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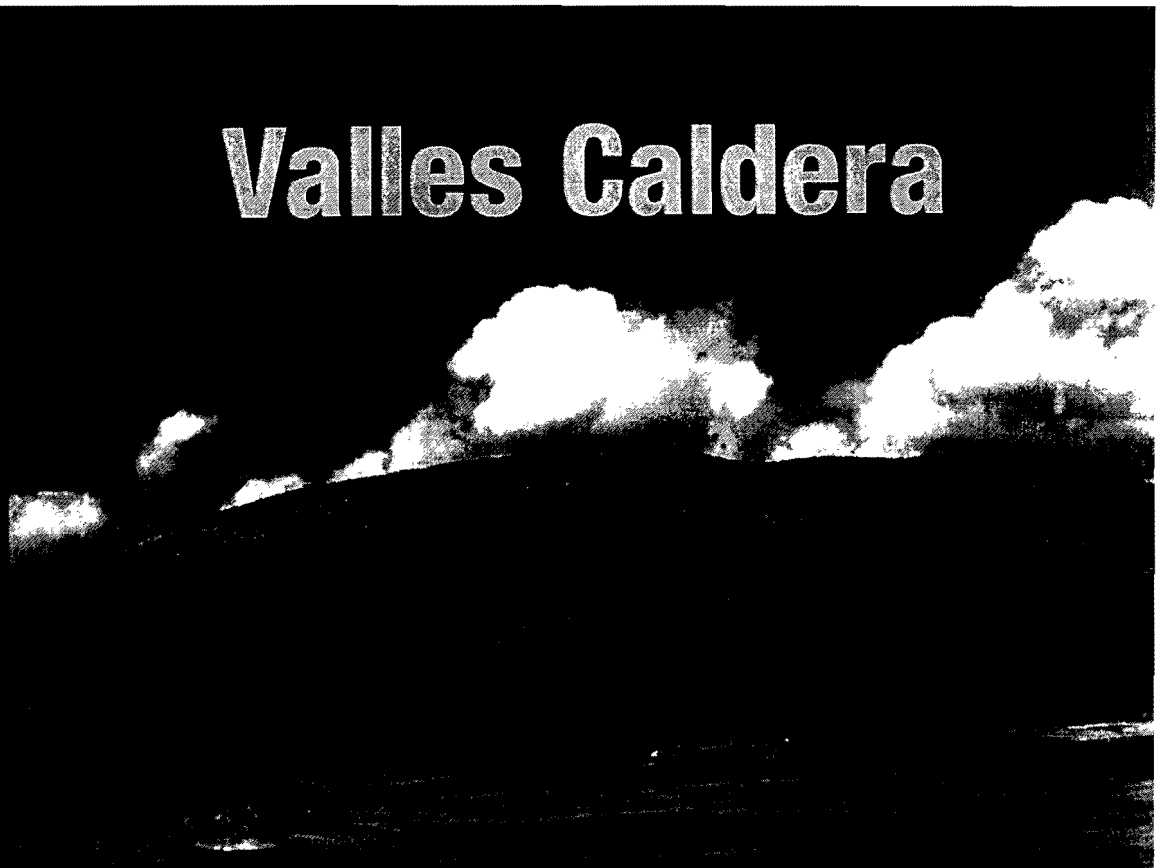
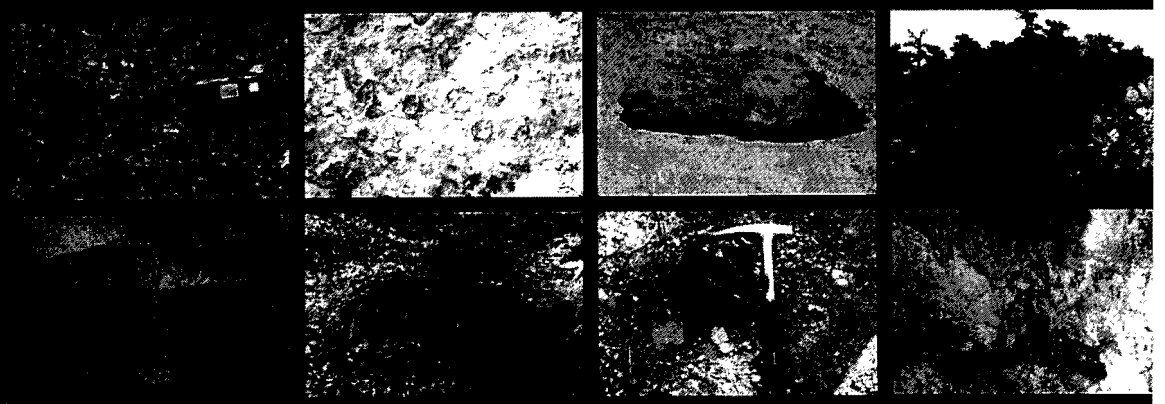
# Valles Caldera



## A GEOLOGIC HISTORY



Fraser Goff

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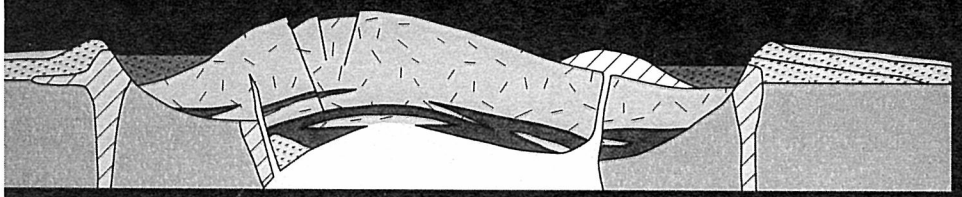
GEOLOGY ■ NEW MEXICO



The Valles Caldera consists of a twelve-mile-wide collapsed volcanic crater and more than ten post-collapse volcanic domes in New Mexico's Jemez Mountains. For over a century, it was safeguarded within the 89,000-acre Baca Ranch. In the year 2000, Congress established the Valles Caldera Trust to purchase the ranch and create a nine-member board of trustees responsible for the protection and development of the Valles Caldera National Preserve.

With special permission, qualified geologists interested in volcanic processes and hydrothermal systems have been allowed to conduct research on the Preserve. One of those volcanologists, Fraser Goff, collaborated with the Valles Caldera Trust to provide an accessible scientific overview of the caldera's geologic wonders.

Presented in two parts, *Valles Caldera* first offers a summary of significant geologic events that have taken place in the Valles Caldera region. Goff then describes the geology, volcanism, and geothermal characteristics of the Caldera and the Jemez volcanic field. Geologic terms and names unfamiliar to all but professional geologists are defined in a summarizing glossary.

■

Fraser Goff is adjunct professor in the Department of Earth and Planetary Sciences at the University of New Mexico. A Fellow of the Geological Society of America, Goff retired from the Geology/Geochemistry Group at New Mexico's Los Alamos National Laboratory in 2004 after twenty-six years of service. Goff has worked on more than forty geothermal systems and fifteen active volcanoes during his LANL career.

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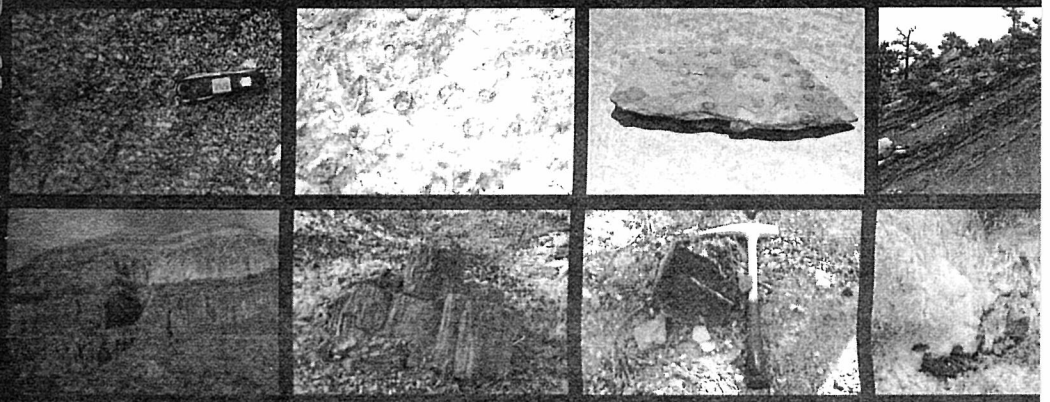
Valles Caldera Fraser Goff

# Valles Caldera

## A GEOLOGIC HISTORY



Fraser Goff

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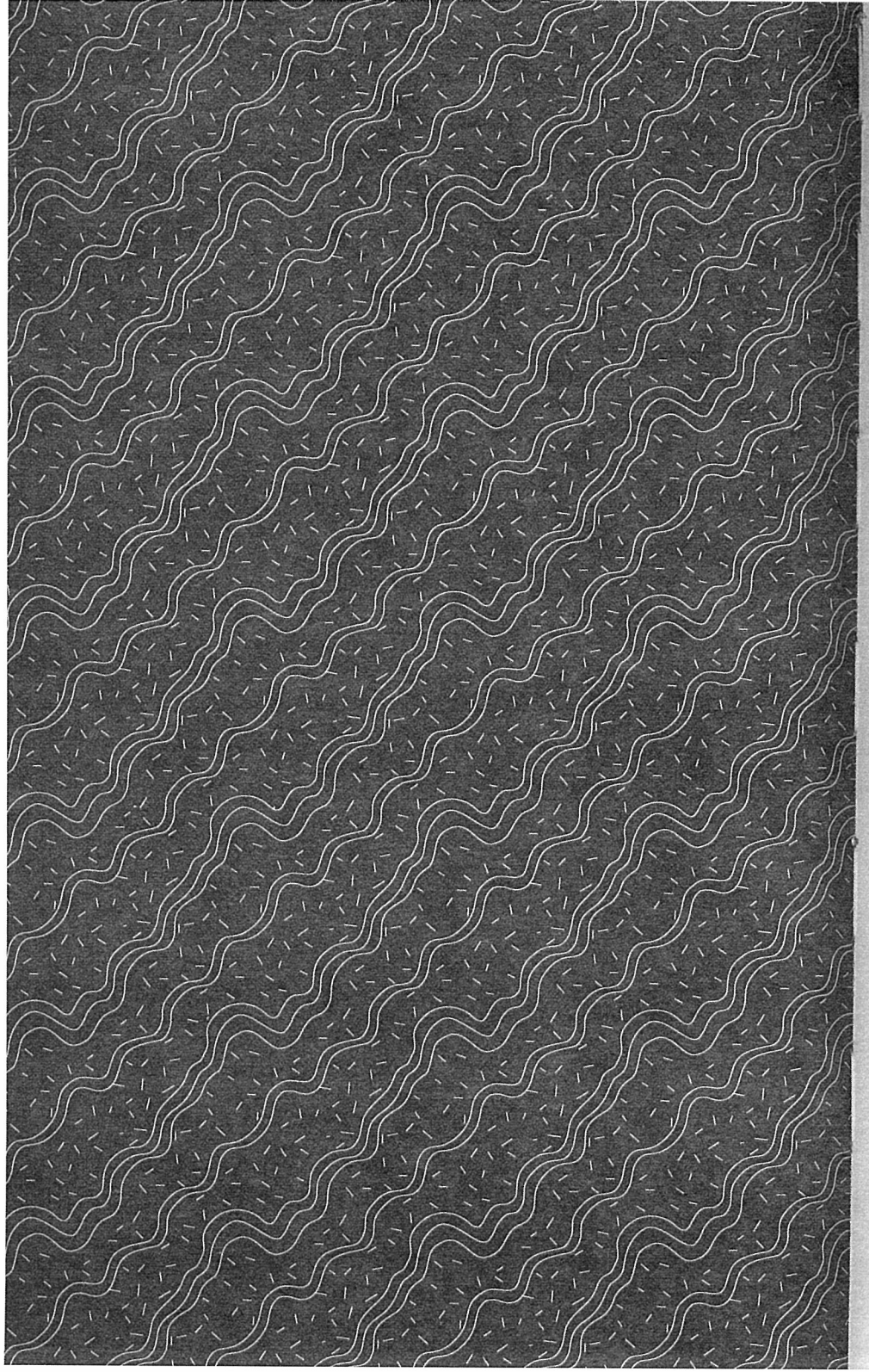

## Jemez Volcanic Field

As mentioned above, the Jemez volcanic field lies at the intersection of the Rio Grande rift and the Jemez lineament, the two youngest and most significant tectonic features in New Mexico (fig. 1). The Jemez volcanic field (fig. 17) contains a diverse collection of basalt, **andesite**, **dacite**, and **rhyolite** erupted as **lava domes** and flows, cinder cones, and a variety of pyroclastic deposits. A multitude of dates bracket the Jemez volcanic field from about 14 Ma to 40 **ka**. The Jemez volcanic field overlies the Colorado Plateau on the west and the Rio Grande rift on the east.

Over the years, many geologists have subdivided the Jemez volcanic field into various groups and formations, based on the age and location of individual eruptive centers (figs. 17, 18). The major groups as of 2008 consist of (oldest to youngest) the Keres Group, the Polvadera Group, and the Tewa Group. Three peripheral basalt fields (El Alto, Cerros del Rio, and Santa Ana Mesa) flank the main Jemez volcanic field on the north, east, and south, respectively. As more research is conducted, these subdivisions will undoubtedly change. In summary, the volcanic history of the volcanic field has evolved as follows:

1. From roughly 25 to 16 Ma, minor basaltic volcanism occurred in sediments of the Santa Fe Group.

2. From about 14 to 7 Ma, there was widespread basaltic volcanism throughout the Jemez Mountains. These basalts, which have several names, depending on location (Lobato Basalt, etc.), often overlie or are interbedded in sedimentary rocks of the Rio Grande rift (fig. 18).

3. From about 10 to 8 Ma, a cluster of rhyolite domes, flows, and associated **tuffs** (Canovas Canyon Rhyolite) was erupted in the southern part of the volcanic field.

4. From about 10 to 7 Ma, large volumes of andesite and subordinate dacite were erupted in the south central part of the volcanic field. This unit (Paliza Canyon Formation) represents the most voluminous period of volcanism,

and it probably produced **composite cones** and volcanic **shields** dotted with numerous domes and cones. Erosion and faulting has since obscured their original shapes.

5. From about 7.6 to 4.5 Ma, a second but larger rhyolitic event, named the Bearhead Rhyolite, occurred in the south and north parts of the volcanic field.

6. From about 10 to 2 Ma, an impressive group of large dacite domes (Tschicoma Formation) and small rhyolite centers (El Rechuelos Rhyolite) erupted in the north and central parts of the field. Tschicoma Peak, Polvadera Peak, and the Sierra de los Valles are part of the Tschicoma Formation (fig. 19).

7. From about 4.0 to 1.5 Ma, three peripheral basaltic centers were constructed around the margins of the volcanic field. The Cerros del Rio includes some andesite and dacite. Note that these basaltic centers formed on the boundary of or within the Rio Grande rift, and that eruptions were probably aided by rift faulting.

8. Toledo caldera, the lower Bandelier Tuff, and associated rhyolites formed and erupted from 1.6 to 1.2 Ma.

9. Valles Caldera, the upper Bandelier Tuff, and associated rhyolites formed and erupted from 1.2 Ma to 40 ka.

Volcanic rocks formed by events 2 though 5 constitute most of what is presently called the Keres Group (figs. 17, 18). Rocks of events 6 and 7 make up the Polvadera Group, and those of events 8 and 9 form the Tewa Group. The above geochronology shows that there is considerable overlap among the various events, **magma** compositions, and styles of eruption. Except for a period from about 7 to 4 Ma, basaltic volcanism is fairly common throughout the history of the Jemez volcanic field. In general, though, magmatic activity has changed from predominately andesitic to predominately rhyolitic through time. In this respect, volcanism in the Jemez Mountains resembles Oligocene–early Miocene volcanism in the San Juan volcanic field (southern Colorado) and in the Mogollon-Datil volcanic field (southwestern New Mexico). It should also be obvious that volcanism has been relatively continuous (in a geologic sense) for the last 14 Myr and that eruptions will probably occur in the Jemez volcanic field in the future.



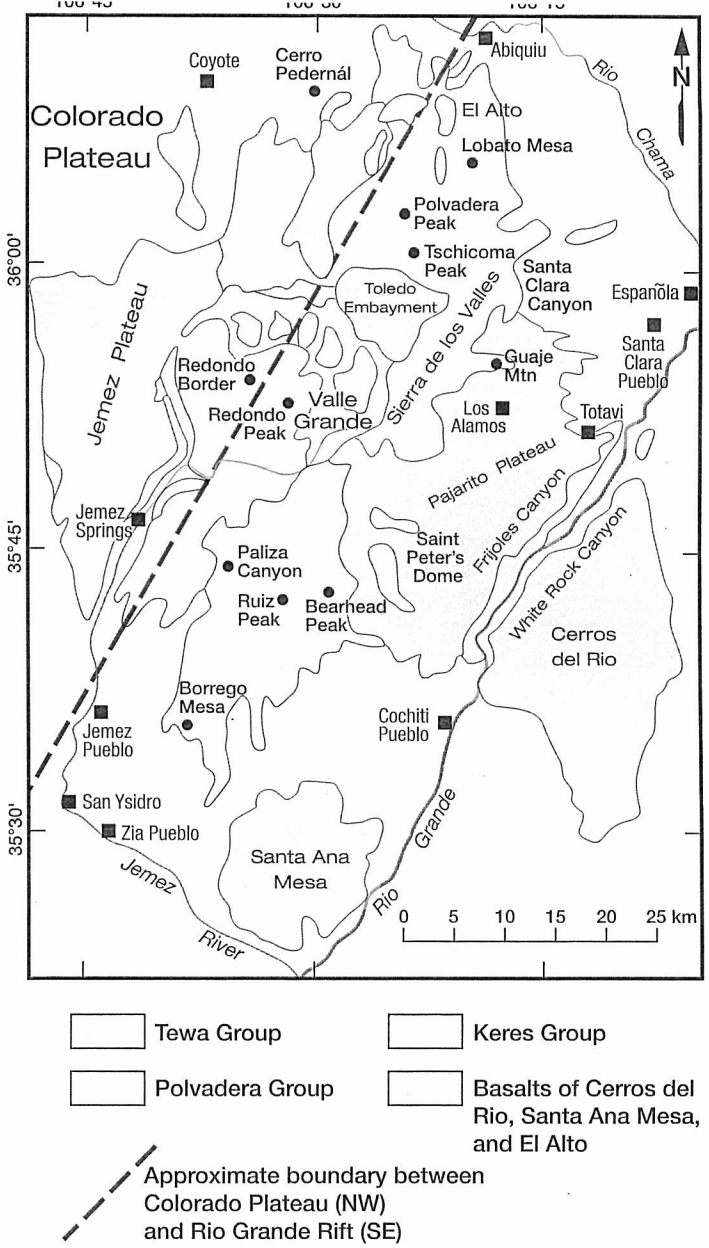


**Figure 17.** Schematic geologic map of the Jemez volcanic field, showing the distribution of the major stratigraphic groups as of 2008. Also shown are the peripheral basalt fields and the approximate boundary between the Colorado Plateau and the Rio Grande rift (modified from Goff and Gardner 2004, p. 297, fig. 3).

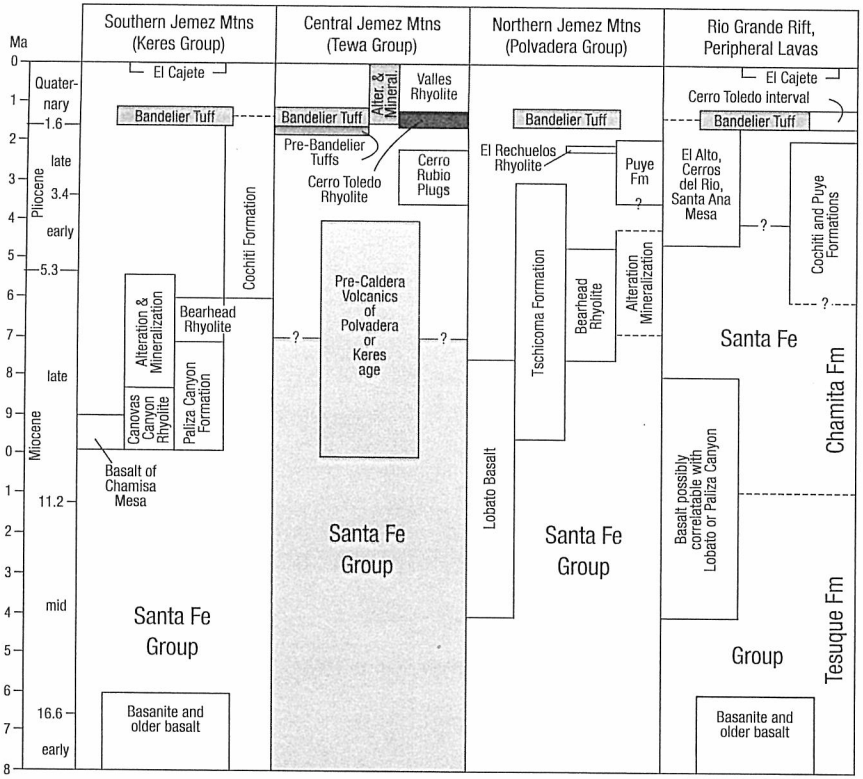


**Figure 18.** Correlation chart of stratigraphic units by subregion within the Jemez volcanic field as of 2008. Rocks of the Keres Group dominate the southern Jemez Mountains; the central Jemez Mountains are composed mostly of rocks of the Tewa Group; and the northern Jemez Mountains are constructed primarily of rocks of the Polvadera Group. In contrast, the Rio Grande rift is filled mostly with basin-fill sedimentary rocks of the Santa Fe Group, subordinate volumes of basaltic lavas from peripheral basalt fields and earlier volcanism, and volcanic sediments derived from the Jemez volcanic field. The only widespread stratigraphic markers throughout the region are the Bandelier Tuff and the Santa Fe Group (modified from Goff and Gardner 2004, p. 299, fig. 5).

This sustained volcanism during a long period of time transferred considerable mass and heat as magmas rose from the mantle and lower crust through the upper crust to the Earth's surface. About 500 mi³ (2000 km³) of magma was erupted during construction of the Jemez volcanic field, roughly equivalent to a pyramid of rock 15 mi square at the base



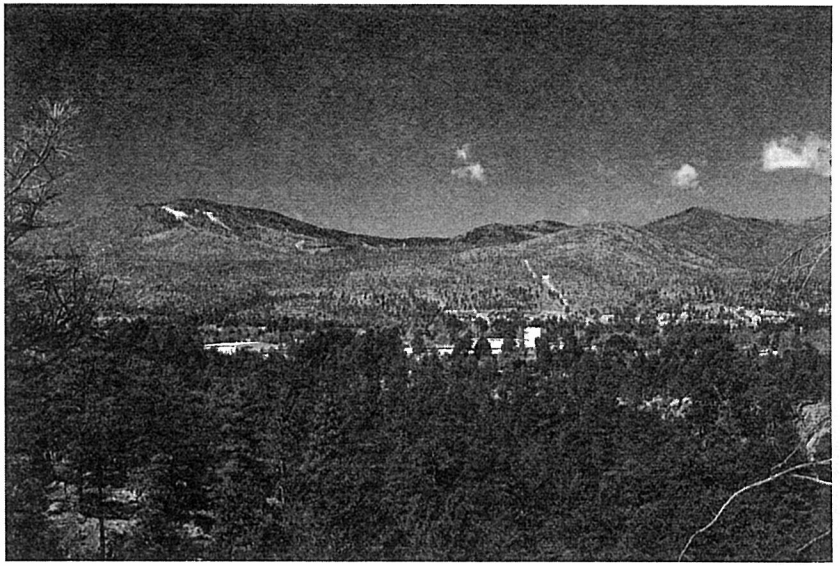

**Figure 19.** Looking across Acid Canyon toward the Sierra de los Valles west of Los Alamos. These large, lumpy mountains are composed mostly of dacite and rhyodacite lavas of the Tschicoma Formation. Volcanic dome on left is Pajarito Mountain (10,440 ft, about 3 Ma); cluster of ridges on right are part of the Rendija Canyon eruptive center (about 4.5 Ma). (Photo by F. Goff.)

and 5.5 mi high (the height of Mount Everest). Much of the heat from these eruptions was emitted to the atmosphere or was absorbed by relatively shallow groundwaters. The active geothermal system inside Valles Caldera (≤600°F) has absorbed heat from relatively young caldera magmatism, but mineralization caused by earlier volcanism and **hydrothermal activity** can be found in older rocks.

The best example of early hydrothermal activity is found in the Cochiti mining district, just northeast of Bearhead Peak in the southeastern Jemez Mountains (fig. 17). In this area, deep canyons have exposed shallow **dikes**, **sills**, and **necks** of andesite and rhyolite intruding slightly older volcanic rocks. The various rocks were altered by ancient hot waters to a variety of orange and green colors from growth of secondary minerals. The rocks became honeycombed with quartz veins (fig. 20). The veins, containing gold and silver with minor copper, zinc, and lead minerals, supported the mining towns of Bland and Albemarle from 1890 to 1916. Other zones of alteration exist in older rocks in canyon bottoms of the

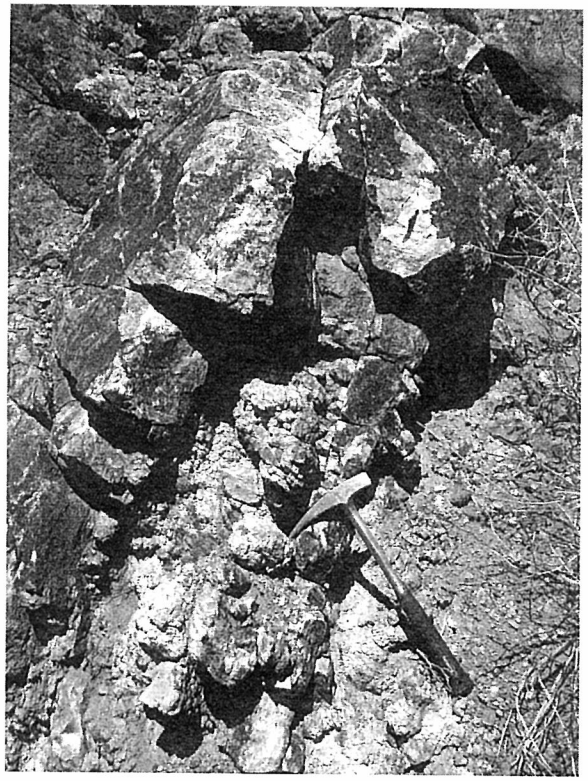

**Figure 20.** One of the many iron-stained quartz veins in the Cochiti mining district, southeast Jemez Mountains. Mined around the turn of the last century, these veins trend mostly to the north and contain small amounts of gold and silver, plus minerals of copper, lead, and zinc. (Photo by F. Goff.)

southern Jemez Mountains and in older rocks along the lower walls of Valles Caldera.

Rapid construction of the Jemez volcanic field during simultaneous development of the Rio Grande rift resulted in stream development and formation of large alluvial fans on the eastern side of the Jemez Mountains. The Cochiti Formation is a large fan complex that developed in the southeastern part of the volcanic field after eruption of the Paliza Canyon Formation and Bearhead Rhyolite (figs. 18, 21). In the northeastern Jemez Mountains, the Puye Formation is a large fan complex derived largely from erosion of the Tschicoma Formation (figs. 22, 23).

By the end of the Pliocene (1.6 Ma), the Jemez volcanic field, including peripheral basalt fields, was elliptical in shape (60 x 48 mi), elongated parallel to the Rio Grande rift. The core of the volcanic field was made of large dacitic dome and flow complexes probably not much higher than



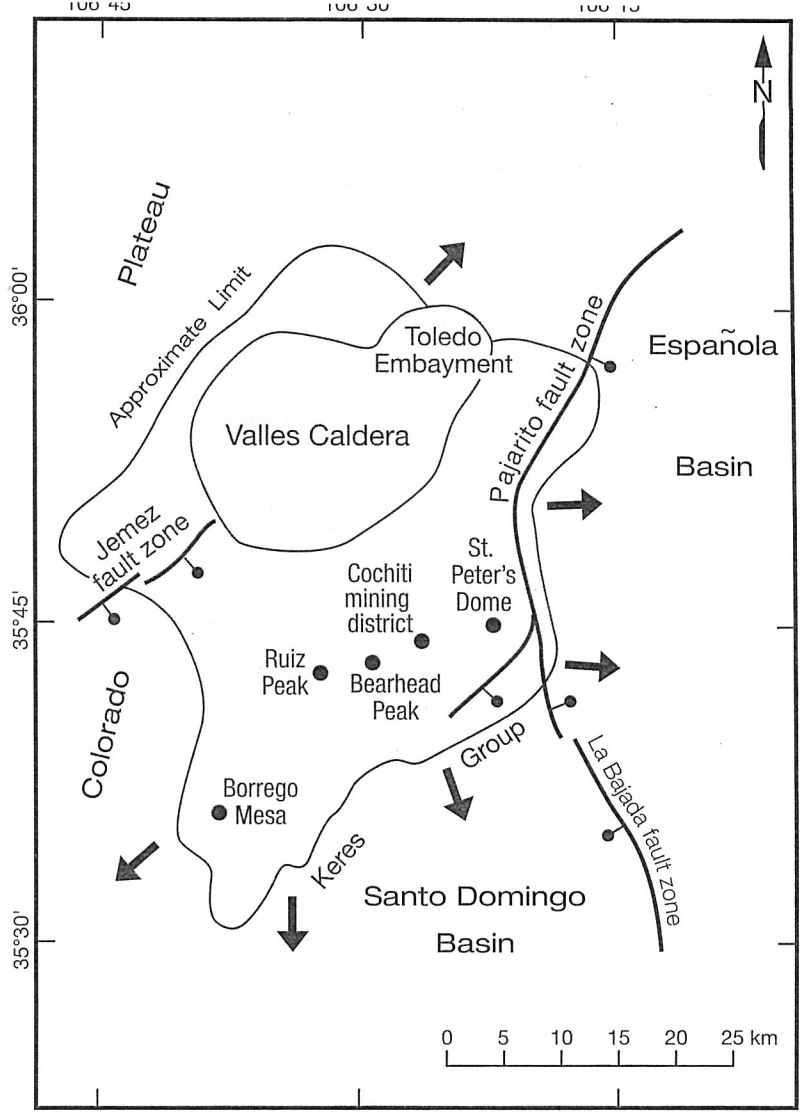


**Figure 21.** Sketch showing distribution and approximate limits of Keres Group rocks (10 to 6 Ma) with respect to the present positions of the Valles Caldera and Toledo embayment. Most Keres Group rocks are found south of the Valles Caldera. During growth of the Keres complex, volcanic debris was shed to the northeast, east, southeast, south, and southwest (shown by arrows), particularly into basins of the evolving Rio Grande rift. Much of the debris in the southeast eventually formed the Cochiti Formation. Comparatively little Keres material was shed onto the Colorado Plateau (modified from Goff and Gardner 2004, p. 300, fig. 6).

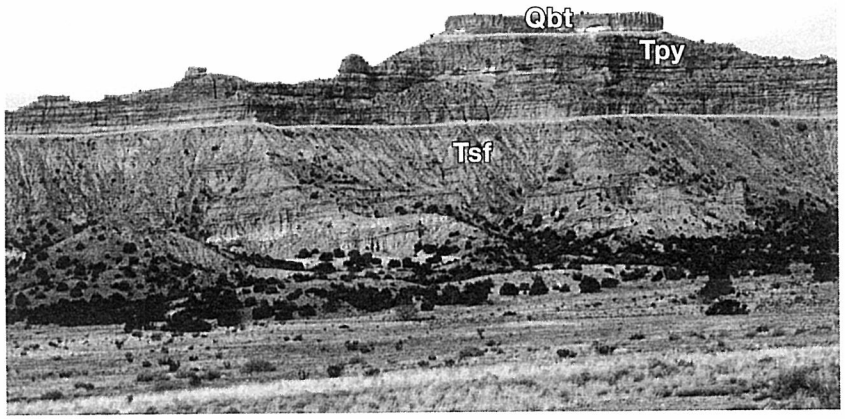


**Figure 22.** Photo of the Pliocene Puye Formation (Tpy), looking west from NM Hwy. 30 (same location as fig. 16). The Puye is an old alluvial fan sequence filling the west margin of the Rio Grande rift and constructed during erosion of dacite domes of the Polvadera Group (fig. 23). In a beautiful example of stratigraphy, the photo shows the Puye overlain by the Quaternary Bandelier Tuff (Qbt; 1.25 Ma) and underlain by the Miocene Chamita Formation of the Santa Fe Group (Tsf). Toward Los Alamos, the Puye overlies basalt lava dated at 2.4 Ma. Thus, the Puye is bracketed between about 2.4 and 1.25 Ma. Note that the Chamita sediments have a steeper dip (to southwest) than the Puye strata. (Photo by F. Goff.)

present Tschicoma Peak (11,600 ft). These domes and flows surmounted an extensive complex of older volcanic rocks that overlapped the Colorado Plateau–Rio Grande rift boundary. Erosion had created drainage systems radiating out of the volcanic field and had developed extensive alluvial fans extending into the western rift.



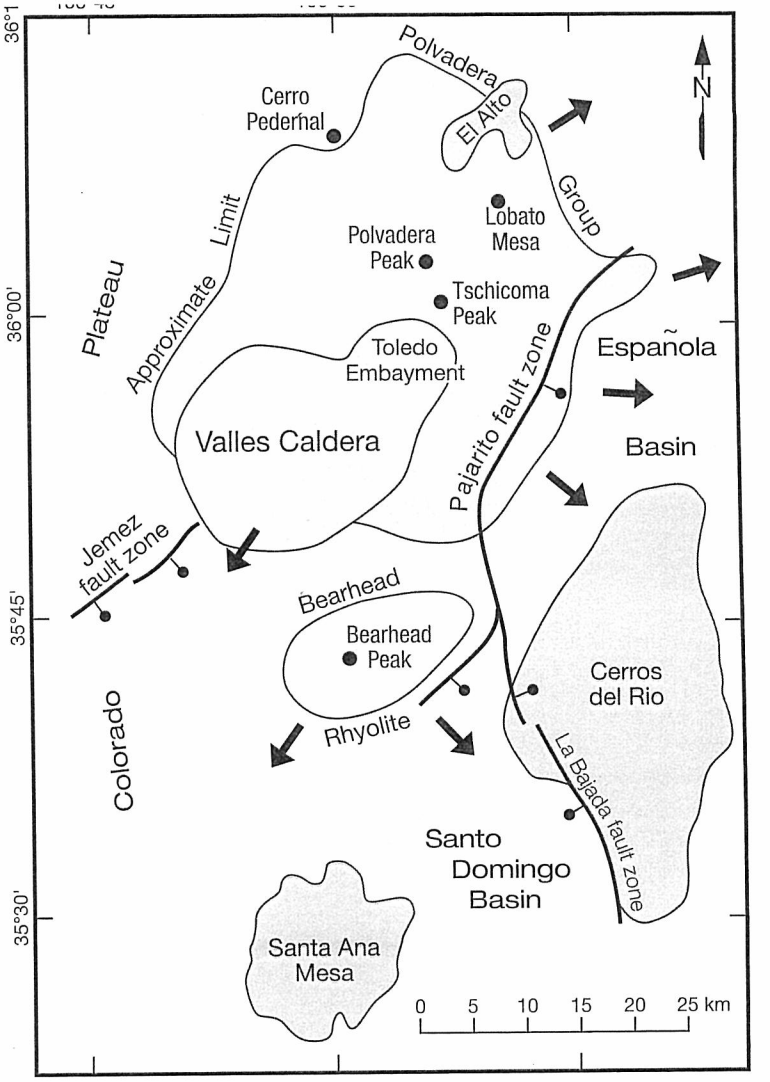


**Figure 23.** Sketch showing distribution and approximate limits of Polvadera Group rocks (14 to 2 Ma) with respect to the present positions of Valles Caldera and the Toledo embayment. Most Polvadera Group rocks were erupted north and east of Valles Caldera. During growth of the Polvadera complex, volcanic debris was shed to the northeast and east into the developing Española Basin. This debris formed much of the Puye Formation. Also shown is the distribution of most of the Bearhead Rhyolite, Keres Group (7.6 to 4.5 Ma). Bearhead rocks, particularly the pyroclastic phases, were shed southeast toward the developing Santo Domingo Basin. Peripheral volcanic fields formed from about 4.6 to 1.6 Ma. Fault labels are the same as in figure 21 (modified from Goff and Gardner 2004, p. 302, fig. 7).