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Outline of the petrology and geochemistry of the Keres Group lavas and tuffs

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New Mexico Geological Society Guidebook, 47th Field Conference, Jemez Mountains Region, 1996

OUTLINE OF THE PETROLOGY AND GEOCHEMISTRY OF THE KERES GROUP LAVAS AND TUFFS

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Abstract—The Keres Group lavas and tuffs are the earliest products of volcanism from the Jemez Mountains volcanic field, ranging in age from 12.4 to 6.2 Ma. Compositions include olivine tholeiite through high-silica rhyolite lavas and tuffs. Isotope data reveal that Keres Group rocks can be assigned to three petrogenetic trends, each of which contains a chemical component similar to ocean island basalts (OIB). Assimilation-fractional crystallization models of trace element and Sr, Nd and Pb isotope ratio data suggest that one of the petrogenetic groups of magmas assimilated mafic lower crust concurrent with differentiation. The second trend can be modeled as having been contaminated by felsic lower crust. The third petrogenetic trend of samples includes the latest products of Keres Group magmatism, with chemical signatures that suggest they were contaminated by the upper crust.

INTRODUCTION

The oldest rocks of the Jemez Mountains volcanic field are lavas and tuffs of the 13–6 Ma Keres Group. The Keres Group volumetrically comprises more than 1000 km^3 of lavas, pyroclastic rocks, and volcaniclastic sediments, which range in composition from olivine-tholeiite basalt to high-silica rhyolite (Gardner et al., 1986) (Figs. 1, 2). Here we present petrographic geochemical data of samples collected from the Keres Group, using the mapped units of Gardner (1985) and Goff et al. (1990) as the field area. These data are used in petrogenetic models to represent the evolution of the magmas of Keres Group samples.

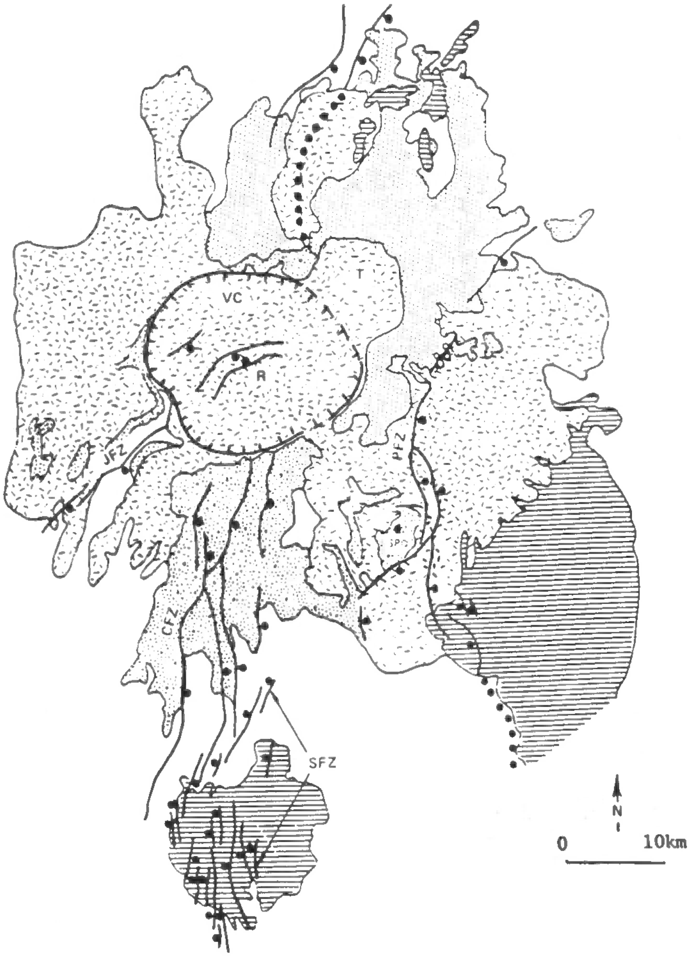

FIGURE 1. Generalized map of the Jemez Mountains volcanic field, showing distribution of stratigraphic groups. Keres Group is represented by irregular stipple pattern, Polvadera Group by regular stipple pattern, Tewa Group by random dash pattern, and young basalt fields (including Cerros del Rio and Basalts of El Alto), by horizontal rule. Fault zones are abbreviated as JFZ, Jemez fault zone; CFZ, Canada de Cochiti fault zone; PFZ, Pajarito fault zone. VC and the outlined, hatched curve mark the Valles Caldera, BP is Bearhead Peak, BSP is Bear Springs Peak, CC marks the approximate outline of Canovas Canyon, and SPD marks St. Peter's Dome. Modified from Gardner (1985).

The rocks of the Keres Group are most accessible and best exposed south of Valles caldera (Fig. 1). Extensive mapping and field interpretations have resulted in the designation of three separate formations of the Keres Group (Goff et al., 1990; Gardner, 1985; Smith et al., 1970; Bailey et al., 1969). Although the true base of the Keres Group has not yet been found, stratigraphic relations and radiometric dating indicate that some of the oldest Keres Group rocks are high-silica rhyolite lavas and tuffs of the Canovas Canyon Rhyolite (Goff et al., 1990), which are best exposed in the southern portion of the field area, east of Canovas Canyon, south of Bear Springs Peak (Fig. 1).

Olivine-tholeiites, andesites and dacites of the Paliza Canyon Formation erupted from >13 Ma until about 7 Ma (Gardner et al., 1986). The Paliza Canyon Formation is exposed throughout the field area, and andesite volumetrically dominates the Keres Group, notably in the western

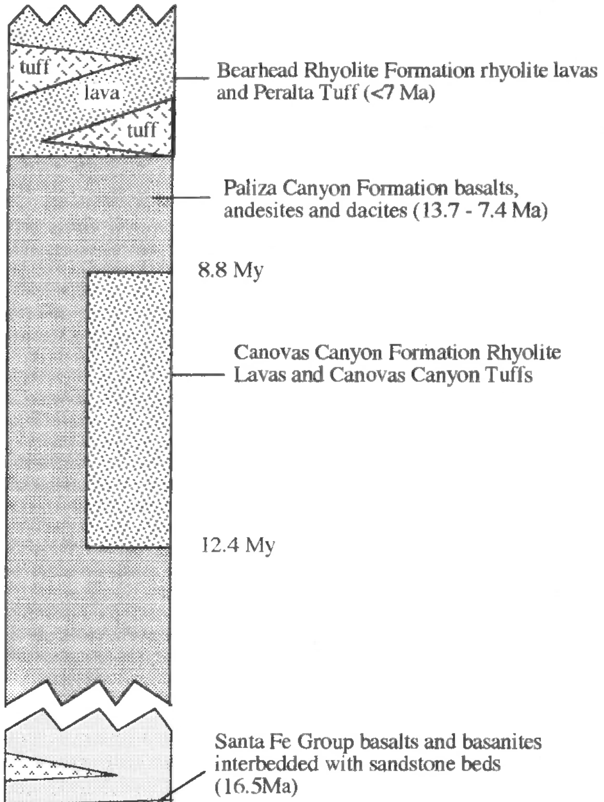

FIGURE 2. Schematic stratigraphic section of Keres Group units, not to vertical scale.

portion of the field area, west of Bearhead peak. Paliza Canyon basalt, andesite and dacite are all exposed in the east, south of St. Peters Dome. Some dacite and andesite lavas of the Paliza Canyon Formation contain mafic xenoliths.

The eruptions of the high silica rhyolite lavas and tuffs of the Bearhead Rhyolite are considered to be the final stages of Keres Group magmatism. The Bearhead Rhyolite includes the 275-m-thick Peralta Tuff, which is the product of more than 30 separate eruptions (Smith et al., 1991). Compositionally and mineralogically the lavas and tuffs are similar to the Canovas Canyon Rhyolite but are distinguished by their field relations and age; that is, rhyolites approximately 7 Ma and younger (overlying rocks of the Paliza Canyon Formation), are considered to be Bearhead Rhyolite (Gardner et al., 1986). Most vents for the Bearhead Rhyolite are located in the central portion of the field area, along faults of the Cañada de Cochiti fault zone (Fig. 1), suggesting that local tectonic activity may have played a role in a pulse of rhyolitic volcanic activity during the final stages of magmatic activity associated with the Keres Group (Gardner, 1985; Gardner et al., 1986).

Remnant outcrops of older alkali basalt and basanite of the Santa Fe Group are exposed southeast of St. Peters Dome. A radiometric date indicates that one of these primitive lavas is 16.5±1.4 Ma (Gardner and Goff, 1984). Their proximity in age and location to Keres Group rocks and their mafic compositions suggest a genetic relationship between the two groups of rocks, so samples from each are considered here.

The Cochiti Formation (Smith et al., 1970; Gardner, 1985; Goff et al., 1990) is a sequence of volcaniclastic sediments with basalt, andesite, dacite and rhyolite clasts predominately derived from Keres Group lavas. The Cochiti Formation is interbedded with flows of Keres Group lavas (Goff et al., 1990; Gardner, 1985), which indicates that it developed as volcanism of the Keres Group proceeded.

Rocks of the Keres Group are classified as basalts, trachybasalts, basaltic trachyandesites, andesites, trachyandesites, dacites, trachydacites and rhyolites (Fig. 3), based on the TAS classification of Le Bas et al. (1986). The SiO_2-poor "basalt" of the Santa Fe Group is a basanite. Keres Group samples straddle the curve distinguishing them as alkalic or subalkalic. Rhyolites and dacites are subalkalic; samples with less than 60 wt% SiO_2 straddle the subalkalic/alkalic curve on Figure 3.

Samples analyzed for this work include lavas and tuffs of the Keres Group and the basanite and basalts mapped as the Santa Fe Group (Goff et al., 1990). Collectively, samples are referred to as the Keres Group suite unless otherwise specified. In several cases, mapped unit names do not correspond with the chemical classification of the rocks collected. For the sake of clarity in models and plots presented later, samples have been designated as basalts, andesites, dacites, or rhyolites, rather than the more specific classification of Figure 3 and the categories used by Gardner (1985) and Goff et al. (1990).

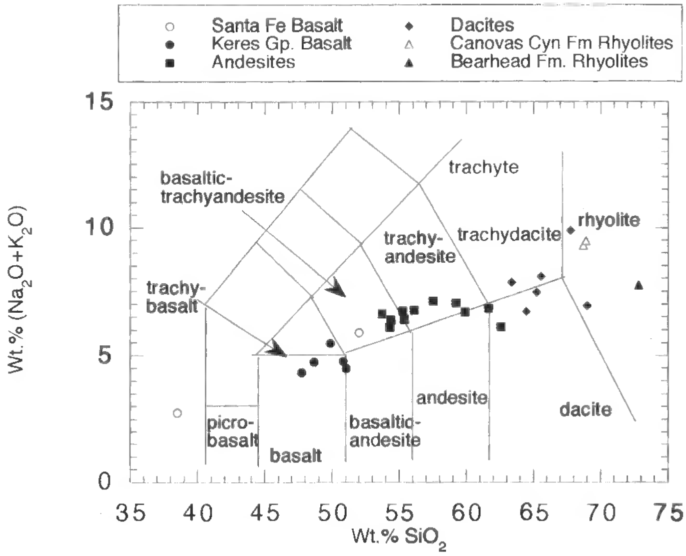

FIGURE 3. Major element classification of Keres Group samples with composition fields from Le Bas et al. (1986).

PETROGRAPHY

Keres Group samples are generally porphyritic, with phenocrysts of plagioclase, clinopyroxene, orthopyroxene, and olivine in basalts and andesites. More evolved samples contain potassium feldspars and sometimes quartz. Phenocrysts of biotite and hornblende are found in some andesites and dacites. Plagioclase phenocrysts range between An_{16} and An_{75}. In general, samples with more anorthite-rich compositions of plagioclase also have more mafic whole-rock compositions. The plagioclase with the lowest An composition is from a Bearhead Rhyolite lava.

Pyroxene phenocrysts are variably zoned, but lack consistent compositional trends from core to rim. Most clinopyroxenes in Keres Group samples are augite and salite, and all orthopyroxenes analyzed are hypersthene. Olivine phenocrysts range in composition from Fo_{53} to Fo_{83}. The forsterite content of olivines, and weight-% Mg in pyroxene phenocrysts tend to increase as the whole-rock Mg increases.

Basalts

Typical plagioclase phenocrysts in Keres Group basalts range in composition from An_{30} to An_{52} (Gardner, 1984; Ellisor, 1995), generally have reaction rims, and are often embayed and resorbed, indicating disequilibrium with the host liquid. Many Keres Group basalts have plagioclase phenocrysts that are normal zoned or resorbed. Olivine grains are resorbed and have reaction rims with the host liquids. Pyroxenes are less common and are generally not as altered (or resorbed) as olivine. The groundmass in some basalt samples is glassy with laths of plagioclase and fragments of olivine and fine-grained magnetite (Fig. 4).

The Santa Fe Group basanite (JM93141) has olivine and nepheline, but no plagioclase phenocrysts. Nepheline phenocrysts are resorbed, indicating disequilibrium with the residual melt. Clinopyroxene phenocrysts are rare and are salitic in composition. Reaction rims and embayed faces indicate disequilibrium between the host liquid and pyroxene grains. The basanite contains amygdaloidal calcite and many olivine phenocrysts are in reaction with chlorite.

Andesites

Typical plagioclase phenocrysts in Keres Group andesites range in composition from An_{30} to An_{60} (Gardner, 1985; Ellisor, 1995). Oligoclase grains tend to be more extensively resorbed and/or zoned than andesine grains. Several andesite samples with coarse-grained andesine phenocrysts commonly also contain medium- to fine-grained oligoclase in equilibrium with the host liquid, and have very well defined albite twins, and no reaction rims. Plagioclase phenocrysts generally have normal zoning, but several samples additionally have reverse and oscillatory zoning. Potassium feld-

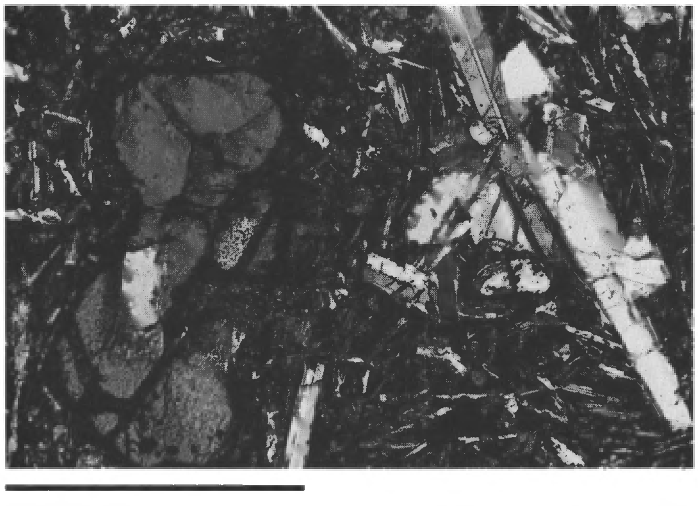

FIGURE 4. Photomicrograph (crossed polars) of Paliza Canyon basalt, sample JM93199. Phenocrysts include olivine, clinopyroxene and plagioclase. Bar scale is 1 mm.

spar xenocrysts are extensively altered; some are resorbed, zoned, anhedral, have broad reaction rims, and/or are embayed when olivine is also present.

Orthopyroxene phenocrysts in andesite samples are hypersthene, with 51 to 70 wt% $MgSiO_3$. With a few exceptions, olivine phenocrysts exist in all Keres Group andesites (e.g., Fig. 5). Mafic minerals are in disequilibrium with either the host liquid or coexisting phenocrysts. When two pyroxenes and olivines occur together, they are altered, zoned or resorbed. Hornblende is present in two andesites but has extensive Fe-alteration.

The groundmass of andesites varies from glassy, with acicular plagioclase and nearly trachytic textures, to glassy, with microphenocrysts of plagioclase and mafic phases. Generally, glass color ranges between black and reddish brown.

Dacites

Plagioclase phenocrysts in Keres Group dacites are An_{16} to An_{53} (Gardner, 1985; Ellisor, 1995), and are resorbed and/or have normal zoning. Some dacites also have resorbed potassium feldspar or quartz phenocrysts. Olivine phenocrysts in dacites have disequilibrium textures, including resorbed cores, reaction rims, and embayed rims (Stimac and Pearce, 1992). Magnetite inclusions are common in olivine phenocrysts. Pyroxene phenocrysts are fine to medium grained, often with plagioclase and occasionally hornblende as glomerocrysts. Biotite and hornblende are fine to medium grained, with reactions rims that are probably due to post-eruptive decomposition. Biotite phenocrysts are generally more extensively altered than hornblende. Zircon xenocrysts with reaction rims are present in some dacite samples. The groundmass of most Keres Group dacites is dominated by brown glass and acicular plagioclase.

Rhyolites

Samples from the Canovas Canyon Rhyolite and the Bearhead Rhyolite are difficult to distinguish in thin section. Plagioclase phenocrysts vary from An_{17}–An_{36} and are generally medium- to fine-grained fragments that are altered or resorbed. Potassium feldspars in some of the Bearhead Rhyolite samples have faint exsolution lamellae. Quartz grains are subhedral, medium to fine grained, have variable degrees of resorption, and are often embayed. Medium- to fine-grained clinopyroxene, biotite and hornblende grains are present in both rhyolite formations, but are resorbed, and/or have other disequilibrium textures.

Groundmass makes up approximately 70% (modal) of rhyolitic lavas. The glass of Keres Group rhyolites is tan to reddish brown, with fine shards of feldspar, quartz, opaques, and occasionally biotite. Pumices of the Peralta Tuff and Canovas Canyon tuff have potassium feldspar and quartz fragments and some have plagioclase and biotite. Bearhead Rhyolite lavas are extensively flow banded (Gardner, 1985) and localized flow textures are observed in some Canovas Canyon Rhyolite samples.

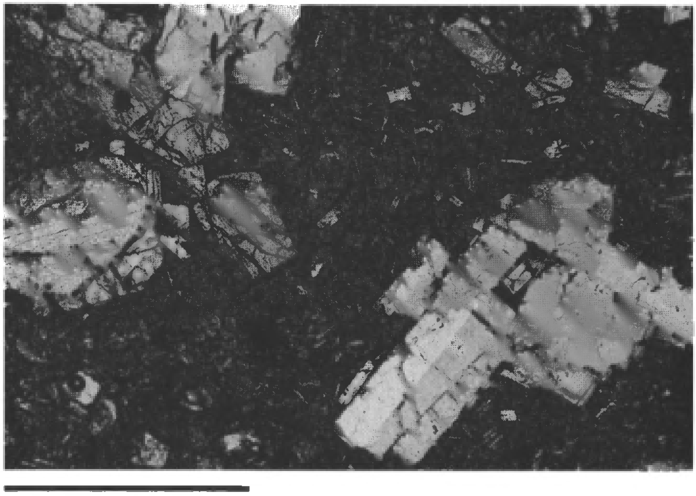

FIGURE 5. Photomicrograph of Paliza Canyon andesite, sample JM9313. Phenocrysts include zoned plagioclase, olivine and clinopyroxene. Bar scale is 1 mm.

MAJOR AND TRACE ELEMENT GEOCHEMISTRY

Silica content of Keres Group suite samples ranges from 38.5 wt.% for the Santa Fe Group basanite to 76.8 wt.% SiO_2 for a lava from the Bearhead Rhyolite (Table 1). The Santa Fe Group basalts and basanite are more K_2O-rich, and have lower Al_2O_3 and higher Fe_2O_3, MnO, MgO, and CaO compositions than the Keres Group basalts.

Basalts and Bearhead Rhyolite samples have the lowest Sr contents of the Keres Group samples. Rhyolites of the Canovas Canyon Formation are enriched in Nd and Sm, relative to Bearhead Rhyolites with similar wt% SiO_2. Basalt, andesite and dacite samples that have low Pb contents, generally also have low concentrations of Th and Nb (4–24 ppm and 14–53 ppm). Tuffs of the Bearhead Rhyolite have lower Nb (<30 ppm) and Zr (100 ppm) concentrations than Canovas Canyon Rhyolite and generally have high Nd (26–41 ppm) concentrations. The lower concentration of Sr, Zr, Nb and Nd in Bearhead Rhyolite samples are criteria by which they can be distinguished from Canovas Canyon Formation rhyolites.

RADIOGENIC ISOTOPE DATA

Sr and Nd isotope ratios

The $^{87}Sr/^{86}Sr$ ratios of Keres Group samples range from 0.70395 to 0.70930 (age corrected values, Table 1). $^{143}Nd/^{144}Nd$ ratios range from 0.512353 to 0.512717 (Table 1). Bearhead Rhyolite lavas and tuffs have very radiogenic Sr relative to the rest of the Keres Group suite (including the Canovas Canyon Formation rhyolite lavas and tuffs), but do not have especially low Nd isotope ratios. One rhyolite sample, with an anomalously high $^{87}Sr/^{86}Sr$ of 0.70893, is a rheomorphic welded tuff which stratigraphically belongs to the Canovas Canyon Formation, but is difficult to categorize because geochemically, it does not consistently plot with the older rhyolites. A low Sr concentration (47 ppm) probably made this sample more susceptible to contamination, leading to anomalously high $^{87}Sr/^{86}Sr$. The range in isotopic composition of Keres Group andesites is very broad, with $^{87}Sr/^{86}Sr$ values lower than basalts and as high as the most radiogenic dacites.

Keres Group basalts, andesites, dacites, and the Canovas Canyon Formation rhyolite lavas and tuffs are similar to ocean island basalts (OIB) in $^{87}Sr/^{86}Sr$ (0.7040–0.7055) and $^{143}Nd/^{144}Nd$ (0.512403–0.512717) (Sun, 1980; White and Hofmann, 1982; Zindler and Hart, 1986). Keres Group lavas are comparable in $^{87}Sr/^{86}Sr$ to lavas from the southeastern transition zone (the physiographic boundary between the Basin and Range and Colorado Plateau, designated SETZ in Kempton et al., 1991) but generally have more radiogenic Nd.

Pb isotope ratios

Pb isotope ratios of the most Keres Group samples plot within, or slightly lower than the OIB and mid-ocean ridge basalt (MORB) fields (Fig. 6). The Pb isotope ratios of samples JM93198, JM93239 and JM93252 plot on, or near, the northern hemisphere reference line (NHRL) of Hart (1984). The samples plot directly on the NHRL, or very close to the NHRL, which suggests they crystallized from primitive magmas similar to those derived from MORB and OIB sources. Proximity to, or trends toward, the field of Archean granulites (Leeman, 1985) suggests the possibility that an Archean component was involved in the genesis of the Keres Group suite, but Archean crust has not been reported beneath the Jemez Mountains volcanic field.

INTERPRETATIONS

OIB-type mantle source

Isotope data indicate that Keres Group rocks were generated by contamination of a mafic magma derived from a mantle source, similar to that for OIB (Fig. 6). OIB-like magmas have been suggested as source material for volcanic rocks of the Colorado Plateau (Alibert et al., 1986; Leat et al., 1989) and for southern Cordilleran magmatic centers, including the trans-Pecos volcanic field (James and Henry, 1991; Wolff and Davidson, in press), the San Luis Hills (Johnson and Thompson, 1991), and basalts of the southern Cordillera (Cameron et al., 1989). The OIB-like component is characterized by $^{143}Nd/^{144}Nd$ of approximately 0.5130 and a K/Nb ratio less than or equal to the chondritic value, approximately 343 (Wolff and Davidson, in press).

TABLE 1. Chemical, elemental and isotopic data for Keres Group units discussed in text.

sample	JM9302	JM9307	JM9325	JM9338	JM9369	JM93123	JM93141	JM93176	JM93198	JM93251
	Paliza Cyn And	Paliza Cyn And	Paliza Cyn And	Paliza Cyn Dac	Paliza Cyn Dac	CanovasCyn Rho	StaFe Basanite	Paliza Cyn Bas	Paliza Cyn Bas	Bearhead Rho
approx age(Ma)	>11.3	<16.5	<16.5	8.96		12.4	16.5			6.74
SiO2	57.498	61.635	55.251	68.991	64.436	76.456	38.493	47.720	50.811	75.680
TiO2	1.178	0.874	1.157	0.744	0.654	0.097	2.083	1.608	1.465	0.101
Al2O3	16.331	16.042	16.882	13.351	16.156	11.961	10.236	17.513	15.447	11.411
Fe2O3	6.918	5.307	6.943	3.841	4.091	1.405	11.702	11.072	10.569	0.576
MnO	0.113	0.083	0.112	0.089	0.057	0.033	0.184	0.148	0.151	0.055
MgO	3.629	2.364	3.650	0.774	1.453	0.000	15.363	4.236	7.025	0.002
CaO	6.199	4.624	6.330	2.620	4.156	0.158	13.505	9.414	9.201	0.331
Na2O	4.225	3.823	4.240	3.966	3.590	3.848	1.983	3.418	3.655	2.761
K2O	2.891	3.006	2.482	2.962	3.125	4.502	0.767	0.924	1.120	4.455
P2O5	0.576	0.358	0.549	0.304	0.210	0.022	1.144	0.472	0.364	0.019
%LOI	0.590	1.340	1.120	2.100	1.810	0.060	3.760	2.700	0.000	3.870
total	100.148	99.455	98.716	99.742	99.738	98.486	99.221	99.226	99.808	99.261
Si Satn	25.310	32.615	24.025	45.027	36.326	51.554	0.712	17.576	18.223	52.559
Mg#	34.73	31.12	34.78	16.97	26.48	0.00	57.11	27.96	40.27	0.35
sample	JM9302	JM9307	JM9325	JM9338	JM9369	JM93123	JM93141	JM93176	JM93198	JM93251
Pb	20	19	20	17	16	16	6	6	6	24
Th	12	9	13	12	4	19	12			15
Rb	49	54	27	54	49	148	33	10	18	113
Sr	1244	778	1241	485	609	17	1291	1062	808	8
Y	26	26	27	25	16	46	25	28	28	27
Zr	283	253	290	291	170	215	243	147	143	91
Nb	35	29	35	35	14	65	69	20	18	27
Ga	19	17	20	13	17	20	16	19	18	12
Zn	74	58	69	31	58	49	93	86	81	31
Cu	38	21	31	10	23	5	82	69	58	
Ni	44	21	49	8	14	4	421	82	101	4
Ba	1305	925	1297	862	932	160	909	408	435	238
Cr	30	6	36		3	16	552	58	236	3
Be	2	2	1	2	1	7	2	1	1	2
Sc	14	8	13	5	7	2	23	26	24	4
Yb	0.112	0.049	0.112	0.071	0.066	0.161	0.071	0.109	0.114	0.121
Nd	47.325	12.6	43.922	30.611	21.113	39.463	77.555	33.869	30.93	21.805
Ce	130.241	37.35	120.955	83.11	53.246	79.175	142.929	75.346	63.333	57.075
Sm	10.731	3.27	10.463	6.524	4.949	10.197	15.488	8.471	8.06	6.895
sample	JM9302	JM9307	JM9325	JM9338	JM9369	JM93123	JM93141	JM93176	JM93198	JM93251
87/86Sr	0.704767	0.704705	0.704766	0.704728	0.704800	0.705668	0.704430	0.704460	0.704459	0.710499
87/86Sr	0.704767	0.704705	0.704766	0.704728	0.704800	0.704390	0.704430	0.704460	0.704459	0.709300
±	10	9	9	9	10	11	10	11	10	11
143/144Nd	0.512470	0.512512	0.512497	0.512583	0.512403	0.512508	0.512717	0.512545	0.512441	0.512355
±	8	8	8	15	15	8	8	13	9	10
208/204Pb	37.821	37.643	37.541	37.784	37.334	36.949	na	37.272	36.325	37.607
207/204Pb	15.586	15.474	15.472	15.496	15.471	15.438	na	15.533	15.450	15.497
206/204Pb	17.806	17.814	17.771	17.986	17.313	17.833	na	17.369	17.200	17.842
"trend #"	2	2	2	2	3	2	1	1	3	3

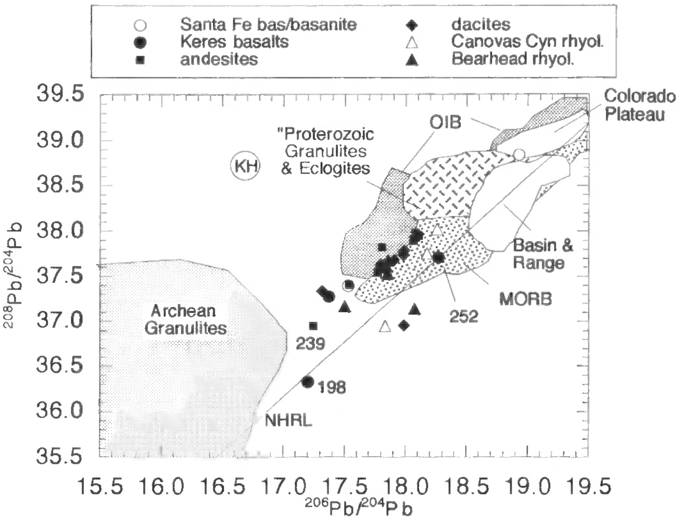

FIGURE 6. Keres Group suite $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$. OIB and MORB fields are from Hart (1984), Leat (1989) and White and Hofmann (1982). NHRL is from Hart (1984). "KH" (Kilbourne Hole), and Proterozoic granulites and eclogites are from Kempton et al. (1990), and Archean granulites are from Leeman et al. (1985).

The composition used to model the mantle source material of the Keres Group is based on a combination of trace element and isotopic compositions of two mantle xenoliths from the Geronimo volcanic field (data from Kempton et al., 1991). Data from these pyroxene metacumulate xenoliths are used to represent the OIB-like characteristics of the Keres Group mantle source (Fig. 7), which is reflected in the subchondritic values of the Th/Nb,Ba/Nb, and K/Nb ratios fo the xenoliths.

Nd-Pb isotope variations of the Keres Group suite suggest that crustal material was assimilated in varying proportions by mantle-derived magma. Except for the Santa Fe Group basanite, samples with high $^{143}Nd/^{144}Nd$ are more homogenous in $^{206}Pb/^{204}Pb$ than those with low $^{143}Nd/^{144}Nd$ (Fig. 7). The samples that reflect increased variability in Pb isotope ratios generally have more evolved compositions and reflect diverse Sr isotope ratios and K/Nb composition. Increasing diversity of K/Nb, and $^{87}Sr/^{86}Sr$ in more evolved samples suggests an increased influence of assimilated crustal material in the more evolved magmas, and can be modeled using calculations for assimilation-fractional crystallization (AFC).

Variation of the composition of the crust

Three trends are identified based on variation of trace element and isotopic compositions of the Keres Group suite (Fig. 7). These trends are attributed to contributions from local crust of variable compositions. Distinct isotopic domains in the crust beneath the Jemez Mountains volca-

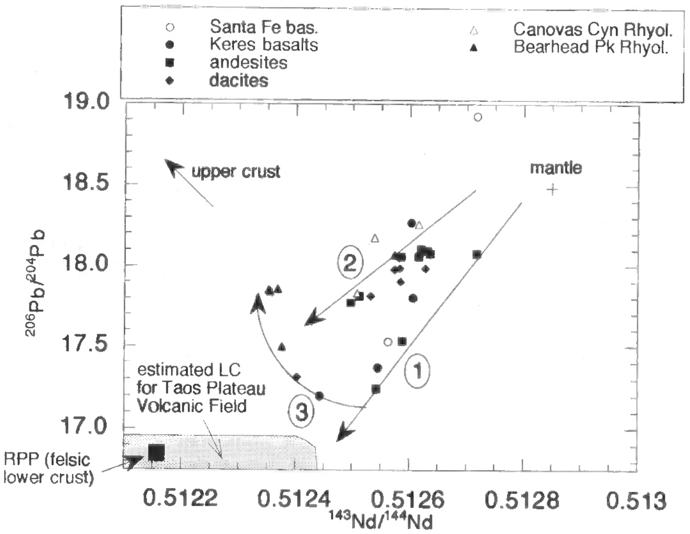

FIGURE 7. $^{143}Nd/^{144}Nd$ vs. $^{206}Pb/^{204}Pb$ with the Keres Group suite, by sample type. RPP (representative pelagic paragneiss from Reid et al., 1989) is the estimate of the felsic lower crust used in AFC models. Mantle is represented by a xenolith from the Geronimo volcanic field (Kempton et al., 1990). Field of TPVF represents the range of the mafic lower crust estimated by McMillan and Dungan (1988) for the Taos Plateau volcanic field. The upper crust (from Skuba, 1990) plots off the scale of the figure. Numbers 1, 2 and 3 refer to the geochemical trends of the Keres Group suite described in the text.

nic field may relate to lateral variation across the field, or by subjacent relationships of the upper crust, felsic lower crust and mafic lower crust.

The location of the Jemez Mountains volcanic field, at the southeastern boundary of the Colorado Plateau and the western edge of the Rio Grande rift, suggests that the crust may vary in composition from one part of the volcanic field to another. Trend 1, 2 and 3 samples plotted by the latitude and longitude of their locations do not indicate a correlation with their composition. Trend 1 and 2 samples were collected from the western and eastern portions of the field area and are intermingled in terms of general location. Four of the trend 3 samples were collected from outcrops centered around vents of the Bearhead Rhyolite. Additional trend 3 samples in the southwest and northeastern portions of the field illustrate that in general, trend 3 samples occur across the volcanic field.

The lack of correlation between the general isotopic character of samples and their locations, suggests that the distinct crustal compositions beneath the volcanic field are due to vertical variation of the crust. Density contrasts of rock types and geophysical data indicate that mafic lower crust resides above the mantle, and below the felsic lower crust, with upper crust at (or closest to) the surface (Reid et al., 1988).

The estimate of the lower crust beneath the Taos Plateau volcanic field is used to model the mafic lower crust of the Jemez Mountains field. Proximity of the two fields, and their similarities in isotopic composition (McMillan and Dungan, 1988 and Ellisor, 1995) suggest that the mafic lower crust of the two volcanic fields is geochemically similar.

The isotopic composition of the felsic lower crust is modeled using the composition of a representative pelitic paragneiss xenolith (RPP) extracted from the lower crust by the Kilbourne Hole maar in southern New Mexico (Reid et al., 1989). The Pb composition of RPP is nonradiogenic, but in all other trace element and isotopic systems tested, it is well suited to characterize the felsic lower crust suggested by Keres Group samples (trend 2, Fig. 7). High Pb concentrations and low $^{206}Pb/^{204}Pb$ values of the felsic lower crust composition distinguish mafic and felsic lower crustal components.

The upper crust of the Jemez Mountains volcanic field has been represented by a Proterozoic basement granite (sample B8 of Skuba, 1990, and Duncker et al., 1991). Sample B8 is a leucogranite collected from Joaquin Canyon in the Nacimiento Mountains, and has previously been used to represent the upper crust in models of the evolution of the Bandelier Tuff and the basalts of the Cerros del Rio volcanic field (Skuba, 1990; Duncker et al., 1991).

Evolution of the Keres Group magmatic system

The Keres Group suite can be modeled as having been generated by AFC (DePaolo, 1981). Proposed models incorporate a source magma, similar in composition to OIB-like magma, to which varying proportions (12–20% of total magma volume) of either mafic lower crust, felsic lower crust, and/or upper crust were assimilated as the magma fractionated (Fig. 7). Trend 1 samples are modeled as OIB-type source magmas, contaminated by mafic lower crust. Trend 2 samples can be modeled with the same source magma or a derivative (on the former trend), but with contamination by the felsic lower crust. The trend 3 sample set includes the young Bearhead Rhyolite lavas and tuffs and can be modeled by assimilation of upper crust material by a mafic magma similar to a composition along the nonradiogenic end of trend 1.

A schematic cross-section depicts the roles of end member compositions postulated to have generated samples of the Keres Group (Fig. 8). Evolution of Keres Group magmas may have begun with injection of mantle-derived magma into the mafic lower crust, which was assimilated into developing magma chambers. Eruptions of these magmas are represented by trend 1 samples

Geochemical models indicate that the primitive magma or derivatives thereof, were injected into the felsic lower crust. Late Miocene extension of the Rio Grande rift and the increased left-slip component of faulting along the Jemez lineament could have resulted in thinning of the crust (Cordell, 1982), which may have facilitated injections of magma into the felsic lower crust. Fractionation of the magma and assimilation of felsic lower crust generated the compositions of magma represented by trend 2.

The magma chamber(s) of the Bearhead Rhyolite can be modeled as having developed from injection(s) of trend 1-type magma into the upper crust. Trend 3 represents these magmas.

CONCLUSIONS

Major element, trace element, electron microprobe, and isotope data have resulted in a more complete view of the geochemical composition of the Keres Group suite. Located in north-central New Mexico, the Keres Group suite is a good test case for petrogenetic models of continental magmatism. AFC models indicate that the Keres Group suite is best represented by injections of an OIB-type mantle magma into at least three compositionally distinct levels of the crust. Assimilation of mafic lower crust, felsic lower crust, or upper crust material occurred simultaneously with fractionation of the magmas.

The parameters used in the AFC models of the Keres Group suite are not necessarily applicable to other lithologic groups of the Jemez Mountains volcanic field, but AFC models with similar constraints and/or end members may readily apply. AFC models have been attributed to the evolution of the Polvadera Group (Singer and Kudo, 1986), and the compositions of the end members for the Keres Group suite are consistent with those required for the younger Bandelier Tuff and Cerros del Rio basalts (Skuba, 1990; Duncker et al., 1991).

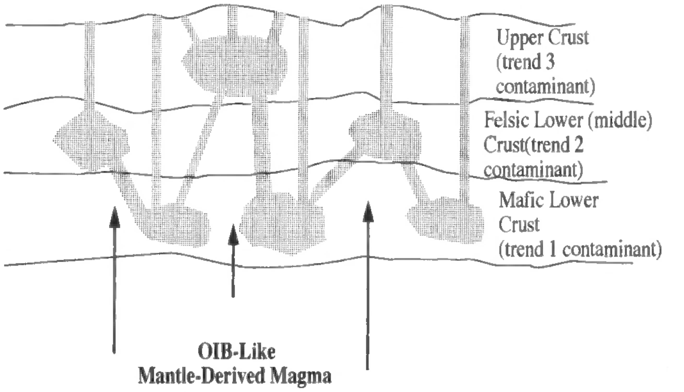

FIGURE 8. Schematic cross section of the Jemez Mountains volcanic field, as suggested by AFC models of the Keres Group suite. Topographic profile is also schematic.

The Keres Group is of interest to the evolution of the Jemez Mountains volcanic field because it has recorded the contribution of three distinct compositions of the crust to magma gneiss. Petrogenetic models have also constrained a point at which mafic magmas may have begun to assimilate felsic, rather than mafic lower crust, suggesting significant modification of crust during the early stages of volcanism. AFC petrogenetic models represent the geochemical composition of Keres Group samples, whereas models for multiple source magmas (Perry et al., 1987, 1990) and crustal hybridization (Johnson et al., 1990) do not readily explain the isotopic variation of the Keres Group suite (Ellisor, 1995). The Keres Group-type AFC model constraints may apply to younger rocks of the Jemez Mountains volcanic field (e.g., Cerros del Rio basalts).

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