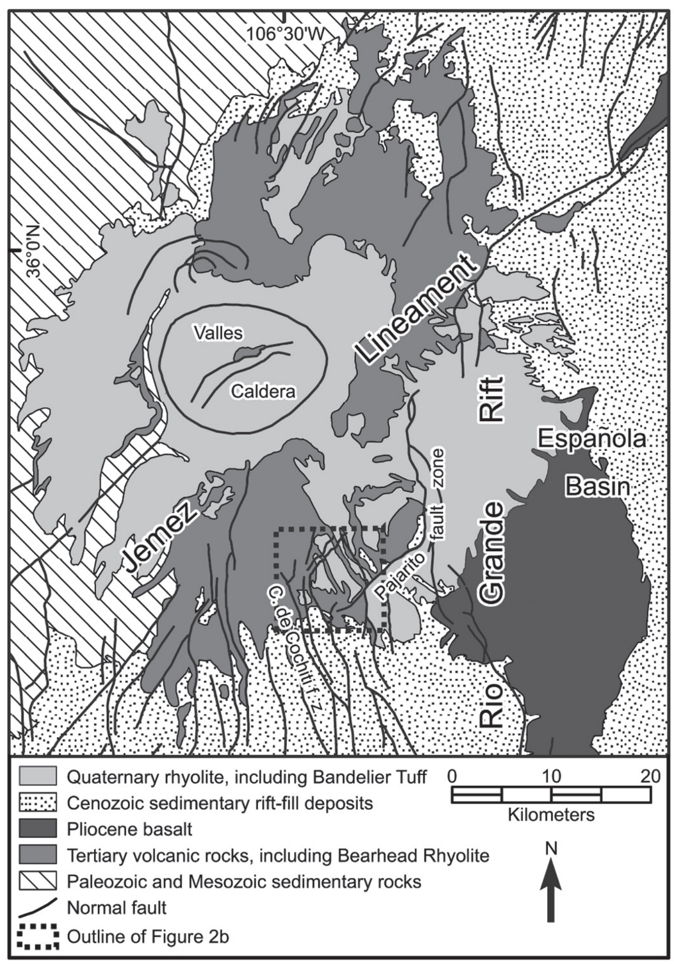

FIGURE 1. Generalized geologic map of the Jemez Mountains showing the relationship of the volcanic field to north-striking faults of the Rio Grande rift and NE-striking faults of the Jemez lineament. Modified from New Mexico Bureau of Geology and Mineral Resources (2003).

of the stepped margin of the Española basin (Fig. 1). West of the Pajarito fault is the Cañada de Cochiti fault zone, which Gardner et al. (1986) attributed to middle Miocene strain, followed by late Miocene and early Pliocene tectonic quiescence that culminated in major displacements farther east along the Pajarito fault. In contrast, Smith (2004) argued for a long history of normal motion across the Pajarito fault that is recorded by abrupt westward thinning of early to middle Miocene rift-basin strata onto its footwall block in addition to displacement of Pleistocene rocks. In addition, recent maps (Smith and Kuhle, 1998a; Kempter et al., 2003; Lynch et al., 2005; Goff et al., 2005) show displacements of Pleistocene Bandelier Tuff by as much as 100 m (Smith et al., 2001) across faults within the Cañada de Cochiti fault zone. The Jemez volcanic field, therefore, occupies a position within the step-faulted margin of the Rio Grande rift in a broad zone of long-active faults.

BEARHEAD RHYOLITE MAGMATIC EPISODE

The Bearhead Rhyolite erupted in the southeastern Jemez Mountains between about 7 and 6 Ma. This felsic magmatism followed and slightly overlapped with an earlier episode of basaltic to rhyolitic, but mostly intermediate-composition, volcanism represented by the Paliza Canyon Formation and Canovas Canyon Rhyolite (Bailey et al., 1969). Bearhead Rhyolite was erupted from at least 20 separate vents within a 300 km^2 area of the southeastern volcanic field (Fig. 2a). Rhyolite of comparable age and mineral content is also present in and north of the northeastern wall of the Valles caldera (Kempter et al., 2004; Gardner et al., 2006), which implies that part of the Bearhead Rhyolite is buried below caldera-filling Pleistocene tuff. Rhyolite domes, plugs, and a few flows mark the locations of vents. Most vents coincide with mapped faults, and rhyolite dikes parallel to NNW-

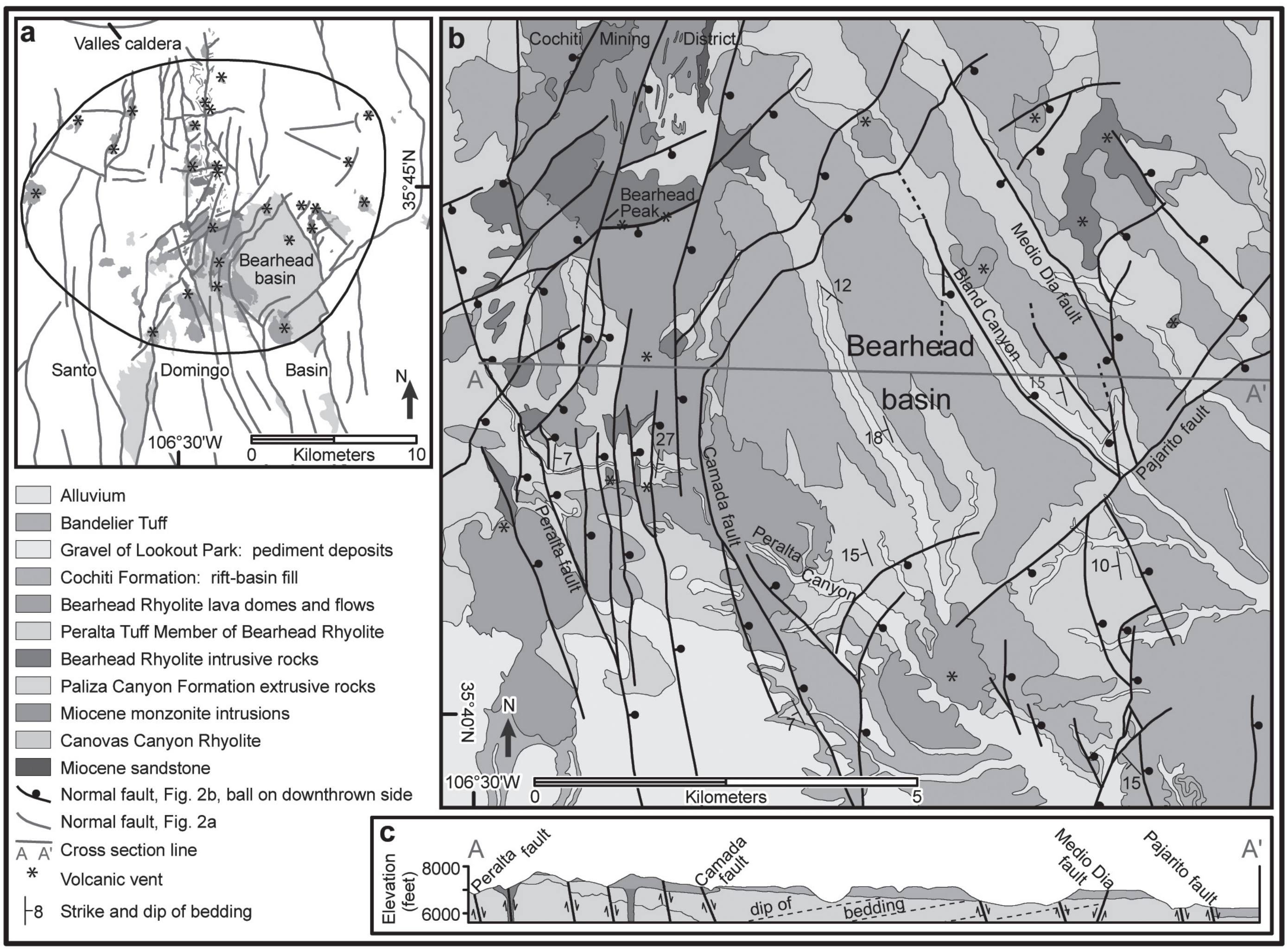

FIGURE 2. **a.** Distribution of Bearhead Rhyolite and faults in the southern Jemez Mountains. Bearhead Rhyolite was erupted along faults and fault intersections above a hypothesized batholith. Modified from Lynch et al. (2005) and Goff et al. (1990, 2005, 2006). **b.** Geologic map of the Bearhead basin. The basin is outlined by north- and northeast-striking faults that enclose a thick fill of Peralta Tuff. Rhyolite was primarily erupted along the western and northwestern margins of the basin. Miocene intrusive rocks are exposed in the uplifted footwall north of the basin. After Lynch et al. (2005). **c.** Cross-section along line A-A'. See Plate 11, page 141, for color version of this figure.

striking rift faults are common in the region north of Bearhead Peak within the Cochiti Mining District (Fig. 2b). Coeval pyroclastic deposits and intercalated sedimentary strata are assigned to the Peralta Tuff Member of the Bearhead Rhyolite (Bailey et al., 1969; Smith, 2001).

^{40}Ar/^{39}Ar geochronological data reported by McIntosh and Quade (1995), Smith et al. (2001), and Justet and Spell (2001) demonstrate the short duration of Bearhead Rhyolite magmatism in the southern Jemez Mountains. Figure 3 summarizes these data, which include samples from the entire stratigraphic extent of the Peralta Tuff Member as well as scattered rhyolite plugs and domes.

Four aspects of Bearhead Rhyolite magmatism are particularly noteworthy to the subject of this paper:

1. Dozens of discrete eruptions occurred almost entirely in the short interval between 7.1 and 6.5 Ma (Justet and Spell, 2001; Smith, 2001) and produced more than 40 km^3 of rhyolite (volume of eroded pyroclastic deposits is unknown). A single stratigraphic section contains the pyroclastic deposits of at least 40 separate eruptions, each deposit separated by fluvial sediment and weakly developed soils (Smith, 2001). Individual eruptions likely extruded 2 km^3 or less of tephra and lava.
2. Nearly all of the main phase (7.1-6.5 Ma) Bearhead eruptive products are uniform in mineral content (1-3% phenocrysts of quartz, sanidine, biotite, plus minor plagioclase and oxides) and in major, minor, and trace-element composition (Justet and Spell, 2001), which is consistent with derivation from a single magma chamber (Smith, 1999; Justet and Spell, 2001). The younger Cerrito Yelo eruptive center (~6.15-6.20 Ma) extruded products with a slightly different composition (Justet and Spell, 2001).
3. Lead-isotope data suggest that Bearhead Rhyolite originated by upper-crustal melting (Ellisor et al., 1996), which may have resulted from lower crustal ponding of mantle-derived magma. A 7.1 Ma mugearite lava flow (Chamberlin et al., 1999) erupted within the Cañada de Cochiti fault zone southwest of the main Bearhead Rhyolite outcrop belt is evidence for the hypothesized mantle melts. This youngest-known Paliza Canyon Formation lava flow shares major- and minor-element characteristics with potassium-poor alkaline lavas that Wolff et al. (2005) attributed to crustal contamination of basaltic melts derived from melting of lithospheric mantle.
4. Widespread hydrothermal alteration in the southern Jemez Mountains, including small-volume but high-grade epithermal gold mineralization in the Cochiti Mining District (Fig. 2b), occurred at 8-5.6 Ma (WoldeGabriel and Goff, 1989; Goff and Gardner, 2004), encompassing the time of Bearhead Rhyolite magmatism.

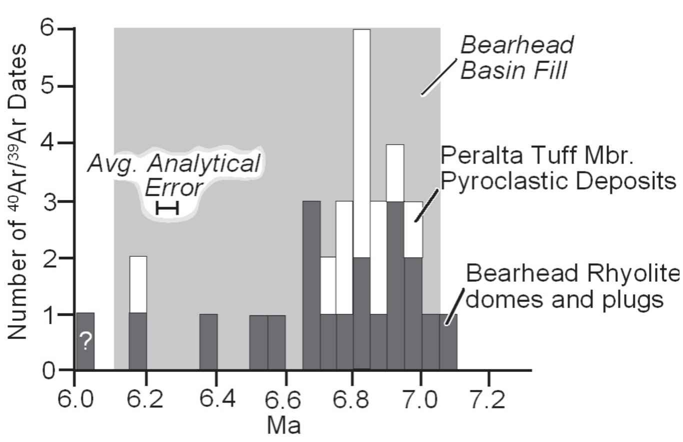

FIGURE 3. Histogram of ^{40}Ar/^{39}Ar ages for Bearhead Rhyolite, including pyroclastic deposits of the Peralta Tuff Member. Shaded part of graph shows the temporal range of the Bearhead basin fill. After Smith (2001).

BEARHEAD BASIN

Bearhead Rhyolite magmatism was synchronous with subsidence of a fault-bounded basin that contains most of the erupted rhyolite. The Bearhead basin (Smith, 1999, 2001) is a rectilinear depression covering an area of about 25 km^2 within the outcrop pattern of rhyolitic extrusive rocks (Fig. 2b). The basin is bounded on the east (Media Dia fault) and west (Peralta fault) by NNW-striking faults, on the north by a NE-striking fault zone, and partly truncated on the southeast by a NE-striking segment of the Pajarito fault. The Peralta and Camada faults along the western margin continue southward as major intrabasinal structures within the Santo Domingo basin of the Rio Grande rift (Fig. 2; Smith and Kuhle, 1998a; Smith et al., 2001). The Bearhead basin has the form of an asymmetric, west-tilted graben (Fig. 2).

Within the Bearhead basin, the Peralta Tuff Member is about 400 m thick and contains a stacked succession of more than 40 pyroclastic-flow, surge, and fall deposits intercalated with tuffaceous sedimentary strata (Fig. 4; Smith, 2001). The age of the basin-filling strata, based on ^{40}Ar/^{39}Ar dates of tuffs and lavas, encapsulates essentially the entire duration of Bearhead Rhyolite magmatism (Fig. 3). The basin is the only area where Peralta Tuff Member contains sedimentary deposits and products of multiple eruptions stacked one above the other. Outside the basin, in contrast, the Peralta Tuff consists of thin, localized pyroclastic-flow and surge deposits that form aprons around some of the Bearhead Rhyolite domes and plugs. This relationship between the Peralta Tuff and the Bearhead basin shows that the basin was subsiding during volcanism and allowed for the locally thick accumulation and preservation of the Peralta Tuff.

The largest area of Bearhead Rhyolite intrusions and domes coincides with the western structural margin of the Bearhead basin and in the uplifted block that forms the northern footwall of the basin (Fig. 2). The largest eruptive center, Bearhead Peak, is a polygenetic dome complex that formed at the intersection of north-northwest and northeast-striking faults at the northwestern basin margin. Contemporaneous eruptions of Bearhead Rhyolite domes from multiple, aligned vents near the western structural margin of the Bearhead basin (e.g., Gay and Smith, 1996) indi-

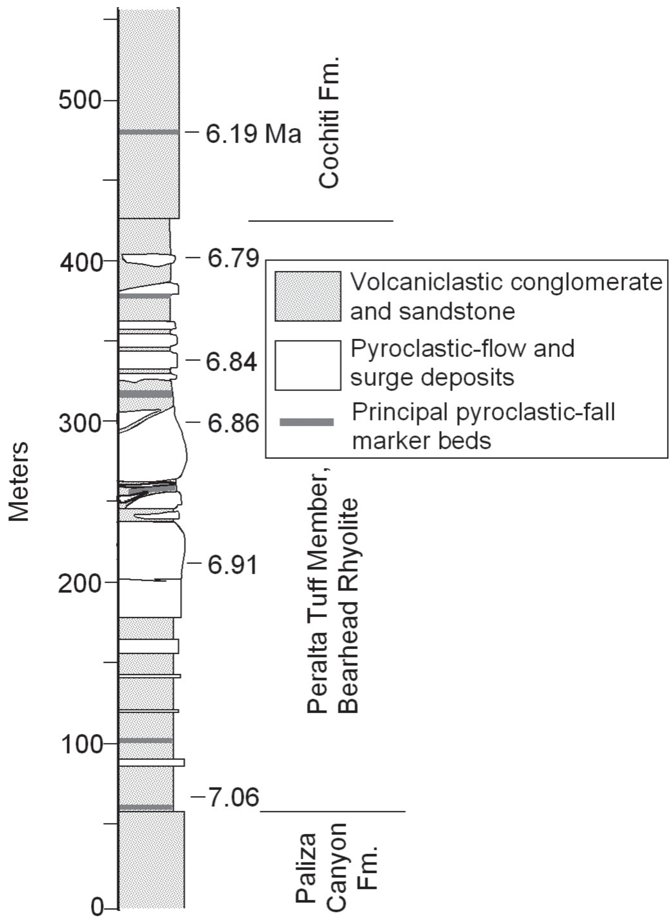

FIGURE 4. Generalized stratigraphic section within the Bearhead basin measured along structural dip from Bland Canyon to Peralta Canyon. At other locations lava flows and domes occupy large parts of the section. The exposed basin fill includes andesitic volcaniclastic sandstone and conglomerate of the Paliza Canyon Formation that passes conformably into rhyolitic volcaniclastic sediment of the Peralta Tuff Member, which is interbedded with rhyolitic pyroclastic-fall and flow deposits. The Peralta Tuff is gradationally overlain by nontuffaceous volcaniclastic strata of the Cochiti Formation. Stratigraphic positions of selected $^{40}Ar/^{39}Ar$ dates summarized in Smith (2001) are also shown.

cate the intrusion of magma along faults. Indeed, Bearhead Rhyolite dikes intrude faults and some dikes feed directly to flows. North- and north-northwest-striking Bearhead Rhyolite dikes are also present in the northern footwall block of the Bearhead basin, where they follow the strikes of regional rift faults (Fig. 2).

The uplifted northern footwall of the Bearhead basin exposes Miocene quartz monzonite, which represents the plutonic plumbing system to some of the Paliza Canyon Formation lava flows (Fig. 2b; Lynch et al., 2005; Goff et al., 2005). These magmas intruded and metamorphosed fine- to medium-grained quartz sandstones that likely correlate to regional middle Miocene eolianites (e.g., Zia Sandstone, Ojo Caliente Sandstone of the Tesuque Formation; Connell, 2004, Smith, 2004).

The subsidence history of the basin both predates and postdates the Bearhead magmatic episode. A pre-Bearhead Rhyolite history for the basin is implied by the presence of more than 50 m of volcaniclastic sediments of the Paliza Canyon Formation (Fig. 4) faulted against Paliza Canyon lava flows along the Media Dia fault. The northeast-striking faults that form the stepped northern margin of the basin also place rhyolitic intrusions adjacent to tuffaceous Bearhead-basin fill and displace Pleistocene Bandelier Tuff, which indicates motion along this basin boundary from at least late Miocene to Quaternary (Lynch et al., 2005).

Within the Bearhead basin, the Peralta Tuff Member grades up into more than 100 m of nontuffaceous gravel of the Cochiti Formation (Fig. 4), which extends southward into the Santo Domingo basin as part of the upper Miocene to lower Pleistocene rift-basin fill (Smith et al., 2001). The Peralta Tuff–Cochiti section in the Bearhead basin is tilted to the west and overlain unconformably by non-tilted, but faulted, lower Pliocene pediment gravel (Smith and Kuhle, 1998a; Smith et al., 2001; Lynch et al., 2005). This angular unconformity indicates that subsidence of the basin waned in the late Miocene or early Pliocene. The Pleistocene Bandelier Tuff fills in paleocanyons cut through the pediment gravel and underlying basin fill. Faults on the east, west, and north margins of the Bearhead basin displace the Bandelier Tuff by 10 to 80 m, and the Pajarito fault displaces it by approximately 100 m. These relationships indicate that basin subsidence was rapid during Bearhead Rhyolite magmatism (roughly 1 km/m.y.), waned during the Pliocene, and continued or resumed at a diminished rate through the Pleistocene. The late Miocene subsidence of the Bearhead basin was synchronous with west-tilting of strata in the western Santo Domingo basin, which was followed by Pliocene erosion before Quaternary fault reactivation (Smith et al., 2001).

SYNTHESIS AND CONCLUSIONS

Petrologic data (e.g., Justet and Spell, 2001) point to the likelihood that the Bearhead Rhyolite erupted from a single magma chamber, despite extrusion during dozens of eruptions from at least a score of vents (Smith, 2001). Assuming that the footprint of Bearhead Rhyolite vents (Fig. 2a) approximately outlines this magma chamber, then the intrusion was of batholith dimensions. The silicic magma likely resulted from crustal melting (Ellisor et al., 1996; Justet and Spell, 2001) related to intrusion of mafic, mantle-derived melts into the lower crust within a region where magmatism had been ongoing for about 10 m.y. Hydrothermal circulation around this intrusion caused pervasive alteration and mineralization (WoldeGabriel and Goff, 1989).

Magma was tapped incrementally in dozens of eruptions focused along faults and at fault intersections, rather than evolving into a vapor-rich chamber whose evolution might otherwise have culminated with a large ignimbrite-producing, caldera-forming eruption. Faults forming the western stepped margin of the Rio Grande rift, and also faults reactivated along northeast-striking Jemez-lineament structures, ruptured the roof of the batholith or its satellite magma chambers to draw off small volumes of melt in many eruptions over a period of only about half a million years. Bearhead Rhyolite eruptive centers coincide with faults and many, including the large polygenetic center at Bearhead Peak, formed at intersections of northerly striking Rio Grande rift faults and northeast-striking Jemez lineament faults.

The Bearhead basin formed where the NNW-striking Rio Grande rift faults of the Santo Domingo basin intersect the NE-striking Jemez lineament faults in the southern Jemez Mountains. The NE-striking faults exist only as far south as the most southerly volcanoes in the Jemez volcanic field, and are not present in the Santo Domingo basin (Smith and Kuhle, 1998a; Smith et al., 2001). This relationship suggests a close correspondence between magma generation and its rise to the surface within a wide, buried, basement structural zone, of likely lithosphere scale (Karlstrom and Humphreys, 1998).

The late Miocene was a time of active faulting and basin formation in the southern Jemez Mountains, rather than previously postulated tectonic quiescence. Rapid subsidence of the Bearhead basin coincided with Bearhead Rhyolite magmatism. The basin formed above part of the postulated batholith and magma withdrawal during the dozens of Bearhead Rhyolite eruptions, many of which occurred along or near the basin margins, may have enhanced subsidence. Coeval subsidence and volcanism allowed preferential accumulation and preservation of the thickest and most complete Peralta Tuff Member section within the Bearhead basin. Given the highly eroded nature of Bearhead Rhyolite centers outside the basin, it is unlikely that the importance of explosive eruptions during this magmatic episode would be recognized without the preservation of primary and reworked pyroclastic deposits within the basin fill.

ACKNOWLEDGMENTS

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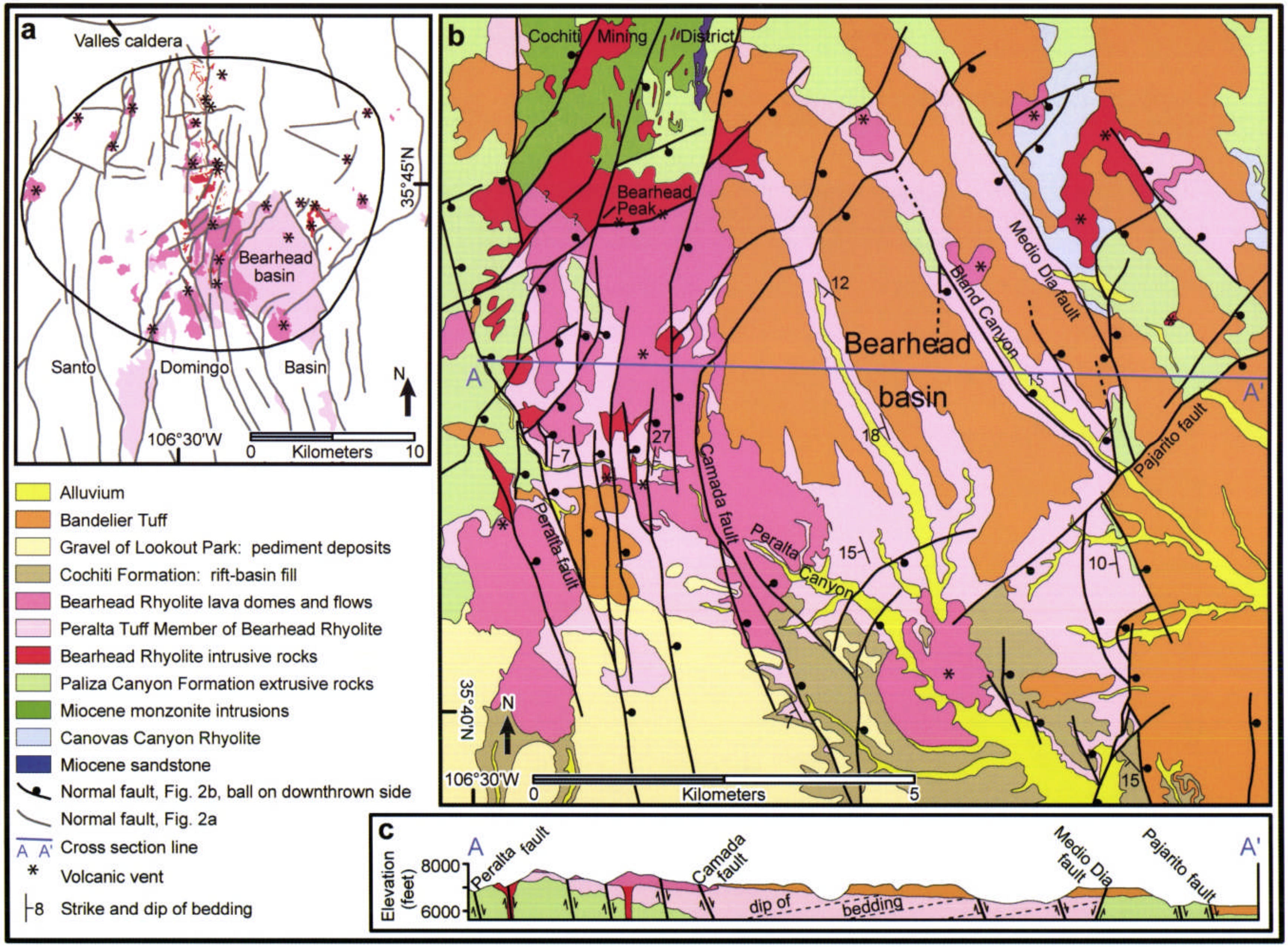
PLATE 11: DISTRIBUTION OF BEARHEAD RHYOLITE AND GEOLOGIC MAP OF THE BEARHEAD BASIN



a. Distribution of Bearhead Rhyolite and faults in the southern Jemez Mountains. Bearhead Rhyolite was erupted along faults and fault intersections above a hypothesized batholith. Modified from Lynch et al. (2005) and Goff et al. (1990, 2005, 2006). **b.** Geologic map of the Bearhead basin. The basin is outlined by north- and northeast-striking faults that enclose a thick fill of Peralta Tuff. Rhyolite was primarily erupted along the western and northwestern margins of the basin. Miocene intrusive rocks are exposed in the uplifted footwall north of the basin. After Lynch et al. (2005). **c.** Cross-section along line A-A'. See article by Smith and Lynch on page 262.