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GEOLOGY AND GEOCHEMISTRY OF SYENITES AND ADJACENT PROTEROZOIC GRANITIC AND METAMORPHIC ROCKS IN THE ZUNI MOUNTAINS, CIBOLA COUNTY, NEW MEXICO

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Abstract—Lenticular to elongate bodies of brick-red syenite occur in Proterozoic granites and metarhyolites in the Zuni Mountains, northwestern New Mexico. The syenites consist of microcline and perthite with subordinate amounts of plagioclase, sericite, hematite and quartz. Accessory minerals include apatite, calcite, zircon and magnetite. Pervasive hematitization has obscured the texture and mineralogy of some syenites; however, other syenites exhibit relict hypidiomorphic-granular texture similar to the granitic rocks. Porphyritic texture similar to the texture of the metarhyolite has been replaced in the syenites by growth of K-feldspar and plagioclase crystals. Geochemically, the syenites are similar to other high-K syenites found in New Mexico and consist of 11–16% K_2O, 0.9–1.0% Na_2O, 17–20% Al_2O_3 and 53–65% SiO_2. Outcrop relationships, textures, trace element distributions and high K_2O/Na_2O ratios suggest the syenites may be a result of potassium metasomatism. The syenites may be associated with a widespread alkalic magmatic event characterized by carbonatites, syenites and metasomatism that affected New Mexico and southern Colorado during the Cambrian to Ordovician.

INTRODUCTION

Cambrian-Ordovician syenites and alkali granites, once thought to be rare in New Mexico, are now recognized in many Proterozoic terrains throughout New Mexico (McLemore and McKee, 1988; McLemore, 1987a, b, 1989; Loring et al., 1987; Evans and Clemons, 1987, 1988). Only a few of these syenites and alkali granites have been dated (Loring and Armstrong, 1980; Matheney et al., 1988; Clemons, in press), however, similar field relationships, textures, mineralogy and geochemistry of these unmetamorphosed syenites and alkali granites suggest a common Cambrian-Ordovician age. Syenite bodies occur in the Proterozoic terrain in the Zuni Mountains (Lambert, 1983; reconnaissance mapping by the authors) that are similar in emplacement, texture, mineralogy and chemistry to Cambrian-Ordovician syenites in the Lobo and Pedernal Hills in central New Mexico (Loring and Armstrong, 1980). Geologic, mineralogic and geochemical studies of the Zuni Mountains syenites are presented in this report as part of a regional study of alkalic rocks in New Mexico. This regional study is intended to characterize the alkalic rocks, evaluate their economic potential and suggest a possible tectonic setting and origin.

GEOLOGY

Geologic setting

The Zuni Mountains trend northwest-southeast at the southern end of the San Juan Basin in the Colorado Plateau physiographic province (Fig. 1). A complex Proterozoic granitic and metamorphic terrain is exposed in five separate outliers. The southern outliers were mapped by Goddard (1966) as part of a regional study of fluorspar deposits that occur in fractures and along faults in the Proterozoic rocks. Goddard (1966) subdivided the Proterozoic rocks into 17 units, many of which are very minor. Elsewhere, in the central and northern Zuni Mountains, the Proterozoic terrain has not been mapped in detail, but reconnaissance mapping suggests gneissic granite is the predominant rock type (Fitzsimmons, 1967; Hackman and Olson, 1977).

The gneissic granite and associated biotite granodiorite have been dated by the Rb-Sr isochron whole rock method as 1.49±0.09 by (Brookins et al., 1978). The younger metarhyolite is 1.38±0.03 by (Brookins et al., 1978). The metarhyolite has been interpreted by Goddard (1966) and Lambert (1983) as being younger than the granite, even though the errors of the two dates overlap. Distinctive brick-red syenites also occur in the Proterozoic terrain in the southern Zuni Mountains (Fig. 2; Lambert, 1983). The Proterozoic rocks are unconformably overlain by Pennsylvanian(?) and Permian sedimentary rocks (Smith, 1958; Smith et al., 1959; Goddard, 1966; Fitzsimmons, 1967).

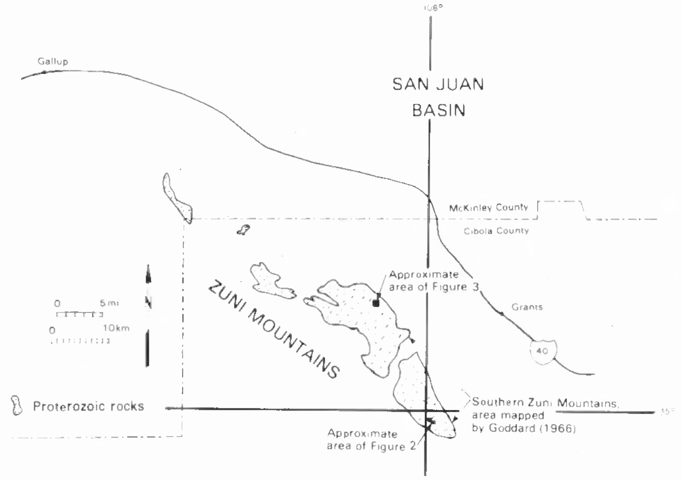

FIGURE 1. Regional setting of the Zuni Mountains (from Dane and Bachman, 1965).

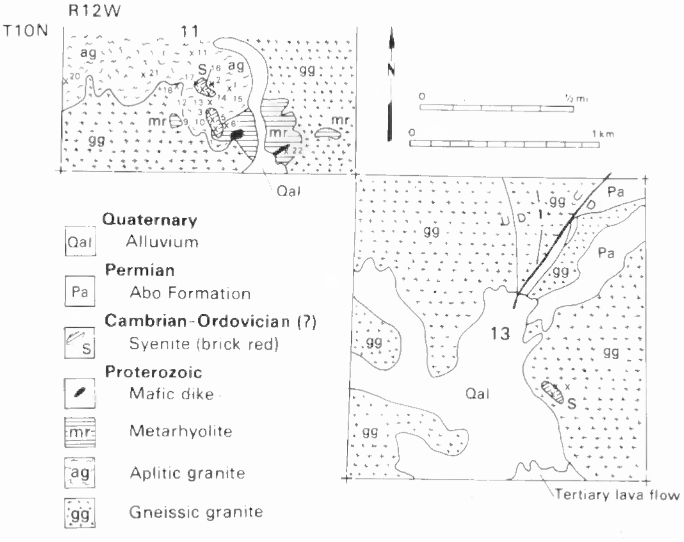

FIGURE 2. Geologic map of secs. 11 and 13, T10N, R12W (from Goddard, 1966). Number locations refer to sample sites of chemical analyses in Table 1.

Gneissic granite

Gneissic granite is the predominant rock type in the Zuni Mountains (Figs. 2, 3; Goddard, 1966; Fitzsimmons, 1967) and varies in color, texture, composition and alteration. These differences are due to: (1) magmatic differentiation (Condie, 1978), (2) different ages of intrusion, (3) alteration by Proterozoic(?) base and precious metals mineralization and Tertiary fluorite mineralization, (4) inclusions and assimilation of older igneous and metamorphic rocks (Lambert, 1983) and (5) metasomatism related to formation of the brick-red syenites.

Typically the gneissic granite is orange to pink to gray, fine to coarse grained, locally porphyritic and characterized by a distinctive weak foliation produced by alignment of biotite. A hypidiomorphic-granular texture predominates, and myrmekite and graphic intergrowths are locally common. The gneissic granite generally contains 30–40% plagioclase, 20–30% K-feldspar, 15–25% quartz and 2–10% biotite and/or chlorite and is classified as a granite according to the IUGS classification (Streckeisen, 1976). Accessory minerals (trace–30%) include epidote, calcite, sericite, apatite, magnetite, hematite, pyrite, zircon, sphene and hornblende. Plagioclase is white to pink to orange, up to 10 mm long and usually subhedral. Both albite and Carlsbad twinning are present. Most plagioclase is partially altered to sericite and calcite. The majority of plagioclase is reportedly An_{01}-An_{12} (Lambert, 1983). K-feldspars are pink to orange, up to 5 mm long, anhedral and only slightly altered. Perthite and microcline predominate, and both contain inclusions of quartz, plagioclase, apatite and zircon. Anhedral to euhedral quartz is up to 5 mm long and typically displays undulatory extinction. Biotite varies from euhedral blades to irregular aggregates. Pleochroism and intergrowths with chlorite are common. Inclusions of accessory minerals are characteristic.

Aplitic granite

Aplitic granite differs somewhat from the gneissic granite but is probably part of the same batholith. The aplitic granite is finer grained and a lighter color (pink to light orange) than the gneissic granite. A weak foliation is produced by the alignment of small biotite crystals.

The aplitic granite contains more quartz and less feldspar than the gneissic granite. Typically the aplitic granite contains 40–50% quartz, 20–30% plagioclase and 20–30% K-feldspar. Accessory minerals (trace–20%) include epidote, biotite, chlorite, sericite, magnetite, hematite and zircon. This unit is also classified as a granite according to the IUGS classification (Streckeisen, 1976). Mineral grains are similar to those described in gneissic granite, only smaller (up to 2 mm).

Metarhyolite

Metarhyolite crops out in several places within the Zuni Mountains (Fig. 2; Goddard, 1966; Lambert, 1983). It is grayish pink to orange, well foliated and porphyritic. Foliation is produced by alignment of large bluish quartz (up to 10 mm), pink K-feldspar (up to 10 mm) and white plagioclase (up to 5 mm) crystals in a very fine-grained matrix.

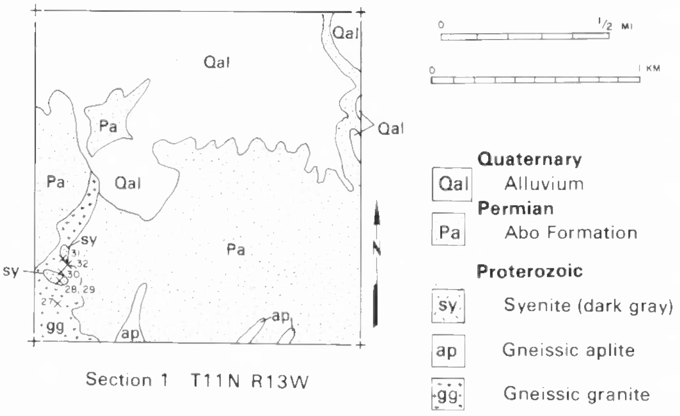

FIGURE 3. Geologic map of sec. 1, T11N, R13W (from Goddard, 1966). Number locations refer to sample sites of chemical analyses in Table 2.

The metarhyolite consists of 25–50% phenocrysts (10–30% quartz, 10–30% K-feldspar and 5–10% plagioclase) and 50–75% matrix (equal amounts of quartz, K-feldspar and sericite). Accessory minerals in the matrix are minor and include magnetite, hornblende, epidote, biotite and zircon.

Dark gray syenite

Goddard (1966) mapped two small lenticular bodies of dark gray syenite in sec. 1, T11N, R13W (Fig. 3) and believed they were related to the biotite granite. These syenites were examined by the authors to determine the relationship, if any, to the gneissic granite and brick-red syenites in the southern area (Fig. 2). The biotite granite mapped by Goddard (1966) was not recognized by the authors.

The dark gray syenite is medium to fine grained and porphyritic with large red to orange feldspars. The syenite occurs in two small stocklike bodies. Migmatite composed of the dark gray syenite and pink gneissic granite, forms much of the outcrop bodies. The syenite consists of 30–50% equant grains of K-feldspar, 30–40% green chlorite, 10–20% plagioclase and trace amounts of quartz, apatite, hornblende, magnetite and zircon.

Mafic dikes

Two mafic dikes in the vicinity of the brick-red syenite were sampled (Fig. 2). These dikes are thin (less than one meter) and cannot be traced laterally for more than a few tens of meters. The dikes are gray to black, medium to fine grained and poorly exposed due to weathering and/or alteration. Hematite is common. The dike near the syenite contains red K-feldspar. Typically, the dikes consist of hornblende, biotite, chlorite, epidote, K-feldspar and plagioclase.

Brick-red syenite

Brick-red syenite crops out in two separate areas in the southern Zuni Mountains (Fig. 2). The syenite is dark to bright red to pink to orange, medium to coarse grained, slightly foliated and forms resistant lenticular to elongated outcrops (Fig. 4). Obvious igneous textures such as zoning and chilled margins are absent in the syenites. Contacts with the granites and metarhyolite generally are not exposed, although Lambert (1983) interpreted the body to be intrusive. The syenite-metarhyolite contact is exposed in one locality near samples 9 and 10 (Figs. 2, 5). It is irregular, diffuse and marked by a sharp color change from the lighter grayish pink of the metarhyolite to bright red-orange of the syenite. The change in mineralogy between the quartz-poor syenite and quartz-rich metarhyolite is abrupt at the contact when exposed. The grain size is similar at the contact in both rock types. Foliation can be locally traced from the metarhyolite into the syenite (Fig. 5).

Textures and mineralogy of the syenites are partially obscured by pervasive hematitization and sericitization. The syenites typically con-

FIGURE 4. Syenite forming resistant outcrops on a ridge in sec. 13, T10N, R12W.

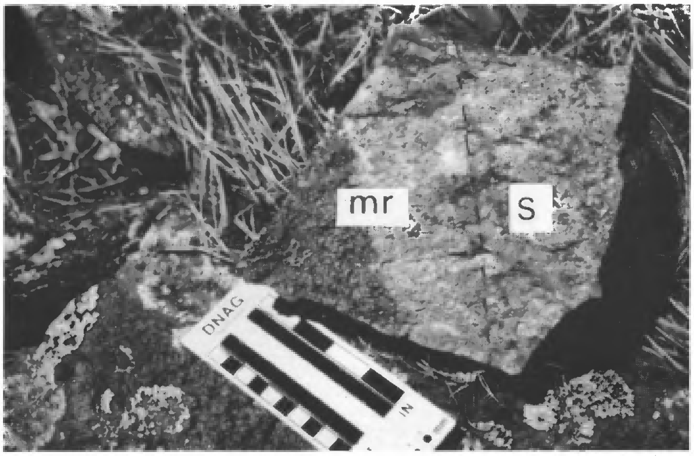

FIGURE 5. Contact between brick-red syenite (s) and metarhyolite (mr). Subtle foliation crosses contact from metarhyolite into syenite.

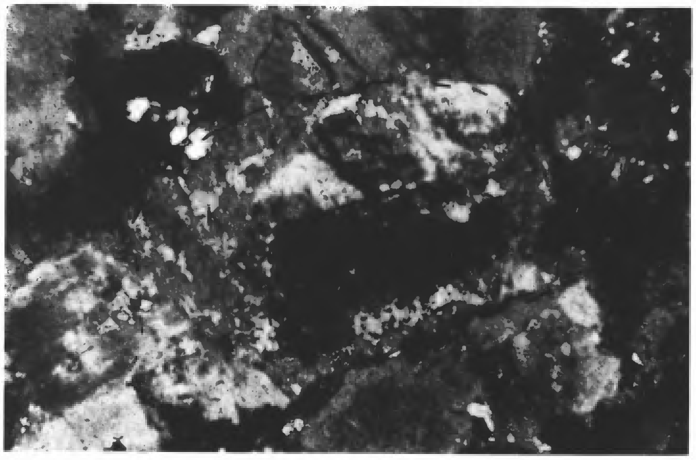

FIGURE 7. Microphotograph of plagioclase (P) core surrounded by K-feldspar (K). Crosspolars. Field of view is 85 μm.

sist of 50–70% microcline and some perthite, 30–40% plagioclase and 5–10% accessory minerals (sericite, hematite, biotite, apatite, calcite and quartz). The microcline and perthite grains are turbid due to hematitic and sericitic alteration. The typical cross-hatched lamellae are absent in the microcline. Most are classified as syenites according to the IUGS system (Streckeisen, 1976), although a few quartz syenites are present.

The feldspars are bright red to orange, which is a result of finely disseminated hematite. Hematite also forms a partial rim around some feldspar grains. The small red-brown hematite inclusions may be a result of oxidation of iron originally within the feldspar lattice (Heinrich, 1966; Heinrich and Moore, 1970; McLemore, 1986).

The syenites have a relict hypidiomorphic-granular texture where adjacent to gneissic granite. Sometimes foliation is preserved in the syenite (Fig. 6). K-feldspar partially replaces plagioclase (Fig. 7) or forms a rim around plagioclase grains. The porphyritic texture of the metarhyolite is preserved in the syenite in hand specimens; however, in thin section large K-feldspar and plagioclase crystals have replaced the fine-grained matrix. Mortar textrues are common. Small veins of syenite intrude the granite and metarhyolite locally.

The syenites of the Zuni Mountains are similar to other brick-red syenites throughout New Mexico (McLemore, 1986; McLemore and McKee, 1988; Loring and Armstrong, 1980). They are not metamorphosed and cut across the Proterozoic granite and metarhyolite. Hematite is common. The Zuni Mountains syenites contain more sericite than other syenites elsewhere in New Mexico.

FIGURE 6. Relict foliation preserved in the syenite similar to that in gneissic granite.

GEOCHEMISTRY

The syenites and adjacent Proterozoic granite and metarhyolite were sampled and analyzed for major and trace elements. Chemical analyses are given in Table 1 and locations shown in Figure 2. The dark gray syenite and adjacent granite were also sampled and analyzed for major and trace elements (Table 2, Fig. 3).

Major elements were determined by x-ray fluorescent spectrometry (XRF) on fused discs at the NMBMMR following the procedure of Norrish and Hutton (1969). Some major elements were determined by XRF using the fundamental parameters program of Criss software (Criss, 1980). Trace elements were determined by XRF using pressed powder briquettes. Iron ratios were determined by titration.

Geochemical studies by Brookins et al. (1978), Brookins and Rautman (1978), Condie (1978) and Brookins (1982) indicate that there are three geochemically distinct granites in the Zuni Mountains: high Ca, high Si and high K (Fig. 8). The granites sampled for this study (Figs. 2, 3) are similar in chemical composition to high-K and high-Si granites elsewhere in New Mexico (Figs. 8, 9; Condie, 1978). Two samples (Z18, Z23A) are higher in CaO and Na_2O and lower in K_2O than most high-K and high-Si granites and may be a result of alteration or heterogeneity of the Zuni Mountains granitic rocks.

Two samples of metarhyolite were sampled for this study (Table 1), and they are similar in chemical composition to metarhyolite sampled by Brookins and Rautman (1978, table 2, #ZS-5). The metarhyolite is high in SiO_2 and Al_2O_3 and intermediate in alkalies (Fig. 8, 9). The dark gray syenites are lower in SiO_2 and K_2O and higher in CaO than the granites (Table 2, Figs. 8, 9). They may be related to the granites geochemically because they plot in similar fields (Figs. 8, 9, 10).

The Zuni Mountains brick-red syenites are high in potassium and similar in composition to high-K syenites from Lobo Hill (Loring and Armstrong, 1980; McLemore, unpubl. data, 1988), Caballo Mountains (McLemore, 1986) and Burro Mountains (McLemore and McKee, 1988). These syenites from throughout New Mexico are characterized by high K_2O (9–16%), high Al_2O_3 (12–20%), low Na_2O (0.3–1.5%) and low to intermediate SiO_2 (53–71%). Samples of the syenite near the contact with the granite or metarhyolite are similar in chemical composition to samples from the center of the syenite body (Table 1, Fig. 2). The Zuni syenites are lower in Sr and higher in Rb and Ba than adjacent granites and metarhyolites (Fig. 10). This trend in Rb, Sr and Ba has been observed in the Caballo and Burro mountains syenites (McLemore, 1986; McLemore and McKee, 1988).

ECONOMIC POTENTIAL

Unlike similar syenite bodies found in the Caballo Mountains near Truth or Consequences, New Mexico (McLemore, 1986), the Zuni syenites have little or no economic potential. A few brick-red syenites are slightly radioactive and slightly enriched in Nb and Y and possibly

TABLE 1. Geochemistry of syenites, granites, metarhyolites and mafic dikes from the Zuni Mountains. See Figure 2 for location of samples. Oxides are in percent, trace elements in parts per million. *Total iron reported as Fe_2O_3.

	Granites		Metarhyolite							Mafic dikes	
	Z-1	Z-12	Z-18	Z-20	Z-21	Z-21I	Z-23A	Z-8	Z-26	Z-2	Z-22
SiO_2	77.9	77.5	68.4	77.4	76.0	76.0	71.8	75.9	78.6	48.0	37.7
TiO_2	0.18	0.19	0.38	0.11	0.07	0.06	0.18	0.19	0.25	0.96	0.12
Al_2O_3	11.7	11.7	15.5	12.0	13.0	13.0	14.8	12.7	11.7	12.6	3.45
Fe_2O_3	1.02	0.13	3.35*	0.70	0.54	0.45	1.12	1.39	0.14	2.37	8.53
FeO	0.61	1.28	--	0.44	0.40	0.62	0.56	0.33	1.38	7.85	4.61
MgO	0.70	0.25	1.69	0.10	0.35	0.27	0.86	0.58	0.82	13.1	33.5
CaO	0.64	0.25	3.45	1.01	1.03	0.93	2.23	1.29	0.19	10.2	0.54
Na_2O	2.42	3.06	4.56	3.68	2.93	2.88	4.27	3.19	1.71	1.38	0.18
K_2O	4.66	4.72	2.42	4.55	5.38	5.55	2.92	3.68	4.24	1.20	0.07
MnO	0.06	0.05	0.07	0.04	0.03	0.03	0.05	0.06	0.04	0.23	0.18
P_2O_5	0.03	0.03	0.14	0.02	0.02	0.02	0.05	0.05	0.04	0.40	0.04
LOI	0.56	1.03	0.88	0.43	0.33	0.33	0.96	0.46	1.12	3.12	10.73
	100.48	100.19	100.84	100.48	100.08	100.14	99.80	99.82	100.23	101.41	99.65
Ba	663	666	710	1158	--	267	1001	717	--	573	31
V	14	30	58	17	--	9	26	18	--	214	32
Cr	34	24	57	17	--	45	41	37	--	840	2119
Pb	23	24	12	20	19	23	--	10	--	--	11
Rb	165	56	65	54	99	101	41	174	156	33	--
Sr	91	312	114	235	184	175	413	52	46	608	6
Y	38	9	7	8	--	--	5	28	47	24	4
Zr	124	105	84	37	36	41	77	119	176	127	15
Nb	14	4	5	5	--	--	--	13	15	9	3

Syenites									
	Z-3	Z-5	Z-9	Z-10	Z-14	Z-16	Z-17	Z-Sy	Z-24
SiO_2	60.3	60.2	58.1	53.4	57.7	62.0	62.9	57.3	57.9
TiO_2	0.22	0.25	0.26	0.57	0.33	0.13	0.12	0.34	0.44
Al_2O_3	19.2	18.4	19.8	18.3	18.9	18.6	18.1	19.7	17.6
Fe_2O_3	3.08	4.32	5.60	7.09	4.14	1.38	2.28	4.09*	6.64
FeO	1.22	0.47	0.72	1.60	0.51	0.48	0.32	--	0.40
MgO	0.93	0.61	0.64	7.39	2.68	0.87	0.22	2.46	0.59
CaO	0.19	0.21	0.18	0.42	0.41	0.17	0.14	0.27	0.27
Na_2O	0.19	0.11	0.23	0.09	0.21	0.34	0.40	0.23	0.33
K_2O	14.4	14.8	14.0	11.0	13.1	15.1	15.6	13.8	14.0
MnO	0.04	0.04	0.04	0.10	0.06	0.03	0.03	0.05	0.05
P_2O_5	0.06	0.07	0.07	0.15	0.11	0.04	0.02	0.12	0.14
LOI	1.12	0.77	1.18	0.43	2.56	0.45	0.43	2.09	1.00
	100.95	100.25	100.82	100.54	100.71	99.59	100.56	100.45	99.17
Ba	1756	1658	1832	881	--	--	1092	1230	--
V	66	49	81	113	--	--	29	--	--
Cr	32	33	30	108	--	--	26	125	--
Pb	--	--	--	9	--	9	13	--	10
Rb	263	275	265	184	181	277	189	839	282
Sr	14	32	13	14	76	36	75	217	19
Y	12	20	28	13	4	29	9	147	15
Zr	85	135	162	75	77	147	55	337	99
Nb	6	6	8	15	5	9	6	284	10

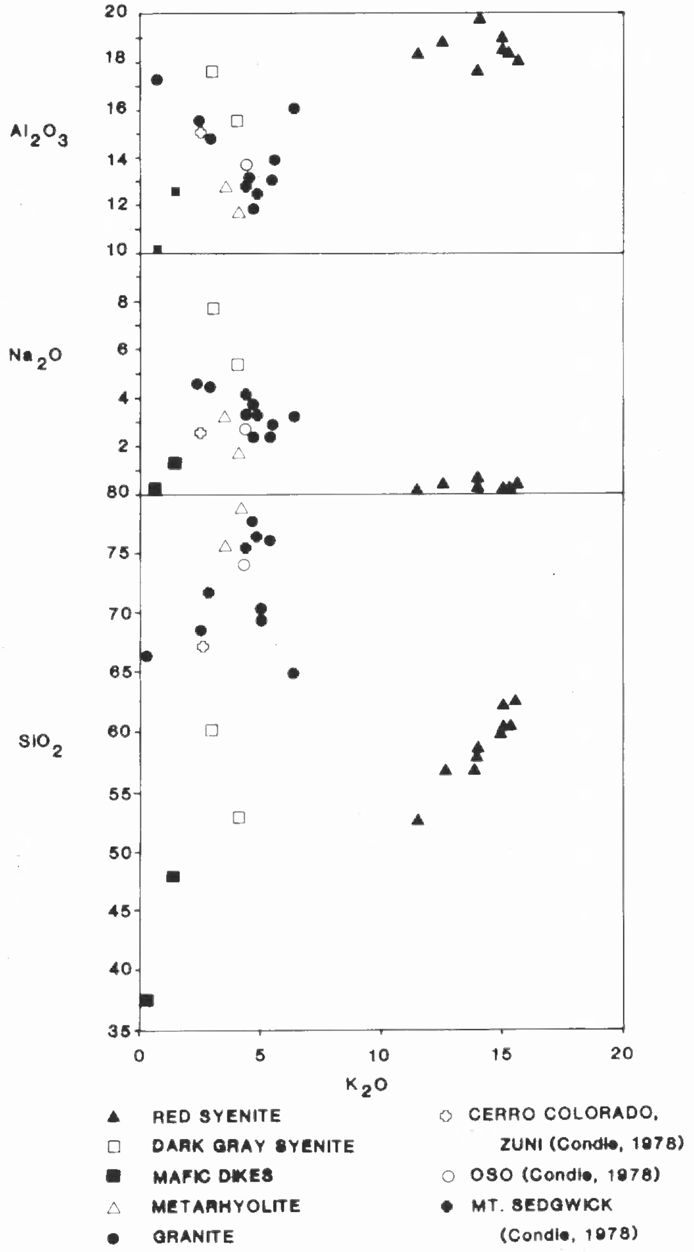

FIGURE 8. Variation diagram of selected oxides (in percent) versus K_2O of Proterozoic rocks and syenites from the Zuni Mountains. Each symbol may represent more than one sample. Note the bimodal population between the granitic rocks and the syenites.

REE (Table 1, sample #Z-54), however, distribution of these elements is sporadic, discontinuous and, therefore, low grade.

DISCUSSION

Origin of Proterozoic granitic rocks from the Zuni Mountains

TABLE 2. Geochemistry of dark gray syenites and granites from sec. 1, T11N, R13W in the Zuni Mountains. See Figure 3 for location of samples. Oxides are in percent, trace elements in parts per million.

	Z-27	Z-29	Z-30	Z-32	Z-28	Z-31
SiO_2	69.1	64.8	70.0	66.1	53.2	61.1
TiO_2	0.72	0.79	0.63	0.81	1.11	0.60
Al_2O_3	13.8	16.2	13.2	17.1	15.5	17.7
Fe_2O_3	3.03	1.46	2.25	2.18	3.04	4.06
FeO	2.23	2.82	1.98	1.34	5.57	1.39
MgO	1.14	1.73	1.04	1.05	6.42	0.76
CaO	1.38	2.05	1.36	0.41	5.86	2.37
Na_2O	3.09	3.04	3.15	9.61	3.34	7.98
K_2O	5.41	6.33	4.41	0.37	3.89	2.97
MnO	0.10	0.08	0.09	0.03	0.16	0.07
P_2O_5	0.15	0.22	0.14	0.17	0.41	0.14
LOI	0.20	1.35	0.96	0.74	1.85	1.31
TOTAL	100.35	100.87	99.21	99.91	100.35	100.45
Ba	1166	3107	--	--	1237	694
V	61	88	--	--	203	76
Cr	50	37	--	--	139	57
Pb	22	44	16	12	12	28
Rb	174	239	153	14	183	102
Sr	119	506	156	101	368	164
Y	48	16	46	53	27	34
Zr	325	298	302	351	236	344
Nb	14	11	15	14	11	16

Geochemical modeling by Condie (1978) suggested that high-K and high-Si granites, similar to those found in the Zuni Mountains, can be produced by either partial melting of a granulite parent or fractional crystallization of a high-Ca granite, such as that found in the Zuni Mountains. The metarhyolite may be an extrusive equivalent of the high-K and high-Si granite because of similar geochemical composition and age (Table 1, Figs. 8, 9, 10). The dark gray syenite is probably a younger magmatic differentiation of the high-K and high-Si granite. The presence of high-Ca, high-K and high-Si granites and other possibly related rocks in the Zuni Mountains indicates this is an excellent area for geochemical modeling to determine the source and origin of these rocks.

Origin of the Zuni brick-red syenite

The brick-red, high-K syenites are most likely of metasomatic origin. Metasomatism is the process of replacement of minerals introduced by external fluids. The strongest evidence supporting a metasomatic origin is the preservation of foliation within the Zuni syenite which is similar to that within adjacent granite or metarhyolite. Locally, foliation can be traced from the metarhyolite into the syenite. Replacement of plagioclase by K-feldspar is consistent with a metasomatic origin. The contact between the syenite and metarhyolite, where exposed, is irregular and diffuse, but marked by a sharp color change and change in mineralogy and chemistry. The high K_2O and low Na_2O of the syenite are consistent with metasomatism and difficult to achieve by magmatic processes. Selective enrichment of potassium with respect to sodium

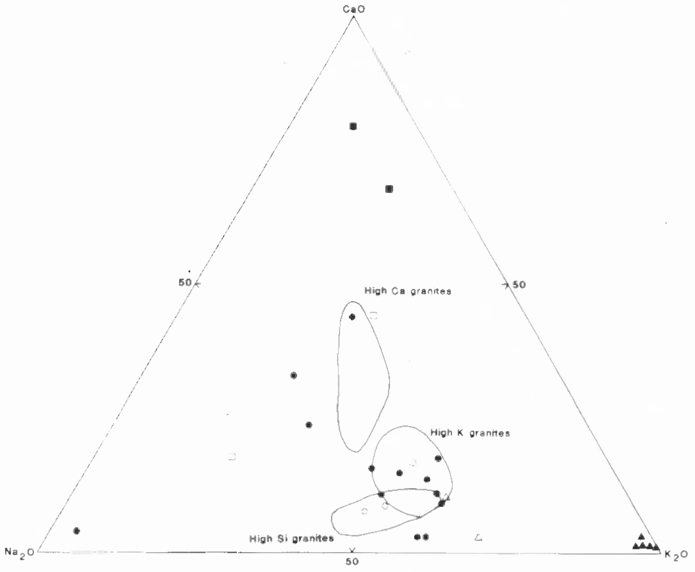

FIGURE 9. CaO-Na_2O-K_2O (in percent) diagram of Proterozoic rocks and syenites from the Zuni Mountains. Fields shown are high-Ca, high-K and high-Si group granites of Proterozoic age in New Mexico (Condie, 1978). Each symbol may represent more than one sample. Symbols explained in Figure 8.

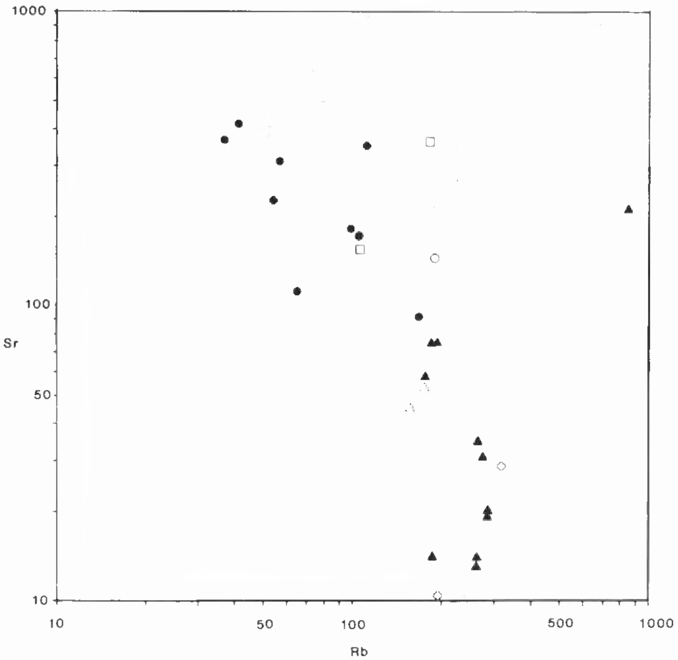

FIGURE 10. Rb-Sr (in parts per million) plot of Proterozoic rocks and syenites from the Zuni Mountains. Symbols explained in Figure 8.

occurs in some magmatic systems in volcanic to subvolcanic environments (Sahama, 1974); however, most potassium-rich rocks associated with alkalic rocks and carbonatites are attributed to metasomatism or fenitization (Sutherland, 1965; Heinrich and Moore, 1970; Kinnarid et al., 1985). Fenitization is alkalic metasomatism associated with intrusion of carbonatites, kimberlites and alkalic rocks (Heinrich, 1966).

Similar high-K syenites occur elsewhere in New Mexico and also have been attributed to metasomatism (McLemore, 1986; McLemore and McKee, 1988). High-Na syenites (4–9% K_2O, 3–6% Na_2O) have been found in a few of these areas (Burro Mountains, Caballo Mountains, Florida Mountains; McLemore, 1986; McLemore and McKee, 1988) and may be of magmatic origin. High-Na syenites are not recognized in the Zuni Mountains.

Two possible models are envisioned for the origin of the Zuni syenites. A high-Na syenite intruded the Proterozoic rocks and was subsequently metasomatized along with adjacent country rocks by postmagmatic, potassium-rich solutions. A similar process is described for the Ririwai alkaline complex in northern Nigeria (Kinnarid et al., 1985). Alternatively, potassium-rich solutions, possibly related to a deeper syenitic magma, may have traveled along fractures and metasomatized the Proterozoic rocks to syenite. Similar models are envisioned for syenites found in the Caballo and Burro mountains (McLemore, 1986; McLemore and McKee, 1988). Detailed isotopic studies are required to evaluate these models.

Regional setting

Alkalic rocks of apparent Late Proterozoic to Cambrian-Ordovician age are not as uncommon in New Mexico as once thought (Fig. 11). A syenite complex was emplaced at Pajarito Mountain during the Late Precambrian (Kelley, 1968; Moore and Foord, 1986). A Cambrian-Ordovician alkalic magmatic event was widespread in southern Colorado and New Mexico and is characterized by carbonatites and syenites with isotopic ages between 400 and 600 my (McLemore and McKee, 1988; McLemore, 1989). Potassium metasomatism forming high-K syenites, including the Zuni Mountains syenites, may be part of this Cambrian-Ordovician event, although a Proterozoic age for the syenites in the Zuni Mountains cannot be ruled out without isotopic dating.

Periodic episodes of carbonatite and alkalic magmatism are commonly associated with continental 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). Although theories have been suggested placing rift systems similar to the St. Lawrence and East African systems in New Mexico during the Precambrian through Paleozoic (Larson et al., 1985; Condie and Budding, 1979; Evans and Clemons, 1987, 1988), specific geographic boundaries of the rift systems in New Mexico and southern Colorado are difficult to determine because of complex tectonic overprinting related to Rio Grande rifting and other tectonic events. More comprehensive evaluation of the tectonic regime during the Cambrian-Ordovician is needed to fully understand the wide distribution of these rocks in New Mexico.

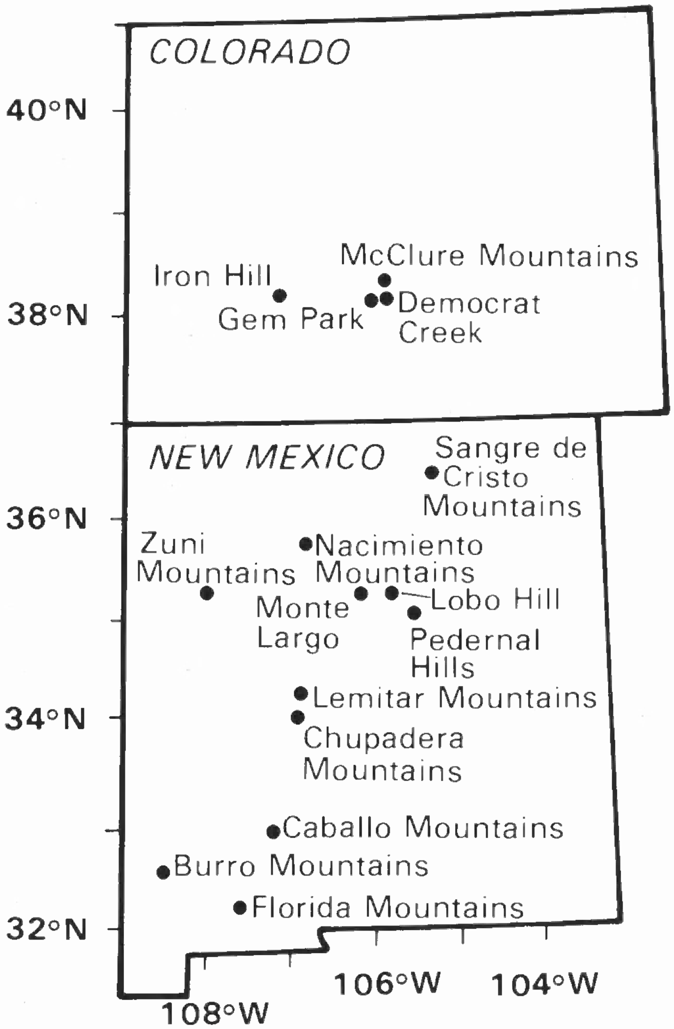

FIGURE 11. Locations of carbonatites and alkalic rocks of known and possible early Paleozoic age in New Mexico and southern Colorado.

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Critical reviews and comments by Lee Woodward and Kent Condie are greatly appreciated. Ferrious/ferric iron ratios were determined by Lynn Brandvold and associates (NMBMMR Chemical Laboratory). Lynne McNeil typed the manuscript.

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El Rancho Inn, Gallup, New Mexico, featuring "the charm of yesterday." Photo by O. J. Anderson.