LA-UR-84-1210

Gardner and Goff
1984
ER ID # 44021

(31)

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: POTASSIUM-ARGON DATES FROM THE JEMEZ VOLCANIC FIELD: IMPLICATIONS FOR TECTONIC ACTIVITY IN THE NORTH-CENTRAL RIO GRANDE RIFT

AUTHOR(S): Jamie N. Gardner and Fraser Goff, ESS-1

SUBMITTED TO: New Mexico Geological Society Guidebook, 35th Annual Field Conference

Received by ER-RPF
FEB 02 1995

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed

7345

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

POTASSIUM-ARGON DATES FROM THE JEMEZ VOLCANIC FIELD: IMPLICATIONS FOR TECTONIC ACTIVITY IN THE NORTH-CENTRAL RIO GRANDE RIFT

By: Jamie N. Gardner and Fraser Goff, Earth and Space Sciences Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Submitted to: New Mexico Geological Society Guidebook
35th Annual Field Conference, 1984

INTRODUCTION

Volcanism in the Jemez Mountains has been intimately related to mid-Miocene through Quaternary tectonic activity of the Rio Grande Rift (i.e., tectonic activity following the mid-Miocene volcanic hiatus of Chapin and Seager, 1975). Recent work in the volcanic field (Gardner, 1982; 1983; 1984) has shown that tectonic activity has had a major influence on the dominant magmatic processes that were operative during various episodes of the volcanic field's development. In this paper we integrate the petrologic conclusions of Gardner (1984) and Loeffler (1984) with new and existing radiometric dates, and propose a model for the development of the volcanic field that has bearing on the tectonic evolution of the north-central portions of the Rio Grande Rift (see Fig. 1).

OUTLINE OF GEOLOGY AND PETROGENESIS

The stratigraphy of the volcanic and volcaniclastic rocks of the Jemez Mountains as defined by Bailey and others (1969) and Smith and others (1970) and modified by Gardner (1984) is shown in Figure 2. Gardner (1984) has concluded that the Keres Group, which comprises nearly half the volume of the entire volcanic field, consists of rocks derived from magmas from two distinct sources: the upper mantle and the lower crust. Mafic magmas derived from the upper mantle differentiated through a broad spectrum of compositions, but gave rise to about 1000 km^3 of two pyroxene andesite. Magmas derived by partial melting of lower crust produced relatively minor volumes of chemically distinctive high silica rhyolite. Keres Group volcanism was accompanied by intense rifting, as suggested by field relations of mafic-intermediate rocks interbedded with widespread deposits of lahars and immature basin-fill gravels

of the Cochiti Formation, and fault control of the locations of high silica rhyolite vents.

Gardner (1982; 1983; 1984) and Loeffler (1984) have suggested that the best model for the genesis of the Tschicoma Formation, whose latites and quartz latites volumetrically dominate the 500 km^3 Polvadera Group (J.D. MacGregor, National Science Foundation, pers. comm., 1981), involves mixing of mafic and silicic magmas. End member compositions for this mixing are approximated by basalt or basaltic andesite and high silica rhyolite of the Keres Group. Smith and others (1970) indicate a paucity of faults in the Tschicoma Formation, and no apparent relations of vent locations to faults. While volcaniclastic debris derived from the Polvadera Group formed deposits of substantial volume (Puye Formation) further east in the Española Basin, field reconnaissance indicates virtually no significant basin-fill deposits intercalated with the Polvadera volcanic pile. Petrologic models of Gardner (1983; 1984) further suggest that Tschicoma volcanism occurred in a period of relative tectonic inactivity (see Summary and Discussion).

Mantle-derived magmas erupted peripheral to the main body of the volcanic field on the south, east, and north as the basalt fields of Santa Ana Mesa, Cerros del Rio, and El Alto, respectively (Smith and others, 1970; Baldridge, 1979). Tewa Group volcanism, dominated by the rhyolitic Bandelier Tuff, provided the culminating phase of the development of the Jemez Volcanic Field. Greater than 500 km^3 of tuff erupted from a large, zoned magma chamber whose bulk composition was probably identical to Tschicoma latitic compositions (Smith, 1979; Self and others, in prep.). Spatial and temporal overlap of Bandelier magma and Tschicoma-like latite eruptions supports this suggestion for the probable bulk composition of the Bandelier magma chamber, and strongly suggests parental relations of the Tschicoma Formation to the Tewa Group

(Doell and others, 1968; Smith and others, 1970; Smith, 1979; Gardner, 1983; 1984; Self and others, in prep.).

POTASSIUM-ARGON DATES

Twenty new potassium-argon dates (Table 1) have been obtained to constrain Keres Group volcanism, representative of the earliest episode of Jemez volcanic actitity. Sample F81-50, a basanite from a sequence of alkali basalts interbedded with lower Santa Fe Group arkosic sediments east of St. Peter's Dome, has yielded the oldest date in the area of 16.5 ± 1.4 m.y. (see Table 1). While these basalts are probably not petrogenetically related to volcanism in the Jemez Volcanic Field, they may be indicative of episodes of revived rifting that initiated and enabled development of the volcanic field (Gardner, 1984; see also Manley, 1979, and Manley and Mehnert, 1981). Field relations together with the data of Table 1 (samples JG80-53 and F82-108) indicate Keres Group volcanic activity began >13 m.y. ago. Keres Group volcanism apparently waned by about 6 m.y. ago (samples JG80-49, JG81-62, F82-77, and F82-117, Table 1), and overlapped with early Tschicoma Formation volcanism.

A compilation of approximately ninety-five available dates from the Jemez Volcanic Field and nearby areas is tabulated in Table 2. Figure 3 is a graphic depiction of the compilation of dates plotted with respect to predominant petrogenetic magma type as outlined above. A number of features of Figure 3 are particularly noteworthy, as follows:

1. While mantle-derived basaltic magmas were erupted spanning the volcanic field's entire >13 m.y. history, there was a gap in basaltic volcanism in the period 7-4 m.y. ago. Those mantle-derived basalts that were erupted after the 7-4 m.y. ago lull in basaltic volcanism

are the basalts of Santa Ana Mesa, Cerros del Rio, and El Alto which are distinctly peripheral to and partially encircle the main body of the volcanic field (Fig. 4). Earlier basaltic volcanism in the period >13-7 m.y. ago comprises the basalts of the Paliza Canyon Formation and the Lobato Basalt of the Keres and Polvadera groups, respectively (Fig. 2 and Table 2).

2. Magmas derived by differentiation of mantle-derived material were erupted early in the volcanic field's history, in the period >10-7 m.y. ago. These magmas are predominantly represented by the andesites and less voluminous latites of the Paliza Canyon Formation of the Keres Group (Table 2).

3. High silica rhyolite magmas, derived by partial melting of lower crust, were continuously erupted in the period >13-6 m.y. ago, early in the field's history. These crustal partial melts are the tuffs and domes of the Canovas Canyon and Bearhead rhyolites of the Keres Group.

4. Latites, quartz latites, and dacites formed by mixing of basalt or basaltic andesite and high silica rhyolite magmas began to be erupted at about 7 m.y. ago, the same time as the beginning of the 7-4 m.y. ago lull in basaltic volcanism, mentioned in (1), above. Furthermore, the onset of the eruption of these mixed latites and dacites was essentially contemporaneous with the cessation of eruption of differentiates of basalt (Paliza Canyon intermediate rocks) and the high silica rhyolites discussed in (2) and (3) above, respectively.

5. The onset of Tewa Group volcanism ("Bandelier cycles") was essentially contemporaneous with the revival of basaltic volcanism at

about 4 m.y. ago, discussed in (1), above, and overlapped with the waning eruptions of mixed magmas discussed in (4), above.

FAULT ZONES

Figure 4 shows the four major fault zones in the immediate vicinity of the Jemez Volcanic Field as the Jemez, Santa Ana Mesa, Pajarito, and older rift-bounding fault zones. The older rift-bounding and Santa Ana Mesa fault zones are commonly referred to as a single zone, also known as the San Felipe fault zone. Gardner (1984), however, distinguishes two fault zones based on age and sense of displacement: the Santa Ana Mesa fault zone is the active eastern boundary of the Albuquerque Basin, south of the Jemez Mountains, and the older rift-bounding zone is the inactive (see below) western boundary of the Española Basin, east of and containing the Jemez Mountains. While all fault zones shown in Figure 4, except the older rift-bounding zone, are currently seismically active (Cash and others, 1982), most important to this discussion are the Pajarito and older rift-bounding zones.

The older rift-bounding fault zone is a broad swath of north-trending normal faults that cuts Keres Group rocks in the southern Jemez Mountains. The fault zone is obliterated by the Valles Caldera, but is exposed in Mesozoic-Tertiary rocks north of a paleo-valley, eroded along the faults and filled with unfaulted Bandelier Tuff (dotted fault in Fig. 4) (Smith and others, 1970; Lawrence, 1979). Most faults in this older rift-bounding fault zone have a down-to-the-east sense of displacement. Because Keres Group volcanic and volcaniclastic deposits are both cut by faults of this zone and thicken to the east across the fault zone, these faults were active during Keres Group volcanism. Rhyolites of the Canovas Canyon and Bearhead

formations are intruded along these faults, but commonly the Bearhead domes (see Table 2) are not themselves faulted. Hence, faults of this zone originally represented the western boundary of the Española Basin of the Rio Grande Rift, and became inactive sometime prior to about 6 m.y. ago.

The Pajarito Fault Zone is a narrow band of north-trending and northeast-trending normal faults (Griggs, 1964; Smith and others, 1970; Golombek, 1981) which, we suggest, defines the present western boundary of the Española Basin of the Rio Grande Rift. A very deep part of the Española Basin is adjacent to this fault zone, as suggested by more than 1500 m of basin-fill sediments immediately east of the fault zone (Bussing, 1978; Cordell, 1978; Goff and Grigsby, 1982). Faults of this zone show predominantly down-to-the-east sense of displacement, and evidence of episodic or multiple faulting events, indicated by progressively larger amounts of offset in older rock units (Griggs, 1964). The Pajarito Fault Zone offsets 1.1 m.y. Bandelier Tuff more than 100 m, and, as mentioned above, is currently seismically active. Based in part on the work of Manley (1976a; 1979) in the northern Española Basin, Golombek (1981; 1983) and Golombek and others (1983) have suggested the Pajarito Fault Zone became active sometime since about 5 m.y. ago. Thus, fault activity bounding the western margin of the Española Basin apparently shifted from the older rift-bounding fault zone, discussed above, to the Pajarito Fault Zone sometime since roughly 6-5 m.y. ago.

The northeast-trending segment of the Pajarito Fault Zone southeast of St. Peter's Dome appears to be older than portions of the fault zone further north, and is probably not directly related to the Española Basin (Fig. 4). Movements on this segment of the fault have caused tilting of large blocks northwest of the fault trace with increasing amounts of tilt in progressively older rock units (Smith and others, 1970). Eocene Galisteo Formation rocks

dip 25-45° NW, Santa Fe Group deposits dip 5-15° NW, and lower Keres Group rocks dip ≤10° NW (Gardner, 1984; Goff, in prep.), indicating this segment of the Pajarito Fault Zone is at least older than lower Santa Fe Group deposits in this locality (>16.5 m.y. ago, see sample F81-50 in Table 1). The northeast trend and substantially older age than portions of the fault zone further north suggest this segment of the Pajarito Fault Zone may be associated with the northeast-trending Santo Domingo Basin. Alternatively, this older, northeast-trending segment of the fault zone may reflect the structural grain imparted to the area by the Jemez Lineament, which is locally manifested as the Jemez Fault Zone, resurgent and subsurface structures in Valles Caldera, and the Toledo embayment (Fig. 4) (Smith and others, 1970; Goff and Kron, 1980; Goff and Gardner, 1980; Goff, 1983; Gardner, 1983; 1984; Self and others, in prep.).

SUMMARY AND DISCUSSION

Following the mid-Miocene volcanic hiatus of Chapin and Seager (1975), revived rifting in the vicinity of the Jemez Mountains began about 16.5 m.y. ago as indicated by the age of the basanite within the lower Santa Fe Group (sample F81-50, Table 1) and the age of the northeast-trending segment of the Pajarito Fault Zone near St. Peter's Dome. From 13-10 m.y. ago tectonic activity was probably intense. Basalts and high silica rhyolites were vented during this period along faults of the older rift-bounding zone, and are interbedded with immature basin-fill gravels and lahars of the Cochiti Formation. Cochiti Formation deposits thicken [illegible]tically from west to east into the rift across the older rift-boun[illegible] zone. In the period 10-7 m.y. ago basalt, high silica rhyolite, a[illegible]tiates of basalt were rapidly vented

(Fig. 5) because open conduits were provided by on-going extension across the older rift-bounding fault zone. Golombek and others (1983) suggest that intense tectonic activity in the area occured somewhere around 10 m.y. ago, which, for the most part agrees with our inferences from field relations and the fact that more than half the volume of the entire volcanic field was erupted during the brief 3 m.y. period 10-7 m.y. ago (Fig. 5).

At about 7-6 m.y. ago basalt, differentiates of basalt, and high silica rhyolite stopped being erupted, mixed magmas began to be erupted, and there was a sharp reduction in the "rate" of volcanic activity (Fig. 5). At about this same time, the beginning of the 7-4 m.y. ago lull in basaltic volcanism occurred, and the older rift-bounding fault zone became inactive. Furthermore, the 7-4 m.y. ago lull in basaltic volcanism has been noted elsewhere in or near the rift (Baldridge and Perry, 1983; A. W. Laughlin, Los Alamos National Laboratory, pers. comm., 1983) and may be indicative of events of regional significance. We suggest, because of the intimate association of basaltic volcanism and intense tectonism earlier in the volcanic field's history, that the gap in basaltic volcanism is indicative of a lull in tectonic activity. Gardner (1983; 1984) asserts that the reduction in the rate of volcanic activity and the petrogenetic transition from differentiates of basalt to hybrid latites at about 7 m.y. ago reflect a change in the dominant magmatic processes in response to the tectonic lull. Instead of being rapidly vented, as in earlier more tectonically active stages of the field's development, pockets of basalt or basaltic andesite began to coalesce with pockets of high silica rhyolite, and continued to grow into large magma chambers, from which small portions were erupted as hybrid latitic lavas.

Manley (1976a; 1979) suggests intense faulting in the period 5-3 m.y. ago in the Velarde Graben in the northern Española Basin, and Golombek (1981; 1983) and Golombek and others (1983) estimate that the Pajarito Fault Zone became active around 5 m.y. ago. As a refinement of this estimate, we suggest that rift-bounding activity shifted from the older rift-bounding zone to the north-trending part of the Pajarito Fault Zone at about 4 m.y. ago. This shift of rift-bounding faulting was probably caused by the development of the large, hybrid magma chambers, centrally located beneath the main body of the volcanic field, during the 7-4 m.y. ago tectonic lull. Renewed basaltic volcanism at about 4 m.y. ago, enabled by revived tectonic activity, gave rise to the basalt fields that are peripheral to and partially encircle the main body of the volcanic field. The peripheral positions of these young basalt fields also may indicate the existence of the large magma chambers beneath the center of the volcanic field. Tectonic activity has continued from about 4 m.y. ago to the present, accompanied by the voluminous eruptions of Bandelier Tuff from the large, hybrid magma chambers.

Certain aspects of our model, outlined above, have bearing on or are not in agreement with statements that appear in the literature; therefore, further discussion is deserved:

(1) Golombek's (1981; 1983) model for the tectonic evolution of the Española Basin involves a buried graben in the central Española Basin, east of the Pajarito Fault Zone, to account for the apparent discrepancy between estimates of maximum offset on the Pajarito Fault Zone and the tremendous thickness of basin-fill material immediately adjacent to the fault, as indicated by various geophysical studies. Golombek (1981; 1983) cites the gravity interpretation of Budding (1978), and Golombek and others (1983) cite the gravity model of

Cordell (1979) for evidence of this hidden graben. Other geophysical studies in the same area (detailed gravity by Williams, 1979; seismic reflection by E. F. Momuth, Los Alamos National Laboratory, pers. comm., 1979; see also summary in Goff and Grigsby, 1982, and Cordell, 1979, profile C-C') do reveal intrabasin faults, but do not corroborate the existence of a large, buried graben. Furthermore, scrutiny of Budding's (1978) interpretive cross-sections reveals that the position of the Pajarito Fault Zone is plotted incorrectly: the gravity low ("buried graben") is not some distance east of the Pajarito Fault Zone, it is bounded by the fault zone on the west. Our work indicates that displacement across the older rift-bounding fault zone together with post-4 m.y. ago displacement on the Pajarito Fault Zone can adequately accommodate the 1500 m of basin-fill sediment immediately east of the Pajarito Fault Zone. Hence, tectonic activity prior to 10 m.y. ago was probably not restricted to central parts of the Española Basin, but rather was concentrated within the older rift-bounding fault zone, defining the western boundary of the basin.

(2) Golombek and others (1983) present rates of extension for the Española Basin which, in light of the new K-Ar dates presented herein and our evidence for episodic rifting for >16.5 m.y., are probably unrealistic. Golombek and others (1983) also provide an estimate of about 10 percent total extension across the basin. It is not clear from their discussion what data were used to generate this estimate, but if they did not include the movements on the older rift-bounding fault zone, as may be inferred from the discussion of the "buried graben," above, their estimate is much less than a minimum.

(3) Golombek (1981; 1983) states that the Galisteo, Santa Fe, and Keres deposits are uniformly tilted. He constrains tilting to 7.5 m.y. ago, and concludes, because this is greater than his estimate of the age of the Pajarito Fault Zone, that movements on the Pajarito could not have been responsible for the tilting. He mentions "faults defining the western margin of the Española Basin" as probably being responsible for the tilting; however, units between the western margin of the basin and the Pajarito Fault Zone (with the obvious exception of the tilted units immediately adjacent to and west of the Pajarito zone) are largely horizontal or have, at the most, depositional dips. As discussed above (see Fault Zones), the contacts between the Galisteo, Santa Fe, and Keres deposits along the northeast-trending segment of the Pajarito Fault Zone near St. Peter's dome are not conformable, and progressively older units have larger dips. Our detailed mapping is independently corroborated by the regional map of Smith and others (1970). Thus, not all of the Pajarito Fault Zone is the same age, and movements on portions of the Pajarito are responsible for some tilting in the area from >16.5 m.y. ago.

(4) Golombek (1981; 1983) suggests that the position of the Pajarito Fault Zone is controlled by the location of an abrupt facies change from volcanic to volcaniclastic rocks. It is improbable that these deposits, which constitute a thin veneer relative to the sequence of units cut by the fault zone and the minimum depth of penetration of the fault (see, for example, Goff and Grigsby, 1982), could control the position of the fa[illegible] suggest, instead, that the development of large, hybrid magma [illegible]ers within the crust beneath the center

of the volcanic field, caused a shift in basin-bounding faulting from the older rift-bounding zone to the Pajarito zone with revived tectonism at about 4 m.y. ago.

(5) Finally, the period of time that we suggest as a tectonic lull (7-4 m.y. ago) is the precise period that is widely cited as one of rapid uplift throughout the Rio Grande Rift (for example, Chapin, 1979). The works of Axelrod and Bailey (1976), Taylor (1975), and Scott (1975) are cited in support of rapid uplift occurring 7-4 m.y. ago; however, these authors only state that uplift in the Rio Grande region must have occurred sometime since 7 m.y. ago. Manley (1979) presents evidence that relatively intense faulting occurred in the Velarde Graben in the northern Española Basin sometime during the period 5-3 m.y. ago. Our suggestion of the 7-4 m.y. ago tectonic lull is, therefore, consistent with and/or supported by the works of Axelrod and Bailey (1976), Scott (1975), Taylor (1975), and Manley (1979).

ACKNOWLEDGMENTS

This work has been supported by the U. S. Department of Energy's Office of Basic Energy Science and Division of Geothermal Energy, and the University of California's Institute of Geophysics and Planetary Physics. We thank Dan Krummenacher and Donna Martin of San Diego State University, and Geochron Laboratories for providing the potassium-argon dates. Our collegues Scott Baldrige, Kim Manley, Bill Laughlin, Frank Perry, Mat Golombek, Bruce Loeffler, Bob Riecker, and Roy Bailey have provided encouragement, discussions, and/or data.

REFERENCES

Axelrod, D. I., and Bailey, H. P., 1976, Tertiary vegetation, climate, and altitude of the Rio Grande depression, New Mexico-Colorado: Paleobiology, v. 2, p. 235-254.

Bachman, G. O., and Mehnert, H. H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America Bulletin, v. 89, p. 283-292.

Bailey, R. A., Smith, R. L., and Ross, C. S., 1969, Stratigraphic nomenclature of volcanic rocks in the Jemez Mountains, New Mexico: U. S. Geological Survey Bulletin, 1274-P, 19 p.

Baldridge, W. S., 1979, Petrology and petrogenesis of basaltic rocks from the central Rio Grande Rift, New Mexico, and their relation to rift structure: in Riecker, R. E., ed., Rio Grande Rift: tectonics and magmatism: American Geophysical Union, Washington D. C., Special Publication, p. 323-353.

_____, and Perry, F. V., 1983, Spatial and temporal patterns of late Cenozoic basaltic volcanism of the central Rio Grande Rift area: EOS, Transactions of the American Geophysical Union, v. 64, no. 45, p. 753.

_____, Damon, P. E., Shafiqullah, M., and others, 1980, Evolution of the central Rio Grande Rift: new potassium-argon ages: Earth and Planetary Sciences Letters, v. 51, p. 309-321.

_____, Bartov, Y., and Kron, A., 1983, Geologic map of the Rio Grande Rift and southeastern Colorado Plateau, New Mexico and Arizona: supplement to Riecker, R. E., ed., Rio Grande Rift: tectonics and magmatism: American Geophysical Union, Washington D. C., Special Publication, scale 1:500,000.

Budding, A. J., 1978, Gravity survey of the Pajarito Plateau, Los Alamos and Santa Fe counties, New Mexico: Los Alamos Scientific Laboratory report LA-7419, 15 p.

Cash, D. J., Olsen, K. H., McFarland, N. J., and others, 1982, Earthquake catalog for northern New Mexico: Los Alamos National Laboratory report LA-9467-PR, 20 p.

Chapin, C. E., 1979, Evolution of the Rio Grande Rift: a summary: in Riecker, R. E., ed., Rio Grande Rift: tectonics and magmatism: American Geophysical Union, Washington D. C., Special Publication, p. 1-6.

_____, and Seager, W. R., 1975, Evolution of the Rio Grande Rift in the Socorro and Las Cruces areas: New Mexico Geological Society Guidebook, Las Cruces Country, 26th field conference, p. 297-322.

Cordell, L., 1978, Regional geophysical setting of the Rio Grande Rift: Geological Society of America Bulletin, v. 89, p. 1073-1090.

_____, 1979, Gravimetric expression of graben faulting in Santa Fe County and the Española Basin, New Mexico: New Mexico Geological Society Guidebook, Santa Fe Country, 30th field conference, p. 59-64.

Dalrymple, G. B., 1979, Critical tables for conversion of K-Ar dates from old to new constants: Geology, v. 7, p.558-560.

_____, Cox, A., Doell, R. R., and others, 1967, Pliocene geomagnetic polarity epochs: Earth and Planetary Science Letters, v. 2, p. 163-173.

Doell, R. R., Dalrymple, G. B., Smith, R. L., and others, 1968, Paleomagnetism, potassium-argon ages, and geology of rhyolites and associated rocks of the Valles Caldera, New Mexico: Geological Society of America, Memoir 116, p. 211-248.

Gardner, J. N., 1982, Petrogenesis of the Jemez Mountains Volcanic Field: EOS, Transactions of the American Geophysical Union, v. 63, p. 1131.

_____, 1983, Tectonic controls of petrogenesis, Jemez Volcanic Field, New Mexico: Geological Society of America, abstracts with programs, v. 15, no. 5, p. 380-381.

_____, 1984, Tectonic and petrologic evolution of the Keres Group: implications for the development of the Jemez Volcanic Field, New Mexico: University of California, Davis, Ph.D. dissertation, (in prep.).

Goff, F., 1983, Subsurface structure of Valles Caldera: a resurgent cauldron in northern New Mexico: Geological Society of America, abstracts with programs, v. 15, no. 5, p. 381.

_____, and Gardner, J. N., 1980, Geologic map of the Sulphur Springs area, Valles Caldera geothermal system, New Mexico: Los Alamos Scientific Laboratory report, LA-8634-MAP, scale 1:5000.

_____, and Grigsby, C. O., 1982, Valles Caldera geothermal systems, New Mexico, U. S. A.: Journal of Hydrology, v. 56, p. 119-136.

_____, and Kron, A., 1980, In-progress geologic map of Cañon de San Diego, Jemez Springs, New Mexico, and lithologic log of Jemez Springs geothermal well: Los Alamos Scientific Laboratory report, LA-8276-MAP, scale 1:12000.

Golombek, M. P., 1981, Structural analysis of the Pajarito Fault Zone in the Española Basin of the Rio Grande Rift, New Mexico: University of Massachusetts, Amherst, Ph.D. dissertation, 129 p.

_____, 1983, Geology, structure, and tectonics of the Pajarito Fault Zone in the Española Basin of the Rio Grande Rift, New Mexico: Geological Society of America Bulletin, v. 94, p. 192-205.

_____, McGill, G. E., and Brown, L., 1983, Tectonic and geologic evolution of the Española Basin, Rio Grande Rift: structure, rate of extension, and relation to the state of stress in the western U. S.: Tectonophysics, v. 94, p. 483-507.

Griggs, R.L., 1964, Geology and groundwater resources of the Los Alamos area, New Mexico: U. S. Geological Survey Water-supply Paper 1753, 107 p.

Lawrence, J. R., 1979, Geology of the Cerro del Grant area, Rio Arriba County, north-central New Mexico: University of New Mexico, M. S. thesis, 131 p.

Luedke, R. G., and Smith, R. L., 1978, Map showing distribution, composition, and age of late Cenozoic volcanic centers in Arizona and New Mexico: U. S. Geological Survey Miscellaneous Investigations Series Map I-1091-A.

Loeffler, B. M., 1984, Major- and trace-element and strontium- and oxygen-isotope geochemistry of the Polvadera Group, Jemez Volcanic Field, New Mexico: implications for the petrogenesis of the Polvadera Group: University of Colorado, Boulder, Ph.D. dissertation, 259 p.

Manley, K., 1976a, The late Cenozoic history of the Española Basin, New Mexico: University of Colorado, Ph.D. dissertation, 171 p.

_____, 1976b, K-Ar age determinations of Pliocene basalts from the Española Basin, New Mexico: Isochron/West, no. 16, p. 29-30.

_____, 1979, Stratigraphy and structure of the Española Basin, Rio Grande Rift, New Mexico: in Riecker, R. E., ed., Rio Grande Rift: tectonics and magmatism: American Geophysical Union, Washington D. C., special publication, p. 71-86.

_____, and Mehnert, H. H., 1981, New K-Ar ages for Miocene and Pliocene volcanic rocks in the northwestern Española Basin, and their relationships to the history of the Rio Grande Rift: Isochron/West, no. 30, p. 5-8.

Scott, G. R., 1975, Cenozoic surfaces and deposits in the southern Rocky Mountains: Geological Society of America Memoir 144, p. 227-248.

Smith, R. L., 1979, Ash-flow magmatism: Geological Society of America Special Paper 180, p. 5-28.

_____, Bailey, R. A., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico: U. S. Geological Survey Miscellaneous Geological Investigations Map, I-571, scale 1:125000.

Stieger, R. H., and Jager, E., 1977, Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359-362.

Taylor, R. B., 1975, Neogene tectonism in south-central Colorado: Geological Society of America Memoir 144, p. 211-226.

Williams, L. M., 1979, Gravity study of the Los Alamos area, New Mexico: Los Alamos Scientific Laboratory report, LA-8154-MS, 18 p.

CAPTIONS

Figure 1: Locality map showing generalized relations of the Jemez Volcanic Field (Jemez Mountains) to basins of the north-central Rio Grande Rift. Major fault zones of the region are shown schematically. Random dash is preCambrian rocks; coarse, regular stipple is Tertiary-Quaternary rift-fill sediments; and irregular stipple is Tertiary-Quaternary volcanic rocks. LA, SF, and A are towns of Los Alamos, Santa Fe, and Albuquerque, respectively. (modified from Baldridge and others, 1983)

Figure 2: Generalized stratigraphic relations of major units in the vicinity of the Jemez Volcanic Field. Irregular stipple is Keres Group formations; coarse, regular stipple is Polvadera Group formations; random dash is Tewa Group formations; and horizontally ruled pattern is young basalt fields, as indicated. Dashed lines indicate uncertainty. Figure is also a schematic section south-to-north (left-to-right) through the volcanic field. (from Gardner, 1984; modified from Bailey and others, 1969)

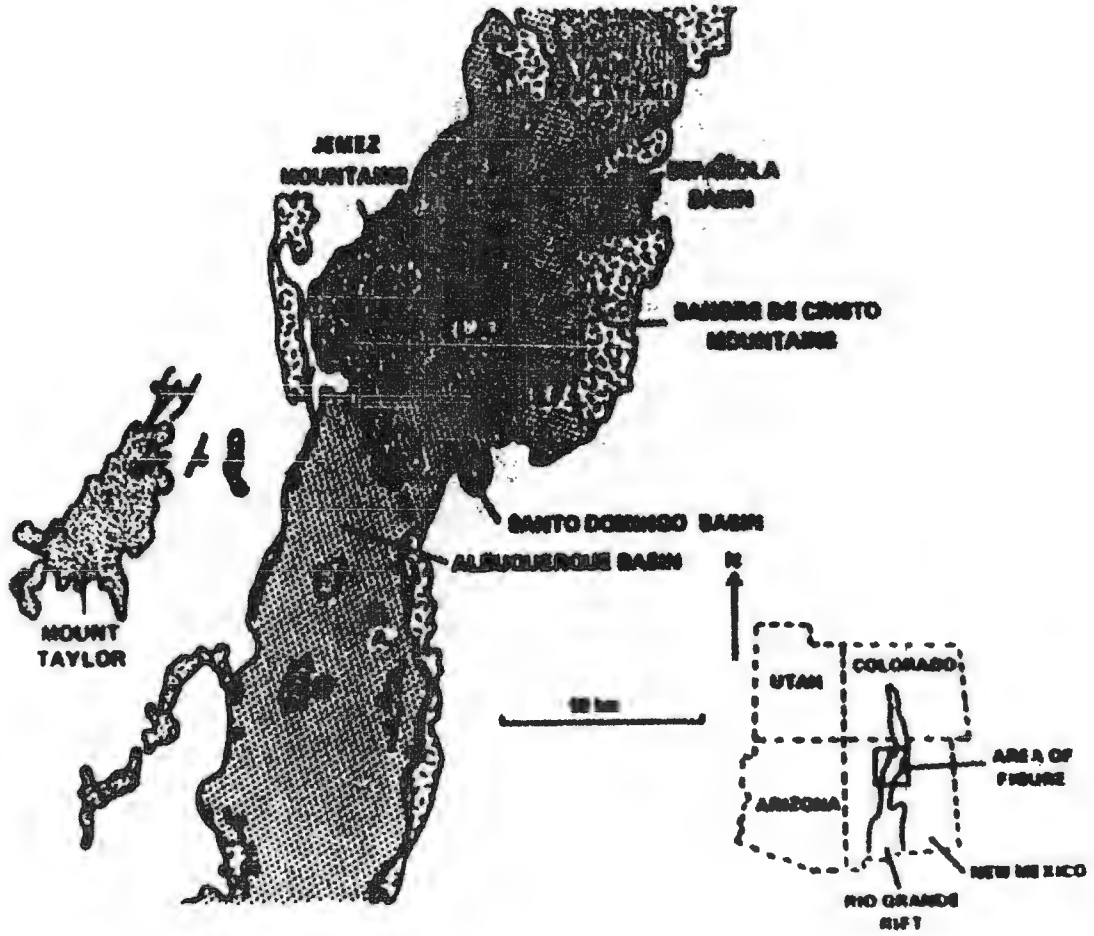
Figure 3: Dates of Jemez volcanic rocks (Table 2) plotted with respect to dominant magma type as outlined in text. Each vertical line represents a K-Ar date. Solid lines indicate continuous eruption of a given magma type, inferred from field relations, and dashed lines indicate uncertainty. (Numerous dates from Tewa Group -solid line for "Bandelier cycles"--not plotted for clarity.)

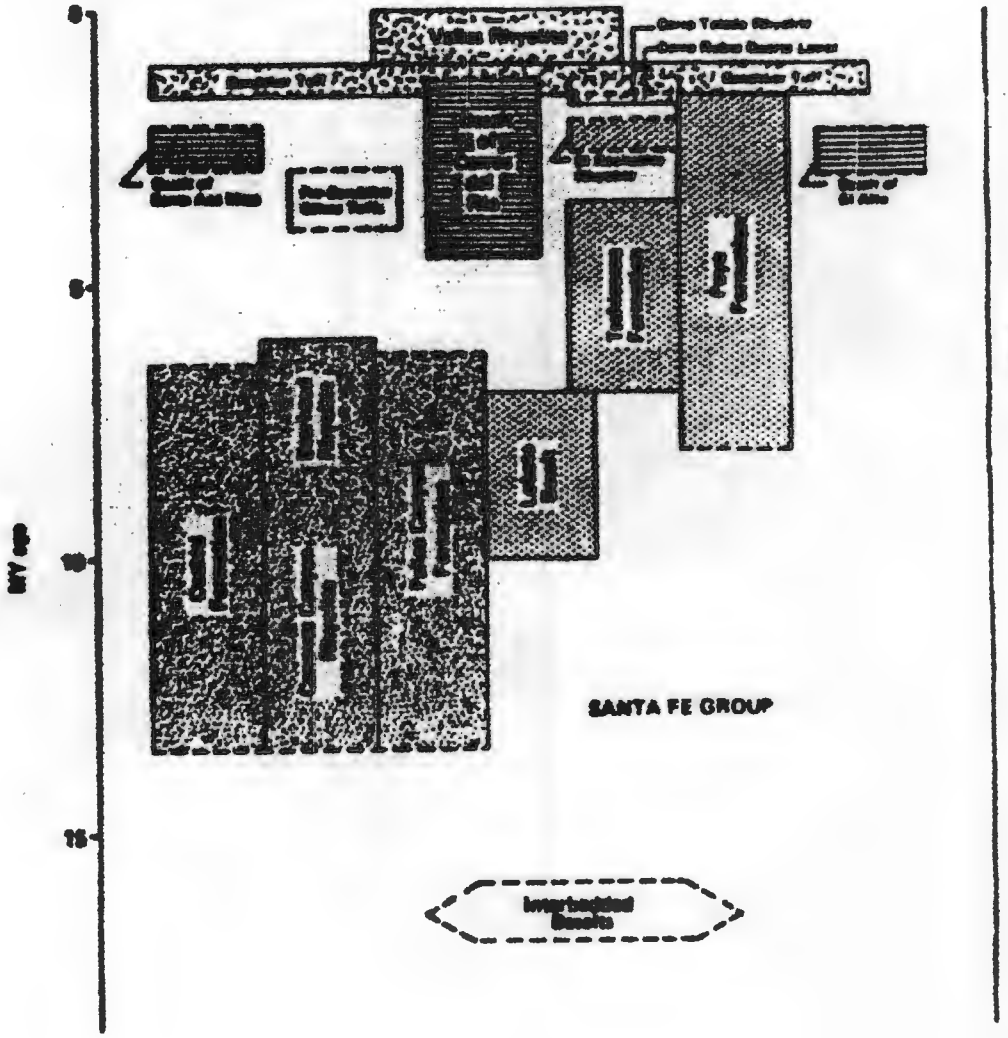
Figure 4: Generalized map showing distribution of major stratigraphic groups (patterns are the same as Fig. 2), and major fault zones in the Jemez Mountains. JFZ=Jemez Fault Zone; SFZ=Santa Ana Mesa Fault Zone; OFZ=older rift-bounding fault zone; PFZ=Pajarito Fault Zone; VC=Valles Caldera; R=resurgent dome of VC; T=Toledo embayment; and, SPD=St. Peter's Dome. (from Gardner, 1984; modified from Smith and others, 1970)

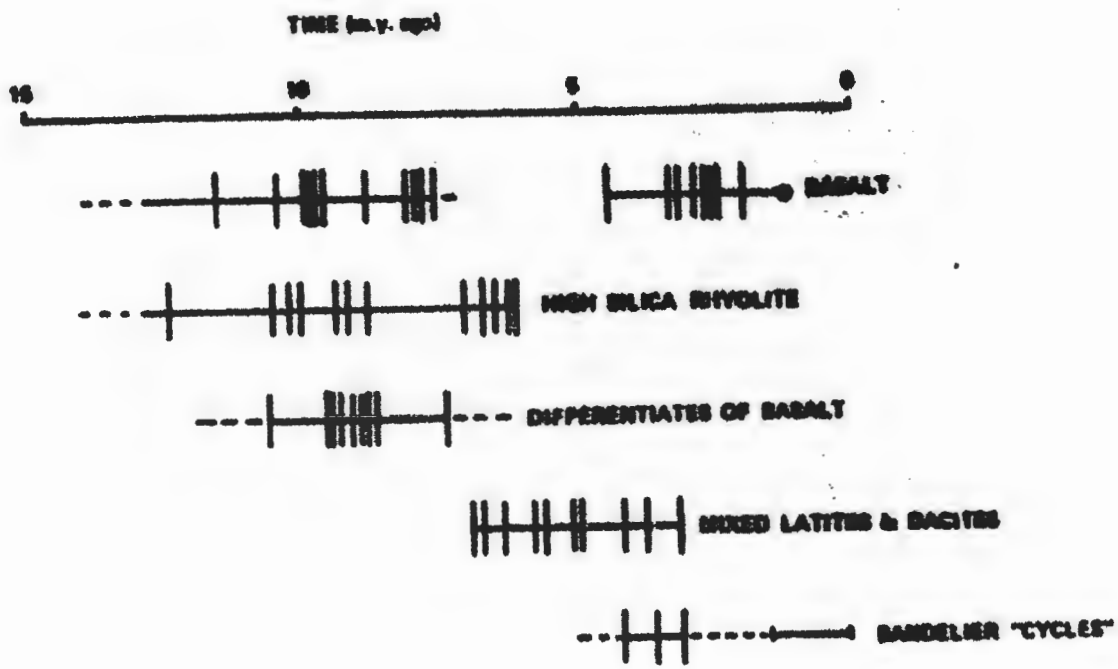
Figure 5: "Rate" of volcanism (volume per unit time) versus time (m.y. ago) for Jemez volcanic activity. Plot goes off-scale with major Bandelier ash-flow eruptions. (from Gardner, 1984)

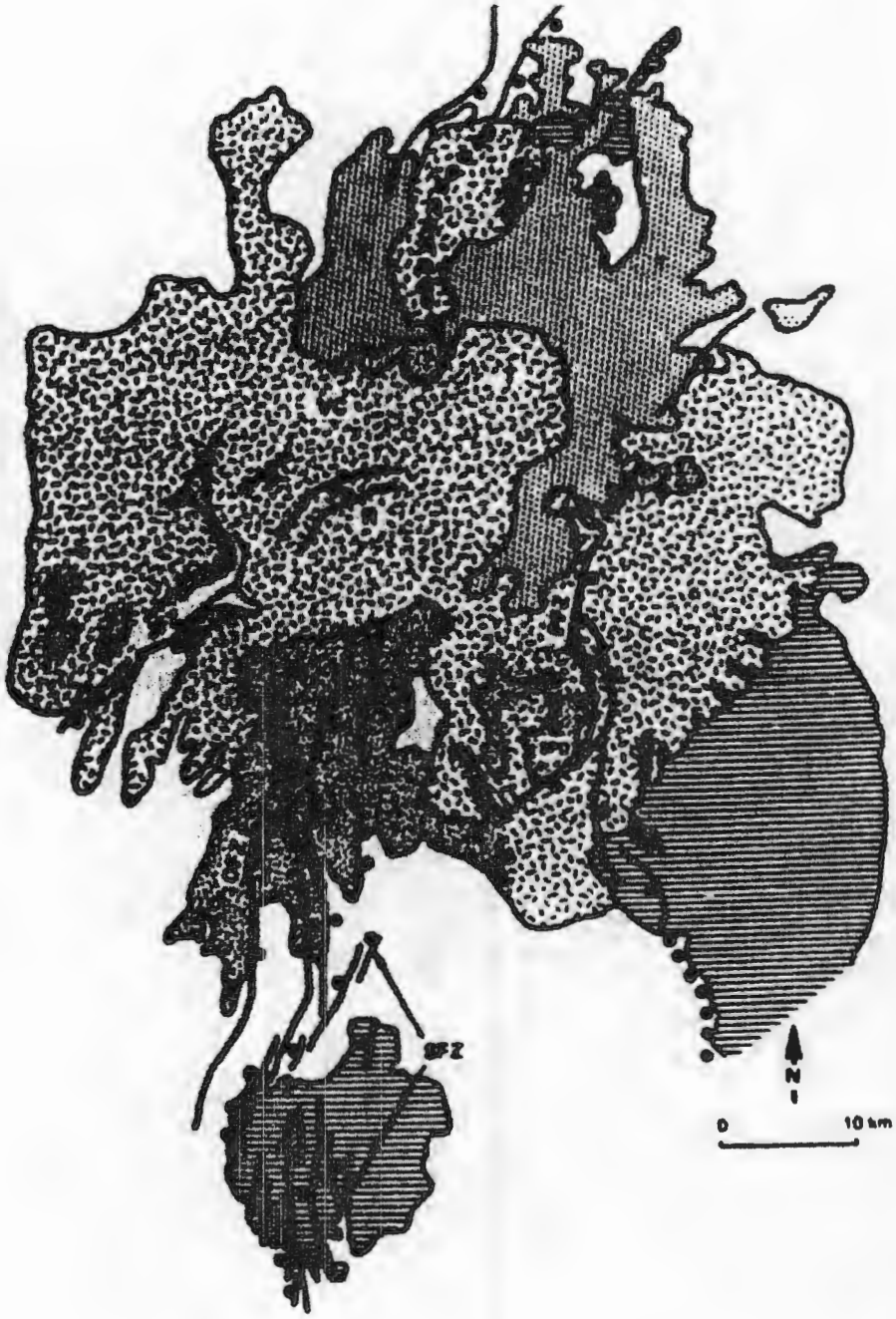
Table 1: New K-Ar dates of rocks from the Jemez Volcanic Field, and immediate vicinity.

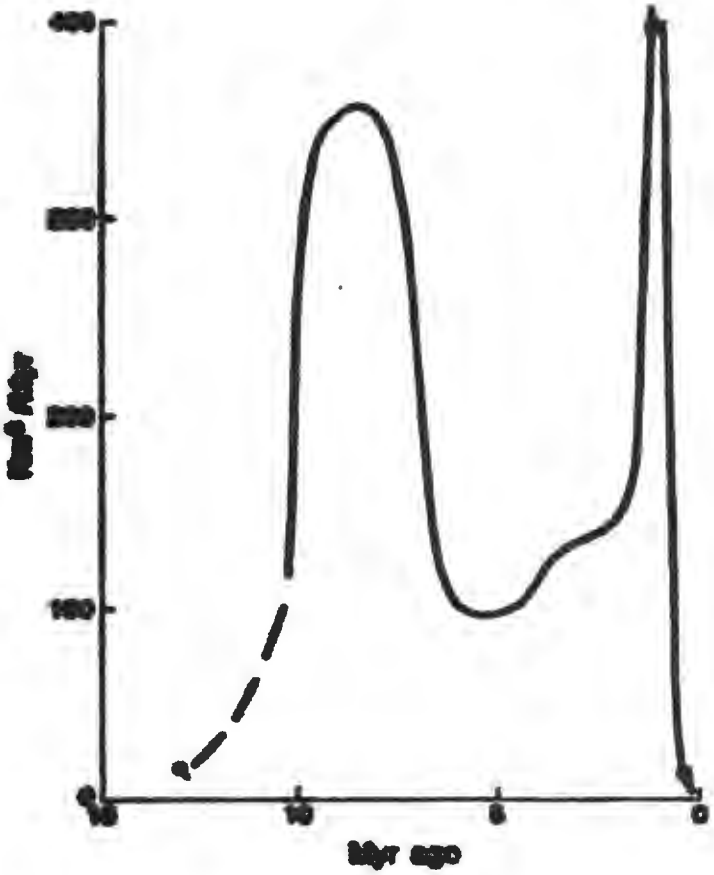
Table 2: Compilaaion of K-Ar dates of only Jemez volcanic rocks.


JEMEZ
MOUNTAINS
ESPAÑOLA
BASIN
SANGRE DE CRISTO
MOUNTAINS
SANTO DOMINGO BASIN
ALBUQUERQUE BASIN
MOUNT
TAYLOR
N
UTAH
COLORADO
ARIZONA
NEW MEXICO
AREA OF
FIGURE
RIO GRANDE
RIFT


SANTA FE GROUP


TIME (m.y. ago)
15
10
5
0
BASALT
HIGH SILICA RHYOLITE
DIFFERENTIATES OF BASALT
MIXED LATITES & DACITES
BANDELIER "CYCLES"


SFZ
N
0
10 km


400
300
200
100
0
10
10
5
0
Myr ago

Sample No.	Location	Rock Type	Material[2]	%K	Weight Sample, g	Moles Radiogenic ^{40}Ar	% Radiogenic ^{40}Ar	Age, Myr[1]	Comme
FB2-102	East edge, SE 1/4, Sec 5, T17N, R6E, Cañada Quad., east side Medio dia Canyon	Rhyolite	W/R	4.47	0.67200	$4.[illegible]\times10^{-11}$	12	9.24 ± 1.6	Dome overlain by Per Medio dia Canyon
FB2-103	35°43.5' N. Lat., 106°22.7' W. Long., of Sanchez Canyon	Rhyolite	W/R	3.96	0.[illegible]	$4.[illegible]\times10^{-11}$	19	10.5 ± 0.9	Dome intrudes lahari wall Sanchez Canyon
FB2-108	35°43.5' N. Lat., 106°22.7' W. Long., bottom of Sanchez Canyon	Rhyolite	W/R	3.154	0.4614	$3.[illegible]\times10^{-11}$	6	13.2 ± 3.3	
			W/R	3.098	0.4914	3.475×10^{-11}	6		
			W/R	3.329	0.70743	4.734×10^{-11}	8	11.6 ± 2.3 (12.4 ± 1.98)	Flow overlies tuff,
GFB2-117	35°44' N. Lat., 106°, 26.5' W. Long., bottom of Bland Canyon	Rhyolite	W/R	4.39	0.78136	$3.[illegible]\times10^{-11}$	19	6.52 ± 0.50	Rhyolite intrudes Pe Bland Canyon
GFB2-1	35°44' N. Lat., 106° 24.5' W. Long., west side Cerro Boletas	Rhyolite	W/R	4.88	0.77410	$3.701\times^{-11}$	23	6.74 ± 0.47	Rhyolite intrudes Pe side Cerro Boletas
FB3-19	35°44.6' N. Lat., 106°22.8' W. Long., north side Cerro Picacho	Rhyolite	W/R	3.873	0.6322	25.51×10^{-12}	48.8	7.12 ± 0.4	Cerro Picacho Dome

EXPLANATION: 1. All dates calculated with decay and abundance constants of Steiger and Jager (1977).
2. Material analyzed: W/R = whole rock; W/R* = whole rock with magnetic fraction removed; Hbd = hornblende; plag = plagioclase.
3. Laboratory: K = D. Krummenacher, Dept. of Geology, San Diego State Univ., CA.
G = N. Krueger, Geochron Laboratories, MA.

Sample No.	Location	Rock Type	Material[2]	%K	Weight Sample, g	Moles Radiogenic ^{40}Ar	% Radiogenic ^{40}Ar	Age, Myr[1]	Comments
JG80-44	35°49.8'N.Lat., 106°37.7' W. Long. from Cinder Cone @ 7736' elev., Ponderosa Quad.	Andesite	W/R	2.90	0.66078	3.530×10^{-11}	14	10.6 ± 1.4	Borrego Mesa
JG80-47c	SW 1/4, NE 1/4, Sec 24, T18N, R3E, 8000' elev., Redondo Peak Quad.	Rhyolite	W/R	4.07	0.46864	2.886×10^{-11}	24	8.79 ± 0.66	Dome near Cerro Pelado
JG80-48	SW 1/4, SW 1/4, Sec 27T18N, R3E; 1 km west of Cerro del Pino, Redondo Peak Quad.	Latite	Mbd	1.07	0.41310	7.763×10^{-12}	7	10.1 ± 2.6	Cerro del Pino
JG80-49	NW 1/4, SE 1/4, Sec 34, T18N, R3E; 1-3/4 km south of Cerro del Pino, Bear Springs Peak Quad.	Rhyolite	W/R	4.51	0.78161	3.786×10^{-11}	58	6.18 ± 0.80	Dome south of Cerro del Pin
JG80-53	Center Sec 2 T17N, R3E, 7720' elev., north wall of Paliza Cyn. Bear Springs	Basalt	W/R	1.27	0.48151	1.223×10^{-11}	24	11.5 ± 0.8	Lava flow overlies Canovas tuff
			W/R	1.14	0.64379	1.987×10^{-11}	10	14.9 ± 2.7 (13.2 ± 1.24)	
JG80-56	NW 1/4, SE 1/4, NW 1/4, Sec 10; NW wall of Paliza Cyn. Bear Springs Peak Quad.	Andesite	W/R	3.07	0.69060	3.313×10^{-11}	6	8.88 ± 2.7	Plug in bottom of Paliza C
JG81-60	35°42.9'N. Lat., 106°33' W. Long.; 1/4 km east of BM8000, Bear Springs peak Quad.	Latite	Plag.	0.93	1.04681	1.252×10^{-11}	8	7.49 ± 1.6	Ruiz Peak area
JG81-62	35°46.1'N. Lat., 106°32.8' W. Long.; 1/2 km NW of Paliza Cyn., 1-3/4 km south of Cerro Pelado; Redondo Peak Quad.	Andesite	W/R	2.19	0.94874	2.297×10^{-11}	12	6.36 ± 0.95	Plug in Paliza Canyon
FB6-79	Center Sec 7, T19N, R3E; Jemez Springs 15' Quad.	Latite	W/R*	2.44	0.71482	1.276×10^{-11}	7	4.21 ± 1.3	Tschicoma flow overlies Ka in west wall, Valles Cald
FB1-50	35°43.7' N. Lat., 106°22' W. Long. in Medio Canyon, Cochiti Dam Quad.	Basalt	W/R	0.964	0.4419	1.623×10^{-11}	11		Basalt in lower Santa Fe (east side St. Peter's Dom
			W/R	1.020	0.4608	1.381×10^{-11}	16	16.5 ± 1.4	
			W/R	1.220	0.4446	1.236×10^{-11}	10		
FB2-33	35°46'N. Lat., 106°21' W. Long. 3/4 km southwest of Boundary Peak, Frijoles Quad.	Latite	W/R	2.62	1.89414	7.927×10^{-11}	20	9.19 ± 0.74	Dome overlies Santa Fe Gr side St. Peter's Dom
			W/R	2.383	0.57225	23.176×10^{-12}	10.4	9.77 ± 0.8 (9.48 ± 0.44)	
FB2-77	35°47.2' N. Lat. 106°22.3' W. Long., west side of conical dome.	Rhyolite	W/R	4.36	0.76275	3.587×10^{-11}	9	6.22 ± 1.2	Rabbit Mill Dome
FB2-79	NW 1/4, SE 1/4, Sec 20, T18N, R6E, Bland Quad., east side Cochiti Canyon	Latite	W/R	2.70	0.5624	23.2×10^{-12}	23	0.8 ±	Dome in Upper Cochiti Ca
FB2-84	35° 44.5' N. Lat., 106° 24.8' W. Long., Canada Quad., east side Cochiti Canyon	Rhyolite	W/R*	4.04	0.73427	4.888×10^{-11}	10	9.32 ± 1.6	Rhyolite intrudes andesi by Peralta Tuff, Cochiti

TEMA GROUP

Valles Rhyolite Date	Ref.	Tschirege Member (Bandelier Tuff) Date	Ref.	Toledo Rhyolite Date	Ref.	Otowi Member (Bandelier Tuff) Date	Ref.	Pre-Bandelier Silicic Tuffs Date	Ref.	El Alto, Santa Ana Mesa, and Cerros del Rio "Basalt Fields" Date	Ref.
0.434 ± 0.015	(4)	1.02 ± 0.04	(4)	1.22 ± 0.04	(4)	1.37 ± 0.04	(4)	3.15 ± 0.09	(9)	1.95 ± 0.06	(6)
0.494 ± 0.015	(4)	1.05 ± 0.03	(4)	1.25 ± 0.03	(9)	1.44 ± 0.04	(4)	3.04 ± 1.44	(9)	2.4 ± 0.1	(6)
0.542 ± 0.015	(4)	1.09 ± 0.03	(4)	1.28 ± 0.02	(9)	1.48 ± 0.09	(4)	4.2 ± 0.2(?)	(4)	2.5 ± 0.3	(1)
0.535 ± 0.015	(4)	1.1 ± 0.1	(2)	1.28 ± 0.07	(4)					2.6 ± 0.4	(1)
0.692 ± 0.015	(4)	1.19 ± 0.04	(4)							2.6 ± 0.4	(1)
0.707 ± 0.019	(4)	1.24 ± 0.05	(4)							2.6 ± 0.2	(6)
0.726 ± 0.015	(4)									2.78 ± 0.04	(6)
0.823 ± 0.074	(4)									2.76 ± 0.04	(7)
0.884 ± 0.020	(4)									2.8 ± 0.7	(8)
0.885 ± 0.019	(4)									2.8 ± 0.5	(8)
1.04 ± 0.05	(4)									2.8 ± 0.1	(6)
1.15 ± 0.03	(4)									2.8 ± 0.1	(6)
1.25 ± 0.11	(4)									3.1 ± 1.0	(8)
										3.2 ± 0.1	(2)
										4.4 ± 0.1	(2)

POLVADERA GROUP

El Rechuelos Rhyolite Date	Ref.	Tschicoma Formation Date	Ref.	Lobato Basalt Date	Ref.
2.07 ± 0.06*	(3)	3.15 ± 0.28	(6)	7.6 ± 0.4	(8)
		3.77 ± 0.12*	(3)	7.63 ± 0.16*	(3)
		4.2 ± 0.3	(6)	7.8 ± 0.5	(8)
		4.21 ± 1.3	(5)	7.8 ± 0.7	(8)
		5.0 ± 0.7	(6)	7.9 ± 0.5	(8)
		5.16 ± 0.13*	(3)	8.1 ± 0.2	(6)
		5.66 ± 0.02*	(3)		
		5.78 ± 0.18*	(3)	9.6 ± 0.3	(6)
		6.36 ± 0.95	(5)	9.6 ± 0.2	(2)
		6.82 ± 0.17*	(3)	9.7 ± 0.3	(2)
		6.87 ± 0.33*	(3)	9.8 ± 0.4	(1)
				9.9 ± 1.0	(8)

Bearhead Rhyolite		KERCS GROUP Palisa Canyon Formation (Latitic Rocks)		(Andesitic Rocks)		(Basaltic Rocks)		[illegible] Rhyolite	
Date	Ref.	Date	Ref.	Date	Ref.	Date	Ref.	Date	Ref.
6.18 ± 0.09	(5)	7.4 ± 1.6	(5)			8.8 ± 0.3	(6)	9.34 ± 1.5	(5)
6.22 ± 1.2	(5)	8.8 ± 0.5	(5)	8.69 ± 0.30*	(3)	10.4 ± 0.5**	(6)	9.32 ± 1.6	(5)
6.52 ± 0.80	(5)	9.11 ± 0.19*	(3)	8.88 ± 2.7	(5)	13.2 ± 1.36	(5)	10.0 ± 0.3	(6)
6.74 ± 0.47	(5)	9.33 ± 0.19*	(3)	9.0 ± 0.3	(6)			10.2 ± 0.3	(6)
7.1 ± 0.2	(6)	9.48 ± 0.44	(5)	9.5 ± 2.5	(6)			10.5 ± 0.9	(5)
7.12 ± 0.4	(5)	10.1 ± 2.6	(5)	10.6 ± 1.4	(5)			12.4 ± 1.88	(5)
8.79 ± 0.46	(5)								

* = Date recalculated with decay and abundance constants of Steiger and Jager (1977) or by methods of Dalrymple (1979).

** = Date on basalt of Chemisa Mesa (Bailey et al., 1969).

References:
(1) Bachman and Hubert (1978)
(2) Baldridge et al. (1980a)
(3) Dalrymple et al. (1967)
(4) Doell et al. (1968)
(5) This work
(6) Loudke and Smith (1978)
(7) Manley (1976b)
(8) Manley and Hubert (1981)
(9) Self et al. (in prep.)