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MIOCENE RHYOLITIC VOLCANISM IN THE SOCORRO AREA OF NEW MEXICO

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INTRODUCTION

During the post-20 my. development of the Rio Grande rift, basaltic volcanism has been widespread, both within the rift and in surrounding areas of New Mexico and Colorado (Christiansen and Lipman, 1972; Leeman, 1982; Elston and Bornhorst, 1979; Baldridge, 1979). These basaltic lavas are variable in composition and both tholeiitic and alkalic varieties have been described (Lipman, 1969; Aoki and Kudo, 1976; Baldridge, 1979; Warren and others, 1979). Rhyolitic rocks younger than 20 my. occur in only a few places in the Rio Grande rift. These areas include the Taos Plateau (Lipman and Mehnert, 1979), Jemez volcanic field (Smith, Bailey, and Ross, 1970), and the Socorro area (Chapin and others, 1978). This paper is a progress report on a detailed chemical study of the Miocene, rift-related rhyolites of the Socorro area. K-Ar ages cited herein are from Osburn and Chapin (1983) unless otherwise noted.

Tertiary volcanism has been widespread in the Socorro area since about 39 my. ago. The earliest phase of volcanism consists of widespread calc-alkaline andesites, with rhyodacite and rhyolite ash-flow tuffs locally interbedded in the upper third of the sequence (Osburn and Chapin, this guidebook). Bimodal rhyolite and basaltic andesite volcanism replaced the calc-alkaline volcanism about 32 m.y. ago (Elston and Bornhorst, 1979; Osbum and Chapin, this guidebook). This sequence consists of interbedded rhyolite to high-silica rhyolite ash-flow tuffs and basaltic-andesite lava flows. Ash-flow volcanism ended about 27 m.y. ago and basaltic-andesite volcanism about 24 my. ago; 24- to 18-my-old volcanic rocks are sparse in the Socorro area. Following this volcanic lull, moderately voluminous silicic lavas began to be erupted near Magdalena. Rhyolitic volcanism continued sporadically at several eruptive centers until about 7 my. ago. Basaltic volcanism began prior to the rhyolitic eruptions and continued until at least Pliocene time (4 my., Bachman and Mehnert, 1978) as scattered small-volume basalt and basaltic andesite flows.

The location of vents and domes for the 18 to 7 my. old silicic and mafic lavas is believed to be controlled largely by the Morenci lineament (called the transverse shear zone in this area, Chapin and others, 1978), and caldera-margin ring-fracture zones (Chapin and others, 1978; Chamberlin, 1980; fig. 1). At lower- to middle-crustal depths the Morenci lineament provides a less resistant path for rising magma, while at shallow, upper crustal depths, the caldera ring fracture zones are a zone of weakness allowing magmas easier access to the surface.

FIELD RELATIONSHIPS AND PETROGRAPHY

Previous field studies of the Socorro-Magdalena area have defined several areas where Miocene rhyolitic and basaltic lavas are interbedded with basin-filling sedimentary sequences of the Santa Fe Group. For this study, the Miocene rhyolites have been informally grouped into four centers based on the general location of clusters of vents for the flows. Figure 1 shows the location of the four volcanic centers, the approximate aerial extent of rhyolitic and basaltic rocks within these centers, and the associated vents. Previous field studies have clearly defined the stratigraphic relationships in most of these areas and these relationships have been largely confirmed during reconnaissance and sampling for this study. Exceptions are the northern part of Squaw Peak center and the vent area for the Magdalena Peak center which were unmapped. The Magdalena Peak vent area was mapped in detail during this study and it was found that more flows could be defined in the Magdalena Peak center than indicated by Allen (1979). In addition, a small area of lava near Squaw Peak was found to have been miscorrelated by Donze (1980). The small outcrop southwest of Squaw Peak correlates with the rhyolites exposed near Alameda Springs and not with the Squaw Peak rhyolites. Only the northern part of the Squaw Peak center remains unmapped.

Three petrographic groups of rhyolitic rocks have been recognized. The most voluminous group is a porphyritic rock containing 8 to 15 percent plagioclase phenocrysts and 2 to 4 percent amphibole and/or biotite. In the field, these rocks can be separated into subgroups which contain either amphibole or biotite as the major mafic phase. Chemically, the rocks containing amphibole with only minor biotite are dacites and those containing more abundant biotite are rhyolites. Within the rhyolites, the silica content increases as the proportion of biotite to amphibole increases. The second group of rocks are rhyolites with typical rhyolitic phenocryst assemblages. These rocks contain between 20 and 25 percent phenocrysts consisting of subequal amounts of plagioclase, sanidine, and quartz, plus a few percent biotite. The third group, represented by only a few domes, is a high-silica rhyolite containing 1 to 10 percent phenocrysts of quartz, sanidine, plagioclase, and minor biotite. Several mafic lavas, spanning the range from basalt to high-K andesite (fig. 3) were also analyzed. These lavas are typically fine grained, have pilotaxitic to trachytic groundmass textures, and contain 10 to 20 percent phenocrysts of plagioclase, olivine, and/or pyroxene (table 1). Stratigraphically, all the mafic lavas occur below the associated salic lavas except the basalt of Bear Canyon which occurs stratigraphically above the rhyolites.

Chemical analyses of the rocks generally show chemical groups similar to the petrographic groups: Minor differences in chemistry between centers probably represent small changes due to local differentiation or small variations in source material. In the following discussion chemical rock names are used; comparison between petrography and chemistry is given in Table 1.

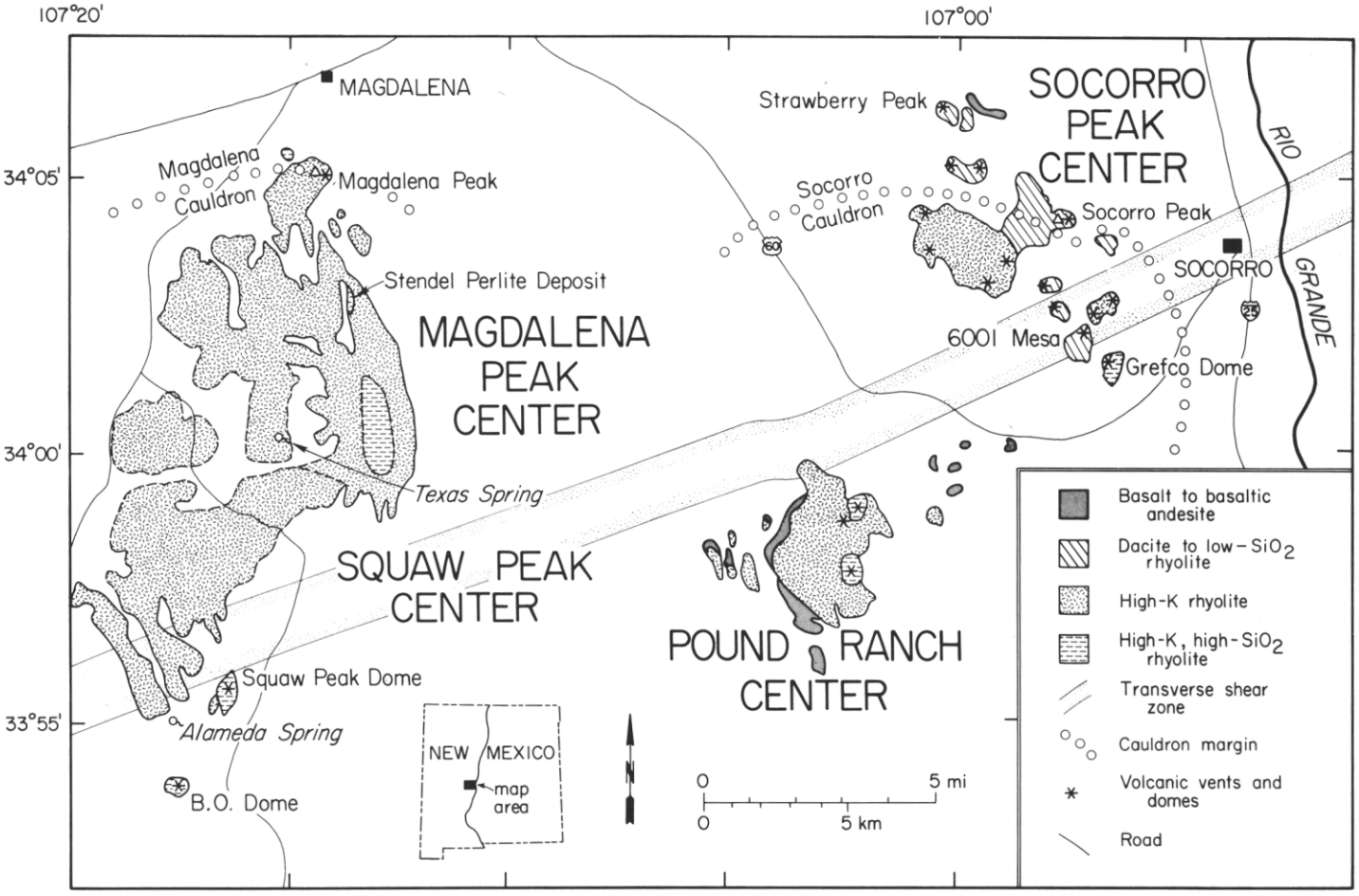

Figure 1. Distribution of middle to late Miocene volcanic rocks of the Socorro-Magdalena area.

FIELD OCCURRENCES

Socorro Peak Center

In the Socorro Peak center (fig. 1) the lavas were erupted onto the floor of a playa in the Popotosa basin, contemporaneously with deposition of upper Popotosa sediments (Chamberlin, 1980). Structural controls for volcanism were the transverse shear zone and the 33-my.-old Socorro cauldron margin. The vents and domes for the lavas are located within a few kilometers of the transverse shear zone and form an arc roughly paralleling the ring-fracture zone of the Socorro cauldron (fig. 1).

The oldest volcanic rocks are the volumetrically small (0.02 km3), xenocryst-rich, high-K basaltic andesite of Kelly Ranch. East of Strawberry Peak and northwest of Socorro Peak, faulted outcrops of Kelly Ranch dip under landslide deposits surrounding the rhyolitic domes which cap these peaks. Thus, the basaltic andesite of Kelly Ranch is interpreted to be stratigraphically below the Socorro Peak Rhyolite (Chamberlin, 1980). Although a K/Ar age of 9.3 my. on the basaltic andesite of Kelly Ranch is younger than the dacites, a fission-track age of 11.9 my. (Kim Manley, unpublished data) on a stratigraphically higher dacitic tephra (Chamberlin, 1980), petrographically correlative to the high-K dacites, implies an age for the basaltic andesite of at least 12 my. The dacites are overlain by porphyritic, high-K rhyolites and finally by the 7-my-old high-K, high-silica rhyolite of the recently exhumed Grefco Dome (Chamberlin, 1980). Lavas of the Socorro Peak center are therefore characterized by a trend of increasing SiO, with time.

Pound Ranch Center

The eruptive sequence in the Pound Ranch center consists of an older basic unit (the basalt of Madera Canyon), followed by the upper and lower rhyolites of Pound Ranch, and finally the basalt of Bear Canyon (Osburn, 1978; figs. 1 and 2). The age of the basalt of Madera Canyon is poorly constrained. It overlies the 27-my-old tuff of South Canyon and is in turn overlain by the 10.8-my-old upper rhyolite of Pound Ranch (fig. 2; Osburn 1978).

The 12.1-m.y.-old lower rhyolite of Pound Ranch occurs at two separate outcrops, both are topographically higher than the surrounding upper rhyolite of Pound Ranch that dips away from the contact. This suggests that the lower unit was a topographically higher dome(s) when the overlying unit was emplaced (Osburn, 1978). The high-K, high-silica lower rhyolite of Pound Ranch is mineralogically similar to the high-K rhyolites of Socorro Peak and to the high-K, high-silica Squaw Peak dome (table 1).

The upper rhyolite of Pound Ranch unconformably overlies all older units above the Lemitar Tuff (28 my.); at one limited exposure the upper Pound Ranch is overlain by upper Popotosa mudstones. The original eastward extent of the upper rhyolite of Pound Ranch is uncertain because it is downfaulted and covered. The upper Pound Ranch consists of a basal black vitrophyre, overlain by a finely flow-banded interval that grades upward into a more massive flow. Mineralogically, it is similar to the Socorro Peak dacites and to the Magdalena Peak dacites and rhyolites (table 1).

The high-K basalt of Bear Canyon is exposed at the top of several small hills to the northwest of the rhyolites. The basalt overlies upper

*Table 1. Field, geochemical, and petrographic characteristics of the stratigraphic units. Abbreviations are: * = after Ewart (1979), Pl = plagioclase, Sa = sanidine, Qtz = quartz, Bt = biotite, Amph = amphibole, Pyx = pyroxene, Ol = olivine, Mag = magnetite, Sph = sphene, Ap = apatite, Zr = zircon, An = anorthite, t = trace.*

	Stratigraphic unit	Field rock type	Geochemical rock type*	Estimated volume km³	Color texture	Phenocryst phases (volume % of whole rock) Pl	Sa	Qtz	Bt	Amph	Pyx	Ol	Mag	Sph	Ap	Zr	Anorthite content of plagioclase
SOCORRO PEAK CENTER	Grefco dome	rhyolite	high-K high-SiO_2 rhyolite	0.05	gray to buff perlitic, glassy	1	.4	.4	t								An_{25}
	rhyolite of Socorro Peak	rhyolite	high-K rhyolite	4.7	light-pink to gray porphyritic	15	4	4	1	.5			.2	t	t	t	An_{22-45}
	dacite of Socorro Peak	dacite	dacite to high-K rhyolite	3.1	reddish-brown to gray, porphyritic to glomeroporphyritic	7-13			.5	2-4			.3		t		An_{24-58}
	basalt of Kelly Ranch	basalt	high-K basaltic andesite	0.02	dark-gray to black microporphyritic, xenocrystic	9					0-5	0-5	.3		t		An_{40-60}
POUND RANCH CENTER	lower rhyolite of Pound Ranch	rhyolite	high-K high-SiO_2 rhyolite	0.7	pale-red to brown coarsely porphyritic	8	6	7	3	.5			.5	t		t	An_{22-37}
	upper rhyolite of Pound Ranch	dacite	high-K rhyolite	4.1	pale-red to gray porphyritic	7-15	t	t	1-2	2-3			.5			t	An_{29-50}
	basalt of Madera Canyon	basalt	basalt to high-K andesite	1.0	dark-gray microporphyritic to porphyritic	3-15					4-11	0-5	.5		.5		An_{49-70}
	basalt of Bear Canyon	basalt	high-K basalt	0.1	greenish-black to ochre, sugary	8					0-3	0-3	t		1		An_{52-58}
MAGDALENA PEAK CENTER	dacite of Magdalena Peak	dacite	high-K dacite	0.2	light-gray to medium-gray, porphyritic	9			t	3	t		.5		t		An_{43-48}
	rhyolite of Magdalena Peak	dacite	high-K rhyolite	11 to 17	light-brown to pinkish-gray, porphyritic	5-13	0-3	0-3	2	1-3			t	t		t	An_{25-44}
	rhyolite of Alameda Springs	dacite	high-K rhyolite		pinkish-brown porphyritic	6	t	t	3	2	t		t	t	t	t	An_{25-35}
	rhyolite of Stendel prospect	rhyolite	high-K high-SiO_2 rhyolite	no data	medium-gray to pink perlitic, porphyritic	3	2	2	.5	t			t			t	An_{21-30}
SQUAW PEAK CENTER	rhyolite of McDaniel Tank	rhyolite	high-K high-SiO_2 rhyolite	4.1	medium-gray microporhyritic	2	1		1							t	An_{20}
	Squaw Peak dome	rhyolite	high-K high-SiO_2 rhyolite	0.5	light-pink to light-gray, porphyritic	4	7	8	1	t			t			t	An_{21-26}
	B.O. Ranch dome	rhyolite	high-K high-SiO_2 rhyolite	0.6	light-gray microporphyritic	.5	1	2	t				t			t	no data

Popotosa mudstones and is overlain by sands and conglomerates, possibly of the upper Santa Fe Group (Osburn, 1978).

Magdalena Peak Center

Four distinct lava flows can be delineated at the Magdalena Peak center, although chemical analyses suggest that there may be more than four. The high-K rhyolites of Magdalena Peak are the most voluminous unit with an estimated volume of 11 to 17 km' (table 1). Beneath the rhyolite is a volumetrically minor (<0.5 km') high-K dacite. The dacite and rhyolite lavas overlie the upper Popotosa Formation. Their source vent is marked by a prominent plug that is exposed on the east face of Magdalena Peak.

The rhyolite of Alameda Springs (Bobrow, 1983) is an informal name for the Magdalena Peak-like rhyolite found at Alameda Springs (Donze, 1980), approximately 20 kilometers south of Magdalena Peak. It also occurs at Texas Spring and above the Stendel perlite deposit (fig. 1) nearer to Magdalena Peak. Although mineralogically similar to other Magdalena Peak rhyolites it differs chemically (table 2). The flow probably originated from Magdalena Peak and moved south within a topographic basin (Allen, 1979), reaching at least to Alameda Springs (fig. 1). Near Squaw Peak this unit unconformably overlies the Popotosa Formation. It also lies unconformably on previously tilted strata of the Lemitar tuff (28 m.y.), early Miocene andesitic lavas, the early Miocene lower Popotosa Formation, and the early Miocene rhyolite of McDaniel Tank (Donze, 1980).

The rhyolite of Stendel perlite deposit is an informal name for the high-K, high-silica rhyolite which occurs at the Stendel perlite deposit (Weber, 1957) and to the south (Bobrow, 1983; fig. 1). The source vent for this flow has not been located.

Squaw Peak Center

Three distinct mid- to late-Miocene rhyolite flows and domes are present in the Squaw Peak area (table 1, fig. 2). The oldest is the finely flow-banded, phenocryst-poor, high-K, high-silica rhyolite of McDaniel Tank (18.3 m.y.) that blankets the northern part of the Squaw Peak area (fig. 1). It is interbedded with the Popotosa Formation and is

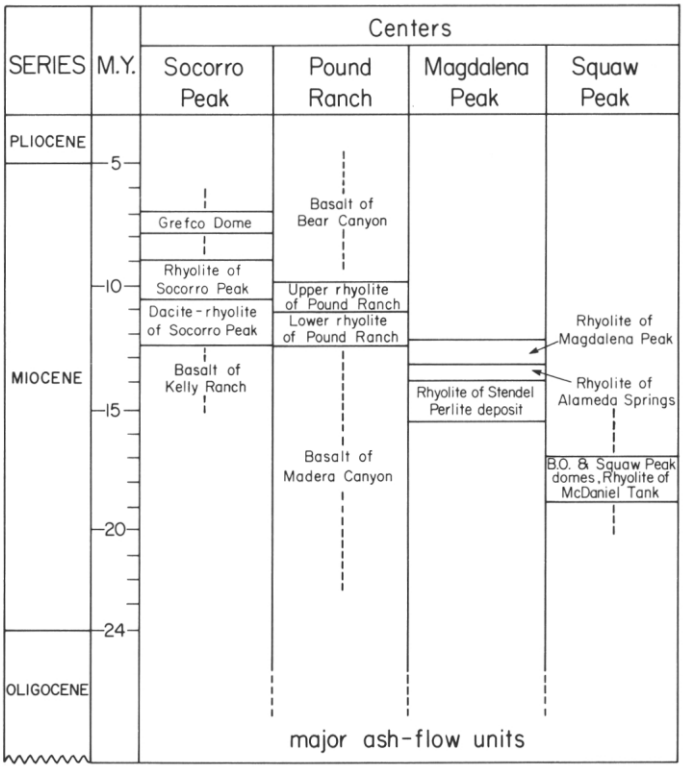

Figure 2. Stratigraphic equivalence chart for Miocene rhyolitic centers in the Socorro area. Dashed lines indicate ranges of uncertainty in ages of units.

unconformably overlain by the 16. 1-my-old rhyolite of Alameda Springs from the Magdalena Peak center.

The B.O. Ranch high-K, high-silica, phenocryst-poor rhyolite dome occurs south of Squaw Peak where it is interbedded in the Popotosa Formation and overlies early Miocene andesites that overlie the 27-my-old South Canyon Tuff (Donze, 1980).

Squaw Peak is a prominent high-K, high-Si02, moderately crystal-rich rhyolite dome; its age constraints are similar to those for the B.O. Ranch dome. The B.O. Ranch and Squaw Peak domes, although they differ mineralogically, have similar chemical compositions and are therefore grouped together in Table 2.

GEOCHEMISTRY

More than 150 samples were analyzed for major-element composition by X-ray fluorescence (XRF) using a modified version of the Norrish and Hutton (1969) procedure. Analyses have been normalized to 100 percent volatile free with the total iron expressed as FeO* (table 2). Representative samples were also analyzed for selected trace elements (table 2) by XRF. A complete list of the analytical data, along with additional trace-element analyses made by instrumental neutron-activation analysis, are available in Bobrow (1983).

Samples examined in this study have been classified using the K20 versus SiO, plot of Ewart (1979) (fig. 3), with rhyolites containing 74 percent or more SiO, classified as high-silica rhyolites. The majority of the dacites and rhyolites fall in the high-potassic fields; a few samples fall in the dacite and rhyolite fields. Representative analyses of the basalt-to-andesite suite are also plotted in Figure 3.

Average analyses of the salic lavas from the four volcanic centers are given in Table 2. The main features of the major- and trace-element chemistry are displayed on representative Harker variation diagrams using SiO, as the abscissa (figs. 4 and 5). The basic lavas have been omitted for the sake of clarity.

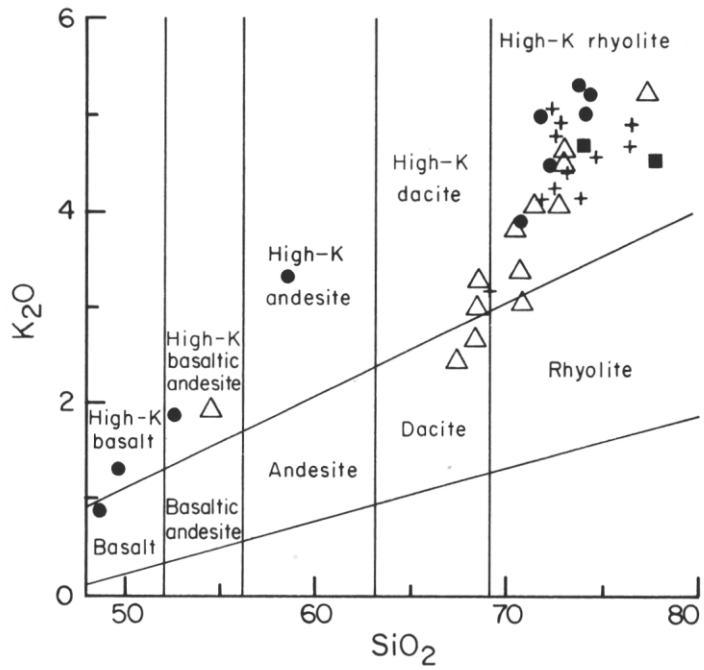

Figure 3. K_2O versus SiO_2 plot modified from Ewart (1979) and used here to classify the salic rocks. All analyses are calculated as volatile free. Symbols are: open triangles = Socorro Peak center, solid circles = Pound Ranch center, crosses = Magdalena Peak center, solid squares = Squaw Peak center.

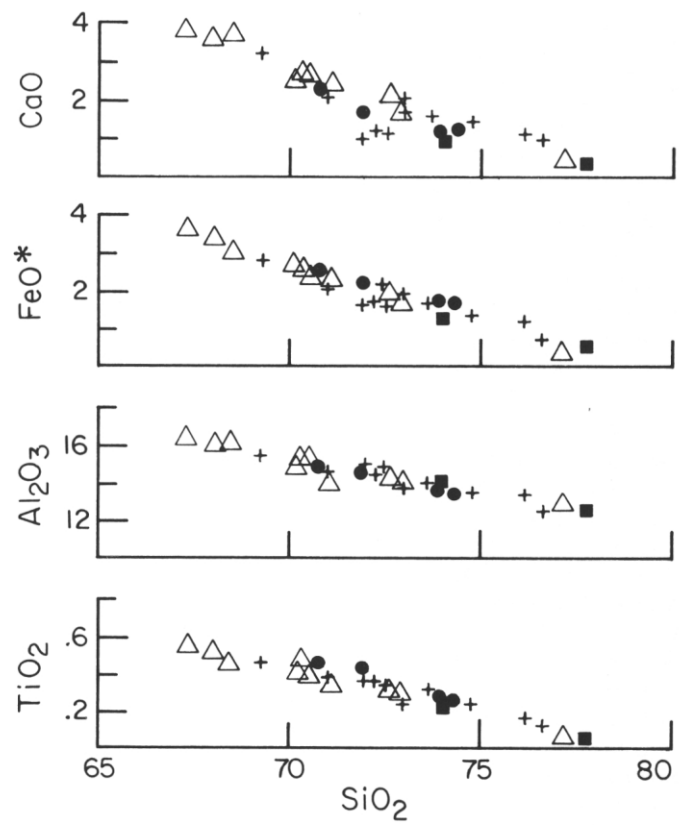

Figure 4. Representative major-element variation diagrams. All analyses are calculated as volatile free and total iron is expressed as FeO. Symbols are: open triangles = Socorro Peak center, solid circles = Pound Ranch center, crosses = Magdalena Peak center, solid squares = Squaw Peak center.*

*Table 2. Average chemical analyses of middle to late Miocene salic lavas from the Socorro-Magdalena area. Values in parentheses express one standard deviation. Major element analyses calculated as volatile free. * = total iron expressed as FeO*. n = number of samples averaged.*

	POUND RANCH		SOCORRO PEAK				MAGDALENA PEAK			SQUAW PEAK	
Strata. unit	Upper Rhyolite of Pound Ranch	Lower Rhyolite of Pound Ranch	Dacite of Socorro Peak	Rhyolite of Socorro Peak	Grefco Dome	Dacite of Magdalena Peak	Rhyolite of Magdalena Peak	Rhyolite of Alameda Springs	Rhyolite of Stendel prospect	Rhyolite of McDaniel Tank	Squaw Peak & B.O. Ranch Domes
Major Elements (wt%)											
n	6	3	10	3	1	2	9	7	2	2	2
SiO_2	71.75(0.5)	74.11(0.2)	69.59(1.4)	72.77(0.1)	77.12	69.77(0.8)	72.82(1.5)	72.30(0.2)	76.45(0.3)	73.95(0.1)	77.47(0.1)
TiO_2	0.45(.02)	0.28(.02)	0.46(.08)	0.31(.01)	0.05	0.41(.07)	0.33(.05)	0.36(.01)	0.15(.04)	0.25(.01)	0.08(.01)
Al_2O_3	14.62(.27)	13.74(.10)	15.63(.63)	14.30(13)	12.99	15.62(.18)	14.40(.72)	14.71(.04)	13.15(.52)	14.24(.21)	12.76(.11)
FeO*	2.28(.26)	1.67(.03)	2.87(.43)	1.96(.08)	0.46	2.65(.29)	1.80(.33)	1.73(.05)	1.00(.23)	1.23(.05)	0.56(.03)
MnO	0.06(.01)	0.04(.01)	0.05(.02)	0.05(.01)	0.09	0.05(.01)	0.05(.01)	0.08(.01)	0.04(.01)	0.08(.01)	0.07(.01)
MgO	0.47(.16)	0.34(.05)	0.75(.32)	0.54(.07)	<0.01	1.15(.01)	0.61(.20)	0.35(.05)	0.21(.10)	0.23(.06)	<0.01(.01)
CaO	1.94(.28)	1.24(.05)	3.29(.55)	1.99(.14)	0.52	3.15(.05)	1.91(.39)	1.16(.05)	1.04(.06)	0.09(.02)	0.42(.01)
Na_2O	3.70(.20)	3.31(.09)	3.89(.16)	3.52(.09)	3.48	3.83(.26)	3.74(.33)	4.33(.22)	3.15(.52)	4.52(.13)	4.02(.03)
K_2O	4.60(.51)	5.18(.12)	3.33(.55)	4.45(.29)	5.28	3.24(.05)	4.24(.34)	4.89(.25)	4.78(.17)	4.55(.24)	4.60(.08)
P_2O_5	0.13(.01)	0.08(.01)	0.14(.01)	0.09(.01)	0.01	0.13(.02)	0.09(.01)	0.08(.01)	0.03(.01)	0.05(.02)	0.01(.01)
Trace elements (ppm)											
n	5	3	10	3	1	2	8	7	2	2	2
Rb	141(27)	193(7)	66(10)	91(2)	256	66(6)	102(19)	150(4)	143(18)	170(4)	372(11)
Sr	338(44)	199(6)	441(43)	242(21)	2	633(32)	350(103)	184(12)	132(37)	134(16)	4(1)
Y	31(2)	30(3)	22(2)	24(5)	37	17(3)	23(3)	40(1)	17(1)	43(1)	45(11)
Zr	189(10)	174(1)	169(19)	147(18)	76	136(17)	151(26)	282(14)	94(15)	255(2)	77(6)
Nb	21(1)	26(1)	10(1)	15(2)	34	12(4)	15(1)	35(1)	14(1)	43(2)	72(8)
Pb	20(1)	21(1)	16(1)	19(1)	35	15(3)	21(3)	24(2)	29(1)	24(2)	32(2)
Th	15(1)	25(1)	4(2)	7(1)	21	6(2)	10(3)	21(1)	17(2)	24(1)	42(4)

Socorro Peak Center

The eruptive sequence in the Socorro Peak center was bimodal, with the high-K basaltic andesite of Kelly Ranch containing about 55 percent Si02 in contrast to the salic lavas which range from 68 to 77 percent SiO2. Although the basalts are volumetrically small, their close spatial relationships to the younger, more voluminous salic lavas suggests there may be a genetic relationship. Geochemically, the Kelly is a high-K basaltic andesite (fig. 2) with calc-alkaline affinities. The presence of gabbro and quartzite zenoliths as well as quartz xenocrysts suggest that contamination may mask the original magma composition.

The salic lavas at the Socorro Peak center display the most complete range in composition of the four centers studied. The major elements, excluding Na20 and K20, show excellent negative linear covariance when plotted against Si02 (fig. 4). Na20 and K20 show positive linear covariations with SiO2. Some scatter observed for MgO and MnO may be due to analytical errors and/or secondary remobilization such as weathering or hydrothermal alteration.

The trace elements show obvious trends which in many cases are not linear. Sr, for example, remains constant at about 450 ppm from 68 percent to 71 percent SiO, and then decreases (fig. 5). Zr, on the other hand, decreases in a linear fashion. Y, Nb, Rb, Pb, and Th all show positive covariations when plotted against SiO2.

Pound Ranch Center

The eruptive sequence at the Pound Ranch center is also bimodal. There is, however, limited age control on the basalt of Madera Canyon and the basalt of Bear Canyon which underlie and overlie the rhyolites, respectively. Although spatially related, it is uncertain if a genetic relationship exists between the basalts and rhyolites. The basalts are variable chemically and mineralogically. The basalt of Madera Canyon consists of three flows which vary from basalt, to high-K basaltic andesite, to high-K andesite (fig. 3). The basalt of Bear Canyon is a high-K basalt using the Ewart (1979) classification. As the basalt contains normative nepheline (6 percent) and olivine (17 percent), it is undersaturated and can be classified as an alkali olivine basalt or basanitoid (Irvine and Baragar, 1971). The chemistry suggests that it may be related to the young alkalic basalts found in the Rio Grande rift.

Insufficient chemical variation exists within the upper and lower rhyolite of Pound Ranch to develop meaningful major- and trace-element variation trends (figs. 4 and 5). Major-element plots representing these silicic flows fall within the composite trend lines that represent the four eruptive centers (fig. 4).

Magdalena Peak Center

The Magdalena Peak center consists of three stratigraphic units: (1) the Magdalena Peak Rhyolite, which consists of a high-K dacite flow containing 69 percent SiO, and high-K rhyolite flows with SiO, contents ranging from 70 to 75 percent; (2) the rhyolite of Alameda Springs, which is a high-K rhyolite; and (3) the rhyolite of the Stendel perlite deposit, which is a high-K, high-silica rhyolite.

Considerable spread in both major and trace elements is present in analyses of the high-K rhyolite from Magdalena Peak; the spread is greater than the variation seen in samples from a single flow at any one location. Therefore, we suggest that, although field observations

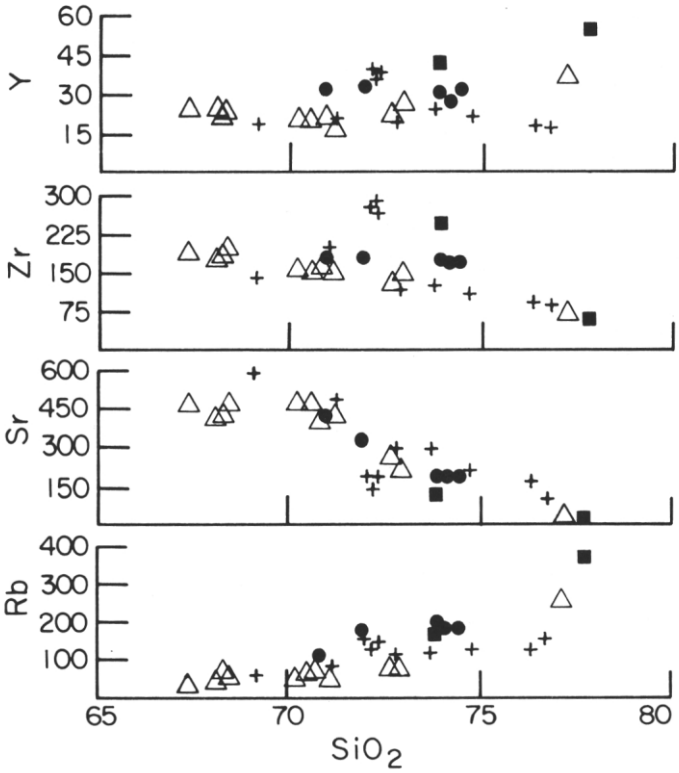

Figure 5. Representative trace-element variation diagrams. Symbols are: open triangles = Socorro Peak center, solid circles = Pound Ranch center, crosses = Magdalena Peak center, solid squares = Squaw Peak center.

indicate only one flow for the rhyolite of Magdalena Peak, the chemistry suggests that there are probably more.

Analyses of all lavas of the Magdalena Peak center exhibit linear trends on major element plots (fig. 4) similar to the Socorro Peak center, with one exception. The rhyolite of Alameda Springs averages 72.5 percent SiO, and has lower FeO, MgO, CaO and higher K20 values than the rhyolite of Magdalena Peak with equivalent SiO2 content (table 2, fig. 4).

On trace-element plots against SiO2, the high-K rhyolite of Alameda Springs once again plots off the trends defined by the other lavas of the Magdalena Peak center with higher Zr, Y, Rb and lower Sr values (fig. 5). For the other lavas of the Magdalena Peak center, Zr and Sr show excellent negative linear trends with increasing Sig, whereas, Rb, Th, and Pb exhibit positive covariance with SiO, (fig. 5). Y and Nb concentrations change little throughout the range in SiO, (fig. 5).

Squaw Peak Center

The rhyolite of Squaw Peak dome and the rhyolite of B.O. Ranch dome are both high-K, high-silica rhyolites. The phenocryst assemblage is similar in both units although the phenocryst proportions and sizes differ markedly (table 1). The Squaw Peak and B.O. Ranch rhyolites are also similar chemically and analyses from both units have been averaged in Table 2; they are plotted as a single point in figures 4 and 5. These two rhyolites are the most silica-rich lavas found in the Socorro area, a factor which could account for them forming domes rather than flows. The major-element composition of the rhyolites of Squaw Peak and B.O. Ranch lie on the trend lines defined by the other salic lavas of the Socorro area (fig. 4). Their trace element compositions show enrichment in Y, Nb, Th, and Rb compared to the other rhyolites of the Socorro area, whereas the Sr content is extremely low (table 2).

The high-K rhyolite of McDaniel Tank has a similar major-element composition to the lower Pound Ranch rhyolite; however, it has a different trace element composition. Y, Zr, and Nb values are higher and Rb and Sr are lower in the rhyolite of McDaniel Tank compared to the lower Pound Ranch rhyolite (table 2, fig. 5).

PETROGENESIS

At the time of this writing, trace element analyses, particularly foi the rare earth elements, have not been completed. Therefore, it premature to make definitive statements about the petrogenesis of the rhyolites. However, there are sufficient data to make some preliminary observations and to suggest several alternative processes which may have occurred.

The most obvious feature of the geochemistry is that all four volcanic centers are very similar in composition (fig. 4). On major-element plot they appear to define a single evolutionary trend with one exception—the rhyolite of Alameda Springs has a lower CaO content. Trace-element data (fig. 5) are not so coherent and there are small, but apparent. differences between each center. For example, trends for Y shown by the Magdalena Peak and Socorro Peak centers appear to diverge at higher SiO2 values.

Four Sr-isotope analyses are available of the lavas (table 3). The basalt of Kelly Ranch is similar isotopically to the dacite from the Socorro Peak center. Two rhyolite samples, one from the Socorro Peak center and the other from the Pound Ranch center, have similar but higher strontium-isotope ratios than the other two rocks. Significantly. the rhyolites have lower initial 87Sr/"Sr ratios than the voluminow Oligocene ash-flow tuffs of the Mogollon-Datil volcanic field (Stinnett. 1980).

Geochemically, isotopically, and petrographically (table 1), the rhyolites are generally similar. It is, therefore, likely that the processes controlling the evolution of the rhyolitic magmas were similar for eact: center. However, as the rocks span a considerable period of time. possibly as much as 10 my., they must represent a series of discrete magma pulses.

Because the lavas from the Socorro Peak center represent the most complete sequence, we can examine them in more detail as a mode for the other eruptive centers. Basalts are found in the Socorro Peak and Pound Ranch centers, but it is not clear that the basalts are genetically related to the rhyolites. Tentatively, we suggest that the basalt of Kelly Ranch is genetically related to the rhyolitic rocks from the Socorro Peak center for the following reasons: (1) it is isotopically (Sr: similar to a dacite from Socorro Peak (table 3), and (2) the basalt h temporally and spatially related to the dacites and rhyolites.

The linear trends seen for the major elements and for some trace elements are typical of those resulting from magma mixing. However. we do not believe magma mixing to be an important process for the evolution of the Socorro rocks even though some petrographic evidence. namely basic plagioclase xenocrysts in the dacites and rhyolites (table

*Table 3. Sr-isotope analyses of samples from the Socorro Peak and Pound Ranch centers. * = determined by XRF (this study). ** = Chapin and others, 1979.*

Sample	Stratigraphic Unit	Age (m.y.)	Rb (ppm)*	Sr (ppm)*	Measured** $^{87}Sr/^{86}Sr$	Initial $^{87}Sr/^{86}Sr$
76-6-3	rhyolite of Socorro Peak	9.2	90	225	0.7065	0.7064
76-6-1a	dacite of Socorro Peak	12.1	62	434	0.7050	0.7049
76-1-9	basalt of Kelly Ranch	∿12.0	38	588	0.7051	0.7051
77-3-1	lower rhyolite Pound Ranch	12.1	185	203	0.7070	0.7066

1), support a mixing model. The general similarities of the initial "Sr/86Sr ratios preclude mixing of a mantle-derived basalt with a high-silica rhyolitic magma derived from melting of the upper crust. Also, the non-linear trends for some trace elements are not compatible with simple mixing.

Although partial melting of a lower crustal source cannot be precluded, the low initial "Sr/"Sr ratios would imply an unusual source. Partial melting of underplated, mantle-derived basalt would be a suitable source material as long as the time between underplating and partial melting was relatively short.

At this time, the most favored model for the evolution of the rhyolitic suite is one involving fractional crystallization, possibly with minor contamination from crustally derived components to account for the slightly elevated initial 8Sr/86Sr ratio. Some mixing may also have occurred to account for the xenocrysts in the rhyolitic rocks. Preliminary mass-balance modeling supports the derivation of a high-K rhyolite from Socorro Peak by removal of plagioclase, amphibole, Fe-Ti oxides, and apatite from a dacite. Due to the large compositional gap between the basalt and the dacite of Socorro Peak, it is difficult to model the evolution of the dacite from the basalt by crystal fractionation; however, the data do not preclude the possibility of such a process.

Crystal fractionation is therefore considered to be the main process controlling the evolution of the salic rocks in all four volcanic centers. The slight differences in trends observed for the trace elements probably reflect slight differences in the compositions and amounts of phases fractionated.

SUMMARY

Following an early- to mid-Miocene volcanic lull (24 to 18 m.y. ago) in the Socorro area there was a marked change in the nature of volcanism from assemblages dominated by basaltic andesites and rhyolitic ash-flow tuffs to smaller volume, bimodal, basaltic and high-K rhyolitic lavas. Although the younger basaltic rocks are poorly represented in the Socorro area, they appear to be genetically related to the rhyolitic rocks. Preliminary data suggest that the rhyolitic rocks evolved by fractional crystallization from a mantle-derived basalt, with some crustal contamination and magma mixing processes also involved in their evolution.

Mineralogically and chemically, the bimodal volcanic rocks in the Socorro area are similar to Ewart's (1979) Tertiary to Recent bimodal suites of the western United States. These bimodal suites may be the volcanic expression of a period of widespread late Cenozoic (17 my. to present) extension in the southern Basin and Range province and the Rio Grande rift (Lipman, 1980), which followed an earlier (32 to 18 my.) extensional period when volcanism was controlled by back-arc extension related to subduction of the Farallon plate (Elston and Bornhorst, 1979).

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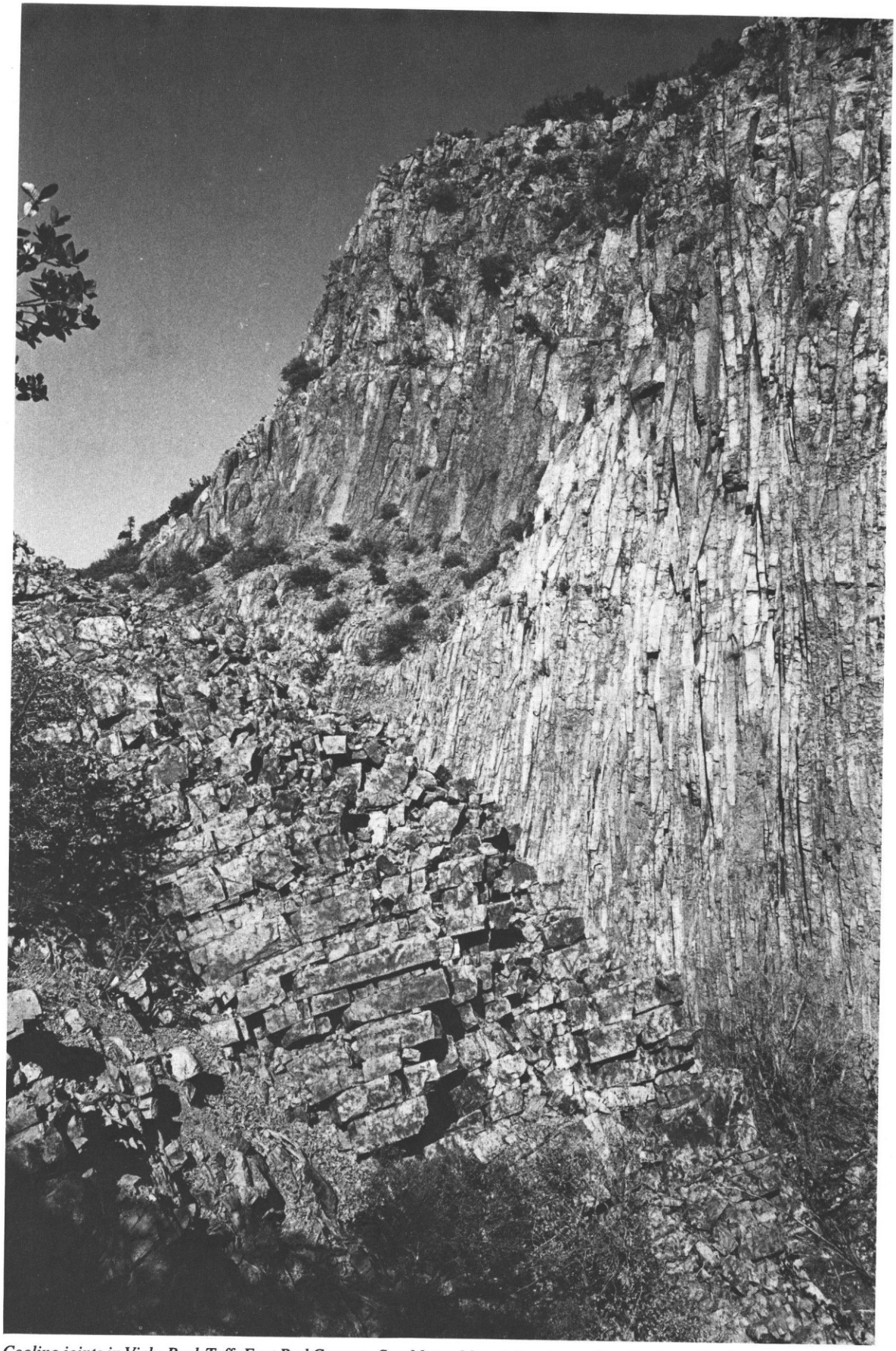

Cooling joints in Vicks Peak Tuff, East Red Canyon, San Mateo Mountains. Anomalous horizontal columns in foreground probably formed along wall of a buried paleovalley. Photo by Bob Osburn.