Geology of Volcanic and Subvolcanic Rocks of the Raton-Springer Area, Colfax and Union Counties, New Mexico

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By GLENN R. SCOTT, RAY E. WILCOX, *and* HARALD H. MEHNERT

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Descriptions, chemical analyses, and ages for an alkalic sill complex and for mafic feldspathoidal and basaltic effusive rocks

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GEOLOGY OF VOLCANIC AND SUBVOLCANIC ROCKS OF THE RATON-SPRINGER AREA, COLFAX AND UNION COUNTIES, NEW MEXICO

By GLENN R. SCOTT, RAY E. WILCOX, and HARALD H. MEHNERT

ABSTRACT

The most prominent geomorphic features of the Raton-Springer area are the widely distributed volcanic and subvolcanic rock formations, consisting of cinder cones, domes, lava-capped mesas, a domed sill complex, and dikes. Rock compositions range from mafic to salic, and many are alkalic. Rock names used in this report are based on the classification of La Roche and others (1980). Sixteen new K-Ar age determinations and three new fission-track age determinations are given here for selected rocks in this area.

The oldest dated igneous rocks, with ages from 37 to 20 m.y. (million years), are included among the rocks of the Chico sill complex, in the southeastern part of the area. This complex has an exposed area of about 140 square miles (363 square kilometers) and consists of alkalic rocks of phonolitic and trachytic compositions. The Cretaceous sedimentary formations intruded by this complex (Purgatoire Formation, Dakota Sandstone, Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation) have been domed up nearly 1,000 feet (305 meters) by the sills. From oldest to youngest in approximate age, the sill rocks are the Slagle Trachyte, the trachyte southwest of Laughlin Peak, the biotite trachyte northwest of Turkey Mountain, the syenite and quartz monzonite vent rocks at Turkey Mountain, a melasyenite dike, small bodies of phonotephrite and tephrite, the Chico Phonolite, and a related nepheline syenite dike on Point of Rocks Mesa. The Chico Phonolite consists of a gradational series, from green phonolite to silver-gray phonolite as silica content increases and alumina content decreases. Magma sources of most rocks of the sill complex appear to have been in the lower crust.

Several diatremes have been found in this reconnaissance study; one kimberlitic diatreme just east of the town of Raton is dated at 30 m.y. West of Cimarron a laccolithic intrusion about 29 m.y. old consists of sill-like bodies of rhyodacite and microsyenite that intrude Upper Cretaceous sedimentary rocks. Mafic dikes, some of them lamprophyric, are common in the central and eastern parts of the area, and vary in age from 24 m.y. to possibly as young as 5 m.y.

A dozen or so conspicuous rhyodacitic domes scattered through the eastern half of the mapped area range in age from 8 to 6 m.y. and are here referred to as the Red Mountain Rhyodacite, formerly Red Mountain Dacite of Collins (1949). The domes are all petrographically and chemically similar, and they include the most silicic rocks of the area.

Mafic lava flows and cinder cones of late Miocene to Holocene ages cover much of the mapped area and extend eastward beyond the edge of the area. Mafic feldspathoidal flows, ranging in age from about 8 m.y. to 2 m.y., form one group, which appears to consist of two petrochemical types—one of basanites and the other of ankaratrites and nephelinites—which are both from source magmas in the upper mantle.

Another major group of extrusives consists of alkali basaltic to latiandesitic rocks of ages from about 4 m.y. to a few thousand years, thus overlapping in age the mafic feldspathoidal lavas. These extrusives are divided into three groups according to age estimated on the basis of physiographic position and roughly controlled by a few radiometric ages. From oldest to youngest, they include a group of alkali basalts corresponding approximately to the Raton Basalt, a group of basalts, trachybasalts, latibasalts, and latiandesites corresponding to the Clayton Basalt, and a group of latibasalts and andesibasalts corresponding to the Capulin Basalt. The petrographic and chemical characteristics suggest strongly that the lavas of the latter two groups were derived from alkali basalt magmas of the first group mainly by contamination in the upper crust, and that the alkali basalts may be genetically related to the basanites of the mafic feldspathoidal lavas.

Manuscript approved for publication, August 13, 1989.

INTRODUCTION

Reconnaissance geologic mapping of the Springer and Raton 30′×60′ quadrangles (September 1980 to May 1982) and preparation of the resulting maps (Scott, 1986; Scott and Pillmore, 1989) provided much field and laboratory data about the igneous rocks of this part of the Great Plains. No published geologic map or report describes adequately the distribution and character of the alkalic rocks of this area. This report presents new descriptive information on field relations, chemical analyses, and K-Ar ages of igneous rocks in the area with the hope that others will be encouraged to investigate the geology of this interesting area in greater detail.

The city of Raton is in the northeastern part of New Mexico a few miles south of the Colorado State line (fig. 1). Springer is in the northern part of the Springer 30′×60′ quadrangle about 40 mi (miles), or 64 km

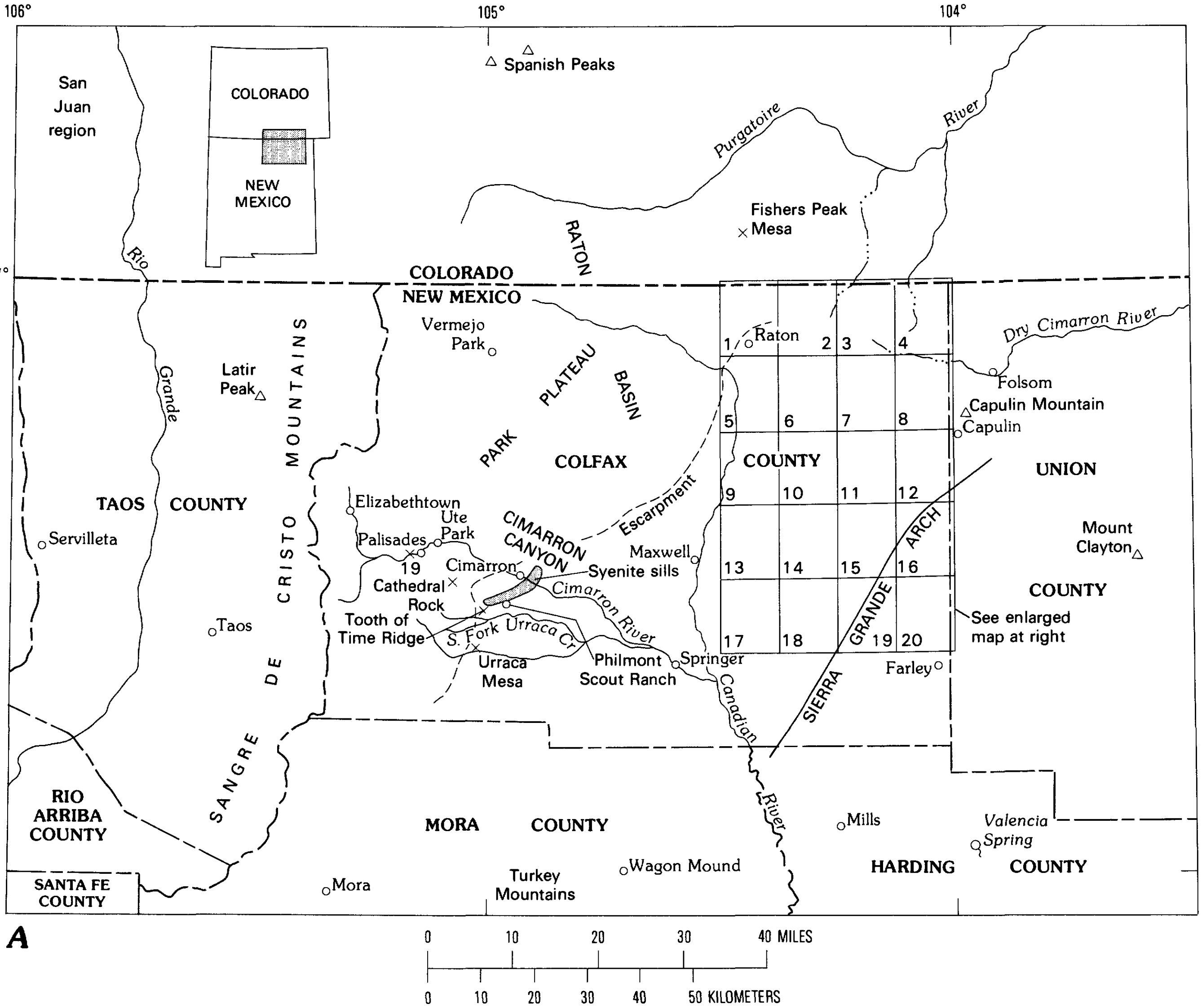
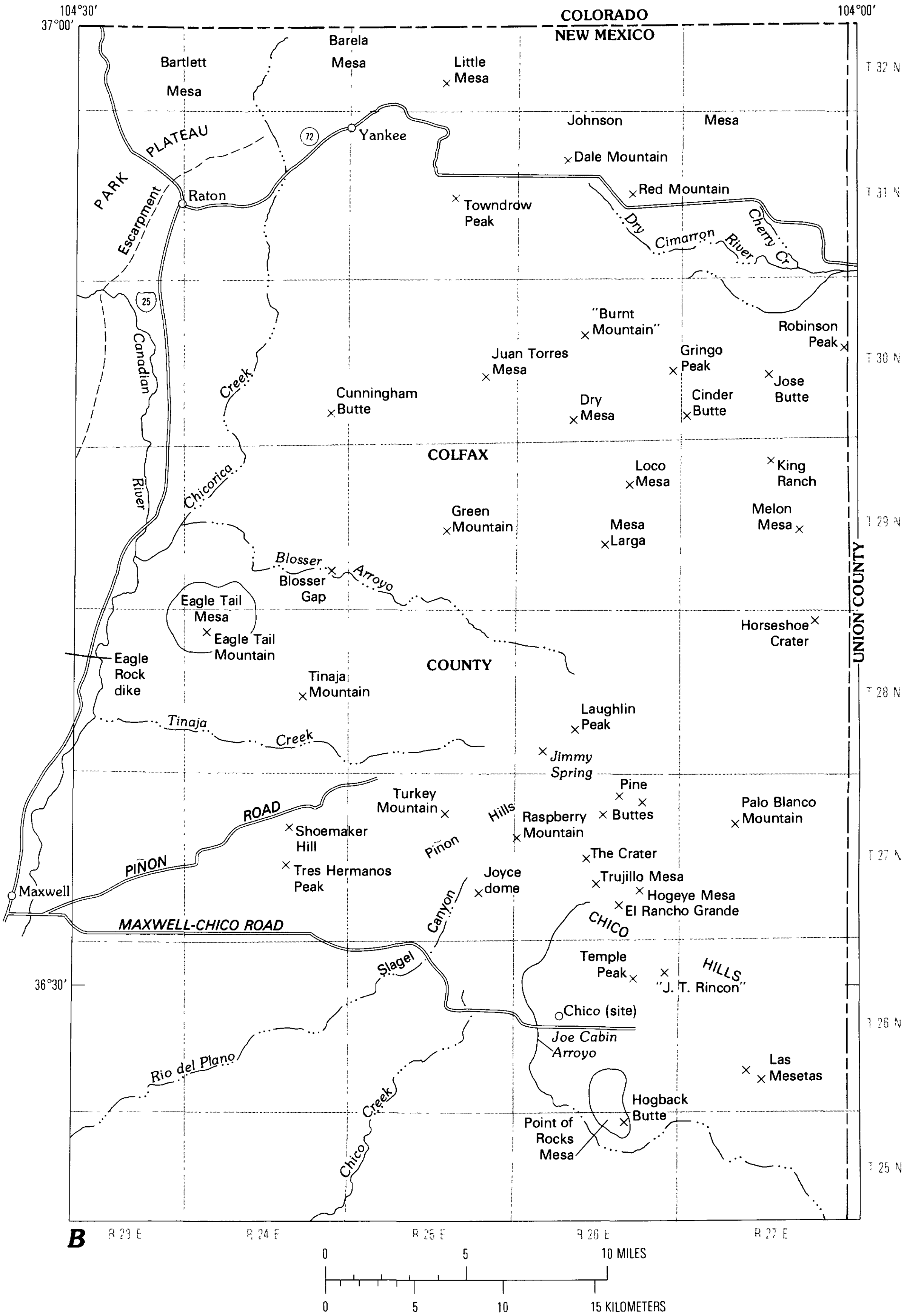


FIGURE 1.—Location of the Raton-Springer area, features mentioned in the text, and 7½-minute quadrangles covering the main study area. *A* (above), Regional setting. Number 19 near Ute Park shows locality of radiometrically dated sample 19 listed in table 2. (All other sample localities for tables 1 and 2 are shown on fig. 6.) *B* (at right), Enlarged map of the main study area. The numbered 7½-minute quadrangles shown in *A* are as follows:

1. Raton
2. Yankee
3. Dale Mountain
4. Trinchera Pass
5. Clifton House
6. Hunter Mesa
7. Johnson Park
8. Robinson Peak
9. Eagle Tail Mountain
10. Tinaja Mountain
11. Mesa Larga
12. Kiowa
13. Loco Arroyo
14. Tres Hermanos Peak
15. Pine Buttes
16. Palo Blanco Mountain
17. Abbott NW
18. Sauble Circle Dot Ranch
19. Point of Rocks Mesa
20. Lawrence Arroyo

(kilometers), south of Raton (fig. 1). The igneous rocks described lie in the western part of the Raton-Clayton volcanic field on the plains between Raton and Capulin, N. Mex. They extend southward 17 mi (27 km) beyond Farley, N. Mex., and crop out in a separate area near Cimarron in the Springer quadrangle. The study area, most of which is in Colfax County, is part of the Raton section of the Great Plains province and is characterized by dissected lava-capped mesas and buttes, gravel-covered pediments, and readily erodible Cretaceous shale. The area slopes generally southeastward from 8,600 ft (feet), or 2,620 m (meters), north of Raton to less


104°30′
37°00′
104°00′
COLORADO
NEW MEXICO
Barela Mesa
Bartlett Mesa
Little Mesa
Johnson Mesa
Dale Mountain
Yankee
72
PARK PLATEAU
Raton
Escarpment
Red Mountain
Towndrow Peak
Dry Cimarron River
Cherry Cr
25
Canadian River
"Burnt Mountain"
Robinson Peak
Juan Torres Mesa
Gringo Peak
Jose Butte
Creek
Cunningham Butte
Dry Mesa
Cinder Butte
COLFAX
Loco Mesa
King Ranch
Chicorica
Green Mountain
Mesa Larga
Melon Mesa
Blosser Arroyo
Blosser Gap
Eagle Tail Mesa
Eagle Tail Mountain
Horseshoe Crater
UNION COUNTY
Eagle Rock dike
COUNTY
Tinaja Mountain
Laughlin Peak
Tinaja Creek
Jimmy Spring
Pine Buttes
Turkey Mountain
Hills
Raspberry Mountain
Palo Blanco Mountain
ROAD
Shoemaker Hill
Piñon
The Crater
PIÑON
Tres Hermanos Peak
Joyce dome
Trujillo Mesa
Hogeye Mesa
Maxwell
Canyon
El Rancho Grande
CHICO
MAXWELL-CHICO ROAD
Slagel
Temple Peak
HILLS
"J. T. Rincon"
36°30′
Chico (site)
Joe Cabin Arroyo
Rio del Plano
Las Mesetas
Creek
Hogback Butte
Point of Rocks Mesa
Chico
T 32 N
T 31 N
T 30 N
T 29 N
T 28 N
T 27 N
T 26 N
T 25 N
R 23 E
R 24 E
R 25 E
R 26 E
R 27 E
0 5 10 MILES
0 5 10 15 KILOMETERS
B

than 6,000 ft (1,830 m) near the southwest corner of the study area along the Canadian River. The igneous rocks, which are the subject of this report, range in age from Oligocene to Holocene. Exposed sedimentary rocks range in age from Triassic to Holocene.

PREVIOUS WORK

The earliest descriptions of the area were brief: St. John (1876, p. 283, 305–308), Stevenson (1881, p. 281), Hill (1892, p. 99), and Lee (1912). The first detailed study was one by Lee (1922) on the geology of the Raton, Brilliant, and Koehler 15-minute quadrangles, which included a section on igneous rocks by J.B. Mertie, Jr. Mertie provided excellent petrographic descriptions and some chemical analyses, and he attempted an age classification that defined four periods of volcanism based on the height of lavas above streams and on the degree of weathering of the olivine in the lavas. The geology of the eastern part of Colfax County was first mapped by Griggs (1948). He divided the volcanic rocks into three age groups, of which two were basalt flows and the third was a sill complex said to be composed of monzonitic porphyries.

The earliest report specifically on the volcanic field, called the Raton-Clayton field, resulted from reconnaissance of eastern Colfax County and western Union County by Collins (1949), who described the regional geology, age, and distribution of the igneous rocks. Most of his work was on the basaltic rocks, which he divided into three periods of Quaternary extrusion: from oldest to youngest, the "Raton basalts," "Clayton basalts," and "Capulin basalts." In addition, he also described "dacite" volcanoes and several types of alkalic rocks, including phonolite and trachyte. The alkalic rocks were all considered to be flows erupted in the Quaternary between the extrusion of the "Raton basalts" and the "Clayton basalts."

Stobbe (1948, 1949) did a comprehensive petrographic and petrologic study of the rocks mapped by Collins, and gave the modes of each rock type, together with a few chemical analyses. Stobbe (1950) found that the dacite on the eroded volcanic cone of Laughlin Peak is mineralogically the same as other dacite bodies in the area, although it has a higher glass content.

The late Cenozoic erosional history of the "Raton Mesa" region was studied by Levings (1951), who followed Collins in assigning the lava flows to three volcanic episodes thought to be separated by discrete erosional episodes.

A geologic map of much of the eastern part of Colfax County was prepared by Wood, Northrop, and Griggs (1953). They continued Griggs' (1948) use of the term "sill complex" for "thick sills of intermediate composition" in the Chico Hills, but suggested that some sets of sills appeared to be small laccoliths. They assigned an early Tertiary age to the sills and suggested an age similar to that of rocks at the Spanish Peaks in southern Colorado (fig. 1). They informally adopted Collins' nomenclature of "Raton, Clayton, and Capulin" for basalt flows of three different ages.

Baldwin and Muehlberger (1959) described in considerable detail the volcanic rocks of Union County, adjacent to Colfax County on the east. They also used the threefold age sequence of Collins, but suggested a Pliocene age for the Raton Basalt of Collins and dated the Capulin Basalt of Collins at between 8,000 and 2,400 years before the present.

Aoki (1967) found the alkaline and calc-alkaline basalts near Capulin Mountain (fig. 1) to be a typical circum-oceanic alkaline suite characterized by high SiO_2, Al_2O_3, and K_2O and by low TiO_2. Lipman (1969) found the Raton Basalt of Collins to be similar in chemistry and petrography to basalt in the Hinsdale Formation of the San Juan region, Colorado, and different from the tholeiitic basalt of the Rio Grande depression near Servilleta, N. Mex. (fig. 1).

The radiometric ages and petrology of basaltic flows and dacite in that part of the Raton-Clayton volcanic field in the area of the Raton $1° \times 2°$ quadrangle were the subjects of two reports by Stormer (1972a, b). The oldest age, determined on a dacite, was slightly greater than 8 m.y.B.P. Flows of the Raton Basalt of Collins were dated at between 7.0 and 3.5 m.y.B.P. Younger flows in the Raton area were not dated radiometrically. Stormer reiterated the suggestion of Wood and others (1953) that the phonolitic sills appeared to represent a still earlier period of igneous activity, probably contemporaneous with the Spanish Peak intrusions. Some basalt flows that had been assigned by Collins to the Clayton Basalt were reassigned by Stormer to the Capulin Basalt, mainly because of petrographic characteristics. We have retained them as Clayton Basalt, based on their physiographic positions.

In an investigation of the content of potassium, thorium, and uranium in basalts of the southern Rocky Mountain region, Lipman and others (1973) found that amounts of all three elements increased away from the Rio Grande depression. Jones and others (1974) studied the strontium isotope ratios of Stormer's (1972a, b) volcanic suite and suggested an upper mantle origin for most of its magmas.

Phelps and others (1979) determined the rare-earth geochemistry of rocks in the Raton-Clayton volcanic field and found little correlation between the rare-earth element abundance and the major-element compositions of the different rock types.

The basalts near Mora, N. Mex. (fig. 1), studied by O'Neill and Mehnert (1980a, b) probably have a sequence similar to those near Raton and range in age from 8.1 to 0.76 m.y. O'Neill and Mehnert recognized six extrusive events, which are related to erosion surfaces that are nearly contemporaneous with the flows.

Pillmore and Scott (1976) described the Quaternary pediments of the Vermejo Park and Raton areas. The heights of the pediments above stream levels suggest that the older pediments probably are contemporaneous with some of the intermediate or Clayton Basalt flows.

Phelps and others (1983) presented analyses of major and trace elements and strontium isotopes of 12 of the feldspathoidal lavas of Colfax and Union Counties. They suggest that most are primary melts from a portion of the upper mantle, which probably had been premetasomatized by CO_2-rich fluids.

ACKNOWLEDGMENTS AND RESPONSIBILITY

The named authors of this report are just three of the many U.S. Geological Survey workers who contributed to this study. Scott made a geologic map of the Raton-Springer area, collected rock specimens characteristic of each igneous unit, and had them prepared for analysis. Wilcox did most of the petrography. Mehnert determined the K-Ar ages of the rocks. Mutsumi Miyachi and Charles W. Naeser determined the fission-track ages of several rocks. Wilcox, assisted by Jane Jenness and Michelle Hutchins, made the calculations for the chemical classification system developed by La Roche and others (1980) for assignment of names to the igneous rocks. Kenneth Segerstrom and Wilcox visited the field area with Scott and gave advice on petrology and field relationships of the volcanic rocks. During the mapping by Scott, Mortimer H. Staatz was mapping the Pine Buttes (Staatz, 1986) and the Tres Hermanos Peak (Staatz, 1987) quadrangles in connection with an investigation of thorium and rare-earth mineralization in the Laughlin Peak area (Staatz, 1985). Staatz cooperated in our geologic studies, and we appreciate the use of his analytical data and his then-unpublished geologic maps of the above two quadrangles. Peter W. Lipman helped select rocks for K-Ar analysis, and Donald M. Cheney separated the minerals for dating. Charles L. Pillmore assisted in mapping part of the area.

We appreciate the kindness of the U.S. National Park Service staff at Capulin Mountain National Monument, who sent specimens of the basalt flows from Capulin Volcano for petrographic examination. Many ranchers were helpful during the mapping, particularly Jim Hennigan of the Hennigan Ranch, Tim Harkness of the McAuliffe Ranch, and John D. Carter of the Carter Ranch.

We are indebted to Carl Orth of the Los Alamos National Laboratory at Los Alamos, N. Mex., for the neutron activation analyses. All other new analyses were performed in the laboratories of the U.S. Geological Survey. Chemical analyses with the specimen designations SM (Scott) or MHS (Staatz) are major-oxide (including total iron) analyses by X-ray fluorescence done by J.S. Wahlberg, J.E. Taggart, Jr., K.C. Stewart, and J.W. Baker. FeO analyses by volumetric titration were by J.L. Ryder, G.R. Mason and H.G. Neiman. The calculated Fe_2O_3 values are the difference between the total iron and the FeO analyses. For chemical analyses of specimens labeled MHS, the CO_2 was by coulometric titration, the H_2O+ by the Penfield method, and H_2O- by weight difference after heating the sample to 105 °C for 2 hours—all done by H.G. Neiman. For analyses lacking direct determinations of H_2O, "volatiles" were calculated from values of loss on ignition, adjusted by assuming all ferrous iron became oxidized to ferric iron. Six-step semiquantitative spectrographic analyses were by L.A. Bradley. Fluorine contents were determined by the specific-ion electrode method by F.D. Newman and H.G. Neiman.

PHYSIOGRAPHY

The report area lies within the Raton section of the Great Plains province (Fenneman, 1946). The study area includes part of the basalt-capped mesas near Raton and generally lies east of the Park Plateau (Raisz, 1939), an area of coal-bearing rocks. Most of the area is drained southward by the Canadian River and its tributaries, but the extreme east side drains eastward through the Dry Cimarron River, and the northeast corner drains north to the Purgatoire River (fig. 1).

The physiography of the Raton-Springer area has been strongly influenced by igneous activity. The most striking features are plateaus as long as 15 mi (24 km) capped by dissected lava flows; buttes, some with bases as broad as 3 mi (5 km), formed by cinder cones and extrusive domes; broad, dissected hills domed by sills and bordered by dipping sedimentary beds; sharp ridges formed by igneous dikes and their baked wall rocks; and long tongues of basalt that have recently flowed down valleys. Other physiographic features are three levels of high gravel-covered pediments, low terraces along major streams, and deep valleys cut through the high basalt-covered plateaus surrounded by large landslide deposits. A broad southeastward-sloping plain in the southeastern part of the area is created by the Ogallala Formation, a fanlike deposit of fluvial sand and gravel of Miocene age. Perhaps the most scenic feature in the area is the deep canyon of the Canadian River.

The amount of dissection differs greatly, probably depending on proximity to the Canadian River and its tributaries. Along the Canadian River near Mills, south of the map area, about 1,000 ft (305 m) of downcutting has taken place since deposition of the Ogallala Formation about 7 m.y. ago. The gravel beneath the high basalt flows on the plateaus north and east of Raton is also considered to be Ogallala Formation because it lies about 1,000 ft (305 m) above modern drainage. From Loco Mesa to near Capulin, just east of the study area, however, erosion since Ogallala time is almost undetectable, drainage is not integrated, many large basins of ephemeral lakes are present, and the principal agent of erosion seems to have been wind rather than water. The lack of much erosion near Capulin and the large amount of erosion near Raton complicates the age correlation of lava flows between the two areas. A lava flow near Raton lying 1,200 ft (365 m) above modern drainage, for instance, may correlate with a flow near the town of Capulin that is only 300 ft (90 m) above modern drainage. Our endeavor to reconcile this complication in assignment of ages is discussed further in the later section on basaltic to latiandesitic effusive rocks.

SEDIMENTARY ROCKS

Figure 2 lists the sedimentary strata that crop out in the Raton-Springer area and vicinity. The extrusive rocks described here overlie most of these rock units, including some of the Quaternary surficial deposits. The sills of the Chico sill complex are interlayered with beds from the Dakota Sandstone up through the Smoky Hill Shale Member of the Niobrara Formation. In the southeastern part of the area intrusive bodies of rhyodacite, trachyte, and phonolite have domed Mesozoic (and Cenozoic?) rocks, some of which are not elsewhere exposed at the surface (Scott, 1986; Scott and Pillmore, 1989).

STRUCTURE

The chief structural features of the Raton-Springer area are the eastern part of the Raton basin and the bounding Sierra Grande arch. The Raton basin is asymmetrical; the eastern limb is broad and dips gently to the west, whereas the western limb is narrow and dips steeply to the east. The axis of the basin lies west of the study area and trends northward parallel to the axis of the Sangre de Cristo Mountains. The crest of the Sierra Grande arch trends about N. 30° E. (Wood and others, 1953) across the southeast quarter of the map area, beginning in T. 23 N., R. 24 E., south of the map area, and extending to T. 28 N., R. 28 E., just east of the map area. The arch is broad and has several small folds superposed on it. Intrusion of sills has increased the structural relief of the arch by nearly 1,000 ft (305 m); possibly structural weakness along the crest of the arch influenced the placement of the sills. Intrusion of the sills caused some folding and faulting of the sedimentary rocks, but preexisting faults and folds apparently did not influence igneous intrusion in any major way.

Holocene	Alluvium, fan alluvium, sheet wash alluvium, colluvium, lake sediments	
Holocene / Pleistocene	Eolian deposits	
Pleistocene	Pediment and terrace alluvium (at least three physiographic levels of pediments)	
Miocene	Ogallala Formation	
Lower Tertiary(?)	Alluvial deposit on east flank of Palo Blanco Mountain	
Paleocene	Poison Canyon Formation	
Paleocene / Upper Cretaceous	Raton Formation	
Upper Cretaceous	Vermejo Formation	
Upper Cretaceous	Trinidad Sandstone	
Upper Cretaceous	Pierre Shale	
Upper Cretaceous	Niobrara Formation	Smoky Hill Shale Member
Upper Cretaceous	Niobrara Formation	Fort Hays Limestone Member
Upper Cretaceous	Carlile Shale	Unnamed upper member
Upper Cretaceous	Carlile Shale	Juana Lopez Member
Upper Cretaceous	Carlile Shale	Codell Sandstone Member
Upper Cretaceous	Carlile Shale	Blue Hill Shale Member
Upper Cretaceous	Carlile Shale	Fairport Member
Upper Cretaceous	Greenhorn Limestone	Bridge Creek Limestone Member
Upper Cretaceous	Greenhorn Limestone	Hartland Shale Member
Upper Cretaceous	Greenhorn Limestone	Lincoln Limestone Member
Upper Cretaceous	Graneros Shale	Thatcher Limestone Member
Upper Cretaceous	Dakota Sandstone	
Lower Cretaceous	Purgatoire Formation	
Upper Jurassic	Morrison Formation	
Middle Jurassic	Bell Ranch Formation	
Middle Jurassic	Exeter Sandstone	
Upper Triassic	Dockum Group	Chinle Formation
Upper Triassic	Dockum Group	Santa Rosa Sandstone

FIGURE 2.—Sedimentary rocks exposed in the Raton-Springer area and vicinity, New Mexico.

IGNEOUS ROCKS

CONCORDANT INTRUSIONS

An assemblage of sills of middle Tertiary age, here called the Chico sill complex as used by Wood and others (1953), crops out in the southeastern part of the study area south of Laughlin Peak and east of Tres Hermanos Peak (fig. 1). This assemblage contains many stacked sill-like bodies of varied compositions, all of which are nearly concordant with the structure of the sedimentary rocks. Wood and others (1953) commented that locally the thick sills appeared to be small laccoliths; the complex is slightly elongate in a southeastern direction and is about 16 mi (26 km) in diameter. The igneous bodies are flat on bottom and top, and the ratio of diameter to thickness is much greater than ten. Based on these characteristics, we avoid the name laccolith and instead adopt the term sill complex as used by Wood and others (1953).

The sill complex has quaquaversal dips and two cross-cutting central intrusions (the only vents found) on Turkey Mountain in the northeastern part of the Tres Hermanos Peak quadrangle. Strata intruded by the sill complex are not only gently domed but also folded into small anticlines and synclines superimposed on the broad dome. In addition, the sills and associated sedimentary rocks are broken by local faults having small throws. Most of the sedimentary rocks that bound the igneous rocks were contact metamorphosed to hornfels, which commonly is more resistant to erosion than the igneous rocks.

Other areas of doming by probable igneous intrusions lie near and west of Cimarron and at the Turkey Mountains, 7 mi (11 km) west of Wagon Mound (fig. 1). Near Cimarron, syenite and rhyodacite sills are widespread and suggest the presence of a large subsurface intrusion that could extend as far to the northwest as the valley of the Rio Grande. Peter W. Lipman (oral commun., 1982) of the U.S. Geological Survey suggested that these sills at Cimarron could be related to the volcanic rocks of the Latir Peak volcanic field, 35 mi (57 km) to the northwest.

Hayes (1957) suggested that the uplift of the Turkey Mountains, west of Wagon Mound (outside the study area), might have resulted from the intrusion of a laccolith. The mountains are about 7 mi (11 km) across, are fairly symmetrical, and expose several small igneous bodies. One of these is a mafic dike, which is described and dated in this report in the section "Mafic and ultramafic dikes and sills."

EXTRUSIONS AND DISCORDANT INTRUSIONS

Several types of extrusions and intrusions are found in the area. At least 10 hornblende rhyodacite volcanoes are known. On the east flank of Palo Blanco Mountain volcano (the only part of the mountain where bordering sedimentary rocks can be seen), sedimentary layers were upturned to nearly vertical during extrusion of the rhyodacite. A kimberlite diatreme cuts the Upper Cretaceous Pierre Shale 2 mi (3.2 km) east of Raton. Many small basaltic and lamprophyric plugs are commonly associated with dike swarms of similar composition. Dikes are extremely numerous south of Eagle Tail Mesa and Tinaja Mountain, and in and around the Chico sill complex. They range widely in thickness and length, some being as much as 8 mi (13 km) long.

Cinder cones formed at the vents of many of the mafic lava flows. Some of the younger cones, such as Capulin Mountain, Horseshoe Crater, Cinder Butte, and Gringo Peak, are little eroded and nearly symmetrical. Older cinder cones are more eroded but still identifiable as the sources of some lava flows.

The lava flows are somewhat tabular sloping bodies of widely varying thickness. Most were deposited on gravel-floored stream valleys, and clasts of gravel or, rarely, large deposits of gravelly alluvium are visible beneath the flows. Figure 3 shows a succession of alluvial deposits beneath a basalt flow. Alluvial deposits such as these probably underlie most of the basalt and mafic feldspathoidal flow series in the area. However, large landslide deposits around most lava-capped mesas obscure the gravel. Nearly all flows were fairly viscous and formed aa having a rough, jagged, clinkery surface. On the younger flows, additional features such as lava spines, tumuli (pressure domes) (fig. 4), and pressure ridges are readily recognized. The initial pyroclastic eruptions commonly laid down continuous mantles of basaltic ash, which underlie most lava flows and overlie the gravel deposits in the ancient stream valleys.

We recognized 66 cinder cones in the eastern part of the map area and found 30 more west of Wagon Mound, southwest of the area. On the flanks of the cinder cones the beds of pyroclastic material lie at the angle of repose, about 30°. Although the cinder cones mark the locations of the main vents, most of the flows issued from the lower parts of the cones, not from craters high on the cones. Many of the cinder cones were breached, probably by lava tunneling from the feeder vent through the lower parts of the cinder cones and eroding the upper parts. Around a few cones the flows accumulated to such a thickness that the cones are largely buried.

TYPES OF IGNEOUS ROCKS

The igneous rocks are both intrusive and extrusive; many are alkalic and some also feldspathoidal. The principal varieties, arranged by age, are shown in figure 5 and on a generalized geologic map, figure 6. The subvolcanic Chico sill complex contains chiefly alkalic rocks, such as the Slagle Trachyte and the Chico Phonolite.

Volumetrically, most of the exposed extrusive rocks are basaltic, andesitic, and latitic. The more silicic rocks occur in the southeastern part of the area and may be

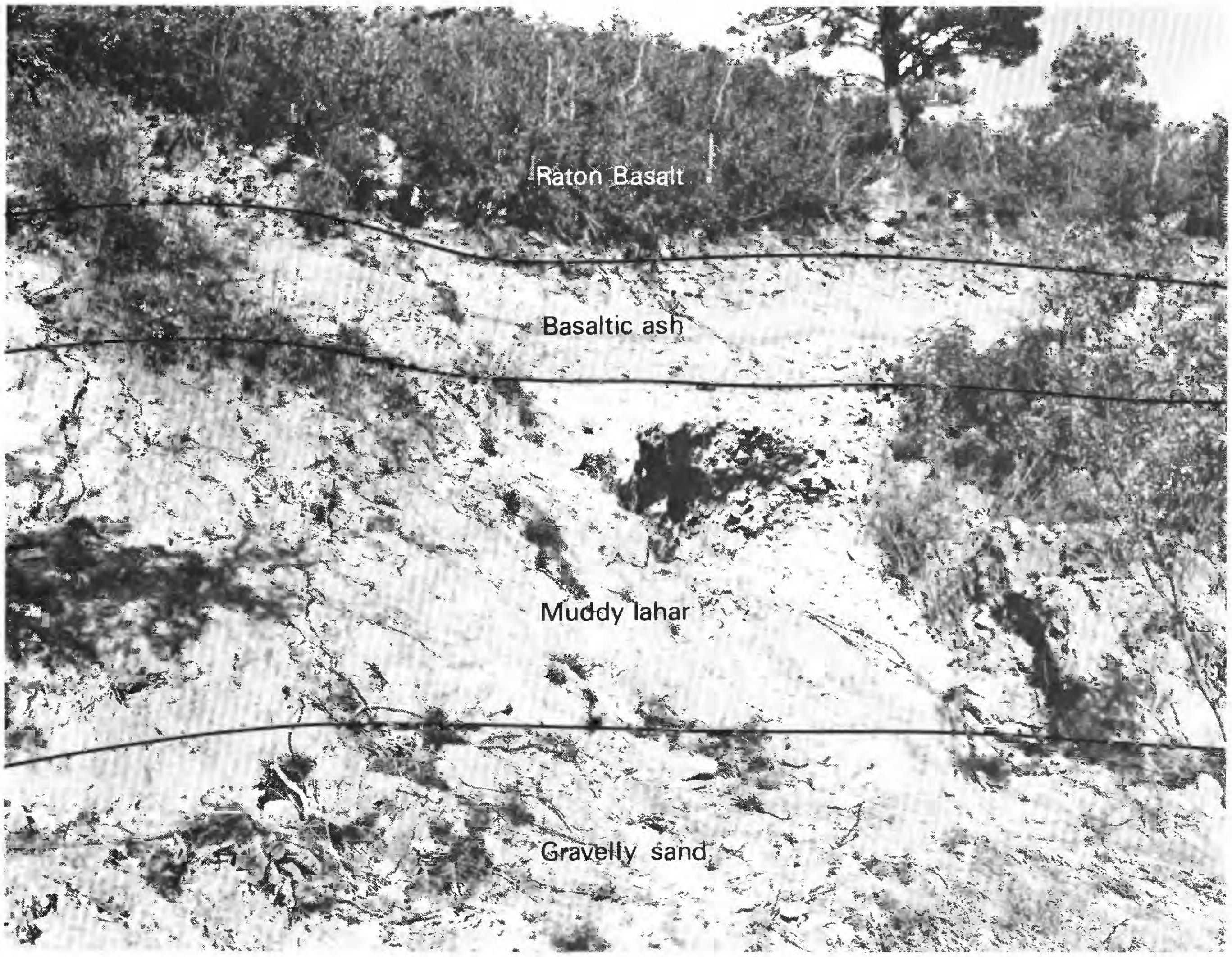


FIGURE 3.—Unconsolidated sediments beneath flow of Raton Basalt on north side of New Mexico Highway 72 at east end of Johnson Mesa in the NE¼SE¼ sec. 21, T. 31 N., R. 27 E., Trinchera Pass quadrangle. From the top downward, the section includes basalt, 3 ft (1 m) of water-laid coarse, loose, black basaltic ash (fine-grained layer in photograph) 12 ft (3.6 m) of muddy lahar containing clasts of basalt, and an unmeasured thickness of poorly exposed tan, gravelly sand containing clasts of Precambrian rocks and basalt several inches long.

time equivalent to the Clayton Basalt. Also present in the area are basanite, nepheline basalt, nephelinite, ankaratrite, and hauyne basalt.

The Red Mountain Rhyodacite apparently is entirely extrusive, and at Laughlin Peak includes some water-laid tuff and volcaniclastic lahars. Dikes and sills of various compositions other than those listed above include lamprophyre (vogesite and monchiquite; Stobbe, 1949), tinguaite, and analcime microfoyaite; few of these were considered in this study.

Most rocks are porphyritic and have a fine-grained groundmass. Size of the phenocrysts varies widely—the largest seen were feldspar crystals about 2 cm long in green phonolite. The phenocrysts in phonolite, trachyte, and rhyodacite commonly show flow lineation.

RADIOMETRIC AGES

The specific ages of the volcanic and subvolcanic rocks near Raton were poorly known when mapping of the Raton and Springer 30′ × 60′ quadrangles was begun. In order to establish the age of volcanic activity more exactly, K-Ar determinations were made of rocks that seemed to represent the whole range of volcanism, from oldest to youngest. Table 1 shows the analytical data for 22 whole-rock or mineral separates that represent the major rock formations. Figures 1 and 6 show the locations where the radiometrically dated rocks were collected. The ages range from Oligocene to Holocene; rocks of the Chico sill complex are the oldest subvolcanic rocks in the area, ranging from more than 36 m.y. (Staatz, 1985, p. E12) to about 20 m.y.

FIGURE 4.—Tumulus or pressure dome on flow of Capulin Basalt in the SE¼ sec. 7, T. 29 N., R. 27 E., Robinson Peak quadrangle. Flow probably was erupted from volcano in the NE¼ sec. 22, T. 30 N., R. 26 E., Johnson Park quadrangle (locally called "Burnt Mountain").

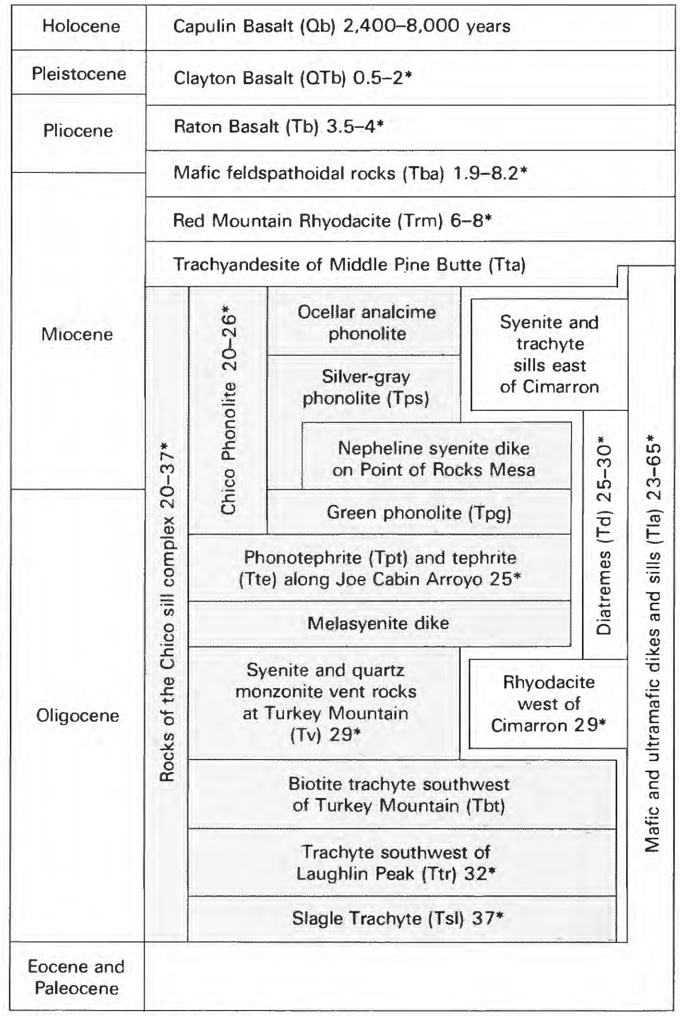
Data from fission-track analysis of three samples, shown in table 2, yield further information on the age of volcanism. Radiometric ages reported previously by Armstrong (1969, table 1), Stormer (1972a, table 2), and Hussey (1971) are shown in table 3. M.J. Aldrich of the Los Alamos National Laboratory, Los Alamos, N. Mex., has recently reported (written commun., 1982) ages of some mafic dikes in and close to the map area. These ages are quoted in the discussion of mafic and ultramafic dikes and sills. K-Ar ages of the Slagle Trachyte, the trachyte southwest of Laughlin Peak, and the Red Mountain Rhyodacite were published by Staatz (1985) and are quoted in table 3 and under discussion of each of those units.

In addition to the above ages, 19 radiometric ages have recently been reported by O'Neill and Mehnert (1980b) for basalt flows in the southwestern part of the Springer 30′×60′ quadrangle. Dated basalt flows in that area range in age from 8.34±0.50 to 0.81±0.14 m.y. The flows range in height above modern streams from 2,000 to 60 ft (610–18 m). Their sequence of basalt flows is similar in age and height above stream level to the flows near Raton; however, no feldspathoidal flows were recognized in that area.

PETROGRAPHY AND PETROCHEMISTRY

A reconnaissance petrographic examination of thin sections (without precise modal analyses) confirmed for the most part the more detailed descriptions of rocks of this area by Stobbe (1949). Some 63 new chemical analyses (18 of which were supplied by M.H. Staatz of the U.S. Geological Survey) are given in the following tables along with some previously published analyses of rocks of the area.

The classification of La Roche and others (1980) is used to assign rock names (see fig. 7*A*) rather than the CIPW



*Radiometric ages in millions of years

FIGURE 5.—Igneous rocks of the Raton-Springer area and vicinity, New Mexico. Shading identifies rocks of the Chico sill complex.

norms. Their parameters R_1 and R_2 are calculated as follows:

$$R_1 = 4\text{Si}-11(\text{Na}+\text{K})-2(\text{Fe}+\text{Ti}),$$
$$R_2 = 6\text{Ca}+2\text{Mg}+\text{Al}$$

where Si, Na, K, and other element symbols represent millications (thousandths of a cation percent) of the element present in 100 grams of the rock. A point is plotted using R_1 as abscissa and R_2 as ordinate on the diagram of figure 7*A*, and the rock name is taken from that of the area on the diagram in which the point R_1R_2 values for each rock analysis plot. For those values that plot on or very near a boundary, both rock names are used.

An important use of the R_1R_2 diagram is to show the chemical relations among members of igneous rock series and to better enable interpretation of the magmatic

TABLE 1.—*Analytical data for K-Ar ages of whole-rock samples and mineral separates in volcanic and subvolcanic rocks, Raton-Springer area, New Mexico*

[Analyses for Na_2O and K_2O by E.L. Brandt, U.S. Geological Survey. Decay constants: ^{40}K $\lambda_\epsilon=0.581\times10^{-10}$/yr; $\lambda_\beta=4.962\times10^{-10}$/yr; $^{40}K/K=1.167\times10^{-4}$]

Map No.[1]	Map symbol	Field No.	Lab. No. DKA-	Rock type	Material analyzed	Na_2O[2] (percent)	K_2O[2] (percent)	^{40}Ar moles/g $\times10^{-10}$	^{40}Ar percent	Age (m.y. $\pm2\sigma$)
1	QTb	80SM1	4415	Basalt --------------	Whole rock	3.43, 3.43	1.30, 1.30	0.0124	12.4	0.66±0.12
2	Qtb	80SM15	4419	Latite/trachyandesite	Whole rock	5.26, 5.21	2.30, 2.29	.0286	8.3	.86± .22
3	QTb	80SM2	4416	Trachybasalt --------	Whole rock	5.26, 5.25	2.08, 2.08	.0273	20.1	.91± .10
4	QTb	80SM16	4427	Latiandesite --------	Plagioclase	5.38, 5.38	.44, .43	.0079	4.5	1.27± .71
5	Tb	80SM31	4422	Alkali basalt -------	Whole rock	2.88, 2.87	1.29, 1.30	.1306	45.6	3.95± .19
6	Tba	80SM8	4418	Basanite ------------	Whole rock	3.33, 3.42	1.09, 1.14	.0300	19.4	1.87± .21
7	Tba	80SM39	4421	Basanite ------------	Whole rock	3.98, 3.94	1.50, 1.49	.0710	50.5	3.30± .15
8	Tba	80SM21	4420	Basanite ------------	Whole rock	3.16, 3.17	1.51, 1.50	.0895	35.7	4.12± .25
9	Tba	80SM44	4423	Basanite ------------	Whole rock	3.46, 3.37	1.34, 1.29	.1554	71.9	8.19± .31
10	Trm	80SM6	4411	Rhyodacite ----------	Hornblende	2.42, 2.41	.62, .62	.0574	21.5	6.43± .67
			4412		Plagioclase	6.73, 6.76	.35, .36	.0293	15.5	5.72± .84
11	Trm	80SM18	4414	Rhyodacite ----------	Hornblende[3]	2.31, 2.31	.63, .65	.0703	14.9	7.6 ±1.1
								.0636	14.9	6.9 ±1.0
			4413		Plagioclase	6.71, 6.71	.40, .40	.0251	7.6	4.35±1.33
12	Trm	80SM22A	4385	Rhyodacite ----------	Hornblende	2.25, 2.25	.58, .58	.0567	10.3	6.79±1.45
			4387		Plagioclase	6.93, 6.95	.40, .42	.0372	10.0	6.30±1.44
	Trm	80SM22B	4386	Rhyodacite ----------	Hornblende	2.13, 2.11	.53, .51	.0558	11.0	7.44±1.49
			4388		Plagioclase	6.99, 7.00	.41, .44	.0366	14.3	5.97± .95
13	Tl	80SM37	4428	Rhyodacite ----------	Hornblende	2.07, 2.09	.69, .71	.0696	18.9	6.90± .80
			4424	Pumice --------------	Plagioclase	6.44, 6.46	.30, .32	.0978	24.2	21.79±2.22
14	Tp	80SM5	4417	Silver-gray phonolite	Whole rock	9.57, 9.64	5.35, 5.32	1.567	54.5	20.29± .90
15	Tps	80SM13	4426	Silver-gray phonolite	K-feldspar	6.77, 6.81	7.05, 7.07	2.736	93.1	25.80± .88
16	Tla	80SM25	4425	Basanite (lamprophyre)	Hornblende	2.51, 2.52	.70, .71	.2469	56.5	24.16±1.01

[1] As shown on figure 6.
[2] Analyses for Na_2O and K_2O done in duplicate for each sample.
[3] Hornblende was analyzed isotopically on two splits of the same sample.

DESCRIPTION OF SAMPLE LOCALITIES

1. 80SM1. South end of mesa in the NW¼SE¼ sec. 31, T. 30 N., R. 25 E., Colfax County, Hunter Mesa quadrangle.
2. 80SM15. West edge of mesa in the NW¼ sec. 15, T. 26 N., R. 27 E., Colfax County, Lawrence Arroyo quadrangle.
3. 80SM2. South end of Juan Torres Mesa in the SE¼NE¼ sec. 26, T. 30 N., R. 25 E., Colfax County, Johnson Park quadrangle.
4. 80SM16. Northeast of road on flank of Las Mesetas in the NE¼ sec. 33, T. 26 N., R. 27 E., Colfax County, Lawrence Arroyo quadrangle.
5. 80SM31. West edge of Mesa Larga in SW¼SW¼ sec. 334, T. 29 N., R. 26 E., Colfax County, Mesa Larga quadrangle.
6. 80SM8. North edge of mesa in the NW¼NW¼ sec. 6, T. 30 N., R. 28 E., Union County, Robinson Peak quadrangle.
7. 80SM39. South edge of mesa in the SW¼NW¼ sec. 13, T. 26 N., R. 25 E., Colfax County, Point of Rocks Mesa quadrangle.
8. 80SM21. Quarry in southeastern part of Dale Mountain in the NW¼ sec. 16, T. 31 N., R. 26 E., Colfax County, Dale Mountain quadrangle.
9. 80SM44. Roadcut in SE¼NW¼ sec. 10, T. 31 N., R. 25 E., Colfax County, Yankee quadrangle.
10. 80SM6. Western foot of Towndrow Peak in the NW¼SE¼ sec. 22, T. 31 N., R. 25 E., Colfax County, Yankee quadrangle.
11. 80SM18. Dike at the west end of Cunningham Butte in the SW¼ sec. 25, T. 30 N., R. 24 E., Colfax County, Hunter Mesa quadrangle.
12. 80SM22. Southern foot of Red Mountain in the SW¼SW¼ sec. 23, T. 31 N., R. 26 E., Colfax County, Dale Mountain quadrangle.
13. 80SM37. Arroyo on north flank of Laughlin Peak in the NW¼SE¼ sec. 19, T. 28 N., R. 26 E., Colfax County, Mesa Larga quadrangle.
14. 80SM5. North end of Tinaja Mountain in the NE¼ sec. 14, T. 28 N., R. 24 E., Colfax County, Tinaja Mountain quadrangle.
15. 80SM13. Southeastward facing slope at Chico in the SE¼ sec. 17, T. 26 N., R. 26 E., Colfax County, Point of Rocks Mesa quadrangle.
16. 80SM25. Eagle Rock dike on west side of Interstate Highway 25 in the NE¼ sec. 16, T. 28 N., R. 23 E., Colfax County, Eagle Tail Mountain quadrangle.

TABLE 2.—*Analytical data for zircon fission-track ages of volcanic and subvolcanic rocks, Raton-Springer area and vicinity, New Mexico*

[Samples dated by Mutsumi Miyachi in the laboratory of C.W. Naeser, U.S. Geological Survey. Decay constant $\lambda_f=7.03\times10^{-17}yr^{-1}$]

Map No.[1]	Field No.	Lab. No. DF-	Rock unit	Fossil-track density, ρ_s[2] (10^6 tracks/cm^2)		Induced-track density, ρ_i[2] (10^6 tracks/cm^2)		Neutron flux, ϕ (10^{15}n/cm^2)	Number of grains	Age (m.y.±2σ)
17	80SM33	4000	Kimberlite at Raton	3.03	(928)	6.14	(940)	1.02	7	30.1±1.2
18	81SM9	3951	Hornblende syenite at Turkey Mountain vent.	3.09	(1952)	6.20	(1954)	.971	13	29.0±1.6
19	81SM24	4001	Rhyodacite west of Cimarron.	5.76	(1944)	10.32	(1744)	.877	6	29.1±1.4

[1]As shown on figure 1 or 4.
[2]Numbers in parentheses show total number of tracks counted in each determination.

DESCRIPTION OF SAMPLE LOCALITIES

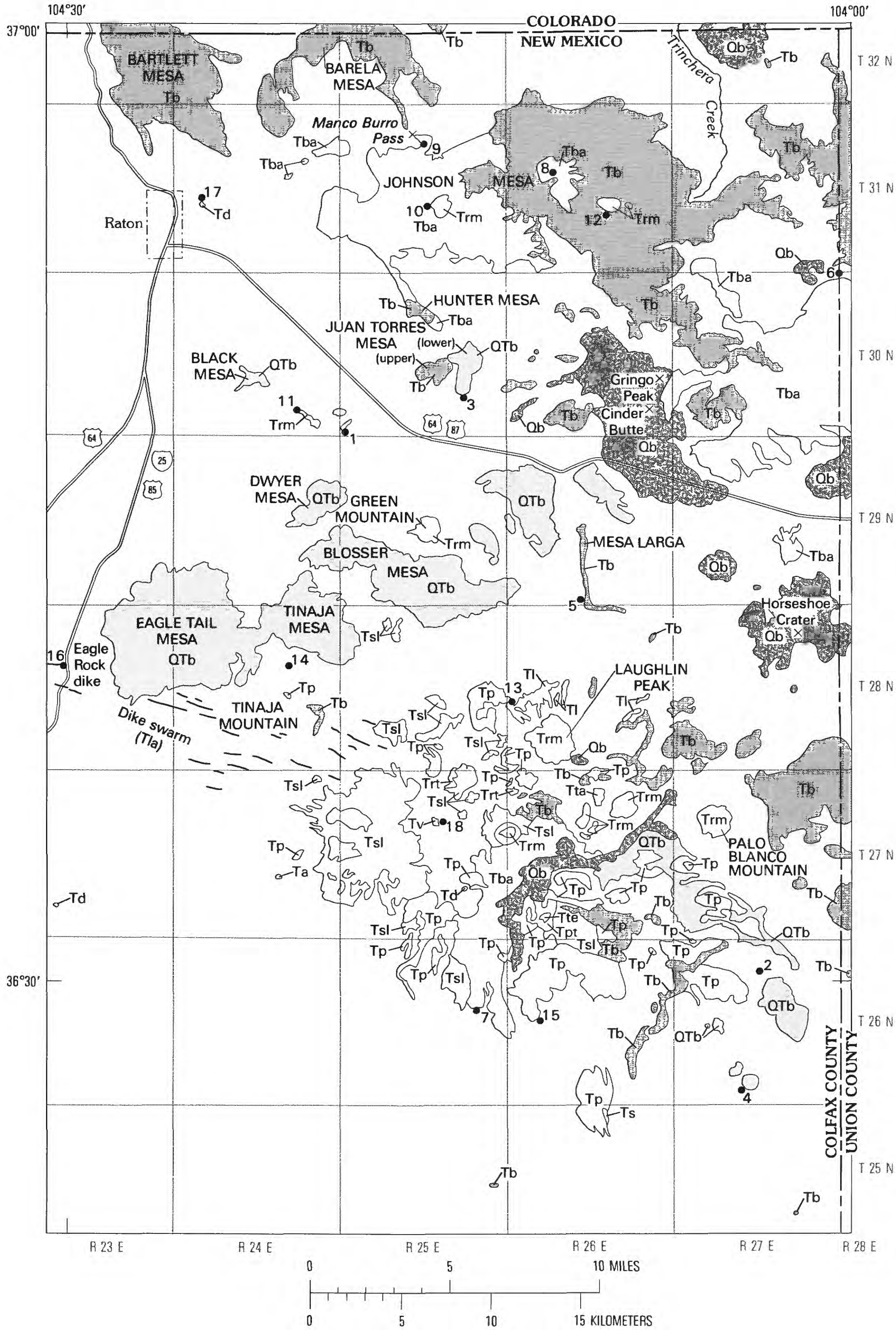
17. 80SM33. Diatreme in a low rounded hill in the NE¼NW¼SE¼ sec. 20, T. 31 N., R. 24 E., about 9,600 ft (2,926 m) east of the Colfax County Courthouse on the Olen Caviness Ranch, Raton quadrangle.
18. 81SM9. Crest of eastern peak of Turkey Mountain, altitude 7,888 ft (2,404 m), in the center of the SW¼ sec. 11, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle.
19. 81SM24. Roadcut ½ mi east of Palisades in Cimarron Canyon on U.S. Highway 64, Touch-Me-Not Mountain quadrangle.

TABLE 3.—*Analytical data for previously published K-Ar ages of igneous rocks from the Raton-Springer area, New Mexico*

[All ages recalculated using new decay constants shown in table 1. n.d., no data given in original reference]

Rock Name	Locality	Material dated	K_2O (percent)	^{40}Ar (percent)	Age (m.y.)	Reference
Raton Basalt ---	Bartlett Mesa; 36°51'32" N., 104°24'55" W.	Whole rock	.89	43	3.59±0.2	Stormer (1972a, sample 855-293).
	Urraca Mesa, 36°24'15" N., 104°59'18" W.	Whole rock	1.850	56.48	4.4 ±0.1	Hussey (1971, sample M-FRL1388).
Basanite -------	Johnson Mesa, lowest flow; NW¼ sec. 10, T. 31 N., R. 25 E.	Plagioclase	1.95	64	[1] 7.38±0.3	Stormer (1972a, sample 855-117).
Red Mountain Rhyodacite.	SW¼SW¼ sec. 3, T. 27 N., R. 26 E.	Hornblende	n.d.	n.d.	7.7 ±0.5	Staatz (1986).
	NW¼NE¼ sec. 18, T. 27 N., R. 26 E.	Hornblende	n.d.	n.d.	8.1 ±0.6	Staatz (1985).
	Cunningham Butte, sec. 31, T. 30 N., R. 24 E.	Hornblende	.55	23	[2] 8.4 ±0.8	Stormer (1972a, sample 855-277).
Trachyte SW. of Laughlin Peak.	SE¼SW¼ sec. 6, T. 27 N., R. 26 E.	Hornblende	n.d.	n.d.	32.3 ±1.5	Staatz (1985).
Rhyodacite west of Cimarron.	Palisades in Cimarron Canyon; 36°32'15" N., 105°9'30" W.	Biotite[3] --	3.386 3.361	60	[4] 34.6	Armstrong (1969, sample 733).
Slagle Trachyte	SE¼NE¼ sec. 2, T. 27 N., R. 25 E.	Hornblende	n.d.	n.d.	36.7 ±1.3	Staatz (1985).

[1]See table 1, sample 9, in this report for K-Ar age of another sample of this rock.
[2]See table 1, sample 11, in this report for K-Ar age of another sample of this rock.
[3]Includes 25 percent chlorite and 20 percent rock.
[4]See table 2, sample 19, in this report for zircon fission-track age of another sample of this rock.


104°30′
104°00′
37°00′
36°30′
COLORADO
NEW MEXICO
BARTLETT MESA
BARELA MESA
Manco Burro Pass
JOHNSON MESA
Trinchera Creek
Raton
HUNTER MESA
JUAN TORRES MESA
(lower)
(upper)
BLACK MESA
Gringo Peak
Cinder Butte
DWYER MESA
GREEN MOUNTAIN
MESA LARGA
BLOSSER MESA
TINAJA MESA
EAGLE TAIL MESA
Eagle Rock dike
Horseshoe Crater
LAUGHLIN PEAK
TINAJA MOUNTAIN
Dike swarm (Tla)
PALO BLANCO MOUNTAIN
COLFAX COUNTY
UNION COUNTY
T 32 N
T 31 N
T 30 N
T 29 N
T 28 N
T 27 N
T 26 N
T 25 N
R 23 E
R 24 E
R 25 E
R 26 E
R 27 E
R 28 E
0
5
10 MILES
0
5
10
15 KILOMETERS

EXPLANATION

Symbol	Unit	Age
Qb	Capulin Basalt	Holocene
QTb	Clayton Basalt	Pleistocene
Tb	Raton Basalt	Pliocene
Tba	Mafic feldspathoidal rocks	Miocene
Trm	Red Mountain Rhyodacite	Miocene
Tl	Lahar (related to Red Mountain Rhyodacite)	Miocene
Tta	Trachyandesite of middle Pine Butte	Miocene
Tla	Mafic and ultramafic dikes and sills (Tertiary)	Miocene and Oligocene
Ta	Ankaratrite	Miocene and Oligocene
Td	Diatreme	Miocene and Oligocene
	Chico sill complex:	
Tp	Chico Phonolite	Miocene and Oligocene
Ts	Nepheline syenite dike on Point of Rocks Mesa	Miocene and Oligocene
Tte	Tephrite	Oligocene
Tpt	Phonotephrite	Oligocene
Tv	Vent rocks at Turkey Mountain	Oligocene
Ttr	Trachyte southwest of Laughlin Peak	Oligocene
Tsl	Slagle Trachyte	Oligocene

•14 Sample locality of radiometrically dated rock listed in table 1

FIGURE 6 (above and facing page).—Generalized geologic map of the Raton-Springer area showing only volcanic, subvolcanic, and volcaniclastic rocks. Figure shows sample localities 1–18 of radiometrically dated rocks listed in tables 1 and 2; locality 19 is shown on figure 1*A*. For a geologic map of the rocks discussed in this report that lie south of the area shown here, in the Springer 30′×60′ quadrangle, see Scott (1986).

evolution and position of a rock series in the orogenic cycle (see for example Batchelor and Bowden, 1985). Here it will be used mainly to provide a consistent nomenclature and to show relations between the rock types of the area.

In the diagram, the diagonal line extending upward to the right corresponds to the "critical plane of silica undersaturation" of the Cpx-Ol-Ne-Qz tetrahedron of Yoder and Tilley (1962, p. 350). Generally, the rocks that plot above and to the left of this diagonal may be regarded as undersaturated in silica. It is worth noting here that the calculations of R_1R_2 are not affected by posteruption changes in the ferrous-ferric ratio, which in the calculation of the CIPW norm can force the appearance of spurious amounts of normative quartz and in some cases imply silica saturation for an originally undersaturated magmatic rock. Thus, a few rocks showing low values of quartz in the norm will actually seem to be undersaturated from their plotted positions on the R_1R_2 diagram.

On figure 7*B* the R_1 and R_2 values of all the samples of the various rock units in the Raton-Springer area are plotted on the diagram of La Roche and others (1980), and the fields covered by the various mapped rock types are outlined.

CHICO SILL COMPLEX

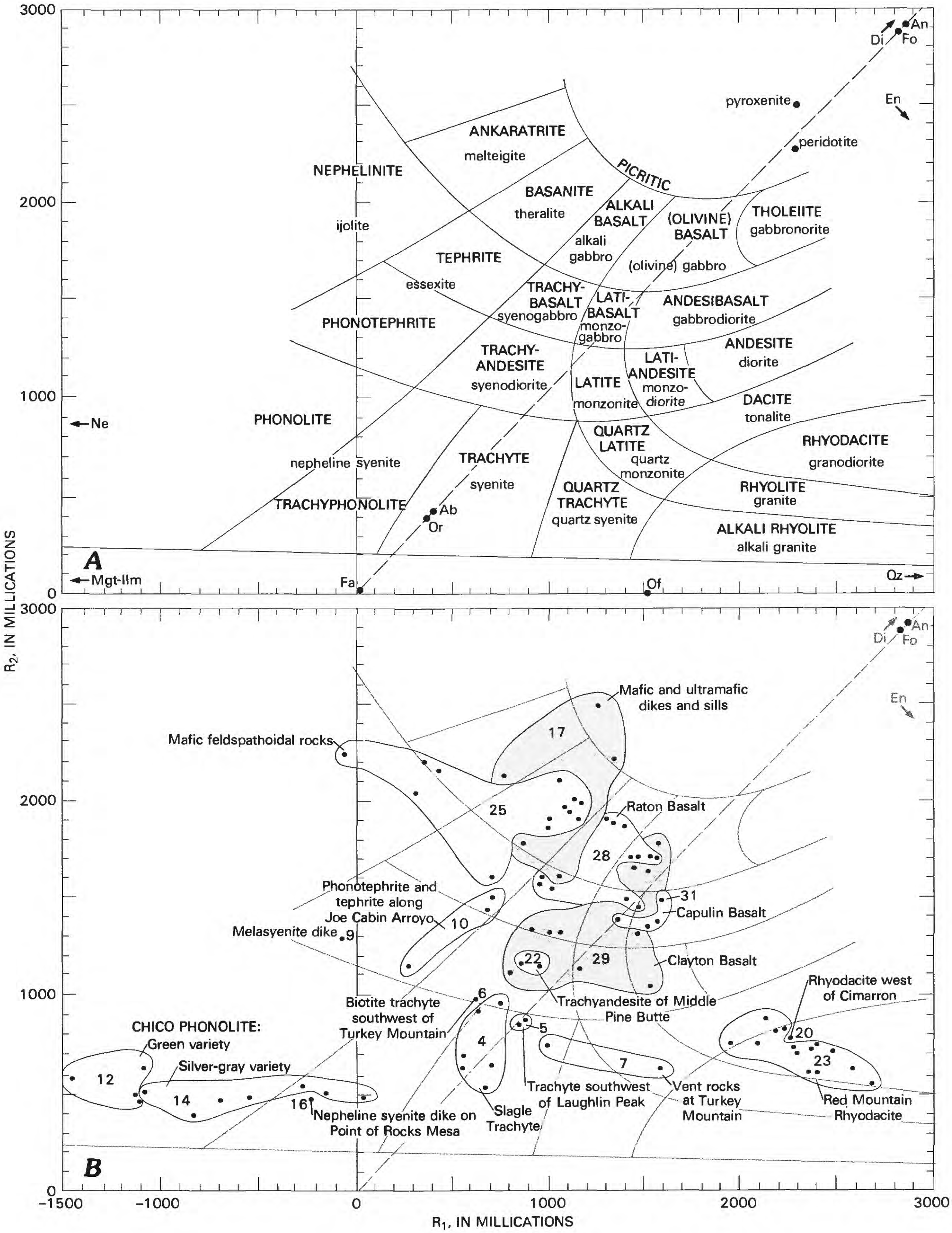
The Chico sill complex occupies a broad domal area, about 16 mi (26 km) in diameter in the southeastern part of the Raton-Springer area, where the Cretaceous rocks have been arched upward by the intrusion of many nearly flat, nearly tabular, sill-like bodies of alkalic rock. We infer that the sills were intruded between 37 and 20 m.y. ago from dikes or from pipelike feeders such as those on Turkey Mountain.

The Chico sill complex contains two principal rock types, the Slagle Trachyte and the Chico Phonolite. The phonolite is of two major types, a green variety and a silver-gray variety, which intergrade. Minor rock types within the Chico sill complex include tephrite, phonotephrite, and syenite. Most of these minor units are sill-like; however, most of the syenitic units form dikes rather than sills. The two vents on Turkey Mountain, containing syenite and biotite quartz monzonite, probably are plugs that formed late during intrusion of the sill complex and appear to be related chemically to the hornblende trachyte of the Slagle; however, they are not contemporaneous with the Slagle. Thin border zones of epidotized breccia cemented by iron oxide characterize both of the vents.

In the area of the sill complex, the igneous material probably makes up only about one-fourth of the thickness of the rocks in hillsides, the remainder being sedimentary rock, primarily Greenhorn Limestone down through Dakota Sandstone of Late Cretaceous age. However, in the Chico Hills and in the western part of the Piñon Hills, the igneous rock makes up the greater part of the hillsides (M.H. Staatz, written commun., 1984).

Only one possible feeder has been found in the Chico sill complex, that on Turkey Mountain, which includes a vent of syenite and a vent of quartz monzonite. The syenite vent rock occurs at the high point on Turkey Mountain.

Collins (1949, p. 1034) suggested that one source vent of the Chico Phonolite possibly was in the steep-walled valley just east of Temple Peak, an area he called the "J.T. Rincon." The rincon is a deeply eroded structural dome, and Collins surmised that the vent for the Chico Phonolite is concealed beneath a younger (Clayton) basalt flow on the valley floor. That proposal now seems doubtful, because the rincon is floored by readily erodible Triassic sedimentary rock, and no vestige of a vent facies


A
B
ANKARATRITE
melteigite
NEPHELINITE
ijolite
PICRITIC
BASANITE
theralite
ALKALI BASALT
alkali gabbro
(OLIVINE) BASALT
(olivine) gabbro
THOLEIITE
gabbronorite
TEPHRITE
essexite
PHONOTEPHRITE
TRACHY-BASALT
syenogabbro
LATI-BASALT
monzo-gabbro
ANDESIBASALT
gabbrodiorite
TRACHY-ANDESITE
syenodiorite
LATITE
monzonite
LATI-ANDESITE
monzo-diorite
ANDESITE
diorite
DACITE
tonalite
PHONOLITE
nepheline syenite
TRACHYTE
syenite
QUARTZ LATITE
quartz monzonite
RHYODACITE
granodiorite
TRACHYPHONOLITE
QUARTZ TRACHYTE
quartz syenite
RHYOLITE
granite
ALKALI RHYOLITE
alkali granite
pyroxenite
peridotite
Ne
Mgt-Ilm
Fa
Of
Qz
Ab
Or
An
Di
Fo
En
Mafic and ultramafic dikes and sills
Mafic feldspathoidal rocks
Raton Basalt
Phonotephrite and tephrite along Joe Cabin Arroyo
Melasyenite dike
Capulin Basalt
Clayton Basalt
Trachyandesite of Middle Pine Butte
Rhyodacite west of Cimarron
Biotite trachyte southwest of Turkey Mountain
CHICO PHONOLITE:
Green variety
Silver-gray variety
Nepheline syenite dike on Point of Rocks Mesa
Slagle Trachyte
Trachyte southwest of Laughlin Peak
Vent rocks at Turkey Mountain
Red Mountain Rhyodacite
4
5
6
7
9
10
12
14
16
17
20
22
23
25
28
29
31
3000
2000
1000
0
-1500
-1000
0
1000
2000
3000
R2, IN MILLICATIONS
R1, IN MILLICATIONS

was found there. The J.T. Rincon dome more likely is a result of uplift by a subsurface igneous intrusion. A more likely source of the phonolite is near Trujillo Mesa, which is underlain by the highest phonolite sill in the area. Phonolite is most abundant in the southeastern part of the sill complex, but it also occurs at and southeast of Tinaja Mountain, near Tres Hermanos Peak, and near Laughlin Peak; these outcrops also could have been small intrusive centers for the phonolite.

The distribution of the Slagle Trachyte is limited to the area around Turkey Mountain, extending to Blosser Arroyo 7 mi (11 km) to the northwest, nearly to Shoemaker Hill 5 mi (8 km) to the west, just beyond Raspberry Mountain 2 mi (3.2 km) to the east, and to Chico Creek 6½ mi (10.4 km) to the south.

SLAGLE TRACHYTE

The Slagle Trachyte was named by Collins (1949, p. 1033) for outcrops of what he called soda trachyte on the east side of Slagel Canyon of Rio del Plano, 1 mi (1.6 km) north of the Maxwell-Chico road (Tres Hermanos Peak quadrangle). However, the only trachyte 1 mi north of the road is on the west side of the canyon; though not originally designated, we assume that is Collins' type locality. The type area of the Slagle is herein considered to be exposures on the west side of Slagel Canyon in SW¼ sec. 34, T. 27 N., R. 25 E., Colfax County, N. Mex. All outcrops of the Slagle Trachyte are within the area of the Chico sill complex, where it occurs as numerous sills interlayered with the sedimentary rocks, but also as dikes. The trachyte is a light-olive-gray, hard, porphyritic rock having numerous prominent hornblende phenocrysts set in a gray finely crystalline groundmass. The rock weathers pervasively, and unweathered outcrops are few. Weathered trachyte is pale orange, dark yellowish gray, or brown; black hornblende crystals, which are as large as 8 mm, gradually alter to pale-brown iron oxide. Where little weathered, the hornblende crystals reflect the sunlight brilliantly, and the groundmass has a slight silvery sheen similar to that of the silver-gray phonolite. Flow structure is well displayed by the hornblende crystals in dikes and sills.

The K-Ar age of a sample of Slagle Trachyte was reported by Staatz (1985, p. E12) as 36.7±1.3 m.y. The sample was from the SE¼NE¼ sec. 2, T. 27 N., R. 25 E., Colfax County, N. Mex.

All specimens of the trachyte are generally similar, though in some the hornblende or pyroxene phenocrysts are replaced by carbonate, quartz, and pyrite, and in others the hornblende and pyroxene occur in glomeroporphyritic groups. Xenocrysts of quartz are found locally.

In thin section, trachyte specimen 81SM18 (table 4, analysis 4) is porphyritic, bostonitic in texture, and contains the following: about 7 percent corroded green hornblende phenocrysts as much as 3 mm long, optic angle about (–)40°, zoned with Z:c 13°–16°, rimmed with opaque oxide; 6 percent plagioclase (andesine?) phenocrysts as large as 3 mm; 1 percent corroded clinopyroxene phenocrysts as large as 1 mm, optic angle about (+)70°; and 1 percent opaque oxide crystals as much as 0.4 mm long. Groundmass is dominantly dusty alkali feldspar but contains scattered altered plagioclase, many small opaque oxide crystals, and traces of apatite, titanite, and brown pyroxene(?). Scattered xenoliths of altered schists and other metamorphic rock were observed.

The trachyte specimen 81SM5 (table 4, analysis 2) is porphyritic and contains about 6 percent olive green hornblende phenocrysts; 4 percent stubby clinopyroxene phenocrysts as large as 1 mm, some in clumps with hornblende, opaque oxide, and, rarely, dark mica; scattered equant opaque oxide crystals as large as 0.1 mm; and sparse phenocrysts of dark mica as large as 0.4 mm. Groundmass is subtrachytic in texture and consists predominantly of dusty alkali feldspar, many tiny clinopyroxene crystals, opaque oxide grains, and apatite.

Chemical analyses of the Slagle Trachyte (table 4) show that SiO_2 ranges from 56.6 to 62.6 percent; all the R_1R_2 plotted points fall within or on the edge of the trachyte field in figure 7*B*. Note that although quartz appears in the norm of analysis 5, the R_2 parameter is slightly greater than R_1, and therefore the sample plots as unsaturated in SiO_2 on figure 7*B*.

TRACHYTE SOUTHWEST OF LAUGHLIN PEAK

This medium-gray, dense, hard porphyritic rock forms sills southwest of Laughlin Peak interlayered with sills of the Slagle Trachyte and with Cretaceous sedimentary

FIGURE 7 (facing page).—Classification of principal volcanic and subvolcanic rocks of the Raton-Springer area, New Mexico, according to the system of La Roche and others (1980).

A, The R_1R_2 diagram of La Roche and others, showing names of volcanic rocks in upper case and names of plutonic rocks in lower case italics. R_1 and R_2 are defined as follows:

$$R_1 = 4Si - 11(Na+K) - 2(Fe+Ti) \qquad R_2 = 6Ca + 2Mg + Al$$

where amounts of the elements are expressed as "millications" (thousandths of a cation percent). Oblique dashed line represents the "critical plane of silica undersaturation" of Yoder and Tilley (1962, p. 350). Mineral plotted positions: Ab, albite; An, anorthite; Di, diopside; En, enstatite; Fa, fayalite; Fo, forsterite; He, hedenbergite; Mgt-Ilm, magnetite-ilmenite; Ne, nepheline; Of, orthoferrosilite; Or, orthoclase; Qz, quartz.

B, Analyzed samples from the Raton-Springer area plotted on the R_1R_2 diagram. Each group of samples is identified by name and by the number of the table that lists analytical data for the group.

TABLE 4.—*Chemical analyses and norms of Slagle Trachyte samples from Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample --	1	2	3	4	5	6
Field No.	81SM19	81SM5	80SM17	81SM18	MHS-35-80	MHS-36-80
Lab No.--	D242009	D237459	D229697	D242008	D229964	D229965
			Major oxides			
SiO_2 ----	56.6	57.0	59.2	60.7	61.5	62.6
Al_2O_3 ---	16.5	17.2	17.8	18.6	18.1	18.3
Fe_2O_3 ---	3.91	3.43	1.34	3.12	3.25	3.18
FeO -----	1.40	2.74	2.11	0.99	0.73	0.35
MgO -----	1.56	2.05	0.85	0.73	0.66	0.3
CaO -----	4.73	4.62	2.52	2.17	1.97	1.21
Na_2O ----	5.84	5.25	7.0	5.95	7.10	6.5
K_2O -----	3.92	4.24	3.41	4.73	3.78	4.65
H_2O+ ----	n.d.	n.d.	n.d.	n.d.	0.98	1.14
H_2O- ----	n.d.	n.d.	n.d.	n.d.	0.20	0.13
Volatiles[1]	3.69	1.32	2.47	1.34	n.d.	n.d.
TiO_2 ----	0.66	0.79	0.42	0.46	0.46	0.36
P_2O_5 ----	0.35	0.37	0.2	0.25	0.2	0.2
MnO -----	0.14	0.16	0.13	0.14	0.15	0.11
CO_2 -----	n.d.	n.d.	n.d.	n.d.	1.14	0.60
Total	99.3	99.2	97.5	99.2	100.2	99.6
			La Roche and others (1980) classification			
R_1 ------	630	765	572	711	585	684
R_2 ------	908	941	678	634	605	509
Name ----	Trachyte/ trachyandesite/ trachyphonolite.	Trachy-andesite/ trachyte.	Trachyte	Trachyte	Trachyte	Trachyte
			Normative composition			
q -------	0.00	0.00	0.00	3.02	4.25	6.26
or ------	24.22	25.60	21.21	28.56	22.55	27.93
ab ------	49.78	45.39	62.08	51.45	60.65	55.91
an ------	7.56	11.08	7.45	9.33	1.27	0.92
c -------	0.00	0.00	0.00	0.35	1.88	2.28
ne ------	1.03	0.00	0.15	0.00	0.00	0.00
wol -----	1.39	0.00	0.00	0.00	0.00	0.00
di-wo ---	4.70	4.12	1.81	0.00	0.00	0.00
di-en ---	4.06	3.02	0.85	0.00	0.00	0.00
di-fs ---	0.00	0.71	0.93	0.00	0.00	0.00
hy-en ---	0.00	1.81	0.00	1.86	1.66	0.76
hy-fs ---	0.00	0.42	0.00	0.00	0.00	0.00
ol-fo ---	0.00	0.27	0.96	0.00	0.00	0.00
ol-fa ---	0.00	0.07	1.16	0.00	0.00	0.00
mt ------	3.20	5.08	2.05	2.37	1.52	0.45
hm ------	1.88	0.00	0.00	1.56	2.23	2.92
il ------	1.31	1.53	0.84	0.89	0.88	0.70
ap ------	0.87	0.90	0.50	0.61	0.48	0.48
cc ------	0.00	0.00	0.00	0.00	2.62	1.39

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Slagle Trachyte from type(?) locality in the NE¼SW¼ sec. 34, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle.
2. Slagle Trachyte in the NW¼SE¼NW¼ sec. 22, T. 26 N., R. 25 E., Tinaja Mountain quadrangle.
3. Slagle Trachyte from quarry in the NE¼ sec. 1, T. 27 N., R. 24 E., Tres Hermanos Peak quadrangle.
4. Slagle Trachyte from hillslope in the NW¼NE¼ sec. 28, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle.
5. Slagle Trachyte from southwest end of sill, just north of Jimmy Spring Canyon in the NE¼ sec. 36, T. 28 N., R. 25 E., Pine Buttes quadrangle (M.H. Staatz, 1985).
6. Slagle Trachyte from north end of dike adjacent to large sill just south of county road A-8 in the SW¼ sec. 36, T. 28 N., R. 25 E., Pine Buttes quadrangle (M.H. Staatz, 1985).

rocks. According to M.H. Staatz (written commun., 1982), phenocrysts range in size from 0.5 to 2 mm and are set in an aphanitic groundmass. Phenocrysts include greenish-brown euhedral to subhedral crystals of hornblende, which commonly are zoned; anhedral to subhedral crystals of clinopyroxene; some poorly twinned, zoned, euhedral sodic plagioclase, having extinction angles X:(010) no greater than 20°; black anhedral to subhedral magnetite grains; and traces of apatite and titanite. The groundmass is composed of a mat of elongate alkali feldspar crystals, a light-brown aphanitic, partially devitrified glass, and magnetite and other opaque oxides. Staining by sodium cobaltinitrite shows that the groundmass contains a moderate amount of potassium. Vugs contain well-formed crystals of smoky quartz and calcite. The vugs also contain bitumen, and bitumen forms inclusions in the quartz crystals. The chemical analyses and norms for the trachyte and trachyandesite southwest of Laughlin Peak are shown on table 5.

The K-Ar age of the rock of analysis 1 on table 5 was reported by Staatz (1985, p. E14) as 32.3±1.5 m.y. The sample came from the SE¼SW¼ sec. 6, T. 27 N., R. 26 E., Colfax County, N. Mex.

The samples (table 5) have a low content of normative quartz, only about 3.5 percent. Their high potassium content results in 21–26 percent orthoclase in the norm (Staatz, 1985).

TABLE 5.—*Chemical analyses and norms of trachyte southwest of Laughlin Peak, Raton-Springer area, New Mexico*

[Data in weight percent]

Sample --	1	2
Field No.	MHS-133-80	MHS-134-80
Lab No.	D230348	D230349
Major oxides		
SiO_2 ---	57.6	55.0
Al_2O_3 --	18.6	16.1
Fe_2O_3 --	4.53	5.49
FeO ----	1.44	2.89
MgO ----	1.5	2.8
CaO ----	3.39	3.68
Na_2O ---	5.6	4.4
K_2O ----	3.56	4.20
Vols.[1]--	1.72	2.94
TiO_2 ---	0.80	1.02
P_2O_5 ---	0.5	0.55
MnO ----	0.12	0.16
Total	99.4	99.2

	1	2
	MHS-133-80	MHS-134-80
	D230348	D230349
La Roche classification		
R_1 --	857	898
R_2 --	820	878
Name	Trachyte	Trachyte
Normative composition		
q ---	3.39	3.58
or --	21.54	25.77
ab --	48.52	38.65
an --	13.87	12.23
c ---	0.58	0.00
di-wo	0.00	1.25
di-en	0.00	1.08
hy-en	3.82	6.16
mt --	2.78	7.14
hm --	2.72	0.77
il --	1.56	2.01
ap --	1.21	1.35

[1]Volatiles, probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Trachyte from small knoll, 230 m northeast of county road A-8 in the SE¼SW¼ sec. 6, T. 27 N., R. 26 E., Pine Buttes quadrangle (M.H. Staatz, 1985).
2. Trachyte from low hill, 380 m north of county road A-8 in the SW¼SE¼ sec. 6, T. 27 N., R. 26 E., Pine Buttes quadrangle (M.H. Staatz, 1985).

BIOTITE TRACHYTE SOUTHWEST OF TURKEY MOUNTAIN

Biotite trachyte dikes crop out 1½–2 mi (2.4–3.2 km) west of Slagel Canyon in secs. 29, 32, and 33, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle. The best preserved dikes are in the SW¼ sec. 29 and in the SE¼ sec. 32. At the latter locality the dikes make a prominent outcrop with large rounded knobs. The rock is light olive gray, yellowish-gray, pink, or red and generally is so dense that it does not readily weather. In thin section (specimen 81SM42, table 6) the texture is porphyritic intersertal. The rock contains about 5 percent stubby clinopyroxene phenocrysts as large as 2 mm, $(+)2V\,60°$, that are replaced by carbonate and quartz; 4 percent biotite phenocrysts as large as 1 mm, commonly in groups with the clinopyroxene; 2 percent poorly formed opaque oxides as large as 0.3 mm; and scattered apatite crystals as long as 0.3 mm. The groundmass contains kaolinized alkali feldspar laths as large as 0.2 mm, biotite as large as 0.3 mm, opaque oxides, and carbonate that permeates the interstices between feldspar crystals.

A similar rock, called a hornblende biotite trachyte, occurs nearby in sills intruded into the Greenhorn Limestone and Carlile Shale. This trachyte is light olive gray and porphyritic, has an aphanitic groundmass, and contains hornblende, biotite, and clinopyroxene phenocrysts. These two trachytic rocks appear to be nearly contemporaneous. The chemical analysis and norm for the biotite trachyte are shown on table 6. This rock lacks quartz in the norm, but otherwise is chemically quite similar to the trachyte southwest of Laughlin Peak and to the Slagle Trachyte. However, hand specimens show little resemblance to these rocks.

A generally nonporphyritic, dark-yellowish-gray to pale-yellowish-brown trachyte crops out as vertical dikes, a few feet thick, in sec. 33, T. 27 N., R. 25 E., and in sec. 4, T. 26 N., R. 25 E. The rock has a trachytic texture and is finely crystalline to aphanitic. At its north end one dike contains platy phenocrysts as large as 1 inch (2.5 cm), apparently of feldspar, parallel to its walls.

TABLE 6.—*Chemical analysis and norm of biotite trachyte dike southwest of Turkey Mountain, Raton-Springer area, New Mexico*

[Data in weight percent]

Field No.	81SM42	La Roche classification	
Lab No.	D242014		
Major oxides		R_1	639
		R_2	960
		Name	Trachyte
SiO_2	53.4	**Normative composition**	
Al_2O_3	16.7		
Fe_2O_3	3.88	or	22.51
FeO	3.37	ab	43.96
MgO	3.08	an	11.88
CaO	4.47	ne	1.39
Na_2O	5.24	di-wo	3.41
K_2O	3.63	di-en	2.47
Volatiles[1]	3.99	di-fs	0.63
TiO_2	0.84	ol-fo	3.91
P_2O_5	0.47	ol-fa	1.10
MnO	0.19	mt	5.90
		il	1.67
Total	99.3	ap	1.17

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITY

Biotite trachyte from dike in NE¼SE¼ sec. 32, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle.

SYENITE AND QUARTZ MONZONITE VENT ROCKS AT TURKEY MOUNTAIN

In the summit area of Turkey Mountain in the SW¼ sec. 11, T. 27 N., R. 25 E., are several outcrops of rocks similar to the Slagle Trachyte in composition but coarser grained. Originally these were thought to be feeders of the sills of the Slagle Trachyte, but they are now known to be much younger. Two outcrops at the main summit of Turkey Mountain are syenite, and another outcrop on a subsummit about 1,200 ft (366 m) to the southwest is quartz monzonite. The syenite forms prominent outcrops confined to the area atop Turkey Mountain. The rock is gray, nearly equigranular, and shows no obvious flow structure or alignment of hornblende crystals.

The age of the syenite at the summit of Turkey Mountain (locality 18 on figure 6) was determined as 29.0±1.6 m.y. by Mutsumi Miyachi using the fission-track method on zircon (table 2, no. 18).

In thin section the syenite (specimen 81SM9, tables 7 and 8) has an intergranular texture and is composed of the following: about 80 percent compound feldspar crystals as large as 1.5 mm, consisting of oligoclase-andesine cores and strongly kaolinized alkali feldspar overgrowths; 4 percent interstitial quartz as large as 0.2 mm; 6 percent pale-green clinopyroxene as large as 1 mm; 4 percent opaque oxide crystals as large as 0.2 mm; 3 percent apatite crystals as much as 0.3 mm length; and 2 percent titanite crystals as large as 0.4 mm.

The quartz monzonite forms knobby outcrops typical of granitoid rocks. It is light brownish gray to pinkish gray. In thin section (specimen 81SM26, tables 7 and 8) it is porphyritic and composed of composite feldspar phenocrysts as large as 1.5 mm, consisting of slightly saussuritized albite-oligoclase cores (about 30 volume percent) zoned to kaolinized alkali feldspar rims (about 10 percent). The groundmass interstitial to the dominant feldspar crystals consists of about 20 percent quartz, as large as 0.2 mm, containing inclusions of euhedral feldspars; 25 percent strongly kaolinized alkali feldspar; 10 percent albite; 2 percent biotite; 3 percent titanite; traces of apatite; amphibole(?) as thin pale-green needles; and equant crystals of a clear, colorless unknown mineral of moderate birefringence and high relief.

Chemical analyses of the syenite and quartz monzonite (tables 7 and 8) show SiO_2 contents of 61.8 and 66.1 percent, respectively, which are significantly greater than those of the normal Slagle Trachyte (table 4). Their plotted positions on the R_1R_2 diagram of figure 7*B* are well into the SiO_2-saturated zone but are considered to be within an extension of the Slagle Trachyte field. They probably are genetically related to the Slagle Trachyte. Judging from the relatively small amounts of elements barium and titanium, a crustal source rather than a mantle source is preferred for the vent rocks.

MELASYENITE DIKE

Fine-grained melasyenite crops out as a prominent dike in the NE. corner of the SE¼ sec. 4, T. 26 N., R. 27 E., Palo Blanco Mountain quadrangle. The dike is medium gray and contains prominent amphibole crystals and segregations of amphibole and a serpentine-like mineral. In thin section (specimen 80SM26) the texture is seriate, and the relative mineral composition is as follows: 30 percent amphibole crystals as large as 1 mm, which exhibit olive-brown to pale-yellowish-brown pleochroism (extinction angle $Z{:}c$ about 18°, (–)2V 80°); 25 percent labradorite plates as large as 0.6 mm; 15 percent stubby pale-green crystals of clinopyroxene as large as 0.1 mm ((+)2V 60°); 15 percent white alkali feldspar that is interstitial and rich in inclusions; 6 percent clear interstitial analcime(?) or sodalite(?) that is isotropic and has negative relief; 5 percent a dusty interstitial mineral that has very low birefringence and negative relief (zeolite?); and 3 percent opaque oxide crystals as much as 0.03 mm. The chemical analysis and norm for the melasyenite are shown on table 9.

TABLE 7.—*Chemical analyses and norms of syenite and quartz monzonite vent rocks at Turkey Mountain, Raton-Springer area, New Mexico*

[Data in weight percent]

Sample --	1	2
Field No.	81SM9	81SM26
Lab No.	D237461	D242012
Major oxides		
SiO_2 ---	61.8	66.1
Al_2O_3 --	17.1	17.1
Fe_2O_3 --	3.03	1.89
FeO ----	1.44	0.81
MgO ----	0.93	0.53
CaO ----	3.02	2.19
Na_2O ---	5.37	4.64
K_2O ----	4.62	4.61
Vols.[1]--	1.11	0.72
TiO_2 ---	0.56	0.33
P_2O_5 ---	0.25	0.11
MnO ----	0.13	0.08
Total	99.4	99.1

Sample	1	2
Field No.	81SM9	81SM26
Lab No.	D237461	D242012
La Roche classification		
R_1 --	1006	1603
R_2 --	709	596
Name	Syenite	Quartz monzonite
Normative composition		
q ---	6.81	16.56
or --	27.78	27.69
ab --	46.24	39.90
an --	9.07	10.31
c ---	0.00	0.77
di-wo	1.89	0.00
di-en	1.63	0.00
hy-en	0.73	1.34
mt --	3.50	1.95
hm --	0.67	0.58
il --	1.08	0.64
ap --	0.60	0.26

[1]Volatiles, probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Syenite vent rock from crest of Turkey Mountain, altitude 7,888 ft (2,404 m) in center of SW¼ sec. 11, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle.
2. Quartz monzonite plug on southwestern spurs of west peak of Turkey Mountain in the SW¼ sec. 11, T. 27 N., R. 25 E., Tres Hermanos Peak quadrangle.

TABLE 8.—*Neutron-activation analysis of syenite and quartz monzonite vent rocks at Turkey Mountain, Raton-Springer area, New Mexico*

[Elemental compositions in parts per million. See table 7 for description of sample localities. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Sample -----	1		2	
Field No.---	81SM9		81SM26	
Lab. No.----	925109		925111	
Na	42,200	±500	36,800	±400
Mg	6,000	±1,000	<3,000	
Al	96,000	±2,000	90,000	±2,000
Cl	<200		150	±40
K	34,000	±3,000	37,000	±2,000
Ca	23,000	±2,000	15,000	±2,000
Ti	2,800	±300	2,400	±200
V	80	±6	32	±3
Mn	1,110	±10	843	±8
Cu	<400		<400	
Sr	1,400	±200	1,200	±100
I	<20		<20	
Ba	1,520	±100	1,470	±70
Dy	4.2	±0.4	3.3	±0.3
U	5.53	±0.03	3.95	±0.02
Ga	<100		<100	
As	<4		<3	
Br	<3		<3	
Sb	<0.5		<0.5	
La	72.7	±0.9	56.4	±0.7
Sm	8.6	±0.4	5.3	±0.2
W	<6		<5	
Au	<0.02		<0.01	
Sc	5.4	±0.1	3.07	±0.06
Cr	18	±2	6.0	±0.9
Fe	35,000	±1,000	21,300	±600
Co	8.1	±0.3	3.3	±0.2
Zn	130	±20	47	±8
Se	4.5	±0.5	4.5	±0.5
Rb	152	±8	139	±8
Cs	1.5	±0.2	2.1	±0.2
Ce	127	±4	93	±4
Eu	2.0	±0.1	1.22	±0.07
Tb	0.64	±0.08	0.59	±0.08
Yb	3.4	±0.2	2.7	±0.2
Lu	0.39	±0.04	0.34	±0.04
Hf	8.8	±0.8	6.2	±0.6
Ta	3.0	±0.3	1.9	±0.2
Th	27	±1	18.3	±0.8

PHONOTEPHRITE AND TEPHRITE ALONG JOE CABIN ARROYO

Phonotephrite and tephrite crop out as a nearly flat sheet in a 2 mi^2 (5 km^2) area along Joe Cabin Arroyo in secs. 28–33, T. 27 N., R. 26 E., Pine Buttes quadrangle. It is visibly inhomogeneous and apparently intruded Cretaceous sedimentary rocks. It is younger than the Slagle Trachyte and older than the Chico Phonolite. (See below.) In hand specimen the rocks are medium dark gray and somewhat similar to the Slagle Trachyte. However, they are very resistant to weathering, except for the formation of a 1-mm-thick brown rind, and form prominent outcrops.

In thin section, a tephrite from an outcrop in SW¼SW¼ sec. 28, T. 27 N., R. 26 E., on the east side of Joe Cabin Arroyo (specimen 81SM23–2, table 10, analysis 2; table 11), has a complex seriate texture and is composed of the following· about 60 percent plagioclase, strongly zoned from labradorite to oligoclase, in laths as

TABLE 9.—*Chemical analysis and norm of melasyenite dike near Alamo Creek, Raton-Springer area, New Mexico*

[Data in weight percent]

Field No.---	80SM26
Lab No.-----	D231891
Major oxides	
SiO_2 -------	47.2
Al_2O_3 ------	19.1
Fe_2O_3 ------	3.73
FeO --------	3.61
MgO --------	2.98
CaO --------	7.15
Na_2O -------	6.14
K_2O --------	3.38
Volatiles[1]--	3.92
TiO_2 -------	1.01
P_2O_5 -------	0.85
MnO --------	0.18
Total	99.3

La Roche classification	
R_1 --------	(-)42
R_2 --------	1,290
Name ------	Melasyenite
Normative composition	
or --------	20.94
ab --------	19.15
an --------	15.28
ne --------	19.14
di-wo -----	6.72
di-en -----	4.73
di-fs -----	1.41
ol-fo -----	2.14
ol-fa -----	0.70
mt --------	5.67
il --------	2.01
ap --------	2.11

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITY

Melasyenite dike in the NE corner SE¼ sec. 4, T. 26 N., R. 27 E., Palo Blanco Mountain quadrangle.

large as 2.5 mm; 20 percent stubby, pale-green pyroxene crystals as large as 1.2 mm, some in clots; 15 percent skeletal dark mica crystals as large as 1.5 mm, which show strong brownish-yellow pleochroism and have a skeletal structure so marked that in some sections the mica crystals appear as beads or poikilitic inclusions in the feldspar; 5 percent irregularly distributed opaque oxide crystals as large as 0.05 mm; and traces of dusty prisms of apatite (or eudialyte?) as large as 0.5 mm having pronounced basal cleavage or parting. Rare rounded xenocrysts of grass-green clinopyroxene are present.

Another specimen (81SM23–1), from the SW¼SW¼ sec. 28, T. 27 N., R. 26 E., has a porphyritic, subtrachytic texture and contains about 10 percent olive-green hornblende phenocrysts as long as 1.5 mm; 5 percent nearly colorless to pale-green clinopyroxene phenocrysts as large as 1.5 mm; sparse plagioclase (andesine?) phenocrysts as large as 0.5 mm, some veined; and sparse opaque oxide crystals as large as 0.3 mm. Groundmass is mostly plagioclase but also contains clinopyroxene, biotite, and sparse apatite, containing interstitial analcime(?).

Tephrite (specimen MHS–22–82, table 10, analysis 3) occurs in a small area in the NE¼ sec. 32, T. 27 N.,

TABLE 10.—*Chemical analyses and norms of phonotephrite and tephrite in the Chico sill complex, Raton-Springer area, New Mexico*

[Data in weight percent]

Sample---	1	2	3
Field no.	MHS-86-81	81SM23-2	D243303
Lab no.--	D240837	D242010	MHS-22-82
Major oxides			
SiO_2 -----	48.9	50.9	51.1
Al_2O_3 ----	17.7	17.3	17.1
Fe_2O_3 ----	4.26	2.78	2.94
FeO ------	3.40	4.27	4.42
MgO ------	3.11	3.99	4.57
CaO ------	5.95	7.99	8.43
Na_2O -----	5.62	4.86	4.87
K_2O ------	3.13	3.17	3.09
Volatiles[1]	4.84	2.07	0.75
TiO_2 -----	1.22	1.10	1.16
P_2O_5 -----	0.64	0.56	0.58
MnO ------	0.18	0.17	0.17
Total	99.0	99.2	99.2
La Roche and others (1980) classification			
R_1 ------	302	711	730
R_2 ------	1,140	1,395	1,467
Name ----	Phono-tephrite.	Tephrite/ trachyandesite.	Tephrite
Normative composition			
or ------	19.65	19.29	18.54
ab ------	31.91	27.11	25.45
an ------	14.69	16.50	15.92
ne ------	10.08	8.25	8.89
di-wo ---	5.11	8.58	9.48
di-en ---	4.00	5.66	6.44
di-fs ---	0.54	2.30	2.31
ol-fo ---	2.96	3.20	3.59
ol-fa ---	0.44	1.44	1.42
mt ------	6.56	4.15	4.33
il ------	2.46	2.15	2.24
ap ------	1.61	1.37	1.40

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Phonotephrite northwest of Joe Cabin Arroyo in the NE¼SE¼ sec. 29, T. 27 N., R. 26 E., Pine Buttes quadrangle (M.H. Staatz, 1985).
2. Tephrite/trachyandesite from roadcut on east side of Joe Cabin Arroyo in SW¼SW¼ sec. 28, T. 27 N., R. 26 E., Pine Buttes quadrangle.
3. Tephrite in NW¼SE¼NE¼ sec. 32, T. 27 N., R. 26 E., Pine Buttes quadrangle (M.H. Staatz, 1985).

TABLE 11.—*Neutron-activation analysis of phonotephrite from Joe Cabin Arroyo, Raton-Springer area, New Mexico*

[Elemental compositions in parts per million. See table 10 for description of sample locality. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No.	81SM23-2		Sb	<0.5	
Lab. No.	925109		La	112	±1
			Sm	10.8	±0.3
Na	37,400	±400	W	<6	
Mg	25,000	±1,000	Au	<0.01	
Al	87,000	±2,000	Sc	13.9	±0.2
Cl	410	±90	Cr	99	±9
K	23,000	±2,000	Fe	58,000	±2,000
Ca	58,000	±3,000	Co	21.6	±0.8
Ti	7,500	±400	Zn	<9	
V	156	±6	Se	3.7	±0.5
Mn	1,400	±10	Rb	76	±7
Cu	<400		Cs	1.2	±0.2
Sr	900	±100	Ce	156	±5
I	<20		Eu	2.3	±0.1
Ba	1,470	±80	Tb	0.9	±0.1
Dy	5.0	±0.4	Yb	3.2	±0.2
U	4.68	±0.03	Lu	0.37	±0.04
Ga	<100		Hf	6.1	±0.5
As	<4		Ta	4.3	±0.4
Br	<3		Th	18.2	±0.7

R. 26 E. It is dark gray, very hard, and dense, and on weathering it forms only a thin grayish-orange rind. In thin section, according to M.H. Staatz (written commun., 1983), the rock has a porphyritic, subtrachytic texture and contains the following: pale-green zoned clinopyroxene phenocrysts as large as 0.8 mm showing bright-green interiors, the crystals commonly in groups; hornblende phenocrysts, now opacite pseudomorphs, as large as 0.7 mm; and a few plagioclase (labradorite) phenocrysts as large as 0.4 mm. The groundmass consists of plagioclase (zoned labradorite to oligoclase) in subparallel plates, abundant clinopyroxene crystals, poorly formed skeletal crystals of dark mica, alkali feldspar(?), and abundant tiny crystals of opaque oxide. Xenocrysts of quartz with coronas of green acmite-augite crystals are fairly common.

The tephrite is regarded by Staatz as most probably a separate sill or a flow. However, in view of the marked inhomogeneity of the main phonotephrite sill of the area and the similarity of chemical and mineralogical composition between the tephrite and the phonotephrite, we see no compelling reason to believe this tephrite to be a separate body.

CHICO PHONOLITE

The Chico Phonolite was named by Collins (1949, p. 1023) after exposures of this rock in the township of Chico, Colfax County, N. Mex. We consider the type area of the Chico to be in sec. 17, T. 26 N., R. 26 E., Colfax County, N. Mex.

Three related varieties of intrusive phonolite were recognized in the area—green phonolite, silver-gray phonolite, and an ocellar analcime phonolite—which together make up a large part of the Chico sill complex. Except for a few dikes and a remnant of a sill on Tinaja Mountain, the phonolites are confined to the main area of the complex. The green and silver-gray varieties seem to be parts of a gradational series ranging from green phonolite having almost no alkali feldspar but abundant acmite, to green phonolite having twinned and platy alkali feldspar phenocrysts and much acmite, to silver-gray phonolite having platy and twinned alkali feldspar phenocrysts and sparse acmite, to silver-gray phonolite having curved pearly alkali feldspar phenocrysts and very little acmite, and finally to nonporphyritic silver-gray phonolite. This gradation is also well shown chemically in the plotted fields on figure 7*B*. Rocks with the greatest amount of acmite are tinguaites. The green and silver-gray varieties of phonolite appear to occupy about equal sized areas of the sill complex.

Radiometric ages determined by the K-Ar method on two samples are given in table 1. These two ages suggest that the Chico Phonolite varieties were intruded between 26 and 20 m.y. ago.

GREEN PHONOLITE

The green phonolite was described by Staatz (1985) in a recent report on thorium and rare earth veins near Laughlin Peak. Contrary to Collins' report (1949, p. 1034), none of the green phonolite bodies was found as a surface flow. This rock is characterized by prominent columnar jointing (fig. 8*A*) and weathers to a thin, dark-yellowish-brown rind in which white feldspar phenocrysts stand out (fig. 8*B*). The green phonolite is very resistant to weathering and shows little effect except for the formation of a thin brown rind. In the dense vitric phase the phenocrysts are generally sparse; however, where they are locally abundant, they may reach sizes as large as 20 mm. Stobbe (1949, p. 1073–1076) gave the mineral composition as mainly soda orthoclase (having a pearly luster where fresh) and nepheline, with lesser amounts of analcime and acmite (aegirine) and rare acmite-diopside, magnetite, and titanite. Flow structure is obvious in both hand specimens and thin sections. In phenocryst-rich outcrops the phonolite locally has a platy fracture pattern parallel to the flow structure.

Two thin sections illustrate the porphyritic character of the green phonolite:

Our specimen 80SM29 (table 12, analysis 1; table 13), from the valley of the Rio del Plano, is porphyritic and contains about 20 percent pseudomorphs of natrolite

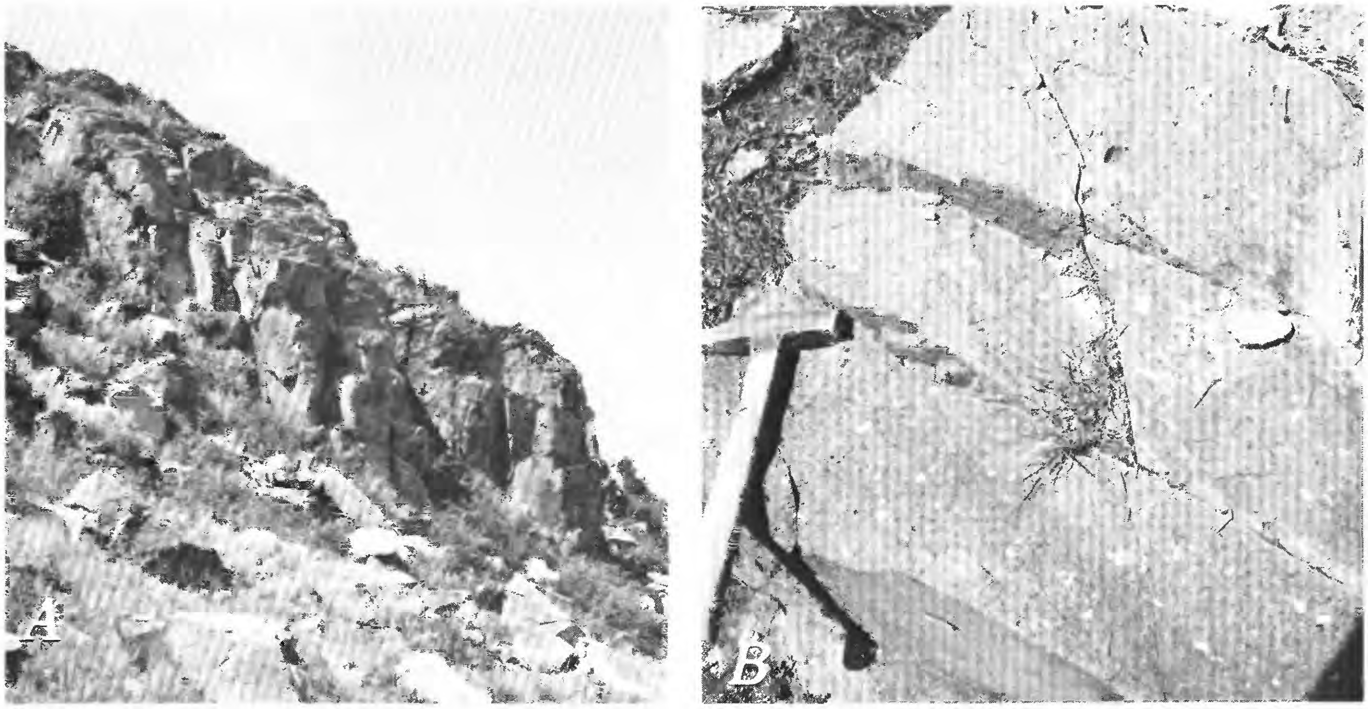


FIGURE 8.—Characteristic features of the green variety of Chico Phonolite. *A*, Columnar jointing at east end of Trujillo Mesa, in the NE¼NW¼ sec. 27, T. 27 N., R. 26 E., Pine Buttes quadrangle. *B*, Closeup showing conspicuous white alkali feldspar crystals.

after sodalite(?) as large as 0.6 mm, some with inclusions of apatite crystals and concentric bands of ankerite; sparse dark mica phenocrysts as large as 0.3 mm, having altered rims; sparse alkali feldspar phenocrysts as large as several millimeters; and sparse stubby crystals of green clinopyroxene. The groundmass has a taxitic texture and is mainly a mat of riebeckite (and acmite?) needles, having green to blue pleochroism, in an unknown mineral of low birefringence and strong negative relief; analcime(?) in scattered lenses is penetrated by riebeckite needles.

Another green phonolite (specimen 80SM27, table 12, analysis 3) from a quarry in sec. 16, T. 26 N., R. 27 E., is porphyritic and contains about 7 percent ghosts of amphibole(?) phenocrysts, now composed of jackstrawed acmite needles, some with cores of clinopyroxene or dark mica; 5 percent alkali feldspar phenocrysts in thick plates as large as 0.6 mm; 2 percent equant nepheline phenocrysts as large as 0.1 mm, many containing aligned inclusions; and 1 percent of an unknown isotropic mineral that forms stubby crystals as large as 0.7 mm with low negative relief. The groundmass has a tinguaitic texture and consists mainly of alkali feldspar, plagioclase, and moderate amounts of acmite needles and nepheline.

The green phonolite (table 12) has a low silica content and no normative quartz. All samples show more than 25 percent nepheline in the norms. As seen in figure 7*B*, the green phonolites are part of a gradational series with the silver-gray phonolites. The neutron-activation analysis (table 13) shows low abundances of barium, chromium, magnesium, and titanium, suggesting a crustal origin for the phonolite.

SILVER-GRAY PHONOLITE

This unit crops out as a sill on Tinaja Mountain and as sills and dikes over much of the area of the Chico sill complex. In places the silver-gray phonolite is younger than the green phonolite, and in other places older. For instance, a dike of silver-gray phonolite cuts a green phonolite in the NE¼ sec. 3, T. 27 N., R. 25 E., but according to M.H. Staatz (written commun., 1984), the green phonolite generally intrudes the silver gray. For example, east of the county road along Joe Cabin Arroyo in the SE¼ sec. 32, T. 27 N., R. 26 E., a long green phonolite dike cuts silver-gray phonolite.

The silver-gray phonolite in most occurrences is a medium-gray, dense, hard porphyritic rock containing pearly, curved, and deformed alkali feldspar phenocrysts in a finely crystalline groundmass. Feldspar crystals are less abundant than in the green phonolite. The silver-gray phonolite is more readily weathered than the green, and a slab about 4 inches (10 cm) thick is required in order to obtain a fresh interior. The rock weathers

TABLE 12.—*Chemical analyses and norms of samples of green variety of the Chico Phonolite, Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample --	1	2	3	4
Field no.	80SM29	MHS-85-80	80SM27	MHS-46-80
Lab. no.	D231893	D229968	D231892	D229967
		Major oxides		
SiO_2 ----	51.3	53.9	54.4	54.8
Al_2O_3 ---	21.2	21.3	21.6	21.0
Fe_2O_3 ---	1.80	2.86	2.31	2.94
FeO -----	0.98	0.36	0.56	0.20
MgO -----	0.26	0.2	0.45	0.2
CaO -----	1.86	0.60	1.13	0.42
Na_2O ----	9.53	10.3	10.5	9.6
K_2O -----	4.29	4.14	5.33	4.96
H_2O+ ----	n.d.	4.70	n.d.	4.90
H_2O- ----	n.d.	0.65	n.d.	0.25
Volatiles[1]	6.50	n.d.	1.65	n.d.
TiO_2 ----	0.31	0.30	0.28	0.30
P_2O_5 ----	0.08	<0.1	0.07	<0.1
MnO -----	0.19	0.22	0.20	0.20
CO_2 -----	n.d.	0.10	n.d.	0.08
Total	98.3	99.6	98.5	99.9
		La Roche and others (1980) classification		
R_1 ------	(-1067)	(-1136)	(-1452)	(-1109)
R_2 ------	639	497	576	469
Name ----	Phonolite	Phonolite	Phonolite	Phonolite
		Normative composition		
or ------	27.61	25.93	32.53	30.93
ab ------	32.21	39.80	21.98	37.91
an ------	2.61	0.00	0.00	0.00
ne ------	30.14	28.12	33.65	25.43
ac ------	0.00	0.60	6.75	0.77
wol -----	1.90	0.28	0.07	0.00
di-wo ---	0.96	0.61	2.15	0.55
di-en ---	0.71	0.53	1.16	0.48
di-fs ---	0.17	0.00	0.93	0.00
ol-fo ---	0.00	0.00	0.00	0.03
mt ------	2.84	1.07	0.08	0.45
hm ------	0.00	2.09	0.00	2.52
il ------	0.64	0.60	0.55	0.60
ap ------	0.21	0.13	0.17	0.12
cc ------	0.00	0.24	0.00	0.19

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Phonolite in valley of Rio del Plano in the SE¼SE¼ sec. 4, and NE¼NE¼ sec. 9, T. 26 N., R. 25 E., Tres Hermanos Peak quadrangle.
2. Phonolite from just west of road, 3,214 ft (980 m) south of Jimmy Spring in the south central part of sec. 31, T. 28 N., R. 26 E., Pine Buttes quadrangle. (M.H. Staatz, 1985).
3. Phonolite at quarry in the NE¼ sec. 16, T. 26 N., R. 27 E., Lawrence Arroyo quadrangle.
4. Phonolite from top of massive sill, 4,395 ft (1,340 m) south of Jimmy Spring near the northern border of sec. 6, T. 27 N., R. 26 E., Pine Buttes quadrangle. (M.H. Staatz, 1985).

TABLE 13.—*Neutron-activation analysis of a sample of green variety of the Chico Phonolite, Raton-Springer area, New Mexico*

[Elemental compositions in parts per million. See table 12 for description of sample locality. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No. 80SM29
Lab. No. 925107

Element	Value	Accuracy	Element	Value	Accuracy
Na	74,000	±700	Sb	<0.9	
Mg	<5,000		La	133	±2
Al	110,000	±3,000	Sm	12.3	±0.4
Cl	<300		W	<10	
K	40,000	±3,000	Au	<0.03	
Ca	17,000	±3,000	Sc	0.71	±0.03
Ti	1,500	±400	Cr	6	±1
V	53	±6	Fe	24,600	±800
Mn	1,390	±10	Co	1.5	±0.2
Cu	<600		Zn	90	±20
Sr	<600		Se	6.0	±0.7
I	<30		Rb	131	±10
Ba	560	±90	Cs	1.4	±0.2
Dy	5.7	±0.4	Ce	205	±9
U	24.86	±0.07	Eu	2.0	±0.1
Ga	<200		Tb	0.65	±0.10
As	<6		Yb	3.8	±0.2
Br	<5		Lu	0.55	±0.07
			Hf	14	±1
			Ta	5.7	±0.6
			Th	72	±3

yellowish gray or yellowish brown and is slightly platy or shaly (fig. 9).

A less abundant part of the silver-gray phonolite that is not so obviously silver gray and does not show the curved and deformed alkali feldspar phenocrysts is well exposed on Point of Rocks Mesa (Pecks Mesa) and in a small area at the south edge of the Tinaja Mountain quadrangle. Two thin sections of each of these two varieties are described.

In thin section the silver-gray phonolite is somewhat variable in mineral composition. Textures are generally porphyritic in trachytic, subtrachytic, or tinguaitic groundmasses. Specimen 80SM13, (table 14, analysis 1; locality 15 on fig. 6) from Chico in the Point of Rocks Mesa quadrangle, is porphyritic and contains the following: about 10 percent alkali feldspar phenocrysts as large as 5 mm, showing strain extinction and kaolinized margins; 4 percent analcime(?) pseudomorphs after sodalite(?) phenocrysts as large as 0.4 mm; and sparse plagioclase (oligoclase) phenocrysts associated with the alkali feldspar. The groundmass is trachytic in texture and composed mainly of alkali feldspar, moderate amounts of green acmite, and scattered equant nepheline in a mesostasis of an unknown isotropic mineral; also present are scattered unknown minerals, the most prominent of which are interstitial masses that have low relief and a birefringence about 0.02.

FIGURE 9.—Near-vertical jointing and platy weathering in silver-gray variety of the Chico Phonolite in Tres Hermanos Peak quadrangle in the NE¼NW¼ sec. 27, T. 27 N., R. 26 E. Field notebook, 5¼ inches (13 cm) wide, gives scale.

A quarry in the NW¼NW¼ sec. 3, T. 25 N., R. 26 E., at the western edge of Point of Rocks Mesa, is in relatively coarse phonolite, which lacks the silvery sheen. The rock at this locality contains sparse amounts of several rather rare minerals, such as the water-soluble fluoride villiaumite (Stormer, 1970, 1981), serandite, and eudialyte (Hlava and others, 1984). Other rare minerals from this locality are described by DeMark (1983, 1984, 1985), Hlava and others (1985), and Modreski (1985).

In thin section one specimen (80SM40, table 14, analysis 5) from this quarry is porphyritic and contains the following: about 15 percent stubby phenocrysts of alkali feldspar as large as 2 mm, marginally altered; 10 percent well-formed prisms of acmite as large as 0.5 mm; 5 percent blocky phenocrysts of nepheline as large as 1 mm containing many inclusions; scattered colorless square skeletal phenocrysts as large as 0.3 mm of an unknown mineral having rather strong positive relief, moderate birefringence, and an optic angle of about (+)40°; sparse sodalite(?) phenocrysts associated with fibrous zeolite; and scattered masses of an unknown isotropic mineral as large as 0.5 mm, which are crowded with alkali feldspar tablets of the same size as those of the groundmass but without the parallel orientation. The groundmass is chiefly alkali feldspar tablets in trachytic arrangement.

Specimen 80SM5 (table 14, analysis 6; table 15; locality 14 on figure 6), from the north end of Tinaja Mountain, is nonporphyritic and trachytic in texture and contains about 70 percent alkali feldspar in aligned laths as large as 0.3 mm; 10 percent poorly formed stubby nepheline crystals as large as 0.5 mm; 7 percent acmite prisms as long as 0.2 mm; about 3 percent of an unknown, colorless, nearly isotropic mineral of negative relief; and about 3 percent of another unknown, colorless mineral of moderate birefringence and moderate positive relief.

Phonolite specimen 81SM4 (table 14, analysis 7), from the SE¼SE¼ sec. 28, T. 28 N., R. 25 E., at the south edge of the Tinaja Mountain quadrangle, like the rock at the quarry on Point of Rocks Mesa, lacks the customary silvery sheen. It is porphyritic and contains about 35 percent alkali feldspar phenocrysts, which are as large as 2.5 mm and have shadowy extinction, and some of which have hourglass structure. The groundmass has trachytic texture and consists of about 50 percent alkali feldspar laths and ragged green acmite-augite(?) crystals with amphibole overgrowths; also present are scattered felted, brownish, fine-grained intergrowths of high birefringence and moderate relief.

Distinction between the green and silver-gray phonolites is based chiefly on weathering characteristics displayed in hand specimens and thin sections, but chemically (fig. 7*B*) they appear to be part of a single gradational series. Chemical analyses show the silver-gray phonolite (table 14) to be generally higher in SiO_2 and lower in Al_2O_3 than the green phonolite (table 12).

The neutron-activation analysis of silver-gray phonolite on table 15 shows its elemental composition to be close to average crustal abundance and indicates a crustal source for the silver-gray phonolite.

NEPHELINE SYENITE DIKE ON POINT OF ROCKS MESA

A nepheline syenite dike (the analcime microfoyaite of Stobbe, 1949, p. 1081) apparently intrudes the phonolite along the east side of Point of Rocks Mesa, forming a narrow 200-ft-high ridge called Hogback Butte. In hand specimen, the rock is medium gray, is mottled with very light gray spots, and appears somewhat fibrous. Microscopically, the rock (specimen number 81SM41, table 16) is porphyritic and trachytic in texture and contains about 20 percent curved, pearly alkali feldspar phenocrysts as large as 10 mm that show a faint grill pattern; about 10 percent veined and pockmarked nepheline as large as 1.5 mm; some exsolved and some kaolinized plagioclase(?); and sparse titanite crystals. The groundmass

TABLE 14.—*Chemical analyses and norms of samples of silver-gray variety of the Chico Phonolite from Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample	1	2	3	4	5	6	7
Field No.	80SM13	MHS-88-81	Stormer (1981) villiaumite locality	81SM44	80SM40	80SM5	81SM4
Lab No.	D229693	D240838		D251099	D237456	D229685	D237458
Major oxides							
SiO_2	55.6	58.7	59.5	59.5	59.8	60.4	61.7
Al_2O_3	20.8	20.2	19.0	19.8	19.0	19.9	19.6
Fe_2O_3	1.43	1.91	[1] 1.84	1.36	2.29	1.58	1.51
FeO	0.28	0.45	[1] 0.50	0.56	0.28	0.36	0.35
MgO	0.1	0.31	0.02	0.17	0.10	0.10	0.18
CaO	0.78	1.25	0.07	0.59	0.77	0.72	0.96
Na_2O	10.1	8.47	10.00	7.76	9.64	9.2	8.25
K_2O	5.08	4.68	4.80	4.68	4.98	5.30	5.39
Volatiles[2]	2.55	2.14	n.d.	2.97	1.03	1.02	0.81
TiO_2	0.14	0.27	0.20	0.18	0.20	0.14	0.15
P_2O_5	>0.1	0.06	0.02	<0.05	<0.05	<0.10	<0.05
MnO	0.26	0.19	0.40	0.32	0.63	0.36	0.26
Total	98.1	98.6	96.35	97.9	98.7	99.1	99.2
La Roche and others (1980) classification							
R_1	(-1070)	(-254)	(-770)	(64)	(-683)	(-540)	(-132)
R_2	506	546	382	460	464	477	500
Name	Phonolite	Trachyphonolite/ phonolite.	Phonolite	Trachy- phonolite.	Phonolite	Phonolite	Trachy- phonolite.
Normative composition							
or	31.39	28.66	29.44	29.14	30.11	31.92	32.37
ab	35.31	49.62	47.19	57.72	42.96	44.05	52.58
an	0.00	3.40	0.00	3.08	0.00	0.00	0.54
c	0.00	0.00	0.00	0.94	0.00	0.00	0.00
ne	25.46	13.35	14.36	6.21	15.53	16.36	9.95
ac	4.33	0.00	5.52	0.00	6.78	4.49	0.00
ns	0.50	0.00	1.83	0.00	0.96	0.00	0.00
wol	0.54	0.17	0.00	0.00	0.03	0.14	1.19
di-wo	1.01	0.93	0.09	0.00	1.52	1.24	0.53
di-en	0.26	0.80	Trace	0.00	0.25	0.25	0.46
di-fs	0.80	0.00	0.10	0.00	1.39	1.07	0.00
ol-fo	0.00	0.00	0.03	0.31	0.00	0.00	0.00
ol-fa	0.00	0.00	0.99	0.16	0.00	0.00	0.00
mt	0.00	1.33	0.00	2.08	0.00	0.09	1.57
hm	0.00	1.06	0.00	0.00	0.00	0.00	0.45
il	0.28	0.53	0.39	0.36	0.39	0.27	0.29
ap	0.12	0.15	0.05	<0.12	0.07	0.12	0.07

[1]Assumed amount.

[2]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Phonolite at Chico in the SE¼ sec. 17, T. 26 N., R. 26 E., Point of Rocks Mesa quadrangle.
2. Trachyphonolite/phonolite from north side of Joe Cabin Arroyo in the SE¼ sec. 28, T. 27 N., R. 26 E., Pine Buttes quadrangle. (M.H. Staatz, 1986).
3. Phonolite from quarry in the NW¼NW¼ sec. 3, T. 25 N., R. 26 E., Point of Rocks Mesa quadrangle. From quarry that contains villiaumite (Stormer, 1981).
4. Trachyphonolite from east wall of valley in the NE¼NE¼ sec. 9, T. 26 N., R. 25 E., Tres Hermanos Peak quadrangle.
5. Phonolite from quarry in the NW¼NW¼ sec. 3, T. 25 N., R. 26 E., Point of Rocks Mesa quadrangle.
6. Phonolite from north end of Tinaja Mountain in the NE¼ sec. 14, T. 28 N., R. 24 E., from a block in the landslide deposit from Tinaja Mountain, Tinaja Mountain quadrangle.
7. Trachyphonolite that underlies trachyte in the SE¼SE¼ sec. 28, T. 28 N., R. 25 E., Tinaja Mountain quadrangle.

TABLE 15.—*Neutron-activation analysis of a sample of silver-gray variety of the Chico Phonolite from Tinaja Mountain, Raton-Springer area, New Mexico*

[Elemental compositions in parts per million. See table 14 for description of sample locality. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No.	80SM5				
Lab No.	925104				
Na	67,400	±700	Sb	1.1	±0.2
Mg	6,000		La	103	±1
Al	99,000	±3,000	Sm	7.7	±0.4
Cl	680	±100	W	<8	
K	40,000	±5,000	Au	<0.02	
Ca	<4,000		Sc	0.14	±0.01
Ti	2,000		Cr	16	±2
V	<20		Fe	22,800	±700
Mn	2,870	±30	Co	1.06	±0.10
Cu	<700		Zn	200	±30
Sr	<800		Se	7.6	±0.7
I	<50		Rb	320	±10
Ba	<400		Cs	8.2	±0.6
Dy	5.9	±0.8	Ce	178	±7
U	20.43	±0.06	Eu	1.03	±0.07
Ga	<200		Tb	0.79	±0.10
As	9	±2	Yb	7.8	±0.2
Br	<4		Lu	1.1	±0.1
			Hf	23	±2
			Ta	7.1	±0.7
			Th	85	±3

consists of kaolinized alkali feldspar tablets; abundant euhedral crystals of acmite as large as 0.6 mm, which are zoned and somewhat altered; nepheline as gray, irregularly formed crystals as large as 0.4 mm; a few clear parallel plates of plagioclase; mica partly altered to an isotropic dusty material; and opaque black material. The presence of curved pearly alkali feldspar phenocrysts and the similarities in chemical composition (fig. 7*B*, fields 14 and 16) suggest that the nepheline syenite bears a genetic relationship to the silver-gray phonolite; perhaps it was a feeder dike to the Point of Rocks phonolite sill.

OCELLAR ANALCIME PHONOLITE

From Hogeye Mesa in sec. 26 northeastward to secs. 13 and 24, T. 27 N., R. 26 E., an ocellar analcime phonolite crops out. This phonolite is medium gray and porphyritic and has a trachytic to intergranular texture.

In thin section, specimen 81SM17 (no analysis) from the S½SW¼ sec. 13, T. 27 N., R. 26 E., Pine Buttes quadrangle, had abundant phenocrysts of colorless, well-formed analcime crystals as large as 1 mm, some clustered in groups; many acmite-augite prisms, pleochroic green to greenish-brown, zoned from light-colored centers to dark rims, as much as 1 mm in size; a few crystals of sphene; and a few crystals of alkali feldspar. The groundmass consists mostly of parallel laths of alkali feldspar and small prisms of acmite in a mesostasis of analcime(?) crystals.

TABLE 16.—*Chemical analysis and norm of nepheline syenite dike on Point of Rocks Mesa, Raton-Springer area, New Mexico*

[Data in weight percent]

Field No.	81SM41
Lab. No.	D242013
SiO_2	60.1
Al_2O_3	19.3
Fe_2O_3	2.45
FeO	0.11
MgO	0.14
CaO	0.82
Na_2O	8.49
K_2O	4.90
Volatiles[1]	1.62
TiO_2	0.20
P_2O_5	<0.05
MnO	0.63
Total	98.8

La Roche classification	
R_1	(-222)
R_2	473
Name	Nepheline syenite.
Normative composition	
or	29.80
ab	53.50
an	0.08
ne	11.07
wol	1.21
di-wo	0.42
di-en	0.36
mt	1.88
hm	1.22
il	0.39
ap	0.07

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITY

Nepheline syenite dike that cuts(?) gray phonolite on Point of Rocks Mesa in SW¼SE¼SE¼ sec. 34, T. 26 N., R. 26 E., Point of Rocks Mesa quadrangle.

According to Stobbe (1949, p. 1073), the ocellar variety has a mode comparable to that of the other phonolites considering that analcime and nepheline are measured together as feldspathoid content. She found the analcime ocelli to be round or oval shaped, and all are bordered by aegirine crystals; turbid zeolitic alteration affected some analcime crystals. She believed the ocelli to have been gas vesicles in a crystallizing magma, which were later filled by analcime as a product of the last residual liquid.

MAFIC AND ULTRAMAFIC DIKES AND SILLS (INCLUDING LAMPROPHYRIC ROCKS)

Mafic dikes are common from Raton southward to beyond Eagle Tail Mesa, but less common in the area of the Chico sill complex. An extensive dike swarm just south of Eagle Tail Mesa and Tinaja Mountain, trending east by southeast, contains more than 20 dikes per mile (12 per kilometer) in a belt as much as 3 mi (4.8 km) wide. One of the thickest of these is the spectacular Eagle Rock dike, 30 ft (9 m) wide where it is cut by Interstate Highway 25 about 17 mi (27 km) south of Raton (locality

16 on fig. 6; also fig. 10*A*). This basanitic dike is composite and has several thin parallel members of varied texture.

Several dikes are traceable for as much as 3 mi (4.8 km), and one, extending eastward from sec. 16, T. 22 N., R. 21 E., to sec. 12, T. 22 N., R. 22 E., can be traced for 9 mi (14 km). Most dikes have chilled selvages, and sedimentary rocks adjacent to these have been baked to hornfels. Because the hornfels is more resistant to weathering than either the dike or the enclosing normal sedimentary rock, it commonly stands out above the ground surface as paired ribs and scattered plates, and is easily traced on the ground or on aerial photographs. Trenches have been dug in some of the dikes, but, except for one that was used for road metal, the purpose of the trenching is unknown to us. The dikes are dark gray to olive gray or olive black and are generally very dense and hard. Most weather to round nodules having a friable outer layer, which readily spalls, around a core that can be broken only with the hardest blows of a hammer.

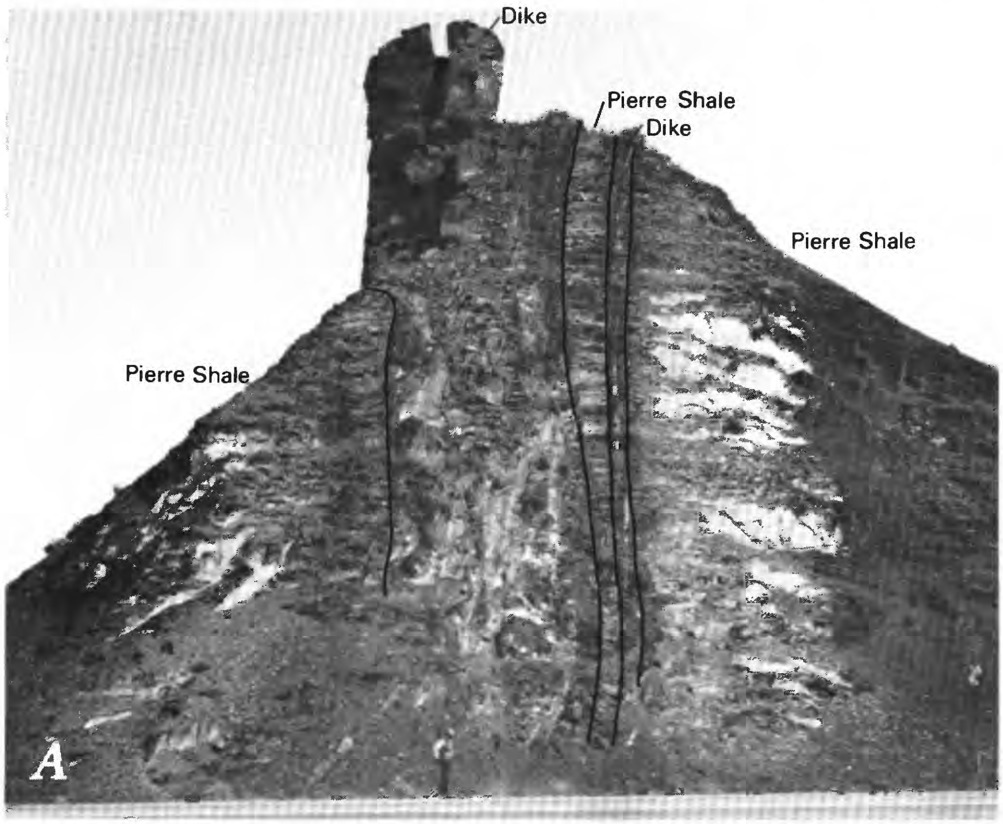
The ages of the mafic dikes appear to cover a wide range through most of the Tertiary. Many dikes cut the alkalic rocks of the Chico sill complex, which itself covers a wide range of ages. (See section on Chico sill complex.) A K-Ar age of the Eagle Rock dike was determined to be 24.16±1.01 m.y. (table 1). M.J. Aldrich (written commun., 1983) determined a whole-rock K-Ar age of 15.6±0.7 m.y. for a mafic dike on the north flank of the Turkey Mountains (fig. 1*A*), about 2 mi (3.2 km) south of the south edge of the Springer 30′×60′ quadrangle (not to be confused with Turkey Mountain of the Tres Hermanos Peak quadrangle, shown on fig. 1*B*). The dike described by Aldrich is part of a linear dike swarm that extends northward into the Springer 30′×60′ quadrangle.

Although these mafic dikes and sills have been described as various types of lamprophyres—including vogesites, minettes, kersantites, and spessartites (Mertie, 1922; Stobbe, 1949, p. 1082)—many of them do not fit a commonly accepted part of the definition of lamprophyres which states that lamprophyres are *porphyritic* rocks with dominantly ferromagnesian phenocrysts (Rock, 1977; Hughes, 1982; Williams and others, 1984; Bates and Jackson, 1987). Concerning the dikes in this region, Mertie (1922, p. 12) states that some lamprophyres are "coarse grained and others are almost aphanitic. Almost without exception they are nonporphyritic. Their fabric is in some places ophitic or diabasic. Most commonly, perhaps, it is granular and here or there it is intersertal." In view of the varying definitions and usages of the term lamprophyre, we generally avoid it here; instead, we use the common rock name indicated by the bulk chemistry or, lacking that, simply refer to it as a mafic rock. Many of the nonporphyritic rocks, however, do fit other important elements of the definition of lamprophyres, particularly in the abundance of hydrous minerals (biotite, hornblende, and analcime) and carbonate; these minerals imply a deep-seated parent magma of relatively high volatile content (H_2O, CO_2) and high temperature.

In thin sections the main minerals are plagioclase, clinopyroxene, hornblende (in part kaersutitic), and olivine, all in widely varying proportions. Less abundant are opaque oxides, biotite, apatite, nepheline, analcime, and carbonate minerals.

The Eagle Rock dike appears to be compound—that is, made up of successive injections of magma. It has the chemical composition of a basanite (specimen 80SM25, table 17, analysis 3). Grain size varies from fine to coarse between different intruded sheets; where it is relatively coarse grained (fig. 10*B*) and the texture is lamprophyric, the corresponding phaneritic term, theralite, might be justified. In thin section a specimen has an intersertal texture and consists of the following approximate proportions: 40 percent plagioclase (labradorite) as much as 1.5 mm in length, strongly veined by zeolite(?) and feldspathoid(?); 30 percent pale-green clinopyroxene as stubby crystals as much as 2 mm long having a positive optic angle about (+)50°; 15 percent kaersutitic hornblende in crystals as much as 2 mm in length, pleochroic russet brown to pale yellow brown; 8 percent black opaque oxide as much as 0.2 mm long; 5 percent pale-green chlorite interstitial to other crystals; 1 percent scattered pseudomorphs as much as 0.7 mm long of green smectite after olivine(?); 1 percent apatite as thin prisms as much as 1 mm long; traces of dark mica as plates and irregular crystals associated with the opaque oxide; and traces of carbonate. Chemical analyses of the mafic dike rocks (table 17) show that SiO_2 ranges from about 40 to 43 percent, typical of a variety of mafic rocks. Na_2O plus K_2O ranges from 3.32 to 5.38 percent; CaO ranges from about 9 to 15 percent.

Another dike (specimen 81SM14, table 17, analysis 4) cut by Interstate Highway 25 about 15¾ mi (25 km) south of Springer, in the Colmor quadrangle, has the composition of a trachybasalt, and in some parts is coarse enough to be called a syenogabbro. In thin section the specimen consists of the following: about 40 percent plagioclase (zoned labradorite to oligoclase) in lathes as much as 0.8 mm long having interiors strongly laumontitized(?); 35 percent irregular crystals of kaersutitic hornblende as long as 1 mm; 10 percent smectite as interstitial masses of fronds; 7 percent opaque oxide crystals as long as 0.1 mm, many in groups; 6 percent pale-green-brown clinopyroxene as long as 0.6 mm, many altered and rimmed with hornblende; scattered


Dike
Pierre Shale
Dike
Pierre Shale
Pierre Shale
A


B

crystals of apatite, commonly in clusters; and a few masses of carbonate filling interstices.

A sample (specimen 81SM2B, table 17, analysis 5) from the more southern of a pair of contiguous dikes in the center of S½ sec. 5, T. 28 N., R. 25 E., in the Tinaja Mountain quadrangle, has the chemical composition of a picritic basanite. In thin section it has equigranular (cumulate?) texture, shows some shear fracturing, and has the following approximate mineral composition: 75 percent euhedral clinopyroxene crystals as long as 0.2 mm, 16 percent euhedral olivine crystals mostly less than 0.2 mm long (though a few crystal fragments are larger); 2 percent calcic plagioclase laths as much as 0.1 mm long; 2 percent equant opaque oxide crystals as long as 0.05 mm; 3 percent unknown colorless mineral of low birefringence and moderate relief in interstitial bundles; and 1 percent interstitial chlorite.

A sample from the northern of the two dikes (81SM2A) (same locality as 81SM2B, above) is porphyritic, containing abundant phenocrysts of clinopyroxene and olivine as long as 0.6 mm. The olivine is altered to carbonate and smectite. The groundmass is composed of plagioclase, altered olivine, clinopyroxene, and opaque oxide. A few vugs, as much as 1.5 mm in diameter, are filled with analcime(?) and carbonate.

A specimen (specimen 82SM1) from a sill in the extreme northeastern corner of the Eagle Tail Mountain quadrangle, in the NW¼SE¼SW¼ sec. 15, T. 29 N. R. 24 E., appears to be a monchiquitic lamprophyre. It contains abundant stubby phenocrysts of pale-brown clinopyroxene as large as 1 mm. The crystals are zoned and have an optic angle about (+)60° in the center and (+)40° at the somewhat darker edges. The rock also contains abundant brown amphibole phenocrysts, which are moderately pleochroic and have an extinction angle Z:c of 17°; many olivine phenocrysts as large as 2 mm, altered to smectite; and scattered crystals of dark-brown mica as large as 0.3 mm. The groundmass is made up of interstitial analcime(?), altered sodic plagioclase, many opaque oxide grains, and long needles of apatite.

A dike of ankaratritic composition (specimen 80SM36, table 17, analysis 2) forms the crest of Tres Hermanos Peak in the southern part of sec. 23, T. 27 N., R. 24 E., Tres Hermanos Peak quadrangle. The rock is medium dark gray and dense. In thin section it has a porphyritic to seriate texture and is composed of the following: about 21 percent olivine phenocrysts as large as 1.5 mm with many broken fragments; 8 percent pale-yellow nepheline

FIGURE 10 (facing page).—Eagle Rock dike on east side of Interstate Highway 25 in the NE¼ sec. 16, T. 28 N., R. 23 E., Eagle Tail Mountain quadrangle. *A*, View of outcrop showing dike intruding lower part of Pierre Shale (Upper Cretaceous). Heat of dike has baked adjacent parts of the shale to hornfels. *B*, Closeup of dike rock showing large hornblende crystals.

TABLE 17.—*Chemical analyses and norms of samples of mafic dike rocks from the Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample --	1	2	3	4	5
Field No.	VCK 82-NM-059	80SM36	80SM25	81SM14	81SM2B
Lab. No.--	---	D237455	D231890	D242007	D237457
			Major oxides		
SiO_2 ----	40.17	42.2	43.0	43.2	43.3
Al_2O_3 ---	11.92	12.6	17.1	16.8	11.0
Fe_2O_3 ---	4.08	3.15	5.81	6.67	2.70
FeO -----	6.34	7.06	6.02	5.88	8.64
MgO -----	11.74	13.3	4.95	5.58	14.5
CaO -----	15.34	11.1	10.8	9.15	11.8
Na_2O ----	2.32	3.54	4.02	3.26	2.59
K_2O -----	1.00	1.84	0.81	1.14	1.0
H_2O^+ ----	2.45	n.d.	n.d.	n.d.	n.d.
H_2O^- ----	0.26	n.d.	n.d.	n.d.	n.d.
Vols.[1] --	n.d.	1.50	4.49	4.14	1.50
TiO_2 ----	1.78	2.05	2.05	2.48	1.72
P_2O_5 ----	1.66	0.75	0.35	0.52	0.69
MnO -----	0.205	0.17	0.16	0.15	0.18
SrO -----	0.26	n.d.	n.d.	n.d.	n.d.
Total	99.53	99.3	99.6	99.0	99.6
			La Roche and others (1980) classification		
R_1 ------	1,298	802	887	1,064	1,384
R_2 ------	2,464	2,110	1,740	1,589	2,206
Name ----	Picritic ankaratrite.	Ankaratrite.	Basanite	Trachybasalt/ syenogabbro.	Picritic basanite.
			Normative composition		
or ------	0.00	6.67	5.03	7.10	6.02
ab ------	0.00	0.00	18.93	26.25	4.31
an ------	19.84	13.35	27.58	29.35	15.72
lc ------	4.80	3.49	0.00	0.00	0.00
ne ------	11.01	16.59	9.13	1.53	9.76
cs ------	0.21	0.00	0.00	0.00	0.00
di-wo ---	19.66	15.84	11.01	6.23	16.42
di-en ---	14.79	11.73	7.96	4.98	11.49
di-fs ---	2.89	2.58	2.04	0.53	3.54
ol-fo ---	10.86	15.52	3.51	6.77	17.73
ol-fa ---	2.34	3.76	0.99	0.79	6.02
mt ------	6.13	4.67	8.86	10.20	3.99
il ------	3.50	3.98	4.09	4.97	3.33
ap ------	4.07	1.82	0.87	1.30	1.66

[1]Volatiles, probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Picritic ankaratrite dike in the NE¼NE¼ sec. 24, T. 31 N., R. 23 E., on the north side of Raton (36°54.7' N., 104°26.5' E.) Raton quadrangle (M.J. Aldrich, Los Alamos National Laboratory, unpub. data, 1983).
2. Ankaratrite from Tres Hermanos Peak, SW¼SE¼ sec. 23, T. 27 N., R. 24 E., Tres Hermanos Peak quadrangle.
3. Basanite dike at Eagle Rock on Interstate Highway 25 in the NE¼NE¼ sec. 21, T. 28 N., R. 23 E., Eagle Tail Mountain quadrangle.
4. Trachybasalt or syenogabbro dike crossing Interstate Highway 25 in the SW¼NW¼ sec. 14, T. 22 N., R. 21 E., Colmor quadrangle.
5. Picritic basanite dike in the SW¼SE¼ sec. 5, T. 28 N., R. 25 E., Tinaja Mountain quadrangle (southern of two dikes).

FIGURE 11.—Smoky Hill Shale Member of the Niobrara Formation brecciated by a lamprophyre dike along a tributary of Tinaja Creek in the NE¼SW¼NE¼ sec. 35, T. 28 N., R. 24 E., Tres Hermanos Peak quadrangle.

phenocrysts as large as 0.2 mm, some with thin needles of clinopyroxene and apatite(?) as inclusions; 5 percent poorly formed plagioclase phenocrysts as large as 0.4 mm; and 4 percent prismatic, pale-dirty-green clinopyroxene phenocrysts as large as 0.2 mm. The groundmass consists of abundant clinopyroxene and nepheline; moderate amounts of inclusion-rich plagioclase; scattered spots of a cloudy, brown unknown mineral of negative relief; and a clear, colorless unknown isotropic mineral of positive relief.

Many of the mafic dikes in the region appear to be members of a gradational series ranging from simple dikes to more forcefully injected bodies, such as diatremes. The intensity of intrusion is illustrated by one mafic body, exposed along a tributary of Tinaja Creek in the NW¼NE¼ sec. 35, T. 28 N., R. 24 E., which has severely brecciated the Upper Cretaceous Niobrara Formation it intrudes. Some of the breccia fragments (fig. 11) are more than 1 ft (0.3 m) in length.

DIATREMES

Several diatremes were noted during the reconnaissance mapping of this area, and more could probably be found with careful search. A small kimberlitic diatreme crops out in a low knoll east of Raton, on the Olen Caviness ranch in the NE¼NW¼SE¼ sec 20, T. 31 N., R. 24 E. (locality 17 on fig. 6). Most of the knoll (fig. 12*A*) is occupied by disoriented masses of sedimentary sandstone, limestone, claystone and other types that range in size from a fraction of an inch to several feet. The diatreme is apparently less than 300 ft (90 m) in diameter and intrudes the Pierre Shale in the middle of the formation at about the faunal level of *Didymoceras cheyennense*, an approximately 72-m.y.-old fauna (Obradovich and Cobban, 1975). Much of the sedimentary rock in the neck of the diatreme is brecciated and altered to hornfels (fig. 12*B*), and so the stratigraphic origins of most of the fragments are hard to determine. It seems probable, however, that they were from the overlying Trinidad Sandstone, the Pierre Shale, the underlying Niobrara Formation, or an underlying Permian sandstone. One fossiliferous block of limestone from the diatreme contained specimens of the pelecypod *Inoceramus (Platyceramus)* cf. *I. cycloides* Wegner, which traces that block to the Smoky Hill Shale Member of the Niobrara Formation (identified by W.A. Cobban, U.S. Geological Survey). A radiometric age of the diatreme was obtained by the fission-track method on zircon in a sandstone block (table 2). The age, 30.1±1.2 m.y., which represents the time of resetting resulting from the heat of the intrusion (thus the age of emplacement), was determined by Mutsumi Miyachi in the laboratory of C.W. Naeser, U.S. Geological Survey. A second sample of zircon from the same sandstone yielded a fission-track age of 25.5±1.3 m.y.

Allen V. Heyl, U.S. Geological Survey, examined with a binocular microscope many hand specimens of the igneous rock and the breccia from the diatreme and concluded that the ultramafic igneous rock was a mica peridotite, a common rock type in many diatremes. The peridotite contains spheroidal dunite lapilli, which formerly were composed of olivine but now are largely altered to serpentine (probably antigorite). Phlogopite mica occurs in small sheeted aggregates as primary fragments in the lapilli and in the groundmass. Minute quartz crystals occur in vugs. Opaque minerals include diamond-shaped crystals, probably of chromite, and smaller square crystals of probable perovskite. Heyl noted the apparent absence of several minerals--such as garnet, chrome spinel, and chrome diopside—that are characteristic of many kimberlitic diatremes.

The ultramafic igneous rock (fig. 12*C*), which is only a small part of the diatreme body, can be called a kimberlite. In thin section (specimen 80SM33, tables 18 and 19) the rock is porphyritic and includes about 45 percent smectite pseudomorphs after olivine phenocrysts, as large as 1.5 mm, and scattered pseudomorphs of horn-

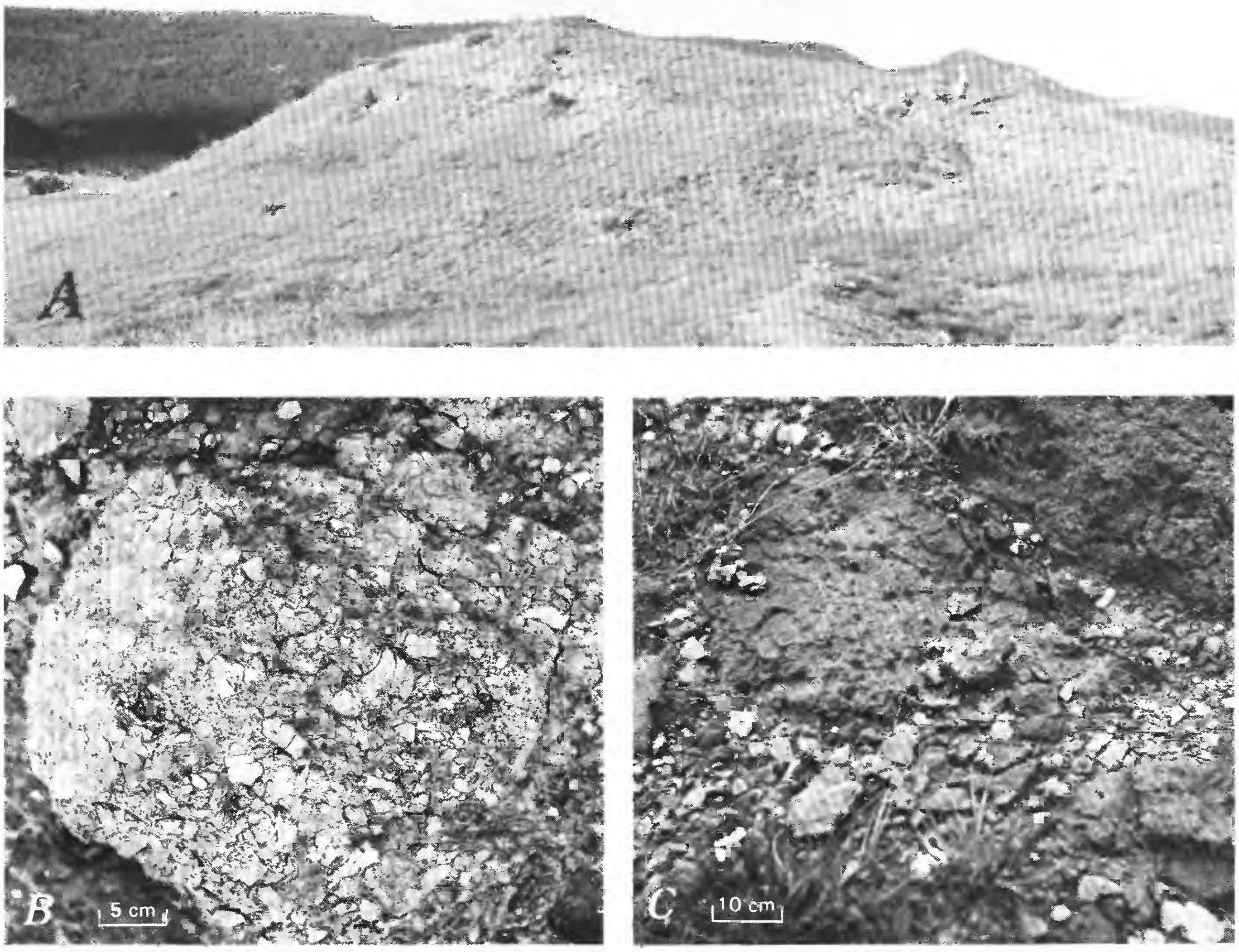


FIGURE 12.—Kimberlite diatreme east of Raton in the NE¼NW¼SE¼ sec. 20, T. 31 N., R. 24 E., Raton quadrangle. *A*, Low knoll formed by the diatreme. *B*, Closeup of brecciated sedimentary rock in the diatreme. *C*, Closeup of mica peridotite in the diatreme, containing spheroidal dunite lapilli.

blende(?) and mica(?). The groundmass is smectite, opaque oxide grains, and masses of a brown, fine-grained, undetermined isotropic mineral of high relief (garnet?).

A diatreme 2.5 mi (4.0 km) east of Maxwell and north of the Piñon Road, in the SE¼ sec. 28, T. 27 N., R. 23 E. (symbol Td in southwest corner of fig. 6), crops out as an irregularly shaped plug of peridotite about 40 ft (12 m) in diameter intruding the calcareous uppermost shale unit of the Smoky Hill Shale Member of the Niobrara Formation. Anastomosing tongues of peridotite extend out into the shale (now hornfels). Internally the structure contains chaotic nodules and blocks of fine- and coarse-grained mafic igneous rock and fragments of probable Precambrian pegmatite and granitic gneiss. In thin section the fine-grained igneous rock (specimen 81SM59, table 19) is porphyritic and contains about 15 percent olivine phenocrysts as long as 2 mm, partly altered to smectite(?), and about 5 percent colorless clinopyroxene phenocrysts as large as 0.5 mm having an optic angle of about (+)60°. The groundmass consists of about equal parts of clinopyroxene, plagioclase, and alkali feldspar and a minor amount of dark mica. A thin section from another block (specimen 82SM5) from the same diatreme shows euhedral altered olivine, kaersutitic hornblende, stubby pale-brown clinopyroxene, equant opaque oxide crystals, a few plagioclase crystals, scattered needles of apatite, and sparse dark mica, all in an interstitial mixture of a dusty isotropic material of strong negative relief (zeolite?) and carbonate.

An irregular body about 1,000 ft (305 m) long and 200 ft (60 m) wide at the faulted Joyce dome (Staatz, 1986) in the Pine Buttes quadrangle (NW¼NW¼ sec. 25, T. 27 N., R. 25 E.) has many of the aspects of a diatreme. The principal rock is hornblende-rich and contains inclusions of Precambrian gneiss, pegmatite, and possible Precambrian quartzite. According to M.H. Staatz (written commun., 1981), chemical analysis shows the rock is trachyandesite. In thin section a specimen (No. 81SM25, table 19) is porphyritic and includes the following: about 10 percent green hornblende phenocrysts that are generally less than 2.5 mm across but locally form coarse crystal segregations as much as 7.5 cm in diameter; 5 percent blue-green pseudomorphs of smectite after pyroxene(?) as large as 1.5 mm; 1 percent dark-brown mica crystals as large as 1.2 mm; 1 percent plagioclase (andesine?) phenocrysts as large as 1.2 mm with oscillatory zoning; 1 percent opaque oxide crystals; and broken crystals of apatite. The groundmass is chiefly feathery appearing feldspar and secondary carbonate. Other minerals in the groundmass include opaque oxides, pyrite, and an unknown yellowish-brown mineral of strong birefringence. Vugs are filled with quartz and carbonate.

Tables 18 and 19 show spectrographic analyses and neutron-activation analyses of the igneous rocks in the diatremes. Despite the lesser precision of the spectrographic analyses, both analyses are included because each shows some elements not included in the other. Table 19 also shows that many elements are more abundant in the diatremes than in average crustal rocks. These higher abundances suggest that the diatreme rocks were derived from the mantle. Elements whose concentrations are particularly diagnostic of a mantle source are barium, chromium, iridium, magnesium, nickel, thorium, titanium, and yttrium.

TABLE 18.—*Semiquantitative six-step spectrographic analyses of rocks from diatremes in the Raton-Springer area, New Mexico*

[Table lists only the elements detected. Other elements looked for but not detected (and their lower limits of determination, in parts per million) are Ag (0.5), As (1,000), Au (20), B (20), Bi (10), Cd (50), Eu (100), Ge (10), Hf (100), In (10), Li (100), Pd (2), Pt (50), Re (50), Sb (200), Sm (100), Sn (10), Ta (500), Te (2,000), Th (200), Tl (50), U (500), W (100), and Zn (300). N=not detected; < =element detected but below the limit of determination, which is value shown; --- =element not looked for. Analyst L.A. Bradley; fluorine by the specific ion electrode method by H.G. Neiman and F. Newman]

Sample -----	1	2	3
Field No.---	80SM33	81SM25	81SM59
Lab. No.----	D237463	D241840	D241941
	Data in percent		
Al ---------	1.5	5	7
Ca ---------	3	7	7
Fe ---------	7	7	7
K ----------	1.5	3	1.5
Mg ---------	5	2	5
Na ---------	.15	3	1.5
P ----------	N	0.5	0.3
Si ---------	7	10	10
Ti ---------	0.3	0.7	1
F ----------	0.11	0.14	0.06
	Data in parts per million		
Ba ---------	700	1,000	1,500
Be ---------	<1	2	1.5
Ce ---------	<200	200	200
Co ---------	30	30	30
Cr ---------	700	70	300
Cu ---------	70	70	70
Ga ---------	---	30	20
La ---------	100	70	70
Mo ---------	N	<3	5
Nb ---------	30	30	70
Nd ---------	70	150	100
Ni ---------	300	30	200
Pb ---------	N	20	15
Sc ---------	15	30	30
Sr ---------	300	500	700
V ----------	150	200	150
Y ----------	20	50	30
Yb ---------	---	3	---
Zr ---------	70	150	150

DESCRIPTION OF SAMPLE LOCALITIES

1. Kimberlite diatreme in the NE¼NW¼SE¼ sec. 20, T. 31 N., R. 24 E., Raton quadrangle.
2. Diatreme at the Joyce faulted dome in the NW¼NW¼ sec. 25, T. 27 N., R. 25 E., Pine Buttes quadrangle.
3. Diatreme north of the Pinon road in the SE¼ sec. 28, T. 27 N., R. 23 E., Loco Arroyo quadrangle.

IGNEOUS ROCKS NEAR CIMARRON, NEW MEXICO

The igneous rock exposures in the vicinity of Cimarron are separated from the main area of igneous rock outcrops east of Interstate Highway 25 by some 40 mi (64 km) of sedimentary rock exposures. The geology of the area immediately south of Cimarron has been mapped by Scott (1986). West of Cimarron is an extensive series of felsic sills, and east and south of Cimarron are outcrops of syenite sills over an area 2–3 mi (3–5 km) wide. Both rock units probably are parts of a large intrusive complex. Although syenite sills are found only east of the escarpment of the Park Plateau (fig. 1), rhyodacite sills project northwestward from Tooth of Time Ridge into the mountains beyond Elizabethtown (fig. 1). Similar rocks also extend northwestward from Elizabethtown to the valley of the Rio Grande (P.W. Lipman, oral commun., 1982).

TABLE 19.—*Neutron-activation analyses of rocks from diatremes in the Raton-Springer area, New Mexico*

[See table 18 for description of sample localities. "<" indicates element concentration is below the limit of determination, which is the value shown. Analyst: Carl Orth, Los Alamos National Laboratory]

Sample---	1		2	3	Average
Field No.	80SM33		81SM25	81SM59	crustal
Lab. No.	RB-11	RB-41	RB-98	RB-99	abundance
Elemental compositions in percent					
Al	3.4	3.6	6.6	7.1	8.1
Ca	6.9	7.2	7.0	7.1	3.6
Fe	7.5	7.6	7.2	7.1	5
Mg	11.4	12.3	1.9	4.9	2.1?
Elemental compositions in parts per million					
Ba	1,880	1,900	700	1,815	425
Ce	237	245	156	132	60
Co	65	≤35	31	48	100
Cr	1,500	1,170	66	390	100
Cs	≤2	≤2	≤2	2.7	3
Dy	5.1	4.8	11.6	4.5	3.0
Eu	3.3	3.1	2.4	2.0	1.2
Hf	4	4	3.6	2.6	3
K	9,170	17,200	≤15,000	≤13,000	26,000
La	106	113	55	61	30
Lu	0.5	0.8	0.5	0.2	0.5
Mn	1,600	1,580	1,750	1,620	950
Na	496	650	25,500	25,360	28,300
Rb	≤60	≤50	36	≤28	90
Sc	27	25	22	24	22
Sm	10	20	15	6?	6
Sr	≤330	600	≤1,100	1,500	375
Ta	2.3	2.3	1.4	2.0	2
Th	22	23	9.0	9.5	7.2
Ti	8,290	8,190	10,950	9,850	4,400
U	4.4	4.8	2.4	3.7	1.8
V	207	185	240	210	135
Yb	≤2.6	≤3.1	3.2	3.9	3.4
Zr	≤150	≤150	150	200	165
Elemental composition in parts per trillion					
Ir	140	220	80	36	8

RHYODACITE WEST OF CIMARRON

A large sill complex or laccolith(?) of porphyritic rhyodacite to dacite crops out southwest of Cimarron and west of the Philmont Scout Ranch headquarters (fig. 1). This mass is resistant to weathering and forms bold monoliths, pinnacles, ridges, and fluted columnar outcrops, such as Tooth of Time Ridge, Cathedral Rock, and the Palisades. The sills northwest of Tooth of Time Ridge have fairly gentle dips and are intricately interlayered with Cretaceous and older sedimentary rocks. The sediments intruded by the rhyodacite generally have been baked to hornfels near the contacts.

The radiometric age of the rhyodacite was determined by Armstrong (1969) to be 33.8 m.y. (34.6 m.y. by the new constants) using the K-Ar method on biotite (table 3). On a different sample from Cimarron Canyon ½ mi (0.8 km) east of the Palisades (specimen 81SM24; locality 19 on fig. 1), Mutsumi Miyachi obtained a fission-track age of 29.1±1.4 m.y. (table 2). The latter age is close to that of the quartz latite in the Latir Peak volcanic field, about 25 mi (40 km) northwest of Cimarron Canyon (fig. 1*A*). H.H. Mehnert and P.W. Lipman (oral commun., 1982), obtained K-Ar ages ranging from 20 to 28 m.y. for samples from the Latir Peak field, and they suggest that the intrusive body west of Cimarron was contemporaneous with the extrusive rocks at Latir Peak.

The rocks west of Cimarron were called porphyritic monzonite by Smith and Ray (1943, p. 904) and dacite by Wanek (1963), Wanek and others (1964), and Robinson and others (1964). The eastern tip of the complex was mapped by Simms (1965), who referred to granodiorite porphyry intrusives occurring as sills in an elongate laccolith. The variety of rock names applied to the mass is apparently due in part to variation in size and abundance of phenocrysts and to some variation in composition, as well as to different petrographic nomenclatures used by the authors.

Rhyodacite from the valley of the South Fork Urraca Creek (tables 20 and 21) in the NE¼SW¼ sec. 2, T. 25 N., R. 18 E., south of Tooth of Time Ridge, is a light-gray rock containing abundant large phenocrysts of feldspar. A thin section of this rock (specimen 80SM45; table 21 contains about 15 percent oligoclase-andesine phenocrysts (some laumontitized), many larger than 8 mm; 5 percent relics of hornblende phenocrysts altered to a gold-yellow mineral; 1 percent dark mica partly altered to an olive-green mineral with optic angle near (–)0° (smectite?); scattered prismatic crystals of apatite as large as 0.15 mm; scattered titanite and black opaque oxide crystals; and, rarely, rounded and embayed crystals of quartz as large as 10 mm. The groundmass is finely holocrystalline and sugary textured and is made up of quartz, alkali feldspar, scattered interstitial mica, and opaque oxides.

Chemical analysis and neutron activation analysis of the rhyodacite (tables 20 and 21) show that it contains about 67 percent SiO_2. The R_1R_2 parameters of the sample fall well within the rhyodacite field of figure 7*B*. The neutron activation analysis (table 21) shows concentrations of elements close to that of average crustal abundance; hence the rhyodacite apparently had a source in the Earth's crust.

SYENITE AND TRACHYTE SILLS EAST OF CIMARRON

Scattered outcrops of syenite and trachyte sills from 1 to 6 ft (0.3–1.8 m) thick intrude the Pierre Shale over an area of nearly 25 mi^2 (64.8 km^2) east and south of Cimarron. The rock is medium gray to pale yellowish brown, aphanitic, and very hard, and weathers light

TABLE 20.—*Chemical analysis and norm of rhyodacite west of Cimarron, New Mexico*

[Data in weight percent]

Field No.	81SM24
Lab. No.	D242011
Major oxides	
SiO_2	66.9
Al_2O_3	16.6
Fe_2O_3	1.33
FeO	1.13
MgO	0.84
CaO	3.03
Na_2O	4.14
K_2O	2.92
Volatiles[1]	1.72
TiO_2	0.25
P_2O_5	0.14
MnO	0.05
Total	99.1

La Roche classification	
R_1	2237
R_2	692
Name	Rhyodacite
Normative composition	
q	24.65
or	17.73
ab	35.99
an	14.50
c	1.49
hy-en	2.15
hy-fs	0.67
mt	1.98
il	0.49
ap	0.34

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITY

Rhyodacite from outcrop one-half mile (0.8 km) east of the Palisades in Cimarron Canyon on U.S. Highway 64, Ute Park quadrangle.

TABLE 21.—*Neutron-activation analysis of a sample of rhyodacite west of Cimarron, New Mexico*

[Elemental compositions in parts per million. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No.	80SM45	
Lab No.	925108	
Na	33,000	±300
Mg	3,800	±800
Al	84,000	±2,000
Cl	<110	
K	24,000	±2,000
Ca	19,000	±1,000
Ti	1,300	±200
V	26	±3
Mn	251	±3
Cu	<300	
Sr	820	±90
I	<20	
Ba	1,450	±60
Dy	<0.8	
U	1.44	±0.02
Ga	<120	
As	<3	
Br	<2	

Sb	<0.4	
La	20.7	±0.4
Sm	3.4	±0.2
W	<5	
Au	<0.01	
Sc	1.96	±0.04
Cr	5.1	±0.9
Fe	17,500	±500
Co	4.1	±0.2
Zn	48	±8
Se	2.6	±0.3
Rb	66	±5
Cs	2.3	±0.2
Ce	35	±1
Eu	0.78	±0.05
Tb	0.22	±0.07
Yb	0.30	±0.07
Lu	<0.03	
Hf	3.8	±0.3
Ta	0.30	±0.08
Th	3.0	±0.1

DESCRIPTION OF SAMPLE LOCALITY

Rhyodacite from outcrop in the valley of South Fork Urraca Creek in the NE¼SW¼ sec. 2, T. 25 N., R. 18 E., south of Tooth of Time Ridge, Miami 15-minute quadrangle.

olive gray. In thin sections (specimen 81SM10, from SW¼SW¼ sec. 12, T. 26 N., R. 19 E., on south side of New Mexico Highway 58, and specimen 81SM39, from NW¼SW¼ sec. 6, T. 26 N., R. 20 E.) the texture is jackstraw-like. Alkali feldspar laths as much as 0.4 mm in length are abundant in bundles and rosettes. Dark mica crystals as long as 0.3 mm are common, along with amphibole(?) as slender needles as much as 0.4 mm in length, having low birefringence, positive elongation, and parallel extinction. Yellow pseudomorphous(?) masses as large as 0.3 mm are also present. Quartz is scattered throughout the rock as small grains and is also associated with carbonate in vugs and veins. Titanite is present as an accessory.

TRACHYANDESITE OF MIDDLE PINE BUTTE

A large trachyandesite dome forms the steep-sided middle Pine Butte in the northeastern part of the Pine Buttes quadrangle. The butte rises 600–800 ft (180–240 m) above the surrounding area and lies between two even higher rhyodacite domes that form the eastern and western Pine Buttes. Rock composing middle Pine Butte, termed phonolite by Collins (1949, p. 1035), was determined by Stormer (1972b) to be a trachyandesite (table 22, analysis 1). It is a light-gray porphyritic rock showing dark-red oxyhornblende crystals set in a finely crystalline groundmass.

In thin section (specimen 81SM60, table 22, analysis 2) the porphyry is subtrachytic and contains about 15 percent embayed oxyhornblende as large as 2 mm having opacite rims, a few dusty pseudopleochroic apatite crystals as large as 0.5 mm, and traces of plagioclase. The groundmass is composed chiefly of subparallel plates of plagioclase (oligoclase?), clinopyroxene prisms, and abundant opaque oxides in an alkali feldspar(?) mesostasis; some secondary carbonate is present.

The chemical analyses and norms (table 22) show that the trachyandesite has a low SiO_2 content and is nearly quartz free in the norm. It has a fairly high potassium content and about 15.5 percent orthoclase in the norm.

RED MOUNTAIN RHYODACITE

The name "Red Mountain dacites" was given by Collins (1949, p. 1031) to rocks that crop out at Red Mountain volcano (fig. 13*A*) on Johnson Mesa in eastern Colfax County and to similar rocks at other volcanoes in

TABLE 22.—*Chemical analyses and norms of trachyandesite porphyry of middle Pine Butte, Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample --	1	2
Field No.	199	81SM60
Lab No.--	---	D242015
Major oxides		
SiO_2 ---	54.78	55.5
Al_2O_3 --	17.59	17.7
Fe_2O_3 --	6.06	6.75
FeO ----	0.55	0.04
MgO ----	2.60	2.36
CaO ----	6.35	6.34
Na_2O ---	5.64	5.42
K_2O ----	2.54	2.65
H_2O^+ ---	0.88	n.d.
H_2O^- ---	0.19	n.d.
Vols.[1]--	n.d.	0.55
TiO_2 ---	0.92	0.88
P_2O_5 ---	0.87	0.91
MnO ----	0.16	0.15
Total	99.1	99.3

Sample --	1	2
Field No.	199	81SM60
Lab No.--	---	D242015
La Roche classification		
R_1 --	871	965
R_2 --	1,166	1,144
Name	Trachy-andesite.	Trachy-andesite.
Normative composition		
q ---	0.00	1.34
or --	15.30	15.86
ab --	48.64	46.44
an --	15.47	16.35
di-wo	4.34	2.98
di-en	3.75	2.57
hy-en	1.23	3.38
ol-fo	1.13	0.00
hm --	6.18	6.84
il --	1.53	0.41
tn --	0.32	1.66
ap --	2.10	2.18

[1]Volatiles, probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Trachyandesite from blocks on north slope of middle Pine Butte, SW¼ sec. 3, T. 27 N., R. 26 E., Pine Buttes quadrangle. (Sample 199 of Stormer, 1972b, tables 1 and 7).
2. Trachyandesite from middle Pine Butte in the SE¼SW¼ sec. 3, T. 27 N., R. 26 E., Pine Buttes quadrangle.

the area. Collins' type locality at Red Mountain occurs in secs. 22 and 23, T. 31 N., R. 26 E., Colfax County, N. Mex. In the classification used here (La Roche and others, 1980) the rock at Red Mountain itself plots as rhyodacite close to dacite, whereas those at most of the other localities sampled are clearly rhyodacite (fig. 7*B*, field 23). In addition to the occurrence at Red Mountain volcano, this is the chief rock type at Palo Blanco Mountain (fig. 13*B*), Pine (Timber) Buttes, Green Mountain, Towndrow Peak, Cunningham Butte volcano, Raspberry Mountain, and Laughlin Peak (fig. 13*C*). Staatz (1985) gives detailed descriptions of the rhyodacite at Raspberry Mountain and Laughlin Peak.

Diameters of the bases of these volcanoes, excluding flanking landslides, range from 0.25 to 1.5 mi (0.4 to 2.4 km), and the crests range in elevation above the surrounding country from 400 to 1,200 ft (120–360 m). Gullies channeling the flanks of the volcanoes provide access to the least weathered rock. The forms of these edifices and the persistent presence of oxyhornblende and opacite in their rocks, rather than common green hornblende, indicate that they are volcanic domes; that is, they were extruded slowly as hot but highly viscous magma, with time for the hornblende to be roasted to oxyhornblende or opacite pseudomorphs.

That at least some explosive activity accompanied the extrusion of the domes is indicated by the local occurrences of pumiceous pyroclastic deposits, such as in the lahar (mudflow; Tl on fig. 6) on the north flank of Laughlin Peak, which extends downslope to the north and northeast for almost 4 mi (6 km). The lahar contains blocks of pumice as large as 6 ft (1.8 m) across (fig. 14). The pumice has a subparallel flowage texture. This deposit is pinkish gray to medium gray and is unsorted; blocks of pumice, vitrophyre, and banded rhyodacite are not in contact with each other but apparently moved in a suspension of fine sand- and silt-sized vitrophyre during transport. The lahar is at least 25 ft (7.6 m) thick. Along a circling road south of Laughlin Peak, an unmapped stratified pumiceous deposit containing vitrophyre and pumice lumps and glass shards apparently is a water-laid tuff. Artifacts composed of vitrophyre show that local Indian tribes used this deposit as a source of stone for tools.

A K-Ar age of the hornblende in a probably weathered rhyodacite at Cunningham Butte was determined by Stormer (1972a) as 8.2±0.8 m.y. (8.40±0.8 m.y. based on new decay constants). In the present study the hornblende of a less weathered sample of rock from a quarry in the dike at the west end of Cunningham Butte was dated as 6.9±1.0 m.y. and 7.6±1.1 m.y. (table 1). Four other K-Ar ages on hornblendes from three of the domes (table 1) range from 6.43±0.67 to 7.6±1.1 m.y., giving a mean of 7.01 m.y. K-Ar ages determined on plagioclase in the same rocks showed greater scatter and were generally younger. A K-Ar age of hornblende from a large block of pumice in the lahar deposit at Laughlin Peak (specimen 80SM37, table 1) was determined to be 6.90±0.80 m.y., similar to the hornblende ages of the domes and the dike. One measured K-Ar age of the plagioclase, 21.79±2.22 m.y., is anomalously old, possibly due to contamination of the pumice by old detrital feldspar. A K-Ar age of 8.1±0.6 m.y. on hornblende was reported by Staatz (1985, p. E17) from a sample on the northeast part of Raspberry Mountain in sec. 18, T. 27 N., R. 26 E., Colfax County, N. Mex. He reported another age of 7.7±0.5 m.y. for a sample from the knoll at the north end of southwest Pine Buttes dome (Staatz, 1986).

The rhyodacite ranges from gray to orange pink or pale red, is generally nonvesicular, and has textures variously porphyritic or seriate. Phenocrysts are plagioclase and hornblende (in most cases oxyhornblende) in a hyalocrystalline, pilotaxitic, or totally glassy ground-

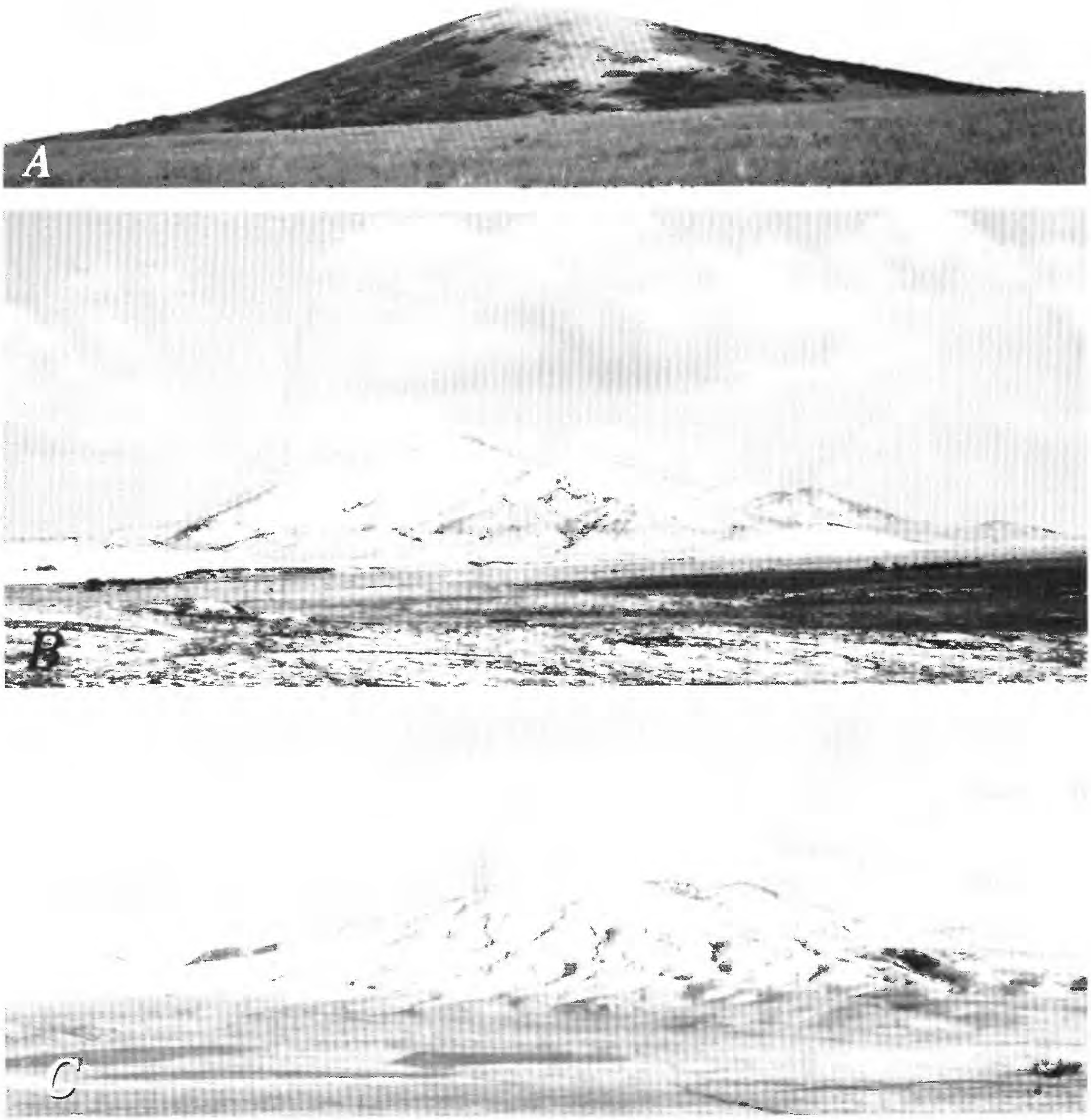


FIGURE 13. Volcanoes consisting of Red Mountain Rhyodacite in the Raton-Springer area.

A, Red Mountain from the northwest, the type locality. Mountain lies in the E½ sec. 22 and the W½ sec. 23, T. 31 N., R. 26 E., Dale Mountain quadrangle.

B, Palo Blanco Mountain from the north. Mountain lies in secs. 8, 9, 16, and 17, T. 27 N., R. 27 E., Palo Blanco Mountain quadrangle. East (left) side has steeply tilted sedimentary beds.

C, Laughlin Peak from the north, showing deep erosion into pumiceous laharic deposits on flank of cone. Mountain is in secs. 28, 29, 32, and 33, T. 28 N., R. 26 E., Mesa Larga and Pine Buttes quadrangles. Outcrop of Dakota Sandstone (Upper Cretaceous) is at crest of mountain (M. H. Staatz, oral commun., 1980).

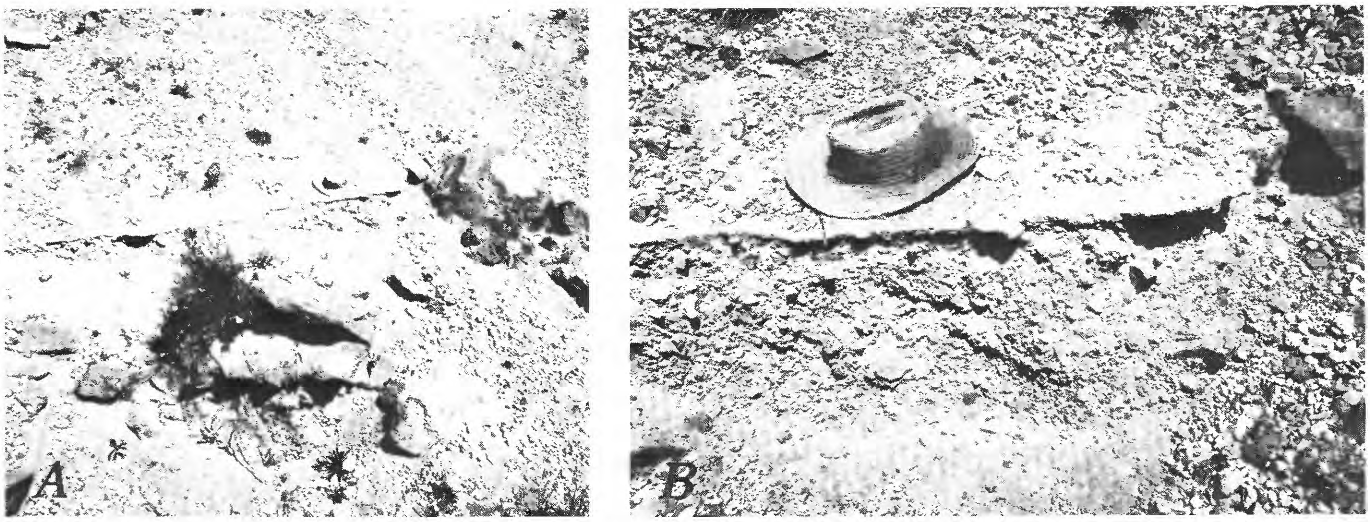


FIGURE 14.—Pumiceous rhyodacitic lahar on north flank of Laughlin Peak in the SE¼ sec. 19, T. 28 N., R. 26 E., Mesa Larga quadrangle. *A*, Wide view showing large blocks of pumice. *B*, Closeup of lahar, showing smaller clasts. Hat is approximately 12 inches (30 cm) across.

mass. The rock ranges from a red and gray, fluidally banded variety having as much as 85 percent glassy groundmass (at Laughlin Peak and Green Mountain) to a crystal-rich porphyry having little more than 30 percent glassy or finely crystalline groundmass. The rapid quenching during eruption of the glassy phases prevented the conversion of the hornblende to oxyhornblende and preserved the common green hornblende. Green hornblende is also preserved in dikes of rhyodacite, such as that trending northwestward from Cunningham Butte. In the dikes, the confining pressure during intrusion of the magma would have prevented breakdown of the hydroxyl-bearing minerals.

Mertie (1922, p. 10) gave the modal composition of rhyodacite lava from Towndrow Peak as 21 percent feldspar, 10 percent basaltic hornblende (oxyhornblende), 2 percent magnetite (opaque oxide), and 67 percent glass. Stobbe (1949, p. 1068) gave the modal composition of the dacite at Red Mountain as 28.7 percent plagioclase, 9.7 percent hornblende, 4.4 percent magnetite, and 57.2 percent glass.

In thin section, specimen 80SM6 from the west end of Towndrow Peak (table 23, analysis 1; locality 10 on fig. 6) is porphyritic to seriate in texture and contains about 30 percent plagioclase (oligoclase-andesine) phenocrysts as large as 1.5 mm, 10 percent oxyhornblende phenocrysts as long as 2 mm (extinction angle $Z{:}c=2°$), and sparse stubby crystals of apatite. The groundmass consists mainly of glass containing microlitic needles of opaque oxide (pseudomorphs of hornblende microlites?).

Specimen 80SM12 (table 23, analysis 60) from Palo Blanco Mountain is porphyritic and contains about 35 percent plagioclase phenocrysts as large as 1.4 mm, 15 percent oxyhornblende phenocrysts as long as 0.5 mm, 5 percent opaque oxide crystals as large as 0.05 mm, and a few crystals of corroded oxybiotite. The groundmass is isotropic and has strong negative relief (glass?).

Specimen 80SM3 (table 23, analysis 13) from Green Mountain is porphyritic and contains about 12 percent plagioclase phenocrysts of two types: (a) clear euhedral crystals of andesine as large as 0.3 mm and (b) internally corroded crystals as large as 1 mm with clear rims. It also includes 3 percent prismatic oxyhornblende phenocrysts as large as 0.2 mm, some in clots having opacite rims. The groundmass has hyalocrystalline texture, is composed of plagioclase glass(?) and small amounts of oxyhornblende and opaque oxide, is inhomogeneous, is both clear and cloudy brown (buff in reflected light), and contains rusty colored hornblende crystals.

Specimen 80SM37 (table 23, analysis 12; also table 1; locality 13 on fig. 6), from a vesicular, glassy pumice block in the lahar on the north side of Laughlin Peak, is porphyritic and contains about 3 percent strongly zoned plagioclase (andesine) phenocrysts and 2 percent olive-green hornblende as large as 0.4 mm. Its trachytic groundmass is about one-half plagioclase tablets and one-half glass (or cristobalite?) containing a few hornblende needles and opaque oxide grains.

Specimen 80SM18 (table 23, analysis 3; locality 11 on fig. 6), from a quarry in a dike that trends northwestward from Cunningham Butte, is porphyritic and contains about 5 percent prismatic green hornblende as long as 1 mm and 3 percent stubby plagioclase (andesine-labradorite) phenocrysts as large as 0.7 mm. Its groundmass is pilotaxitic in texture, and about one-half is plagioclase (oligoclase-andesine) and the rest opaque

TABLE 23.—*Chemical analyses and norms of Red Mountain*

[Data in weight percent.

Sample -----	1	2	3	4	5	6	7
Field No.---	80SM6	(From Stobbe,	80SM18	277	MHS-16-81	80SM12	MHS-94-80
Lab No.-----	D229686	1949)	D231887	---	D240836	D229692	D229972
			Major oxides				
SiO_2 -------	65.2	66.01	66.9	67.04	67.2	67.7	67.8
Al_2O_3 ------	16.1	14.57	15.60	15.6	15.4	15.2	15.1
Fe_2O_3 ------	3.62	4.16	1.82	1.84	2.87	2.90	2.31
FeO --------	0.08	n.d.	1.01	0.89	0.24	0.09	0.20
MgO --------	1.9	0.20	1.28	1.29	1.24	1.2	1.2
CaO --------	4.24	3.71	3.96	3.96	3.18	3.13	3.09
Na_2O -------	4.4	5.24	4.50	4.61	3.96	4.1	3.6
K_2O --------	2.28	2.34	2.38	2.36	2.80	2.99	3.01
H_2O^+ -------	n.d.	n.d.	n.d.	1.34	n.d.	n.d.	2.23
H_2O^- -------	n.d.	n.d.	n.d.	0.38	n.d.	n.d.	0.45
Volatiles[1]--	1.36	n.d.	1.06	n.d.	2.03	1.55	n.d.
TiO_2 -------	0.47	n.d.	0.37	0.43	0.38	0.36	0.32
P_2O_5 -------	0.3	n.d.	0.23	0.21	0.22	0.2	0.2
MnO --------	0.05	n.d.	0.02	0.04	0.05	0.04	0.04
CO_2 --------	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.09
Total	100.0	96.23	99.1	99.99	99.6	99.5	99.6
			La Roche and others (1980) classification				
R_1 ---------	2,142	1,958	2,237	2,203	2,297	2,282	2,482
R_2 ---------	864	720	800	797	705	696	692
Name---------	Dacite/ rhyodacite.	Dacite/ rhyodacite.	Rhyodacite/ dacite.	Rhyodacite/ dacite.	Rhyodacite	Rhyodacite	Rhyodacite
			Normative composition				
q ----------	20.44	21.08	22.92	22.49	26.05	25.00	28.61
or ---------	13.66	14.37	14.34	14.19	16.96	18.04	18.34
ab ---------	37.74	46.08	38.82	39.69	34.35	35.43	31.41
an ---------	17.68	9.69	15.64	15.16	14.70	14.52	13.87
c ----------	0.00	0.00	0.00	0.00	0.61	0.01	1.02
wol --------	0.00	3.34	0.00	0.00	0.00	0.00	0.00
di-wo ------	0.21	0.60	1.19	1.43	0.00	0.00	0.00
di-en ------	0.18	0.52	1.03	1.24	0.00	0.00	0.00
hy-en ------	4.61	0.00	2.22	2.03	3.17	3.05	3.08
hy-fs ------	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mt ---------	0.00	0.00	2.29	1.78	0.00	0.00	0.00
hm ---------	3.67	4.32	0.27	0.64	2.94	2.96	2.38
il ---------	0.28	0.00	0.72	0.83	0.63	0.28	0.52
tn ---------	0.81	0.00	0.00	0.00	0.00	0.00	0.00
ru ---------	0.00	0.00	0.00	0.00	0.06	0.22	0.05
ap ---------	0.72	0.00	0.56	0.51	0.53	0.48	0.49
cc ---------	0.00	0.00	0.00	0.00	0.00	0.00	0.21

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of

DESCRIPTION OF SAMPLE LOCALITIES

1. Rhyodacite/dacite from the west end of Towndrow Peak in the NW¼SE¼ sec. 22, T. 31 N., R. 25 E., Yankee quadrangle.
2. Dacite/rhyodacite from Cunningham Butte in sec. 36, T. 30 N., R. 24 E., Hunter Mesa quadrangle (Stobbe, 1949, p. 1067).
3. Rhyodacite from quarry in dike trending northwestward from Cunningham Butte in the SW¼ sec. 25, T. 30 N., R. 24 E., Hunter Mesa quadrangle.
4. Rhyodacite from quarry in dike west of Cunningham Butte in the north center of sec. 31, T. 30 N., R. 24 E., Hunter Mesa quadrangle (sample 277 of Stormer, 1972b, figure 2 and table 5).
5. Rhyodacite from top of western Pine Butte in the SW¼SW¼ sec. 10, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).
6. Rhyodacite from Palo Blanco Mountain in the SW¼SE¼ sec. 17, T. 27 N., R. 27 E., Palo Blanco Mountain quadrangle.
7. Rhyodacite from southeast flank of eastern Pine (Timber) Buttes in the SE¼SE¼ sec. 11, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).

Rhyodacite samples from Raton-Springer area, New Mexico

n.d., not determined]

Sample -----	8	9	10	11	12	13	14
Field No.---	M-15	MHS-67-80	MHS-93-80	MHS-74-80	80SM37	80SM3	MHS-119-80
Lab No.-----	---	D229966	D229971	D229970	D231895	D229683	D229973
				Major oxides			
SiO_2 -------	67.98	68.0	68.1	69.0	69.7	70.6	70.9
Al_2O_3 ------	15.53	15.1	15.7	16.0	15.0	15.4	15.6
Fe_2O_3 ------	2.68	2.30	2.11	1.50	0.83	1.43	1.40
FeO --------	0.18	0.39	0.88	0.43	0.83	0.21	0.36
MgO --------	1.47	1.1	1.3	0.3	0.55	0.61	0.1
CaO --------	3.39	3.20	3.34	2.47	2.49	2.50	1.90
Na_2O -------	4.53	4.0	4.0	3.7	4.13	4.6	4.0
K_2O --------	3.00	2.94	2.68	2.83	3.13	2.86	2.64
H_2O^+ -------	1.05	1.36	1.25	2.28	n.d.	n.d.	1.06
H_2O^- -------	0.11	0.23	0.28	0.55	n.d.	n.d.	0.22
Volatiles[1]--	n.d.	n.d.	n.d.	n.d.	2.64	1.34	n.d.
TiO_2 -------	0.34	0.33	0.38	0.22	0.20	0.17	0.21
P_2O_5 -------	0.33	0.2	0.2	<0.1	0.07	<0.1	<0.2
MnO --------	0.04	0.05	0.05	<0.02	0.02	0.04	<0.02
CO_2 --------	n.d.	0.11	0.08	0.02	n.d.	n.d.	0.01
Total	100.63	99.3	100.4	99.3	99.6	99.85	98.4
			La Roche and others (1980) classification				
R_1 ---------	2,126	2,367	2,397	2,592	2,405	2,360	2,675
R_2 ---------	736	700	729	600	590	601	523
Name -------	Rhyodacite/ dacite.	Rhyodacite	Rhyodacite	Rhyodacite	Rhyodacite/ rhyolite.	Rhyodacite/ rhyolite.	Rhyodacite/ rhyolite.
				Normative composition			
q ----------	22.06	26.45	26.58	32.10	28.36	27.32	34.30
or ---------	17.82	17.78	16.02	17.34	19.08	17.15	16.06
ab ---------	38.53	34.63	34.25	32.45	36.04	39.51	34.85
an ---------	13.25	14.20	14.93	12.57	12.27	11.93	9.64
c ----------	0.00	0.26	0.82	2.49	0.47	0.44	2.79
wol --------	0.00	0.00	0.00	0.00	0.00	0.00	0.00
di-wo ------	0.48	0.00	0.00	0.00	0.00	0.00	0.00
di-en ------	0.42	0.00	0.00	0.00	0.00	0.00	0.00
hy-en ------	3.26	2.80	3.28	0.77	1.41	1.54	0.26
Hy-fs ------	0.00	0.00	0.00	0.00	0.56	0.00	0.00
mt ---------	0.00	0.47	1.92	0.78	1.24	0.32	0.57
hm ---------	2.69	2.03	0.81	1.02	0.00	1.23	1.05
il ---------	0.47	0.64	0.73	0.43	0.39	0.33	0.41
tn ---------	0.23	0.00	0.00	0.00	0.00	0.00	0.00
ru ---------	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ap ---------	0.79	0.48	0.48	0.00	0.17	0.24	0.00
cc ---------	0.00	0.26	0.18	0.05	0.00	0.00	0.02

loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

8. Rhyodacite from Red Mountain in center of W½ sec. 23, T. 31 N., R. 26 E., Dale Mountain quadrangle (sample M-15 of Mertie, 1922, p. 11).
9. Rhyodacite from steep northeast flank of Raspberry Mountain in NW¼NE¼NE¼ sec. 18, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).
10. Rhyodacite from lower south flank of Palo Blanco Mountain in the SW¼SE¼ sec. 17, T. 27 N., R. 27 E., Palo Blanco quadrangle (Staatz, 1985).
11. Rhyodacite tuff from north side of county road A-8, 951 ft (290 m) northeast of ranch house in the SE¼ sec. 5, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).
12. Rhyodacite glassy block in pumiceous lahar on north flank of Laughlin Peak in the NW¼SE¼ sec. 19, T. 28 N., R. 26 E., Mesa Larga quadrangle.
13. Rhyodacite from Green Mountain in the NW¼NW¼ sec. 23, T. 29 N., R. 25 E., Tinaja Mountain quadrangle.
14. Rhyodacite/rhyolite from peak 8632 on southwest flank of Laughlin Peak in NE¼ sec. 32, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).

oxide grains in an extremely fine mesostasis of tridymite(?) and glass(?); carbonate occurs rarely.

The rhyodacite unit includes the most siliceous rock type in the area, and normative quartz ranges from 20 to 34 percent (table 23). All of the samples contain very little Fe_2O_3, FeO, and MgO, and as a result have only small amounts of iron oxide and ferromagnesian minerals in their norms.

Neutron activation analysis of a sample from the unit (table 24; specimen 80SM12) shows an elemental composition similar to average crustal abundance as listed by Carl Orth in table 19. The high amount of barium possibly is the result of enrichment from local sedimentary rocks.

TABLE 24.—*Neutron-activation analysis of a sample of Red Mountain Rhyodacite, Raton-Springer area, New Mexico*

[Elemental compositions in parts per million. See table 23 for description of sample locality. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No.	80SM12			
Lab. No.	925106			
Na	31,400	±300	Sb	<0.4
Mg	9,400	±1,000	La	30.9 ±0.6
Al	81,000	±2,000	Sm	3.0 ±0.1
Cl	230	±50	W	<5
K	22,000	±2,000	Au	<0.01
Ca	21,000	±2,000	Sc	4.38±0.09
Ti	2,600	±200	Cr	15 ±2
V	40	±3	Fe	22,700 ±700
Mn	422	±5	Co	7.2 ±0.3
Cu	<300		Zn	<5
Sr	900	±100	Se	2.2 ±0.4
I	<20		Rb	34 ±5
Ba	1,390	±60	Ce	44 ±2
Dy	2.0 ±0.3		Eu	0.75±0.06
U	2.75±0.02		Tb	<0.2
Ga	<120		Yb	0.9 ±0.1
As	<3		Lu	0.10±0.02
Br	<2		Hf	2.9 ±0.3
			Ta	1.6 ±0.2
			Th	7.3 ±0.3

MAFIC FELDSPATHOIDAL ROCKS

The mafic feldspathoidal rocks are chiefly flows, but also include cinder cones and plugs. They are predominantly basanitic, although some are nephelinitic and tephritic. The rocks called nepheline basalt and hauyne basalt by Stobbe (1949, p. 1060) are nephelinite and hauyne basanite in the chemical classification of La Roche and others (1980). The mafic feldspathoidal rocks crop out over a broad area from near Raton eastward to Capulin, just east of the map area. They comprise both old flows on high mesas, such as Johnson Mesa, as much as 1,200 ft (360 mm) above modern drainage, and young flows only a few hundred feet above the drainage. Dale Mountain on Johnson Mesa (fig. 15) is a shield volcano of gently sloping basanite flows. In outcrop, the lavas are medium light gray to dark gray, finely crystalline to aphanitic, dense, hard, and slightly vesicular, and they weather spheroidally (fig. 16). Many vesicles are filled with calcite. Phenocrysts are not obvious in hand specimen.

Although the feldspathoidal character of many of the rocks is not readily apparent even in thin section, it shows up in the normative minerals and also becomes apparent on sawed surfaces treated with phosphoric acid and stained with methylene blue (Shand, 1939). Inasmuch as this test for feldspathoidal content was not made on all the mafic extrusives, some feldspathoidal flows and their cinder cones may be included with the basalt on the geologic map (fig. 6).

FIGURE 15.—Dale Mountain, a shield volcano of basanite in the NE¼ sec. 17, T. 31 N., R. 26 E., Dale Mountain quadrangle.

FIGURE 16.—Spheroidal weathering and vesicles in basanite (specimen 80SM44) in roadcut on north side of New Mexico Highway 72 near Manco Burro Pass in the NW¼SE¼NW¼ sec. 10, T. 31 N., R. 25 E., Yankee quadrangle. Most vesicles are filled with calcite. Long dimension of boulder is 2 ft (0.6 m).

The basanite cinder cones are steep-flanked hills composed of scoria, bombs, lapilli, and ash. Many cones have breached craters. Most of the cinder cones are in the Robinson Peak quadrangle, and Robinson Peak itself and Jose Butte were the vents for many basanite flows. Erosion has removed some cinder cones and exposed the central conduits as conical knobs. Two of these crop out in the SW¼ sec. 32, T. 27 N., R. 25 E., and in the NW¼NW¼ sec. 3, T. 26 N., R. 24 E.

Ages of the basanite flows (table 1, numbers 6, 7, 8, and 9) range from late Miocene to at least the end of Pliocene time and probably into Pleistocene time in the Robinson Peak quadrangle. A K-Ar age on plagioclase from the basanite on Johnson Mesa near Manco Burro Pass was determined as 7.2±0.3 m.y. by Stormer (1972a) (7.38 by the new decay constants, table 3); our specimen from the same locality yielded an age of 8.19±0.31 m.y. (specimen 80SM44, table 1).

In thin section, most of the mafic feldspathoidal rocks have porphyritic textures and intersertal, pilotaxitic or hyalopilitic groundmasses. Only basanites were found in the present study, but nephelinites and ankaratrites have been described by other workers (Mertie, 1922; Aoki, 1967, table 1; Stobbe, 1949; Stormer, 1972b). The basanites contain phenocrysts of olivine and clinopyroxene; some also contain plagioclase and opaque oxide. Where groundmasses are coarse enough for the recognition of minerals, clinopyroxene, plagioclase, opaque oxide, and, in some samples, nepheline are seen. Sparse xenocrysts of quartz with pyroxene coronas are seen in some specimens. As to the nephelinites, according to Stormer (1972b, p. 3302) the olivine nephelinite contains phenocrysts of nepheline or hauyne in addition to those of olivine and augite. The groundmass is fine grained and consists of augite accompanied by either nepheline or plagioclase. In addition, Stobbe (1949, p. 1062) noted the presence of quartz xenocrysts in some specimens.

Among the samples collected in this study, a basanite (specimen 80SM7, table 25, analysis 5) contains about 10 percent olivine phenocrysts as large as 0.5 mm, many with dark rims; 3 percent clinopyroxene phenocrysts as large as 0.4 mm, some zoned and with mottled cores; and about 5 percent quartz xenocrysts, as large as 0.7 mm in diameter, having reaction coronas. Its groundmass is inhomogeneous and fine grained and is composed of about equal amounts of yellow-brown clinopyroxene prisms and equant opaque oxide grains, small amounts of intersertal nepheline(?), scattered clumps of an unknown material having radiating needles of high positive relief and low birefringence, and an unknown colorless isotropic material of negative relief.

Specimen 80SM8, a basanite from sec. 6, T. 30 N., R. 28 E. (table 25, analysis 6; locality 6 on fig. 6), is porphyritic and contains about 30 percent olivine phenocrysts as large as 0.6 mm showing yellow alteration along fractures; 3 percent clinopyroxene phenocrysts as large as 0.8 mm, mostly in groups; and sparse quartz xenocrysts having coronas of fine pyroxene and opaque oxide. The groundmass has a finely intersertal texture and is composed of about equal amounts of clinopyroxene, plagioclase, and opaque oxide.

Specimen 80SM21, a basanite from a quarry in the NW¼ sec. 16, T. 31 N., R. 26 E. (table 25, analysis 7; locality 8 on fig. 6) is porphyritic and contains about 30 percent olivine phenocrysts as large as 0.6 mm; 20 percent yellow clinopyroxene phenocrysts; and 10 percent plagioclase (labradorite) phenocryst tablets as large as 0.8 mm. The groundmass is a dense, nearly opaque glass and an opaque oxide. About 10 percent of the rock is vesicles lined with a material of high relief, white in reflected light.

Specimen 80SM44, a basanite from a roadcut in the NW¼ sec. 10, T. 31 N., R. 25 E. (table 25, analysis 8; locality 9 on fig. 6) is porphyritic and contains about 20 percent brown-green clinopyroxene phenocrysts as large as 0.6 mm, showing hourglass zoning and an optic angle of about (+)45°; 10 percent olivine phenocrysts as large as 0.6 mm with iddingsitized rims; and scattered

TABLE 25.—*Chemical analyses and norms of mafic*

[Data in weight percent.

Sample -------	1	2	3	4	5	6
Field No.-----	1	1861	B-15	116	80SM7	80SM8
Lab No.-------	---	---	---	---	D229687	D229688
			Major oxides			
SiO_2 ---------	36.74	40.66	40.72	41.31	42.1	44.2
Al_2O_3 --------	13.70	12.76	15.03	13.91	12.9	13.9
Fe_2O_3 --------	10.85	8.91	5.52	5.49	7.12	4.14
FeO ----------	1.75	2.89	6.86	6.77	4.21	8.42
MgO ----------	7.65	9.27	8.29	8.32	8.74	9.91
CaO ----------	14.37	13.17	13.95	12.35	12.9	11.4
Na_2O ---------	4.68	4.22	4.01	4.66	3.4	3.2
K_2O ----------	1.90	1.71	2.34	1.46	0.77	1.12
H_2O^+ ---------	1.42	1.07	0.32	1.03	n.d.	n.d.
H_2O^- ---------	1.35	0.20	0.12	0.09	n.d.	n.d.
Volatiles[1] ---	n.d.	n.d.	n.d.	n.d.	3.38	0.98
TiO_2 ---------	1.83	2.10	0.99	1.99	1.92	1.79
P_2O_5 ---------	2.87	1.99	1.75	1.97	1.9	1.1
MnO ----------	0.24	0.24	0.18	0.29	0.20	0.20
Total ---	99.35	99.19	100.08	99.64	99.5	100.4
		La Roche and others (1980) classification				
R_1 -----------	(-)26	458	387	381	1,078	1,158
R_2 -----------	2,230	2,141	2,199	2,016	2,076	1,977
Name ---------	Olivine nephelinite.	Ankaratrite/ nephelinite.	Ankaratrite/ nephelinite.	Nephelinite	Basanite	Basanite
			Normative composition			
or -----------	0.00	10.31	0.00	8.75	4.73	6.66
ab -----------	0.00	2.01	0.00	5.00	16.84	13.14
an -----------	11.14	11.04	16.16	12.90	18.35	20.37
lc -----------	9.12	0.00	10.88	0.00	0.00	0.00
ne -----------	22.21	18.65	18.45	18.95	7.07	7.63
di-wo --------	15.94	17.68	15.15	15.10	14.71	12.22
di-en --------	13.77	15.28	10.49	10.98	12.72	8.18
di-fs --------	0.00	0.00	3.42	2.73	0.00	3.13
ol-fo --------	4.17	5.80	7.17	7.03	6.93	11.66
ol-fa --------	0.00	0.00	2.58	1.93	0.00	4.92
cs -----------	1.60	0.00	1.71	0.00	0.00	0.00
mt -----------	1.16	4.09	8.03	8.07	8.99	6.04
hm -----------	10.43	6.27	0.00	0.00	1.19	0.00
il -----------	3.6	4.07	1.89	3.83	3.79	3.42
ap -----------	7.04	4.81	4.16	4.73	4.68	2.62

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Oxidized olivine nephelinite from Johnson Mesa 15 mi (24 km) east of Raton, probably from quarry on Dale Mountain in the SW¼NW¼ sec. 16, T. 31 N., R. 26 E., Dale Mountain quadrangle (Aoki, 1967, table 1).
2. Ankaratrite-nephelinite flow from Robinson Peak, near northeast corner sec. 9, T. 29 N., R. 27 E., from flow forming low mesa northwest and west of King Ranch headquarters, Robinson Peak quadrangle (sample 1861 of Stormer, 1972b, tables 1 and 7).
3. Ankaratrite/nephelinite from flow near Yankee, probably from SE¼ sec. 12, T. 31 N., R. 24 E., Yankee quadrangle (sample B-15 of Mertie, 1922, p. 11).
4. Nephelinite from flow near Yankee, center of sec. 14, T. 31 N., R. 24 E., from outlying remnant of flow at top of hill just east of Chicorica Creek, Yankee quadrangle (sample 116 of Stormer, 1972b, tables 1 and 7).
5. Basanite from SW¼NW¼NE¼ sec. 8, T. 29 N., R. 27 E., Robinson Peak quadrangle.
6. Basanite from NW¼NW¼ sec. 6, T. 30 N., R. 28 E., Robinson Peak quadrangle.

feldspathoidal rocks from Raton-Springer area, New Mexico
n.d., not determined]

Sample -----	7	8	9	10	11	12	13	14
Field No. --	80SM21	80SM44	380	80SM38	80SM39	117	80SM23	110
Lab No. ----	D231888	D231897	---	D231896	D229694	---	D229690	---
Major oxides								
SiO_2 -------	44.2	44.5	44.54	45.4	46.0	46.03	46.6	47.03
Al_2O_3 ------	14.7	14.2	14.73	14.8	14.6	14.78	14.9	16.88
Fe_2O_3 ------	6.05	5.09	6.40	6.50	3.50	5.32	6.70	6.89
FeO --------	4.90	5.32	4.68	3.20	6.90	5.19	2.90	3.78
MgO --------	9.71	8.24	9.67	8.93	8.27	7.91	8.17	5.50
CaO --------	11.0	11.3	10.89	10.5	11.2	9.47	10.6	9.05
Na_2O -------	3.11	3.37	3.27	3.26	3.8	3.86	4.2	4.69
K_2O --------	1.48	1.36	1.43	1.70	1.55	1.37	1.34	1.80
H_2O^+ -------	n.d.	n.d.	0.63	n.d.	n.d.	2.43	n.d.	0.57
H_2O^- -------	n.d.	n.d.	0.14	n.d.	n.d.	0.49	n.d.	0.12
Volatiles[1]--	0.56	3.09	n.d.	1.30	1.18	n.d.	0.90	n.d.
TiO_2 -------	1.84	2.01	1.93	1.75	1.59	1.90	1.74	1.90
P_2O_5 -------	1.20	1.05	1.16	1.21	1.2	0.99	1.3	1.23
Mno --------	0.20	0.17	0.18	0.15	0.19	0.18	0.16	0.17
Total --	99.0	99.7	99.65	98.7	100.0	99.92	99.5	99.61
La Roche and others (1980) classification								
R_1 ---------	1,171	1,126	1,137	1,187	1,031	1,055	1,009	724
R_2 ---------	1,968	1,902	1,943	1,880	1,895	1,705	1,839	1,580
Name -------	Basanite	Basanite	Basanite	Basanite	Basanite	Alkali basalt/ basanite.	Basanite	Tephrite
Normative composition								
or ---------	8.88	8.31	8.54	10.31	9.26	8.34	8.02	10.75
ab ---------	16.57	18.02	17.80	20.97	16.34	26.32	24.39	28.40
an ---------	22.12	20.28	21.52	21.27	18.41	19.53	18.08	19.89
lc ---------	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ne ---------	5.50	6.22	5.51	3.97	8.77	3.97	6.30	6.34
di-wo ------	10.58	12.78	10.62	10.05	12.47	9.27	11.11	7.24
di-en ------	8.78	10.09	9.05	8.68	8.44	7.35	9.60	6.26
di-fs ------	0.48	1.26	0.17	0.00	3.07	0.87	0.00	0.00
ol-fo ------	11.06	7.81	10.72	9.90	8.69	9.07	7.72	5.31
ol-fa ------	0.67	1.07	0.22	0.00	3.49	1.18	0.00	0.00
cs ---------	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mt ---------	8.91	7.63	9.38	5.88	5.13	7.95	4.89	7.30
hm ---------	0.00	0.00	0.00	2.61	0.00	0.00	3.42	1.92
il ---------	3.55	3.95	3.70	3.41	3.05	3.72	3.35	3.65
ap ---------	2.89	2.57	2.78	2.94	2.87	2.42	3.12	2.94

DESCRIPTION OF SAMPLE LOCALITIES

7. Basanite from quarry on Dale Mountain, in the SW¼NW¼ sec. 16, T. 31 N., R. 26 E., Dale Mountain quadrangle.
8. Basanite from Johnson Mesa in road cut in the SE¼NW¼ sec. 10, T. 31 N., R. 25 E., Yankee quadrangle. Same locality as sample 117 of Stormer (1972b, tables 1 and 7).
9. Basanite from quarry at Dale Mountain in SW¼NW¼ sec. 16, T. 31 N., R. 26 E., Dale Mountain quadrangle (Sample 380 of Stormer, 1972b, tables 1 and 7).
10. Basanite from the NW¼NE¼ sec. 20, T. 29 N., R. 28 E., Capulin quadrangle, Union County.
11. Basanite from SW¼NW¼ sec. 13, T. 26 N., R. 25 E., Point of Rocks Mesa quadrangle.
12. Alkali basalt/basanite from northwestern part of Johnson Mesa in a road cut in NW¼ sec. 10, T. 31 N., R. 25 E., Yankee quadrangle (sample 117 of Stormer, 1972b, tables 1 and 7).
13. Basanite from a quarry in the SW¼NW¼ sec. 23, T. 29 N., R. 27 E., Kiowa quadrangle.
14. Tephrite from mesa south of buildings at El Rancho Grande in the SW¼ sec. 28, T. 27 N., R. 26 E., Pine Buttes quadrangle (sample 110 of Stormer, 1972b, tables 1 and 7).

plagioclase phenocrysts as large as 0.5 mm. The groundmass has an intersertal texture and is composed of plagioclase, opaque oxide, iddingsitized olivine, clinopyroxene, and an unknown interstitial material of negative relief and low birefringence. The specimen also has scattered carbonate vesicle fillings.

Specimen 80SM38, a basanite from the NE¼ sec. 20, T. 29 N., R. 28 E., in Union County just outside the mapped area (table 25, analysis 10), is porphyritic and contains about 15 percent cloudy, pale-greenish-yellow clinopyroxene in stubby phenocrysts as large as 0.3 mm and in aggregates; 10 percent poorly formed olivine phenocrysts as large as 0.5 mm; and, rarely, platy plagioclase phenocrysts as large as 0.3 mm. The groundmass is composed of abundant clinopyroxene and opaque oxide and moderate amounts of plagioclase and feldspathoids(?). One feldspathoid is of low birefringence and low positive relief (nepheline?), and another is isotropic and has strong negative relief. Scattered vesicles have irregular shapes.

Specimen 80SM39, a basanite from the NW¼ sec. 13, T. 26 N., R. 25 E., Point of Rocks Mesa quadrangle (table 25, analysis 11; locality 7 on fig. 6) has a porphyritic texture and contains about 20 percent stubby pale-yellow-green clinopyroxene phenocrysts as large as 0.3 mm; 15 percent well-formed olivine phenocrysts as large as 2.5 mm and rimmed orange brown; and 5 percent opaque oxide crystals as large as 0.2 mm that are in part included in the olivine and clinopyroxene phenocrysts. The groundmass is composed of abundant clinopyroxene and opaque oxide and many plagioclase tablets. Sparse xenocrysts of quartz with coronas are present. Vesicles are lined with carbonate and acmite(?).

Specimen 80SM23, a basanite from a quarry in the NW¼ sec. 23, T. 29 N., R. 27 E., Kiowa quadrangle (table 25, analysis 13) is porphyritic and contains about 10 percent olivine phenocrysts as large as 0.2 mm; 10 percent zoned pale-yellow-green clinopyroxene phenocrysts as large as 0.3 mm (rarely 1 mm); 5 percent equant opaque oxide phenocrysts as large as 0.5 mm; and about 5 percent quartz, hornblende (opacite) xenocrysts, and aggregates. The groundmass is a pilotaxitic mat of clinopyroxene prisms, plagioclase laths, opaque oxide, and scattered carbonate.

Chemical analyses and norms of the mafic feldspathoidal rocks (table 25) show considerable variation. None of the norms include quartz, although SiO_2 ranges in abundance from 36.74 to 47.03 percent, and xenocrystic quartz is present in a few samples. The relation between the high CaO content and the low K_2O and Na_2O contents is also expressed in the norms as a high anorthite content and low orthoclase and albite contents.

TABLE 26.—*Neutron-activation analysis of a sample of basanite from near Folsom, New Mexico*

[Elemental compositions in parts per million. See table 25 for description of sample locality. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No.	80SM8		Sb	<0.6	
Lab. No.	925105		La	93	±1
			Sm	9.4	±0.4
Na	26,000	±300	W	<7	
Mg	60,000	±2,000	Au	<0.02	
Al	75,000	±2,000	Sc	27.6	±0.5
Cl	720	±60	Cr	350	±30
K	<5,000		Fe	99,000	±3,000
Ca	82,000	±4,000	Co	57	±2
Ti	8,800	±400	Zn	180	±30
V	254	±9	Se	<2	
Mn	1,680	±20	Rb	<20	
Cu	<400		Cs	<0.8	
Sr	1,300	±200	Ce	148	±5
I	<30		Eu	2.7	±0.1
Ba	840	±70	Tb	1.0	±0.1
Dy	4.5	±0.4	Yb	2.9	±0.2
U	2.95	±0.02	Lu	0.33	±0.04
Ga	<100		Hf	4.1	±0.4
As	<4		Ta	2.6	±0.3
Br	<3		Th	11.9	±0.5

Neutron activation analysis of a young basanite (80SM8) shows that five elements, barium, chromium, magnesium, thorium, and titanium, regarded by Carl Orth (written commun., 1983) to be diagnostic of mantle origin, exceed average crustal abundance and suggest to us a probable upper mantle origin. (See discussion and conclusions.) Basanite from the mafic feldspathoidal rocks is shown in table 26.

BASALTIC TO LATIANDESITIC EFFUSIVE ROCKS

The basaltic and latiandesitic rocks of the Raton-Springer area range in age from Pliocene to Holocene, overlapping the ages of some of the mafic feldspathoidal lavas. They form dark lava flows, most of which issued from vents now marked by steep-sided (30°) cinder cones. (The Raton 1°×2° quadrangle contains 96 such cones, of which 66 are in the eastern part under consideration here.) A few vents lack prominent cinder cones (fig. 17), either because the easily eroded cinders have been removed or because relatively little pyroclastic material was erupted; these vents are surrounded by gently sloping lava flows, forming low shield volcanoes and mesas. Exposures of dikes are few. One crops out near the northeast corner of the map area but is not shown on figure 6; it extends for 9 mi (14.5 km) northeastward into Colorado and locally is 10 ft (3 m) thick and has well-developed columnar jointing (fig. 18).

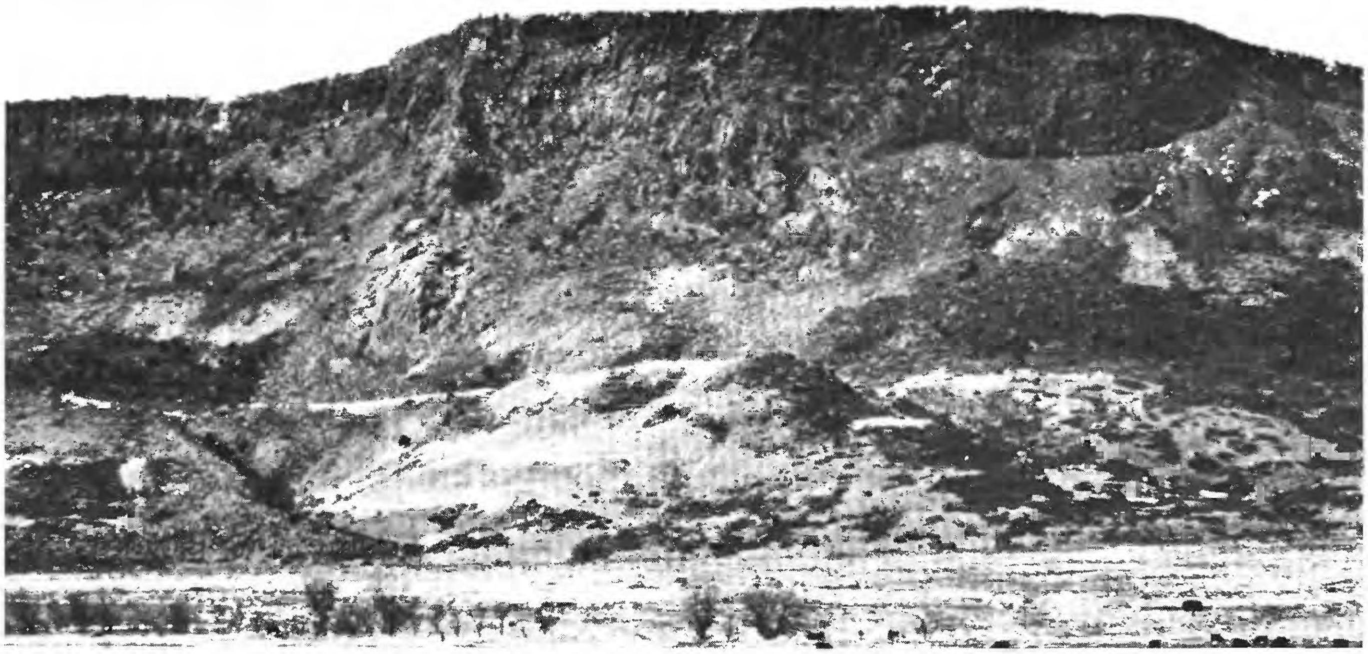


FIGURE 17.—Volcanic vent at south edge of Juan Torres Mesa, revealed in cross section by erosion. Vent lies just north of the TO Ranch headquarters in the SE¼ sec. 22, T. 30 N., R. 25 E., Hunter Mesa quadrangle.

FIGURE 18.—Olivine basalt dike with joints perpendicular to its walls in the SW¼SW¼ sec. 14, T. 35 S., R. 60 W., Trinchera Pass quadrangle.

Individual flow sheets may represent separate eruptions or merely separate surges of magma in the same eruptive episode. Flows generally are disconformable with the underlying and overlying flows, from which they are commonly separated by scoria, reddened zones, and ash. Under the lowermost flow of a series, a layer of basaltic ash and lapilli, locally more than 6 ft (1.8 m) thick, may lie between the flow itself and the gravel floor of a former valley.

Several approaches have been used in the past for subdividing these rocks. Mertie (1922) and Collins (1949, p. 1025–1026) divided them according to relative age estimated on the basis of degree of weathering and depth of dissection. Collins (1949), without distinguishing between basaltic and feldspathoidal lavas, assigned them to "Raton" (oldest), "Clayton" (intermediate), and "Capulin" (youngest) lavas. Stormer (1972b) set apart the mafic feldspathoidal lavas as a separate group overlapping in age with the basaltic rocks. He noted that the rate of dissection in the western part of the area was markedly greater than in the eastern part, owing to the Canadian River and its tributaries, and divided the basaltic rocks into only two groups: "Raton-Clayton" (older) and "Capulin" (younger). His "Raton-Clayton" group consisted mainly of alkali basalts that have a holocrystalline groundmass and contain only large olivine crystals as phenocrysts. His "Capulin" group consisted of those basalts that contain resorbed and cloudy plagioclase phenocrysts in addition to large olivine phenocrysts and that have a fine-grained, commonly clouded glassy groundmass.

Here we will follow an arrangement similar to those proposed by Mertie (1922) and by Collins (1949). These units, as given in figures 5 and 6, are the Raton (oldest), Clayton (intermediate), and Capulin (youngest). Based on comparative physiographic studies in this area and in adjacent areas to the north (Levings, 1951; Pillmore and Scott, 1976), rough allowance has been made here for rates of dissection that are less in the poorly drained eastern part of the area than in the western part. As an example, the basanite flow in the SW¼NW¼ sec. 23, T. 29 N., R. 27 E., on Melon Mesa in eastern Colfax County, might appear to be very young, judged merely on its topographic position a few tens of feet above stream level. Overlying this flow, however, is a well-developed calcrete layer, apparently equivalent to the prominent calcrete soil horizon on the Ogallala Formation of Miocene age, which could make this flow as old as 3–6 m.y. It has been assigned here as age-equivalent to the Raton Basalt. Another flow of basaltic composition in the NW¼ sec. 34, T. 27 N., R. 27 E., lies at stream level; however, it also has a well-developed calcrete layer on it; therefore we consider it contemporaneous with the Clayton Basalt.

TABLE 27.—*Heights of basaltic and latitic flows above major nearby streams or valley floors in the Raton-Springer area, New Mexico*

[Age correlations by Collins (1949) and by us]

Map No.[1]	Location	Feet	Meters
	Raton Basalt (Tb on fig. 19)		
1	Barela (Barilla) Mesa	1,200	366
2	Bartlett Mesa	1,200	366
3	Horse Mesa	1,200	366
4	Johnson Mesa (west end)	1,200	366
5	Hunter Mesa	1,200	366
6	Upper Juan Torres (Meloche) Mesa	1,200	366
7	Chavez Mesa	1,100	335
8	Kelleher Mesa	1,100	335
9	Dry Mesa	1,000	305
10	Buckhorn Mesa	600	180
11	Johnson Mesa (southeastern part)	600	180
12	Mesa Larga	600	180
13	Kiowa Mesa[2]	500	150
	Clayton Basalt (Qcb on fig. 19)		
14	Lower Juan Torres (Meloche) Mesa	550	165
15	Eagle Tail Mountain	400	120
16	Griego Mesa	400	120
17	Black Mesa	300	90
18	Dwyer Mesa	300	90
19	Blosser Mesa	300	90
20	Tinaja Mesa	300	90
21	Flows near Cunningham Butte	240	72
22	Troyburg Mesa	200	60
23	Loco Mesa	200	60
24	Flow in NE¼ Lawrence Arroyo quadrangle[3]	200	60
25	Flow in NW¼ Lawrence Arroyo quadrangle[3]	200	60
26	Round Mesa (Not Round Mesa of Collins, 1949)	200	60

[1]On figure 19.
[2]Assignment to the Raton Basalt is uncertain.
[3]Not shown on figure 19.

Table 27, on the other hand, shows the heights above modern valley floors of some of the more westerly basaltic flows. Those assigned to Raton Basalt age, for instance, range in heights from 500 to 1,200 ft (150 to 366 m) above valley floors. Several high-standing flows assigned by Stormer (1972b) to his "Capulin" group—among them those of Eagle Tail, Tinaja, Dwyer, and Blosser Mesas (fig. 6)—are here deemed equivalent to the Clayton Basalt. The few radiometric ages determined for the Raton, Clayton, and Capulin rocks in the present study (table 1) and those taken from the literature (table 3) range from about 4 m.y. to somewhat less than 8,000 years (Baldwin and Muehlberger, 1959, p. 129). Thus far no alkali basalt has been found to be as old as the 8.2-m.y. age of the basanite flow near Manco

Burro Pass on the north edge of Johnson Mesa (locality 9, table 1 and fig. 6). To establish the limits of each age unit and to identify the lava flows contained in each would require a much more detailed field and laboratory study.

In addition to measuring the heights of the Raton, Clayton, and Capulin flows above modern drainage, we have also attempted to infer the drainage system of the area near Raton during late Tertiary and early Quaternary time. Reconstructed paleovalleys of Raton Basalt, Clayton Basalt, and Quaternary ages are drawn on a map of the northern part of the Raton-Springer area (fig. 19). The areas encompassed by the Raton and Clayton paleovalleys were delimited by using K-Ar ages of rocks and heights of the mesas above present valley floors. The heights shown in table 27 can be used by the reader to assess the validity of the paleovalleys shown on figure 19. Notice that there are no topographically low (Clayton) surfaces within the bounds of the Raton paleovalley and conversely no high (Raton) surfaces within the limits of the Clayton surface. The Raton paleovalley obviously was much wider before the creation of the Clayton paleovalley; indeed we saw no preserved valley wall on either the north or south flank of the ancient Raton paleovalley, surely owing to later erosion when streams cut downward to a new Clayton valley.

The mid-Pleistocene paleovalley is shown only by a line which marks the approximate center of a buried valley that extends toward Capulin. The subsurface expression of this valley was located by drilling and described to us by ranchers living west of Capulin. We have shown no Capulin paleovalleys on figure 19 because the Capulin flows (Qb on fig. 6) still occupy the valleys and therefore are easy to recognize. The Capulin paleovalleys are essentially the same as the present drainage system.

The radiometric ages of the dated Raton, Clayton, and Capulin basaltic and latitic rocks range from about 4 m.y. to somewhat less than 8,000 years (Baldwin and Muehlberger, 1959, p. 129). Thus far, no olivine basalt has been dated that is as old as the 8.2±0.3 m.y. basanite flow near Manco Burro Pass, although the oldest flow on Fishers Peak Mesa (Fishers Peak quadrangle, Colorado), just north of Raton, could be older than 4.0 m.y.

Five samples of the basaltic-latiandesitic rocks were analyzed for K-Ar age. An alkali basalt from Mesa Larga (80SM31, table 1; locality 5 on fig. 6) shows an age of 3.95±0.19 m.y., which is very close to the age of 3.5±0.2 m.y. obtained by Stormer (1972a) (3.59±0.2 m.y. by the new decay constants) for the olivine basalt on Bartlett Mesa north of Raton (table 3). Both of these flows are included here as the Raton Basalt. The four other basaltic to latiandesitic flows dated by us (table 1) range from 1.27 to 0.66 m.y. and are included here as the Clayton Basalt.

RATON BASALT

Raton Basalt caps the highest and longest mesas in the area. Many sheets of lava are included in the unit, but their vents are generally no longer marked by cinder cones. Collins (1949) named the Raton after Raton Mesa in Colorado, considered here to be the type area. Most of the analyzed specimens of the Raton Basalt flows and cinder cones are olivine basalts and alkali basalts; a few are trachybasalts and latibasalts. In hand specimen the rocks are medium gray to black, very hard, and in part vesicular. Some have a silvery sheen on a fresh break, apparently owing to fine diktytaxitic texture. They are visibly porphyritic, typically having only olivine phenocrysts, though some flows include phenocrysts or xenocrysts of other minerals. Altered phenocrysts of olivine appear as red or brown specks.

Rocks of the Raton examined in thin section are porphyritic and contain phenocrysts of one or more of these minerals: olivine, plagioclase, clinopyroxene, apatite, and opaque oxides. Some samples also have xenocrysts of hornblende (opacite). Specimen 80SM31 (table 28, analysis 1; locality 5 on fig. 6), an alkali basalt from Mesa Larga, is porphyritic and contains 10 percent stubby olivine phenocrysts as large as 2 mm, rimmed with orange-brown iddingsite alteration, and scattered opaque oxide. The groundmass is intergranular in texture and composed of abundant stubby clinopyroxene crystals and plagioclase (labradorite) plates, and many olivine and opaque oxide crystals.

Specimen 80SM11 (table 28, analysis 10), a trachybasalt/alkali basalt from the SW¼ sec. 30, T. 28 N., R. 27 E., Kiowa quadrangle, is porphyritic and contains about 10 percent plagioclase (andesine?) phenocrysts as thin laths ranging from 0.3 mm down to groundmass size; 5 percent hornblende (opacite) ghosts as long as 1 mm; 3 percent equant opaque oxide crystals; traces of pale-green-yellow clinopyroxene phenocrysts as large as 0.6 mm; and apatite. The groundmass is somewhat vesicular, has subtrachytic texture, and is composed of plagioclase, clinopyroxene(?), and opaque oxide.

Specimen 81SM6 (table 28, analysis 11), a trachybasalt/alkali basalt from the middle of sec. 36, T. 27 N., R. 26 E., Pine Buttes quadrangle, is porphyritic and contains about 10 percent altered hornblende (now opacite) phenocrysts as long as 0.4 mm; 5 percent clear pale-yellow clinopyroxene phenocrysts as long as 1.5 mm; and scattered dusty apatite as large as 0.2 mm. The groundmass has a trachytic texture, consists mainly of plagioclase (labradorite?), and has lesser amounts of clinopyroxene and opaque oxide crystals in alkali feldspar(?). Also present are a few fine-grained xenoliths.

TABLE 28.—*Chemical analyses and norms of samples of Raton Basalt from the Raton-Springer*

[Data in weight percent. n.d., not determined]

Sample --	1	2	3	4	5	6	7	8	9
Field No.	80SM31	MHS-88-80	81SM11	MHS-68-82	293	2	80SM24	L-515	3
Lab No.--	D231894	D229969	D237462	D246866	---	---	D231889	---	---
					Major oxides				
SiO_2 ----	45.4	45.6	46.2	46.2	48.82	48.87	49.1	49.73	49.74
Al_2O_3 ---	13.8	15.1	15.1	17.0	15.34	15.75	16.5	15.46	14.98
Fe_2O_3 ---	5.35	7.00	3.91	7.27	3.28	3.28	4.37	3.32	7.42
FeO -----	6.07	5.20	7.91	3.54	7.94	8.29	6.51	8.14	4.68
MgO -----	11.0	6.86	9.18	4.80	7.44	7.35	7.28	7.20	5.79
CaO -----	9.76	11.4	10.3	9.40	9.28	9.26	9.47	9.63	8.43
Na_2O ----	2.95	3.1	3.01	3.73	3.45	3.53	3.32	3.30	3.59
K_2O -----	1.34	1.06	0.99	1.82	0.90	0.85	0.88	0.87	1.25
H_2O^+ ----	n.d.	1.79	n.d.	n.d.	0.64	0.55	n.d.	0.32	1.40
H_2O^- ----	n.d.	0.20	n.d.	n.d.	0.06	0.19	n.d.	0.16	0.46
Volatiles[1]	1.00	n.d.	1.14	2.22	n.d.	n.d.	0.86	n.d.	n.d.
TiO_2 ----	1.82	1.45	1.52	1.86	1.59	1.13	1.54	1.59	1.15
P_2O_5 ----	0.83	1.1	0.61	1.33	0.42	0.50	0.40	0.42	0.53
MnO ------	0.17	0.18	0.19	0.18	0.18	0.15	0.16	0.13	0.18
CO_2 -----	n.d.	0.12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	99.5	100.2	100.1	99.4	99.34	99.70	100.4	100.27	99.60
				La Roche and others (1980) classification					
R_1 ------	1,321	1,334	1,419	994	1,488	1,468	1,550	1,321	1,334
R_2 ------	1,870	1,859	1,852	1,580	1,673	1,672	1,691	1,689	1,496
Name ----	Olivine alkali basalt.	Basalt	Alkali basalt.	Trachy-basalt.	Alkali basalt.	Olivine alkali basalt.	Olivine basalt.	Olivine basalt.	Olivine alkali basalt/lati-basalt.
				Normative composition					
q -------	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.25
or ------	8.04	6.38	5.91	11.06	5.39	5.07	5.22	5.15	7.56
ab ------	20.59	25.94	21.43	30.34	29.59	30.18	28.22	27.98	31.07
an ------	20.76	24.59	25.03	24.97	24.03	24.87	27.64	24.85	21.55
c -------	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ne ------	2.57	0.42	2.34	1.16	0.00	0.00	0.00	0.00	0.00
di-wo ---	9.55	10.39	9.43	5.87	8.29	7.61	7.07	8.46	7.38
di-en ---	7.42	8.35	6.25	5.08	5.14	4.53	4.86	5.16	6.09
di-fs ---	1.09	0.83	2.50	0.00	2.66	2.70	1.64	2.83	0.38
hy-en ---	0.00	0.00	0.00	0.00	2.42	1.48	6.05	5.52	8.66
hy-fs ---	0.00	0.00	0.00	0.00	1.25	0.88	2.03	3.03	0.54
ol-fo ---	14.28	6.34	11.81	5.06	7.86	8.75	5.12	5.10	0.00
ol-fa ---	2.32	0.70	5.20	0.00	4.48	5.76	1.90	3.08	0.00
mt ------	7.87	10.33	5.73	6.80	4.82	4.80	6.36	4.82	11.00
hm ------	0.00	0.00	0.00	2.79	0.00	0.00	0.00	0.00	0.00
il ------	3.51	2.80	2.92	3.63	3.06	2.17	2.94	3.03	2.23
ap ------	2.00	2.65	1.46	3.24	1.01	1.20	0.95	1.00	1.28
cc ------	0.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of

Chemical analyses and norms of the rocks of the Raton Basalt (table 28) show a broad range in composition, including alkali basalt, olivine basalt, latibasalt, and trachybasalt. The analyzed basalts contain from 45.4 to 51.68 percent SiO_2, but most have no normative quartz.

CLAYTON BASALT

The Clayton Basalt includes olivine basalt, trachybasalt, trachyandesite, and latiandesite. Collins (1949) named the Clayton after outcrops in the area he called *area, New Mexico*

Sample --	10	11	12
Field No.	80SM11	81SM6	L-512
Lab No.--	D229691	D237460	---
	Major oxides		
SiO_2 ----	50.4	50.4	51.68
Al_2O_3 ---	17.2	15.9	15.05
Fe_2O_3 ---	5.65	5.48	5.22
FeO -----	2.61	2.60	5.64
MgO -----	3.8	5.08	5.63
CaO -----	9.25	9.13	8.30
Na_2O ----	4.6	4.65	3.75
K_2O -----	1.91	2.10	1.39
H_2O^+ ----	n.d.	n.d.	0.62
H_2O^- ----	n.d.	n.d.	0.72
Volatiles[1]	1.98	1.10	n.d.
TiO_2 ----	1.08	1.26	1.54
P_2O_5 ----	1.2	1.46	0.45
MnO -----	0.17	0.15	0.12
CO_2 -----	n.d.	n.d.	n.d.
Total	99.9	99.3	100.11
	La Roche and others (1980) classification		
R_1 ------	1,037	980	1,468
R_2 ------	1,518	1,551	1,471
Name ----	Trachybasalt/ alkali basalt.	Trachybasalt/ alkali basalt.	Latibasalt/ andesi- basalt.
	Normative composition		
q -------	0.00	0.00	1.88
or ------	11.52	12.63	8.31
ab ------	37.40	36.01	32.12
an ------	21.08	16.59	20.37
c -------	0.00	0.00	0.00
ne ------	1.27	2.18	0.00
di-wo ---	7.42	8.26	7.65
di-en ---	6.41	7.14	5.50
di-fs ---	0.00	0.00	1.46
hy-en ---	0.00	0.00	8.69
hy-fs ---	0.00	0.00	2.31
ol-fo ---	2.28	4.02	0.00
ol-fa ---	0.00	0.00	0.00
mt ------	5.96	5.31	7.66
hm ------	1.66	1.91	0.00
il ------	2.09	2.43	2.96
ap ------	2.90	3.52	1.08
cc ------	0.00	0.00	0.00

loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Olivine Alkali basalt from Mesa Larga in the SW¼SW¼ sec. 34, T. 29 N., R. 26 E., Mesa Larga quadrangle.
2. Basalt from 100 m north of county road A-8 between two drainages of Tinaja Creek in the NW¼SE¼ sec. 5, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).
3. Alkali basalt from the SW¼SE¼ sec. 9, T. 21 N., R. 28 E., Valencia Spring quadrangle, south of the Raton-Springer area.
4. Trachybasalt on top of bluff south side of Joe Cabin Arroyo, directly south of El Rancho Grande in the SW¼SE¼SE¼ sec. 27, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).
5. Alkali basalt from Bartlett Mesa, 36°51'32" N., 104°24'55" W., probably from road in NE¼NW¼ sec. 8, T. 31 N., R. 24 E., Raton quadrangle (sample 293 of Stormer, 1972b, tables 1 and 7).
6. Olivine alkali basalt from Bartlett Mesa, probably from same locality as sample 5 above (Aoki, 1967, table 1), Raton quadrangle.
7. Olivine basalt that overlies red zone in road cut just south of Wagon Mound in the SW¼SE¼ sec. 33, T. 21 N., R. 21 E., Wagon Mound quadrangle. Collected by C.L. Pillmore.
8. Olivine basalt from the south rim of Barela Mesa at the mouth (source?) of Chicorica Creek, Yankee quadrangle (sample L-515 of Mertie, 1922, p. 11).
9. Olivine alkali basalt/latibasalt from Little Mesa, probably in the NE¼ sec. 3, T. 31 N., R. 25 E., Yankee quadrangle (Aoki, 1967, table 1).
10. Olivine trachybasalt/basalt from the SW¼ sec. 30, T. 28 N., R. 27 E., Kiowa quadrangle.
11. Trachybasalt/alkali basalt from landslide deposit near middle of sec. 36, T. 27 N., R. 26 E., Pine Buttes quadrangle.
12. Olivine latibasalt/andesibasalt from the east rim of Barela Mesa near Yankee, Yankee quadrangle (sample L-512 of Mertie, 1922, p. 11).

the Folsom-Clayton Mesa near Clayton, N. Mex. We consider a widespread basalt flow on the mesa surmounted by Mount Clayton to be the type area. The physiographic positions of the flows (table 27), about 100 to 400 ft (30 to 120 m) above major drainage, suggest ages between 2.0 and 0.5 m.y. K-Ar ages determined on four Clayton rocks (table 1, analyses 1–4) range from 1.27±.71 m.y. to 0.66±.12 m.y. From geomorphic evidence we infer an age range of 2 to 0.5 m.y. The conical cinder cones of ash, cinders, and bombs are much better preserved and less modified by erosion than are the cones of the Raton Basalt.

In hand specimen, the Clayton rocks are black to medium gray, fine to medium grained, porphyritic, and mostly dense. The Clayton flows are more scoriaceous than the Raton flows. Some have a silvery sheen. Some have obvious flow structure and the lava commonly shows well-formed to crudely formed columnar joints. Some flows contain xenoliths, the most common of which are rhyodacite.

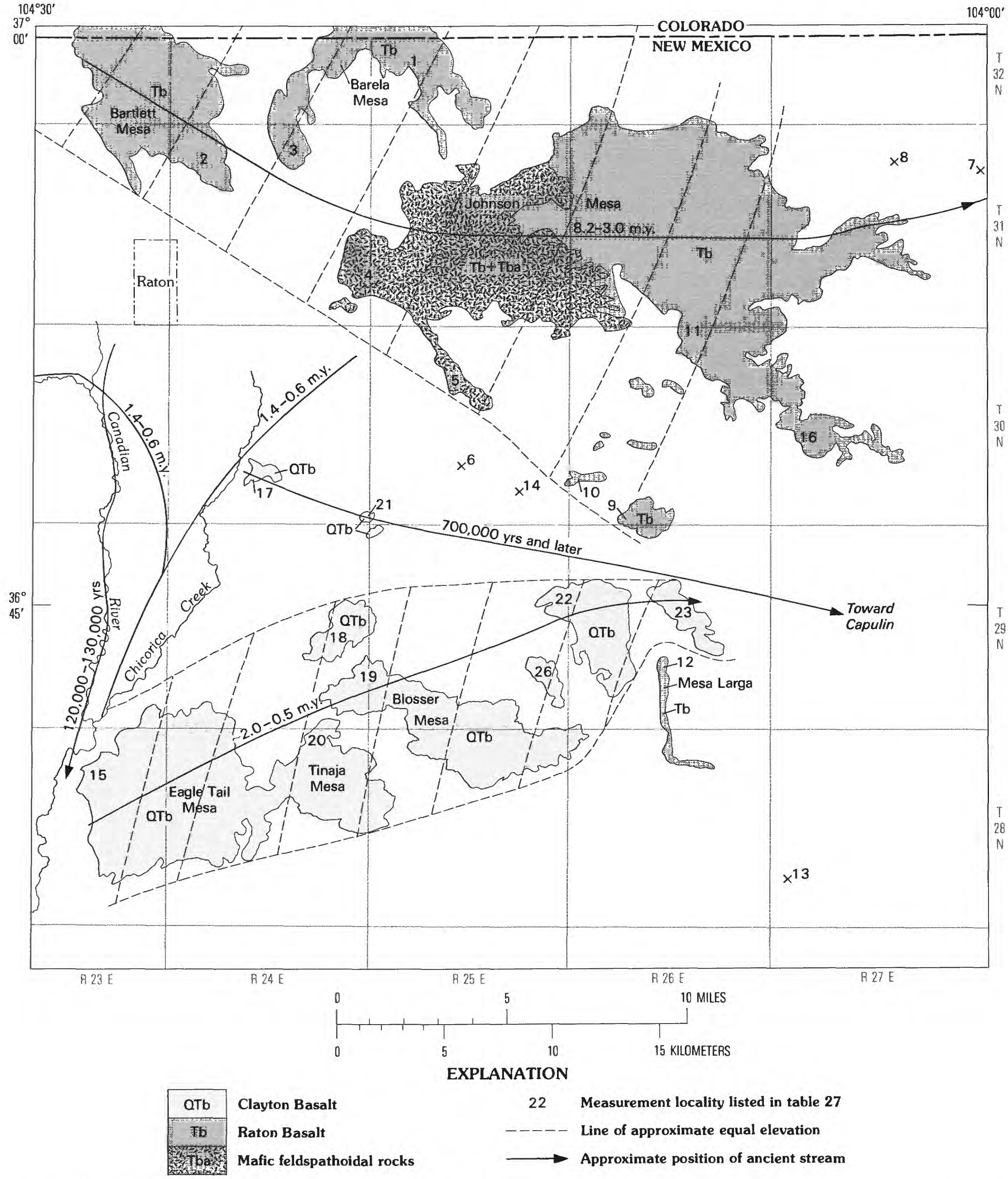


FIGURE 19.—Inferred paleovalleys of late Tertiary and Quaternary age near Raton, N. Mex. Stream positions shown represent the times of the Raton Basalt and mafic feldspathoidal rocks (8.2–3.0 m.y.), the Clayton Basalt (2.0–0.5 m.y.), the ancestral Canadian River and tributary (1.4–0.6 m.y.), the eastward channel toward Capulin (700,000 years and later), and the present channel of the Canadian River (commencing about 120,000–130,000 years ago). The lines of approximate equal elevation (dashed) also show the inferred shapes and slopes of the valley floors.

Microscopic examination of four samples of basalt and latiandesite of the Clayton shows them to be more phenocryst rich than the Raton Basalt. Phenocrysts include olivine, augite, plagioclase, and, less commonly, orthopyroxene and oxyhornblende. Xenocrysts of quartz and feldspar are sporadically present. Some flows contain no obvious phenocrysts.

Specimen 80SM1 (table 29, analysis 1; locality 1 on fig. 6), from an olivine basalt flow containing scattered large xenoliths of rhyodacite, is porphyritic and contains about 15 percent olivine phenocrysts as large as 1.6 mm, 5 percent clinopyroxene (augite) phenocrysts as large as 0.4 mm, some in clots as large as 1 mm, and 3 percent plagioclase (labradorite) phenocrysts as large as 0.4 mm. The groundmass is intergranular in texture and is composed of plagioclase tablets, stubby clinopyroxene crystals, opaque oxide crystals, and sparse quartz xenocrysts.

Specimen 80SM4 (table 29, analysis 3; table 30), a basalt from a road cut at the east end of Eagle Tail Mountain, is porphyritic and composed of the following: about 15 percent plagioclase (labradorite) phenocrysts as large as 1 mm; 10 percent clinopyroxene phenocrysts as large as 0.2 mm, commonly in groups; and 5 percent olivine phenocrysts as large as 1.2 mm. The groundmass has an intergranular texture and consists of much plagioclase and lesser amounts of clinopyroxene and opaque oxide.

Specimen 80SM2 (table 29, analysis 5; locality 3 on fig. 6), a trachybasalt from Juan Torres Mesa in the Johnson Park quadrangle, is porphyritic and contains about 10 percent olivine phenocrysts as large as 2 mm, 10 percent clinopyroxene phenocrysts as large as 1.5 mm, and scattered plagioclase (labradorite) phenocrysts in tablets as large as 1 mm. Its groundmass is inhomogeneous, has an intersertal texture, and is composed of plagioclase, clinopyroxene, and opaque oxide in varying proportions. Also present are scattered xenocrysts of strongly fritted alkali feldspar with labradorite overgrowths, and quartz with coronas of clinopyroxene.

Specimen 80SM15 (table 29, analysis 9; locality 2 on fig. 6), a latite/trachyandesite from the NW¼ sec. 15, T. 26 N., R. 27 E., Lawrence Arroyo quadrangle, is vesicular, has a trachytic to pilotaxitic texture, and is composed of the following: about 45 percent plagioclase tablets as large as 0.1 mm, 35 percent interstitial alkali feldspar, 15 percent opaque oxide grains, 5 percent of an unknown, red, nearly opaque mineral as tiny platelets, and scattered opacite pseudomorphs after hornblende.

Specimen 80SM16 (table 29, analysis 10; locality 4 on fig. 6), a latiandesite from the southeastern flow of Las Mesetas, Lawrence Arroyo quadrangle, has a seriate texture and is composed of the following: about 65 percent plagioclase (andesine) as large as 1.5 mm, 15 percent pleochroic pale-green to pale-brown orthopyroxene crystals as large as 0.4 mm, 7 percent strongly opacitized oxyhornblende crystals, 7 percent clinopyroxene as large as 0.6 mm, 6 percent fine opaque oxide grains, and sparse titanite and sphene crystals.

Chemical analyses and norms of the Clayton Basalt (table 29) show that almost all of the rocks are higher in SiO_2 than rocks of the Raton Basalt. In addition, a few of the rocks have quartz in their norms. CaO exceeds combined Na_2O and K_2O in the less silicic, more mafic rocks of the Clayton, whereas in the more silicic, less mafic rocks the Na_2O and K_2O together are nearly equal in abundance to CaO. As a result the normative anorthite of the more mafic group greatly exceeds normative orthoclase, but in the less mafic rocks these two are roughly equal.

The result of a neutron activation analysis (table 30) of specimen 80SM4 shows that amounts of 23 elements exceed average crustal abundance, including 5 of the most diagnostic elements. We infer that the source of this specimen, and possibly of the Clayton unit, was the lower crust.

CAPULIN BASALT

The Capulin Basalt is widespread in the eastern part of the Raton-Springer area, cropping out as flows and cinder cones along Trinchera Creek just south of the Colorado–New Mexico border, at the confluence of Cherry Creek and the Dry Cimarron River, and in the valleys east and west of Dry Mesa. To the south it caps Loco Mesa and forms Horseshoe Crater (fig. 20*A*) and The Crater (Twin Craters) southwest of Pine Buttes. To the east of the map area it forms Capulin Mountain (fig. 20*B*) and other nearby vents and flows. Collins (1949) named the Capulin after the cone and flows of Capulin Mountain. We consider the type area to occur in sec. 4, T. 29 N., R. 28 E., Union County, N. Mex.

The flows of this group, where not mantled by ash, generally are only sparsely vegetated, have rough clinkery and spinose surfaces, and commonly have tumuli on their surfaces. The steep-flanked cones (fig. 20*B*) range in height from a few hundred feet to 1,500 ft (450 m) and are composed of ash (fig. 21), scoria, bombs, and blocks in various states of induration. Mertie (1922, p. 11) observed that Capulin volcanism, compared to the Raton and Clayton episodes, was characterized by greater development of central eruption and by more explosive activity, which produced a greater abundance of pyroclastics and more vesicular lava.

The rocks of the Capulin Basalt are strikingly inhomogeneous, even within a single thin section. Sample analyses (table 31) show that they range from andesibasaltic to latibasaltic, but some alkali basalts have also

TABLE 29.—*Chemical analyses and norms of samples of Clayton Basalt from the Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample	1	2	3	4	5	6	7	8	9	10
Field No.	80SM1	147	80SM4	332	80SM2	L-542	L-541	279	80SM15	80SM16
Lab No.	D229681	---	D229684	---	D229682	---	---	---	D229695	D229696
Major oxides										
SiO_2 ---	50.0	51.00	51.4	52.67	53.4	53.52	54.08	55.54	56.0	58.8
Al_2O_3 --	14.6	15.68	15.8	17.75	17.8	17.88	21.87	15.33	17.9	17.0
Fe_2O_3 --	2.06	1.71	1.90	5.26	4.64	4.21	5.22	1.54	5.30	2.35
FeO ----	7.50	7.75	7.40	2.79	3.32	3.51	0.88	5.58	1.82	3.40
MgO ----	9.97	6.33	6.22	3.72	3.7	3.90	2.69	5.87	2.80	2.5
CaO ----	9.45	9.39	9.36	7.14	7.22	7.36	5.53	6.53	6.06	5.28
Na_2O ---	3.2	3.75	3.6	5.08	5.0	5.19	5.46	4.08	5.10	4.3
K_2O ----	1.26	1.33	1.36	1.97	2.05	2.39	2.88	2.42	2.32	2.86
H_2O^+ ---	n.d.	0.32	n.d.	0.42	n.d.	0.00	0.00	0.41	n.d.	n.d.
H_2O^- ---	n.d.	0.04	n.d.	0.05	n.d.	0.15	0.16	0.08	n.d.	n.d.
Vols.[1]--	0.84	n.d.	0.83	n.d.	0.45	n.d.	n.d.	n.d.	0.69	1.44
TiO_2 ---	1.29	1.40	1.32	1.22	1.17	1.14	0.98	1.18	0.95	1.00
P_2O_5 ---	0.50	0.63	0.61	1.06	1.2	1.26	0.91	0.51	0.93	0.71
MnO ----	0.16	0.18	0.15	0.13	0.13	0.11	0.09	0.14	0.12	0.08
CO_2 ----	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Total	100.8	99.51	100.0	99.26	100.1	100.62	100.75	99.21	100.0	99.7
La Roche and others (1980) classification										
R_1 -----	1,593	1,468	1,538	1,011	1,063	927	805	1,474	1,169	1,546
R_2 -----	1,777	1,635	1,619	1,307	1,304	1,325	1,147	1,302	1,138	1,025
Name ---	Olivine basalt.	Basalt	Olivine basalt.	Trachy-basalt.	Olivine trachy-basalt.	Augite trachy-basalt.	Augite trachy-andesite.	Latibasalt/ latiande-site.	Latite/ trachy-andesite.	Latiande-site.
Normative composition										
q ------	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.68	4.00	9.32
or -----	7.44	7.92	8.11	11.78	12.15	14.05	16.91	14.48	13.80	17.19
ab -----	27.07	31.99	30.72	43.49	42.44	43.32	45.91	34.96	43.44	37.01
an -----	21.75	22.20	23.13	20.04	20.13	18.33	21.35	16.58	19.22	18.96
c ------	0.00	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.00	0.00
ne -----	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
di-wo --	9.13	8.61	8.22	3.67	3.31	4.09	0.00	5.37	2.06	1.24
di-en --	6.00	4.88	4.74	3.17	2.73	3.21	0.00	3.36	1.78	0.80
di-fs --	2.48	3.36	3.10	0.00	0.17	0.43	0.00	1.68	0.00	0.36
hy-en --	0.83	1.72	4.70	4.87	6.51	0.00	0.04	11.44	5.24	5.53
hy-fs --	0.34	1.18	3.07	0.00	0.40	0.00	0.00	5.70	0.00	2.49
ol-fo --	12.61	6.51	4.33	0.94	0.00	4.52	4.63	0.00	0.00	0.00
ol-fa --	5.73	4.94	3.12	0.00	0.00	0.66	0.00	0.00	0.00	0.00
mt -----	2.99	2.50	2.78	5.95	6.75	6.07	0.29	2.26	3.53	3.47
hm -----	0.00	0.00	0.00	1.22	0.00	0.00	4.99	0.00	2.90	0.00
il -----	2.45	2.68	2.53	2.34	2.23	2.15	1.85	2.27	1.82	1.93
ap -----	1.18	1.50	1.46	2.54	2.85	2.97	2.14	1.22	2.22	1.71
cc -----	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1]Volatiles, probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES FOR TABLE 29

1. Olivine basalt that contains hornblende rhyodacite inclusions in the NW¼SE¼ sec. 31, T. 30 N., R. 25 E., Hunter Mesa quadrangle.
2. Basalt from west flank of Eagle Tail Mountain, 36°41'12" N., 104°28'12" W., probably in the SW¼ sec. 2, T. 28 N., R. 23 E., Eagle Tail Mountain quadrangle (sample 147 of Stormer, 1972b, tables 1 and 7).
3. Olivine basalt from east end of Eagle Tail Mountain in a road cut in the NE corner sec. 16, T. 28 N., R. 24 E., Eagle Tail Mountain quadrangle.
4. Trachybasalt from east Juan Torres Mesa (locally called "Meloche Mesa") in the NW¼ sec. 25, T. 30 N., R. 25 E., Johnson Park quadrangle, from thick flow forming the lower eastern part of mesa (sample 332 of Stormer, 1972b, tables 1 and 7). Nearly the same locality as samples 5 and 6.
5. Olivine trachybasalt from Juan Torres Mesa in the SE¼NE¼ sec. 26, T. 30 N., R. 25 E., Johnson Park quadrangle. Nearly the same locality and composition as samples 4 and 6.
6. Augite trachybasalt from Juan Torres Mesa, probably in the NW¼ sec. 25, T. 30 N., R., 25 E., Johnson Park quadrangle. Nearly the same locality as samples 4 and 5 (sample L-542 of Mertie, 1922, p. 11).
7. Augite trachyandesite from western, higher part of Juan Torres Mesa, probably in the W½ sec. 23, T. 30 N., R. 25 E., Hunter Mesa quadrangle (sample L-541 of Mertie, 1922, p. 11).
8. Latibasalt/latiandesite from flow forming rim of mesa south of Blosser Gap in the SW¼SE¼ sec. 25, T. 29 N., R. 24 E., Tinaja Mountain quadrangle (sample 279 of Stormer, 1972b, tables 1 and 7).
9. Latite/trachyandesite from 200 ft (60 m) above drainage in the NW¼ sec. 15, T. 26 N., R. 27 E., Lawrence Arroyo quadrangle.
10. Latiandesite from northeast of road at southeastern flow of Las Mesetas near the center of NE¼ sec. 33, T. 26 N., R. 27 E., Lawrence Arroyo quadrangle.

been described. A xenocrystic andesibasalt lava was described by Aoki (1967; see table 31, this report) from the south base of Capulin Mountain, about 2 mi east of the map area. Phenocrysts consist of olivine (about 2 percent), augite (0.5 percent), and rarely hypersthene. The olivine is euhedral, as large as 2 mm, and the phenocrysts include tiny crystals of picotite. The augite is euhedral to subhedral and ranges to 0.8 mm in length. The hypersthene, as large as 0.5 mm, has overgrowths of augite. The groundmass is holocrystalline and consists of plagioclase, augite, olivine, and opaque oxide. Xenocrysts are quartz (3.1 percent) and feldspar (0.3 percent). The quartz grains are less than 2 mm in diameter and have reaction rims of augite, some with brown glass. The feldspar xenocrysts are rounded and have glassy cores and thin overgrowths of calcic plagioclase.

TABLE 30.—*Neutron-activation analysis of a sample of olivine basalt of the Clayton Basalt from Eagle Tail Mountain, New Mexico*

[Elemental compositions in parts per million. See table 29 for description of sample locality. "<" indicates element concentration is below the limit of determination, which is the value shown; "±" shows the accuracy of the test. Analyst: Carl Orth, Los Alamos National Laboratory]

Field No.	80SM4		Sb	<0.5	
Lab. No.	925103		La	59.6	±0.8
			Sm	7.3	±0.2
Na	27,600	±300	W	<7	
Mg	39,000	±2,000	Au	<0.02	
Al	83,000	±2,000	Sc	22.1	±0.4
Cl	<200		Cr	160	±10
K	12,000	±2,000	Fe	73,000	±2,000
Ca	63,000	±3,000	Co	37	±1
Ti	8,400	±400	Zn	<10	
V	175	±6	Se	<2	
Mn	1,260	±10	Rb	<20	
Cu	<300		Cs	<0.9	
Sr	1,100	±200	Ce	92	±4
I	<20		Eu	1.65	±0.10
Ba	690	±60	Tb	1.2	±0.2
Dy	5.0	±0.3	Yb	2.8	±0.2
U	2.00	±0.02	Lu	0.28	±0.04
Ga	<200		Hf	3.2	±0.3
As	<4		Ta	1.6	±0.2
Br	<3		Th	7.6	±0.3

Another specimen (85RW5) from the chilled rind of the same flow is subtly banded. In thin section one set of bands has normal calcic plagioclase, olivine, and clinopyroxene phenocrysts along with xenocrystic quartz, internally melted alkali feldspar with plagioclase overgrowths, and a few pseudomorphs of clinopyroxene after hornblende(?), all set in a matrix of dark-brown, dusty glass. The other set of bands is lighter in color and has sparse phenocrysts of calcic plagioclase, olivine, and clinopyroxene, but a greater abundance of the felsic xenocrysts than the first set of bands, all set in a matrix of clear, pale-brown glass that has abundant well-formed microphenocrysts of plagioclase, olivine, and clinopyroxene. These microphenocrysts apparently were new growths in the liquid just before it was chilled to a glass.

DISCUSSION AND CONCLUSIONS

Study of the Chico sill complex and other igneous rocks of the Raton-Springer area was reconnaissance in scope, inasmuch as it was subsidiary to making a geologic map of the entire Raton 1°×2° quadrangle. As the eastern half of the quadrangle was mapped, samples were gathered of all major igneous rocks for use in determining composition, rock names, age, the origin and relationships of the rocks to each other, and the physiographic and structural history during and after emplacement. Because our intent was to produce a geologic map and

FIGURE 20.—Cinder cones of Capulin Basalt in the Raton-Springer area. *A*, Horseshoe Crater, in the SE¼ sec. 2, T. 28 N., R. 27 E., Kiowa quadrangle. *B*, Capulin Mountain, the type area, just east of the main study area, 2.5 mi (4 km) north of the town of Capulin, Folsom quadrangle. Photograph *B* by R. D. Miller, U.S. Geological Survey.

show what kinds of rocks crop out in the Raton-Springer area, we have not done a detailed petrogenetic study. The following summary, however, relates some of the pertinent results.

The Chico sill complex includes phonolite, phonotephrite, trachyte, trachyandesite, and other alkalic rocks, ranging in age from Oligocene to Miocene, which have been intruded between layers of Cretaceous sandstone, limestone, and shale to produce some 1,000 ft (305 m) of structural relief. Judging from the relatively low values of Ba, Cr, Mg, Th, and Ti shown by the neutron activation analyses, the source of the magmas of all these rock types was apparently in the lower crust.

Sills of the Slagle Trachyte are a part of the Chico sill complex and contributed to the general structural doming of the area. The green, silver-gray, and ocellar

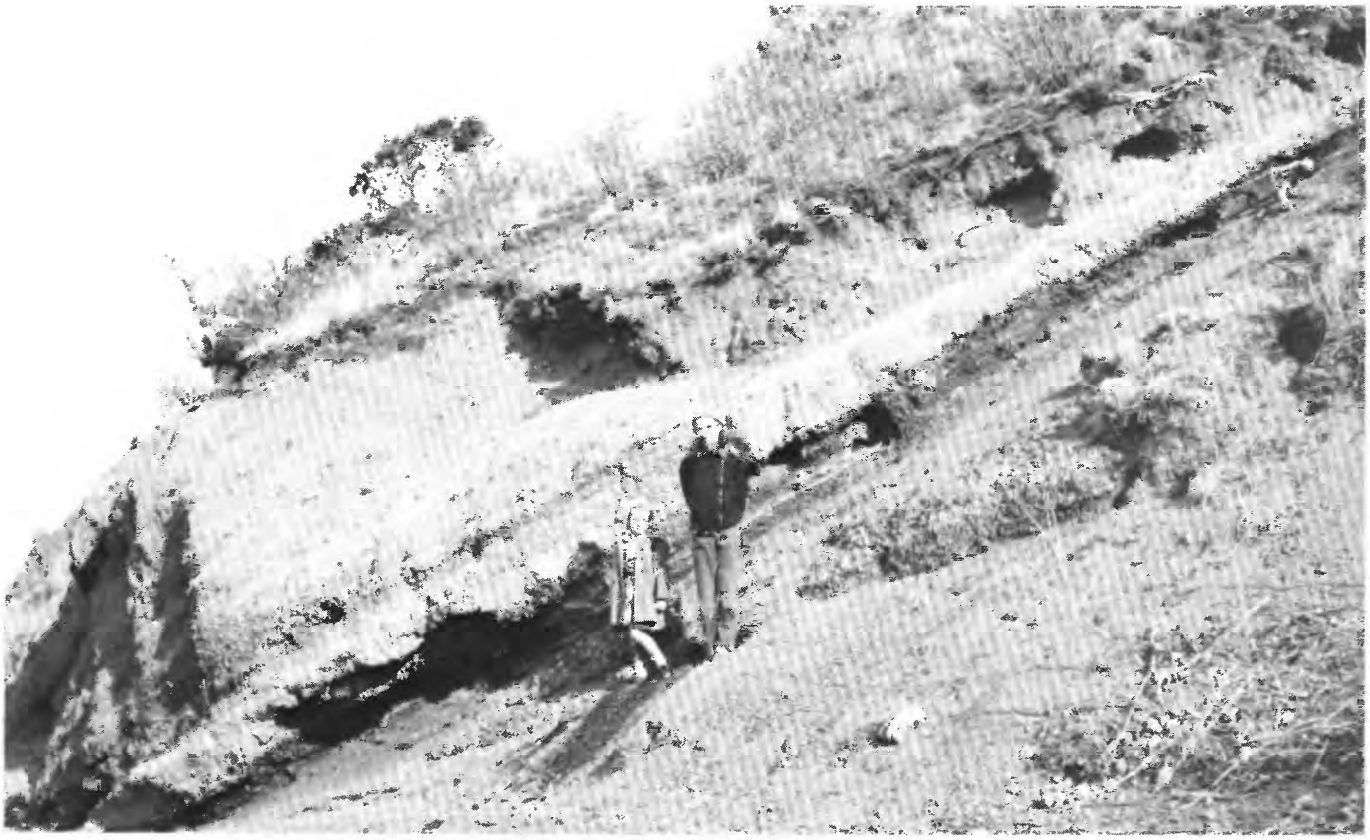


FIGURE 21.—Stratified basaltic ash and volcaniclastics in roadcut on east flank of Capulin Mountain volcano just east of study area. "Field assistant" on left is about 3 ft (1 m) high.

analcime varieties of the Chico Phonolite were assigned separate map units by Scott, recognizing however that they are closely related. From the plot of the chemical analyses on figure 7*B* (fields 12 and 14), it is apparent that the green and silver-gray phonolite units form a gradational series, the green phonolite being the low-silica part. In addition, the nepheline syenite dike on the Point of Rocks Mesa (field 16) plots within the field of the silver-gray phonolite and might well have been a feeder to the system of sills.

Also during this span of Oligocene through Miocene time, kimberlite diatremes were intruded into the sedimentary rocks. Inasmuch as the diatremes are inconspicuous in outcrop, some may well have been overlooked in the present reconnaissance. On the basis of their relatively high values of Ba, Cr, Ir, Mg, and Ti, the sources of the diatremes appear to have been in the upper mantle.

In a study of the mafic feldspathoidal lavas in Union County and parts of eastern Colfax County, Phelps and others (1983) concluded that the magmas of most of these lavas originated as primary melts in the upper mantle, which itself had been metasomatically enriched. A comparison of major oxide analyses of mafic feldspathoidal lavas from Union County (Phelps and others, 1983, table 1) and Colfax County (table 25 of this report), shows that the nephelinites and ankaratrites of Union County are consistently higher in CaO and MgO than those of Colfax County, whereas the basanites of the two areas do not show significant differences in this respect.

These relations between the mafic feldspathoidal lavas of the two counties are clearly brought out in figure 22, a section of the diagram of La Roche and others (1980), in which the R_2 parameters (6Ca+2Mg+Al) serve to distinguish the nephelinites and ankaratrites of Union County from those of Colfax County, possibly an indication of compositional differences between the materials of the respective source regions of these upper mantle melts. In contrast, the plots of the basanites of the two counties overlap, and they are separated from the plots of the ankaratrites and nephelinites by an appreciable gap in the R_1 parameter values [4Si–11(Na+K)–2(Fe+Ti)], suggesting that the basanites form a separate igneous series. (See also fig. 7*B*, fields 25 and 28.)

Among the basaltic to latiandesitic rocks, as grouped in the present study, there is a progressive increase in silica and a less regular increase in potash content from

TABLE 31.—*Chemical analyses and norms of samples of Capulin Basalt from the Raton-Springer area, New Mexico*

[Data in weight percent. n.d., not determined]

Sample	1	2	3	4
Field No.	MHS-69-82	L-571-A	111	8
Lab No.	D246867	---	---	---
	Major oxides			
SiO_2	51.8	53.27	55.04	55.54
Al_2O_3	16.4	15.43	15.62	15.40
Fe_2O_3	3.20	2.43	1.57	0.91
FeO	6.30	6.50	5.93	7.74
MgO	4.60	6.16	5.62	5.45
CaO	7.34	8.18	7.23	7.07
Na_2O	3.71	3.51	3.91	3.95
K_2O	1.90	1.71	1.96	2.05
H_2O^+	n.d.	0.62	0.80	0.39
H_2O^-	n.d.	0.00	0.11	0.07
Volatiles[1]	1.67	n.d.	n.d.	n.d.
TiO_2	1.59	1.30	1.19	1.00
P_2O_5	0.77	0.50	0.43	0.40
MnO	0.18	0.12	0.13	0.14
Total	99.46	99.73	99.54	100.11
	La Roche and others (1980) classification			
R_1	1,380	1,631	1,594	1,553
R_2	1,338	1,487	1,366	1,328
Name	Latibasalt	Andesi-basalt.	Andesi-basalt.	Andesi-basalt.
	Normative composition			
q	1.46	0.83	1.55	0.15
or	11.48	10.19	11.74	12.15
ab	32.09	29.96	33.54	33.53
an	22.98	21.48	19.54	18.30
di-wo	3.80	6.75	5.83	5.96
di-en	2.28	4.17	3.53	3.07
di-fs	1.32	2.18	1.98	2.73
hy-en	9.43	11.30	10.66	10.55
hy-fs	5.48	5.90	5.99	9.38
mt	4.74	3.55	2.31	1.32
hm	0.00	0.00	0.00	0.00
il	3.09	2.49	2.29	1.91
ap	1.86	1.19	1.03	0.95

[1]Probably mainly H_2O and CO_2, calculated assuming all FeO was oxidized to Fe_2O_3 during determination of loss on ignition.

DESCRIPTION OF SAMPLE LOCALITIES

1. Latibasalt flow correlated with the Capulin Basalt on east side of county road north of Hogeye Mesa and south of the eastern Pine Butte in SW¼SE¼ sec. 14, T. 27 N., R. 26 E., Pine Buttes quadrangle (Staatz, 1985).
2. Olivine andesibasalt from Capulin Mountain, possibly from secs. 6 or 7, T. 29 N., R. 28 E., Folsom quadrangle, Union County, east of map area (sample L-571(a) of Mertie, 1922, p. 11).
3. Andesibasalt from flow from Capulin Mountain volcano in road cut on north side of U.S. Highway 64 in the center of S½ sec. 16, T. 29 N., R. 28 E., Capulin quadrangle, east of the map area (sample 111 of Stormer, 1972b, tables 1 and 7).
4. Andesibasalt from flow from Capulin Mountain volcano in road cut on north side of U.S. Highway 64 in the center of S½ sec. 16, T. 29 N., R. 28 E., Capulin quadrangle, east of map area (Aoki, 1967, table 1).

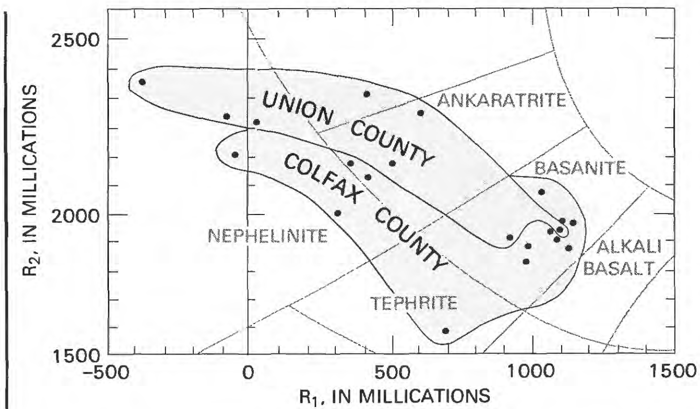


FIGURE 22.—Comparison of the major element compositions of the mafic feldspathoidal lavas of Colfax County (table 25 of this study) with those of Union County, adjacent on the east (Phelps and others, 1983, table 1), as plotted on the diagram of La Roche and others (1980).

older to younger (from the alkali basalt of the Raton, table 28; through the basalt, latiandesite, and trachyandesite of the Clayton, table 29; and into the latibasalt and andesibasalt of the Capulin, table 31). Under the microscope the Clayton rocks contain scattered reacted xenocrysts of feldspar and quartz. The xenocrysts appear to be even more abundant in the few Capulin rocks examined in this study, and the groundmasses are subtly inhomogeneous both in hand specimen and under the microscope, having variable grain sizes and being glassy in places. Stormer (1972b, p. 3306) considered the possibility that these features might be the result of crustal contamination of Raton-like magma, but rejected it because of the apparent lack of potassium-bearing xenoliths to account for the increase in potash through the groups. Actually, some scattered felsic xenoliths were noted during the mapping for the present study, and the plagioclase phenocrysts with clouded interiors (the resorbed plagioclase phenocrysts of Stormer, 1972b, p. 3303) match well the attributes of alkali-feldspar xenocrysts caught in basaltic magmas. Xenocrysts in that situation first undergo internal melting, then acquire overgrowths of calcic plagioclase (Knopf, 1938; Wilcox, 1944). Progressive assimilation of these alkali feldspars, along with the reacting quartz xenocrysts, could have produced the observed chemical characters of these rocks.

Support for the probability of significant contamination is also found in the strontium isotope study by Jones and others (1974, fig. 1) on the suite of specimens collected from the rocks of the region by Stormer (1972a, b). Of this suite, three specimens—one from Stormer's "Raton-Clayton" group and the two from his "Capulin" group—show anomalously high Sr^{87}/Sr^{86} ratios, which are interpreted by Jones and others (1974) as indicating crustal contamination.

If these various rock types (trachybasalt, latibasalt, andesibasalt, trachyandesite, and latiandesite) of the "Clayton" and "Capulin" groups have been derived by contamination of Raton-related magmas, there must have been a wide variety of compositions among the contaminants. Such a scatter of the plots of the R_1R_2 diagram (fig. 7*B*, fields 28, 29, and 31) could conceivably result from the assimilation of differing proportions of alkali feldspar and quartz, and the proportions of these components could vary widely in the common sedimentary and felsic volcanic rocks of the crust contacted by the magmas as they rose.

Assignment of formation names to the mafic eruptive rocks on the basis of relative ages within early Pliocene to Holocene time has been complicated by the setting aside of the mafic feldspathoidal lavas as a separate group, even though the ages of some overlap with those of the Raton and Clayton basaltic lavas. As noted above in the discussion of the mafic feldspathoidal lavas as plotted on figure 7*B*, the basanites plot in a group away from the nephelinites and ankaratrites and very close to some of the alkali basalts of the Raton. This juxtaposition raises the possibility that the alkali basalts are closely related to the basanites, possibly derived from common parent magmas, and that the basanites might more logically be grouped with the alkali basalts as an age unit.

The results of the present reconnaissance have pointed to a number of interesting aspects of the igneous rocks in the study area and to logical directions for further investigations. The new radiometric age determinations of the igneous rocks enable a better understanding of their geologic history and structural development. The new chemical analyses of the igneous rocks, in conjunction with their plots on the R_1R_2 diagram of La Roche and others (1980), outline several probable igneous magmatic events and invite more thorough investigations for their interpretations. The geologic maps of the Springer quadrangle (Scott, 1986) and the Raton quadrangle (Scott and Pillmore, 1989) accurately show the placement of all major rock units and should facilitate future detailed mapping and petrographic study. The above accomplishments, despite their reconnaissance nature, provide an excellent springboard for solution of the many important research problems that remain. We emphasize that a satisfactory understanding of the magmatic development and volcanic history within the Pliocene to Holocene time span, however, does not seem attainable without extensive integrated field work, petrography, petrochemistry, isotopic geochemistry, and more radiometric age determinations.

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