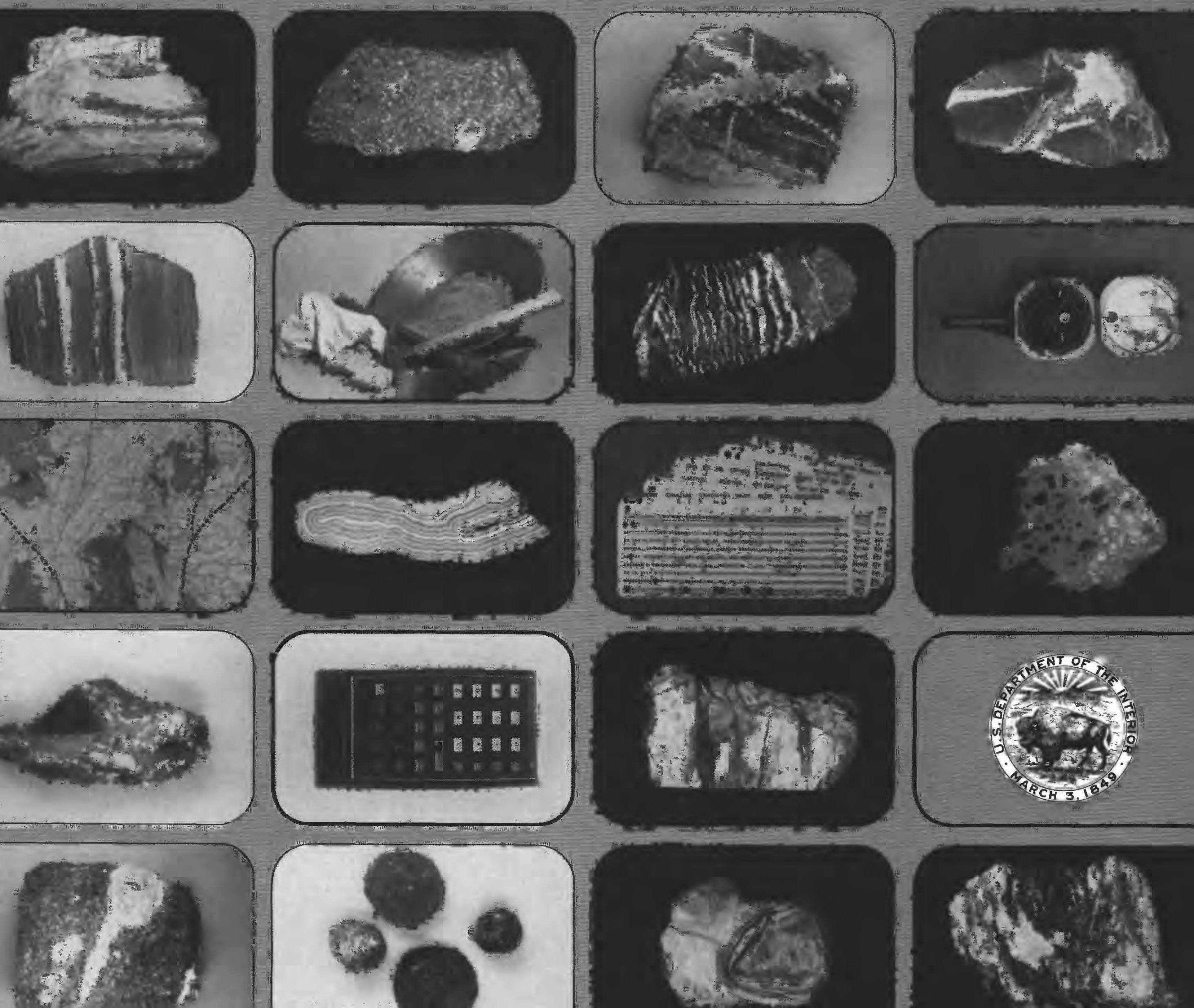
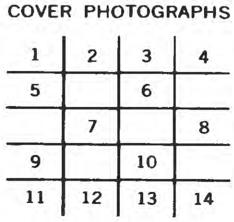
Geology and Description of the Thorium and Rare-Earth Veins in the Laughlin Peak Area, Colfax County, New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1049-E



COVER PHOTOGRAPHS



1. Asbestos ore
2. Lead ore, Balmat mine, N. Y.
3. Chromite-chromium ore, Washington
4. Zinc ore, Friedensville, Pa.
5. Banded iron-formation, Palmer, Mich.
6. Ribbon asbestos ore, Quebec, Canada
7. Manganese ore, banded rhodochrosite
8. Aluminum ore, bauxite, Georgia
9. Native copper ore, Keweenawan Peninsula, Mich.
10. Porphyry molybdenum ore, Colorado
11. Zinc ore, Edwards, N. Y.
12. Manganese nodules, ocean floor
13. Botryoidal fluorite ore, Poncha Springs, Colo.
14. Tungsten ore, North Carolina

Geology and Description of the Thorium and Rare-Earth Veins in the Laughlin Peak Area, Colfax County, New Mexico

By MORTIMER H. STAATZ

GEOLOGY AND MINERAL RESOURCES OF THORIUM IN THE UNITED STATES

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1049–E

Geologic setting and size, shape, mineralogy, and chemistry of veins that contain thorium and rare-earth elements northeastern New Mexico

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GEOLOGY AND DESCRIPTION OF THORIUM AND RARE-EARTH VEINS IN THE LAUGHLIN PEAK AREA, COLFAX COUNTY, NEW MEXICO

By Mortimer H. Staatz

ABSTRACT

This study concerns the geologic setting of 29 veins that contain thorium and rare earths. The study area comprises about 40 km^2 near Laughlin Peak, about 38 km southeast of Raton in northeastern New Mexico. The veins range in length from 0.5 to 550 m and in thickness from 0.2 to 70 cm. The thorium- and rare-earth-bearing minerals are brockite, xenotime, and crandallite. Gangue minerals are potassium feldspar, quartz, or calcite. Other common minerals include goethite, magnetite, barite, zircon, rutile, and a manganese oxide mineral. Brockite and xenotime consist principally of yttrium-group rare earths, and crandallite of cerium-group rare earths. Thorium content of 30 samples ranges from 30 to 24,200 ppm (parts per million), and the total rare-earth content from 147 to 19,030 ppm. Most of the veins are richer in yttrium-group than in cerium-group rare earths. Veins that have a high yttrium-group rare-earth content tend to have high thorium content. Uranium content of these veins is generally low, and in most samples the ratio of thorium to uranium ranges between 18 and 860. The veins were probably formed in late Tertiary by fluids derived from a thorium- and rare-earth-rich phonolitic magma.

The Dakota Sandstone of Early and Late Cretaceous age is the oldest rock exposed in this area. Exposures of this unit are widespread, especially in the western part of the area. The Dakota is overlain in ascending order by the Graneros Shale, Greenhorn Formation, Carlile Shale, and Niobrara Formation—all of Late Cretaceous age. The middle three units are principally shales but have some sandstone and limestone interbeds. The five formations total about 170 m in thickness. Seven kinds of igneous rocks were intruded into and extruded upon the sedimentary rocks in late Tertiary time. Olivine basalt flows blanket the southeastern part of the area. Five different types of alkalic rocks occur within the area: trachyte, trachyandesite, phonolite, rhyodacite, and lamprophyre. Trachyte forms two massive sills, underlying areas of 2.5 and 3.3 km^2, and numerous narrow dikes. Phonolite forms one thick sill that forms a prominent scarp for 3.3 km, as well as several small dikes and sills. Trachyandesite, which generally is altered, occurs principally as poorly exposed sills. Rhyodacite is found in several forms: Rhyodacitic vitrophyre flows, and some breccias, make up the large volcano of Laughlin Peak; porphyritic rhyodacite forms a plug that makes up Raspberry Mountain; and a white ashy rhyodacitic tuff is found low on the south flank of Laughlin Peak. The content of thorium and uranium in all these igneous rocks increases as the total alkali content ($Na_2O + K_2O$) of the rocks increases. Lamprophyre, of several types, makes up a few small dikes. In addition, intrusive breccia occurs as cross-cutting dikes and pipes. These rocks are made up of fragments of volcanic, sedimentary, and plutonic rocks set in a matrix of crystal fragments and finely granulated material. Intrusive breccia in some areas contains granite fragments that are derived from a concealed underlying pluton.

Rocks of Quaternary age commonly cover the flanks of the principal mountains, as well as some of the flatter areas. The Quaternary rock types are terrace gravels, landslide deposits, colluvium, and alluvium.

The structure of the Laughlin Peak area is marked by gently dipping sedimentary rocks and small crisscrossing faults. A broad east-west-trending anticline is the only major fold in the area.

INTRODUCTION

The thorium- and rare-earth-bearing veins of the Laughlin Peak area are similar to the thorium- and rare-earth-bearing veins in other districts. Common features are their association with alkalic igneous rocks, their steep dip, and their fractured and brecciated character. Thorium- and rare-earth-bearing veins that have similar features are found in the following districts: Wet Mountains, Colorado (Olson and others, 1977); Powderhorn area, Colorado (Olson and Hedlund, 1981); Mountain Pass district, California (Olson and others, 1954); Bear Lodge Mountains, Wyoming (Staatz, 1983); and Wausau district, Wisconsin (Vickers, 1956). The principal difference between veins in the Laughlin Peak area and these other areas is in the thorium and rare-earth minerals, which in the Laughlin Peak area are brockite and crandallite, rather than the more commonly found thorite and monazite. Geology of this district is complex; it has seven different varieties of igneous rock, which occur as sills, dikes, plugs, and flows. The present report describes the shape, mineralogy, and chemical composition of the thorium and rare-earth deposits and describes the petrology and geologic setting of the igneous and sedimentary rocks.

LOCATION AND ACCESSIBILITY

The Laughlin Peak thorium and rare-earth area lies along the southwest flank of Laughlin Peak in east-central Colfax County, N. Mex. As shown in figure 1, its northeast corner is near the top of Laughlin Peak. Its dimensions are 5.6 km in an east-west direction and 6.9 km in a north-south direction. This area lies approximately 38 km southeast of the town of Raton and 31 km east-northeast of the village of Maxwell. A county dirt road, A–8, follows Tinaja Creek across this area from its northwest corner to the central part of its east edge (fig. 1). Ranch roads branching off the county road lead to within 1 km of most parts of the area. The best maintained route from Raton follows U.S. Highways 64 and 87 east for 19.0 km to State Highway 193. This State road is followed south and southeast for 19.5 km to county road A–8. The distance along county dirt road A–8 from its junction with Highway 193 to the east edge of the Laughlin Peak area is approximately 8.5 km. The distance from the northwest corner of the area along county road A–8 to Maxwell is 31 km.

GEOGRAPHY

The Laughlin Peak area is in the northwest part of the Pine Buttes quadrangle, which is mainly in the eastern part of the Piñon Hills. These hills cover about 62 km^2, most of which lies to the west in the adjoining Tres Hermanos Peak quadrangle. The Piñon Hills are oval-shaped and are cut by numerous canyons that radiate out from their center. The canyons drain either northward into Tinaja Creek or southward into Rio del Plano. Most of the hills rise from 60 to 120 m above the adjacent canyons, although Turkey Mountain, just west of the mapped area (pl. 1) rises 210 m above the headwaters of the Rio del Plano on the west edge of the map area, and Raspberry Mountain at the southeast corner of the Piñon Hills towers 220 m above the plains to the south. The Piñon Hills differ from the surrounding country in that, as their name suggests, they are covered with trees. The trees that cover the Piñon Hills, in addition to the New Mexico piñon pine (*Pinus edulis*), include Rocky Mountain juniper (*Juniperus scopulorum*), western yellow pine (*Pinus ponderosa*), limber pine (*Pinus flexilis*), birch-leaf mountain mahogany (*Cercocarpus montanus*), and Emory oak (*Quercus emoryi*). The surrounding area is devoid of trees and is covered with grasses and wild flowers.

Northeast of the Piñon Hills is Laughlin Peak. This extinct volcano underlies an area of approximately 28 km^2. Its peak, which has an elevation of 2,688 m, is one of the tallest volcanoes in northeastern New Mexico. The mapped area covers only the southwest part of this mountain. The remaining part of the mapped area, south of Laughlin Peak and east of the Piñon Hills, is a gently sloping open area underlain by basalt flows. These flows originated from The Crater, which lies just east of the southeast corner of the mapped area (fig. 1).

PREVIOUS INVESTIGATIONS

The region surrounding Laughlin Peak has been included in several reconnaissance studies. The volcanic rocks of northeastern New Mexico were investigated by R. F. Collins in 1925, 1926, and 1930. The petrology of these same rocks was studied by H. R. Stobbe, who visited this area in 1940 and 1948. The results of these two investigations were published in companion articles (Collins, 1949; Stobbe, 1949). A reconnaissance map of eastern Colfax County, which includes the Laughlin Peak area, was made by Woods, Northrop, and Griggs (1953); this map, which covers some 4,860 km^2, was made as part of an oil and gas investigation.

Prospecting for radioactive materials began in the Laughlin Peak area in the early 1950's. Some of these prospects were visited by Charles Tschanz of the U.S. Geological Survey in 1954 who called my attention to the area (written commun., 1955). I visited the area for 2 days in 1964 and collected samples from several of the veins. Mineralogic and chemical data on these veins was later published as part of an overall study of thorium veins in the United States (Staatz, 1974).

PRESENT INVESTIGATIONS AND ACKNOWLEDGMENTS

The present work in the Laughlin Peak area was undertaken in 1980 to describe the thorium and rare-earth veins and their geologic setting. The study covers an area of about 40 km^2 that contains most of the known thorium and rare-earth veins. The area underlain by veins is not well defined, as it was poorly explored, and some of the veins were first reported by me. Mapping was done on the northwest part of the Pine Buttes 7½-minute topographic quadrangle that was enlarged

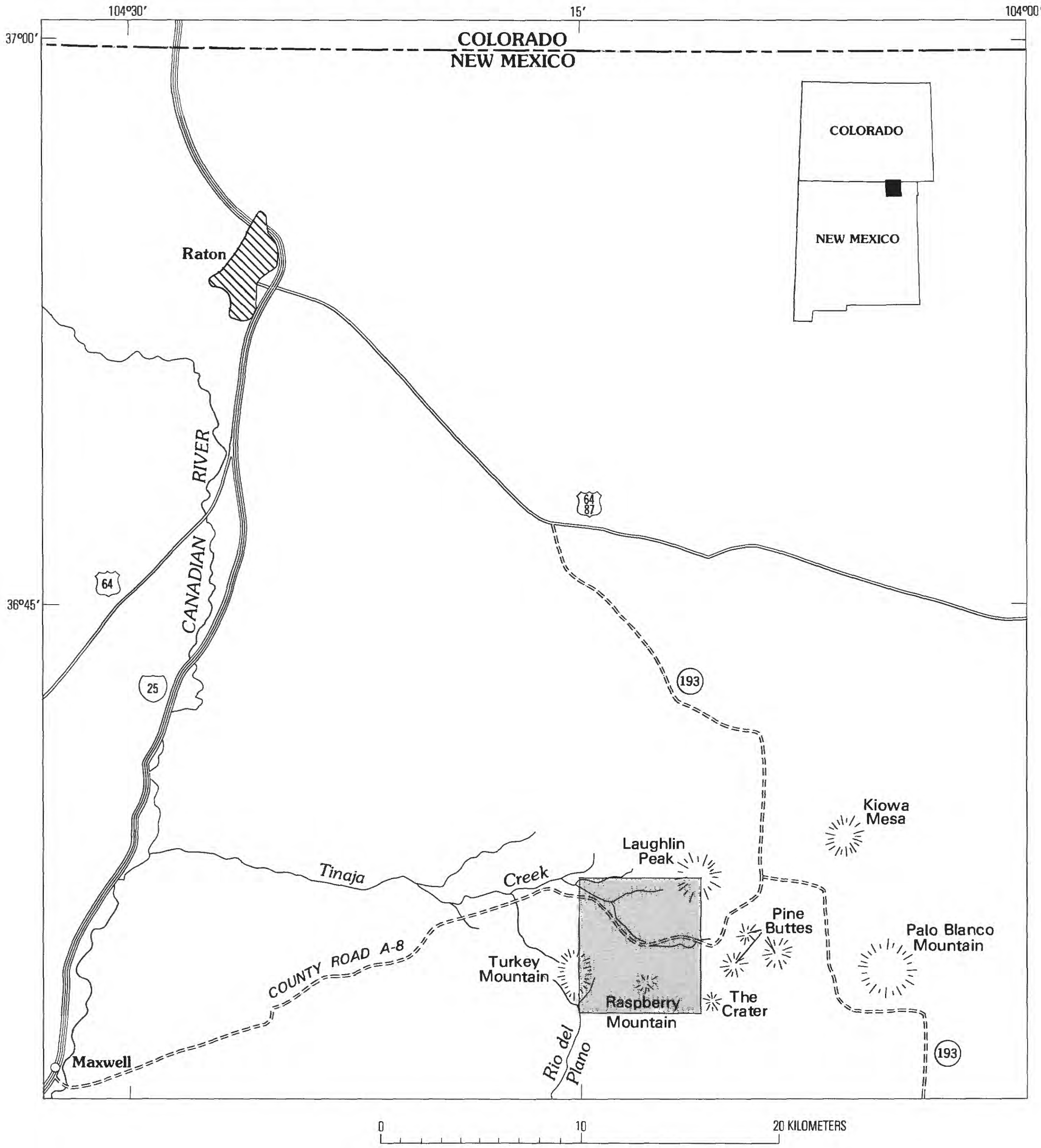

FIGURE 1.—Index map showing the location of the Laughlin Peak area of northeastern New Mexico, and adjacent landmarks.

to a scale of 1:12,000. Aerial photographs proved especially useful in tracing faults through the wooded hills. This area was mapped during the summer of 1980. I was assisted at various times during the summer by William F. Robinson IV, Frank T. Perniciaro, and Daniel S. Morris.

A second part of the work was a detailed study of veins. Samples were taken of various radioactive deposits and both their mineralogic and chemical composition studied. Minerals were determined by separating them from each other by means of heavy liquids, a magnetic separator, and handpicking. All visually unrecognized minerals were identified by means of their X-ray diffraction patterns. I was assisted in this work by Isabelle Brownfield, William F. Robinson IV, Timothy E. Mower, and Daniel S. Morris. Thorium, uranium, and potassium were analyzed with a quantitative gamma-ray spectrometer by Carl M. Bunker and Charles A. Bush. Other elements were determined by semiquantitative spectrographic analysis by Nancy M. Conklin. In addition, the major elements in 13 samples of various igneous rocks were determined by H. G. Neiman, J. S. Wahlberg, J. E. Taggart, Jr., and J. W. Baker.

The Kiowa Land and Cattle Co. and the Hennigan ranch own both the land and most of the mineral rights of the Laughlin Peak area. I want to thank James Hennigan, principal owner of both these properties, for permission to work in this area and for the many discussions about this land. I would also like to acknowledge fruitful discussions on the general geology of the region with Glenn R. Scott of the U.S. Geological Survey.

ROCK TYPES

Three major groups of rocks are exposed in the Laughlin Peak area: (1) clastic sedimentary rocks of Cretaceous age, (2) igneous rocks of Tertiary or Quaternary ages, and (3) unconsolidated deposits of Quaternary age. The sedimentary rocks of Cretaceous age are approximately 170 m thick and consist principally of gently dipping sandstones and shales. Most of the sandstones occur in the Dakota Sandstone at the base of the exposed section of Cretaceous rocks. Outcrops of Dakota underlie much of the west half of the mapped area. The rocks overlying the Dakota Sandstone are mostly shales with some interbedded limestone. These rocks are the Graneros Shale, the Greenhorn Formation, the Carlile Shale, and the Niobrara Formation.

The sedimentary rocks were cut and overlain by a variety of fine-grained igneous rocks ranging from phonolite to basalt in composition. Basalt flows cover the southeast part of the area and are part of extensive late Tertiary and Quaternary flows in northeast New Mexico. Glassy rhyodacite flows have been piled up to form the 435-m-high Laughlin Peak in the northeast part of the mapped area. A separate rhyodacite intrusive forms Raspberry Mountain in the southern part of the area. Trachyte forms two massive sills and numerous small dikes that intrude and cut the sedimentary rocks of Cretaceous age. Phonolite, as one thick sill intruded mainly into the Carlile Shale, forms the upper edge of several flat-topped hills along the southwest flank of Laughlin Peak. Phonolite also occurs in several dikes. Trachyandesite intrusives underlie both the trachyte and the phonolite at various locations along the drainage of Tinaja Creek. A few small lamprophyre dikes intruded the trachyte and Dakota Sandstone. Intrusive breccia dikes and pipes were emplaced within the drainage basin of Tinaja Creek during late Tertiary time. A medium-grained gray granite also occurs in this area, although it is not exposed at the surface. This rock has been found in fragments in several intrusive breccia bodies and as inclusions in the basalt and in a rhyodacite flow, all in the north half of the area. Thus, granite underlies a part of the Laughlin Peak area, and at one time may have been exposed at the surface.

Unconsolidated deposits conceal the underlying rocks in about 20 percent of the area; they are especially abundant in the northeastern part, where they cover about 75 percent of the outcrops. These deposits have been divided into (1) terrace gravels, (2) landslide deposits, (3) colluvium, and (4) alluvium. Colluvium, which includes talus and slope wash, covers the flanks of Laughlin Peak and Raspberry Mountain. Landslide deposits are numerous below the massive phonolite sill and cover much of the shaly underlying Carlile and Greenhorn Formations.

SEDIMENTARY ROCKS (CRETACEOUS)

DAKOTA SANDSTONE (LOWER AND UPPER CRETACEOUS)

The Dakota Sandstone is made up principally of sandstone with some shale interbeds. It probably underlies the entire area. It is exposed mainly in the western part of the area south of Tinaja Creek. The Dakota Sandstone is the best exposed sedimentary unit; it forms prominent cliffs along the sides of many canyons (fig. 2*A*) and commonly caps broad flat-topped ridges. The Dakota in this area is made up of three principal members. The upper and lower members are mainly sandstone with some thin shale interbeds; the middle member is mainly shale and siltstone with some sandstone beds. Dakota Sandstone, as mapped here, would also include rocks described elsewhere as Lower Cretaceous Purgatoire Formation (Baltz, 1965, p. 2061).

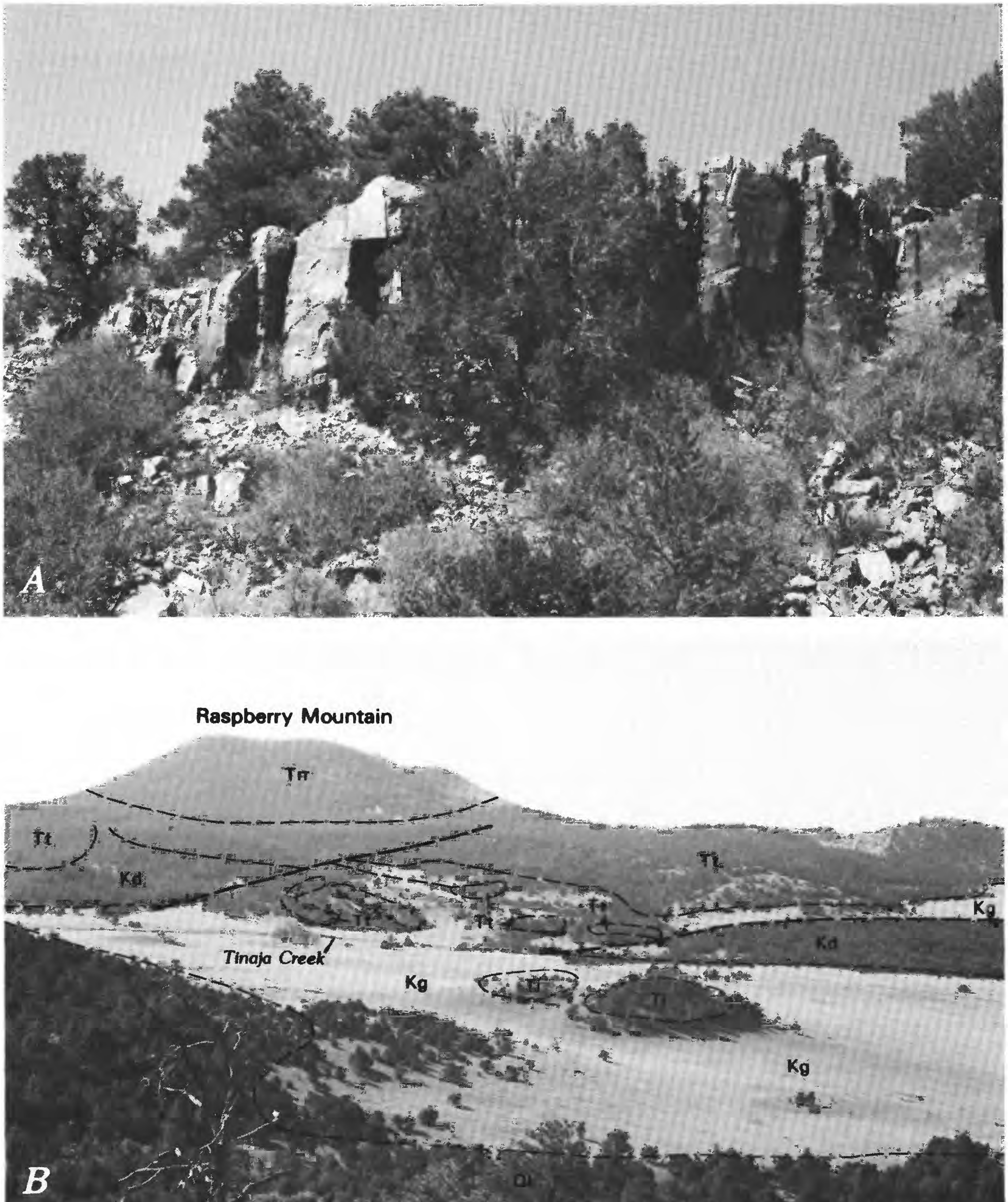

FIGURE 2.—Sedimentary rocks of Cretaceous age. *A*, Dakota Sandstone forming prominent ledge along the north side of Tinaja Creek in the SW¼SW¼ sec. 6, T. 27 N., R. 26 E. *B*, Graneros Shale (Kg) underlies open meadows along Tinaja Creek. Kd, Dakota Sandstone; Tt, trachyte; Ti, intrusive breccia; Trr, rhyodacite of Raspberry Mountain; and Ql, landslide deposits.

The sandstone is light brown, fine to medium grained, and is made up principally of well-rounded quartz grains. A few beds contain some interstitial detrital feldspar. The sandstone is commonly crossbedded, and ripple marks occur in a few places. Sandstone is generally thick bedded to massive.

The middle part of the Dakota is principally shale and siltstone that are poorly exposed. A good exposure of this central part of the Dakota, 5.4 m thick, is exposed along Jimmy Spring Creek 185 m northeast of its junction with Tinaja Creek. Here, thin layers of dark-gray carbonaceous siltstone and brown fine-grained sandstone are interbedded with a black flaky noncalcareous shale.

The base of the Dakota is not exposed in this area. The top of the Dakota is exposed along a branch of Tinaja Creek in the northeast corner of sec. 1, T. 27 N., R. 25 E. The upper meter of Dakota is a dark carbonaceous sandstone. A complete section of the Dakota Sandstone is not exposed here but was calculated to be at least 55 m thick. No fossils were found in the Dakota.

GRANEROS SHALE
(UPPER CRETACEOUS)

The Graneros Shale is mainly black shale. It is poorly exposed throughout the area (fig. 2*B*) and is represented in most places by smooth covered slopes that lie above the Dakota Sandstone and below the first dark-gray limestones of the Greenhorn Formation. Exposures of the Graneros are most commonly found scattered along steep-sided canyons where recent erosion has cut into the banks, as in the northwest part of the mapped area (pl. 1). The best exposure of the Graneros is along a branch of Tinaja Creek in the northeast corner of sec. 1, T. 27 N., R. 25 E. Here the lowermost part of the Graneros Shale and the underlying top of the Dakota Sandstone are exposed.

The Graneros Shale is mainly a fissile, dark-gray to black noncalcareous shale. A bed of brown-weathering gray limestone (Thatcher Limestone Member) is exposed at one place in the central part of this unit. The base of the Graneros is placed at the top of the last massive brown sandstone of the Dakota. The Graneros Shale was not measured in the field, but a measurement from the map (pl. 1) indicates it is approximately 30 m thick. No fossils were found in the Graneros.

GREENHORN FORMATION
(UPPER CRETACEOUS)

The Greenhorn Formation consists of thin-bedded limestones interbedded with shale. This formation has been divided elsewhere into three members, which are from bottom to top: the Lincoln Limestone Member, the Hartland Shale Member, and the Bridge Creek Limestone Member (Hook and Cobban, 1980, p. 43). Because exposures of the Greenhorn in the Laughlin Peak area are both widely scattered and few, this formation was not divided here. The Greenhorn crops out in the northern part of the area, notably along the upper slopes of Tinaja Creek. The best outcrops are found in the NW¼ sec. 36, adjacent to Jimmy Springs Creek (pl. 1).

The Greenhorn Formation consists of light-gray to black, thin-bedded limestones interbedded with black calcareous shales. Most of the outcrops are limestone; the shales rarely are exposed. Limestone beds are most abundant in the lower and upper part of the formation. The base of the formation is placed at the base of the first limestone above a thick shale section. The lower part of the Greenhorn contains several dark-gray to sooty-black, fine-grained limestones. These beds are generally 2–15 cm thick. In the upper part the limestone is a light gray to bluish gray and fine grained; beds are 4–30 cm thick. Limestone beds also occur scattered through the central part of the formation. Many of the limestones contain fossil trash.

The thickness of the Greenhorn Formation in this area is approximately 25 m. The Greenhorn thickens somewhat to the west, and measurements made on the Greenhorn along the Canadian River near Springer, 19 km south of Maxwell by Hook and Cobban (1980, p. 43) and along Gold Creek, 64 km west-northwest of Raton by Pillmore and Eicher (1976, p. 173) indicate that it is 40 m thick at these two localities. No identifiable fossils were found in the mapped area.

CARLILE SHALE
(UPPER CRETACEOUS)

The Carlile Shale consists principally of shale interbedded with some thin limestone units. The Carlile occurs only north of Tinaja Creek on the lower slopes of Laughlin Peak. It is found below the thick phonolite sill that forms the massive rimrock 75–120 m above the valley bottom. This area is, for the most part, covered by landslide. Small, widely scattered outcrops of Carlile occur only where erosion has stripped off the overlying cover. The best exposures of the Carlile occur in the NW¼ sec. 31, adjacent to Jimmy Springs Creek (pl. 1). This formation has been divided elsewhere into four or five members (Pillmore and Eicher, 1976, p. 172–173; Hook and Cobban, 1980, p. 43). Individual members can not be adequately mapped in this area because of the lack of sufficient outcrops.

The Carlile Shale consists mostly of black shale. At the base are black to dark-gray, thin-bedded, argillaceous limestones. These are overlain by black shale with widely scattered thin, gray to brown, limestone beds. A light-gray blocky limestone bed, 3–6 m thick, occurs in the central part of the formation. In places the central part of the Carlile contains a few widely scattered gray septarian limestone concretions. Pelecypods were found at two localities and were identified by William A. Cobban of the U.S. Geological Survey. One collection, which came from within 5 m of the base of the formation at a tributary stream junction of Jimmy Spring Creek in NW¼ sec. 31, was in a thin-bedded dark-gray argillaceous limestone. It contained large flat pelecypods, as much as 15 cm across, which were identified as *Mytiloides hercynius* (Petraschek). Cobban (oral commun., 1980) noted that this fossil is indicative of the Fairport Member (the lowest unit) of the Carlile. The other collection came from about 50 m above the base of the Carlile on a branch of Jimmy Spring Creek just below the thick phonolite sill in the central part of sec. 31. This shale contains *Inoceramus perplexus* Whitfield. Cobban noted that this fossil occurs in the middle part of the Carlile. The Carlile was not measured in this area, but it has been measured along the Canadian River near Springer, 19 km south of Maxwell, by Hook and Cobban (1980, p. 43) and along Gold Creek 64 km west-northwest of Raton by Pillmore and Eicher (1976, p. 172). At these two localities it is 50 and 76.8 m thick, respectively.

NIOBRARA FORMATION
(UPPER CRETACEOUS)

The Niobrara Formation is the youngest Cretaceous formation exposed in the Laughlin Peak area. Where exposed elsewhere in Colfax County it is about 290 m thick and is divided into two members. The lower or Fort Hays Limestone Member is made up of 4.6–6.0 m of limestone, and the upper or Smoky Hill Member of some 285 m of calcareous shales (Griggs, 1948, p. 30–33). Only part of the Fort Hays Limestone Member is exposed in this area in three small outcrops. These outcrops are found above the Carlile Shale in the northwest corner of sec. 31, just below the phonolite sill in the NE¼ sec. 6, and just above the phonolite in the NE¼ sec. 5.

The Fort Hays Limestone Member of the Niobrara Formation consists of limestone beds, 30–75 cm thick, separated by thin interbeds of gray shale. The limestone, which is light gray on a weathered surface and medium gray on a fresh surface, is a very fine grained rock. It fractures into blocky pieces. A maximum of only about 2.5 m of this member is exposed in this area.

IGNEOUS ROCKS
(TERTIARY)

Igneous rocks of at least seven distinct compositions occur in the small Laughlin Peak area. These are fine-grained rocks, which were either extruded on the surface or intruded fairly close to the surface. The emplacement of these rocks occurred during the last half of the Tertiary. The various rock types are (1) trachyte, (2) trachyandesite, (3) phonolite, (4) intrusive breccia, (5) lamprophyre, (6) rhyodacite, and (7) basalt. At least one sizeable body of all but the lamprophyre and intrusive breccia is found within this area, and standard chemical analyses of them are given in table 1. The intrusive breccia can not be compared with the other igneous rocks on the basis of its composition, as its composition varies considerably depending on the country rock types incorporated into it. The five principal rock types represent at least two and possibly three chemical or magmatic lineages. These lineages can be shown on two simple chemical variation diagrams (fig. 3). In figure 3*A* CaO is plotted against the alkalies, and in figure 3*B* MgO is plotted opposite total iron oxides. In both diagrams the points representing phonolite, trachyte, and trachyandesite lie along one trend, but those points representing the five rhyodacite samples lie along a separate trend. Rocks along each of these two linear trends could form by fractionation from a common magma. The separate trends, however, indicate the rhyodacitic rocks that form one of these trends were probably derived from a separate magma then the alkalic rocks which lie along the other trend. The chemical composition of the basalt (sample No. 13) is quite different from the compositions of the other rocks, as can be seen in figure 3 where the points representing basalt are widely separated from those of the other rocks. The basalt is obviously not on the trend formed by the rhyodacites. It might possibly be on the trend of the alkalic rocks, although not sufficient number of chemical analyses are available to verify the continuation of this trend. Although not apparent in the mapped area (pl. 1), basalts are much more widespread in this part of New Mexico than all the other rock types combined. Olivine basalt similar in composition to that exposed in the southeastern part of the mapped area cover broad areas in Colfax and Union Counties (Lee, 1922, p. 9–12; Collins, 1949, p. 1026–1031; Stobbe, 1949, p. 1049–1066). These rocks were extruded at various times in the late Tertiary and Quaternary (Stormer, 1972, p. 2445).

The minor-element contents of these igneous rocks show some significant differences. Table 2 summarizes data of 13 samples from the five principal rock types. The rock types are arranged from left to right in order

TABLE 1.—*Chemical analyses and normative compositions, in weight percent, of igneous rocks in the Laughlin Peak and adjacent area*

[FeO by volumetric titration, CO_2 by coulometric titration, H_2O+ by the Penfield method, and H_2O- by difference after heating to 105°C for 2 hours—all analyses done by H. G. Neiman; other oxides by X-ray spectroscopy done by J. S. Wahlberg, J. E. Taggart, Jr., and J. W. Baker; N.D., not determined]

Constituent or mineral	Sample Number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
						Chemical Analyses							
SiO_2	54.8	53.9	61.5	62.6	68.0	70.9	69.0	67.8	68.1	51.9	57.6	55.0	45.6
Al_2O_3	21.0	21.3	18.1	18.3	15.1	15.6	16.0	15.1	15.7	14.6	18.6	16.1	15.1
Fe_2O_3	2.94	2.86	3.25	3.18	2.34	1.44	1.55	2.36	2.21	5.35	4.69	5.81	7.0
FeO	.20	.36	.73	.35	.39	.36	.43	.20	.88	2.97	1.44	2.89	5.20
MgO	.2	.2	.66	.3	1.1	.1	.3	1.2	1.3	2.6	1.5	2.8	6.86
CaO	.42	.60	1.97	1.21	3.20	1.90	2.47	3.09	3.34	5.57	3.39	3.68	11.4
Na_2O	9.6	10.3	7.1	6.5	4.0	4.0	3.7	3.6	4.0	4.3	5.6	4.4	3.1
K_2O	4.96	4.14	3.78	4.65	2.94	2.64	2.83	3.01	2.68	3.73	3.56	4.20	1.06
TiO_2	.30	.30	.46	.36	.33	.21	.22	.32	.38	1.06	.80	1.02	1.45
H_2O+	4.90	4.70	.98	1.14	1.36	1.06	2.28	2.23	1.25	N.D.	N.D.	N.D.	1.79
H_2O-	0.25	.65	.20	.13	.23	.22	.55	.45	.28	N.D.	N.D.	N.D.	.20
P_2O_5	<.1	<.1	.2	.2	.2	<.2	<.1	.2	.2	.4	.5	.55	1.1
MnO	.20	.22	.15	.11	.05	<.02	<.02	.04	.05	.13	.12	.16	.18
CO_2	.08	.10	1.14	.60	.11	<.01	.02	.09	.08	N.D.	N.D.	N.D.	.12
Total	99.85	99.63	100.22	99.64	99.35	98.43	99.35	99.69	100.45	92.78	97.80	96.61	100.16
						Normative Compositions							
Quartz	--	--	3.72	6.42	26.22	34.38	32.04	28.44	26.22	1.26	3.96	3.12	--
Orthoclase	31.14	26.13	22.80	27.80	17.79	16.12	17.24	18.35	16.12	23.91	21.13	26.13	6.67
Albite	38.25	39.82	60.78	55.54	34.58	34.58	32.49	31.44	34.06	39.30	48.21	38.77	25.68
Anorthite	--	.28	1.95	1.39	14.73	9.73	12.79	14.18	15.57	10.01	13.62	11.95	24.46
Nepheline	25.28	27.83	--	--	--	--	--	--	--	--	--	--	.57
Hypersthene	--	--	1.70	.80	2.80	.30	.80	3.10	3.40	0.90	3.80	6.10	--
Diopside	1.08	1.08	--	--	--	--	--	--	--	13.18	--	2.59	19.44
Wollastonite	.35	.70	--	--	--	--	--	--	--	--	--	--	--
Olivine	--	--	--	--	--	--	--	--	--	--	--	--	7.23
Corundum	--	--	1.53	2.14	.10	2.86	2.45	.61	.61	--	.71	--	--
Magnetite	.46	1.16	1.39	.23	.46	.46	.93	--	1.86	7.89	2.55	6.96	10.21
Hematite	2.72	2.24	2.40	3.04	2.08	1.12	.96	2.40	.96	.32	3.04	1.28	--
Ilmenite	.61	.61	.91	.76	.61	.46	.46	.46	.76	2.13	1.52	2.13	2.89
Apatite	--	--	.34	.34	.34	--	--	.34	.34	1.01	1.34	1.34	2.69
Calcite	--	--	2.60	1.40	.20	--	--	.20	.20	--	--	--	.30
Sphene	--	--	--	--	--	--	--	.20	--	--	--	--	--
Na_2CO_3	.21	.21	--	--	--	--	--	--	--	--	--	--	--
Total	100.10	100.06	100.12	99.86	99.91	100.01	100.16	99.72	100.10	99.91	99.88	100.37	100.14

TABLE 1.—*Chemical analyses and normative compositions, in weight percent, of igneous rocks in and near the Laughlin Peak area*—Continued

SAMPLE DESCRIPTIONS

1. Phonolite from top of massive sill, 1,340 m south of Jimmy Spring near the northern border of sec. 6, T. 27 N., R. 26 E.

2. Phonolite from just west of road, 980 m south of Jimmy Spring in the south-central part of sec. 31, T. 28 N., R. 26 E.

3. Trachyte from southwest end of sill, just north of Jimmy Spring Creek in the NE1/4 sec. 36, T. 28 N., R. 25 E.

4. Trachyte from north end of dike adjacent to large sill just south of county road A-8 in the SW1/4 sec. 36, T. 28 N., R. 25 E.

5. Rhyodacite from steep northeast flank of Raspberry Mountain.

6. Rhyodacite from peak 8632 on southwest flank of Laughlin Peak in the NE1/4 sec. 32, T. 28 N., R. 26 E.

7. Rhyodacite tuff from north side of county road A-8, 290 m northeast of ranch house in the SE1/4 sec. 5, T. 27 N., R. 26 E.

8. Rhyodacite from southeast flank of easternmost of the Pine Buttes in the SE1/4 SE1/4 sec. 11, T. 27 N., R. 26 E., east of mapped area.

9. Rhyodacite from lower south flank of Palo Blanco Mountain in the SW1/4 SE1/4 sec. 17, T. 27 N., R. 27 E., east of mapped area.

10. Trachyandesite from 570 m south of county road A-8 and 115 m east of the west border of the mapped area in SW1/4 SE1/4 sec. 35, T. 28 N., R. 25 E.

11. Trachyandesite from small knoll, 230 m northeast of county road A-8 in the SE1/4 SW1/4 sec. 6, T. 27 N., R. 26 E.

12. Trachyandesite from low hill, 380 m north of county road A-8 in the SW1/4 SE1/4 sec. 6, T. 27 N., R. 26 E.

13. Basalt from 100 m north of county road A-8, between two drainages of Tinaja Creek in the NW1/4 SE1/4 sec. 5, T. 27 N., R. 26 E.

of their decreasing alkali content, which is the same as increasing mafic content. As might be expected, as the mafic content increases in the rocks, so does the content of chromium, cobalt, copper, nickel, and scandium. Other elements, such as gallium, lead, niobium, and zirconium, tend to correlate with the alkali content. The phonolite has a deviant minor-element content. Phonolite contains more rare earths, beryllium, gallium, lead, niobium, and strontium than any other rock type. Beryllium, niobium, and zirconium are especially concentrated in the phonolite, and this rock may contain as much as 10 times that found in the other rock types. Phonolite contains less chromium, cobalt, nickel, and scandium than the other rock types. Two elements common in the thorium- and rare-earth-bearing veins, barium and strontium, occur in phonolite in amounts only one-third to one-fifth that of other rocks.

The thorium and uranium contents of various igneous rock types are shown in table 2. The lowest thorium contents are found in the five samples with rhyodacitic composition. Trachyandesite contains a little more thorium, and, surprisingly, the basalt has about the same amount. Trachyte in general is higher in thorium than the trachyandesite. The thorium content of phonolite is much higher than that of any of the other rock types. The least uranium occurs in the five samples of rhyodacite and the one of basalt. Uranium content generally follows that of thorium, and phonolite contains six to seven times as much uranium as trachyte, which has the next highest content of uranium. The rocks with the higher alkali content tend to have a higher content of thorium and uranium. This can be seen graphically in figure 4 where thorium and uranium are plotted against the Na_2O+K_2O content of each rock. The two curves are similar and show a gradual increase in thorium and uranium content as the alkali increases from basalt to trachyte. A large increase in the amounts of thorium and uranium occurs as the

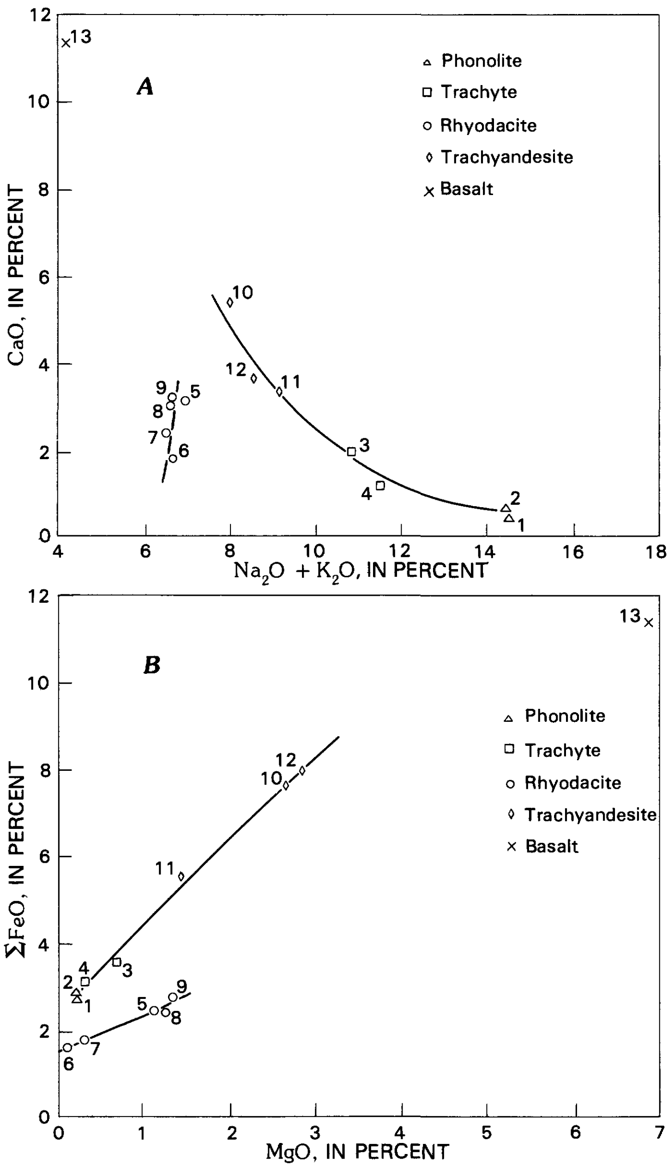

FIGURE 3.—Graphs showing chemical relations in rocks in and near the Laughlin Peak area. Sample numbers correspond to those used in table 1. *A*, CaO to the alkalies ($Na_2O + K_2O$). *B*, MgO to total iron oxides.

$Na_2O + K_2O$ content increases from about 11 to 14 percent.

The increase in thorium and uranium contents can also be noted by the increase in radioactivity measured with a scintillometer, although an increase in radioactivity also reflects an increase in potassium. The radiation due to K^{40} is generally small, but the amounts of potassium in an igneous rock compared with the amounts of thorium and uranium are large. The

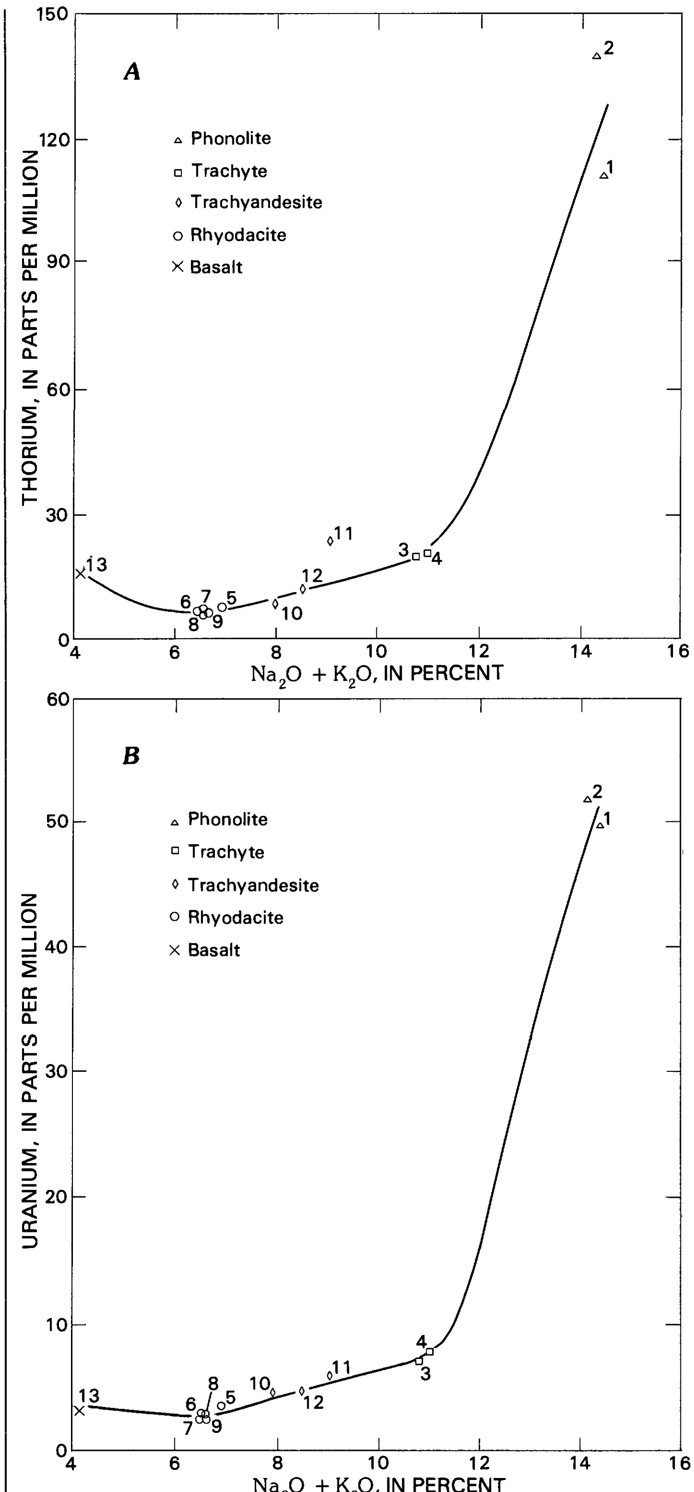

FIGURE 4.—Graphs showing relation between thorium and uranium and the alkalies ($Na_2O + K_2O$) of various rock types. *A*, Thorium; *B*, uranium.

TABLE 2.—*Chemical analyses of minor elements of igneous rocks in and near the Laughlin Peak area*

[Thorium and uranium analyses were done done on a gamma-ray spectrometer by C. M. Bunker and C. A. Bush. All other elements, including 24 elements looked for but not detected, were determined by semiquantitative spectrographic analysis by N. M. Conklin; <, less than value indicated; N.D., not determined; elements looked for but not detected: Ag, As, Au, B, Bi, Cd, Eu, Ge, Hf, In, Li, Mo, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Tl, W, and Zn]

Rock Type......	Phonolite		Trachyte		Rhyodacite					Trachyandesite			Basalt
Sample No......	1	2	3	4	5	6	7	8	9	10	11	12	13
Element													
Lanthanum..........	300	150	150	150	30	N.D.	N.D.	N.D.	N.D.	70	150	70	150
Cerium.............	300	150	200	150	<150	N.D.	N.D.	N.D.	N.D.	<150	200	150	<150
Neodymium..........	150	70	150	100	<70	N.D.	N.D.	N.D.	N.D.	70	150	100	70
Ytterbium..........	7	5	7	3	1	N.D.	N.D.	N.D.	N.D.	3	3	3	2
Yttrium............	50	30	70	30	10	N.D.	N.D.	N.D.	N.D.	30	30	30	20
Total rare earths..	807	405	577	433	41	N.D.	N.D.	N.D.	N.D.	173	533	353	242
Barium.............	150	300	1500	1500	1500	N.D.	N.D.	N.D.	N.D.	1500	1500	3000	1500
Beryllium..........	10	15	1.5	1	<1	N.D.	N.D.	N.D.	N.D.	<1	1	1	<1
Chromium...........	3	<1	3	3	15	N.D.	N.D.	N.D.	N.D.	50	30	150	200
Cobalt.............	<5	<5	7	7	7	N.D.	N.D.	N.D.	N.D.	20	15	30	30
Copper.............	7	1.5	30	30	30	N.D.	N.D.	N.D.	N.D.	70	15	70	150
Gallium............	70	70	30	30	30	N.D.	N.D.	N.D.	N.D.	20	30	30	15
Lead...............	70	70	30	30	15	N.D.	N.D.	N.D.	N.D.	10	15	15	15
Manganese..........	1500	1500	1500	1000	700	N.D.	N.D.	N.D.	N.D.	1000	700	1500	1500
Nickel.............	2	<2	3	2	7	N.D.	N.D.	N.D.	N.D.	15	15	30	150
Niobium............	150	70	30	30	<10	N.D.	N.D.	N.D.	N.D.	15	30	15	20
Scandium...........	<5	<5	7	7	7	N.D.	N.D.	N.D.	N.D.	15	15	15	15
Strontium..........	300	300	1500	1500	1000	N.D.	N.D.	N.D.	N.D.	700	3000	2000	1500
Vanadium...........	70	50	150	70	50	N.D.	N.D.	N.D.	N.D.	300	150	300	150
Zirconium..........	1000	700	300	200	70	N.D.	N.D.	N.D.	N.D.	150	150	150	70
Thorium............	111	139	21	22	8.1	6.5	6.6	6.7	7.3	8.7	23	11	16
Uranium............	50	52	7	8	3.6	3.2	2.6	2.8	3.2	4.4	6.2	3.8	3.5

percentage of radioactivity due to potassium was calculated for the igneous rocks of the Laughlin Peak area. Potassium accounts for 54–58 percent of the radiation in two samples of trachyte. It makes up 59–72 percent of the radiation in three samples of trachyandesite, 71–78 percent in five samples of rhyodacite, and 42 percent in a sample of basalt. Only in the phonolite, where it accounts for only 10–21 percent of the total radiation in two samples, is the radiation principally due to uranium and thorium. In the phonolite the uranium accounts for 56–57 percent of the total radiation and thorium 22–26 percent. Phonolite can be easily identified in the field by its high radioactivity. It is about 3.5 times more radioactive than trachyte, the next most radioactive igneous rock. It also has approximately 4 times the radioactivity of trachyandesite, 5.5 times as much as rhyodacite, and 8.5 times as much as the basalt.

TRACHYTE
(OLIGOCENE)

Trachyte is the most widespread igneous rock in Laughlin Peak area (pl. 1). It occurs principally in dikes and sills from the northernmost to the southernmost part of the area. The bulk of the trachyte occurs in two massive sills. One is in the northwest part of the area just south of Tinaja Creek where a sill at least 45 m thick underlies an area of approximately 2.5 km^2

(fig. 5). The other surrounds Raspberry Mountain. (See sec. *B–B′*, pl. 1.) There, a sill at least 30 m thick underlies an area of about 3.2 km^2. Trachyte outcrops have been seen to the west in the central and western part of the Piñon Hills and southward down into the Chico Hills.

Dikes, smaller sills, and small irregular-shaped intrusions occur in many parts of this area. Dikes are steeply dipping and trend in many directions. Along the northern border near Jimmy Spring Canyon, most of the dikes have a northeasterly strike, and adjacent to the Slagle Canyon, in the southwest corner of the area, most dikes have a east-northeast strike. Dikes range in length from a few meters to at least 860 m. The longest dike and several other long dikes occur in the southwest corner of the area. Dikes range in thickness from a few tenths of a meter to about 10 m. In the northwest corner of sec. 6, northeast of county road A–8, a dike can be traced up a mountain to where it merges with a sill.

The trachyte is the oldest Tertiary igneous rock in the area. Lamprophyre, trachyandesite, and phonolite dikes, and intrusive breccia bodies cut the trachyte, and, in places, inclusions of trachyte are found in intrusive breccia bodies and lamprophyre. Its relations with the rhyodacites and the basalt are not well exposed, although basalt flows appear to lap onto trachyte along the south and east flanks of Raspberry Mountain. Trachyte from widely scattered outcrops is generally altered. The only other igneous rock that is commonly altered is trachyandesite. The trachyte and trachyandesite were altered before the other rocks were emplaced. As previously noted, the trachyte forms many dikes and sills, which were not all emplaced at the same time. Field relations, such as alteration, however, indicate that the trachyte bodies are older than most other igneous rocks of the region. A potassium-argon determination was made on hornblende separated from the large sill in the northwest part of the area. Specifically this sample was collected on a ridge in the SE¼NE¼ sec. 2, T. 27 N., R. 25 E. The analysis, which was made by R. F. Marvin, H. H. Mehnert, and E. L. Brandt of the U.S. Geological Survey, yielded an Oligocene age of 36.7 ± 1.3 m.y. (million years).

Altered trachyte is a tan to light-tan porphyritic rock. Phenocrysts consist principally of chalky white, partly altered plagioclase. In addition, goethite-filled, elongate-shaped crystal molds indicate the former presence of mafic minerals. Where unaltered, trachyte is light gray. Trachyte contains hornblende and augite phenocrysts, and the feldspar phenocrysts are unaltered. Most fresh trachyte contains 10–20 percent phenocrysts, although their total range is from about 4 to 100 percent. The most common phenocrysts are white tabular crystals of plagioclase about 1–3 mm long. Much of the plagioclase is oligoclase to andesine in composition. A few of the feldspar phenocrysts are potassium feldspar. The principal mafic mineral is brown hornblende that makes up about 1–15 percent of the rock; it is pleochroic from light brown to olive green and occurs as elongate crystals as much as 4 mm long. Minor amounts of pyroxene, from less than 1 to 3 percent, are commonly present. Optically, the pyroxene is clear to pale green, nonpleochroic, and occurs as subhedral crystals. The optical properties of this mineral most closely fit those of diopside. The matrix of the trachyte can be either glassy or finely crystalline. Where holocrystalline it is made up principally of feldspars. Studies of all rock specimens stained with sodium cobaltinitrite indicate that the matrix has a high content of potassium feldspar. Twinned plagioclase is also present in the matrix. A little quartz (as much as several percent) occurs interstitially between the feldspar grains in some rocks. Small black grains of magnetite also are common in the matrix. Other accessory minerals that occur in some samples are brown biotite, apatite, and, more rarely, zircon.

Chemical analyses of two samples of trachyte are reported in table 1 (Nos. 3 and 4). Compared with most igneous rocks these samples have a relatively low silica and CaO content and a high K_2O and Na_2O content. These relations can also be seen by the relatively low quartz and anorthite contents and the high orthoclase and albite content of the norms. The relations between the CaO and $Na_2O + K_2O$ and between MgO and total iron oxides in samples of trachyte and various other types of igneous rocks in the Laughlin Peak area are shown in figure 3. Classified on the basis of their chemical composition according to the systems of Rittmann (1952) or De la Roche, Letterrier, Grandclaude, and Marchal (1980), both these samples are trachytes.

TRACHYANDESITE (OLIGOCENE)

Trachyandesite is a rather inconspicuous rock type; it forms subdued outcrops on gently sloping hillsides and on low hills. Most of the trachyandesite occurs in what appear to be sills in three areas. The easternmost of these is a little over 200 m north of county road A–8 near the east edge of the Laughlin Peak area, in sec. 5, where trachyandesite is intruded into the Carlile Shale and lies directly below the phonolite. These outcrops, which are exposed over an area of 650 by 230 m, may represent an irregular intrusive because, although its top underlies the phonolite sill, its base appears to crosscut the Carlile in the one outcrop where the base is exposed. The second major area of the

FIGURE 5.—Trachyte and phonolite sills. *A*, North end of large trachyte sill exposed just south of county road A–8. *B*, Phonolite sill forms skyline of ridge 1 km north of Jimmy Spring Creek.

trachyandesite lies approximately 230 m north of county road A–8, in sec. 6, about 640 m west of the first one. This body is intruded principally into the Graneros Shale. Its top, however, is in the Greenhorn Formation and everywhere lies below the Bridge Creek Limestone Member. The trachyandesite is exposed over an area of 740 by 750 m. The third principal area of trachyandesite occurs south of county road A–8 on the west edge of the area. It underlies the western part of the large trachyte sill and extends westward into the adjoining Tres Hermanos Peak quadrangle. The upper part of this trachyandesite body is in part directly below the trachyte and in part separated from the trachyte by part of the Greenhorn Formation. Its lower part is in the Graneros Shale. In addition to the three principal areas, several small sills and dikes of trachyandesite have been mapped. These small intrusives range in length from 12 to 170 m. The largest has a thickness that ranges from 10 to 60 cm.

A similar rock was reported by Stobbe (1949, p. 1071) on the southwest flank of Turkey Mountain (fig. 1). She called this rock a hornblende andesite, but her nomenclature was based chiefly on the phenocryst content of the rock.

Trachyandesite is for the most part intruded into the Graneros Shale and the Greenhorn Formation. In two of the areas, dikes of trachyandesite cut the older trachyte. Trachyandesite lies below the large phonolite sill, but the contact between these two rock types is poorly exposed. Trachyandesite does not come in contact in this area with basalt, rhyodacite, or lamprophyre, and their relationship to trachyandesite is not known. Trachyandesite and trachyte are the only two igneous rocks that are commonly altered. Thus, the trachyandesite probably was emplaced and altered before the unaltered basalt, rhyodacite, and phonolite were emplaced. Although most of the trachyandesite is altered, fresh porphyritic trachyandesite occurs on a small knoll 230 m northeast of county road A–8 in the SE¼SW¼ sec. 6, T. 27 N., R. 26 E. A potassium-argon age determination was made on hornblende from a sample of this rock by R. F. Marvin, H. H. Mehnert, and E. L. Brandt of the U.S. Geological Survey. They obtained an Oligocene age of 32.3 ± 1.5 m.y. A chemical analysis of this sample is also given in table 1 (No. 11).

Trachyandesite ranges in color from dark gray, where fresh, to olive green and brown, where altered or partly altered. This rock is porphyritic, having 10–30 percent phenocrysts that range in length from 0.2 to 5 mm. Phenocrysts are 8–26 percent greenish-brown euhedral crystals of hornblende, 0–15 percent small laths of plagioclase, 0–3 percent augite, less than 1 to 2 percent magnetite, and trace amounts of apatite, biotite, and sphene. The matrix ranges from entirely crystalline to a glass. Where crystalline it consists of numerous crisscrossing plagioclase microlites with a few percent magnetite and hornblende crystals. This is intermixed with colorless anhedral crystals, which under the microscope have a light-gray birefringence. Yellow coloring as a result of staining of the rock with sodium cobaltinitrite indicates that the matrix contains considerable potassium feldspar. Less than 1 percent of tiny anhedral grains of quartz were noted in one thin section. Fresh trachyandesite, like that described above, is not common. The mafic phenocrysts of many samples have been completely altered to limonite, hematite, magnetite, chlorite, or calcite. Plagioclase phenocrysts are generally altered to clay. All the small dikes and sills are altered, as are much of the larger masses of trachyandesite.

Chemical analyses of three samples of trachyandesite are reported in table 1 (Nos. 10–12). These samples, when compared with those of the other igneous rocks, have a low silica content, having only 1.3–4 percent quartz in the norm. They also have a high potassium content, containing 21–26 percent orthoclase in the norm. The relations between CaO to $Na_2O + K_2O$ and MgO to total iron oxides in these three samples of trachyandesite and other igneous rocks from the Laughlin Peak area are shown in figure 3. The relation between both the alkalic (fig. 3*A*) and mafic elements (fig. 3*B*) in trachyandesite to other rocks suggest that they are related chemically to the trachyte and phonolite, rather than the rhyodacites. Although the dark-colored trachyandesite looks somewhat like the basalt in hand specimen, there is no similarity between their alkali content.

Classified on the basis of its chemical composition according to the system of De la Roche, Letterrier, Grandclaude, and Marchal (1980), this rock could be called either a trachyandesite or a trachyte. I prefer the name trachyandesite, as the composition is considerably different than the trachyte previously described. The trachyandesite has less SiO_2 and Na_2O and has more MgO, Fe_2O_3, and FeO than the trachyte. It is a much more mafic rock and is darker in color than the trachyte.

PHONOLITE
(OLIGOCENE)

Phonolite is one of the most distinctive rocks in the Laughlin Peak area. It consists of large white tabular feldspar and small rounded white ocellar masses of feldspathoids set in a greenish-gray matrix. It is resistant to weathering and commonly forms prominent cliffs (fig. 5*B*). The greater part of the phonolite is in one thick sill on the southwest flank of Laughlin Peak and is exposed over a distance of approximately 3.3 km between Jimmy Spring Canyon and the eastern border of the area. Both ends and part of its upper surface are buried by colluvium derived from Laughlin Peak. The same phonolite sill is also exposed about 1 km north of the mapped area in the adjoining Mesa Larga quadrangle (fig. 5*B*). A much smaller sill, about 320 m long, is exposed 15 m below the larger sill in a canyon along the northern border of the NE¼ sec. 6. Several widely scattered dikes occur in the northwestern part of the area. The largest of these forms a protruding outcrop along the crest of a hill, about 460 m long, north of Jimmy Spring Canyon in the N½ sec. 36. Phonolites are widespread in the Tres Hermanos Peak quadrangle to the west, and in the southern part of the Chico Hills, which lie 5 km to the southeast of the Laughlin Peak area.

The large sill that makes up the bulk of the phonolite is intruded into Cretaceous sedimentary rocks; this sill is 18–25 m thick. Collins (1949, p. 1034–1035) thought this phonolite was a flow, but the presence of sedimentary rocks both above and below the phonolite, the general shape of the unit, and the presence of a smaller sill directly below the larger sill suggest to me that this phonolite body is a sill.

Phonolite is younger than trachyte, as it cuts a trachyte sill in the SE¼ sec. 2. Contacts between phonolite and the other igneous rocks are not exposed. Although phonolite has not been dated within the area of study, an age was reported from a large phonolite sill at the Dorsey Mansion State Monument, which is 10.5 km south-southeast of Raspberry Mountain in the NW¼SE ¼ sec. 17, T. 26 N., R. 26 E. (Scott, Wilcox, and Mehnert, written commun., 1983). This phonolite, which was dated by the K-Ar method on potassium feldspar, had a Oligocene age of 25.80±0.88 m.y.

Although most phonolite is greenish gray, the color of this rock varies from a dark gray through greenish gray to bluish gray. The rock is porphyritic and contains both white rectangular feldspar phenocrysts and white, round to oval-shaped ocellar masses (aggregates of feldspathoids) set in a greenish-gray aphanitic matrix. These white crystals or aggregates constitute about 5–30 percent of the rock. The feldspar is orthoclase and forms elongate tabular crystals as much as 3.8 cm long, although most crystals are in the 0.6–1.0 cm range. The orthoclase may be in part replaced by small laths of plagioclase. Flow structure in the phonolite is brought out by the alinement of these tabular crystals of feldspar. The white ocellar masses are made up of intergrown crystals of nepheline—and lesser amounts of plagioclase. Nepheline is marked by hexagonal and rectangular crystal outlines and has both low relief and low birefringence. The nepheline in some samples has been altered to natrolite or analcime. In some places, small (1–2 mm long) bright green acicular aegirine crystals are present. The groundmass consists chiefly of 10–20 percent aegirine, 1–10 percent plagioclase, and most of the rest intergrown nepheline and orthoclase. In addition, some samples contain less than 1 percent of apatite, light-brown biotite, and magnetite. The aegirine is a distinctive mineral in this rock, occurring as bright-green acicular crystals. These crystals commonly occur in clots, which in some places form rosettes. Nepheline and orthoclase are commonly difficult to distinguish visually under the microscope as both are colorless and have low relief and low birefringence, but the hexagonal or rectangular form of nepheline is diagnostic, and orthoclase is distinguished by sodium cobaltinitrite staining.

Chemical analyses of two samples of phonolite collected from the large sill are reported in table 1 (Nos. 1 and 2). These samples have low silica content and both samples contain more than 25 percent nepheline in the norm. They also have low CaO content, as neither sample exceeds 0.6 percent. The anorthite content of the norm ranges from 0 to 0.2 percent with most of what little CaO there is going into diopside in the norm. The phonolite samples have the highest Na_2O content and one of the highest K_2O content of all the rocks in the region. This is expressed by the high albite, nepheline, and orthoclase contents of the norm. The relations between the CaO to Na_2O+K_2O and MgO to total iron oxides of phonolite to that of the other rocks are seen in figure 3. Phonolite has more alkalies than any other rock in the area. It forms the alkali-rich end of a linear sequence that shows an increase in alkali as the CaO content decreases. Phonolite also has less total iron oxide and MgO than the other rocks and forms part of another linear sequence with the same rock types (fig. 3*B*). Rhyodacite samples lie on separate linear trends in both these graphs and do not appear to have formed from the same source as the phonolite. The two analyzed samples are classified as phonolite on the basis of their chemical composition by the systems of Rittmann (1952), or De la Roche, Leterrier, Grandclaude, and Marchal (1980).

INTRUSIVE BRECCIA (OLIGOCENE)

Intrusive breccia occurs in cross-cutting bodies in the central part of the area. Some of these bodies are dikes (fig. 6) that are as much as 170 m long and range in thickness from about 0.5 to 6 m. These bodies may strike in any direction, but a group of intrusive breccia dikes just south of Tinaja Creek in the northern part of sec. 7 have a west-northwest trend. These bodies occur along fractures, some of which show displacement of a few meters. An intrusive breccia body just south of county road A–8 down Tinaja Creek lies along a small fault that separates the Graneros Shale from the Dakota Sandstone. Intrusive breccia bodies form irregular pipes in two areas. The largest occurs on a hill in the western part of secs. 1 and 12. This intrusive breccia body is roughly 300 by 180 m, although its size and form are not well known because outcrops are scarce. Two smaller pipelike bodies occur on the low hill on the north side of Tinaja Creek in the SW¼ sec. 6. Within the mapped area the intrusive breccia is emplaced into Dakota Sandstone, Graneros Shale, Greenhorn Formation, Carlile Shale, and trachyte. It is, therefore, younger than these rocks. It is also noted cutting phonolite some 6.5 km south of this area in the Chico Hills.

The composition of the intrusive breccia varies, but generally it consists of fine- to pebble-size fragments of sedimentary, volcanic, and plutonic rocks in a matrix of crystal fragments and finely granulated material. Composition of the rock fragments varies from body to body. Some are mainly sedimentary rocks, others mainly trachyte, and some contain a mixture of various

FIGURE 6.—An intrusive breccia dike protrudes out of a plain underlain by Graneros shale south of Tinaja Creek near the northern border of the NW¼ sec. 7, T. 27 N., R. 26 E.

rock types. Fragments were derived from underlying rock types and hence vary as these rock types change. Sedimentary rock fragments include shale, limestone, and sandstone. These may be bleached and recemented so that the original formation is not recognizable. Trachyte fragments are abundant in some intrusive breccias. Three intrusive breccias contain fragments of granite as large as 0.5 m across. Granite is not exposed at the surface in this area. Granite along with black shale, trachyte, and Dakota Sandstone fragments occurs in the intrusive breccia dike south of Tinaja Creek near the northern border of sec. 7. Abundant granite fragments are also found in the westernmost of two small pipes on a low hill about 0.8 km north of this locality. An adjacent pipe to the east of this one contains principally sedimentary rock fragments.

Rock fragments in the intrusive breccia range from angular to subrounded in shape and from a few millimeters to 0.6 m across. Most, however, are from 1 to 5 cm across. The matrix may be a white or tan, or it may be stained brown or black with limonite or manganese oxide minerals. The matrix contains small mineral fragments, mainly quartz and feldspar. These are probably, in turn, derived from disintegration of the rock fragments. The rest of the matrix is extremely finely granulated material, which is too fine to identify even with the aid of petrographic microscope.

LAMPROPHYRE DIKES (OLIGOCENE)

Five small lamprophyre dikes were found during mapping in the Laughlin Peak area. This rock type is generally poorly exposed and most of its exposures are along ridges or in pits. The dikes have been traced from 3 to 18 m and range in thickness from 0.3 to 2 m. They all have a general northwest strike.

The lamprophyres are found in two general areas: (1) in and adjacent to the large trachyte sill in the northwest corner of the area, and (2) near Slagle Canyon in the southwest part of the area. In the northwest part of the area two dikes are exposed along ridge tops where they cut the trachyte sill, and one is exposed in a small working in the Graneros Shale along the east side of the trachyte sill. At the latter locality the lamprophyre contains small inclusions of Graneros Shale. In the southwest part of the area two dikes cut Dakota Sandstone. At one locality the lamprophyre also cuts a trachyte dike, and 3 km southeast of the area along Joe Cabin Arroyo several lamprophyres are found cutting phonolite.

The lamprophyres are black to dark gray, and the individual crystals are not readily apparent. These dikes vary somewhat in mineralogy. Augite is the most abundant mineral in two dikes in the southwest part of the area and in one dike in the northwest part of the area, olivine predominates in the dike in the Graneros Shale, and hornblende is most abundant in the other dike. The two dikes in the southwest part of the area are quite similar in composition and contain 70–75 percent augite, 7–15 percent olivine, 6–8 percent magnetite, 1–5 percent biotite, and 2–5 percent feldspar. These two dikes are holocrystalline. One of the two dikes that intrudes the trachyte in the northwest part of the area contains 45 percent augite, 20 percent pale-brown hornblende, and 5 percent magnetite. The other dike that intrudes the trachyte has 55 percent hornblende, 8 percent magnetite, 5 percent biotite, and 3 percent augite. The dike that intrudes the Graneros Shale is made up of 50 percent olivine, 35 percent augite, 5 percent biotite, and 2 percent magnetite. The remainder of these three dikes consists of a glass.

RHYODACITE (MIOCENE)

Rhyodacite makes up several volcanic cones and intrusions in and around Laughlin Peak (fig. 7). Rocks of rhyodacite composition form the flows on Laughlin Peak, the intrusive that makes up Raspberry Mountain, and a small patch of tuff on the lower part of the southern flank of Laughlin Peak. Rhyodacites also are found in the surrounding area, and occur on Palo Blanco Mountain and the southern two Pine Buttes (fig. 1). Samples taken from these six areas were classified as rhyodacites on the basis of their chemical composition according to the system of either Rittmann (1952) or De la Roche, Leterrier, Grandclaude, and Marchal (1980). Rhyodacites were identified in two other adjacent areas from their chemical analyses according to the same systems. One is the intrusion on Red Mountain some 30 km north of Laughlin Peak (Lee, 1922, p. 11) and the other is from Cunningham Butte some 21.5 km northwest of Laughlin Peak (Stobbe, 1949, p. 1067). These rocks are called the Red Mountain Dacites by Stobbe (1949, p. 1066–1071), who studied the petrography of these rocks in some detail. Her basis for this nomenclature is evidently petrographic as she had few chemical analyses to aid her. A large part of these rocks is either made up of a glassy or a very fine grained matrix. Hence, in these types of rocks a nomenclature based on chemical composition is greatly preferred, and these rocks have been renamed rhyodacite.

The three rhyodacites that are found in the Laughlin Peak area will be discussed separately, as they occur in separate parts of the area and differ from each other in color, texture, and degree of crystallinity.

RHYODACITE OF RASPBERRY MOUNTAIN

The rhyodacite which makes up the central mass of Raspberry Mountain (fig. 7*A*), has an oval-shaped outcrop pattern (pl. 1). In addition, this rock body is steep sided and of fairly uniform composition. Collins (1949, p. 1033) believed Raspberry Mountain to be a small eroded cone. He noted that no crater exists. The shape and uniformity of this rock body, however, indicate that this rhyodacite probably formed as a plug intruded into the largely shaly Graneros, Greenhorn, and Carlile Formations, which have since been eroded away. This plug is approximately 1,200 m in an east-west direction, 900 m in a north-south direction, and protrudes some 220 m above the surrounding countryside. The contact of this rhyodacite with the adjacent trachyte and basalt are everywhere hidden by talus (colluvium) derived from the rhyodacite plug. An age determination made on this rhyodacite indicates it is younger than the trachyte and older than the basalt. This determination was made on hornblende using the K-Ar method by R. F. Marvin, H. H. Mehnert, and E. L. Brandt of the U.S. Geological Survey from a sample collected on the northeast part of Raspberry Mountain. This rock was intruded in Miocene time and has an age of 8.1 ± 0.6 m.y.

The rhyodacite of Raspberry Mountain is a light-brownish-gray, fine-grained, porphyritic rock. Small phenocrysts, 0.05–2 mm long, make up 20–30 percent of the rock. Plagioclase is the most abundant phenocryst; it makes up 15–20 percent of the rock. Other phenocrysts are oxyhornblende, which make up 5–10 percent of the rock, and magnetite, which accounts for less than 1 percent. The plagioclase occurs as subhedral to euhedral crystals that are commonly zoned. The centers of many of these crystals have been partly destroyed. The plagioclase is both oligoclase and andesine. Oxyhornblende ranges in color in thin section from a distinctive dark reddish brown to a greenish brown. These crystals are subhedral and a little smaller than those of plagioclase. The groundmass is made up partly of recognizable small grains intermixed with those of low birefringence and little crystal form; some glass is also present in some samples. The recognizable grains consist of a few percent each of magnetite and reddish-brown oxyhornblende. Much of the rest is small plagioclase laths. Groundmass minerals with low birefringence may be potassium feldspar—as this part of the rock takes on a yellow sodium cobaltinitrite stain.

A chemical analysis of a sample of rhyodacite collected from the steep northeast flank of Raspberry Mountain is given in table 1 (No. 5). All five analyses of rhyodacite from Laughlin Peak and surrounding

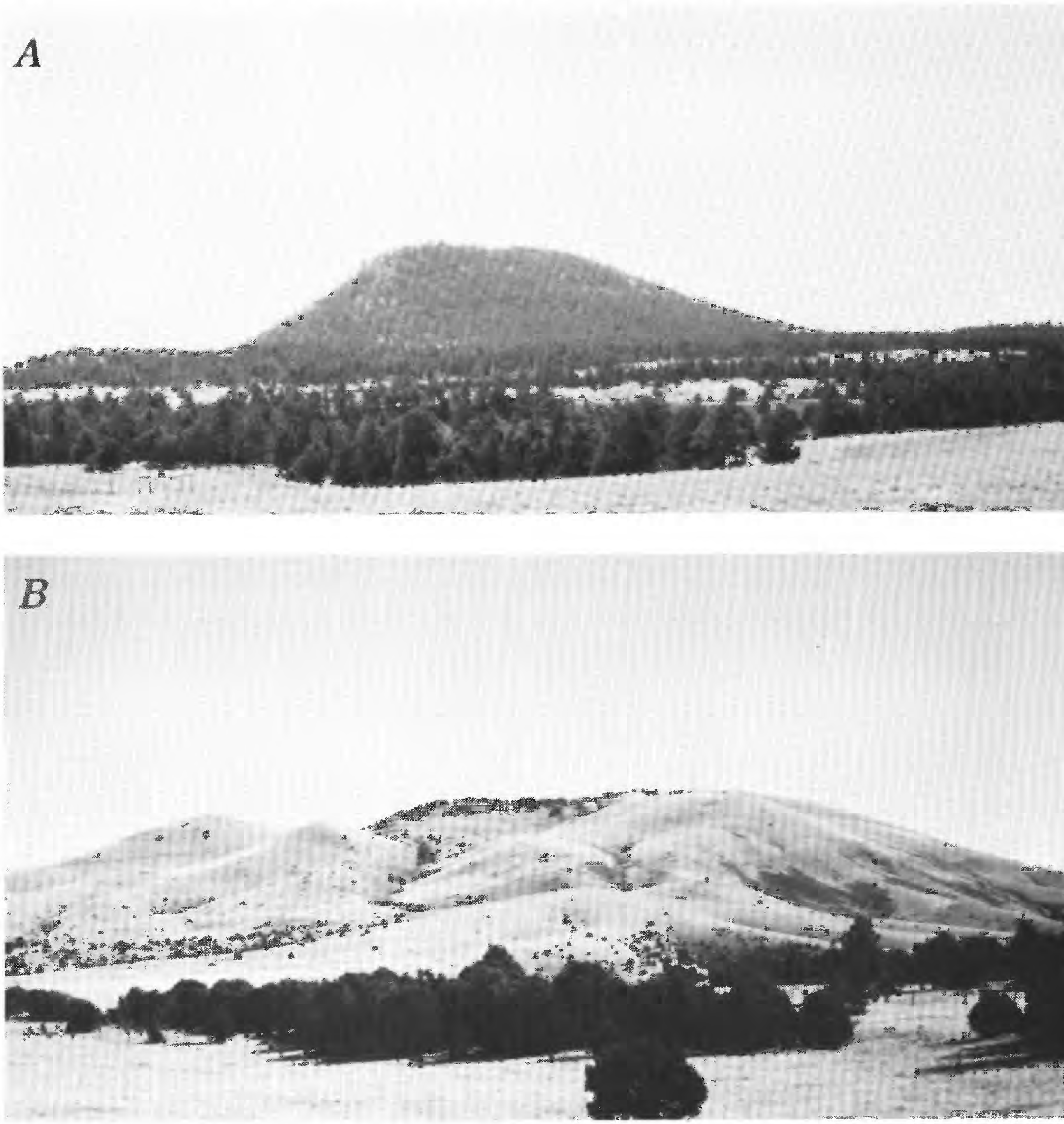

FIGURE 7.—Rhyodacites. *A*, Raspberry Mountain, a plug of rhyodacite, rises some 200 m above the surrounding countryside. *B*, Laughlin Peak, a volcano made up principally of glassy rhyodacite flows; view from the southwest.

areas are generally similar but differ from other rock types in the Laughlin Peak area (fig. 3). The rhyodacites are the most siliceous rock type in this area, and the rhyodacite from Raspberry Mountain has 26 percent quartz in the norm. This rhyodacite has a fairly low MgO content (1.1 percent). The chemical composition of the rhyodacite sample from Raspberry Mountain is quite similar to that of the samples from Palo Blanco Mountain and Pine Buttes (table 1; fig. 3). The amount of difference in the composition of the three samples is no more than one would expect to find between three samples taken from the same intrusive.

RHYODACITE OF LAUGHLIN PEAK

Rhyodacite makes up the entire upper part of Laughlin Peak (fig. 7*B*). Most of it occurs as gray or red flows, but a little is in the form of volcanic breccia. Less than a quarter of the rhyodacite of Laughlin Peak is shown on plate 1. The top of Laughlin Peak lies only 45 m north of the northeast corner of this map area. Two breached craters also lie just north of the mapped area. Rhyodacite is exposed only on the upper one-third of the mountain; the lower two-thirds is covered by colluvium made up of a thick blanket of rhyodacite debris. Near the top of Laughlin Peak is a large block, about 380 m long, of sedimentary rocks. These rocks consist of Dakota Sandstone and Graneros Shale that were carried upward by the rhyodacite magma. This block of sedimentary rocks is now about 400 m above the Dakota-Graneros contact along Tinaja Creek.

An age determination of the rhyodacite was made on a lahar block from the north flank of Laughlin Peak (Scott, Wilcox, and Mehnert, written commun., 1983). The age, which was determined on oxyhornblende by the K-Ar method, is 6.9 ± 0.6 m.y. (Miocene).

The rhyodacite of Laughlin Peak is principally a light-gray or brownish-red vitrophyre, which in places is made up of red and gray bands. This rock consists of 1–5 percent small phenocrysts, which range in length from 0.4 to 2 mm, set in a fine-grained to glassy matrix. Tiny vesicles, 0.5–4 mm across, generally make up 1–10 percent of the rock. The phenocrysts are principally plagioclase and oxyhornblende. The plagioclase—which may be either andesine or labradorite—occurs as euhedral crystals that commonly exhibit zoning. Oxyhornblende occurs in several colors and may be brown or green. A little biotite was noted in one sample. The matrix is made up of 10–25 percent plagioclase microlites, a few percent magnetite, some light-gray anhedral birefringent material, and the rest, glass. Some of the glassy parts of the rock contain potassium, as is indicated by a yellow color brought out by staining the rock with sodium cobaltinitrite.

A chemical analysis of a sample of rhyodacite of Laughlin Peak is given in table 1 (No. 6). This rock is the most siliceous of all the rocks analyzed, and although it contains no visible quartz, it contains 34 percent quartz in the norm. It also has one of the lowest contents of Fe_2O_3, FeO, and MgO (fig. 3*B*), which is reflected in the small amounts of iron oxide and ferromagnesium minerals in the norm.

RHYODACITIC TUFF

Rhyodacitic tuff is exposed on the south flank of Laughlin Peak. Here it is found on the north side of county road A–8 near the east edge of the area. Similar tuff has been observed by Glenn Scott (oral commun., 1981) to be fairly extensive on the northern flank of Laughlin Peak.

The tuff is a white, thin-bedded, noncalcareous stratified rock. Beds are 2.5–10 cm thick, and the bedding is horizontal. The tuff consists of 15–40 percent fragments of volcanic glass set in fine-grained white ash. The glass fragments are subangular to subrounded, white to light gray in color, and range in size from less than 1 mm to 2 cm. A few oxyhornblende fragments are also found in this rock.

A chemical analysis of a sample of the rhyodacitic tuff is reported in table 1 (No. 7). The composition of the tuff resembles that of the other rhyodacites given in this table (Nos. 5, 6, 8, and 9), in particular, the rhyodacite from Laughlin Peak (No. 6). The normative corundum contents of the rhyodacitic tuff and the rhyodacite of Laughlin Peak are noticably higher than that of the other rhyodacites (table 1), and the anorthite and hypersthene contents are lower.

BASALT
(PLIOCENE)

Basalt blankets the southeastern part of the Laughlin Peak area. The basalt, which covers trachyte and the sedimentary rocks of Cretaceous age, originated from The Crater, a small double cratered cone just east of the southeast corner of the area (fig. 1). Close to the cone the basalt has piled up into small ridges (fig. 8). Farther from the source the basalt has spread out forming a flat-topped unit that slopes gently away from its source at The Crater. The basalt in this area is younger than the sedimentary rocks of Cretaceous age and the trachyte, which it partially covers. A sample was taken for age determination by Scott (written commun., 1983) near the southern distal edge of this flow, some 6.5 km south of the mapped area in the SW¼NW¼ sec. 13, T. 26 N., R. 25 E. A Pliocene age of 3.3 ± 0.15 m.y. was determined on a whole-rock sample by the K-Ar method.

Basalts are common in Colfax and Union Counties in northeastern New Mexico, and Collins (1949, p. 1023) estimated that in this area more than 1,800 km^2 is overlain by basalt flows. The basalts originated from many different sources over a period of about 7 million years. The youngest flows are the basalt flows from Capulin Mountain, 25 km northeast of the northeast corner of the area. Carbon isotopic dating has established that these flows were erupted between 8,000 and 2,500 years before present (B.P.) (Baldwin and Muehlberger, 1959, p. 156). Stormer (1972, p. 2445) dated five other basalts from Colfax and Union Counties by the K-Ar method. His dates indicated at least four other periods of extrusion ranging from 1.8 to 7.2 million years B. P.

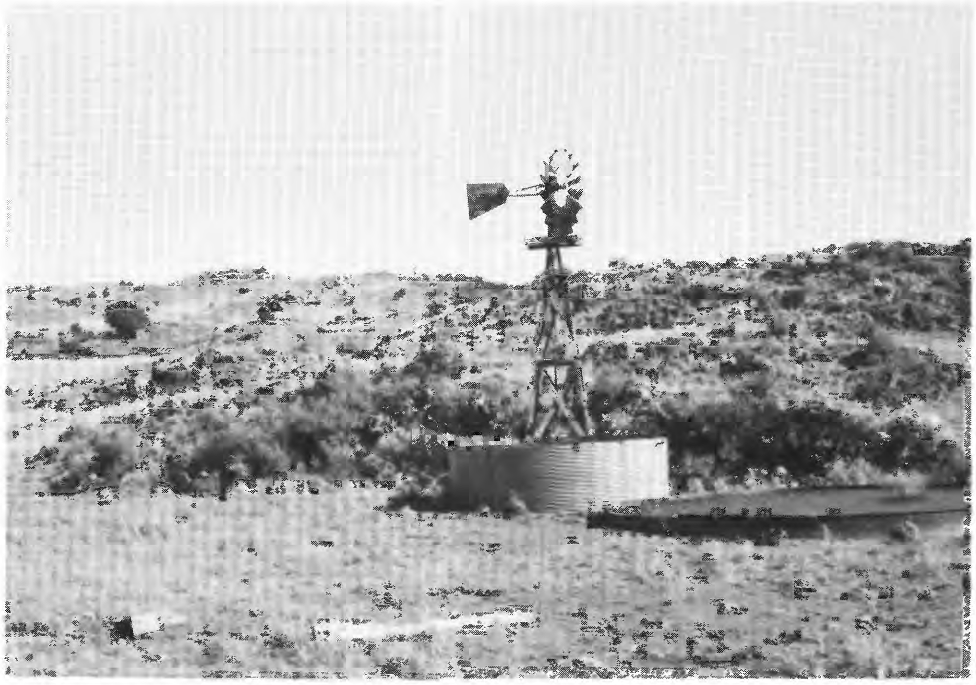

FIGURE 8.—Piles of basalt form a small ridge west of The Crater in the southeast corner of the area.

The basalt is a black vesicular rock. Vesicles make up as much as one-third of the rock. They are round to oval, and the oval ones are generally alined parallel to the direction of flow. They range in size from less than a millimeter to several centimeters. Some of the vesicles are filled or partially filled with chalcedony and calcite. Small pheonocrysts—a millimeter or less in size—make up 5–25 percent of the rock. They consist chiefly of pale-brown glassy olivine and in some places a few percent of smaller subhedral augite crystals. The olivine has numerous conchoidal fractures, and it commonly alters along these fractures and along grain boundaries to bright-orange iddingsite. The matrix is generally fine grained and consists of 40–60 percent plagioclase, 15–35 percent augite, 5–15 percent magnetite, and 4–10 percent of olivine or iddingsite. Plagioclase in the groundmass occurs as rectangular-shaped microlites and interstitial patches. Augite occurs as pale-green faintly pleochroic prismatic crystals that are found in between the plagioclase laths. Olivine may be partly or completely altered to iddingsite.

A chemical analysis of a sample of basalt collected on the lower south flank of Laughlin Peak at the northernmost exposure shown on plate 1 is given in table 1 (No. 13). The basalt contains less SiO_2, Na_2O, and K_2O and more CaO, MgO, and FeO than any other rocks in the Laughlin Peak area. The very low silica content is also shown by the presence of olivine and a small amount of nepheline in the norm. This analysis is similar to that of several basalts reported near Raton (Lee, 1922, p. 11).

UNCONSOLIDATED DEPOSITS (QUATERNARY)

TERRACE GRAVELS

Terrace gravels are found only in the northwest corner of the mapped area (pl. 1). The terrace gravels form smooth high level benches and consist of well-rounded pebbles and cobbles mixed with sand and soil. The pebbles are principally gray-and-red rhyodacite from Laughlin Peak and olive-green phonolite. A few are also of tan trachyte and of dark-gray limestone from the Greenhorn Formation. Although the terrace gravels in this area lie astride Tinaja Creek, these gravels were not derived from the headwaters of this valley. Most of the gravels came from the northwest flank of Laughlin Peak and were brought down the drainage shown on plate 1 just below the northern border of the map. This subsidiary stream to present day Tinaja Creek was once a much larger stream, judging from the amount and size of the debris.

LANDSLIDE DEPOSITS

Landslides are fairly common in the Laughlin Peak area. They are formed where thick units of resistant rock overlie a soft shaly unit. These conditions occur north and northeast of Tinaja Creek, where a thick layer of phonolite that forms a prominent ledge overlies the soft incompetent shale of the Carlile Shale; along the headwaters of Tinaja Creek, where massive basalt flows overlie the incompetent Graneros Shale; and in the southwest part of the area, where the upper massive sandstone layer of the Dakota Sandstone overlies shale in the central part of the Dakota. Landslide deposits form a continuous belt below the phonolite ledge from near the east edge of the area to Jimmy Spring Creek, a distance of 5 km. These deposits may be as much as 640 m broad. Landslides below the basalt and the Dakota Sandstone are smaller. The maximum breadth of the former is only about 140 m and that of the latter about 370 m. All the landslides are marked by a hummocky surface, and little hillocks containing jumbled pieces of the competent rock type are common. Landslide deposits in the upper part of Jimmy Spring Canyon form chaotic topography consisting of broken ledges of phonolite. The upper ends of some of the landslides are marked by arcuate scarps. One of the best examples is in the basalt along Tinaja Creek at the east edge of the area, where an arcuate scarp is outlined by the topography (pl. 1). This small landslide, which is only 150 m wide, has dropped only about 12 m.

COLLUVIUM

Colluvium, as used here (pl. 1), consists of several types of unconsolidated sediments that cover the sides and flanks of various mountains. Mainly it is a mixture of talus and sediments deposited by sheet wash. It was mapped in three areas: south and west flanks of Laughlin Peak, around Raspberry Mountain, and near the head of Slagle Canyon on the lower slopes of Raspberry Mountain. The area on the south and west flanks of Laughlin Peak is part of a much larger area that completely surrounds this peak. Within the mapped area it ranges in width from 980 to 1,980 m, but on the north side of Laughlin Peak it extends down the mountain for at least 3,200 m. All the material here has been derived from the rhyodacite on Laughlin Peak and consists of soil intermixed with subrounded to subangular clasts of gray-and-red aphanitic rhyodacite. Some of the clasts may be as much as 1 m across. Much of the material was derived high on Laughlin Peak, has been carried many meters down the mountain, and now covers other sedimentary and igneous rocks. Water courses cutting into it on the lower slopes of Laughlin Peak indicate that some of it is at least 12 m thick.

The colluvium at the head of Slagle Canyon is derived by slope wash from the hills on the southwest flank of Raspberry Mountain. Clasts are all derived from the light-tan trachyte that makes up the adjacent hills. Subangular to subrounded trachyte pieces, of all sizes up to 0.5 m across, are found here intermixed with soil.

The colluvium surrounding Raspberry Mountain is a fairly narrow band, 50–300 m wide, consisting of talus derived from the rhyodacite on Raspberry Mountain. This material is mainly a jumble of angular pieces as much as several meter across, but the colluvium contains some soil.

ALLUVIUM

Alluvium includes various unconsolidated sediments formed in Holocene time along stream valleys. It occurs where the stream gradient lessens, thereby allowing the sediment to settle out. Areas of alluvium occur along the valleys of Tinaja Creek, Rio del Plano, and that of an upland drainage 1 km northeast of Tinaja Creek. In the Laughlin Peak area alluvium consists of a mixture of soil with sand, gravel, and boulders. Boulders along Tinaja Creek are subrounded to subangular and consist principally of olive-green phonolite, red or gray rhyodacite of Laughlin Peak, and brown Dakota Sandstone. Near the western border of the area brown trachyte boulders are also found. Boulders along Rio del Plano are mainly of Dakota Sandstone. Coarser material most commonly is found along the present stream drainage. These sediments, which are formed during short periods of stream runoffs, are generally poorly sorted.

STRUCTURE

The structure of the Laughlin Peak area is marked by gently dipping sedimentary rocks, and small crisscrossing faults. The attitude of the sedimentary rocks was modified in local areas by the intrusion of numerous bodies of igneous rocks. This is best illustrated in sec. 36, in the northwest corner of the mapped area, where trachyte dikes and sills have distorted the predominately shaly Graneros, Greenhorn, and Carlile Formations so that their beds strike in almost every direction. The more competent Dakota Sandstone does not appear to be as affected by the intrusions, but the presence of crossbedding in many layers commonly makes accurate measurement of bedding attitudes difficult. The Dakota is, however, by far the best exposed sedimentary unit in the area, and the overall structure can be best seen in the outcrop of this formation.

A broad east-west-trending anticline (pl. 1) is the only major fold in this area. In the western part of the area, the top of a broad ridge lies about 0.5 km south of the crest of this anticline. From here the Dakota Sandstone can be traced down dip to the north for about 2 km to Tinaja Creek and to the south for about 1.7 km to Slagle Canyon. To the east the fold is hidden by a trachyte sill, but near the west edge of Raspberry Mountain the fold is offset by a steep-dipping north-northeast-trending fault. The anticline is offset approximately 1.3 km to the northeast, where it lies along the hillside on the south side of Tinaja Creek.

Faults were mapped principally in the west-central part of the area. They strike in most directions; the area is too small to determine if there is any overall significance to the pattern of faulting. Dip exposures on the faults are rare, but the trace of the faults suggest that most are steeply dipping. Horizontal offset along them ranges from about 12 m to 1.3 km. Vertical offset is generally not large and in many is from 30 to 75 m. The faults cut and are, therefore, younger than the Dakota, Graneros, and Greenhorn Formations, and the trachyte and trachyandesite igneous units. They do not offset either the basalt or phonolite. The faults probably formed in the late Tertiary and may have been a result of adjustment during volcanism. Not all the faults formed at exactly the same time, as is evidenced by a long northeast-trending fault that offsets a northwest-trending fault approximately 140 m near the west edge of sec. 12 (pl. 1).

THORIUM- AND RARE-EARTH-BEARING VEINS

Known thorium- and rare-earth-bearing veins are scattered over an area of approximately 12 km^2. Many occur either in or adjacent to the large trachyte sill on Raspberry Mountain; a few occur in or adjacent to the trachyte sill that lies along the western border of the area, south of Tinaja Creek (pl. 1). The veins lie along fracture zones and consist of either one large vein or a series of parallel smaller veins lying in the same fracture zone. Veins were noted at 29 localities (pl. 1). The veins were given numbers for the purpose of identification. Number 1 is the northwestmost vein and 29 the southernmost vein.

Where present, exploration generally consists of a few small pits. The most development work has been on vein No. 27, which has six pits along it. The next most developed vein, No. 4, was exposed by a shallow shaft (now filled with silt) and some drilling, where it crossed Tinaja Creek, and by another small shaft near its east end. Some veins, such as Nos. 2, 5, 8, 9, 10, 11, 13, 14, 15, 18, and 20, have not been explored. These veins, which commonly are covered by a thin soil cover, were found with a scintillation counter.

Veins cut trachyte, Dakota Sandstone, intrusive breccia, and trachyandesite. Most are in trachyte and Dakota Sandstone (table 3). None have been found in the Graneros Shale. Vein No. 4, however, cuts a shale unit in the Dakota Sandstone, and the apparent lack of veins in the Graneros may be due to the paucity of outcrops rather than a lack of veins. The occurrence of veins in intrusive breccia is of particular interest as this rock type makes up only a small percentage of the total exposed rocks. Veining here is generally confined to one or more fractures within the intrusive breccia body. The overall radioactivity of some intrusive breccia bodies is slightly greater than that of the surrounding country rock. Other intrusive breccia bodies, however, are not anomalous.

The known length of the 29 veins ranges from 0.5 to 550 m. More than half of them are 30 m or less in length (table 3). Although some of these veins are undoubtedly quite short, others could be longer. Vein No. 4 is exposed at several places over a strike length of 550 m. Exposures on this vein occur at the east and west ends and near the center.

The thickness of the veins ranges from 0.2 to 70 cm (table 3). The thickness of vein No. 27 is best known, as it is cut by six trenches. This vein varies from 20 to 48 cm in thickness. The thicknesses of about half the veins are poorly known, because their presence is traced only by radioactive zones in the soil.

The attitude of the individual veins considerably, but three-fourths of the veins strike between N. 30° W. and N. 85° W. The most common strike direction of the veins is parallel to that of some of the early faults in this area. Northeast-trending veins are most common where the host rock is intrusive breccia. The veins in intrusive breccias commonly cut across the trend of the intrusive breccia body.

TABLE 3.—*Host rock, dimensions, and attitudes of the veins in the Laughlin Peak area*

[N. D., not determined]

Location No.	Vein type	Host rock	Exposed length (m)	Thickness (cm)	Strike	Dip
1	Single--	Trachyte--------	180	20	N. 50° W.	90°
2	---do---	-------do-------	9	N.D.	N. 65° W.	N.D.
3	Multiple	Dakota Sandstone	15	0.2-0.4	N. 58° W.	73° SW.
4	Single--	-------do-------	550	15-40	N. 85° W.	77° SW.-90°
5	--do----	Trachyte--------	6	N.D.	N. 85° W.	Steep
6	Multiple	Dakota Sandstone	3	N.D.	N. 60° W.	86° NE.
7	Single--	Intrusive breccia	38	15	N. 7° E.	Steep
8	--do----	Dakota Sandstone	9	N.D.	N. 72° W.	78° NE.
9	--do----	-------do-------	9	15	N. 74° W.	N.D.
10	--do----	Trachyandesite--	30	20	N. 55° W.	N.D.
11	--do----	-------do-------	27	N.D.	N. 52° W.	N.D.
12	--do----	Intrusive breccis	46	3	N. 30° W.	84° SW.
13	--do----	Trachyte--------	12	N.D.	N. 30° W.	N.D.
14	--do----	Intrusive breccia	3	N.D.	N. 66° E.	N.D.
15	Multiple	Trachyte--------	215	1-70	N. 75° W.	N.D.
16	Single--	-------do-------	60	30	N. 72° W.	80° NE.
17	--do----	-------do-------	15	15	N. 50° W.	90°
18	--do----	-------do-------	45	N.D.	N. 82° E.	N.D.
19	--do----	Intrusive breccia	9	30	N. 60° E.	N.D.
20	--do----	Dakota Sandstone	45	N.D.	N. 33° W.	N.D.
21	--do----	-------do-------	.5	N.D.	N.D.	N.D.
22	--do----	-------do-------	3	2.5	N. 76° W.	N.D.
23	--do----	Trachyte--------	45	N.D.	N. 78° W.	N.D.
24	--do----	-------do-------	6	N.D.	N. 35° W.	N.D.
25	--do----	-------do-------	9	45	N. 54° W.	83° SW.
26	--do----	-------do-------	36	15	N. 28° E.	Steep
27	--do----	-------do-------	165	20-48	N. 70° W.	64° NE.-90°
28	--do----	-------do-------	3	N.D.	N. 70° W.	N.D.
29	--do----	Dakota Sandstone	11	N.D.	N. 68° E.	N.D.

The dip of many of the veins could not be determined owing to poor exposures. Those that were exposed dip steeply from 64° to 90°. Dips show some variation along the same vein; in the best exposed vein (No. 27), dips range from 64° to 90°.

MINERALOGY

Twenty-nine minerals were found in a detailed examination of 26 samples (table 4). Some of them occur in minor quantities in only a few samples. Mineral abundance varies considerably from sample to sample, notably in the principal gangue minerals—potassium feldspar, quartz, and calcite. Only 12 minerals occur in more than one-fourth of the samples: the three principal gangue minerals plus goethite, magnetite, a manganese oxide mineral, barite, brockite, crandallite, xenotime, zircon, and rutile. Other minerals may occur in some veins but were either not present in the samples taken or were too fine grained to be separately discerned under the binocular microscope. The various minerals are commonly fine grained and in places stained with iron oxides. Few minerals are identifiable in hand specimens. In order to identify the minerals, they were separated from each other by routine heavy-liquid and magnetic-separation procedures. They were then examined under a binocular microscope, and any mineral not readily identifiable by this method was picked out and identified by X-ray diffraction pattern.

The veins occur in brecciated country rock and commonly contain inclusions of it. Some of the minerals in the veins are probably derived from the country rock. Thus, the small amounts of amphibole, pyroxene, and micas found in a few of the samples probably were derived from this source. Other minerals, such as potassium feldspar and quartz, occur both in the country rocks and as a part of the vein filling.

The suite of thorium and rare-earth minerals in these veins is unusual when compared with that of veins in other thorium and rare-earth districts. In the Laughlin Peak area this suite is made up of brockite ($(Ca,Th,Ce)PO_4{\cdot}H_2O$), crandallite ($(Ca,Sr,Ce)Al_3(PO_4)_2(OH)_6$), and xenotime ($YPO_4$). In most other thorium-vein districts in the United States, such as the Lemhi Pass district of Idaho and Montana (Staatz, 1979, p. A44–A45), Hall Mountain, Idaho (Staatz, 1972, p. 246), Wet Mountains, Colorado (Staatz, 1974, p. 498), and Powderhorn district, Colorado (Olson and Hedlund, 1981, p. 22), thorite is the principal thorium-bearing mineral and monazite is commonly abundant. Brockite has been found in some veins in these districts, but it is not common in any district. In the Laughlin Peak district neither thorite nor monazite have been identified.

Brockite is the most common thorium or rare-earth mineral in the Laughlin Peak area. It has been identified in six of the veins (Nos. 4, 7, 11, 12, 27, and 28). Here it is a white, fine-grained, opaque mineral. In many places it may be tan or light orange owing to iron oxide staining. In some veins it is intergrown with xenotime. Brockite-bearing veins here all have more yttrium-group rare earths than cerium-group rare earths. This has also been found true in brockite-bearing veins in the Lemhi Pass district, Idaho–Montana (Staatz, 1979, p. A45) and the Bear Lodge Mountains, Wyo. (Staatz, 1983, p. D41). Although brockite is not a common mineral, it is most common in thorium-bearing veins and has been found in veins in the following areas: Wet Mountains, Colo. (Fisher and Meyrowitz, 1962); Lemhi Pass, Idaho and Montana (Staatz, 1979, p. A44); Bear Lodge Mountains, Wyoming (Staatz, 1983, p. D34–D36); Diamond Creek district, Idaho (Staatz, 1974, p. 498); Monroe Canyon, Utah (Staatz, 1974, p. 498); Hicks Dome, Ill.; and the Rawhide Mountains, Ariz.

Crandallite has been identified in four veins (Nos. 1, 4, 16, and 27), and in three of these veins (Nos. 1, 4, and 16) it is the principal thorium and rare-earth mineral. In general, it is not found with either brockite or xenotime. Crandallite forms aggregates of white to cream-colored rhombic crystals, although it may be stained yellow or brown by goethite. Crandallite is a member of the crandallite group of isostructural hydrous aluminum phosphate minerals that have an ideal chemical formula of $XAl_3(PO_4)_2(OH)_6$ (Lefebvre and Gasparrini, 1980, p. 301), where X is predominantly calcium in crandallite, strontium in goyazite, rare earths in florencite, barium in gorceixite, and lead in plumbogummite. Being isostructural, all have similar X-ray diffraction patterns. In the Laughlin Peak area this mineral was determined to be a member of the crandallite group by its X-ray pattern. The composition of this phosphate mineral separated from vein No. 4 was obtained by semiquantative spectrographic analysis (table 5). This mineral contained 100,000 parts per million (ppm) strontium, 70,000 ppm calcium, 38,900 ppm total rare earths, 3,000 ppm barium, and 300 ppm lead. In addition, it also contained 20,000 ppm thorium, which probably proxies for the rare earths. The molecular amount of each end member in this mineral is approximately as follows: 53 percent of the calcium member, crandallite; 34 percent of the strontium member, goyazite; 12 percent of the rare earth and thorium member, florencite; 0.7 percent of the barium member, gorceixite; and 0.04 percent of the lead member, plumbogummite. In the florencite molecule there are about four parts total rare earths to one part thorium. The mineral is called crandallite after its principal constituent. The

TABLE 4.—*Mineralogy of the veins in the Laughlin Peak area*

[Minerals underlined were identified by their X-ray diffraction pattern]

Loc. No.	Number of samples examined	Minerals -- relative amounts			
		Large	Moderate	Small	Rare
1	1	Potassium feldspar--	Goethite--	Hematite, manganese oxide mineral, calcite, jarosite, barite, crandallite.	Nacrite.
4	5	Quartz------	Potassium feldspar, goethite, crandallite.	Jarosite, calcite, barite, brockite.	Magnetite, lepidocrocite, zircon, fluorite, rutile, clay, biotite, hematite, manganese oxide mineral.
6	1	Quartz-----	Goethite---	Magnetite---	Zircon, manganese oxide mineral, pyroxene.
7	1	Potassium feldspar, quartz.	Goethite---	Pyrite, brockite, barite.	Magnetite, rutile?, zircon.
10	1	Calcite, quartz.	Manganese oxide mineral, goethite, barite.		Magnetite, xenotine(?).
11	1	Potassium feldspar	Brockite, xenotime.	Quartz, barite, goethite.	Magnetite, biotite, amphibole, pyrite.
12	3	Potassium feldspar	Quartz, goethite, xenotime.	Barite, brockite	Magnetite, zircon, rutile, thorite, plagioclase, mucovite, pyrite, anatase, amphibole.
16	1	Calcite----	Goethite, potassium feldspar, barite, quartz(?).	Crandallite--	Magnetite.
19	1	Quartz-----	Nacrite, goethite	Calcite, rutile, xenotime(?), anatase, barite.	Magnetite, zircon.
22	1	Quartz-----	Barite, goethite	Amphibole, zircon	Magnetite, rutile, spinel, pyroxene, mica, epidote.
25	1	Potassium feldspar	Goethite, cryptomelane, xenotime, barite.	Quartz-----	Magnetite.
26	1	Potassium feldspar	Goethite-----	Magnetite, manganese oxide mineral.	Amphibole, zircon.
27	6	Potassium feldspar	Quartz, goethite, brockite, xenotime.	Manganese oxide mineral, plagioclase.	Magnetite, hematite, apatite, zircon, biotite, anatase, fluorite, crandallite, thorianite-uraninite.
28	2	Potassium feldspar	Quartz-----	Manganese oxide mineral, brockite, goethite.	Magnetite, zircon, fluorite.

TABLE 5.—*Semiquantitative spectrographic analysis of crandallite from vein No. 4*

[Analyst: N. M. Conklin; <, less than value indicated; >, greater than value indicated. Other elements looked for but below the limits of measurement are As, Au, B, Bi, Cd, Co, Ge, Hf, In, Li, Mo, Ni, Pd, Pt, Re, Sb, Sc, Ta, Te, U, W, and Zn]

In percent			
Aluminum	>10	Potassium	<2
Calcium	7.0	Silicon	0.3
Iron	0.7	Sodium	0.1
Magnesium	0.05	Titanium	0.15
Phosphorus	>10		
In parts per million			
Barium	3,000	Lanthanum	7,000
Beryllium	300	Cerium	15,000
Chromium	70	Praesodymium	3,000
Copper	150	Neodymium	7,000
		Samarium	1,500
Gallium	30		
Lead	300	Europium	150
Niobium	500	Gadolinium	700
Strontium	100,000	Terbium	<200
		Dysprosium	700
Thorium	20,000	Holmium	150
Tin	30		
Vanadium	150	Erbium	300
Zirconium	300	Thulium	70
Total rare earths	38,900	Ytterbium	300
		Lutetium	30
		Yttrium	3,000

rare earths in the crandallite are principally the cerium group (light rare earths), comprising 87 percent of the total rare earths. The distribution of the lanthanides in the Laughlin Peak crandallite is shown in figure 9. This distribution pattern might be called the normal distribution pattern as it is quite similar to that found in crustal abundance (Staatz and others, 1976, p. 580). Crandallite is a rare mineral in the thorium veins in the United States. Only at Hicks Dome in Illinois has another member of the crandallite group been reported; a veined breccia exposed in a small trench contained florencite (Trace, 1960, p. B63).

Worldwide, xenotime is by far the most abundant mineral made up principally of the yttrium group of rare-earths minerals. In the Laughlin Peak area, xenotime occurs in six veins (Nos. 10, 11, 12, 19, 25, and 27). The xenotime here is a white to tan, very fine grained opaque mineral that resembles brockite. Although in the Laughlin Peak area xenotime commonly occurs with brockite, it is rarely associated with crandallite. The xenotime is probably associated with brockite because the rare earths in both these minerals belong principally to the yttrium group; whereas, the rare earths in crandallite belong principally to the cerium group.

The iron oxide minerals, goethite and hematite, are relatively rare in the Laughlin Peak area; hematite is but a minor constituent and goethite, although present, rarely makes up more than a few percent of any sample. These two minerals, however, make up a major part of many thorium veins in the Lemhi Pass district, Idaho and Montana; Wet Mountains, Colo.; Powderhorn district, Colorado; Bear Lodge Mountains, Wyo.; and Rawhide Mountains, Ariz. Goethite in the Laughlin Peak area comes in several color and textural varieties. In most places it is dark brown and granular, but even in the same sample some may have a brown shiny or a light-yellowish-brown vesicular appearance. This mineral commonly coats the surface of other minerals imparting a brown to yellow color. Black manganese oxide minerals occur here in about a third of the samples; in none of them is it abundant. Most of the manganese oxide minerals formed late as evidenced by their coating fractures within the veins. These minerals form thin dull-black crusts, some of which are botryoidal. X-ray diffraction patterns of the manganese oxides were commonly diffuse, and in most patterns the particular manganese oxide could not be identified. Only one X-ray pattern was sufficiently distinct to identify the particular manganese oxide mineral as cryptomelane.

Barite, found in half the samples, is common in most thorium vein districts. The barite content of the Laughlin Peak samples does not exceed 1 percent, and in some samples barite is quite rare. Barite generally occurs as clear platy crystals. In vein No. 4 it is also found as small, white, opaque nodules.

Rutile is found in minor amounts in about a third of the samples, either as dull black granular aggregates or as small black shiny crystals. Zircon occurs as tiny

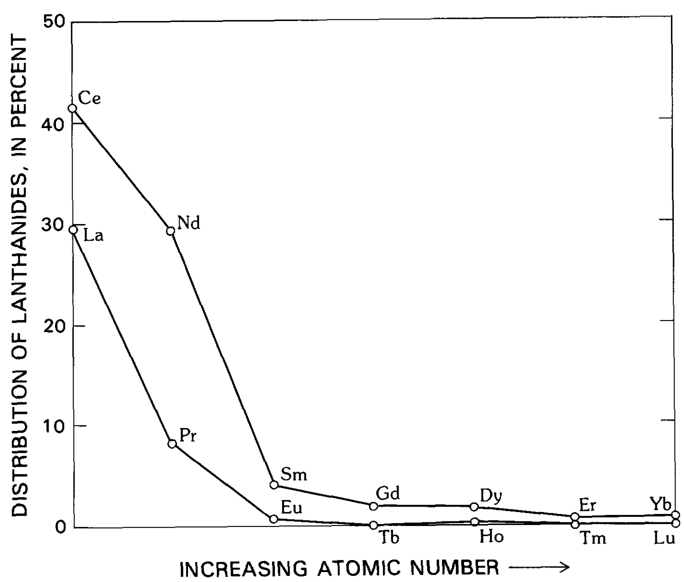

FIGURE 9.—Graph showing distribution of lanthanides in crandallite from vein No. 27 in the Laughlin Peak area. Upper line, even atomic-numbered lanthanides; lower line, odd atomic-numbered lanthanides. The elements are so arranged that pairs of lanthanides that are adjacent in the periodic table fall on the same ordinate.

TABLE 6.—*Chemical analyses of samples from veins in the Laughlin Peak area*

[Symbols: N.D., not determined, <, less than the value indicated]

Vein No.--	1			4			6	7		10	11		12		16
Sample No.--	MHS-27-80	CH-9-64	CH-10-64	Ch-7-73	CH-8-73	MHS-4-80	MHS-8-80	CH-12-64	CH-6-73	MHS-63-80	MHS-65-80	CH-11-64	CH-3-73	MHS-16-80	MHS-23-80
Element	In parts per million														
Thorium	[a]181	[b]500	[b]5,000	[a]30	[a]2,905	[a]5,140	[a]620	[b]3,600	[a]1,885	[a]3,870	[a]14,000	[b]1,200	[a]7,000	[a]8,330	[a]1,890
Uranium	[a]10	[b]<10	[b]50	[a]8	[a]50	[a]37	N.D.	[b]10	[a]8	N.D.	N.D.	[b]10	[a]40	[a]46	[a]44
Lanthanum	[c]70	[d]220	[d]1,100	N.D.	[c]700	[c]1,500	N.D.	[d]90	N.D.	[c]1,500	[c]150	[d]140	[c]150	[c]300	[c]7,000
Cerium	[c]<150	[c]500	[d]2,400	N.D.	[c]1,500	[c]1,500	N.D.	[c]<200	N.D.	[c]2,000	[c]300	[c]200	[c]500	[c]300	[c]7,000
Praesodymium	[c]<100	[c]<100	[c]<100	N.D.	[c]200	[c]200	N.D.	[c]<100	N.D.	[c]200	[c]<100	[c]<100	[c]<100	[c]<100	[c]700
Neodymium	[c]<70	[c]150	[d]1,100	N.D.	[c]700	[c]1,000	N.D.	[c]50	N.D.	[c]700	[c]150	[c]100	[c]200	[c]300	[c]3,000
Samarium	[c]<100	[c]<100	[c]300	N.D.	[c]150	[c]300	N.D.	[c]<100	N.D.	[c]150	[c]<100	[c]<100	[c]<100	[c]150	[c]300
Europium	[c]<70	[c]<100	[c]<100	N.D.	[c]<70	[c]70	N.D.	[c]<100	N.D.	[c]<70	[c]<70	[c]<100	[c]<70	[c]<70	[c]70
Gadolinium	[c]<50	[c]<100	[c]150	N.D.	[c]70	[c]150	N.D.	[c]200	N.D.	[c]<100	[c]500	[c]<100	700	[c]500	[c]100
Terbium	[c]<300	[c]<300	[c]<300	N.D.	[c]<300	[c]<300	N.D.	[c]<300	N.D.	[c]<300	[c]150	[c]<300	[c]150	[c]<300	[c]<300
Dysprosium	[c]<50	[c]<40	[c]200	N.D.	[c]100	[c]300	N.D.	[c]700	N.D.	[c]150	[c]1,500	[c]150	[c]1,500	[c]1,500	[c]70
Holmium	[c]<20	[c]<70	[c]100	N.D.	[c]30	[c]100	N.D.	[c]300	N.D.	[c]<50	[c]500	[c]<70	[c]500	[c]700	[c]<50
Erbium	[c]<50	[c]<40	[c]200	N.D.	[c]70	[c]200	N.D.	[c]500	N.D.	[c]<50	[c]1,500	[c]70	[c]1,000	[c]1,500	[c]<50
Thulium	[c]<20	[c]<100	[c]<100	N.D.	[c]<20	[c]70	N.D.	[d]300	N.D.	[c]<20	[c]150	[c]<100	[c]150	[c]200	[c]<20
Ytterbium	[c]7	[d]31	[d]220	N.D.	[c]100	[c]200	N.D.	[d]520	N.D.	[c]70	[c]1,000	[d]62	[c]1,000	[c]1,000	[c]70
Lutetium	[c]<30	[c]<100	[c]100	N.D.	[c]<30	[c]30	N.D.	[c]150	N.D.	[c]<30	[c]300	[c]<100	[c]150	[c]100	[c]20
Yttrium	[c]70	[d]190	[d]940	N.D.	[c]1,000	[c]2,000	N.D.	[d]3,100	N.D.	[c]700	[c]7,000	[d]520	[c]10,000	[c]10,000	[c]700
Total rare earths	147	1,091	6,810	N.D.	4,620	7,620	N.D.	5,910	N.D.	5,470	13,200	1,242	16,000	16,550	19,030
Barium	[c]1,000	[d]430	[d]420	N.D.	[c]500	[c]5,000	N.D.	[d]8,700	N.D.	[c]3,000	[c]3,000	[d]1,200	[c]3,000	[c]1,500	[c]30,000
Beryllium	[c]1.5	[c]15	[c]50	N.D.	[c]30	[c]7	N.D.	[c]3	N.D.	[c]3	[c]3	[c]5	[c]7	[c]3	[c]20
Copper	[c]15	[c]7	[c]30	N.D.	[c]20	[c]20	N.D.	[c]15	N.D.	[c]70	[c]30	[c]10	[c]15	[c]15	[c]150
Lead	[c]15	[c]10	[c]150	N.D.	[c]100	[c]70	N.D.	[c]50	N.D.	[c]100	[c]30	[c]50	[c]70	[c]70	[c]150
Manganese	[c]2,000	[c]70	[c]70	N.D.	[c]50	[c]150	N.D.	[c]70	N.D.	[c]7,000	[c]70	[c]50	[c]100	[c]150	[c]70
Molybdenum	[c]<3	[c]7	[c]7	N.D.	[c]20	[c]<3	N.D.	[c]5	N.D.	[c]7	[c]<3	[c]10	[c]15	[c]15	[c]<3
Niobium	[c]30	[d]180	[d]1,200	N.D.	[c]500	[c]300	N.D.	[d]360	N.D.	[c]150	[c]700	[d]490	[c]500	[c]300	[c]300
Strontium	[c]700	[d]860	[d]9,700	N.D.	[c]15,000	[c]3,000	N.D.	[d]88	N.D.	[c]7,000	[c]1,500	[d]1,000	[c]3,000	[c]3,000	[c]7,000
Zinc	[c]<200	[c]<300	[c]<300	N.D.	[c]<300	[c]<300	N.D.	[c]<300	N.D.	[c]<200	[c]<200	[c]<300	[c]<300	[c]<300	[c]<200
Zirconium	[c]150	[c]300	[c]300	N.D.	[c]500	[c]300	N.D.	[c]300	N.D.	[c]150	[c]1,500	[c]200	[c]1,500	[c]700	[c]150
	In percent														
Iron	[c]3	[c].7	[c]1.5	N.D.	[c]1.0	[c]1.5	N.D.	[c]1.0	N.D.	[c]3	[c]1.5	[c]1.5	[c]1.5	[c]2.0	[c]7.0
Magnesium	[c].07	[c].02	[c].3	N.D.	[c].15	[c].03	N.D.	[c].05	N.D.	[c].15	[c].07	[c].05	[c].05	[c].03	[c].07
Phosphorus	[c]<.2	[c].5	[c]3.0	N.D.	[c]1.5	[c]1.5	N.D.	[c].5	N.D.	[c]1.5	[c].7	[c]<.2	[c].7	[c].5	[c]1.5
Potassium	[a]2.2	[c]<.7	[c]2.0	N.D.	[a]1.9	N.D.	N.D.	[c]1.5	N.D.	N.D.	[c]3.0	[c]7.0	[a]5.0	[c]5.0	[c]3.0
Sodium	[c].3	[c]<.05	[c].7	N.D.	[c].2	[c].05	N.D.	[c]<.05	N.D.	[c].07	[c]<.1	[c]0.7	[c].5	[c].3	[c]<.05

bipyramidal crystals in almost half the samples. These crystals may be pale purple, pale pink, white, or amber.

In addition, some 17 other minerals occur in a few veins in minor amounts (table 4). Some of these minerals, such as hematite, lepidocrocite, pyrite, muscovite, apatite, and fluorite, are commonly found in veins in other thorium districts, where, except for hematite, they occur only in minor amounts. The nacrite that occurs in some of these samples is probably an alteration product of feldspathoids from inclusions of country rock.

CHEMICAL COMPOSITION

The thorium content of 30 vein samples ranges from 30 to 24,200 ppm and in 18 samples exceeded 2,000 ppm (table 6). All analyses are from chip samples that were cut across the entire thickness of the vein. Thorium analyses were made by C. M. Bunker and C. A. Bush on a quantitative gamma-ray spectrometer. This method has an accuracy of ±3 percent. The highest thorium content comes from vein No. 27. The thorium content of eight samples taken along 165 m of this vein ranges from 1,800 to 24,200 ppm. Five samples were

TABLE 6.—*Chemical analyses of samples from veins in the Laughlin Peak area*—Continued

Vein No.	19	22	25		26		27								28
Sample No.	MHS-52-80	MHS-55-80	CH-8-64	MHS-13-80	CH-7-64	MHS-12-80	CH-2-64	Ch-3-64	CH-4-64	CH-5-64	CH-9-73	CH-10-73	MHS-9-80	MHS-10-80	CH-11-73
Element	In parts per million														
Thorium	[a]114	[a]5,100	[b]2,200	[a]2,270	[b]500	[a]178	[b]8,600	[b]3,400	[b]2,900	[b]1,800	[a]2,970	[a]12,000	[a]24,200	[a]5,725	[a]1,790
Uranium	[a]60	[a]230	[b]<10	N.D.	[b]<10	[a]6.5	[b]10	[b]<10	[b]10	[b]10	[a]6	N.D.	N.D.	N.D.	[a]4.6
Lanthanum	[c]150	[c]300	[d]110	[c]150	[d]80	[c]150	[d]270	[d]220	[d]300	[d]130	[c]150	[c]300	[c]300	[c]150	N.D.
Cerium	[c]150	[c]700	[c]150	[c]200	[c]200	[c]200	[c]300	[c]300	[c]200	[c]200	[c]<150	[c]300	[c]300	[c]150	N.D.
Praesodymium	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	N.D.
Neodymium	[c]70	[c]500	[c]50	[c]150	[c]50	[c]70	[c]300	[c]150	[c]150	[c]70	[c]150	[c]300	[c]300	[c]150	N.D.
Samarium	[c]<100	[c]150	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	[c]<100	N.D.
Europium	[c]<70	[c]<70	[c]<100	[c]<70	[c]<100	[c]<70	[c]<100	[c]<100	[c]<100	[c]<100	[c]<70	[c]<70	[c]<70	[c]<70	N.D.
Gadolinium	[c]<50	[c]150	[c]100	[c]70	[c]<70	[c]<50	[c]70	[c]70	[c]<70	[c]<70	[c]<50	[c]150	[c]150	[c]<50	N.D.
Terbium	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	N.D.
Dysprosium	[c]<50	[c]200	[c]200	[c]300	[c]<50	[c]<50	[c]300	[c]150	[c]100	[c]50	[c]70	[c]300	[c]700	[c]150	N.D.
Holmium	[c]<20	[c]70	[c]100	[c]70	[c]<70	[c]<20	[c]150	[c]70	[c]70	[c]<70	[c]30	[c]150	[c]300	[c]70	N.D.
Erbium	[c]<50	[c]150	[c]150	[c]150	[c]<50	[c]<50	[c]300	[c]150	[c]100	[c]<100	[c]70	[c]300	[c]700	[c]150	N.D.
Thulium	[c]<20	[c]20	[c]<100	[c]30	[c]<100	[c]<20	[c]150	[c]<100	[c]<100	[c]<100	[c]<20	[c]70	[c]150	[c]30	N.D.
Ytterbium	[c]5	[c]150	[d]160	[c]200	[d]8	[c]15	[d]360	[d]110	[d]110	[d]78	[c]100	[c]700	[c]700	[c]150	N.D.
Lutetium	[c]<30	[c]20	[c]<100	[c]30	[c]<100	[c]<30	[c]100	[c]<100	[c]<100	[c]<100	[c]<30	[c]100	[c]70	[c]30	N.D.
Yttrium	[c]50	[c]1,500	[d]920	[c]2,000	[d]71	[c]150	[d]1,400	[d]800	[d]560	[d]460	[c]1,000	[c]5,000	[c]7,000	[c]1,500	N.D.
Total rare earths	425	3,910	1,940	3,350	409	585	3,700	2,020	1,590	988	1,570	7,670	10,670	2,530	N.D.
Barium	[c]1,500	[c]70,000	[d]2,300	[c]5,000	[d]540	[c]700	[d]900	[d]520	[d]710	[d]590	[c]700	[c]1,500	[c]1,500	[c]700	N.D.
Beryllium	[c]1.5	[c]3	[c]3	[c]2	[c]3	[c]1	[c]3	[c]2	[c]5	[c]2	[c]1.5	[c]3	[c]1.5	[c]1.5	N.D.
Copper	[c]30	[c]30	[c]5	[c]10	[c]3	[c]3	[c]15	[c]7	[c]7	[c]3	[c]5	[c]7	[c]15	[c]3	N.D.
Lead	[c]30	[c]1,500	[c]100	[c]150	[c]30	[c]30	[c]50	[c]50	[c]50	[c]50	[c]70	[c]70	[c]70	[c]30	N.D.
Manganese	[c]700	[c]70	[c]200	[c]1,500	[c]1,000	[c]700	[c]300	[c]100	[c]1,000	[c]1,000	[c]200	[c]150	[c]300	[c]1,500	N.D.
Molybdenum	[c]7	[c]70	[c]7	[c]5	[c]7	[c]<3	[c]10	[c]5	[c]5	[c]10	[c]7	[c]5	[c]<3	[c]7	N.D.
Niobium	[c]150	[c]150	[d]270	[c]70	[d]140	[c]70	[d]260	[d]330	[d]320	[d]180	[c]150	[c]150	[c]200	[c]150	N.D.
Strontium	[c]300	[c]1,500	[d]330	[c]700	[d]250	[c]700	[d]880	[d]380	[d]1,400	[d]280	[c]700	[c]3,000	[c]1,500	[c]700	N.D.
Zinc	[c]<200	[c]<200	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<300	[c]<200	[c]<200	[b]<300	[c]<300	N.D.
Zirconium	[c]700	[c]3,000	[c]200	[c]300	[c]500	[c]300	[c]300	[c]300	[c]300	[c]300	[c]300	[c]700	[c]700	[c]500	N.D.
	In percent														
Iron	[c]3.0	[c]1.5	[c]1.5	[c]3.0	[c]1.5	[c]1.5	[c]2.0	[c]1.5	[c]2.0	[c]2.0	[c]1	[c]1.5	[c]1.5	[c]1.5	N.D.
Magnesium	[c].03	[c].03	[c].07	[c].15	[c].07	[c].07	[c].15	[c].2	[c].3	[c].07	[c].1	[c].3	[c].15	[c].07	N.D.
Phosphorus	[c]<.2	[c].3	[c]<.2	[c]<.2	[c]<.2	[c]<.2	[c]<.2	[c]<.2	[c]<.2	[c]<.2	[c]<.2	[c].3	[c].5	[c]<.2	N.D.
Potassium	[a].25	[c]7.0	[c]5.0	[c]7.0	[c]5.0	[a]5.5	[c]5.0	[c]5.0	[c]5.0	[c]5.0	[a]5.0	[c]5.0	[c]3.0	[c]7.0	N.D.
Sodium	[c].05	[c].1	[c]0.7	[c]0.7	[c]5.0	[c]7.0	[c]3.0	[c]3.0	[c]3.0	[c]5.0	[c]3	[c]3	[c]3	[c]5	N.D.

[a]Analyzed by gamma-ray spectrometry by C. M. Bunker and C. A. Bush.

[b]Uranium analyzed chemically; thorium calculated from the chemical uranium and an eU value determined by beta-gamma scaler. Analysts: Lorraine Lee and G. T. Burrow.

[c]Analyzed by semiquantitative six-step spectrographic method by N. M. Conklin.

[d]Analyzed by quantitative spectrographic method by N. M. Conklin.

taken from the longest vein (No. 4), whose thorium content ranges from 30 to 5,140 ppm.

Rare-earth elements were determined by a semiquantitative spectrographic method. Results are identified within brackets whose boundaries are 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, and so forth, but are reported as midpoints between these brackets. Thus, the numbers reported would be 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth. The precision of a reported value is approximately plus or minus one bracket. The total rare-earth content of the 26 samples from 12 veins ranges from 147 to 19,030 ppm (table 6). Large differences in rare-earth content exist between veins, and the rare-earth content of individual veins also varies considerably. For example, the rare-earth content of eight samples taken from vein No. 27 ranges from 988 to 10,670 ppm.

The ratio of total rare earths to thorium in the

Laughlin Peak veins ranges from 0.44 to 10. The total ratio of rare earth to thorium in 24 of the 25 samples measured has a much narrower range and is only from 0.44 to 3.26. These ratios tend to be fairly similar in the same vein, and the ratios of eight samples from vein No. 27 range only from 0.44 to 0.76.

The rare-earth metals comprise the 15 elements having atomic numbers 57 to 71, including lanthanum, cerium, praesodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. Yttrium, with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities. The first seven elements just listed (lanthanum through europium) are called the cerium-group rare earths, after their most common member. The remaining elements (gadolinium through lutetium) together with yttrium are called the yttrium-group rare earths. The two groups are also referred to respectively as the "light" and "heavy" rare earths. The cerium-group rare earths are by far the most common rare earths both in the Earth's crust (Taylor, 1964, p. 1281) and in most thorium- and rare-earth-bearing veins. In the Laughlin Peak area, however, yttrium-group rare earths are generally the most abundant (fig. 10). Seventeen of twenty-six samples have more yttrium-group than cerium-group rare earths. Yttrium-group rare earths are more abundant in some veins and cerium group in others. The ratio of yttrium-group rare earths to total rare earths in the 26 samples ranges from 0.05 to 0.98 The range in individual veins is much smaller: for example, eight samples from vein No. 27 have a range of from 0.59 to 0.92.

The relation between the cerium-group rare earths, yttrium-group rare earths, and thorium is shown in a triangular diagram (fig. 10). This plot shows that, although the amount of cerium-group to yttrium-group rare earths varies considerably between the samples taken, the majority of the samples are much richer in the yttrium-group rare earths. This diagram also shows that the thorium content tends to increase as the yttrium-group rare-earth content increases. Multiple samples from the same vein have generally similar compositions (fig. 10). Most analyses fall in a triangular area having vertices Ce_{100}, $Th_{80}Y_{20}$, $Th_{30}Y_{70}$—that is, thorium- and yttrium-group elements are closely associated, whereas cerium-group elements show a wide range including two or three that are cerium-rich.

The distribution of individual lanthanides in the veins can be shown using a plot originated by Semenov and Barinskii (1958, p. 416). In these graphs, one line connects the values of elements of even atomic number and the other line connects those of elements of odd atomic number. The elements are so arranged that pairs of the lanthanides that are adjacent in the periodic table fall on the same ordinate line. The ordinate represents the percent of each individual rare earth to the total lanthanides. Thus, the relative importance of various rare earths to one another is shown. Graphs were originally made from the analytical data (table 6) of all 26 samples. Four of these graphs showing typical distribution of the lanthanides in the veins of the Laughlin Peak area are shown in figure 11. Figure 11*A* shows the pattern of one of several samples from vein No. 4 and is typical of veins rich in cerium-group rare earths. Here, the cerium-group rare earths make up more than 80 percent of the total lanthanides. Other samples from this vein and samples from veins Nos. 10, 16, 19, 22, and 26 have similar patterns. Lanthanide patterns of samples in which the yttrium-group lanthanides are predominant are more diverse (figs. 11*B*–11*D*). In these samples the yttrium-group rare earths make up more than 50 percent of the total lanthanides. The most abundant lanthanide is generally dysprosium, but in some samples it is erbium or ytterbium. Yttrium, which is not shown on these graphs, is the most common yttrium-group rare earth, and in the 15 samples in which this group is dominant, yttrium makes up from 35 to 66 percent of the total rare earths.

In many districts it is difficult to correlate the rare-earth distribution with the mineralogy, because thorite and (or) monazite are abundant and are the principal sources of rare earths in the the veins. These minerals are not markedly selective in their acceptance of various rare-earth elements, and the proportions of the various rare earths in these minerals may vary considerably (Staatz and others, 1972, p. 75–77, 1976, p. 450; Staatz, 1983, p. D40–D41). The rare-earth minerals that occur in the Laughlin Peak district (xenotime, brockite, and crandallite), however, are fairly selective in the type of rare earths retained. Samples in which xenotime or brockite are common predominate in yttrium-group rare earths. On the other hand, samples in which crandallite is common predominate in cerium-group rare earths.

The uranium content of these radioactive veins is, in general, low; and in 23 samples where measurements were obtained, uranium ranges from 4.6 to 230 ppm (table 6). Fifteen of these samples contain 10 ppm or less of uranium, and only one sample has more than 60 ppm. The Th/U ratios of these samples range from 1.9 to 860. The two lowest Th/U ratios reflect low thorium contents, and the range in Th/U ratios, excluding the two samples that have less than 150 ppm Th, is from 18 to 860. The overall Th/U ratios for veins in this district is higher than that for veins found in the Lemhi Pass district, Idaho–Montana; Hall Mountain district, Idaho; Diamond Creek area, Idaho; Bear

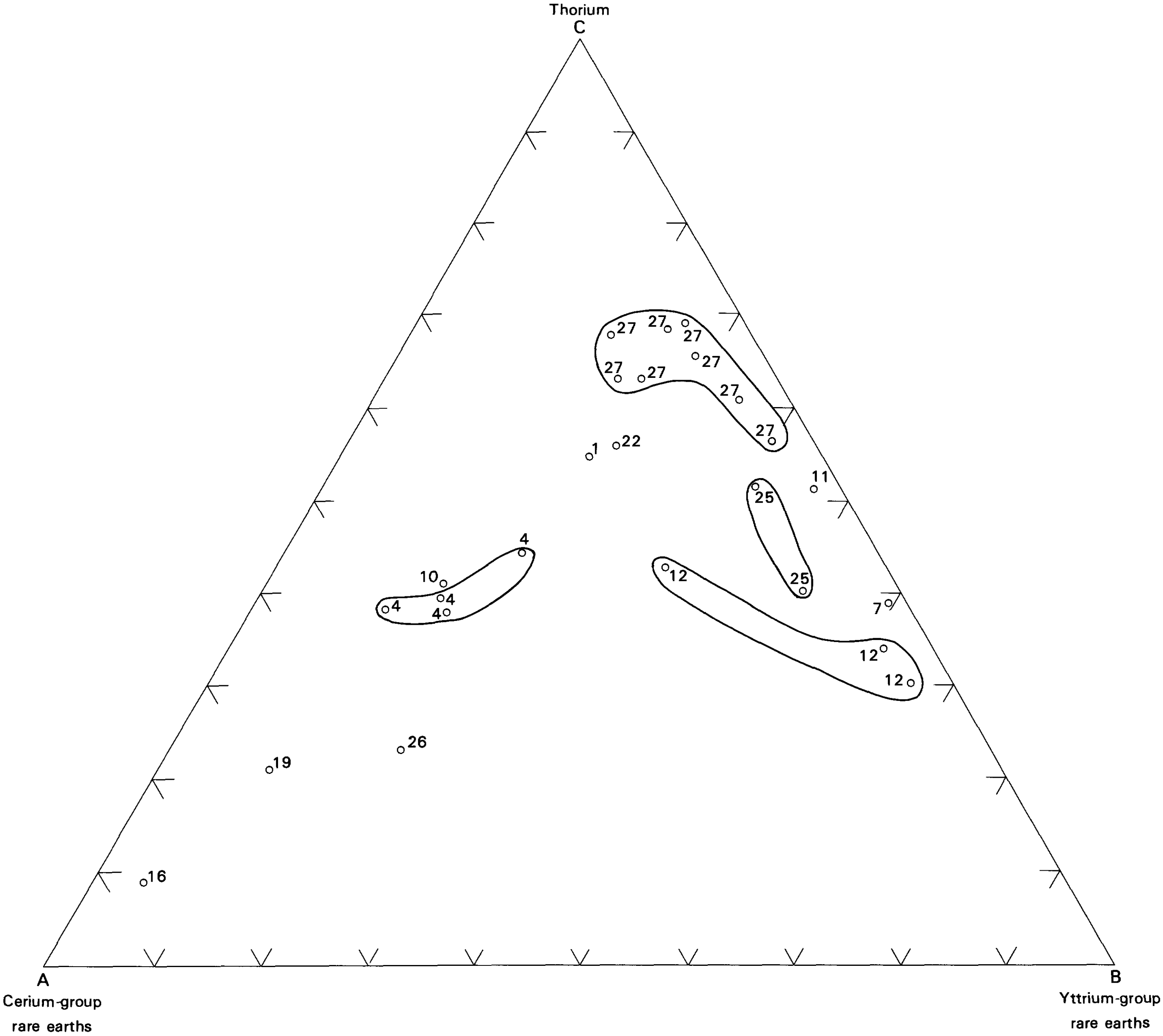

FIGURE 10.—Ternary diagram showing relation of thorium, cerium group of rare earths, and yttrium group of rare earths in veins from the Laughlin Peak area. Number on diagram indicates vein from which each sample came. Lines enclose all samples from the same vein.

Lodge district, Wyoming; Wet Mountains, Colo.; Mountain Pass district, California; or the Bokan Mountain area, Alaska.

Barium content of the 26 samples (table 6) ranges from 420 to 70,000 ppm. Its abundance is erratic among veins, and the greatest amounts of barium occur in veins Nos. 22 and 16. Barium occurs principally in the mineral barite. The amounts of barium in these veins are about the same as those found in the Bear Lodge Mountains, Wyo. (Staatz, 1983, p. D42), somewhat more than found in those of the Lemhi Pass district, Idaho and Montana (Staatz, 1979, p. A49), and considerably less than found in the veins of the Wet Mountains, Colo., where barite has been mined in the past (Christman and others, 1959, p. 527). The strontium content of the veins varies from 88 to 15,000 ppm. The most strontium occurs in samples from veins Nos. 4, 10, and 16. Strontium occurs principally in the mineral, crandallite, one sample of which contains 10 percent strontium (table 5). The veins of the Laughlin Peak area have one of the highest strontium contents of thorium-bearing veins in the United States. The

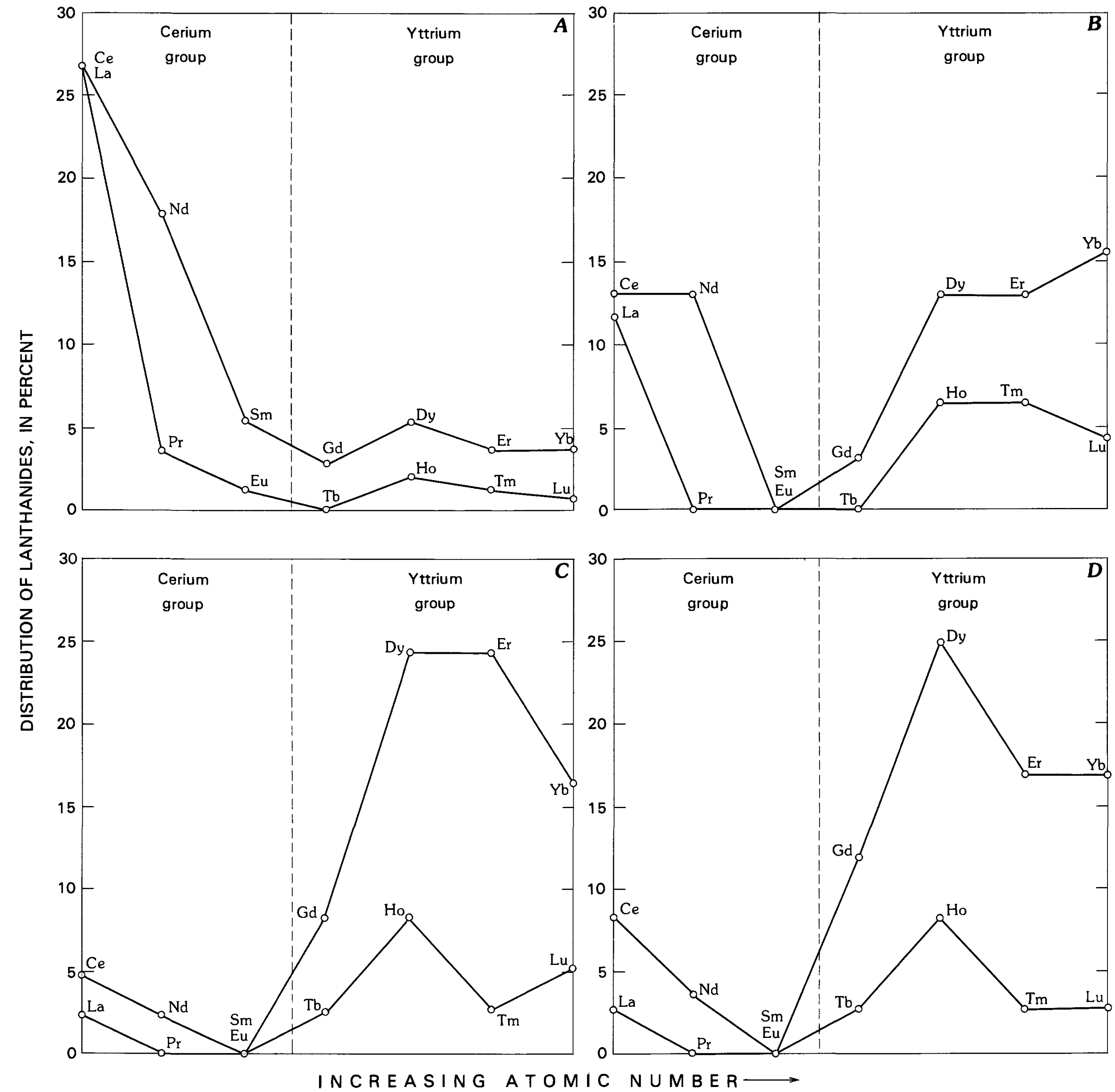

FIGURE 11.—Distribution of lanthanides in four samples from veins in the Laughlin Peak area. Upper line, even atomic-numbered lanthanides; lower line, odd atomic-numbered lanthanides.

A, Sample MHS–4–80 from vein No. 4.
B, Sample CH–2–64 from vein No. 27.
C, Sample MHS–65–80 from vein No. 11.
D, Sample CH–3–73 from vein No. 12.

niobium content of the samples ranges from 30 to 1,200 ppm. No niobium minerals have been found in any of the samples, so the niobium is probably in the titanium minerals—rutile or anatase. This range in niobium values is about half that found in the Lemhi Pass district (Staatz, 1979, p. A49) and the Bear Lodge district (Staatz, 1983, p. D42).

Iron and (or) manganese minerals are a major part of many thorium veins in other districts. The Laughlin Peak area differs from those other districts in low iron and manganese contents. Iron content of 26 samples (table 6) ranges from 0.7 to 7 percent. Iron content of 24 of the 26 samples, however, is in the range of from 1.0 to 3.0 percent. Thus, although the samples commonly are yellowish brown due to the presence of disseminated goethite, iron makes up only a minor amount of the total vein material. Manganese is even less abundant and ranges from 0.005 to 0.7 percent. Most of the manganese appears to be a late addition, as it most commonly occurs as black manganese oxides coating fracture surfaces.

Copper, lead, zinc, and molybdenum commonly occur in minor amounts in thorium veins in other districts. The veins in the Laughlin Peak area contain only scant amounts of these elements, and considerably less than found in veins of most other districts. Lead is the most common of these elements in the Laughlin Peak area and is found in amounts ranging from 10 to 1,500 ppm (table 6). All but one sample, however, contain 150 ppm or less of lead. Copper and molybdenum are less abundant; copper in most samples is in the 10–30 ppm range, and molybdenum in about three-quarters of the samples is 7 ppm or less. The limit of detection for zinc by semiquantitative spectrographic analysis varied from 200 to 300 ppm over the years the analyses were made. None of our samples contain this much zinc. No lead, copper, molybdenum, or zinc minerals have been identified in any of the samples.

ORIGIN

Thorium- and rare-earth-bearing veins are associated with alkalic rocks and carbonatites in many districts in the United States. Alkalic rocks are common in the Laughlin Peak area, and one small carbonatite dike has been found associated with alkalic rocks 2.7 km south of the mapped area in the western part of Joe Cabin Arroyo. In other areas in the United States the thorium veins are believed to have formed from fluids derived from a late-stage, volatile phase of the alkalic magma that formed the alkalic rocks (Staatz, 1974, p. 506).

The veins in the Laughlin Peak area cut the Dakota Sandstone and Graneros Shale of Cretaceous age and the trachyte, trachyandesite, and intrusive breccia of late Tertiary age. These rocks are all older than the faulting (pl. 1). Veins are not found cutting phonolite, rhyodacite, or basalt. Thus, it is likely that the veins were formed along fractures during volcanism after the trachyte and trachyandesite were intruded, but before the phonolite, rhyodacite, and basalt were emplaced. A logical source for the thorium and rare earths found in the veins is from the magma that formed the phonolite. Two samples of phonolite contained 139 and 111 ppm thorium (table 2), or at least five times the amount of thorium found in any other rock type. Rare earths also are concentrated here, and the same two samples contained 807 and 405 ppm total rare earths. Another line of evidence supporting the phonolitic magma as a source for the veins is that both were formed at approximately the same time.

REFERENCES CITED

Baldwin, Brewster, and Muehlberger, W. R., 1959, Geologic studies of Union County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 63, 171 p.

Baltz, E. H., 1965, Stratigraphy and history of Raton Basin and notes on San Luis Basin, Colorado–New Mexico: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 2041–2075.

Christman, R. A., Brock, M. R., Pearson, R. C., and Singewald, Q. D., 1959, Geology and thorium deposits of the Wet Mountains, Colorado—A progress report: U.S. Geological Survey Bulletin 1072–H, p. 491–535.

Collins, R. F., 1949, Volcanic rocks of northeastern New Mexico: Geologic Society of America Bulletin, v. 60, no. 6, p. 1017–1040.

De la Roche, H., Leterrier, J., Grandclaude, P., and Marchal, M., 1980, A classification of volcanic and plutonic rocks using R_1R_2-diagram and major-element analyses—Its relationships with current nomenclature: Chemical Geology, v. 29, p. 183–210.

Fisher, F. G., and Meyrowitz, Robert, 1962, Brockite, a new calcium thorium phosphate from the Wet Mountains, Colorado: American Mineralogist, v. 47, nos. 11–12, p. 1346–1355.

Griggs, R. L., 1948, Geology and ground-water resources of the eastern part of Colfax County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Ground Water Report 1, 187 p.

Hook, S. C., and Cobban, W. A., 1980, Some guide fossils in Upper Cretaceous Juana Lopez member of Mancos and Carlile Shales, New Mexico: New Mexico Bureau of Mines and Mineral Resources Annual Report, July 1, 1978, to June 30, 1979, p. 38–49.

Lee, W. T., 1922, Raton-Brilliant-Koehler folio, New Mexico–Colorado: U.S. Geological Survey Geologic Atlas, Folio 214, 17 p.

Lefebvre, J. J., and Gasparrini, Claudia, 1980, Florencite—An occurrence in the Zairian copperbelt: The Canadian Mineralogist, v. 18, pt. 3, p. 301–311.

Olson, J. C., and Hedlund, D. C., 1981, Alkalic rocks and resources of thorium and associated elements in the Powderhorn district, Gunnison County, Colorado: U.S. Geological Survey Professional Paper 1049–C, 34 p.

Olson, J. C., Marvin, R. F., Parker, R. L., and Mehnert, H. H., 1977, Age and tectonic setting of lower Paleozoic alkalic and mafic rocks, carbonatites, and thorium veins in south-central Colorado: U.S. Geological Survey Journal of Research, v. 5, no. 6, p. 673–687.

Olson, J. C., Shawe, D. R., Pray, L. C., and Sharp, W. N., 1954, Rare-earth mineral deposits of the Mountain Pass district, San Bernardino County, California: U.S. Geological Survey Professional Paper 261, 75 p.

Pillmore, C. L., and Eicher, D. L., 1976, Lower part of the marine Cretaceous at Gold Creek, Vermejo Park, New Mexico: New Mexico Geological Society Guidebook, 27th Field Conference, p. 171–176.

Rittmann, Alfredo, 1952, Nomenclature of volcanic rocks proposed for use in the catalogue of volcanoes, and key tables for the determination of volcanic rocks: Naples, Italy, Bulletin Volcanologique, ser. 2, v. 12, p. 75–102.

Scott, G. R., Wilcox, R. E., and Mehnert, H. H., in press, Geology of volcanic and subvolcanic rocks near Raton, Colfax County, New Mexico: U.S. Geological Survey Bulletin.

Semenov, E. I., and Barinskii, R. L., 1958, The composition characteristics of the rare earths in minerals: Geochemistry, no. 4, p. 398–419.

Staatz, M. H., 1972, Thorium-rich veins of Hall Mountain in northernmost Idaho: Economic Geology, v. 67, no. 2, p. 240–248.

———1974, Thorium veins in the United States: Economic Geology, v. 69, no. 4, p. 494–507.

———1979, Geology and mineral resources of the Lemhi Pass thorium district, Idaho and Montana: U.S. Geological Survey Professional Paper 1049–A, 90 p.

———1983, Geology and description of thorium and rare-earth deposits in the southern Bear Lodge Mountains, northeastern Wyoming: U.S. Geological Survey Professional Paper 1049–D, 52 p.

Staatz, M. H., Adams, J. W., and Wahlberg, J. S., 1976, Brown, yellow, orange, and greenish-black thorites from the Seerie pegmatite, Colorado: U.S. Geological Survey Journal of Research, v. 4, no. 5, p. 575–582.

Staatz, M. H., Shaw, V. E., and Wahlberg, J. S., 1972, Occurrence and distribution of rare earths in the Lemhi Pass thorium veins, Idaho and Montana: Economic Geology, v. 67, no. 1, p. 72–82.

Stobbe, H. R., 1949, Petrology of volcanic rocks of northeastern New Mexico: Geological Society of America Bulletin, v. 60, no. 6, p. 1041–1093.

Stormer, J. C., Jr., 1972, Ages and nature of volcanic activity on the southern high plains, New Mexico and Colorado: Geological Society of America Bulletin, v. 83, no. 8, p. 2443–2448.

Taylor, S. R., 1964, Abundance of chemical elements in the continental crust—A new table: Geochimica et Cosmochimica Acta, v. 28, no. 8, p. 1273–1285.

Trace, R. D., 1960, Significance of unusual mineral occurrences at Hicks Dome, Hardin County, Illinois: U.S. Geological Survey Professional Paper 400–B, p. B63–B64.

Vickers, R. C., 1956, Airborne and ground reconnaissance of part of the syenite complex near Wausau, Wisconsin: U.S. Geological Survey Bulletin 1042–B, p. 25–44.

Wood, G. H., Jr., Northrop, S. A., and Griggs, R. L., 1953, Geology and stratigraphy of Koehler and Mount Laughlin quadrangles and parts of Abbott and Springer quadrangles, eastern Colfax County, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map, OM–141.

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