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1988, pp. 89-98. https://doi.org/10.56577/FFC-39.89

in:

Cretaceous and Laramide Tectonic Evolution of Southwestern New Mexico, Mack, G. H.; Lawton, T. F.; Lucas, S. G.; [eds.], New Mexico Geological Society 39th Annual Fall Field Conference Guidebook, 216 p.
https://doi.org/10.56577/FFC-39

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GEOCHEMISTRY OF THE BURRO MOUNTAINS SYENITES AND ADJACENT PROTEROZOIC GRANITE AND GNEISS AND THE RELATIONSHIP TO A CAMBRIAN-ORDOVICIAN ALKALIC MAGMATIC EVENT IN NEW MEXICO AND SOUTHERN COLORADO

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Abstract—More than 12 brick-red, lenticular to elongate bodies of syenite occur scattered throughout Proterozoic granite and quartzofeldspathic gneiss in the Burro Mountains, southwestern New Mexico. The syenites consist of microcline with subordinant quartz, muscovite, hematite, chlorite and plagioclase. A few syenites consist of subequal amounts of microcline and plagioclase. Accessory minerals include apatite, zircon, calcite, fluorite and magnetite. Pervasive hematitization has obscured the textures and mineralogy of most syenites. Compositions range from syenite to quartz syenite to alkali granite. Two distinct geochemical groups of syenites occur: high-K (9–15% K_2O, 0.3–1.5% Na_2O) and high-Na (4–9% K_2O, 3–6% Na_2O) syenites. Both groups are relatively high in Al_2O_3 (12–18%) and low in SiO_2 (58–71%). The granites contain 69–78% SiO_2, 3–6% K_2O, 3–5% Na_2O and 12–15% Al_2O_3, whereas the gneisses contain 62–82% SiO_2, 3–9% K_2O, 0.4–3% Na_2O and 9–13% Al_2O_3. Outcrop relationships, textures, trace element distributions and high K_2O/Na_2O ratios suggest that the high-K syenites are a result of potassium metasomatism of either a high-Na syenite and/or adjacent granite and gneiss. The syenites may be part of a widespread alkalic magmatic event, characterized by carbonatite dikes, syenites and metasomatism, that affected New Mexico and southern Colorado during late Precambrian to Cambrian-Ordovician times. Radiometric dating of the Burro Mountains syenites is needed.

INTRODUCTION

Recent mapping of various Precambrian outcrops throughout New Mexico indicate that syenites and alkali granites, once thought to be rare in the state, occur in many Precambrian terrains (Fig. 1; Table 1; McLemore, 1987b; Loring et al., 1987). Only a few of these syenites and alkali granites have been dated as Cambrian-Ordovician (Loring and Armstrong, 1980; Evans and Clemons, 1987; Clemons, in press). Syenite bodies have been mapped in the Burro Mountain granite and quartzofeldspathic gneiss of the Bullard Peak Series (Hedlund, 1978a, b, e), that are similar in emplacement, texture and composition to Cambrian-Ordovician syenites in the Florida Mountains (location 15, Fig. 1) and Lobo and Pedernal Hills (locations 9, 10, Fig. 1). Geologic, mineralogic and geochemical studies of the Burro Mountain syenites are part of a regional study of these rocks to characterize them, evaluate their economic potential and suggest a possible tectonic setting and origin.

GEOLOGY

Geologic setting

The Burro Mountains lie in the Mexican highlands section of the Basin and Range physiographic province and are characterized by extensive fault blocks of Proterozoic, Paleozoic, Upper Cretaceous and Tertiary rocks (Fig. 2). The block faulting is predominantly Miocene-Pliocene, although some older reactivated faults are Late Permian-Triassic and Laramide (Stacey and Hedlund, 1983).

The Burro Mountains consist of a complex middle Proterozoic terrain (Fig. 2) with metamorphic rocks of the Bullar Peak Series and Ash Creek Group (1560 ± 50 my) intruded by Proterozoic Burro Mountain granite (1445–1550 my), younger rapakivi granite, tonalite and granodiorite, diabase dikes, syenites of possible Cambrian-Ordovician age and Tertiary rhyolite and diabase dikes and granitic plutons (Hewitt, 1959; Gillerman, 1964, 1970; Hedlund, 1978a–e, 1980; U.S. Geological Survey, 1981; Stacey and Hedlund, 1983; Drewes et al., 1985). Precambrian rocks of similar lithologies and ages are exposed in several other localities in southwestern New Mexico (Condie, 1981; Drewes et al., 1985). The syenites in the Burro Mountains have not been dated but are petrologically similar to Cambrian-Ordovician syenites elsewhere in New Mexico (Fig. 1; Table 1). Mid-Tertiary volcanism and mineralization was extensive in this area and the effect on the geochemistry of the syenites and Proterozoic rocks is unknown.

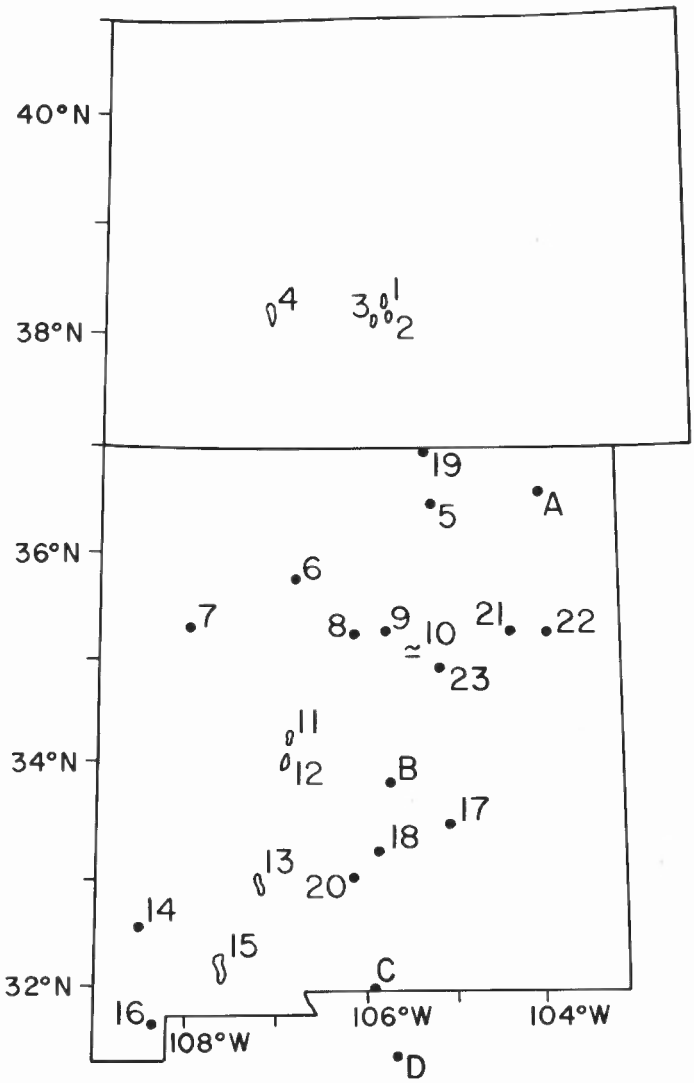


FIGURE 1. Known and possible Precambrian-Paleozoic carbonatite and alkalic rock outcrops in New Mexico and southern Colorado. Locality numbers listed in Table 1 and in the text. Locality letters, representing Tertiary alkalic complexes, are described in the text. Not all outcrops have been dated.

TABLE 1. Known and possible Precambrian-Paleozoic carbonatite and alkalic rock outcrops in New Mexico and southern Colorado. *Locations shown on Figure 1.

No.*	Locality	Age	Method of dating	References
1	McClure Mountains carbonatite - alkalic complex	517-704 m.y.	K-Ar, Rb-Sr, fission-track	Fenton and Faure (1970), Olson et al. (1977), Armbrustmacher (1984)
2	Syenite of Democrat Creek	520-546 m.y.	K-Ar, Rb-Sr, fission-track	Olson et al. (1977), Armbrustmacher (1984)
3	Gem park carbonatite	520-546 m.y.	K-Ar, Rb-Sr, fission-track	Olson et al. (1977), Armbrustmacher (1984)
4	Iron Hill carbonatite complex	550-579 m.y.	K-Ar, Rb-Sr, fission-track	Olson et al. (1977), Fenton and Faure (1970)
5	Sangre de Cristo Mountains syenite and melasyenite	?		Reed et al. (1983), Klich (1983)
6	Nacimiento Mountains syenite	?		Woodward et al. (1977)
7	Zuni Mountains syenite	?		Goddard (1966), Lambert (1983), McLemore (unpublished data)
8	Monte Largo Hills carbonatite	?		Lambert (1961), McLemore (1983)
9	Lobo Hill syenite and carbonatite	640 m.y. (maximum)	Rb-Sr	Loring and Armstrong (1980), McLemore (1984)
10	Pedernal Hills syenite	496 m.y. (maximum)	Rb-Sr	Loring and Armstrong (1980)
11	Lemitar Mountains carbonatite	449±16 m.y.	K-Ar	McLemore (1982, 1983, 1987a)
12	Chupadera Mountains carbonatite	?		McLemore (1983), Kent (1982), Van Allen et al. (1986)
13	Caballo Mountains syenite	?		Staatz et al. (1965), McLemore (1986)
14	Burro Mountains syenite	?		Gillerman and Whitebread (1956), Hedlund (1978a, b, e), this report
15	Florida Mountains syenite and alkali granite	503-550 m.y.	U-Pb	Loring et al. (1987), Evans and Clemons (1987), Clemons (in press)
16	Little Hatchet Mountains granite	605 m.y., 640 m.y.	Zircons	Zeller (1965)
17	Pajarito Mountain	1190±25 m.y.	K-Ar	Kelley (1968), Foord et al. (1983), Moore and Foord (1986)
Miscellaneous Paleozoic igneous rocks				
18	Bent Dome	?		McLemore (unpublished data)
19	Costilla Creek diorite dike	500 m.y.	Rb-Sr	Reed (1984)
20	Houston Oil and Minerals Lewelling No. 2 oil test basalt or andesite.	514±21 m.y.	K-Ar	Loring and Armstrong (1980)
21	Trans-Pecos Resources Latigo Ranch #1A and 1D oil tests gneiss, quartz-feldspar porphyry	720±36 m.y. 604±30 m.y.	K-Ar K-Ar	Setter and Adams (1985)
22	Yates Petroleum T-4 Cattle Co. #1 and #2 granite	376±19 m.y. 664±35 m.y. 766±38 m.y.	K-Ar	Setter and Adams (1985)
23	Rattlesnake Hills basaltic dike	848±42 m.y.	K-Ar	Setter and Adams (1985), Setter (1985)

Bullard Peak Series

The Bullard Peak Series consists of metamorphic sillimanitic quartz-biotite-muscovite gneiss or metapelite, hornblende gneiss and schist, quartzofeldspathic gneiss, granite gneiss and amphibolite. Although these rocks have been described and mapped by numerous geologists (Hewitt, 1959; Gillerman, 1964, 1970; Hedlund, 1978a–e, 1980; Drewes et al., 1985; among others), only a few detailed petrographic and geochemical studies have been done. It is beyond the scope of this paper to describe this metamorphic complex in detail, except for a brief review of petrography of the quartzofeldspathic gneiss, the host of some syenite bodies.

The quartzofeldspathic gneisses are typically brown to orange to gray, medium- to fine-grained and foliated due to mineralogic banding. The gneiss consists of 70–95% quartz, microcline, plagioclase (andesine-oligoclase) and up to 30% muscovite and biotite. Accessory minerals are magnetite, hematite, hornblende, apatite and zircon. A granoblastic texture is predominant. Quartz is typically very small in size (less than one mm) whereas feldspars may be several mm long. White to gray to

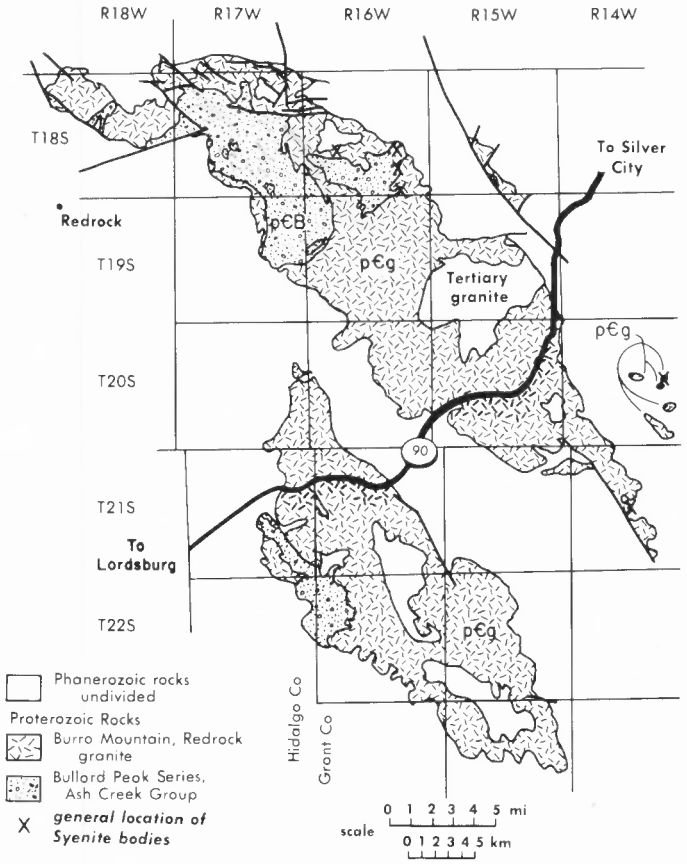


FIGURE 2. Generalized geologic map of the Proterozoic rocks in the Burro Mountains, including areas sampled (modified from Drewes et al., 1985).

pink feldspars are altered by sericite and clay minerals. The quartzofeldspathic gneiss adjacent to the syenites was probably originally an arkosic sandstone, although preserved sedimentary textures are very rare.

Burro Mountain granite

The Burro Mountain granite varies in color, texture, composition, degree of weathering and alteration (Gillerman, 1970). These differences are due to (1) magmatic differentiation, (2) different ages of intrusion, (3) alteration by Tertiary volcanism and mineralization, (4) metasomatism related to syenite intrusion and (5) inclusion and assimilation of older metamorphic rocks.

Typically the unaltered Burro Mountain granite is an orange to pink to gray, fine- to coarse-grained, two feldspar granite consisting of equal amounts of quartz, microcline and twinned plagioclase (oligoclase), comprising 85–95% of the rock. Accessory minerals are muscovite or sericite, biotite, chlorite, hematite, limonite, epidote, hornblende, apatite, magnetite and zircon. The white to pink to gray feldspars, up to a cm across, are typically altered by sericite and clay. The anhedral quartz is up to 1–2 mm long and typically displays undulatory extinction. The granite commonly has a hypidiomorphic-granular texture and is weakly to strongly foliated in places. Younger granodiorite, tonalite, rapakivi granite and leucogranite intrude the Burro Mountain granite in several areas (Hedlund, 1978a–e). Seven samples of leucogranite and hematite granite were sampled (B14.1, B14.2, B14.3, B36.20, B36.22, B36.23, B36.24, Appendix 1). The hematite granite contains 10–50% hematite that is probably a result of hematitization.

The age of the Burro Mountains granite is 1445–1550 my, as determined by U/Pb zircon methods (U.S. Geological Survey, 1981; Stacey and Hedlund, 1983). A younger granite dated as 1380 ± 45 my intrudes the older granite (U-Pb on zircon; U.S. Geological Survey, 1981).

Syenite

The syenite bodies are dark to bright red (or brick-red) to pink to orange, coarse- to fine-grained and form resistant outcrops compared to adjacent granite and gneiss. The syenites are lenticular to elongate, up to 400 m in length and as much as 10 m in width. More than a dozen syenite bodies have been mapped in the Burro Mountains (Hedlund, 1978a, b, e). Most of the contacts are poorly exposed, and when exposed are commonly diffuse, irregular, gradational and marked by a color change from orange, gray or pink to brick-red. Foliation of the gneiss can be traced into the syenite in places. The syenite bodies are only slightly more radioactive than the granite and gneiss. Similar syenites in the Caballo Mountains are more radioactive than the adjacent granite (McLemore, 1986).

The syenites have a hypidiomorphic-granular texture when adjacent to granites and relict foliated and granoblastic texture when adjacent to gneisses. Four samples of microcline-perthite-plagioclase syenites have a hypidiomorphic-granular texture, and typically consist of perthitic microcline with subordinant amounts of quartz, muscovite, hematite, chlorite and biotite. Plagioclase (oligoclase) is rare in most syenites. The microcline grains are turbid owing to sericitic and hematitic alteration and the typical cross-hatched lamellae are absent. Some syenites contain as much as 90–95% microcline, whereas others contain as much as 25% quartz and are quartz syenites or alkali granites (IUGS Subcommission on the Systematics of Igneous Rocks, 1973; De la Roche et al., 1980). Four syenites (samples B21.1, B21.2, B35.9, B35.10, Appendix 1) contain 35–45% perthite and microcline, 40–50% plagioclase (oligoclase) and subordinant amounts of quartz, hematite, magnetite and biotite. Accessory minerals in all syenites are apatite, zircon, calcite, fluorite, magnetite and sphene. One sample (B35.8, Appendix 1) contains normative nepheline (Table 2), but nepheline was not found by optical and whole rock XRD methods; although the nepheline could be present as very small grains obscured by hematite.

Textures and mineralogy of the syenitic rocks are commonly obscured in many samples by pervasive hematitization. The bright red to orange color is a result of disseminated hematite; in some syenites red to reddish-brown hematite veins are common. Small red hematite inclusions within feldspars may be a result of oxidation of iron molecules originally within the feldspar lattice (Heinrich, 1966; Heinrich and Moore, 1970; McLemore, 1986).

The syenites are not metamorphosed and crosscut granite and gneiss of middle Proterozoic age; petrologically similar syenites in the Lobo and Pedernal Hills in Torrance County yielded ages of about 470 my by Rb-Sr methods (Loring and Armstrong, 1980). Syenites and alkalic granites in the Florida Mountains, about 90 km southwest of the Burro Mountains, yielded U-Pb ages on zircon of about 500 my (Loring et al., 1987; Evans and Clemons, 1987; Clemons, in press). The Burro Mountain syenites may be of a similar Cambrian-Ordovician age.

An intrusion of melaquartz syenite in the Harris Canyon area of the Burro Mountains, sec. 22, 27, T18S, R17W (Hedlund, 1980), consists of 25–50% microcline, 0–2% plagioclase, 2–15% quartz, 20–39% hornblende and 10–37% biotite with accessory sphene, apatite and iron oxides. The melaquartz syenite, approximately 1.5 km long and 200 m wide, intrudes migmatite, gneiss and amphibolite of the Bullard Peak Series and is typcially dark gray, medium-grained, allotriomorphic-granular and locally foliated. The relationship and age of this syenite is not known at this time, although the melaquartz syenite appears to be similar in composition and texture to a melasyenite at Pajarito Mountain, Otero County, dated as 1140–1230 my (location 17, Fig. 1; Kelley, 1968; Foord et al., 1983; Moore and Foord, 1986).

GEOCHEMISTRY

Several syenite bodies and adjacent Burro Mountain granite and gneiss of the Bullard Peak Series were sampled and analyzed for major and trace elements. Samples from a younger leucogranite and hematite granite of the Burro Mountain granite were also included. Chemical analyses are in Table 2 and sample locations and descriptions are in Appendix 1.

Major element oxides were determined by x-ray fluorescent spectrom-

TABLE 2. Geochemistry of syenites, gneisses and granites from the Burro Mountains. See Appendix 1 for description and location of samples. Normative minerals: Q—quartz, C—corundum, O—orthoclase, AL—albite, An—anorthite, Ac—acmite, HY—hypersthene, HEM—hematite, MAG—magnetite, IL—ilmenite, R—rutile, SP—sphene, AP—apatite, NE—nepheline, DIO—diopside, OL—olivine. *Total iron reported as Fe_2O_3. Chemical analyses by Lynn Brandvold and associates (NMBMMR chemical laboratory). Oxides and normative minerals in percent; trace elements in parts per million. ND—not detected; ---not determined.

Oxides	B23.2	B23.3	B23.4	B23.5	B23.6	B23.7	B23.8	B27.1	B27.2	B27.3	B27.4	B26.1	B26.2
SiO_2	69.2	70.6	62.6	65.2	70.8	76.8	58.5	64.4	75.1	73.2	15.5	62.2	81.8
TiO_2	0.43	0.34	0.49	0.44	0.46	0.05	0.56	0.30	0.32	0.35	0.09	0.43	0.31
Al_2O_3	13.9	13.3	16.3	16.0	14.9	13.2	6.92	14.9	13.1	12.8	1.17	16.6	9.60
Fe_2O_3	2.70	2.88	3.92	2.11	1.93	1.63	2.11	5.53	1.88	0.99	0.70	3.78	0.45*
FeO	0.18	0.0	0.32	0.08	0.16	0.15	0.98	0.17	0.11	1.49	8.91	0.62	---
MgO	0.64	0.68	0.56	1.13	0.28	2.00	0.97	0.69	1.07	0.96	11.3	1.19	1.82
CaO	2.40	2.12	1.01	0.40	0.77	1.06	2.11	0.08	0.13	0.27	25.6	0.22	0.21
Na_2O	0.76	0.44	0.30	0.86	0.51	3.97	0.98	0.78	0.59	2.71	0.66	0.83	0.88
K_2O	5.40	5.46	11.6	13.5	5.53	4.46	0.75	12.9	5.93	6.62	0.35	14.4	7.23
MnO	0.05	0.08	0.01	0.03	0.04	0.02	0.07	0.01	0.04	0.02	0.03	0.04	0.03
P_2O_5	0.13	0.10	0.07	0.13	0.13	0.03	0.08	0.08	0.09	0.02	0.06	0.14	0.09
LOI	4.60	4.45	2.41	0.92	4.18	1.52	4.50	0.18	2.58	0.11	35.99	0.37	0.33
TOTAL	100.39	100.45	99.59	100.80	99.69	104.89	78.53	100.02	100.94	98.54	100.36	100.82	102.75
Trace Elements													
Ga	16	14	14	8	14	8	37	8	14	13	6	5	6
Zn	57	83	159	19	46	22	375	10	97	40	9200	57	31
Cu	39	15	14	29	7	10	34	10	7	8	9	22	10
Ni	8	8	11	6	9	6	20	5	9	5	23	18	5
Ba	815	860	530	395	653	341	10.5%	405	812	978	53	444	741
V	42	28	44	6	32	23	278	15	20	20	53	32	20
Cr	15	11	19	19	19	11	43	22	16	12	16	135	120
Pb	122	30	44	15	25	5	4.8%	6	28	39	0.26%	9	20
Th	22	21	14	24	26	24	73	27	23	34	8	44	18
Rb	156	147	226	257	175	269	18	307	224	212	15	334	191
U	6	6	4	7	6	6	ND	9	7	7	2	5	6
Sr	51	41	24	17	35	14	2700	9	54	112	127	18	28
Y	56	49	42	43	74	31	25	25	39	65	22	64	13
Zr	253	219	222	235	285	279	111	200	208	238	49	306	171
Nb	9	8	10	10	12	10	ND	11	12	10	7	13	9
Normative Minerals													
Q	38.4	41.9	12.1	6.6	45.0	31.5	--	9.9	47.3	29.5	--	0.1	45.9
C	2.8	3.6	1.2	--	7.0	--	--	--	5.7	0.7	--	--	0.2
O	31.9	32.3	69.7	79.8	32.7	26.4	--	76.2	35.0	39.1	--	84.9	42.7
AL	6.4	3.7	5.0	7.1	4.3	33.6	--	4.8	5.0	22.9	--	5.4	7.4
AN	11.1	9.9	3.4	--	3.0	5.0	--	--	0.1	1.2	--	--	0.4
AC	--	--	--	0.1	--	--	--	1.6	--	--	--	4.1	--
HY	1.6	1.7	2.7	2.8	0.7	5.0	--	1.7	2.7	3.8	--	3.6	4.9
HEM	2.7	2.9	4.1	2.1	1.9	1.3	--	5.0	1.9	--	--	1.7	--
Mag	--	--	0.1	--	--	0.4	--	--	--	1.4	--	0.9	--
IL	0.5	0.2	0.8	0.2	0.4	0.1	--	0.4	0.3	0.7	--	0.8	0.6
R	0.2	0.2	--	--	0.2	--	--	0.1	0.2	--	--	--	--
SP	--	--	--	0.8	--	--	--	--	--	--	--	--	--
AP	0.3	0.2	0.3	0.3	0.4	0.1	--	0.2	0.2	0.1	--	0.3	0.2
NE	--	--	--	--	--	--	--	--	--	--	--	--	--
DIO	--	--	--	--	--	--	--	--	--	--	--	0.1	--
OL	--	--	--	--	--	--	--	--	--	--	--	--	--

Oxides	B35.1	B35.2	B35.3	B35.4	B35.5	B35.6	B35.7	B35.8	B35.9	B35.10	B35.11	B21.1	B21.2	B22.1
SiO_2	67.1	77.0	64.3	75.6	77.4	66.1	58.0	62.1	84.0	79.2	64.2	63.7	62.9	72.0
TiO_2	0.15	0.09	0.11	0.10	0.06	0.21	0.97	0.15	0.23	0.23	0.26	0.05	0.51	0.37
Al_2O_3	16.3	12.1	17.8	12.6	12.5	16.2	16.0	18.5	7.39	9.54	16.3	16.5	18.2	13.5
Fe_2O_3	1.28	0.90	0.53	0.57	0.70	2.33	2.93	1.83	1.30	1.99	2.45	2.12	3.23	2.23
FeO	0.11	0.0	0.58	0.50	0.14	0.10	3.81	0.39	0.30	0.34	0.24	0.03	0.05	0.83
MgO	0.92	0.86	0.68	0.59	0.96	1.37	3.40	1.25	1.66	0.93	0.60	0.16	0.94	2.29
CaO	0.04	0.19	0.02	0.16	0.27	0.08	0.90	1.74	0.12	0.11	0.08	0.10	0.16	0.63
Na_2O	0.56	3.08	0.67	3.11	2.71	0.74	1.08	3.85	1.08	0.68	0.43	5.51	3.38	3.29
K_2O	13.7	5.54	14.8	6.05	0.62	13.3	9.42	9.43	5.44	7.12	13.9	6.44	9.50	5.34
MnO	0.02	0.03	0.03	0.03	0.02	0.02	0.13	0.04	0.03	0.03	0.01	0.06	0.09	0.06
P_2O_5	0.04	0.02	0.03	0.03	0.02	0.04	0.58	0.03	0.06	0.09	0.04	0.01	0.13	0.11
LOI	1.46	1.01	0.68	0.57	0.86	0.43	2.39	1.62	0.34	0.64	0.54	6.22	0.15	1.22
TOTAL	101.68	100.82	100.23	99.91	96.26	100.92	99.61	100.93	101.95	100.90	99.05	100.90	99.24	101.87
Trace Elements														
Ga	9	16	12		14		16	18	6	11	10	16	14	15
Zn	28	17	21		13		106	28	18	27	16	12	126	51
Cu	9	8	9		8		6	9	6	6	9	19	16	11
Ni	6	5	5		4		9	4	5	8	5	4	8	7
Ba	707	274	1300	632	194	990	1590	1950	768	944	1430	158	1210	983

TABLE 2. (continued)

	B35.1	B35.2	B35.3	B35.4	B35.5	B35.6	B35.7	B35.8	B35.9	B35.10	B35.11	B21.1	B21.2	B22.1
V	18	7	17	13	3	27	61	34	18	57	92	24	34	26
Cr	18	27	9	12	9	28	18	13	11	14	23	10	14	28
Pb	37	23	21	16	30	10	11	24	7	7	12	35	17	30
Th	40	31	29	18	22	38	17	10	3	10	10	6	29	24
Rb	439	247	459	200	254	390	233	297	151	197	378	280	274	180
U	4	5	5	5	5	2	6	3	4	3	3	5	4	5
Sr	38	57	64	87	59	41	50	225	29	32	52	19	55	137
Y	10	7	30	6	5	21	66	7	29	47	30	12	63	34
Zr	103	82	49	79	76	133	427	127	98	150	115	22	302	249
Nb	6	4	5	2	3	8	23	3	3	4	5	19	15	11
Normative Minerals														
Q	10.0	36.2	2.5	33.0	57.3	8.8	6.6	--	54.7	46.6	6.3	3.8	5.5	28.0
C	0.6	0.7	0.7	0.7	6.9	0.5	3.3	--	--	0.7	0.2	--	2.4	1.4
O	81.0	32.7	87.4	35.8	3.7	78.6	56.2	55.7	32.2	42.1	82.2	40.0	56.1	31.6
AL	4.7	26.1	5.7	26.3	22.9	6.3	12.0	31.2	7.7	5.7	7.2	51.7	28.6	27.8
AN	--	0.8	--	0.6	1.2	0.1	0.7	5.3	--	--	--	--	--	2.4
AC	--	--	--	--	--	--	--	--	1.2	--	--	0.8	--	--
HY	2.3	2.1	2.2	1.8	2.4	3.4	13.0	--	4.1	2.3	3.0	1.7	2.3	5.7
HEM	1.3	0.9	--	--	0.5	2.3	--	1.2	0.6	1.6	2.6	2.4	3.2	1.0
Mag	--	--	0.8	0.8	0.3	--	4.1	1.0	0.4	0.5	0.3	0.1	--	1.8
IL	0.3	0.1	0.2	0.2	0.1	0.3	1.8	0.3	0.4	0.4	0.4	0.1	0.3	0.7
R	--	0.1	--	--	--	0.1	--	--	--	--	--	--	0.4	--
SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
AP	0.1	0.1	0.1	0.2	0.1	0.1	1.4	0.1	0.1	0.2	0.2	0.1	0.3	0.3
NE	--	--	--	--	--	--	--	0.7	--	--	--	--	--	--
DIO	--	--	--	--	--	--	--	2.4	0.2	--	--	0.1	--	--
OL	--	--	--	--	--	--	--	1.4	--	--	--	--	--	--

Oxides	B16.1	B16.2	B16.3	B16.4	B16.5	B16.6	B16.7	B23.20	B23.22	B23.23	B36.20	B36.21	B36.23	B36.24	B14.1	B14.2	B14.3
SiO_2	60.0	78.1	71.6	62.9	78.0	96.5	69.1	75.5	69.4	72.3	75.7	66.1	75.7	76.6	26.7	67.9	69.7
TiO_2	0.32	0.06	0.18	0.38	0.23	0.0	0.43	0.17	0.17	0.04	0.07	0.47	0.06	0.05	0.73	0.33	0.36
Al_2O_3	18.4	13.2	12.8	17.9	15.1	1.29	14.5	11.9	14.8	15.2	13.3	16.3	12.8	12.7	6.06	16.8	14.4
Fe_2O_3	1.87	0.94*	0.91	1.93	1.66	0.0	1.91	1.39	1.67	0.57	0.6	2.50	2.11	1.00	59.8	3.60	1.04
FeO	1.26	--	0.20	0.07	0.53	0.34	1.62	0.0	0.11	0.15	0.10	0.0	0.23	0.16	1.46	0.14	1.66
MgO	2.08	2.81	0.86	0.64	1.85	1.07	1.53	1.21	0.40	1.02	0.33	1.86	0.87	0.49	0.95	0.76	1.15
CaO	0.16	0.48	0.10	0.16	1.41	0.04	1.74	0.06	0.05	0.31	0.58	0.55	0.84	0.54	0.29	0.30	1.67
Na_2O	1.21	4.87	1.24	0.54	3.47	0.60	3.32	0.97	0.72	4.05	3.18	0.64	4.08	3.49	3.87	9.67	3.55
K_2O	13.3	3.53	9.04	14.4	5.00	0.04	4.79	9.33	11.7	6.27	5.55	13.4	4.61	4.85	0.12	0.11	4.58
MnO	0.06	0.03	0.03	0.05	0.05	0.02	0.08	0.33	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.02	0.07
P_2O_5	0.11	0.02	0.06	0.11	0.07	0.02	0.13	0.07	0.06	0.03	0.02	0.17	0.03	0.02	0.20	0.11	0.10
LOI	1.52	2.34	1.36	0.57	0.39	0.0	0.87	0.0	0.63	0.61	0.29	0.32	0.0	0.48	0.55	0.46	0.78
TOTAL	100.29	106.38	98.38	99.65	107.76	99.90	100.02	100.93	99.74	100.58	99.75	102.35	101.36	100.41	100.76	100.20	99.06
Trace Elements																	
Ga			13	16	18	2	18	10	14	24	21	23	20	21	6	12	17
Zn			24	59	38	11	71	113	22	49	18	20	24	29	62	37	73
Cu			8	10	9	6	15	8	8	35	7	7	7	7	ND	10	9
Ni			5	8	7	7	7	8	6	3	5	7	8	4	ND	5	7
Ba	963	1700	643	1030	665	8	1160	662	600	230	57	151	112	163	22	21	731
V	23	14	11	21	18	2	40	18	22	9	ND	6	2	2	141	ND	21
Cr	50	ND	19	27	7	11	10	15	8	9	5	11	21	10	23	7	18
Pb	52	23	17	24	33	ND	24	30	24	45	51	60	78	69	66	7	26
Th	43	55	35	50	36	ND	32	39	37	10	28	80	147	62	73	35	25
Rb	303	314	379	534	284	2	262	372	491	376	361	328	314	330	9	3	203
U	10	9	6	7	6	3	4	10	7	7	14	17	41	43	3	5	6
Sr	275	97	34	52	102	ND	162	47	38	50	25	32	30	38	102	212	718
Y	14	192	34	102	47	ND	128	179	42	43	50	173	160	76	29	49	37
Zr	176	533	141	233	159	7	389	116	119	39	41	135	412	88	364	247	232
Nb	9	31	19	34	14	ND	28	16	20	31	67	112	153	106	55	13	15
Normative Minerals																	
Q	--	31.1	28.4	3.6	33.1	90.9	25.1	32.4	19.9	22.6	34.3	7.6	31.5	35.9	2.7	9.8	25.7
C	2.0	0.5	0.9	1.4	1.6	0.2	1.0	0.3	1.00	1.3	1.1	0.1	--	0.8	--	0.5	0.8
O	78.6	20.9	53.4	85.1	30.0	0.2	28.3	55.1	69.2	37.1	32.8	79.2	27.2	28.7	0.7	0.7	27.1
AL	10.2	41.2	10.5	4.6	29.4	5.1	28.1	8.2	6.1	34.3	26.9	5.4	34.5	29.5	30.5	81.8	30.0
AN	0.1	2.3	0.1	0.1	6.5	0.1	7.8	--	--	1.3	2.7	1.6	3.0	2.5	--	0.8	7.6
AC	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.0	--	--
HY	1.3	7.0	2.1	1.6	4.6	3.3	4.6	3.0	1.0	2.5	0.8	4.6	1.8	1.2	2.3	1.9	4.6
HEM	--	0.9	0.8	1.9	0.8	--	--	1.0	1.7	0.3	0.4	2.5	1.7	0.7	57.3	3.6	--
Mag	2.7	--	0.2	--	1.2	--	2.7	0.6	--	0.5	0.2	--	0.7	0.5	2.7	--	1.5
IL	0.6	0.1	0.3	0.3	0.4	--	0.8	0.3	0.3	0.1	0.1	0.1	0.1	0.1	1.4	0.3	0.7
R	--	--	--	0.2	--	--	--	--	--	--	--	0.4	--	--	--	0.2	--
SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
AP	0.3	0.1	0.1	0.3	0.2	0.1	0.3	0.2	0.1	0.1	0.1	0.4	0.1	0.1	0.5	0.3	0.2
NE	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DIO	--	--	--	--	--	--	--	--	--	--	--	--	0.8	--	0.1	--	--
OL	3.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

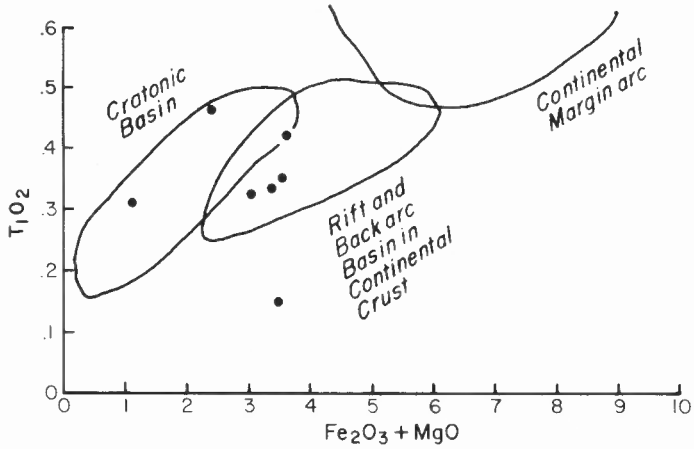


FIGURE 3. TiO_2-Fe_2O_3 + MgO diagram of quartzofeldspathic gneisses from the Bullard Peak Series, Burro Mountains. Tectonic fields modified by Condie (1986) after Bhatia (1983).

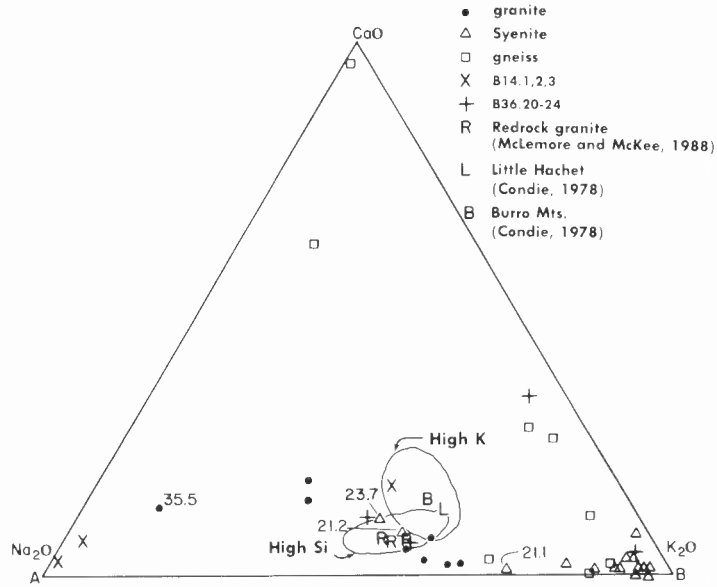


FIGURE 4. CaO-Na_2O-K_2O (in percent) diagram of granites, gneisses and syenites from the Burro Mountains. Fields shown are high-K and high-Sr group granites of Proterozoic age in New Mexico (Condie, 1978). Each symbol may represent more than one sample.

etry (XRF) on fused glass discs following the method of Norrish and Hutton (1969). Some major element oxides were determined by XRF using the fundamental parameters program of Criss Software (Criss, 1980). Trace elements were determined by XRF using pressed powder briquets.

The gneisses of the Bullard Peak Series are grossly similar in composition to other middle Proterozoic metasedimentary rocks in New Mexico (Table 2; Condie and Budding, 1979; Condie, 1986). The gneisses are intermediate in TiO_2, Fe_2O_3 and MgO compositions (Fig. 3), have moderate Al_2O_3/SiO_2 ratios (0.1–0.3) but have high K_2O/Na_2O ratios (0.4–11.0), perhaps as a result of emplacement of nearby syenites. One gneiss (sample B27.4, Appendix 1) is higher in CaO, MgO and LOI (Loss On Ignition), and lower in SiO_2, Al_2O_3 and K_2O than other gneisses due to carbonate replacement of the gneiss. Geochemically, the quartzofeldspathic gneisses are similar to sediments deposited in cratonic basins and rift and back arc basins (Fig. 3; Bhatia, 1983; Condie, 1986).

The granites are metaluminous and grossly similar in chemical composition to middle Proterozoic high-K and high-Si granites in the Caballo Mountains, Redrock area and elsewhere in New Mexico (Table 2, Fig. 4; Condie, 1978; Condie and Budding, 1979; McLemore, 1986; McLemore and McKee, this guidebook). However, some of the Burro Mountain granites are quite variable in major and trace element geochemistry reflecting the heterogeneity of the batholith. More detailed geochemical studies are needed to characterize this granite.

The leucogranite (B36.20, B36.22, B36.23, B36.24, Appendix 1) is of variable composition, ranging from syenite to alkali granite (Figs. 4, 5, 6, 7). The hematite granite (B14.1, B14.2, B14.3, Appendix 1) is grossly similar to the Burro Mountain granite, except for sample B14.1, which is lower in most major element oxides and enriched in Fe_2O_3, owing to the abundance of hematite.

The Burro Mountain syenites can be differentiated into two geochemical groups as a result of differences in mineralogy and chemistry: high K and high Na (Table 2; Fig. 5). The high-K syenites are higher in K_2O (9–15%) and low in Na_2O (0.3–1.5%), whereas the high-Na syenites are high in Na_2O (3–6%) and low in K_2O (4–9%). Both groups are high in Al_2O_3 (12–18%) and low in SiO_2 (58–71%) relative to most granites and gneisses (Fig. 5). The syenites tend to be lower in Sr and higher in Rb content relative to adjacent host rocks (Fig. 6), but are higher in Ba content than adjacent granites and lower in Ba content than adjacent gneisses (Fig. 6).

The high-K syenitic rocks in the Burro Mountains are similar in chemical composition to syenites from Lobo Hill (Loring and Armstrong, 1980; McLemore, unpubl. data 1988), Caballo Mountains (location 13, Fig. 1; McLemore, 1986) and Zuni Mountains (location 7, Fig. 1; McLemore, unpubl. data 1988). The high-Na syenites are similar in chemical composition to syenites in the Florida Mountains (Brookins et al., 1978; Clemons, in press), Sangre de Cristo Mountains (location 5, Fig. 1; Klich, 1983) and Pedernal Hills (Loring and Armstrong, 1980).

ECONOMIC POTENTIAL

Unlike similar syenite bodies found in the Caballo Mountains (location 13, Fig. 1; McLemore, 1986), the Burro Mountain syenites have little or no economic potential. A few syenite bodies are slightly radioactive and slightly enriched in Y and Nb and possibly rare-earth elements; however, the distribution of these elements is sporadic and discontinuous and most likely low grade. However, they have not been explored at depth. Two veins were sampled (B23.8, B16.6, Appendix 1; Table 2), but no gold or silver were detected and one vein contained 10.5% Ba and 4.8% Pb.

DISCUSSION

Origin of Burro Mountain syenites

The high-Na syenites are probably of magmatic origin and intruded into the country rock. Primary igneous textures and geochemical distributions and similarity to other syenites in the world support a magmatic origin.

The high-K syenites are most likely of a metasomatic origin, as suggested by field observations, replacement textures in thin section, high K_2O/Na_2O ratios and distribution of trace elements. Selective enrichment of potassium with respect to sodium occurs locally in magmas of volcanic to subvolcanic environments (Sahama, 1974); however, many potassium-rich rocks associated with alkalic complexes, carbonatites and kimberlites are attributed to metasomatism or fenitization (Sutherland, 1965; Heinrich and Moore, 1970; Kinnarid et al., 1985). Metasomatism is the process of replacement of minerals by introduction of external fluids, whereas fenitization is alkalic metasomatism related to intrusion of carbonatites, kimberlites and alkalic rocks (Heinrich, 1966). The erratic distribution of Ba and Sr with respect to Rb (Figs. 5, 6) is consistent with a metasomatic origin of the Burro Mountain syenites.

Two possible models are envisioned. High-Na syenites may have intruded the Proterozoic terrain and were subsequently metasomatized, along with adajcent country rocks, by postmagmatic potassium-rich

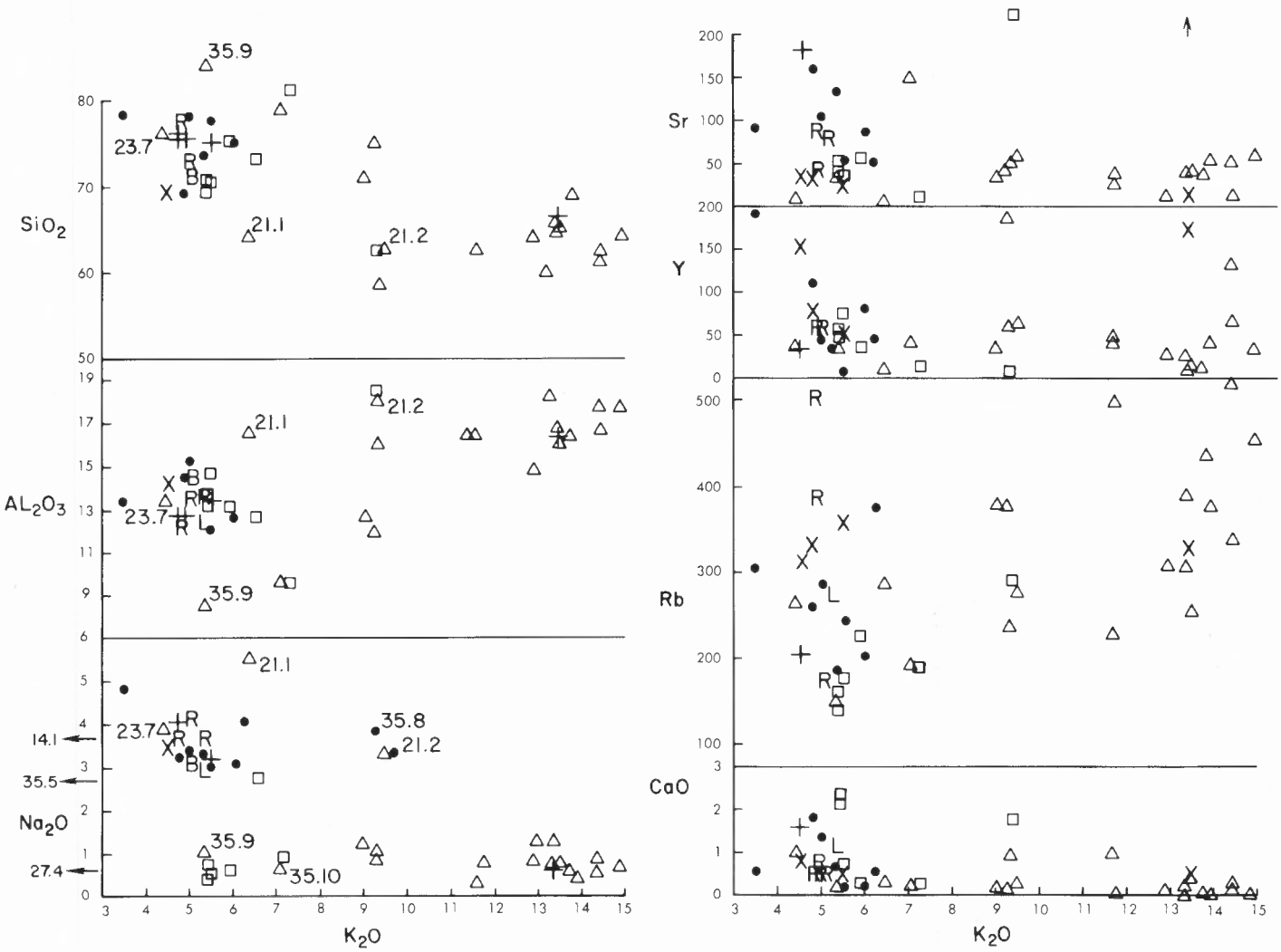


FIGURE 5. Variation diagrams of selected oxides (in percent) and trace elements (in parts per million) versus SiO_2 of granites, gneisses and syenites from the Burro Mountains. Each symbol may represent more than one sample. Symbols explained in Figure 4.

solutions, as observed at the Ririwai alkaline complex in northern Nigeria (Kinnaird et al., 1985). Alternatively, potassium-rich solutions, possibly related to a deeper high-Na syenitic magma, may have metasomatized the granite and gneiss to syenite along fractures. Similar models are envisioned for the Caballo Mountains syenite (McLemore, 1986). Detailed isotopic studies are needed to evaluate these models.

Regional implications

Alkalic rocks of apparent Late Precambrian to Cambrian-Ordovician age are not so uncommon in New Mexico as once thought (Fig. 1; Table 1). A syenite complex at Pajarito Mountain was dated as 1140–1230 my (location 17, Fig. 1; Kelley, 1968; Moore and Foord, 1986). The undated alkali granite (McLemore, unpubl. data 1988) at Bent Dome (location 18, Fig. 1) may be related to the Pajarito Mountain complex.

A Cambrian-Ordovician alkalic magmatic event was widespread in New Mexico and southern Colorado (Fig. 1). This event is characterized by carbonatites and syenites with dates between 400 and 600 my (Table 1) and possible potassium-metasomatism in some areas, such as the Caballo Mountains. In addition, other igneous rocks from throughout New Mexico have been dated between 370 and 850 my and may be related to this event (Table 1; Fig. 1). The Burro Mountain syenites may be part of this Cambrian-Ordovician event, although a Precambrian age for the Burro Mountain syenites cannot be ruled out.

Alkalic magmatism is not restricted to the Precambrian or Early Paleozoic. During the Tertiary, alkalic rocks were emplaced in the Raton-Clayton volcanic field (Stormer, 1972a, b) and the Laughlin Peak area (location A, Fig. 1; Staatz, 1985, 1986, 1987), at Sierra Blanca (location B, Fig. 1; Thompson, 1972; Giles and Thompson, 1972), in the Cornudas Mountains (location C, Fig. 1; Zapp, 1941), and the remainder of the Trans-Pecos volcanic province in west Texas (location D, Fig. 1; Barker, 1977; Barker and Hodges, 1977; Barker et al., 1977). A carbonatite dike intrudes the alkalic complex in the Laughlin Peak area (Staatz, 1986).

Periodic episodes of carbonatite and alkalic magmatism are commonly associated with rift and aborted rift systems which may reactivate periodically throughout time, such as the St. Lawrence Valley system in eastern Canada and the East African rift system (Kumarapeli and Saull, 1966). This is one possible model for the distribution of alkalic rocks in New Mexico.

The distribution of alkalic rocks in New Mexico may be a result of one or more processes requiring deep-seated lower crust-upper mantle sources, as suggested by isotopic studies of the alkalic complexes in southern Colorado (Olson et al., 1977; Armbrustmacher and Hedge, 1982; Armbrustmacher, 1984). Initial $^{87}Sr/^{86}Sr$ isotope ratios of alkaline complexes in the Wet Mountains (locations 1, 2, 3, Fig. 1), indicate that a minimum of three magmatic sources produced the alkalic rocks (Armbrustmacher and Hedge, 1982; Armbrustmacher, 1984). Cam-

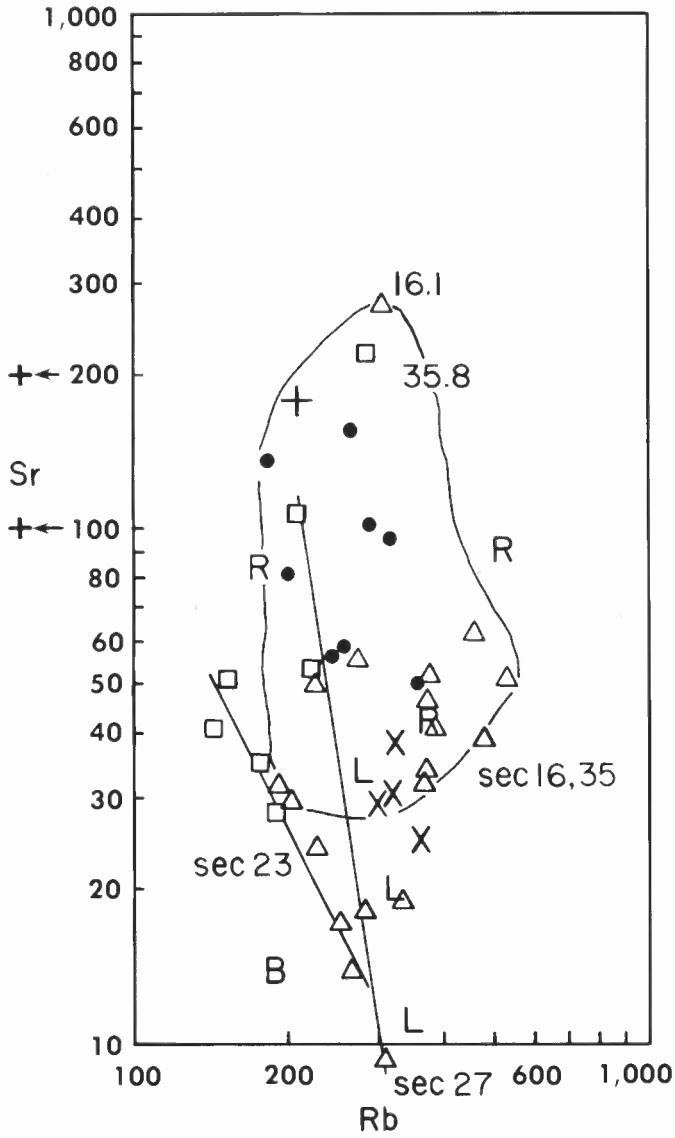


FIGURE 6. Rb-Sr (in parts per million) plot of granites, gneisses and syenites from the Burro Mountains. Symbols explained in Figure 4.

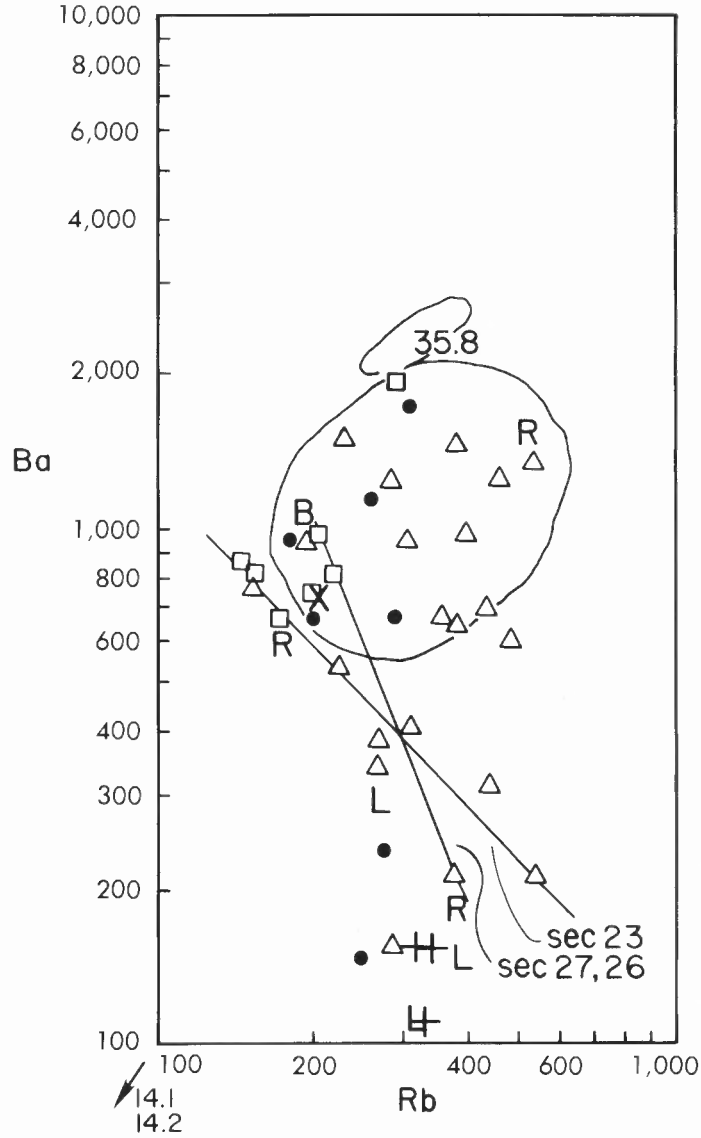


FIGURE 7. Rb-Ba (in parts per million) plot of granites, gneisses and syenites from the Burro Mountains. Symbols explained in Figure 4.

brian-Ordovician and Tertiary alkalic rocks may have been derived from the melting and remobilization of Proterozoic alkalic rocks, similar to that envisioned by Foord et al. (1983) at Sierra Blanca. However, melting of a single or multiple source periodically throughout time could also produce this distribution. Undoubtedly a complex, multi-source system, with associated metasomatism, produced the distribution of alkalic rocks in New Mexico.

Although theories have been suggested placing rift systems similar to the St. Lawrence and East African rift systems in New Mexico and southern Colorado during Precambrian through Paleozoic times (Larson et al., 1985; Condie and Budding, 1979), specific geographic limits of the rift systems in New Mexico and southern Colorado are difficult to determine because of complex tectonic events related to Rio Grande rifting. A more comprehensive evaluation of the tectonic regime during Cambrian-Ordovician times is required to fully understand the wide distribution of these rocks in New Mexico.

ACKNOWLEDGMENTS

Sample preparation was by Shawn Leppert and Mike Knoper (New Mexico Institute of Mining and Technology). Critical reviews by Frank Kottlowski, Russell E. Clemons and David Hedlund are greatly appreciated. Lynne McNeil typed the manuscript. Monte Brown drafted the figures. Ferrious/ferric iron ratios were determined by Lynn Brandvold and associates (New Mexico Bureau of Mines and Mineral Resources chemical laboratory).

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APPENDIX 1:
DESCRIPTION AND LOCATION OF SAMPLES

Syenite body intruding Bullard Peak Series, 1 m wide; SW¼ SE¼ SE¼ sec. 23, T18S, R16W (Wind Mountain quadrangle, geology by Hedlund, 1978a)

B23.2 quartzofeldspathic gneiss, 15 cm from contact
B23.3 quartzofeldspathic gneiss adjacent to contact
B23.4 syenite adjacent to contact
B23.5 syenite in center of body
B23.6 quartzofeldspathic gneiss, 6 m from syenite
B23.7 syenite along strike of B23.5
B23.8 vein adjacent to syenite

Syenite bodies intruding Bullard Peak Series, 75 m wide; SW¼ NW¼ sec. 26 and SW¼ NE¼ sec. 27, T18S, R16W (Wind Mountain quadrangle, geology by Hedlund, 1978a)

B27.1 syenite
B27.2 quartzofeldspathic gneiss adjacent to syenite
B27.3 quartzofeldspathic gneiss, 15 m from contact
B27.4 quartzofeldspathic gneiss, 305 m from contact
B26.1 syenite
B26.2 quartzofeldspathic gneiss near syenite

Syenite bodies intruding granite of Burro Mountain and Bullard Peak Series, 2 m wide; SW¼ NE¼ sec. 35, T18S, R16W (Wind Mountain quadrangle, geology by Hedlund, 1978a)

B35.1 eastern quartz syenite body
B35.2 alkali granite adjacent to B35.1
B35.3 middle syenite body
B35.4 alkali granite 2 m from contact of B35.3
B35.5 alkali granite 6 m from contact of B35.3
B35.6 western syenite body
B35.7 western syenite body
B35.8 quartzofeldspathic gneiss adjacent to syenite (B35.7)
B35.9 quartz syenite
B35.10 quartz syenite
B35.11 syenite without quartz

Syenite dikes near Blackhawk mine intruding granite of Burro Mountains, sec. 21, 22, T18S, R16W (Wind Mountain quadrangle, geology by Hedlund, 1978a)

B21.1 syenite dike
B21.2 syenite dike

Syenite bodies intruding granite of Burro Mountains, 15 m wide; NW¼ NE ¼ sec. 16, T21S, R14W (Werney Hill quadrangle, geology by Hedlund, 1978b)

B16.1 syenite in center of body
B16.2 granite adjacent to syenite
B16.3 quartz syenite near contact
B16.4 syenite adjacent to contact
B16.5 granodiorite adjacent to contact
B16.6 vein in granite near syenite
B16.7 granodiorite 90 m from syenite body

Syenite body intruding granite of Burro Mountains, 2 m wide; sec. 23, T20S, R14W (White Signal quadrangle, geology by Hedlund, 1978e)

B23.20 syenite
B23.22 syenite adjacent to contact
B23.23 alkali granite 25 m from syenite

Granite of Burro Mountains, sec. 36, T21S, R16W (C-Bar Ranch quadrangle, geology by Hedlund, 1978c)

B36.20 leucogranite
B36.21 leucogranite
B36.23 contact between gneissic granite and leucogranite
B36.24 gneissic granite

Granite of Burro Mountains, sec. 14, T20S, R16W (Burro Peak quadrangle, geology by Hedlund, 1978d)

B14.1 hematite granite
B14.2 hematite alkali granite
B14.3 gneissic granite