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STRUCTURE AND IGNEOUS ROCKS OF THE RUIDOSO REGION, NEW MEXICO

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Abstract—Proterozoic igneous rocks (1200 Ma) at Pajarito Mountain are an erosional window of Precambrian basement rocks surrounded by Permian marine rocks. The igneous rocks are hosts to economic zirconium and rare-earth elements. Emplacement of Tertiary igneous rocks began with intrusion of the Black Mountain stock and dike swarm about 39 Ma. The Ruidoso region was then subjected to a period of erosion of about 0.5 Ma before the eruption of the Sierra Blanca volcanic pile. The volcanic pile shows progressive upward enrichment of silica and alkalis. The volcanics in the southern part of the pile range in composition from phonolite through trachyphonolite, trachyandesite, phonotephrite, to trachybasalt, whereas the central and northern parts of the pile range from andesite, latite, to trachyte. The eruption of the volcanic pile and the feeder plugs started about 38 Ma and continued to about 26 Ma. Whole-rock chemistry indicates a single magma source for the Sierra Blanca igneous complex. The Black Mountain stock and dike swarm and the Sierra Blanca volcano and its feeder plugs are intruded along a northeast-trending fault zone that is probably reactivated faults in the Precambrian basement rocks.

INTRODUCTION

The alkalic igneous rocks of the Ruidoso region occur in the northern part of Otero County and the southern part of Lincoln County, New Mexico, about 195 km north-northeast of El Paso, Texas (Fig. 1). Proterozoic and Tertiary alkalic igneous rocks of the Ruidoso region are part of a regional belt of alkalic rocks that extend eastward along the 34th Parallel lineament (Heyl, 1983; Moore and Foord, 1986), southward to the alkalic complexes of the Cornudas Mountains in southern New Mexico and the Trans-Pecos area of northern Texas, and northward into Canada. Unique peralkaline Precambrian rocks crop out as an erosional window within Permian strata in the eastern part of the map area (Fig. 1).

Part of the data presented in this report is from geologic mapping and minerals appraisal of the Mescalero Apache Indian Reservation by the U.S. Geological Survey (Moore et al., 1985) for the Bureau of Indian Affairs. Thompson (1972) mapped the northern part of the Mescalero Apache Indian Reservation and the areas north of the reservation (Fig. 1).

The Proterozoic peralkaline igneous rocks at Pajarito Mountain were mapped and studied by Kelley (1968) and by Moore et al. (1985, 1988a). The first detailed geologic studies of the Tertiary Sierra Blanca igneous complex were by Thompson (1964, 1966, 1972) and Giles and Thompson (1972). These studies outlined three principal stocks cutting a thick volcanic pile and described mineral deposits hosted by the igneous rocks. Subsequent unpublished work on smaller areas within the igneous complex were conducted by Black (1977) and Gander (1982). Segerstrom and Brauch (1976) compiled information on the mineral resources of the Mescalero Apache Indian Reservation. A wilderness report (Segerstrom et al., 1979) focused only on Lincoln County north of the reservation.

STRUCTURAL HISTORY

The earliest evidence of structural deformation in the Ruidoso region is exposed in the erosional window of Precambrian igneous rocks on Pajarito Mountain, in the eastern part of the area, and in Precambrian igneous rocks exposed west of Mescalero in the Bent mining district. The region apparently was uplifted and arched along an east-west-trending zone from the eastern flanks of Pajarito Mountain westward to the Bent mining district (Foord and Moore, 1991). The Precambrian syenite, alkali granite and melasyenite of Pajarito Mountain were domed and intricately shattered by a boxwork of fractures during late Precambrian time. The fractures were later filled with alkalic magma. An east-west-trending mountainous terrain stood above lowlands to the south and to the north, and Paleozoic seas repeatedly inundated the lower elevations of these highlands, depositing marine strata along the flanks of the range from Cambrian to Pennsylvanian time. The lower and middle Paleozoic strata progressively wedge out against the rising topography of the Precambrian terrane from the southern part of the Sacramento Mountains escarpment northward along the escarpment to the southern part of the map area (Pray, 1961). During Early Permian time, the area was again submerged, and the higher elevations of the mountainous Precambrian terrane exposed at Pajarito Mountain and the Bent mining district were inundated by Permian seas. A succession of limestones, evaporites, sandstones and siltstones of the Yeso Formation were deposited on shallow shelf areas northwest of the Delaware Basin. Later the seas deepened, and dolomitic limestone and limestone of the San Andres Limestone were deposited (Moore et al., 1988a).

The region was apparently uplifted again in Late Permian time, and erosion stripped some of the upper limestone beds of the San Andres Limestone from the map area. This period of erosion ended with the deposition of continental Triassic and Jurassic strata, but subsequent widespread erosion stripped all the Jurassic strata and most of the Triassic and Lower Cretaceous strata from the area.

In Late Cretaceous time, the eroded terrain was again inundated by encroaching seas that deposited the marine Dakota Sandstone, Mancos Shale and Gallup Sandstone. The area again emerged and was mantled by continental deposits of carbonaceous shale, siltstone, arkosic sandstone and coal of the Mesaverde Group. During Late Cretaceous or early Tertiary time, an intense period of uplift, doming and faulting occurred, with local intrusion of plugs and stocks and widespread filling of the faults by dikes and dike swarms.

The period of uplift was followed by the eruption of the Sierra Blanca volcanic pile about 38 Ma that blanketed the Cretaceous rocks and the dike swarms in the north-central part of the area (Fig. 1). The volcanic pile was intruded by feeder plugs and stocks from about 38 to 25 Ma. The Ruidoso region was subjected to an extensive period of erosion from about 25 Ma to the present.

RADIOMETRIC AGES

Ages reported by Kelley (1968) for the Pajarito Mountain syenites range from 1135 to 1215 Ma. A potassium-argon (K-Ar) date of 1150 ± 40 Ma on amphibole was obtained for the younger, less-mafic, quartz syenite-alkali granite by Moore et al. (1988a).

Attempts at isotopic dating of the hornblende syenites, quartz syenites, alkali gabbro and syenogabbro of the Black Mountain stock by both K-Ar and Rb-Sr were unsuccessful because the age dates conflicted in all cases with the chronology of igneous rock units, probably because of metasomatic alteration associated with subsequent intrusions.

Radiometric dating of the older basalts and trachyandesites of the Sierra Blanca volcanics has not been attempted, due to extensive propylitic alteration that would result in erratic ages. However, the younger Church Mountain and Godfrey Hills trachyte have yielded K-Ar dates of 31.8 ± 1.3 Ma and 26.1 ± 1.1 Ma (Thompson, 1972).

The older plugs of syenite-nepheline syenite, syenite and essexite

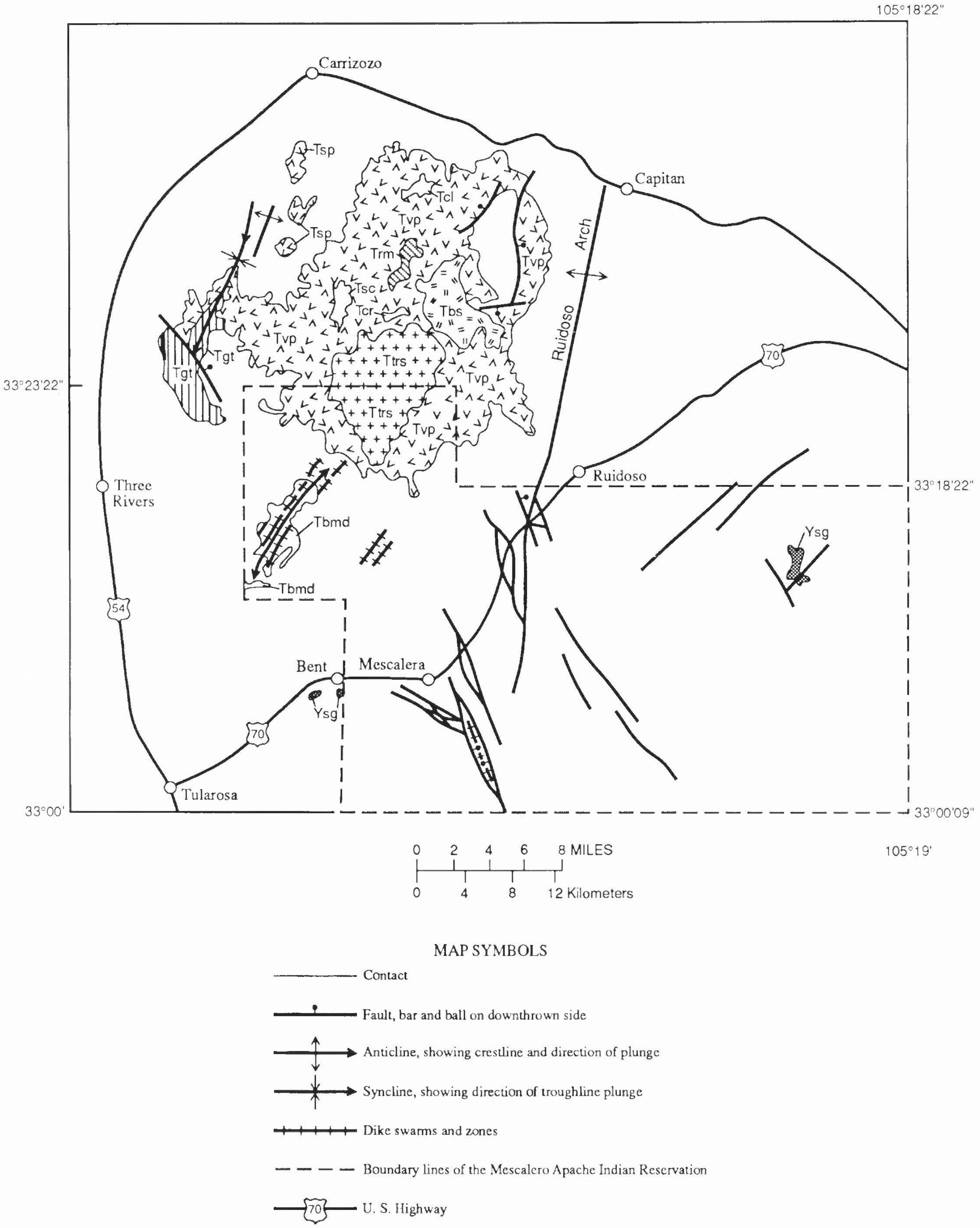
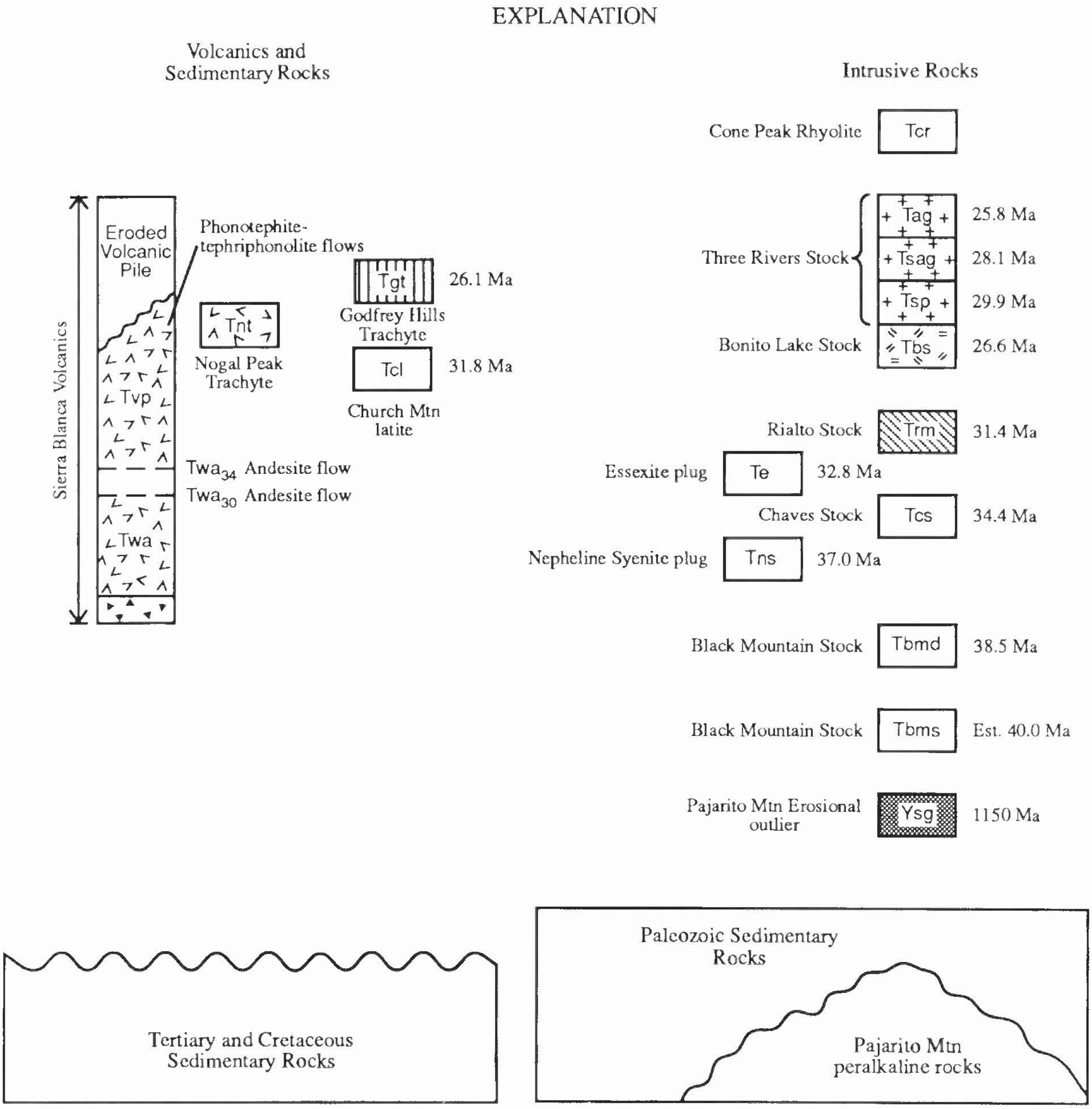


FIGURE 1. Generalized geologic map of the Ruidoso region, south-central New Mexico, emphasizing the Sierra Blanca igneous complex and its location.



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that intrude the southern periphery of the Sierra Blanca volcanic pile and the Paleozoic and Mesozoic strata of the map area range in age from 32.8 ± 1.2 Ma to 37.0 ± 1.3 Ma. The younger plugs of syenite and syenite porphyry, syenite and quartz-syenite porphyry, quartz syenite and alkali granite that intrude the Sierra Blanca volcanic pile and make up the southern part of the Three Rivers stock range in age from 29.9 ± 1.8 Ma to 26.7 ± 1.2 Ma (Moore et al., 1988b). Thompson (1972) dated the Three Rivers stock at 25.8 ± 1.1 Ma.

PETROGRAPHY

Precambrian rocks at Pajarito Mountain

Pajarito Mountain is an erosional window of Precambrian alkalic igneous basement rock surrounded by Permian strata (Fig. 1). The igneous rocks are extensively altered along their contacts with the Permian strata because of a long period of weathering prior to burial and subsequent circulation of ground water.

Several varieties of syenite, melasyenite, quartz syenite and alkali granite are exposed together with alkalic syenite pegmatite dikes and pegmatitic segregations derived from the host rocks. Foliation and lineation are developed locally within the syenite, and xenoliths of altered basement rocks are locally present within the syenites. A few fine- to medium-grained, dark-gray, nonporphyritic, dike-like and irregularly shaped bodies of olivine gabbro and gabbro are also present. The oldest syenite is a fine- to medium-grained, amphibole-rich melasyenite that locally shows gneissic texture. It is characterized by a boxwork of fractures that are filled with medium-grained, light-gray, and less mafic quartz-bearing syenite, quartz syenite and alkali granite. The syenite and melasyenite have a seriate texture that grades to microporphyritic. The rocks are composed of oligoclase-andesine, alkali feldspar, arfvedsonite and locally riebeckite, quartz, eudialyte, fluorite, monazite, and as much as 5% aegirine-augite or aegirine. Accessory minerals include apatite, opaques, biotite, rutile(?) and sphene. Alteration products include calcite, clays, chlorite and several unidentified minerals.

The syenite and quartz syenite are composed of light-colored quartz and feldspar and dark-colored amphibole, together producing a speckled appearance. Some syenites are extremely felsic, whereas other syenites contain as much as 40% combined amphibole and/or altered pyroxene.

The syenites are, in part, foliated and lineated, holocrystalline and medium grained, with seriate and interstitial textures. The younger quartz-bearing syenites and quartz syenites are composed of oligoclase-andesine, alkali feldspar, quartz, riebeckite and aegirine. As much as 5% fluorite and 20% eudialyte are present, but together they commonly make up about 10%. Accessory minerals are monazite, sphene and opaque minerals, and montmorillonite is present where it has replaced eudialyte. Quartz occurs in the groundmass as rounded "eyes."

Alkali granite is characterized by abundant, rounded, light-gray quartz "eyes." Riebeckite is, in part, replaced by aegirine. Some myrmekite and irregular patchwork intergrowths of quartz and feldspar are present. The plagioclase is calcic oligoclase to sodic andesine and the alkali feldspar is generally perthitic to microperthitic microcline.

Pegmatitic segregations range from 0.8 m in width and as much as 1.9 m in length, though most are less than 1.0 m in length. Contacts between the pegmatites and the host rocks vary from gradational to sharp. The pegmatites are extremely varied. Some contain abundant quartz and minor amounts of feldspar, whereas others contain abundant feldspar, quartz and amphibole and/or pyroxene, and still others are composed mostly of quartz and aegirine plus minor amounts of plagioclase and alkali feldspar.

The pegmatites consist of large, single crystals of prismatic, medium- to deep-green and dark-brownish-black amphibole and/or pyroxene 10 to 20 cm long and 2.5 to 5.0 cm across. The crystals are intergrown with and enclosed by clear to milky quartz and pinkish-orange alkali feldspar. Most of the quartz is anhedral, whereas the feldspar is subhedral to euhedral and ranges from 0.2 to 0.8 cm in length. All of the pegmatite minerals show compromise growth surfaces; void spaces between minerals are filled with quartz.

Gabbro and olivine gabbro consist of interlocking and mutually included grains of forsteritic olivine, twinned augite-diopsidic augite and laths of zoned and twinned andesine. These grains are medium reddish buff, orange and tan on weathered surfaces and medium dark gray on fresh surfaces. Grains are equigranular, fine to medium grained; some augite forms holocrystalline poikilitic textures with olivine. Augite is interstitial to olivine and also forms rims on olivine. Minor biotite and chlorite and a small amount of hornblende replacing plagioclase makes up about 50–60% of the rock; olivine and pyroxene compose the remaining 40–50%. Accessory minerals are opaques and apatite.

Syenogabbro that forms dikes in the syenite complex is light to medium gray, contains phenocrysts and xenocrysts of black ferro-hornblende, augite and andesine, and has calcite and zeolite-filled amygdaloidal cavities. It is fine to medium grained and has a gray-green seriate groundmass composed of plagioclase and alkali feldspar, biotite and augite. Plagioclase is more abundant than alkali feldspar. Approximately equal amounts of biotite, amphibole and clinopyroxene compose about 30% of the rock; accessory minerals are magnetite and apatite. Alteration consists of moderate amounts of biotite, zeolites after feldspars and calcite after plagioclase. Calcite makes up about 2% of the rock.

Black Mountain stock and dike swarm

The Black Mountain stock is the oldest stock in the area. It is made up of younger hornblende syenite and quartz syenite in the northeastern part of the stock and older alkali gabbro-syenogabbro in the southwestern part of the stock (Fig. 1). Thermal alteration effects are sparse along the contact between gabbroic and syenitic masses, and they appear to be nearly coeval.

The alkali gabbros are rich in biotite, have a salt-and-pepper texture and contain clinopyroxene and amphibole. Textures range from fine to medium grained and equigranular to seriate. Associated dikes are locally altered to chlorite, calcite and epidote.

The hornblende syenite and quartz syenite are cream-buff to pink, fine to medium grained, equigranular to porphyritic, and are generally extensively propylitized by chlorite, calcite and epidote. A monzonitic variant, thought to be a metasomatically altered syenite, is light to medium gray, and porphyritic with phenocrysts of amphibole, clinopyroxene and plagioclase.

A large northeast-trending, complex dike swarm of alkali gabbro and monzogabbro intrudes the Black Mountain stock and surrounding Paleozoic and Mesozoic rocks along the northeast-trending Black Mountain anticline and on the southwestern slopes of Sierra Blanca Peak (Fig. 1). This dike swarm makes up 10 to 70% by volume of the rock within the dike swarm area, and alkali gabbro and monzogabbro dikes make up about 90% by number of the dikes in the swarm. The dikes are characterized by large phenocrysts and xenocrysts of tschermakitic hornblende as much as 4 cm in length, set in a seriate groundmass of plagioclase with or without phenocrysts of plagioclase and clinopyroxene. Only minor alkali feldspar is present. Accessory minerals include apatite, opaque minerals and sphene. Epidote has formed locally from the hornblende crystals.

Dikes of syenite, nepheline syenite, alkali gabbro, syenogabbro and hornblende andesite occur in the Tularosa Canyon area and on the south flanks of Sierra Blanca. The dikes are intruded into steeply dipping north- to northwest-striking faults in sedimentary rocks. The dikes are resistant to erosion and form ridges within the Tertiary-Quaternary conglomerates and gravels. Sandstone and limestone wall rocks have been thermally altered within 2.5 to 15 cm of the dikes.

Sierra Blanca volcanic pile

The Sierra Blanca volcanic rocks comprise a thick sequence of trachybasalt and trachyte flows. Phonotephrite flow breccias in the southern part of the volcanic pile merge northward into alkali-calcic andesite, phonotephrite and tephriphonolite flow breccias and flows in the central and northern parts of the volcanic pile (Moore et al., 1985, 1988a; Thompson, 1972). The volcanic sequence shows progressive upward silica and alkali enrichment through its preserved thickness, which ranges from 718 to 1020 m (Thompson, 1964). Outliers of trachyte and tephriphonolite occur to the north and west of the volcanic-intrusive complex. The andesite flow breccias came from numerous plugs and dikes near the center of the volcanic field. Flows are pilotaxitic-porphyritic and are generally less than 30 m in thickness. Outliers of Nogal Peak trachyte and Church Mountain latite have no directional indicators to their source, but they are most likely derived from the andesite and trachytic intrusive feeder plugs on the northern slopes of the Sierra Blanca (Thompson, 1972). On the western edge of the complex, the Godfrey Hills trachyte appears to have been locally derived from small plugs. The trachyte flows, flow breccias and welded ash-flow tuffs are localized in an arcuate belt with synclinal dips, suggestive of a partial collapse of the roof over their magma source (Fig. 1).

The trachybasalt, andesite, tephriphonolite and trachyte flows of the northern part of the complex are weakly to distinctly porphyritic with plagioclase and/or sanidine phenocrysts ranging in length from 0.8 to 3 cm. These phenocrysts are set in a finely crystalline matrix of plagioclase microlites, sanidine, augite, olivine and trace nepheline. Biotite becomes more abundant upward in the volcanic pile at the expense of olivine and pyroxene. Magnetite (generally oxidized to hematite) occurs throughout the groundmass.

The andesitic breccias and flows are regionally propylitized to an assemblage of chlorite, epidote, calcite, zeolites and magnetite or hematite. Local tuffs and epiclastic volcanic material are interlayered within the volcanic pile; their textures indicate some fluvial transport.

The southwestern, southern and southeastern parts of the volcanic pile are composed of trachyphonolite porphyry flows, trachyte and phonotephrite flow breccias, trachybasalt flows and volcaniclastic sediments.

Trachyphonolite porphyry flows are porphyritic and rarely vesicular. Flows contain euhedral to subhedral crystals and xenocrysts of intermediate plagioclase as much as 0.8 cm long in a fine- to medium-grained, dark-gray to medium-gray groundmass. Phenocrysts and microphenocrysts of augite and/or olivine may also be present. Interstitial nepheline and alkali feldspar are present in a jackstraw-textured plagioclase that shows varied propylitic and argillic effects.

Trachyte and phonotephrite flow breccias are medium gray to gray-green and contain fragments of varied lithologies, as much as 0.9 m across. The groundmass is very fine grained to fine grained, dark gray and contains more than 50% fragmental material; varied propylitic alteration effects are present. A few thin, lenticular, strongly welded ash-flow tuffs are locally present. Volcaniclastic sediments are fine- to medium-grained, dark-gray arkosic sandstones and siltstones interbedded with trachyphonolite porphyry and breccia flows along the eastern slopes of Sierra Blanca Peak. Some of the volcaniclastics are lahars and mudflows that came from higher terrain to the west.

Intrusive rocks

The Sierra Blanca volcanic pile is intruded by four major stocks—the Rialto, Bonito Lake, Three Rivers and Chaves—and by numerous plugs (Fig. 1). The stocks and plugs are mineralogically and chemically similar to the volcanic rocks and are coeval. The stocks and feeder plugs exhibit progressive mineralogical changes that generally correlate with their older to younger age dates, indicative of fractional crystallization of a single magma source.

Rialto stock

The Rialto stock is a multiple intrusive body exposed over 3 km^2 and consisting of hypidiomorphic-granular low-quartz hornblende-biotite monzonite, biotite monzonite, and six late intrusive phases dominated by quartz monzonite porphyry (Gander, 1982). The ferromagnesian mineral content of the earliest intrusive phase is less than 5%, but the biotite monzonite contains as much as 20% biotite. Biotite constitutes no more than 1% of the rock in the youngest intrusives. A K-Ar date of 31.4 ± 1.3 Ma was obtained on hornblende and biotite.

Chaves Mountain stock

The Chaves Mountain stock intrudes Cretaceous-Paleocene sedimentary rocks. It is a syenite containing anorthoclase phenocrysts up to 6 mm long, with subordinate amounts of hornblende, biotite and oligoclase; trachytic texture of the prismatic minerals is pronounced.

Bonito Lake stock

The Bonito Lake stock extends over 19 km^2 and consists principally of a single monzonite-syenite porphyry. Plagioclase phenocrysts constitute 30–40% of the rock; these are normally zoned with An 38–40 and mantled by a thin (0.5–1.0 mm) rim with $An<17$. Orthoclase constitutes the bulk of the groundmass with lesser hornblende, biotite and clinopyroxene (Black, 1977). Quartz constitutes less than 6% of the rock. A K-Ar date of 26.6 ± 1.4 Ma on biotite from the stock was reported by Thompson (1972).

Three Rivers stock

The Three Rivers stock is a composite of five plugs that are from oldest to youngest: (1) syenite and syenite porphyry (Moore et al., 1985, 1988a); (2) quartz syenite porphyry (nordmarkite of Thompson, 1972); (3) quartz syenite alkali granite (equigranular syenite of Giles and Thompson, 1972); (4) sodalite-nepheline syenite, and (5) alkali granite. Anorthoclase from the syenite porphyry was dated by K-Ar at 25.8 ± 1.1 Ma (Thompson, 1972).

The syenite and syenite porphyry plug underlies Sierra Blanca Peak. It is medium to coarse grained, light pink to gray, seriate, composed of anorthoclase, plagioclase and 3–5% interstitial quartz. Mafic minerals are arfvedsonite and biotite, and accessory minerals are apatite, sphene and magnetite. The syenite porphyry consists of 80 to 85% zoned anorthoclase cryptoperthite phenocrysts (3–20 mm) in a matrix consisting of lesser quartz, biotite, hornblende, arfvedsonite and/or aegirine. The sodic-mafic minerals formed primarily at the expense of hornblende. The quartz occurs as interstitial anhedral grains or as granophyric intergrowths with the anorthoclase. The Or molecule content of the anorthoclase invariably increases from the core (18–32) to the rim (33–40) (Giles and Thompson, 1972).

Quartz syenite porphyry (nordmarkite of Thompson, 1972) is a pinkish-gray porphyry with anorthoclase phenocrysts as much as 2.5 cm across in a very fine-grained groundmass containing about 5% quartz. Mafic minerals are arfvedsonite, aegirine and biotite; accessory minerals are magnetite and apatite. The quartz syenite and alkali granite (equigranular syenite of Giles and Thompson, 1972) is equigranular to sparsely porphyritic, and homogeneous alkali feldspar (Or41) forms the bulk of the rock. The rock becomes progressively finer grained toward the northeastern margin of the Three Rivers stock. The interstitial quartz content ranges from 4 to 37% and lesser amounts of finely crystalline biotite, hornblende, arfvedsonite and/or aegirine. All of the intrusives in the Three Rivers stock contain accessory apatite, zircon and magnetite.

Sodalite-nepheline syenite is light gray, medium grained, nearly equigranular, with interlocking laths of alkali feldspar and plagioclase and subordinate amounts of arfvedsonite and aegirine. The rock contains accessory opaque minerals and apatite.

Alkali granite is fine to medium grained, light gray, and is composed of alkali feldspar and minor plagioclase. It contains abundant interstitial and granophyric quartz-alkali feldspar intergrowths. Mafic minerals include arfvedsonite, aegirine and biotite. Accessory minerals are apatite, sphene and opaque minerals. Sparsely disseminated molybdenite is present.

Cone Peak rhyolite

A small plug and a series of arcuate, steeply flow-banded dikes occur north of the contact of the Three Rivers stock. The plugs and dikes contain 9 to 22.4% quartz and 8 to 17% sanidine phenocrysts (Black, 1977). The groundmass consists of quartz, alkali feldspar, apatite, zircon and fluorite. Silica content ranges between 77.5 and 79%, making the Cone Peak rhyolite the most silica-oversaturated rock in the Sierra Blanca igneous complex. Arcuate distribution of dikes suggests that late-stage subsidence over the magma chamber may have been responsible for upwelling of differentiated siliceous melt.

Other intrusive bodies

Five plugs of alkali rocks intruded the southern and western perimeter of the Sierra Blanca volcanic pile prior to intrusion of the Three Rivers stock. They range in age from middle to early Oligocene and are from oldest to youngest: (1) syenite-nepheline syenite porphyry; (2) nepheline syenite; (3) nepheline syenite porphyry; (4) monzonite; and (5) essexite.

The syenite-nepheline syenite porphyry is composed of a very fine-grained to fine-grained, moderately propylitized groundmass of feldspar, minor biotite and bowlingite after olivine. The groundmass encloses 30 to 40% phenocrysts of plagioclase and alkali feldspar as much as 1.3 cm long.

Nepheline syenite is gray, fine to medium grained, and is composed mostly of alkali and plagioclase feldspars enclosing subordinate amounts of augite-titanaugite, olivine and biotite.

The nepheline syenite porphyry is composed of a fine-grained groundmass containing phenocrysts and clots of alkali and plagioclase feldspar, and microphenocrysts of nepheline, olivine and augite. Red-brown biotite makes up as much as 10% of the rock. Accessory minerals are apatite and opaque minerals.

A monzonite plug intrudes the volcanic pile and has domed the overlying volcanic rocks. The monzonite is porphyritic, gray-green and fine to medium grained. Plagioclase groundmass and the phenocrysts are altered to calcite, chlorite and clay. Augite and lesser amounts of alkali feldspar are present in the groundmass. Pervasive alteration of the plug and part of the enclosing volcanics probably was deuteric. The plug may originally have been a nepheline syenite or a syenite similar to the other alkali feeder plugs within the volcanic pile.

The essexite plug is exposed in the headwaters of the North Fork of the Rio Ruidoso and consists of medium- to coarse-grained rock that has a seriate texture. Alkali and plagioclase feldspars enclose augite and olivine. Nepheline is present along with red-brown and green biotite. Another smaller plug of essexite crops out on a ridge west of the North Fork of the Rio Ruidoso. The essexite intrudes a plug of nepheline syenite. The rock is very fine grained, very dark gray, equigranular and contains plagioclase and some alkali feldspar. Augite and red biotite are the only mafic minerals.

PETROGENESIS

The Proterozoic alkaline igneous rocks of Pajarito Mountain are distinct compositionally as compared to the Tertiary alkalic igneous rocks of Lincoln County (Figs. 2–7). The Proterozoic rocks exhibit no distinct fractionation trend, whereas the Tertiary igneous rocks exhibit progressive alkali and silica enrichments.

The chemical evolution of Tertiary igneous rocks (Fig. 3) in the Sierra Blanca igneous complex suggests that a single magma was responsible for the volcanic and intrusive rocks. Harker variation diagrams (Fig. 3) and TAS (Fig. 8) indicate that silica-undersaturated and -oversaturated rocks had a common parentage. Not only do the Sierra Blanca volcanic rocks exhibit mineralogic and chemical evolution upward, but the complex stocks (i.e., Rialto, Black Mountain and Three Rivers) show similar alkali and/or silica enrichments in the younger intrusives. Ternary variation diagrams AFM, AKC and others (Figs. 4 to 7) show the same chemical evolution of an alkali- and silica-enriched common magma in both volcanic and intrusive rocks of the Sierra Blanca igneous complex. The Black Mountain stock may have been the earliest intrusive derived from the common magma, but it may not have evolved directly from the same single magma source.

Initial strontium isotope ratios for volcanic and intrusive rocks in the Sierra Blanca igneous complex (Fig. 9) range from 0.7038 (Bonito Lake stock), through 0.7041 (Godfrey Hills trachyte) and 0.7045 (syenite porphyry, Three Rivers stock), to 0.7067 (alkali granite, Three Rivers stock). These primitive values indicate little crustal contamination of the magma (Thompson, 1982). The rocks also show increases of Nb, Rb, Mo and F upward through the volcanic pile and in successively younger intrusive bodies, and decreases of TiO_2 and Sr.

The data cited above indicate that all of the igneous rocks in the Black Mountain stock-dike swarm system, the Sierra Blanca igneous complex and the Tularosa Canyon dikes were derived from the mantle-deep crustal source that was little contaminated by crustal assimilation. The magma evolved by crystal subtraction during volcanic eruptions and the early volcanic rocks were enriched in MgO, CaO and total Fe. Subtle mineralogical-chemical changes occurred upward in the Sierra Blanca volcanic pile, reflecting the early removal of olivine, orthopyroxene and calcic plagioclase.

Some late-stage mafic intrusives may reflect primitive magma that had not participated in the earlier fractional crystallization. However, whole-rock chemistry, mineralogy and mode of emplacement of the mafic alkali gabbro, hornblende syenite, and the alkali gabbro dike swarms of the Black Mountain stock may indicate a possible second early magma source. Interpretation of trace elements, REE and Nd-Sm

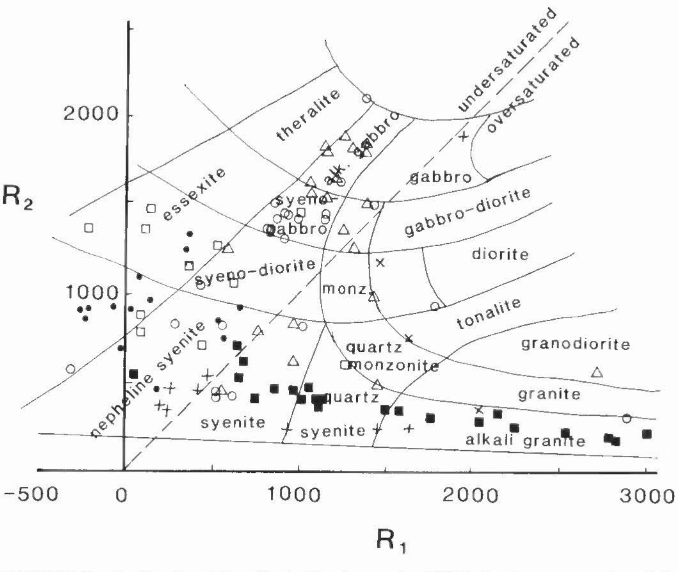

FIGURE 2. R_1-R_2 plot (after De la Roche et al., 1980) for igneous rocks of the Ruidoso region. Plutonic rock names are given for various fields. Symbols are same as in Figs. 3 and 4. Monzonite not plotted.

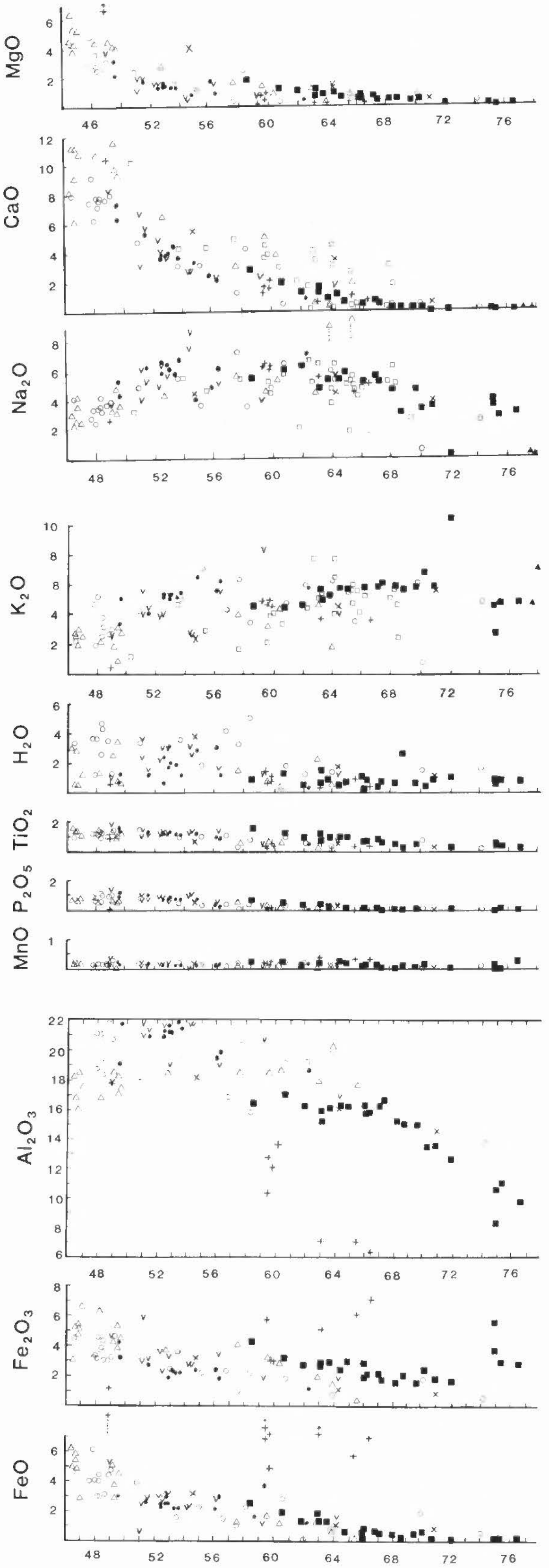

FIGURE 3. Harker diagrams showing chemical variation exhibited by igneous rocks of the Ruidoso region. Symbols are as follows: +—Pajarito Mountain; ■—Three Rivers stock; V—Sierra Blanca volcanic pile; ○—dikes and specials; ●—nephelene syenite dikes and bodies; Δ—Black Mountain stock and associated dikes; X—monzonite plug; ▲—Cone Peak rhyolite (TBT); □—samples collected by Tommy B. Thompson (from Thompson, 1972; Giles and Thompson, 1972).

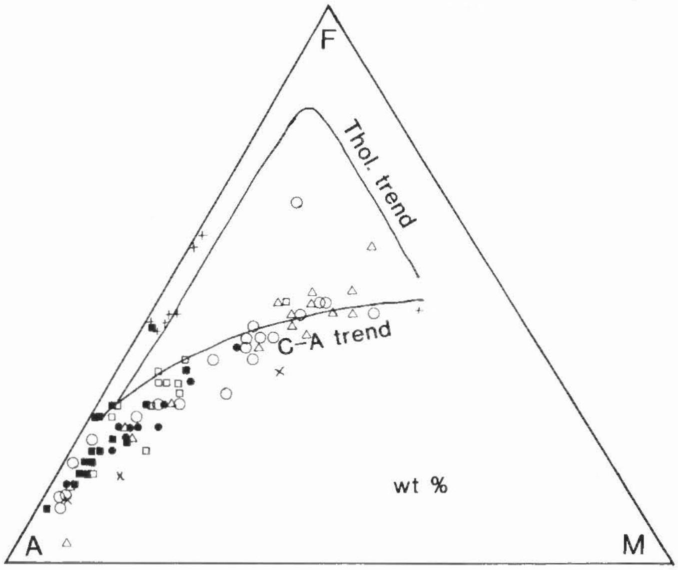

FIGURE 4. Ternary alkali-iron-magnesium (AFM) diagram (in wt%) for rocks of the Ruidoso region. A = $Na_2O + K_2O$, F = $(FeO + 0.8998 \times Fe_2O_3)$, M = MgO. Trend lines from Irvine and Baragar (1971).

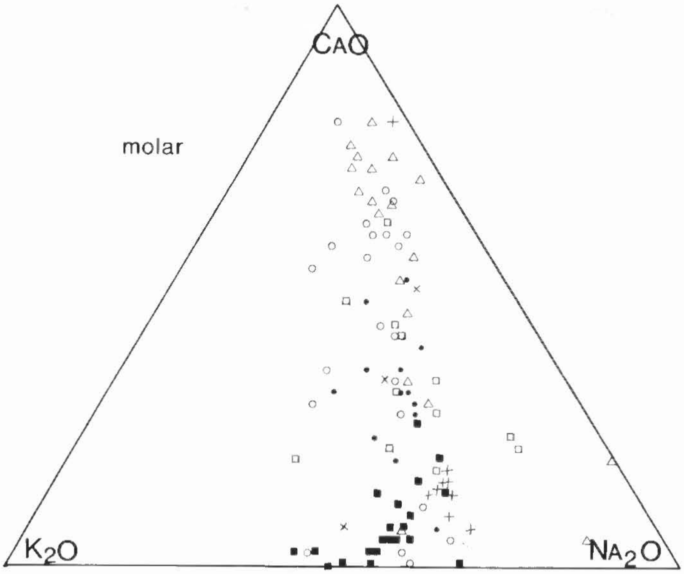

FIGURE 6. Ternary CaO-K_2O-Na_2O diagram (molar) for rocks of the Ruidoso region.

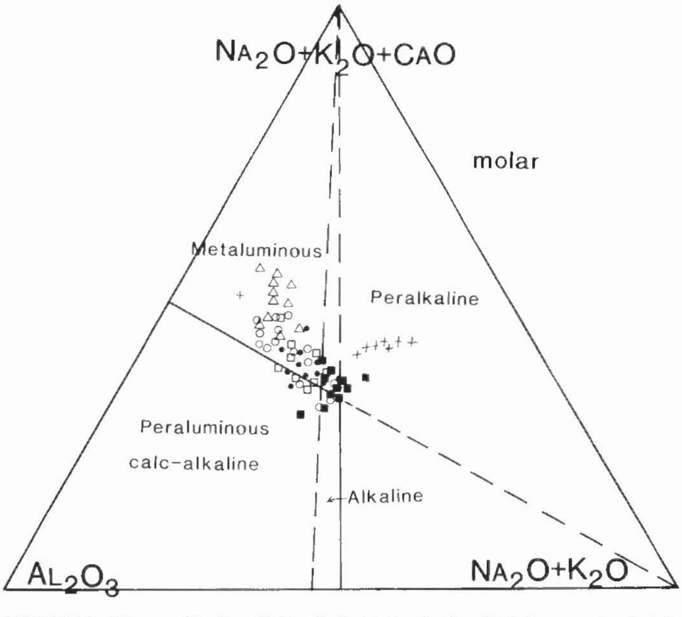

FIGURE 5. Ternary $Na_2O + K_2O + CaO$-Al_2O_3-$Na_2O + K_2O$ diagram (molar) for the rocks of the Ruidoso region.

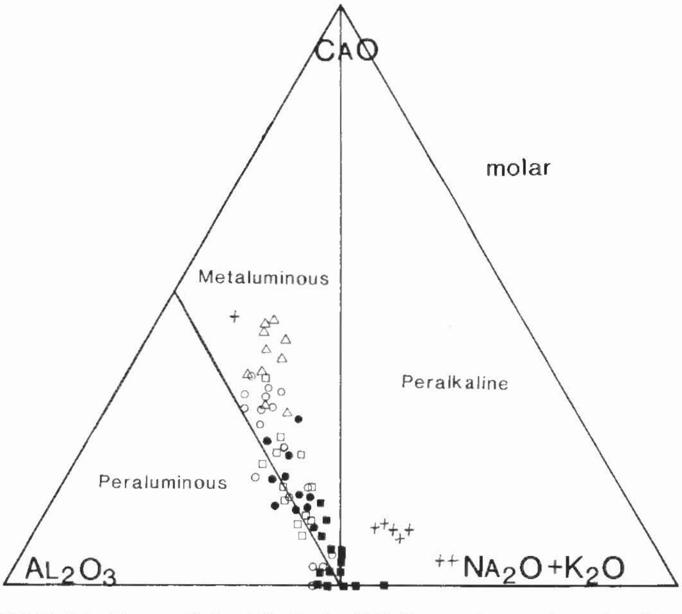

FIGURE 7. Ternary CaO-Al_2O_3-$Na_2O + K_2O$ diagram (molar) for rocks of the Ruidoso region.

isotopic data indicates a multiple magma source (Allen and McLemore, 1991). The Cone Peak rhyolite represents the final differentiate derived from the parent magma of the Sierra Blanca igneous complex.

STRUCTURE

The chronology of faulting, intrusion and erosion that took place during Late Cretaceous and Tertiary time, and the evolution of the Sierra Blanca volcano is shown on diagrammatic isometric block diagrams (Fig. 10, blocks A–F). During the Laramide orogeny in Late Cretaceous and early Tertiary time, flat-lying Paleozoic and Mesozoic strata of the Black Mountain and the Rinconada areas were displaced by anastomosing northeast-trending faults to form the Black Mountain keystone horst (Fig. 10, block A). These transverse faults are downthrown along their northwest and southeastern blocks and have left-lateral throws.

During middle Eocene time, the flat-lying Paleozoic and Mesozoic strata (Fig. 10, block A) of the central part of the Black Mountain keystone horst were elevated by hot, dry, highly viscous, ascending, alkalic magma. The strata were subsequently domed by the rapid rise of the gabbroic and syenitic magma to form the northeast-trending doubly plunging Black Mountain anticline (Fig. 10, block B). As a result of the late intrusion, the cooling and crystallizing upper shell of the Black Mountain stock and its thermally altered sedimentary wall rock were subjected to structural inflation that resulted in the development of countless northeast-trending minor faults and fractures that served as channels for an alkali gabbro and monzogabbro dike swarm (Fig. 10, block C).

The intrusion of the dike swarms was followed by a period of erosion of about 0.5 Ma, which removed large volumes of Paleozoic and Mesozoic strata, the upper part of the Black Mountain stock, and deeply

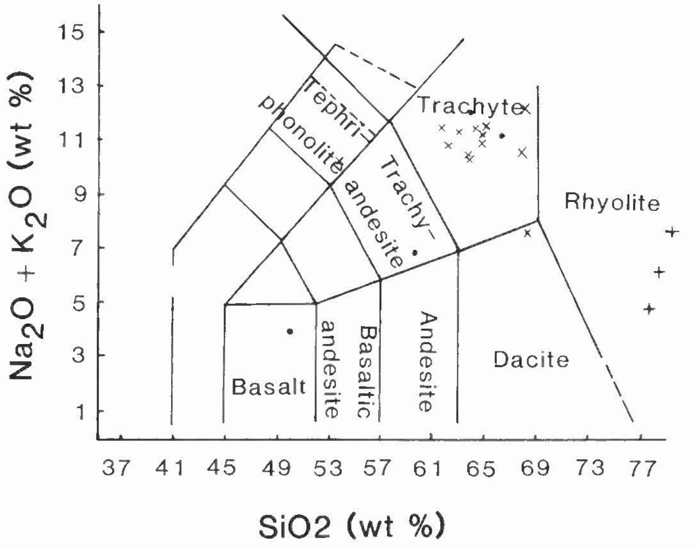

FIGURE 8. TAS (total alkalis vs. silica) for rocks from the Sierra Blanca igneous complex. +—Cone Peak rhyolite; X—Rialto, Bonito Lake, and Three Rivers stocks; ●—Sierra Blanca volcanic pile.

incised a lowland along the axial zone of the northward-plunging Sierra Blanca basin (Fig. 10, block D).

This erosional period culminated with the eruption of a succession of volcaniclastic materials, trachybasalt flows, trachyte and phonotephrite flows, and trachyphonolite flow breccias over a period of about 12 Ma, from about 38 to 26 Ma, forming the Sierra Blanca volcano (Fig. 10, block E). The volcanic eruptions covered the Sierra Blanca area to an estimated depth of about 2500 m; the emplacement of alkali feeder plugs into the volcanic pile probably culminated about 26 Ma. This activity was followed by a long period of erosion that extended to the present, and removed hundreds of cubic kilometers of rock from the Sierra Blanca volcanic pile, the upper part of the Three Rivers stock, and the Black Mountain stock, as well as large volumes of the Paleozoic and Mesozoic strata in the surrounding region (Fig. 10, block F).

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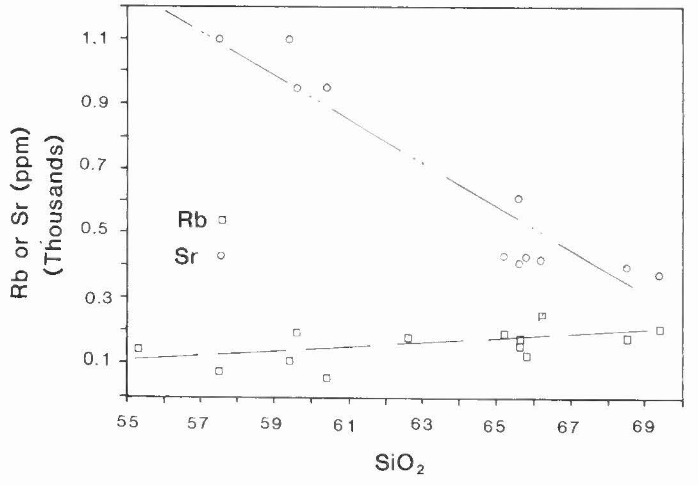

FIGURE 9. Rb and Sr vs. SiO$_2$ for selected rock samples from the Sierra Blanca igneous complex (Thompson, 1972; Giles and Thompson, 1972).

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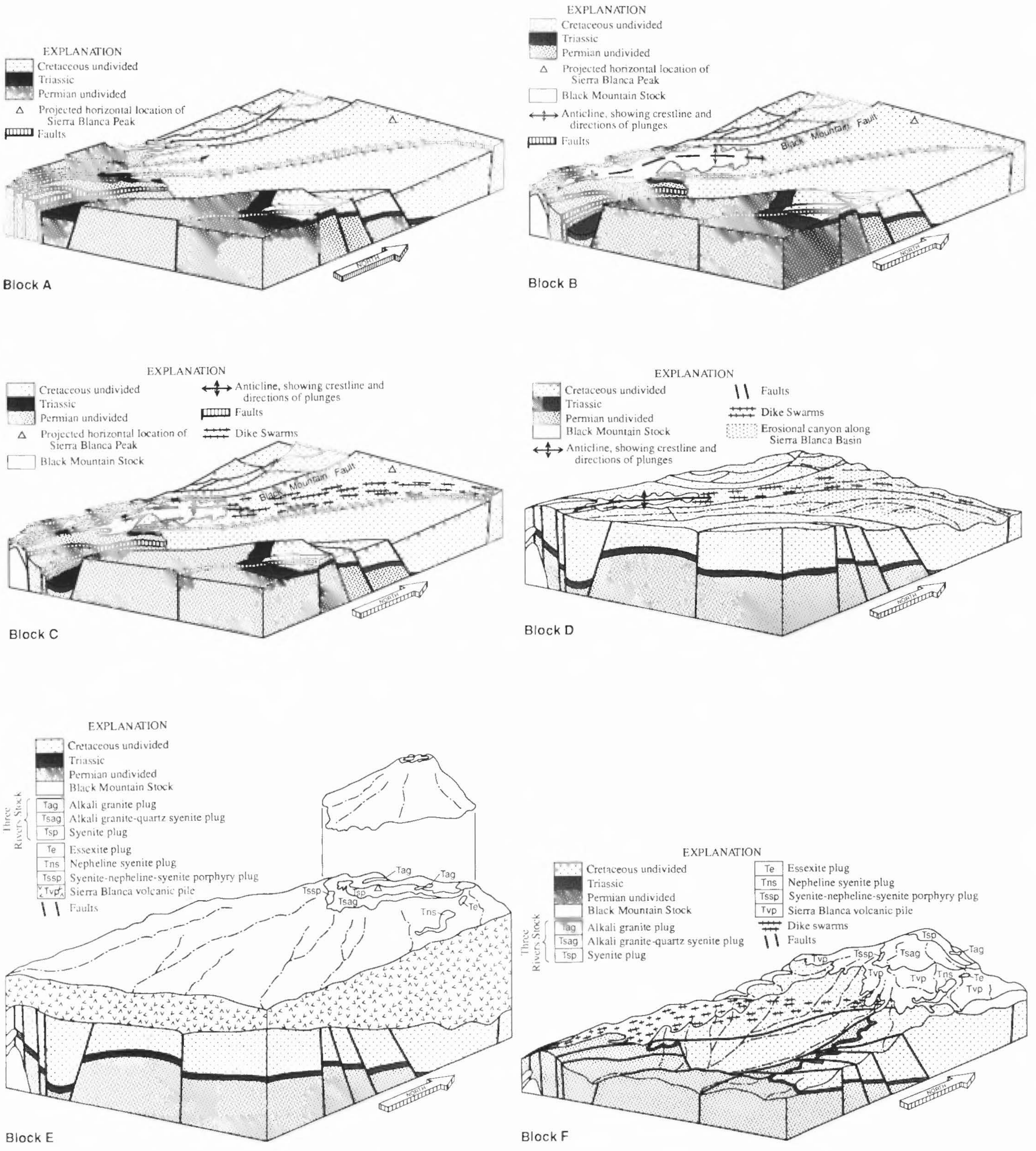

FIGURE 10. Block diagrams depicting the chronology of structure, intrusion, and eruption of igneous rocks, and erosional epochs in the Sierra Blanca igneous complex and Black Mountain areas. Block A, Black Mountain keystone horst was elevated by ascending alkalic magma in late Eocene time. Block B, Renewed ascent of magma domed the Black Mountain keystone horst. Block C, Late Eocene doming and inflation in the Black Mountain and Sierra Blanca areas resulted in the development of countless northeast-trending minor faults and fractures that were then filled with gabbroic dikes. Block D, Erosion at end of Eocene time deeply incised the axial zone of the Sierra Blanca basin. Block E, Massive eruptions of alkalic volcanics covered the Sierra Blanca area to an estimated depth of 2500 m over a period from about 38 to 26 Ma in early Oligocene to middle Oligocene time. The coeval southern part of the Three Rivers stock and the feeder plugs in the pile have similar petrology and chemistry. Block F, Erosion over a period of about 25 Ma removed hundreds of cubic kilometers of rock from the volcanic pile, the upper part of the Three Rivers stock, the Black Mountain stock, and the Paleozoic and Mesozoic strata of the surrounding region.

Impressive columnar jointing in trachydacite porphyry of the Palisades of Cimarron Canyon. Day 2, Stop 1 of the 1990 NMGS Fall Field Conference. Illustration by Louann Jordan of Santa Fe, 1990.