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Geology, geochemistry, and mineralization of synenites in the Red Hills, southern Caballo Mountains, Sierra County, New Mexico--Preliminary observatons

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1986, pp. 151-159. https://doi.org/10.56577/FFC-37.151

in:

Truth or Consequences Region, Clemons, R. E.; King, W. E.; Mack, G. H.; Zidek, J.; [eds.], New Mexico Geological Society 37th Annual Fall Field Conference Guidebook, 317 p. https://doi.org/10.56577/FFC-37

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GEOLOGY, GEOCHEMISTRY, AND MINERALIZATION OF SYENITES IN THE RED HILLS, SOUTHERN CABALLO MOUNTAINS, SIERRA COUNTY, NEW MEXICO: PRELIMINARY OBSERVATIONS

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Abstract—More than 25 radioactive, brick-red, flat-lying tabular bodies and near-vertical pipes of syenite occur within the Precambrian granite in the Red Hills. They consist of microcline with subordinant quartz, muscovite, hematite/goethite, chlorite, and trace of plagioclase. Compositions range from syenite to quartz syenite to alkali granite. Accessory minerals include apatite, zircon, calcite, fluorite, limonite, magnetite, and barite. Small, discontinuous pockets or zones of uranium and thorium mineralization occur in some syenite bodies and consist of anomalous amounts of spinel, rutile, anatase, thorite, thorogummite, and possible uraninite. These zones are uneconomic because of discontinuity, low grade, small size, and poor market conditions. The syenites are higher in K_2O, Al_2O_3, MgO, U, and Th and lower in Na_2O and SiO_2 than the adjacent granites. They have a high K_2O/Na_2O ratio compared to most syenites. Pervasive hematitization, chloritic alteration, and uranium–thorium mineralization have obscured original mineralogy and textures. Field observations, replacement textures in thin sections, mineralogy, and high K_2O/Na_2O ratios suggest that the syenites are a result of potassium metasomatism of either a syenite intrusive or of the adjacent granite. The syenites may be part of an alkalic magmatic event that affected New Mexico during late Precambrian to Cambrian–Ordovician times; radiometric dating of the Red Hills syenites is needed. Additional geochemical studies, isotopic studies, radiometric dating, and detailed mapping of syenites in the Caballo Mountains and elsewhere in Precambrian terranes in New Mexico are required to understand the origin of these rocks.

INTRODUCTION

Alkalic rocks of late Proterozoic to Cambrian–Ordovician age were once thought to be rare in New Mexico; however, recent mapping of areas of Precambrian outcrops indicates that syenites and alkali granites occur in many Precambrian terranes in the state (Woodward et al. 1977, Hedlund 1978a, b, c, Condie & Budding 1979, Loring & Armstrong 1980, Lambert 1983, Reed et al. 1983, McLemore 1982, in press, Clemons in press). Not all of these rocks have yet been dated. Uranium and thorium-bearing-syenite, quartz-syenite, and alkali-granite bodies occur in the Red Hills, southeast of the Caballo dam and reservoir in Sierra County (Fig. 1). Geologic, mineralogic, and geochemical studies were undertaken to characterize these rocks and to evaluate their economic potential. Additional syenite bodies occur to the north in the Precambrian terrane exposed along the western foothills of the Caballo Mountains and studies of these rock are underway.

Radioactive syenite dikes were reported by Melancon (1952) and Boyd & Wolfe (1953) during a reconnaissance for uranium deposits. Subsequently, Staatz et al. (1965) mapped much of the Precambrian terrane in the Red Hills and described the syenites as metasomatic bodies related to alkalic solutions altering the granite, similar to fenitization.

The Red Hills have been examined briefly as part of regional mapping studies by Kelley & Silver (1952) and Seager et al. (1982). Condie & Budding (1979) mapped and briefly described the Precambrian rocks in the Caballo Mountains, including syenites and quartz syenites in the central Caballo Mountains, north of the Red Hills.

The present study involves detailed remapping (at a scale of approximately 1:17,000) of the Precambrian terrane in the Red Hills (Fig. 2) and collecting samples for geochemical and mineralogic studies. Major- and trace-element analyses are by x-ray fluorescence at the New Mexico Bureau of Mines & Mineral Resources. Mineral separates are obtained by heavy-liquid separation and hand separation. Mineralogy is determined by optical and x-ray-diffraction techniques. Thin sections were stained for determination of K-feldspar.

A preliminary examination of geochemical element-distribution maps (Chamberlin & McLemore 1983, McLemore & Chamberlin 1986) compiled from data in Union Carbide Corp. (1981) was made to aid in evaluation of the economic resources. The data are part of the HSSR (Hydrogeochemical and Stream Sediment Reconnaissance) survey of the NURE (National Uranium Resource Evaluation) program of the U.S. Department of Energy and consists of geochemical surveys and analyses for each of the $1° \times 2°$ quadrangles in New Mexico. A few stream-sediment samples from drainages of the Red Hills area are anomalously high in U (5.8–13.8 ppm), Th (10–30 ppm), P (600–700 ppm), and Y (20–50 ppm) as compared with stream-sediment samples from granitic terranes elsewhere in New Mexico.

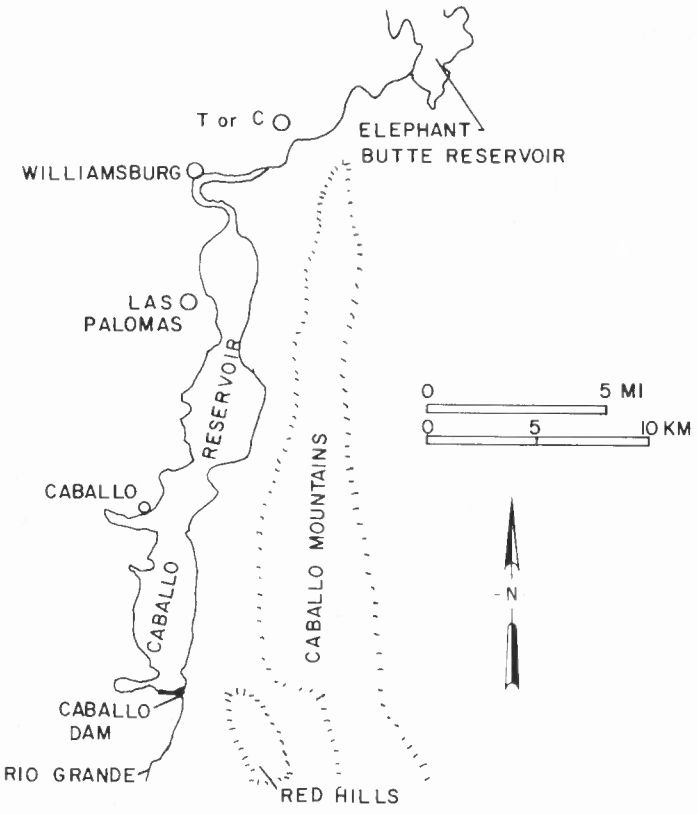


FIGURE 1—Location of south Red Hills, southern Caballo Mountains, Sierra County, New Mexico.

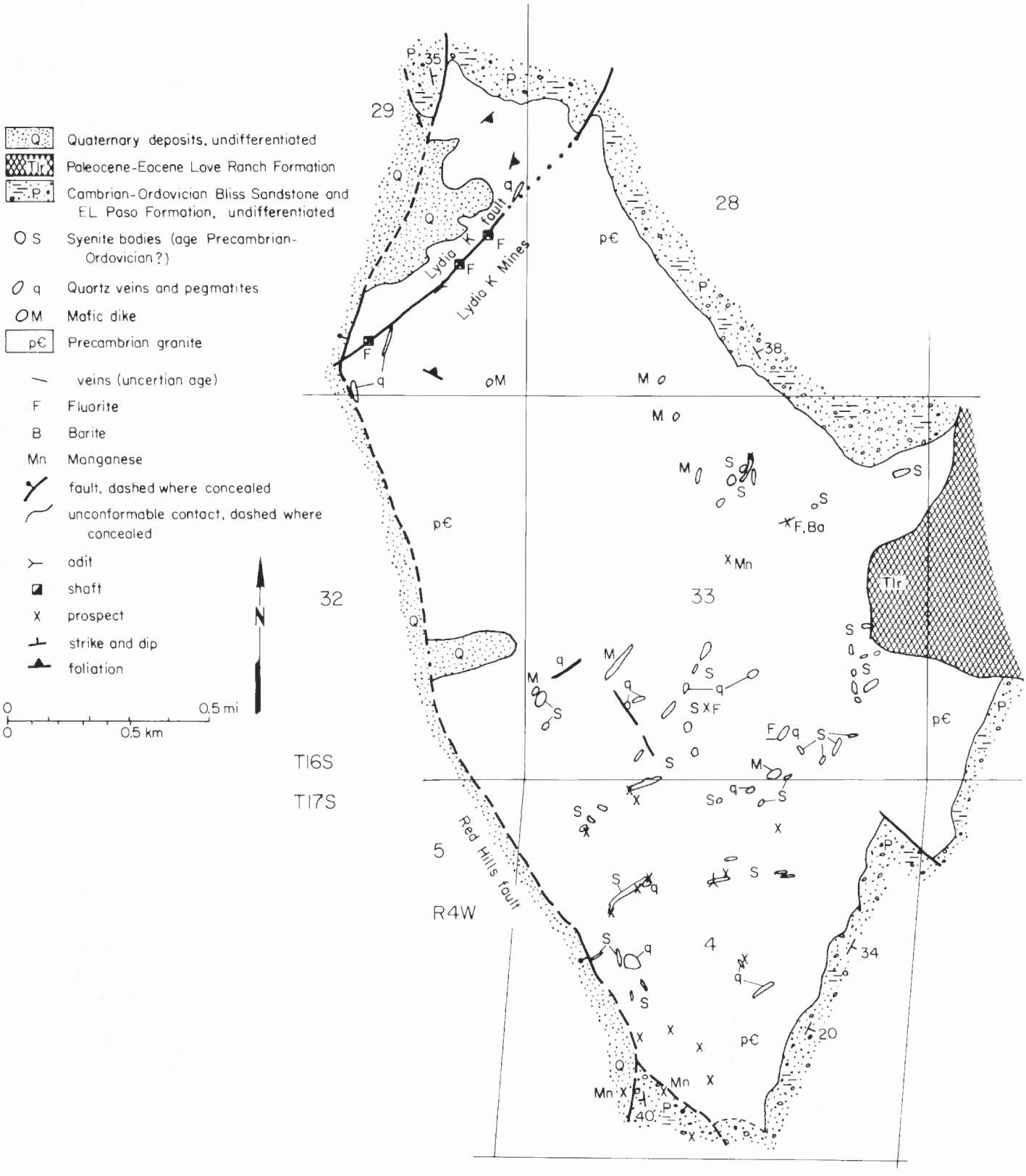


FIGURE 2—Geologic map of south Red Hills, Sierra County, New Mexico.

GEOLOGY

Geologic setting

The Red Hills are a southern extension of the Caballo uplift which forms part of the eastern margin of the Palomas Basin of the Rio Grande rift. Uplift of the area occurred during early and late Tertiary and exposed a small outlier of Precambrian rocks in the Red Hills.

The Precambrian rocks are overlain by either the Bliss Sandstone (Cambrian–Ordovician) or the Love Ranch Formation (Paleocene–Eocene; Fig. 2; Seager et al. 1982). The nonconformity is well exposed in places, especially north and east of the Lydia K fault where it is characterized by a thin (5–15 cm) zone of iron-stained quartzite pebbles overlain by quartz sandstones, sandstones, and shales of the Bliss Sandstone.

The dominant Precambrian lithology in the Red Hills is granite, although quartz monzonites, as defined by the IUGS Subcommission on the Systematics of Igneous Rocks (1973), are common. Syenites, quartz syenites, and alkali granites occur in granite throughout the central portion of the area (Fig. 2). Pegmatite, aplite, and mafic dikes and quartz veins intrude the granite locally. Barite–fluorite and manganese veins, probably of Tertiary age, occur along faults and shears.

The Red Hills fault bounds the Precambrian terrane on the west. The Lydia K fault trends northeast and cuts the Palm Park Formation (Eocene) to the northeast (Seager et al. 1982). Fluorite–barite mineralization occurs along the Lydia K fault and manganese occurs along the southern end of the Red Hills fault (Fig. 2). There are additional minor faults and shears in the Precambrian terrane, but these zones are discontinuous and difficult to trace along strike.

The Precambrian terrane in the Caballo Mountains north of the Red Hills consists dominantly of granitic rocks, ranging in composition from granite and quartz monzonite to syenite, quartz syenite, and alkali granite (Doyle 1951, Mason 1976, Condie & Budding 1979, personal reconnaissance 1985). At least three types of granitic rocks are in this area, with the Caballo pluton being the youngest (Condie & Budding 1979). A small section of metamorphic supracrustal rocks in the central Caballo Mountains is described by Bauer & Lozinsky (1986). Pink granite (Caballo granite) is the youngest granitic intrusive in this area.

Granite

In the Red Hills, granite and quartz monzonite are orange to pink and vary from coarse- to fine-grained. They typically consist of equal amounts of quartz, microcline, and twinned plagioclase (albite–oligoclase), comprising 85–95% of the rock. Accessory minerals include varying amounts of muscovite or sericite, biotite, chlorite, magnetite, hematite/goethite, limonite, and zircon. The feldspars are clear or altered to sericite. Quartz in granite is typically anhedral with undulatory extinction. The granite typically has a hypidiomorphic–granular texture; micrographic and mortar textures are common. Perthites occur in many samples. The granite is weakly foliated to nonfoliated. The entire area north of the Lydia K fault is strongly foliated in a northeast to east direction; a zone about 100 m south of the fault also is foliated (Fig. 2). The granite consists of up to 10% biotite in this foliated area and grades into weakly foliated or nonfoliated granite with little or no biotite.

The granite in the Red Hills is similar in texture and composition to the Caballo pluton of Condie & Budding (1979) and to the pink granite (Caballo granite) of Bauer & Lozinsky (1986). Granitic rocks in the central and northern Caballo Mountains (Doyle 1951, Mason 1976) are also similar in texture and mineralogy to the Red Hills granite.

The age of the granite in the Red Hills and elsewhere in the Caballo Mountains is uncertain, but is presumed to be mid-Proterozoic. The granitic rocks are regionally foliated, although only slightly in places, and overlain by Cambrian–Ordovician rocks. A gneissic granite in the Caballo Mountains was dated as 1,304 ± 72 my (recalculated using new decay constant) by Rb–Sr whole-rock methods (Muehlberger et al. 1966); however, the exact location of this sample is not known.

Syenite

The syenite bodies are brick-red, coarse- to fine-grained, and range in composition from syenite to quartz syenite to alkali granite as defined by the IUGS Subcommission on the Systematics of Igneous Rocks (1973). They typically consist of microcline (as determined by x-ray diffraction) with subordinant amounts of quartz, muscovite, hematite/goethite, and chlorite. Plagioclase occurs in trace amounts and is rarely twinned. Microcline crystals are turbid due to hematitization and sericite alteration; typical grid-iron twinning is absent. Microcline grid-twinning is rare in many hypersolvus syenites in alkalic provinces (Sørensen 1974: 26, Heinrich & Moore 1970: 579). Some syenites in the Red Hills contain as much as 95% microcline, whereas others contain as much as 25% quartz. Large (up to 1 cm in diameter) segregations of either specular hematite or chlorite are common within some bodies. Accessory minerals include apatite, zircon, calcite, fluorite, limonite, magnetite, and barite.

Pervasive hematitization, chloritic alteration, and uranium–thorium mineralization have obscured original textures in many syenites. The syenites typically have a hypidiomorphic–granular texture similar to adjacent granites and quartz monzonites. The syenites are typically not foliated and do not exhibit obvious intrusive textures such as zoning or chilled margins. Most samples have mortar and perthitic textures; micrographic textures are absent. Replacement of grid-iron twinned microcline by untwinned microcline containing red hematite inclusions is common near the contacts with the granite.

The brick-red color is a result of pervasive hematitization. Red hematite veins cut across the syenites, obscuring the texture and mineralogy of some thin sections. Small red hematite inclusions within feldspar crystals may be a result of oxidation of iron molecules originally within the feldspar lattice to hematite (Heinrich 1966, Heinrich & Moore 1970).

The syenite bodies are lenticular to elongate and range from 1 to 100 m in length and from several centimeters to 10 m in width. Well over 25 bodies have been found, but many are extensions of one another or are too small to map. These bodies are typically thin (less than a few meters thick), tabular, flat-lying to gently dipping to the west (Fig. 3). Narrow (several meters wide), near-vertical pipes (Fig. 4) also are present locally. A few areas contain only randomly oriented veins of syenite along fractures of the granite.

Most of the contacts between the syenite and granite are diffuse, irregular, gradational, and marked by a color change from orange or pink to bright red. Some contacts are sharp, especially along fractures and shears. The texture and weak foliation of the granite can be traced into the syenite bodies in many places (Fig. 5). Small veins of syenite intrude the granite locally, especially along fractures. Some of the larger syenite bodies contain relatively unaltered inclusions of orange to pink granite or quartz monzonite.

All of the syenite bodies are radioactive, although most are only two or three times background radioactivity. Radioactivity is produced by anomalous amounts of uranium, thorium, or potassium.

The age of the syenites is unknown. The syenites are not metamorphosed and crosscut the granitic rocks. They are unconformably overlain

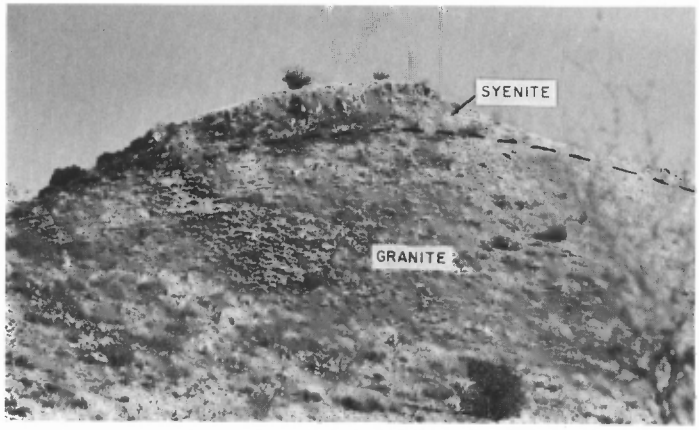


FIGURE 3—Gently dipping (to the west), tabular body of syenite overlying granite, looking southwest at NW¼NW¼SE¼ sec. 33, T16S, R4W.

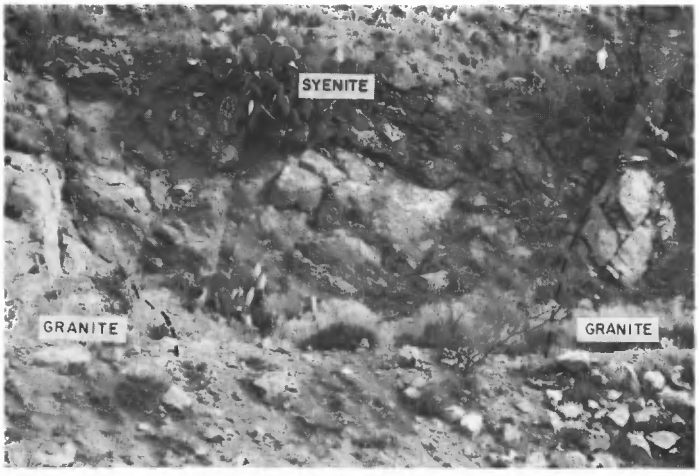


FIGURE 4—Syenite pipe in granite, looking east at SW¼SE¼SE¼ sec. 33, T16S, R4W.

by the Love Ranch Formation of Paleocene–Eocene age (Fig. 2). The relationship with the Bliss Sandstone of Late Cambrian–Ordovician age is not known at this time. Syenites in the Florida Mountains, 90 km south of the Red Hills, have been dated as 503 ± 10 my by the U–Pb concordia method using zircons (Clemons in press). Additional syenites in Torrance County at Lobo Hill and the Pedernal Hills have been dated as 469 ± 7 my by Rb–Sr isochron methods (Loring & Armstrong 1980). The Caballo syenites may be of similar age.

Minor lithologies

Thin, simple pegmatite and aplite dikes locally intrude the granite. These dikes are typically less than one meter wide and rarely exceed a few meters in length. They tend to parallel foliation in the granite when present and probably represent a late stage of granitic magmatism.

Several quartz pods and veins intrude the granite, especially near syenite bodies or near pegmatites (Fig. 2). The quartz is typically milky white and stained by iron and manganese minerals. One sample assayed no gold and 0.16 oz/ton (5.4 ppm) silver, whereas another assayed a trace of gold (<6.8 ppm) and 0.04 oz/ton (1.4 ppm) silver. A third sample contained no detectable silver or gold.

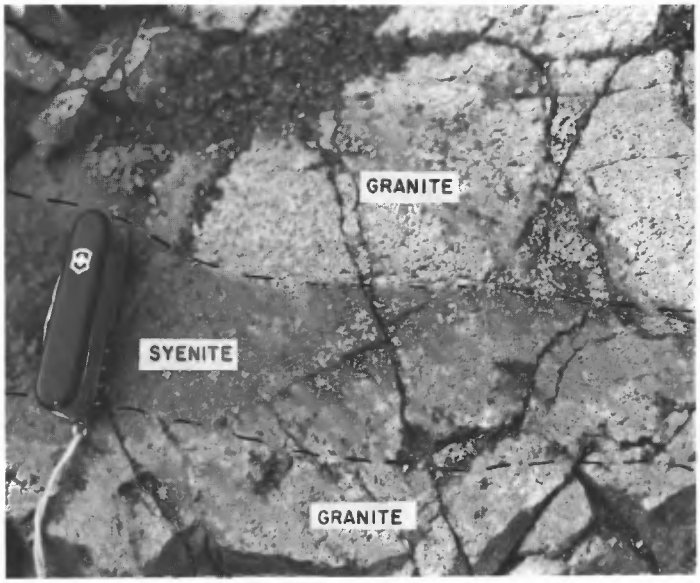


FIGURE 5—Sharp contact of thin syenite within weakly foliated granite, SE¼NW¼NE¼ sec. 33, T16S, R4W. Subtle foliation in syenite parallels that in granite. These relationships suggest replacement of granite by syenite.

Several small mafic dikes intrude the granite (Fig. 2). These black to brown chlorite-rich dikes are poorly exposed and intensely altered.

Age relationships of these minor rocks are uncertain. The pegmatite, aplite, and mafic dikes are slightly metamorphosed and probably of Precambrian age. Age of the quartz veins is unknown.

MINERALIZATION

Uranium–thorium

All of the syenite bodies are radioactive and contain anomalous amounts of uranium and thorium; however, only a few bodies contain small, discontinuous pockets or zones of uranium–thorium mineralization (Tab. 1). One sample (#9039) contained 0.50% U_3O_8 and 0.97% Th, but the mineralized zone was small and spotty. The mineralization is fracture-controlled and sporadically distributed throughout the syenite bodies.

These zones contain minor disseminations of fluorite, calcite, spinel, rutile, barite, apatite, zircon, and anatase. Anomalous high values of U, Th, P, and Y found in the NURE geochemical data may be related to these zones. Fluorite–calcite veins coat fracture surfaces. Radioactive minerals, identified by x-ray diffraction of heavy separates, include fluorite, thorite, thorogummite, and possibly uraninite. Staatz et al. (1965) also reported the occurrence of bastnaesite, pyrite, and uranophane in one or more zones. Thin, fracture-filling calcite veins occur in some of the syenites, but are typically low in uranium and thorium (Tab. 1, #4.141.4). These zones are presently uneconomic for uranium and thorium because of (1) discontinuous mineralization, (2) low overall grade, (3) small size, and (4) poor market conditions.

Fluorite–barite

The most important mineralization in the Red Hills is fluorite, which was produced from the Lydia K mines. Fluorite mineralization with minor amounts of barite, galena, and silver occurs as veins along the Lydia K fault with a gangue of quartz and calcite (Fig. 6). Descriptions of the mineralization and the workings are by Johnston (1928), Rothrock et al. (1946), Williams (1966), and McAnulty (1978). A dump sample assayed 26.66% CaF_2 (Tab. 2).

Several small veins of fluorite and barite occur south of the Lydia K mines (Fig. 2). However, these veins are small and of limited extent. One sample contained 7% CaF_2 and 76% $BaSO_4$ (Tab. 2, #9033).

These veins are probably Tertiary in age, similar to other barite and fluorite deposits in New Mexico (McLemore & Barker 1985, North & McLemore 1986). Barite and fluorite veins of Miocene age occur in the San Diego Mountain area (Seager et al. 1971) and in the Palm Peak area (Seager & Hawley 1973). The Lydia K fault cuts rocks of the Palm Park Formation (Eocene), suggesting that mineralization at the Lydia K mines is younger than Eocene and may be part of the Miocene



FIGURE 6—Looking southeast along the Lydia K fault from dumps of Lydia K mine. Fluorite mineralization occurs as veins along this fault zone.

TABLE 1—Geochemistry of radioactive zones of syenite bodies. Location and description of samples in Appendix 1. Oxides and Y, Sr, Rb, Nb, Zr, Pb, U, Th by x-ray fluorescence. U_3O_8 by colorometric methods, Cu and Zn by atomic-absorption spectrometry, Au and Ag by fire assay, and CaF_2 by fluorometric methods. Fe_2O_3* calculated from total iron. BD = below detection limit.

	9028	9036	3750	9034	9035	9037	7969	9038	9039	9040	4.141.4
Major oxides (in percent)											
SiO_2				59.87	58.26	60.24		53.27	51.81		
TiO_2				0.63	0.62	0.63		1.28	1.39		
Al_2O_3				16.79	16.86	15.54		17.95	15.50		
Fe_2O_3				6.69	3.79	5.35		6.75	9.22		
MnO				—	0.07	0.02		0.02	0.08		
MgO				0.78	4.39	5.52		5.27	5.24		
CaO				0.98	2.35	1.02		0.82	0.58		
Na_2O				0.23	1.79	1.34		2.73	1.24		
K_2O				11.89	8.81	7.41		6.70	6.49		
P_2O_5				0.21	0.27	0.28		0.38	0.26		
LOI				2.18	3.22	3.63		4.49	5.04		
TOTAL				100.25	100.43	101.01		99.66	96.85		
Trace Elements (in ppm)											
Y	318	313	77	621	111	117	506	423	889	1949	34
Sr	57	23		27	29	19	8	22	BD	BD	131
Rb	31	20		483	301	273	298	379	110	116	17
Nb	BD	BD	48	3	46	34	126	72	23	BD	7
Zr	13	10	45	265	310	291	537	157	189	254	15
Pb	326	228	125	62	181	146	173	1091	279	1191	247
U	107	113		35	56	75	2329	147	665	498	4
Th	6	4	104	3233	377	462	1158	1254	9721	1006	8
U_3O_8	120	220	50	110	110	110	4600	300	4980	3800	--
Cu	22	<50	--	<50	<50	<50	--	<50	<50	500	--
Zn	110	210	--	<1	<1	<1	--	460	<1	180	--
Au	<7	<7	0	<7	0	0	0	0	<7	<7	--
Ag	3.4	1.4	0	1.4	4.8	11.6	0	0	3.4	4.1	--
CaF_2(%)	1.36	--	--	--	--	--	--	--	--	--	--
CIPW Norms											
Quartz				8.7	2.9	13.4		2.1	9.1		
Corundum				2.3	0.8	4.1		5.6	6.0		
Orthoclase				70.2	52.1	43.8		39.6	38.4		
Albite				1.9	15.1	11.3		23.1	10.5		
Anorthite				3.5	9.9	3.2		1.6	1.2		
Hypersthene				5.5	11.7	16.1		15.6	18.2		
Magnetite				3.8	2.7	3.2		3.9	4.7		
Ilmenite				1.2	1.2	1.2		2.4	2.6		
Apatite				0.5	0.6	0.7		0.9	0.6		

TABLE 2—Assays of selected samples from fluorite–barite veins, Red Hills (by L. Brandvold and associates, New Mexico Bureau of Mines & Mineral Resources, Chemistry Laboratory). No gold was detected in any of the samples.

	9029	9031	9033
Location	NE NW NE sec. 33	Lydia K dump	SE NE NE sec. 33
CaF_2 (%)	0.72	26.66	7.00
$BaSO_4$ (%)	1.94	<0.03	76.3
Ag (ppm)	0	29	2.7
Cu (ppm)	55	300	1,000
Pb (%)	0.009	4.67	0.004
Zn (ppm)	130	<1	<1
U_3O_8 (%)	0.003	<0.001	<0.001
Th	11	689	2

TABLE 3—Assays of selected samples from manganese veins, Red Hills, Sierra County (by L. Brandvold and associates, New Mexico Bureau of Mines & Mineral Resources, Chemistry Laboratory).

Sample No.	Location	Mn %	Au oz/ton (ppm)	Ag oz/ton (ppm)
8803	4.342.3	5.65	0.00	0.18 (6.1)
8804	4.342.2	15.92	0.00	0.28 (9.5)

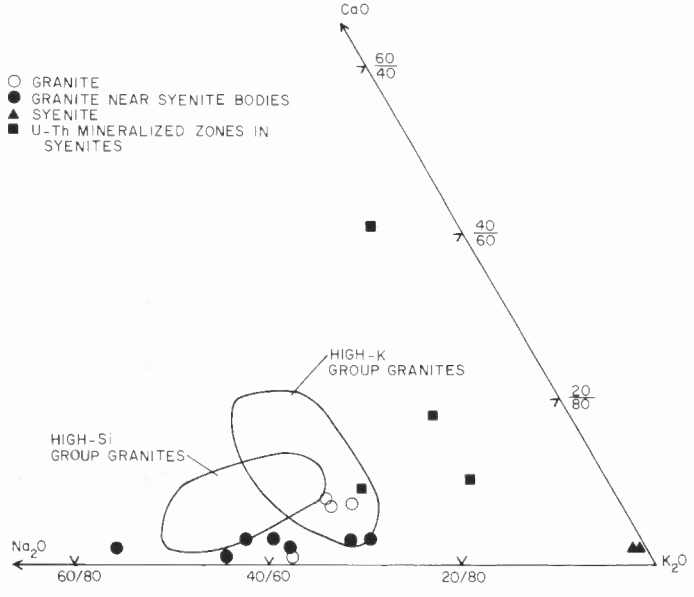


FIGURE 7—CaO–Na_2O–K_2O diagram of syenites and granite from Red Hills. Fields shown are high-K and high-Si group granites (from Condie 1978). Each symbol may represent more than one sample.

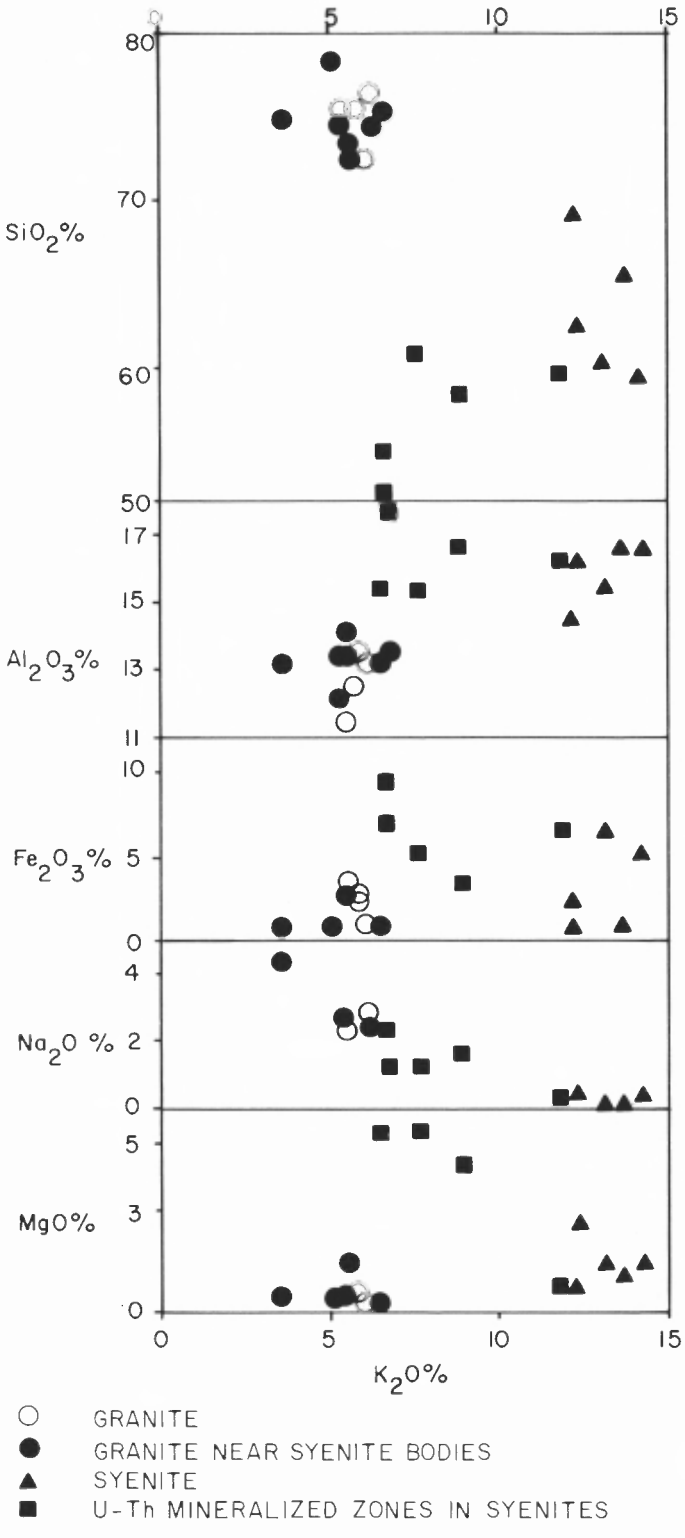


FIGURE 8—Variation diagram of selected oxides versus K_2O of syenites and granites from Red Hills, Sierra County. Each symbol may represent more than one sample.

mineralization present in the San Diego and Palm Park areas. The veins south of the Lydia K fault may be related to mineralization at the Lydia K mines or to the syenite bodies.

Manganese

Manganese-oxide minerals coat fractures and are pervasive throughout the Red Hills. Low-grade mineralization occurs along the southern portion of the Red Hills fault (Fig. 2). Manganese mineralization occurs as thin veins (<10 cm) and small replacement bodies in sandstones and limestones of the Bliss Sandstone and El Paso Formation (Ordovician) and in Precambrian granitic rocks. Mineralization is typically less than 16% Mn and contains minor amounts of silver (Tab. 3).

GEOCHEMISTRY

Two slightly radioactive syenite bodies and adjacent granites were sampled and analyzed for major and trace elements. Two additional

TABLE 4—Geochemistry of syenites and granites. Location and description of samples in Appendix 1. Analyses by x-ray fluorescence. Fe_2O_3* calculated from total iron.

	granite	granite	granite	granite	syenite	syenite	syenite	granite	granite	granite	syenite	syenite	Misc. granite samples			
	33.411.4	33.411	33.411.5	33.411.10	33.411.9	33.411.6	33.411.8	33.411.7	4.141.8	4.141.5	4.141.6	4.141.7	33.133	29.242	C6	C14
Major oxides (in percent)																
SiO_2	75.46	78.27	74.38	73.97	65.55	62.89	69.27	74.28	74.62	72.42	60.02	59.53	72.77	75.42	75.80	76.34
TiO_2	0.07	0.05	0.09	0.08	0.11	0.26	0.03	0.09	0.06	0.30	0.28	0.26	0.20	0.27	0.27	0.11
Al_2O_3	13.16	12.24	13.54	13.57	16.65	16.27	14.64	13.53	13.16	14.12	15.69	16.77	13.61	11.70	12.65	13.36
Fe_2O_3*	1.37	1.06	1.36	1.06	1.25	2.67	1.05	1.26	1.28	2.21	6.73	5.60	2.32	3.86	2.13	1.29
MnO	—	0.01	—	0.01	—	—	—	0.02	—	0.02	0.02	0.02	0.02	—	—	—
MgO	0.49	0.48	0.50	0.65	1.04	2.80	0.82	0.60	0.52	1.43	1.57	1.58	0.59	0.56	0.53	0.32
CaO	0.21	0.18	0.28	0.24	0.26	0.27	0.20	0.25	0.12	0.33	0.25	0.22	0.44	0.58	0.68	0.13
Na_2O	2.66	3.14	2.88	3.41	0.09	0.25	0.06	3.69	4.90	3.37	0.07	0.21	2.91	2.32	2.77	3.69
K_2O	6.51	5.25	6.39	5.38	13.89	12.23	12.19	5.14	3.63	5.47	13.05	14.13	5.78	5.30	5.72	6.05
P_2O_5	0.04	0.04	0.07	0.06	0.08	0.17	0.16	0.07	0.03	0.09	0.12	0.09	0.07	0.06	0.05	0.04
LOI	0.69	0.60	0.74	0.79	1.02	1.62	0.75	0.81	0.55	1.15	1.15	1.19	0.96	0.72	0.99	0.47
TOTAL	100.66	101.32	100.23	99.22	99.94	99.43	99.17	99.74	98.87	100.91	98.85	99.60	99.67	100.79	101.59	101.80
Trace Elements (ppm)																
Y	90	91	13	97	123	108	110	95	58	58	60	65	91	55	64	65
Sr	37	37	38	42	9	15	10	40	23	92	55	49	99	44	53	71
Rb	351	352	44	369	432	383	368	343	203	317	454	431	377	404	160	237
Nb	19	19	10	17	18	11	4	19	44	20	26	16	15	7	9	3
Zr	98	82	293	91	130	271	110	91	69	197	214	241	182	169	247	123
Pb	49	48	35	51	27	44	173	154	90	32	19	18	1023	27	31	58
U	10	10	6	8	16	17	17	8	4	3	9	6	5	5	5	5
Th	40	39	7	36	101	78	112	36	29	39	72	56	75	23	25	32
CIPW Norms																
Quartz	34.0	38.9	32.0	32.2	10.0	10.2	21.1	31.9	31.3	29.3	5.1	0.3	31.9	38.8	35.6	31.3
Corundum	1.5	1.1	1.5	1.8	1.2	2.5	1.4	1.6	1.0	2.2	1.3	0.9	1.9	1.2	0.8	1.0
Orthoclase	38.5	31.0	37.8	31.8	82.1	72.3	72.0	30.4	21.5	32.3	77.1	83.5	34.1	31.3	33.8	21.5
Albite	22.5	26.6	24.4	28.9	.8	2.1	0.5	31.2	41.5	28.5	0.6	1.8	24.6	19.6	23.4	41.5
Anorthite	0.8	0.6	0.9	0.8	.8	0.2	—	0.8	0.4	1.0	0.5	0.5	1.7	2.5	3.0	0.4
Hypersthene	1.2	1.2	1.2	1.6	2.6	7.2	2.0	1.5	1.2	3.6	8.2	6.8	1.8	3.3	1.4	1.3
Magnetite	0.8	0.4	0.7	0.1	—	2.2	0.04	0.5	0.7	1.9	3.8	3.8	1.9	2.4	1.7	0.7
Hematite	0.4	0.6	0.6	0.9	1.1	—	1.0	0.6	0.5	—	—	—	—	—	—	0.5
Ilmenite	0.1	0.1	0.2	0.2	.2	0.5	0.06	0.2	0.1	0.6	0.5	0.5	0.4	0.5	0.5	0.1
Apatite	0.1	0.1	0.2	0.1	.2	0.4	0.4	0.2	0.1	0.2	0.3	0.2	0.2	0.1	0.1	0.1
Rutile	—	—	—	—	.02	—	—	—								

granite samples from the central Caballo Mountains (Bauer & Lozinsky 1986) were also sampled and analyzed. Chemical analyses are in Tab. 4 and sample descriptions and locations are in Appendix 1.

The granites are grossly similar in composition to Precambrian high-K and high-Si group granites elsewhere in New Mexico (Fig. 7), as determined by Condie (1978). However, the Red Hills granites are lower in Fe_2O_3 (total iron), CaO, and TiO_2 and higher in K_2O and MgO than most high-K and high-Si group granites in New Mexico. The Red Hills granites are similar in major- and trace-element geochemistry to the pink granites from central Caballo Mountains and probably represent the same intrusion.

The Red Hills syenites are lower in Na_2O and extremely high in K_2O compared to most syenites (Nockolds 1954). K_2O/Na_2O ratios are very high. They are lower in Na_2O, TiO_2, Al_2O_3 and higher in K_2O than syenites from the Florida Mountains (Clemons in press) and Pedernal Hills, Torrance County (Loring & Armstrong 1980). The Red Hills syenites are similar in composition to syenites at Lobo Hill, Torrance County (Loring & Armstrong 1980), and in the southern Zuni Mountains, Cibola County (miscellaneous chemical analyses by the author).

The syenites are typically higher in Al_2O_3, MgO, K_2O, U, and Th and lower in Na_2O and SiO_2 than the granites (Fig. 8). The syenites from section 4 are higher in K_2O and Fe_2O_3 and lower in U, Th, and Y than syenites from section 33 (Tab. 4). There are no major differences in composition in the granites, even though some samples are adjacent

to the syenite bodies and one sample is an inclusion within a syenite body.

CATHODOLUMINESCENCE STUDIES

Cathodoluminescence is the visible radiation emitted when a substance is bombarded by electrons. Carbonatites, fenites, and genetically associated alkaline igneous rocks contain minerals such as feldspars and apatite, which display distinct luminescence characteristics as a result of a positive lanthanide anomaly and a high oxygen fugacity associated with these rocks (Mariano et al. 1973, Mariano & Ring 1975, Mariano 1978). A suite of samples from sec. 4, T17S, R4W was submitted for cathodoluminescence studies to aid in understanding of the origin of these rocks.

Apatite and feldspar cathodoluminescence of the Red Hills samples is typical of granites and metamorphic rocks of crustal origin and does not display characteristic cathodoluminescence attributed to carbonatites, fenites, and associated alkaline igneous rocks (A.N. Mariano written comm. 4/1/86). Apatites display yellow cathodoluminescence and feldspars display light-blue cathodoluminescence. Some apatites in a syenite from the center of the body display violet cathodoluminescence due to Sm activation, indicative of alkali metasomatism. A carbonate vein contains blue feldspar rimmed with a later red, Fe^{+3}-activated feldspar, also indicative of alkali metasomatism. The Red Hills syenites probably were not affected by any major carbonatite activity as indicated by cathodoluminescence.

DISCUSSION

Selective enrichment of potassium with respect to sodium occurs locally in magmas of volcanic to subvolcanic environments (Sahama 1974); however, most potassium-rich rocks are attributed to metasomatism or fenitization (Sutherland 1965, Heinrich & Moore 1970, Kinnaird et al. 1985). Metasomatism is the process of replacement of minerals by introduction of external solutions. Fenitization is the alkalic metasomatism related to intrusion of carbonatites, kimberlites, or genetically related alkalic rocks (Heinrich 1966).

Field observations, replacement textures in thin section, mineralogy, and high K_2O/Na_2O ratios of the Red Hills syenites are consistent with a metasomatic origin as previously suggested by Staatz et al. (1965) and Heinrich & Moore (1970). However, cathodoluminescence studies indicate this metasomatism is probably not related to intrusion of carbonatites. Therefore, two possible models are envisioned. Syenites may have intruded the Precambrian granite and subsequently metasomatized by postmagmatic solutions, as observed at the Ririwai alkaline complex in northern Nigeria (Kinnaird et al. 1985). Alternatively, potassium-rich solutions, possibly related to a deeper alkalic body, may have metasomatized the granite to syenite along fractures. The generation of the potassium-rich syenites in the Caballo Mountains is complex and is dependent upon the age of the syenites and granites.

If the syenites in the Red Hills are Cambrian–Ordovician in age as speculated, they are part of an alkalic magmatic event that was widespread in New Mexico during late Precambrian to Early Cambrian–Ordovician times (Loring & Armstrong 1980, McLemore 1982, 1983, in press, Clemons in press). This event is characterized by carbonatites of 448 ± 16 my (K/Ar) in the Lemitar Mountains (McLemore 1982) and syenites within the range of 496–604 my in Torrance County (Loring & Armstrong 1980) and the Florida Mountains (Clemons in press). Lithologically similar syenites occur in the Sangre de Cristo (Reed et al. 1983), Nacimiento (Woodward et al. 1977), Zuni (Lambert 1983), and Burro Mountains (Hedlund 1978a, b, c); however, these syenites have not yet been dated. Additional geochemical studies, isotopic studies, radiometric dating, and detailed mapping of syenites in the Caballo Mountains and elsewhere in New Mexico are required to fully understand these rocks.

ACKNOWLEDGMENTS

Special thanks to Anthony Mariano for performing cathodoluminescence studies. X-ray-fluorescence analyses were provided with the assistance of Mark Tuff at the New Mexico Bureau of Mines & Mineral Resources X-ray Laboratory. Peter Copeland and Kris Klein assisted with sample preparation. Atomic-absorption-spectrometry, fire-assay, colorometric, and fluorometric analyses were provided by Lynn Brandvold, Bureau Chemistry Laboratory. Assistance in mapping and sample collection at various times were by Jose Manrique (New Mexico Institute of Mining & Technology) and James McLemore (Petroleum Research & Recovery Center). Samples from the central Caballo Mountains were provided by Paul Bauer and Richard Lozinsky. Discussions with James Robertson, Richard Chamberlin, Jacques Renault, Russell Clemons, Paul Bauer, and Peter Copeland and critical reviews by Russell Clemons, Frank Kottlowski, Mortimer Staatz, Richard Chamberlin, and Kent Condie are greatly appreciated.

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APPENDIX 1—Location of samples

Table 1.

9028	Radioactive zone in syenite, SE¼NE¼SW¼ sec. 33, T16S, R4W.
9036	Radioactive zone in syenite, SE¼NE¼SW¼ sec 33, T16S, R4W.
3750	Radioactive zone in syenite, SE¼NE¼SW¼ sec. 33, T16S, R4W.
9034	Radioactive zone in syenite, SE¼SE¼NE¼ sec 33, T16S, R4W.
9035	Radioactive zone in syenite, SE¼NE¼NW¼ sec. 4, T17S, R4W.
9037	Radioactive zone in syenite, SE¼NE¼NW¼ sec. 4, T17S, R4W.
7969	Radioactive zone in syenite, SE¼NE¼NW¼ sec. 4, T17S, R4W.
9038	Radioactive zone in syenite, SE¼NW¼NE¼ sec. 33, T16S, R4W.
9039	Radioactive zone in syenite, SE¼NW¼NE¼ sec. 33, T16S, R4W.
9040	Radioactive zone in syenite, SE¼NW¼NE¼ sec. 33, T16S, R4W.
4.141.4	Calcite vein in syenite, NW¼SW¼NW¼ sec. 4, T17S, R4W.

Table 2.

Syenite body, NW¼NW¼SW¼ sec. 33, T16S, R4W (17 m wide):

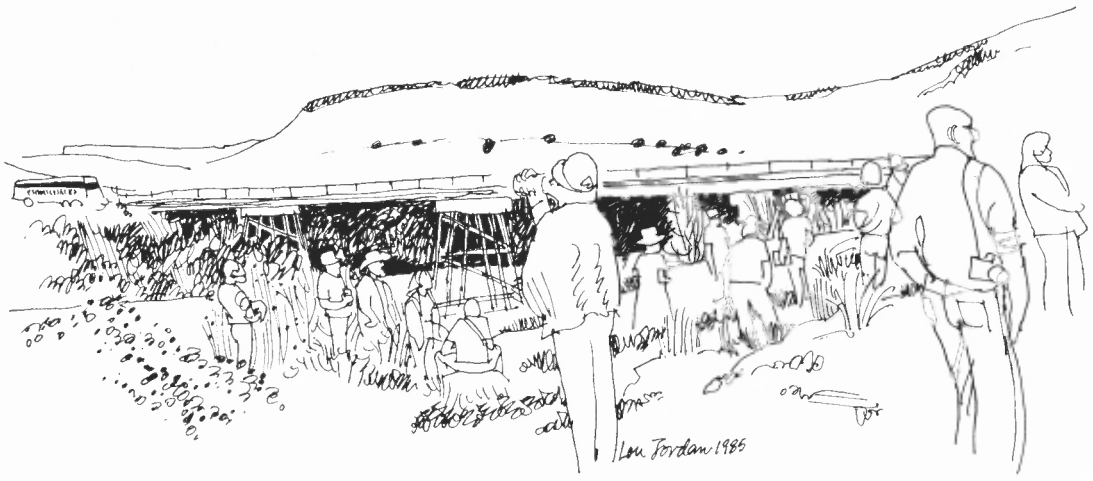
33.411.4	Granite 5 m from syenite.
33.411	Granite 3 m from syenite.
33.411.5	Granite 1.5 m from syenite.
33.411.10	Granite adjacent to contact.
33.411.9	Syenite adjacent to contact.
33.411.6	Syenite 1 m from granite.
33.411.8	Syenite in center of body.
33.411.7	Granite inclusion within syenite.

Syenite body, NW¼SW¼NW¼ sec. 4, T17S, R4W (10 m wide):

4.14.8	Granite 13 m from syenite.
4.141.5	Granite adjacent to contact.
4.141.6	Syenite adjacent to contact.
4.141.7	Syenite in center of body.

Miscellaneous granite samples:

33.133	Granite from SW¼SW¼NW¼ sec. 33, T16S, R4W.
33.123	Granite from SW¼NE¼NW¼ sec. 33, T16S, R4W.
C6	Granite from sec. 26, T15S, R4W.
C14	Granite from sec. 27, T15S, R4W.



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