BULLETIN 30

PreCambrian Geology of the Picuris Range, northcentral New Mexico

BY ARTHUR MONTGOMERY

STATE BUREAU OF MINES AND MINERAL RESOURCES
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY
CAMPUS STATION SOCORRO, NEW MEXICO

FRONTISPIECE

Plate 3. Picuris range from northeast.
VIEW IS FROM A POINT SEVERAL MILES NORTH OF TAOS, PICURIS PEAK IS HIGHEST SUMMIT. *Photograph by Laura Gilpin.*

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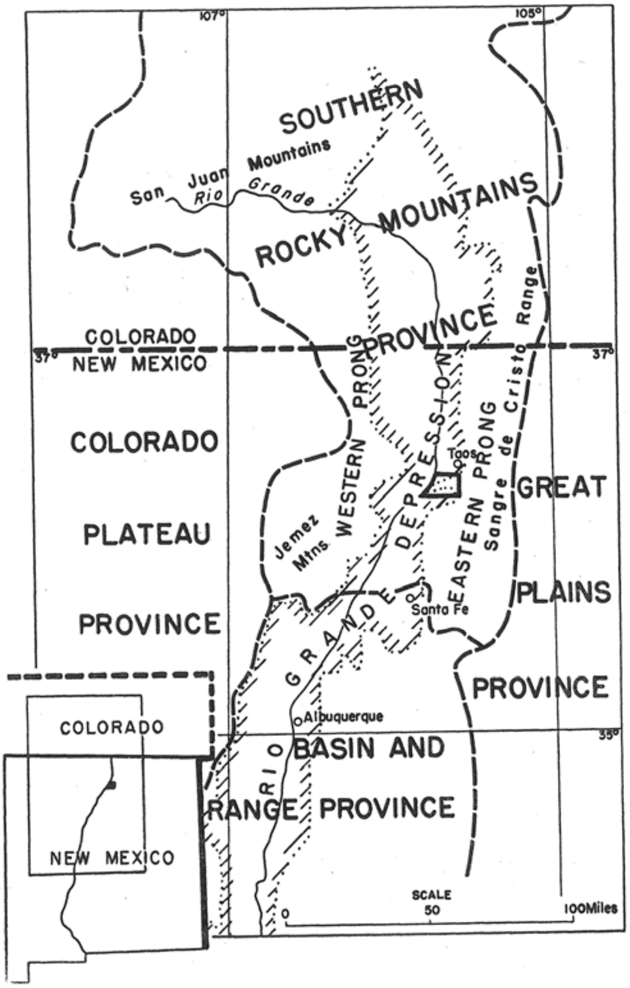

INDEX MAP SHOWING LOCATION OF PICURIS RANGE AND PHYSIOGRAPHIC DIVISIONS IN SOUTH-CENTRAL COLORADO AND NORTH-CENTRAL NEW MEXICO.

Figure 1

Introduction

PURPOSE AND METHODS OF INVESTIGATION

In the course of his operation of the Harding pegmatite mine, a wartime source of tantalum, lithium, and beryllium minerals, the writer recognized the need for detailed field and laboratory study of the enclosing metamorphic and igneous rocks of the Picuris range southwest of Taos, New Mexico. Most of the metamorphic rocks plainly were of sedimentary origin, but metamorphosed igneous rocks also were recognized. Later igneous rocks, only slightly metamorphosed, were intruded into the metamorphic terrane; the notable pegmatites of the area are associated with these rocks. All of these crystalline rocks are older than overlying Pennsylvanian strata, and are interpreted as being of pre-Cambrian age.

A wide variety of quartzites, phyllites, schists, and gneisses is exposed and it was recognized that the continuity of outcrop permits a reasonable interpretation of stratigraphic succession that might provide a geologic column of pre-Cambrian rocks with which similar rocks in other parts of northern New Mexico might be compared. Of particular interest to students of metamorphic rocks and to crystal collectors as well, is the widespread occurrence of the aluminum silicates, andalusite, sillimanite, and kyanite, together with the hydrous iron-aluminum silicate, staurolite. The distribution of these and other minerals has permitted the designation of metamorphic zones in the Picuris range. Overlying and enclosing formations of Paleozoic and Tertiary age were studied only insofar as was necessary to interpret the structure and more recent history of the range.

This report embodies the results of field mapping done during the period 1947 to 1949, and of laboratory studies made in the Department of Geology at Harvard University. The report was submitted during November, 1950, in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Harvard University.

The field work occupied two and a half summer seasons from 1947 to 1949. Areal geology was plotted in the field on aerial photographs purchased from the Soil Conservation Service and having an approximate scale of 2 inches to the mile, then transferred to the base map which is a photostatic compilation of 4 Soil-Conservation planimetric sheets derived from aerial photographs and having a similar scale,. Without topographic control it was impossible to map rock contacts with precision. The U. S. Geological Survey topographic sheet, Taos and Vicinity, on a scale of 1 inch to 2 miles, covers only the northeast corner of the range.

All important rock outcrops were located with Brunton compass. Wherever helpful, altitude readings were taken with aneroid barometer and recorded. More than 2,300 outcrops were located and studied. Numerous rock specimens were collected, and 300 thin sections from these were studied.

PHYSICAL FEATURES

The Picuris range, also termed the Picuris prong, is in north- central New Mexico. It is an isolated mountainous spur of pre-Cambrian rocks that projects southwestward for 16 miles from the main Sangre de Cristo range near Ranches of Taos, in Taos County, to points near Dixon, in Rio Arriba County. As shown in Fig. 1, the mapped area, comprising both the range and the bordering lower ground, is about 15 miles long and 10 miles wide. The towns of Dixon and Embudo are near the narrow western end of the range; the towns of Talpa and Rio Pueblo are near its northeasterly and southeasterly corners, respectively. The Rio Grande and U. S. Highway 64 border the north and west sides of the range, State Highway 3 borders the east side, and the Rio Pueblo and State Highway 75 border much of the southern side.

Along the northwestern border of the range, the Rio Grande has cut a narrow gorge 1,000 feet deep through a basalt- and gravel-capped plateau surface that lies at an altitude of 7,000 feet. Below Pilar (P1. 1) steep cliffs of crystalline rocks rise a thousand feet directly above the Rio Grande. Around Dixon and throughout the Chamisal-Peñasco lowland re-entrant, which is to the south between the range and the southward continuation of the Sangre de Cristo range, a plateau surface rises gently southward toward the high mountains. This surface and the underlying soft Tertiary sediments beneath it, have been considerably dissected by small streams tributary to the Rio Grande. The broad Peñasco and Dixon valleys also were cut into such soft beds by the Rio Pueblo, but where this stream has been superimposed upon the resistant crystalline rocks at the southwestern corner of the Picuris range, it has cut a very deep and precipitous canyon.

The eastern boundary of the Picuris range is placed along the Rio Grande del Rancho canyon, for the ridge adjoining it on the west marks the contact between the pre-Cambrian granite and Pennsylvanian sediments that overlap it from the east. These beds of quartzite, arkose, shale, and minor limestone (Young, 1945) form a thick cover over the southern Taos range from Rio Grande del Rancho canyon to the Moreno valley and also southward towards Mora, where limestone becomes predominant. Much of the higher Truchas range is covered by similar beds, but extensive exposures of pre-Cambrian granite, quartzite, mica schist and amphibolite also occur, especially in the subsidiary Rincon range far to the south and along the western border of the Truchas range.

On the north, west and south of the Picuris range is the vast 7,000 to 7,500 foot Taos plateau, which is underlain by soft Tertiary strata that are capped by Quaternary basalt. The basalt is interbedded with gravel and buff-colored sand and clay that have been largely stripped from the plateau surface. Near Dixon, and in the area to the south and west, most of the basalt has been removed by erosion; in this area much of the plateau surface has been carved out into deeply-dissected badland topography. The Rio Grande canyon, along the northwestern boundary of the Picuris range, widens into such broad-valley topography in the vicinity of Rinconada and Embudo, narrows again to a lava-capped gorge from there to Velarde 7 miles southwestward, thence opens into the extensive lowland plain of the Española valley. As viewed northward and northwestward from the Picuris range across the deep trench of the Rio Grande, the basalt- and gravel-capped plateau extends into the distance for many miles until it vanishes among the ranges of the western prong of the Southern Rockies in New Mexico.

The Picuris range itself is a rugged, maturely-dissected mountain mass, and is a maze of high, steep ridges and deep canyons. Observed from the north, its summit level rises gradually eastward, and near the eastern end is a lofty highland beyond which there is an abrupt drop in summit level of several thousand feet. Total relief in the range is about 4,500 feet.

The western half of the range is characterized by long, narrow east-west ridges, the higher summits of which are 8,000 to 9,000 feet in altitude. The knob of Copper hill and several granite peaks near the Harding mine rise to altitudes of about 8,000 feet, and form the highest points near the western end of the range. The massive 9,000- foot ridge of Copper mountain forms the backbone of the central part of the range. Fairly open but steep-walled canyons separate these western ridges, but the gorge of the Rio Pueblo is an exceptionally narrow gash fully 800 feet deep. East of Picuris canyon, where there is a marked rise in general altitude, the east-west topographic trend continues as far as the crest of the range, the great 10,000-foot main ridge that extends north and south from Picuris peak. The summit of Picuris peak, the highest point in the range, lies at an elevation of 10,700 feet above sea level, From the central part of the main ridge, two subsidiary 10,000-foot ridges extend westward like outflung arms or branches.

Although an east-west trend in the topography is predominant in the range west of the main ridge, some noteworthy breaks in this trend occur in the central and west-central parts of the range. The most clearly-defined of these breaks are the north-south courses of two major canyons, Picuris and Hondo, which penetrate to the central highland from the southern and northern boundaries of the range, respectively, and cut sharply across the east-west ridges; near its head, however, Hondo canyon turns and extends due eastward between the two western arms of the main ridge. At the north-central border of the range near Pilar, three important canyons, Agua Caliente, Piedra Lumbre (formerly called Tierra Amarilla canyon), and Rito Cieneguilla, also transect the east-west topographic trend by turning from their upper westward courses to lower northwesterly ones. These three canyons open into a broad lowland area that forms a distinct break or re-entrant in the northern range front east of Pilar. Less clear-cut but equally noteworthy major breaks in the east-west topographic trend are two broad, irregular, low areas that trend northwest across the range. One is largely defined by Agua Caliente canyon, and the other, by the low pass and road between Copper hill and Copper mountain, From Peñasco on the south, the range shows a striking step-like effect in its summit outline from west to east, with three fairly level stretches separated by these two low areas, as if they were three separate blocks, succeeding one another eastward at altitudes of 8,000, 9,000 and nearly 10,000 feet.

The main ridge not only forms the crest of the range, but also terminates sharply the general east-west trend of ridges and canyons that run throughout the central and western parts of the range. From the main ridge eastward, the trend is wholly a north-south one. Two massive ridges, 6 miles long and 8,000 to 9,000 feet in altitude, extend from north to south in that area and dominate the topography at the eastern end of the range; these ridges are separated by the broad, low valley of Arroyo Miranda. Other major canyons with north-south courses at the eastern end of the range are Rio Grande del Rancho canyon at the far-eastern extremity, narrow Alamo canyon penetrating from the northeastern boundary of the range to the vicinity of Picuris peak, and Telephone and Osha canyons extending northward toward Picuris peak from the southeastern boundary of the range near Vadito.

The drainage pattern of the range is a mixture of re-excavated pre-Tertiary and pre-Pleistocene valleys, of more recent valleys subsequent to the exhumed pre-Cambrian surface, and also of a few valleys consequent upon the deformed surface of alluvial and volcanic beds covering the range in Tertiary time. Because of the arid climate, there is very little active erosion except during floods caused by summer cloudbursts and spring freshets, especially in Agua Caliente, Picuris, Hondo, Telephone and Miranda canyons. The two main streams draining the border of the range are fed from distant high-mountain sources. The Rio Grande forms the main artery or base level for the northern part of the range, and its tributary, the Rio Pueblo, for the southern. A third, but minor, perennial stream, the Rio Grande del Rancho, drains northward to the Rio Grande along the eastern side of the range.

The higher parts of the range are uninhabited, but the valleys are farmed in many places, and support a scattered population. The climate is semiarid. The mean annual precipitation of 10 inches is insufficient for the growth of field and orchard crops, which are irrigated during much of the year. Mining is essentially limited to the well-known Harding mine, from which lithium and tantalum-columbium minerals and beryl are obtained.

PREVIOUS GEOLOGIC WORK

No detailed geologic mapping of the range was done prior to the present investigation. Just (1937) published a generalized geologic map of the area in connection with a three-weeks reconnaissance of the pegmatites, and his formation names have been retained in this report wherever possible. Cabot (1938) mapped the border faults in reconnaissance.

The work of Just in the Picuris area deserves special recognition. His geologic map, though generalized, is remarkable for its clear-cut portrayal of the salient geologic features of the region, and it has been the foundation for the more detailed investigation embodied in this report.

An early description of the copper deposits at Copper hill and of the gold-mining promotion at Glenwoody (on the Rio Grande below Pilar) was given by Graton (Lindgren, Graton, and Gordon, 1910, pp. 89-91). More recent papers on the economic geology of the area have dealt with the occurrence of iceland spar very near the Harding mine (Johnson, 1940; Kelley, 1940), with the mining of lepidolite at the Harding mine (Roos, 1926), and with the recent diamond-drilling of the Harding deposits for tantalum and lithium minerals by the U. S. Bureau of Mines (1943, 1944, 1946, 1949). R. H. Jahns (U. S. Geological Survey report in preparation) mapped the Harding pegmatite in detail in 1942-1943, and in a recent paper (Jahns, 1951) described the general geology and economic minerals of the deposit. Montgomery (1951) described in detail the beryl operations at the Harding mine. Wood (1946) depicted the milling of tantalum ore at the mine.

Minerals of the Harding pegmatite were described by Schaller and Henderson (1926) and Hirschi (1928, 1931). Northrop (1935) described thulite near Pilar, and later, in his report on the minerals of New Mexico (1942), listed various minerals that occur in the range.

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Pre-Cambrian Rocks

INTRODUCTION

The pre-Cambrian rocks other than the intrusive Embudo granite are grouped in two formations, the older of which is termed the Ortega and the younger the Vadito. Each of these formations has been divided into members and some of the members have been subdivided into smaller lithologic units. It was found possible to differentiate and correlate these units with reasonable assurance throughout the Picuris range, even though the range is segmented, as is shown in Plate 1. The Embudo granite occupies large areas in the southern and eastern parts of the range. Pegmatites are widely distributed, but are most abundant near the granite, especially at the southwestern side of the range.

ORTEGA FORMATION

The name Ortega is retained from Just (1937, P. 21) who used it for quartzite exposed in the Ortega mountains, 25 miles northwest of the Picuris range, and correlated it with similar quartzite in the Picuris range. As identified by the writer, the Ortega formation is made up wholly of metasedimentary rocks and

TABLE I. ESTIMATED MODES OF ROCK TYPES IN THE ORTEGA FORMATION

	LOWER QUARTZITE MEMBER	RINCONADA SCHIST MEMBER						PILAR PHYLLITE MEMBER
	1	2	3	4	5	6	7	8[1]
Porphyroblasts								
Biotite		10						
Garnet		1		2	1		1	
Staurolite		1	10	1				
Kyanite	20							
Sillimanite	10							
Andalusite		8						
Hornblende					40		33	
Actinolite						10		
Groundmass								
Quartz	50	50	38	25	30	30	24	70
Albite-oligoclase		10	8					
Andesine					25			
Bytownite							33	
Biotite			20	20	4			tr
Muscovite	5	20	23	50		tr	tr	25
Phlogopite						10		
Sillimanite		tr						
Calcite					tr	50		
Zoisite					tr		2	
Sphene					tr		2	
Sericite		tr			tr	tr	tr	
Pyrophyllite	5							
Ilmenite Hematite Magnetite	10	tr	tr	1	tr		5	5
Carbon	tr							
Zircon	tr							
Tourmaline	tr	tr	1	1				tr
Grain size in mm.								
Porphyroblasts	1-3	10	20	2-10	.5-5	1-5	1-2	
Groundmass	.1-2	.1-.5	.1-.5	.04-.1	.1-.5	.2-.5	.02-.2	.01-.05
Texture[2]	G	G	G to S	G to S	G	G	G	G to S

1. Sillimanite-kyanite gneiss
2. Andalusite-biotite hornfels
3. Staurolite gneiss or schist
4. Muscovite-quartz-biotite-garnet phyllite
5. Hornblende granulite
6. Calcareous granulite
7. Bytownite-hornblende granulite
8. Quartz-muscovite carbonaceous phyllite

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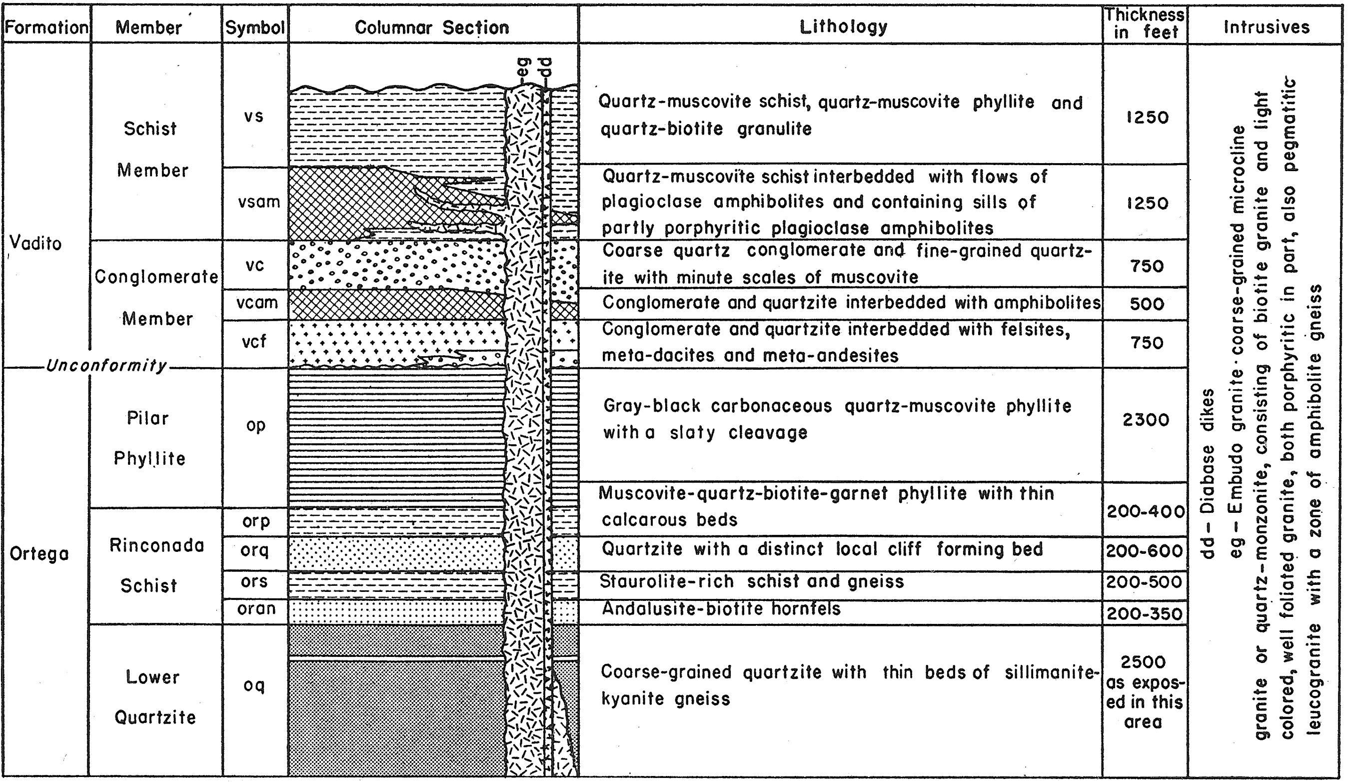
[1] Average of 10 sections

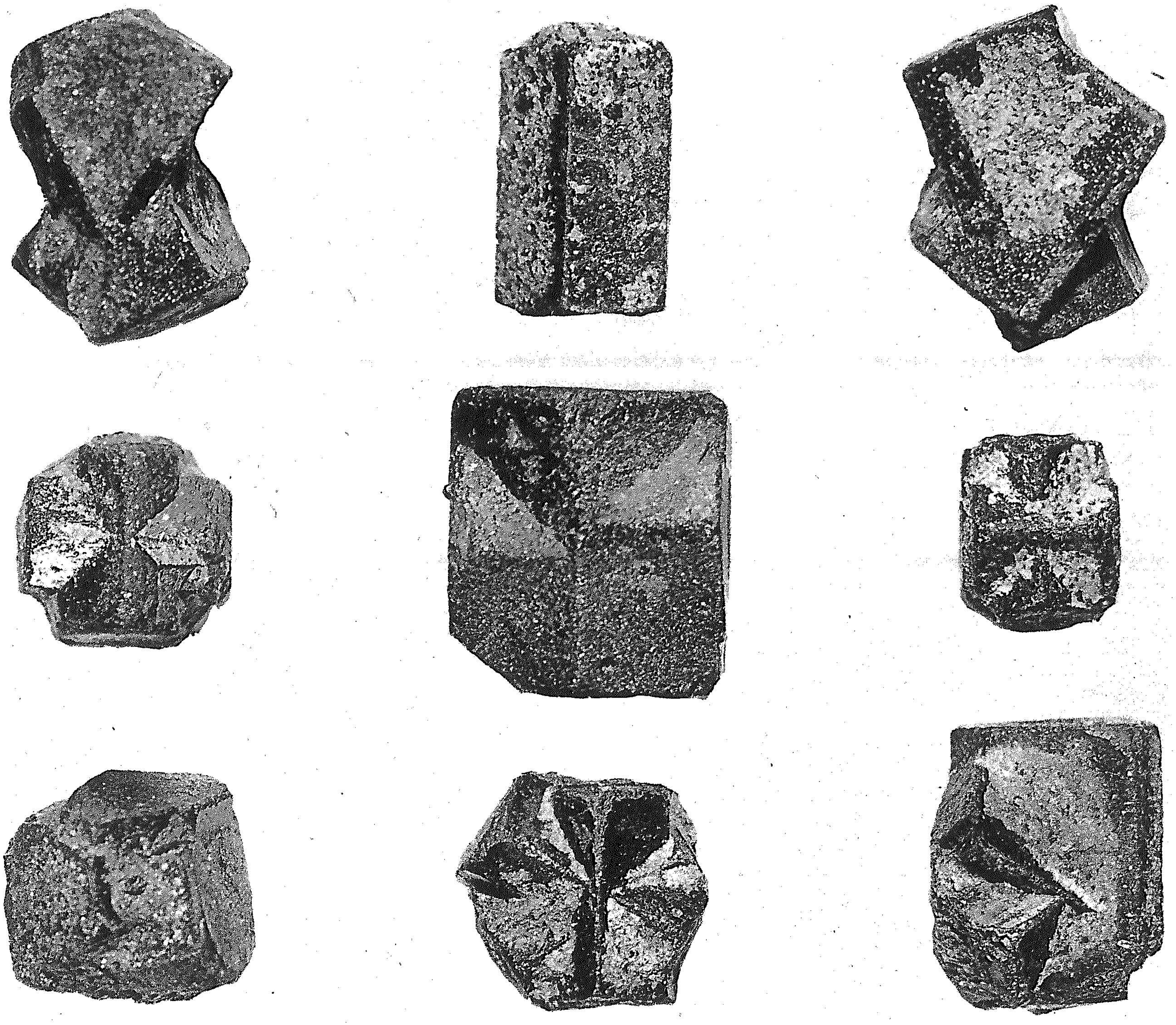
[2] G—granoblastic; S—schistose



Formation	Member	Symbol	Columnar Section	Lithology	Thickness in feet	Intrusives
Vadito	Schist Member	vs		Quartz-muscovite schist, quartz-muscovite phyllite and quartz-biotite granulite	1250	dd – Diabase dikes eg – Embudo granite · coarse-grained microcline granite or quartz-monzonite, consisting of biotite granite and light colored, well foliated granite, both porphyritic in part, also pegmatitic leucogranite with a zone of amphibolite gneiss
		vsam		Quartz-muscovite schist interbedded with flows of plagioclase amphibolites and containing sills of partly porphyritic plagioclase amphibolites	1250	
	Conglomerate Member	vc		Coarse quartz conglomerate and fine-grained quartzite with minute scales of muscovite	750	
		vcam		Conglomerate and quartzite interbedded with amphibolites	500	
		vcf		Conglomerate and quartzite interbedded with felsites, meta-dacites and meta-andesites	750	
Unconformity						
Ortega	Pilar Phyllite	op		Gray-black carbonaceous quartz-muscovite phyllite with a slaty cleavage	2300	
	Rinconada Schist	orp		Muscovite-quartz-biotite-garnet phyllite with thin calcarous beds	200-400	
		orq		Quartzite with a distinct local cliff forming bed	200-600	
		ors		Staurolite-rich schist and gneiss	200-500	
		oran		Andalusite-biotite hornfels	200-350	
	Lower Quartzite	oq		Coarse-grained quartzite with thin beds of sillimanite-kyanite gneiss	2500 as exposed in this area	

COLUMNAR SECTION OF PRE-CAMBRIAN ROCKS, PICURIS RANGE, TAOS COUNTY, NEW MEXICO.

Figure 2



Top row: left and right, twins on (232); center, simple prism. Center row: three right-angle crosses on (032). Bottom row: left, compound twin on (232) and (032); center and right, trillings on (232). Enlarged 1½.

Plate 4. Staurolite crystals.

comprises a quartzite member, which has no exposed base; the Rinconada schist member, named by Just (1937, p. 22) for the settlement of that name 2 miles north of Dixon in the Rio Grande canyon; and the Pilar phyllite member, here named for the village of Pilar, also in the Rio Grande canyon. The last-named unit, a gray-black carbonaceous phyllite, was termed the Hondo slate by Just (1937, p. 23). The total thickness of the Ortega formation as exposed in the range, is estimated to be 6,600 feet. Modal compositions of the several varieties of rock in this formation are shown in Table I.

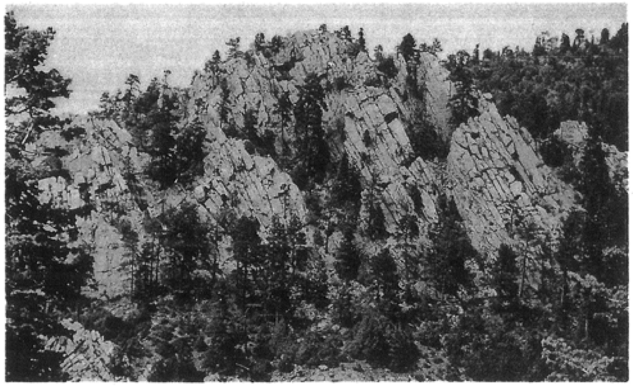
LOWER QUARTZITE MEMBER

Distribution

The lower quartzite member occurs chiefly in two east-west belts that are 1 to 1½ miles wide. One belt lies along the northern border of the range; the other extends from Copper hill to the eastern slope of Picuris peak. Two small additional exposures of the quartzite member are surrounded by Pennsylvanian beds southeast of Picuris peak. The isolated quartzite between Dixon and Embudo is presumed to represent the quartzite member, which also forms the isolated hill of Cerro Azul, 5 miles north of Embudo.

Lithology

Though the lower quartzite member consists very largely of quartzite, it contains also a few thin beds of sillimanite-kyanite gneiss. Thin dark layers are fairly abundant in certain areas. Thin light-colored schistose layers rich in coarse, glistening scales of muscovite, are more rare.



A. STEEPLY-DIPPING NORTH-SOUTH JOINTS IN EAST-WEST TRENDING QUARTZITE BED IN RINCONADA SCHIST AT HEAD OF PIEDRA LUMBRE CANYON.

B. HARDING MINE. THE PEGMATITE SHOWS AS AN ALMOST FLAT BODY CROSSCUTTING DARK AMPHIBOLITE BEDS. LATH-LIKE CRYSTALS OF SPODUMENE ARE PROMINENT.
Photograph by R. H. Jahns.

Plate 5. Views in Picuris Range.

The quartzite is very coarse-grained (grain diameter as much as 1 cm.) and generally is glassy in appearance. The rock is commonly massive, but locally shows a very crude slabby structure. The color is gray to gray-white, but in certain areas the rock has a pale-brown streaky or mottled appearance, largely due to iron-oxide staining. In some places the rock is milky-white, and resembles vein quartz, and in others it is dark-smoky or nearly gray-black. Very rarely the color is a pale bluish-green. Most of the beds consist almost wholly of quartz, and the original rock must have been an unusually pure sandstone. Some tiny grayish or brownish streaks of irregular, curving outline are present; these generally consist of iron-oxide impurities that surround quartz grains. There is a little specking of tiny dark grains, either tourmaline, hematite, or ilmenite, and of minute grayish glades of kyanite or whitish, fibrous aggregates of sillimanite.

Microscopically the quartzite shows a granoblastic mosaic in which the larger quartz grains average 0.5 to 1 mm. in diameter. Grain boundaries usually are invisible in plain light, but may be outlined by films of iron oxide. In polarized light many grains show slight undulatory extinction and indistinct trains of minute liquid inclusions. Some thin scatterings of interstitial muscovite plates 0.2 mm. in diameter also are present. A thin section of slabby quartzite from Picuris ridge reveals elongated grains 1 to 2 mm. long with jagged, sutured borders lined with tiny quartz fragments; these grains exhibit strong undulatory extinction.

Thin sections show the dark layers in the quartzite to consist largely of platy to irregular grains of ilmenite and hematite 0.1 to 0.2 mm. in size; the plates are roughly parallel to the layers. Brownish granular leucoxene is clustered about some of the ilmenite, as are platy muscovite and rare coarsely-prismatic greenish tourmaline and small, rounded grains of zircon. Thin sections of some dark bands, as those near the mouth of Hondo canyon, contain many radiating aggregates of slate-blue tourmaline prisms 0.5 to 1 mm. long. Some of the tourmaline has partly replaced coarse kyanite blades and sillimanite fibers. The sections also show coarse, irregular, dark veinlets of bluish tourmaline crossing dark foliation-banding, and the dark bands themselves are rich in tourmaline near these veinlets.

Under the microscope, the gray-black quartzite contains minute tourmaline prisms or abundant disseminated hematite scales of 1 mm. size. In thin sections of the bluish-green quartzite are minute specks of several metallic minerals, one of which may be chalcocite; the color appears to be caused by disseminated sub-microscopic specks of chrysocolla.

Sillimanite and kyanite are abundant in the thin gneissic layers, and some masses of quartzite are sparsely peppered with these minerals. Sillimanite is absent from the central quartzite belt except near Picuris peak, but both scaly films of kyanite and muscovite pseudomorphs after kyanite are common. A layer of kyanite gneiss several feet thick, which may contain as much as 25% of coarse, bladed kyanite with abundant muscovite and granular ilmenite, can be traced for several miles along its strike south of Copper mountain. Some kyanite adjacent to this gneiss layer occurs in small quartz veinlets as clusters of coarse, pale-bluish blades as much as 5 cm. long. Sillimanite is more abundant than kyanite in the most northerly quartzite zone, but both minerals occur together in two distinctive beds of muscovite schist or gneiss that cross Hondo canyon a mile south of Highway 64. Northeast of this point and near the mountain front, the quartzite is flecked with small, pinkish-white clusters of radiating sillimanite fibers.

The two sillimanite-kyanite beds crossing Hondo canyon were traced for more than a mile along the strike. They are 3 to 25 feet thick, with an average of 10 feet, and are 1,000 feet apart. The southern bed is mainly coarse muscovite-quartz schist that contains sillimanite-kyanite knots as much as 10 cm. across. The northern bed is remarkably rich in both minerals, and contains as much as 50% of them in places; several prospect holes have been dug on this bed along the west side of the canyon. The rock is a grayish to pinkish banded gneiss with layers and lenticular streaks of granular, bluish-gray quartz interspersed between elongate porphyroblasts of white, or pink, fibrous sillimanite and broad, grayish blades of kyanite. The last two minerals show parallel orientation and are partly strung out in continuous bands. Coarse muscovite is locally abundant, and some of it forms broad silvery blades pseudomorphous after kyanite. Some of the rock is highly deformed and in places it is altered to dark patches of iron oxide and whitish streaks and masses of kaolin.

Thin sections show sillimanite and kyanite as lenticular porphyroblastic crystal-aggregates 1 to 3 mm, in average size and in parallel orientation. The sillimanite forms acicular sheaf-like bundles (P1. 6, A), and the kyanite forms irregular broad blades. Broad prisms of sillimanite also occur in parallel intergrowth with kyanite. Some kyanite occurs as dark-stained granulated blades, and shows partial replacement by surrounding acicular sillimanite. Some sillimanite, in acicular sprays that project across the foliation, surrounds and has partly replaced coarse, broken prisms of sillimanite. Some scattered muscovite plates 1 to 3 mm. long lie parallel to the foliation, and others fill cracks across sillimanite bundles and surround granulated blades of kyanite. Pyrophyllite has a similar occurrence and is abundant in several thin sections; it can be distinguished by its clusters of curving flakes.

Quartz, the major constituent, occurs as coarse elongate grains. Small grains of ilmenite and hematite are fairly abundant. One thin section (P1. 6, B), the significance of which will be discussed in the section on metamorphism, shows thin bands of dark carbonaceous specks and scattered muscovite plates of minute size crossing quartz grains and kyanite blades alike; outer rims of the quartz grains are clear. These bands are not perfectly parallel to the plane of foliation. Cataclastic textures are widespread in some sections; the quartz grains are small and elongate, sillimanite, kyanite and iron oxides are in streaks of small granules, and patches of yellowish kaolin and thin seams of cross-scaly pyrophyllite are abundant. Fractures are common in all thin sections, and they cross elongate minerals perpendicular to their elongation.

A thin layer of sillimanite gneiss half a mile farther south in Hondo canyon contains a seam of fibrous sillimanite 1.5 cm. thick. Under the microscope, slender sillimanite prisms are orientated at a large angle to an iron-oxide layer that marks bedding. These prisms are partly fractured and broken apart, and the fragments are surrounded by unorientated needles of sillimanite.

North of the rich sillimanite-kyanite beds in Hondo canyon are some exposures of quartzite with a few thin layers of quartz-muscovite gneiss that is rich in kyanite. Some associated quartz veins contain coarsely-crystallized bluish kyanite. One lenticular vein, 2 feet thick, contains fan-shaped aggregates of broad kyanite blades 10 cm. in maximum dimension, associated with hundreds of rectangular, pinkish- gray prisms of andalusite as much as 8 cm. long and 2 cm. across. A paper-thin layer of white, pearly pyrophyllite coats the prisms. Similar quartzite areas rich in sillimanite and kyanite cross Fletcher canyon a mile south of Pilar.

Where the quartzite has its thickest exposure in the cliffs near Pilar, the rock for several hundred feet above the highway is highly micaceous. Similar micaceous quartzite occupies the hill half a mile north of the highway between Rio Pueblo and U. S. hill pass, and also occurs just west of the mouth of Alamo canyon. Broad, silvery to greenish muscovite plates form thin films that give the quartzite a weakly schistose structure. The flakes vary considerably in size; the coarse ones generally are 0.5 mm. long and 0.1 mm. thick. The quartz grains are about 0.2 mm. across. Pegmatites are present, and close to these the quartzite contains small grains of albite and microcline, which are associated with the micaceous seams. Larger grains of microcline, 1 mm. in maximum size, are present locally.

Much of the micaceous rock near Pilar has a distinctive pinkish color or contains small reddish streaks of piedmontite. The piedmontite forms prisms 0.1 to 2 mm. long and as much as 0.1 mm. wide; they exhibit brilliant pleochroic colors and have a wide range of refractive indices suggesting variation in manganese content [α= 1.717-1.727, β = 1.736-1.741, γ = 1.757-1.761; optically positive; 2V = 85°; $r<v$; X = lemon-yellow, Y = pale violet, Z = bright rose-red]. Northrop (1935) has described thulite from this area. Some of the rock shows mylonitic structure, with quartz lenticles surrounded by curving films of slender muscovite plates averaging 0.2 by 0.02 mm. in size. The quartz grains have a flattened-rectangular shape. Small pegmatites of this area resemble a banded, micaceous quartzite that is locally rich in feldspathic layers. Along the border of one pegmatite, the quartzite contains abundant lenticular grains of white feldspar as much as 1 cm. long strung out in an augen structure. A section of this reveals broken and bent phenocrysts of albite that are much replaced by platy sericite and patches of quartz. A little fine-grained albite also is present.

The quartzite of Cerro Azul, north of the Rio Grande, is identical with the lower quartzite member of the Ortega formation exposed in Hondo canyon. It contains dark layers of hematite-ilmenite grains with a few small zircon crystals; sillimanite is abundant as tiny bundles of fibers and is associated with muscovite films on rock-cleavage surfaces. Translucent brownish-green prisms of andalusite, some of them 12 cm. by 4 cm., are associated with kyanite in a vein-like mass of quartz.

Thickness

Despite repetition by close folding, the lower quartzite member must be at least 2,500 feet thick, as exposed in this area. This estimate is based on quartzite exposures southwest of Pilar.

RINCONADA SCHIST MEMBER

The Rinconada schist member consists of four distinctive and mappable units: andalusite-biotite hornfels, staurolite gneiss and schist, quartzite, and muscovite-quartz-biotite-garnet phyllite. Several thin beds within these units are valuable as horizon markers. One of these markers, a thin unit of quartz-muscovite gneiss with layers and thickly-disseminated crystals of iron-oxide minerals, lies close to the contact between the northern belt of the lower quartzite member and an andalusite-biotite hornfels at the base of the Rinconada schist member. The total thickness of the Rinconada schist member is estimated to be 1,800 feet.

Andalusite-biotite Hornfels Bed

Distribution, A mile south of the sillimanite-kyanite gneiss exposed in Hondo canyon the quartzite gives way to a coarse, knobby, micaceous rock that borders the northern belt of lower quartzite along its entire southern edge, occurs directly above the lower quartzite at Copper hill, and is present at several other places north of both Copper hill and Copper mountain.

Lithology. The matrix of the rock, a coarsely-felted mass of muscovite and quartz, is thickly spotted with rounded, black tablets of biotite averaging 1 cm. in diameter (P1. 8, A). Grayish knobby masses of quartz or of andalusite, up to 1 foot and more in size, are abundant. The biotite crystals are spotted throughout both the knobs of quartz or andalusite and the crudely-schistose micaceous matrix. Thin quartz veinlets are numerous in some parts of the rock, but are so deformed and intermixed with the knobby micaceous matrix that they lack clear-cut continuity. To some degree the veinlets grade into the knobby quartzose masses. The andalusite occurs not only as large nodular masses, but also at some localities as crudely-formed rectangular prisms 10 cm. in maximum length and as a peppering of small pinkish grains. Staurolite crystals, which are fairly rare, occur in the groundmass and inside knobs of andalusite as dark-brown twinned crystals 1 to 3 cm. in length; most of these look fresh, but at some localities they are stained dark and appear corroded and partly altered. Tiny, reddish-brown, dodecahedral crystals of almandite, 0.5 to 1 mm. in diameter, are fairly common.

Thin sections of the hornfels in Hondo canyon show the andalusite masses to be single poikiloblastic crystal-units that contain as much as 50% of small, rounded inclusions of quartz (P1. 6, C). Rare sillimanite prisms 0.5 mm. long occur in parallel growth with enclosing andalusite, and are parallel to the cleavage of the host crystals. Stubby crystals of pale-brown biotite [$\beta = 1.632$] are prominent. The larger ones, 1 to 6 mm. long and 0.5 to 3 mm. thick, are poikilitic and contain small inclusions, chiefly of quartz. The biotite crystals also enclose numerous minute grains of zircon, which are outlined by pleochroic halos, as well as rare small patches of sericitized sodic plagioclase and small plates of ilmenite and hematite. Dark streaks along cleavage planes in the biotite are hematite or ilmenite. A few rods of pale-bluish tourmaline 0.1 mm. long occur also as inclusions in the andalusite, as do crystals of almandite 0.5 to 1 mm. in diameter. Many of the latter are broken apart and partly altered to iron oxide, but some of the smaller crystals are complete and unaltered. Muscovite plates 0.5 mm. long partly surround porphyroblasts of biotite, and a few coarse flakes of pale green chlorite are intergrown with the muscovite. The larger crystals of biotite have been fractured, and the cracks healed with biotite of different optical orientation. Partial rims of granular quartz surround many biotite crystals. The ground-mass is a fine-grained network of quartz grains and small, diversely-orientated muscovite flakes.

Thin sections from outcrops of finer-grained hornfels at Copper hill show both small and large andalusite porphyroblasts, the former as rough prisms 0.5 by 0.2 mm. in size and the latter as crude, rounded, sieve-like masses 1 to 3 cm. in diameter. Some dark skeletal masses of iron oxide, 0.5 to 1 mm. in size, have the stubby prismatic habit and diamond-shaped cross-section characteristic of staurolite. Slender, brownish rods of tourmaline mostly about 0.1 mm. long are abundant throughout. Coarse, platy muscovite forms rims around the larger andalusite masses. The rock matrix is a fine-grained network of muscovite plates crisscrossing in all directions between quartz grains. The entire matrix "flows" around the andalusite knobs in streaks, and prismatic minerals, including tourmaline, are orientated parallel to it, as if caught up in the "flow." Many tourmaline crystals were broken apart in the process, and fragments of some tourmaline prisms are widely separated.

Thickness. Although estimates of thickness are necessarily approximate, the range of thickness of this andalusite-biotite hornfels is estimated to be from 200 to 350 feet.

Staurolite Schist and Gneiss Bed

Distribution. In Hondo canyon the andalusite hornfels grades southward across the strike into a finer-grained, crudely schistose rock that lacks andalusite or quartzose knobs and is very rich in large staurolite crystals. This staurolite schist or gneiss is a good horizon-marker with many outcrops, and, although offset by faulting, can be followed for 8 miles along its strike from the ridge west of Alamo canyon to the fault scarp above the highway 3 miles southwest of Pilar. Although prominent outcrops are present near Copper hill and north of Copper mountain, exposures of this unit are scarce south and east of the latter area. This rock is distinguished from a staurolite phyllite close to the Pilar phyllite by different lithology and greater thickness.

Lithology. Small staurolite crystals occur near the base of the northernmost outcrop in Hondo canyon in a fine-grained but coarsely-foliated, silvery-gray, micaceous groundmass. Tiny, black crystals of biotite, forming lenticular specks 1 mm. long, are densely peppered through the silvery matrix. Dark brown staurolite crystals 5 by 2 mm. in size stand out as abundant knobs on outcrop surfaces. A hundred feet southward and some tens of feet above the base of the bed staurolite crystals attain their average size of 2 cm. long and 1 by 0.5 cm. in cross-section (P1. 8, B). Their maximum length is 4 cm. The crystals are dark-brown to brownish-black, and are sharply faced. Nearly all are interpenetration twins, among which a 60-degree-angle cross twinned on (232) is the dominant habit and a right-angle cross twinned on (032) is common. Simple prisms are rare, and stellate trillings on (232) very rare. Compound twins of three individuals twinned on both (232) and (032) are the rarest identifiable twin type observed. All these types are shown in Plate 4. Reddish, trapezohedral garnet crystals of 1 mm. size are thinly peppered throughout micaceous matrix and staurolite crystals alike. Where the matrix is soft and very micaceous, the ground is covered with weathered-out staurolite crystals; where it is more quartzitic the rock is a highly resistant staurolite gneiss and loose crystals do not occur.

Thin sections (P1. 6, D) show large poikilitic staurolite crystals of pale-yellow color forcing aside continuous parallel trains of thin muscovite flakes 0.1 mm. long and abundant stubby biotite crystals of 0.2 to 0.3 mm. diameter. A mosaic of quartz grains 0.1 to 0.2 mm. in size makes up 25% to 50% of the rock; a scattering of diversely-orientated muscovite flakes occurs interstitial to the quartz grains. About 10% of the rock is made up of albite-oligoclase grains that are almost indistinguishable from the quartz. Rough grains and plates of iron-oxide[1] 0.1 to 0.2 mm. in size and prisms of bluish tourmaline averaging 0.1 mm. in length are abundant. The tourmaline generally is parallel to other elongate minerals, but a few prisms stand across the foliation.

Thickness. The thickness of this staurolite-schist bed ranges from 200 to 500 feet.

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[1] The term *iron-oxide* is understood throughout this report to include ilmenite, hema tite, magnetite and hydrous iron oxides.

Quartzite Bed

A bed of gray-white quartzite occurs near the middle of the Rinconada schist. It differs from the lower quartzite member in having a prominent slabby cleavage, in containing some interbedded layers of staurolite and garnet schist several centimeters thick, and in lacking sillimanite and kyanite. Gray-black quartzite occurs locally, and in places forms a separate layer 50 feet thick higher in the stratigraphy and separated from the gray-white quartzite by a variable thickness of garnet or staurolite schist. Some of the quartzite is glassy-white and translucent. In some areas part of the bed is massive and extremely tough, and forms a distinctive cliff or spine 100 to 200 feet wide that rises tens of feet above the surrounding schists. The total thickness of the bed ranges from 200 to 600 feet.

Muscovite-quartz-biotite-garnet Phyllite

Distribution. The next unit of the Rinconada schist member is a phyllite and schist zone having very widespread exposures. In upper Hondo canyon, much of the half-mile-wide zone lying between the Pilar phyllite exposures to the north and to the south is composed of this rock, and the same zone continues westward along both sides of Rito Cieneguilla. Several minor but distinctive rock types interbedded with this phyllite are described under a separate heading.

Lithology. The average rock is a muscovite-rich phyllite with a pearly-gray to greenish-gray sheen. Quartz is distinctly minor, and the rock is highly schistose and commonly is corrugated from small-scale crinkling. Minute biotite crystals are abundant, and numerous reddish-brown almandite garnet crystals 1 to 2 mm. in size also occur. Garnet crystals are thickly scattered throughout certain layers, which are 1 to 5 cm. thick and commonly are interlaminated with thin quartzitic layers, and locally make up 25% of the rock. Staurolite crystals of distinctive long-prismatic habit are equally numerous in a pearly-gray, densely-felted phyllite layer several feet thick.

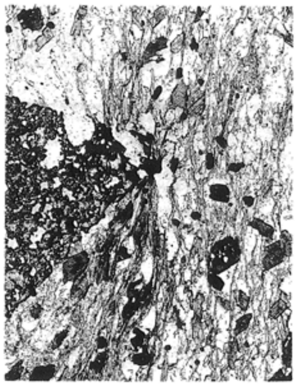
Thin sections show muscovite flakes that range from tiniest discernible size up to 0.2 mm. long, and are densely matted together in parallel orientation. They make up 50% to 75% of the rock. Elongate quartz grains, only 0.04 to 0.1 mm. long, rarely exceed 10% of the rock. Biotite crystals, averaging 0.1 to 0.2 mm. in size, are either thin and parallel-orientated, or are of the usual stubby habit and diverse orientation; many crystals with the latter habit are lenticular and ragged. Iron-oxide is thinly scattered in small streaks and patches. The usual minute rods of tourmaline are locally numerous. Porphyroblasts of garnet have sharp crystal outlines, are not poikilitic, and do not disturb the surrounding micaceous foliation. Staurolite crystals contain quartz inclusions; they also fail to disturb the surrounding schistosity. Thin, dark layers of carbonaceous, quartz-rich material are rarely intercalated with the phyllite.

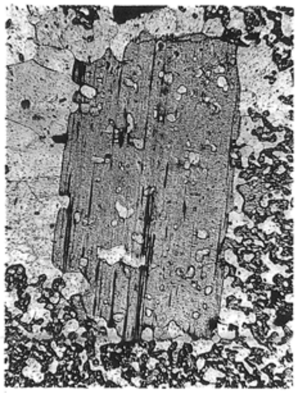
Thickness. The thickness of the muscovite-quartz-biotite-garnet phyllite zone, including the minor associated rock types next described, is estimated to range from 200 to 400 feet.

Minor Rock Types Associated with the Muscovite-quartz-biotite-garnet Phyllite

Hornblende granulite. A gray-green to greenish-black rock occurs in thin beds 2 to 10 cm. thick near the center or toward the top of the muscovite phyllite zone. A good exposure occurs on the east slope of Hondo canyon half-way across the northerly area of Rinconada schist. Greenish-black aggregates of bladed hornblende 0.5 to 1 cm. long are thickly spotted through a gray-green or gray-white matrix; locally they comprise 50% or more of the rock. Some are also spread out on bedding surfaces in flattened stellate clusters. The gray-white groundmass is commonly fine-grained or flinty. This rock is harder than the thin interbedded phyllite layers, and hence protrudes on weathering. Thin sections show the matrix to be a finely granoblastic intergrowth of quartz and sericitized calcic feldspar, generally andesine. Coarse hornblende blades are poikiloblastic and are either diversely orientated as stubby sieve-like prisms 1 to 10 mm. long or occur as densely-matted bladed aggregates; the mineral commonly is partly altered to granular patches of calcite, iron-oxide, and zoisite. This hornblende shows the following optical properties: [$\alpha = 1.638$, $\beta = 1.654$, $\gamma = 1.662$; optically negative; high 2V; $Z \Lambda c = 20°$; X = colorless, Y = brownish-green, Z = bluish-green]. Large brownish garnet crystals of 0.5 mm. size occur sparsely; these contain radially orientated inclusions of quartz. The garnet is an almandite [$n = 1.805$], and is typical of the schists and gneisses of the Rinconada schist. A few coarse, wedge-like crystals of sphene 0.5 mm. long also occur. Scattered patches of pale-brown biotite and small plates and grains of iron-oxide are common.

D





C

PLATE 6. Photomicrographs of metamorphic rocks.

A. SILLIMANITE-KYANITE GNEISS FROM HONDO CANYON. FIBER-BUNDLE OF SILLIMANITE, SURROUNDED BY QUARTZ AND CROSSED BY FRACTURES, IS ELONGATED PARALLEL TO PLANE OF FOLIATION. 30X.

B. SILLIMANITE-KYANITE GNEISS FROM HONDO CANYON. DARK BANDS CONSISTING OF MINUTE SPECKS OF CABONACEOUS MATERIAL AND IRON-OXIDE CROSS GRAINS OF BOTH QUARTZ AND SILLIMANITE-KYANITE. LIGHT AREAS ARE QUARTZ. COARSE GRAINS WITH HIGH RELIEF ARE KYANITE, INTERGROWN WITH AND PARTLY REPLACED BY SILLIMANITE. SMALL BLACK GRAINS ARE IRON-OXIDES. NIc0LS CROSSED. 14X.

C. ANDALUSITE-BIOTITE HORNFELS FROM HONDO CANYON. LARGE BIOTITE CRYSTAL IS SURROUNDED BY COARSE-GRAINED QUARTZ AND POIKILOBLASTIC ANDALUSITE (HIGH RELIEF) FULL OF QUARTZ INCLUSIONS. 30X.

D. STAUROLITE GNEISS FROM EAST OF HONDO CANYON. LARGE STAUROLITE POIKILOBLAST HAS PUSHED ASIDE THE OTHER MINERALS IN ITS GROWTH. GRAY STUBBY SHAPES ARE BIOTITE CRYSTALS. THE LIGHT-COLORED MATRIX SHOWS TRAINS OF SMALL MUSCOVITE FLAKES AND COARSE-GRAINED QUARTZ. 14X.

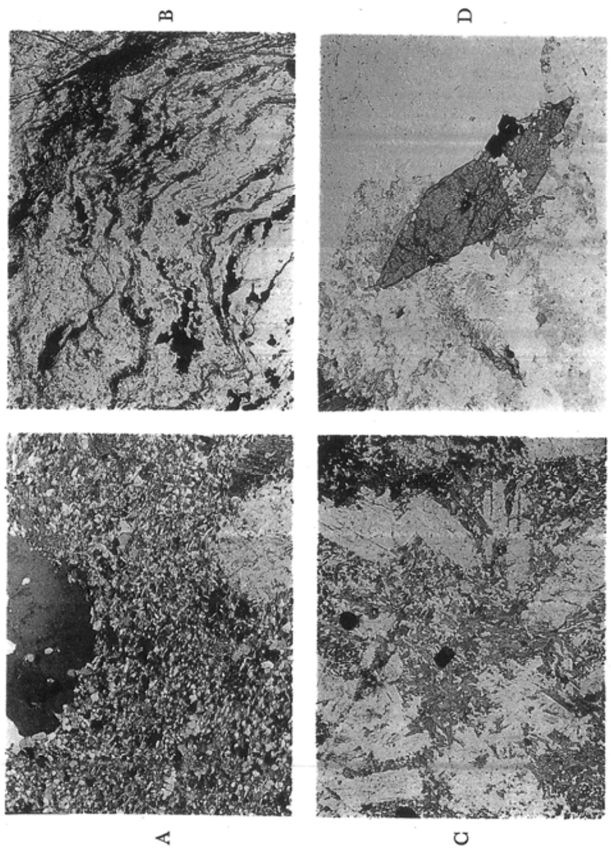


PLATE 7. Photomicrographs of metamorphic and igneous rocks.
A. FELSITE OF THE VADITO FORMATION FROM POINT 1 MILE SOUTHEAST OF COPPER MOUNTAIN RIDGE. LARGE PHENOCRYST OF QUARTZ AT THE TOP; ALBITE PHENOCRYST AT BOTTOM. MATRIX IS FINELY GRANOBLASTIC FELDSPAR AND QUARTZ WITH SCATTERED PARALLEL-ORIENTATED FLAKES OF MUSCOVITE. NICOLS CROSSED. 14X.
B. ANDALUSITE CRYSTAL FROM MUSCOVITE PHYLLITE OF THE VADITO FORMATION ½ MILE NORTH OF THE HARDING MINE. DARK CONTORTED BANDS CONSIST OF TOURMALINE RODS AND IRON-OXIDE GRAINS AND REPRESENT RELIC BANDING. THE LIGHT-COLORED MATRIX OF ANDALUSITE CONTAINS SOME COARSE GRAINS OF IRON-OXIDE. l4X.
C. PORPHYRITIC AMPHIBOLITE FROM MOUTH OF PICURIS CANYON. LARGE ANDESINE PHENOCRYSTS ARE OUTLINED BY GRAYISH GRAINS OF HORNBLENDE INDICATING AN ORIGINAL OPHITIC TEXTURE. BLACK GRAINS ARE MAGNETITE. 14X.
D. GRANITE FROM OUTCROP 1½ MILES EAST OF THE HARDING MINE. THE WEDGE-SHAPED SPHENE CRYSTAL, WHICH IS FRACTURED AND VEINED, OCCURS IN A GROUNDMASS OF COARSE-GRAINED MICROCLINE, ALBITE-OLIGOCLASE AND QUARTZ. COARSE BIOTITE APPEARS IN UPPER LEFT CORNER. BLACK INCLUSIONS ARE MAGNETITE; SMALL WHITE INCLUSIONS OF HIGH RELIEF ARE APATITE. 14X.

Hornblende-garnet hornfels. A dark-green layer, 5 cm. thick, of very coarse hornblende and garnet occurs near the Pilar phyllite contact in several areas. Excellent exposures are present near the northern margin of the Pilar phyllite in Hondo canyon and along its southern margin north of Copper mountain. This bed can be traced for several miles along the strike, although outcrops are widely scattered. The reddish-brown almandite crystals, 0.25 to 0.1 cm. in diameter, are densely spotted through a greenish-black matting of radial-fibrous hornblende; these minerals make up 30% and 50% of the rock, respectively. The rock generally is much weathered, the hornblende stained brown and partly altered to iron oxide. A thin section of fresher rock shows fractured and limonite-stained garnet crystals that enclose the typical radially-orientated quartz inclusions. Coarse, sheaf-like masses of poikilitic hornblende, surround the garnet. This hornblende has somewhat higher refractive indices and stronger pleochroism than the hornblende of the hornblende granulite and is probably less calciferous [$\alpha = 1.655$, $\beta = 1.665$, $\gamma = 1.673$; optically negative; high 2V; $Z \wedge c = 20°$]. Some highly-deformed streaks of fine-grained, intergrown quartz and iron-oxide also are present.

Calcareous granulite. Calcareous granulite forms several thin layers near the middle of the muscovite phyllite zone; good exposures occur far up the Hondo canyon on its south slope and along both sides of Rito Cieneguilla. This distinctive rock, one of the most valuable horizon-markers in the Picuris range, is medium-grained, gray-brown to gray-white in color, and is gritty to the touch. Fan-shaped clusters of pale-greenish actinolite, 1 to 5 mm. in size, are thinly scattered through the calcareous groundmass. The microscope shows fine- to coarse-granular, polysynthetically-twinned calcite comprising 50% or more of the rock. Palest-green, non-pleochroic actinolite [$\alpha= 1.620$, $\beta = 1.635$,$\gamma = 1.642$; optically negative; high 2V; $Z \wedge c = 14°$] is in poikiloblastic sheaf-like aggregates or patchy, skeletal blades intergrown with calcite, and is locally abundant. Phlogopite [$\beta = 1.602$] of palest-brown color forms patches 0.1 to 0.2 mm. in size, and makes up, 10% of the rock. Fine-grained quartz also occurs in variable amounts.

On the east slope of Agua Caliente canyon and a short distance above its mouth are several thin layers of a whitish rock somewhat similar in appearance to the calcareous granulite, but coarser-grained. In thin section some of this proves to be a nearly pure marble. Anhedral calcite grains are of coarse size of 2 mm. maximum diameter. A little fine-grained quartz is present, and coarse muscovite flakes are associated with small scattered clusters of phlogopite. Thin layers of muscovite-biotite phyllite are interbedded with the calcareous beds. Some of the calcite twin lamellae show bending and dislocation, and several thin, dark, mylonitic layers are parallel to the bedding.

Half-way up Rho Cieneguilla several thin, brownish-gray layers consist of coarsely-matted, fibrous aggregates of colorless, slender blades of tremolite, as much as 5 mm. long, and coarse colorless prisms of diopside. The refractive indices of the tremolite are [$\alpha = 1.610$, $\beta = 1.627$, $\gamma = 1.635$]; those of the diopside [$\alpha = 1.680$, $\beta = 1.689$, $\gamma= 1.705$]. Thin sections also show large scattered grains of pyrite, magnetite, ilmenite, and sphene.

Microcline gneiss. A grayish finely-banded rock outcrops on the north slope in upper Hondo canyon. Under the microscope, many patchy lenticular microcline porphyroblasts, 0.5 to 0.75 mm. by 0.25 to 0.5 mm. in size, comprise 60% of the rock. These porphyroblasts are finely sieve-like, and contain numerous flattened and orientated blebs of quartz of 0.02 mm. diameter, scattered, minute muscovite flakes, and a banding or specking of dark impurities. Discontinuous layers of fine-grained quartz 0.5 mm. thick occur between the microcline porphyroblasts, and make up 30% of the rock. Scattered lenticular biotite crystals make up 10%. Scarce muscovite plates range considerably in size, with a maximum of about 0.25 mm. The usual minute tourmaline rods are abundant. Traces of coarse granular sphene and small grains of iron-oxide also occur.

Bytownite granulite. Stratigraphically close to the microcline gneiss are some thin, flinty, dark-gray layers that show stellate clusters of hornblende prisms on bedding surfaces. Under the microscope, pale green hornblende, occurring both as densely-matted groups of prisms and as single slender blades as much as 2 mm. long, is abundant in a granoblastic matrix of bytownite and quartz that averages 0.02 mm. in grain size. Some coarse quartz grains occur also, as do continuous layers of coarse-grained quartz. Sharply-faced stubby prisms of zoisite, some as much as 0.25 by 0.1 mm. in size, and granular, corroded-looking crystals of sphene 1 mm. in maximum dimension are fairly abundant, and a few large crystals of garnet also are present.

Iron-oxide occurs sparsely as small clots and streaks. The hornblende porphyroblasts contain small quartz inclusions and minute dark specks of iron-oxide and carbonaceous matter. The hornblende [$\beta = 1.655$] is similar to that of the hornblende granulite. Separate interbedded layers of the same rock show a very little hornblende and abundant porphyroblasts of pale brown biotite in small flakes as well as in stubby crystals of 0.2 mm. size.

Black hornfels. Just north of the upper Hondo canyon fork and along the south margin of the slaty Pilar phyllite is a dense, black, flinty rock that is 10 to 15 feet in outcrop breadth. This rock is in part tightly folded, and is thinly intercalated with gray and greenish- black layers of calcareous granulite and hornblende granulite. Silvery-white twinned crystals of arsenopyrite 0.5 to 1 cm. in diameter are prominent in some parts of the rock. In thin section patchy porphyroblasts of labradorite, 0.1 to 0.2 mm. in size, are dark from parallel bands of minute carbonaceous inclusions. These feldspar crystals, some of which show albite twinning, are surrounded by granoblastic quartz of 0.04 mm. grain size, and by streaks and clots of carbonaceous material and iron-oxide. About 10% of the rock comprises poikiloblasts of pale-green hornblende that enclose carbonaceous bands; stubby reddish-brown biotite crystals of 0.1 mm. size are clustered about these porphyroblasts and form separate streaky layers together with layers of quartz. Elongate, ragged and corroded-looking sphene crystals of gray-brown color are partly granulated and drawn out into streaks of iron-oxide; they are 1 to 2 mm. long, and comprise 5% of the rock. Sharply-faced crystals of arsenopyrite, haphazard in orientation, are associated with lens-shaped areas of coarse-grained quartz. These crystals are spotty in occurrence, but locally amount to 1 to 10% of the rock.

PILAR PHYLLITE MEMBER

General Statement

The Pilar phyllite, or Hondo slate of Just,[1] is the youngest rock of the Ortega formation and the most distinctive horizon-marker in the Picuris range. The old name, Hondo, had been applied to other rocks prior to Just's usage, and hence seems best abandoned. The new name, Pilar, derives from the village of Pilar, situated at the north-central border of the Picuris range at a point several miles east and north of prominent outcrops of the black, carbonaceous phyllite.

Distribution

The Pilar phyllite occurs in two main east-west belts of ½-mile width that extend from upper Hondo canyon to Piedra Lumbre canyon, and thence is offset to the south to continue as a single, westward-tapering belt. Smaller belts occur northwest and south of Copper hill, as well as southeast of Copper mountain.

Lithology

The rock is dense, homogeneous, and hard, and is gray-black to black in color, with a gray sheen on cleavage surfaces. On these surfaces minute muscovite flakes can be discerned with a hand lens. The slaty cleavage is very irregular in detail, and gives the typical rock a crudely slabby structure. In a few outcrops, where the cleavage is more perfect, the rock might be usable as roofing slate or flagstone. Some cleavage surfaces show a corrugation due to small-scale crinkling.

The rock commonly contains many quartz veins, ranging from large ones that follow joints to paper-thin veinlets parallel to the cleavage. Some of these veins cross the cleavage at various angles and are folded on a minute scale. On some fresh breaks across cleavage thin lenticular cavities in the rock appear along certain layers. Some thin quartzose layers are limonite-rich, and contain irregular cavities, and fracture or cleavage surfaces in certain areas, as along Rito Cieneguilla, are coated with brown limonite and yellowish sulfate staining. Solid masses of dark brown limonite, some of fist size, are commonly weathered out of this rock, and smaller masses also occur in quartz veins that lie within the phyllite.

Thin sections show a very fine-grained mineral aggregate, in which dark, streaky patches of carbonaceous material are very prominent. Crossed nicols show elongate quartz grains, 0.01 to 0.02 mm. long and murky from carbonaceous inclusions, strung out irregularly in sub-parallel orientation. Interspersed with them are muscovite flakes 0.05 by 0.01 mm. in size. The quartz commonly makes up 50% to 75% of the rock; the muscovite 15% to 30%. The muscovite plates are not generally matted together, but some form very thin, continuous trains. Darker parts of the rock, relatively rich in carbonaceous matter, in some places cross the foliation as distinct bedding layers.

Larger quartz grains, as much as 0.25 to 0.5 mm. in size, occupy lenticular areas or criss-crossing veinlets 0.1 to 0.25 mm. wide. The grains rarely are flattened perpendicular to the veinlet walls. Some veinlets offset other veinlets where they cross, and some are complexly folded on a minute scale. Most sections show a scattering of lenticular porphyroblasts 0.1 to 0.5 mm. in size that consist of yellowish or dark-brownish limonitic material. Some of these augen are wisp-like, and a few are bent into pinwheel shapes. Some porphyroblasts show traces of biotite stained dark by iron oxides, and others have a distinct outline, generally rounded, squarish, or diamond-shaped. A few stubby-prismatic shapes stand across the foliation. These crude relic porphyroblasts constitute as much as 5% of the rock in most places.

Thickness

Close folding prohibits accurate determination of thickness, but the Pilar phyllite appears to be 2,300 feet in minimum thickness as exposed in the Picuris range.

[1] The term *slate* is not satisfactory as the rock has undergone middle-grade metamorphism together with associated staurolite-bearing schists.

VADITO FORMATION

GENERAL STATEMENT

The Vadito formation and a southerly-bordering area of granite occupy the southern third of the Picuris range west of the Picuris main ridge and Telephone canyon. This formation is at least the partial equivalent of the Hopewell series of Just (1937, p. 21). Inasmuch as the name Hopewell had been applied to other rocks prior to Just's usage, and inasmuch as the type area lies many miles northwest of the Picuris range, it was considered necessary to rename those rocks younger than the Ortega formation in the Picuris area. The formation has been named after the village of Vadito, located near the southeastern corner of the range and several miles south of excellent outcrops of rocks of this formation. The best exposures of Vadito rocks, however, occur within a one-mile radius of the Harding mine.

The Vadito formation consists of metasedimentary rocks that are interbedded with flows and contain sills of various types of meta-igneous rocks. It seems best to describe all of these rocks under the Vadito formation, rather than to treat separately those meta-igneous rocks of possible intrusive origin, owing to the uncertain origin of many of the meta-igneous rocks, as well as the complex and indeterminate relationships between them and the associated metasediments.

In general, the formation comprises a lower conglomerate member and an upper schist member. The lower member consists of quartzite and conglomerate interlayered with flows and sills of various light-colored meta-igneous rocks, mainly felsites near the base of the member but largely meta-dacitic and meta-andesitic types higher in the stratigraphy. The part of the section that consists chiefly of these light-colored and grayish meta-igneous rocks has been mapped separately as a zone of predominant felsites. Minor amounts of amphibolite also occur in the lower member. A unit of predominant amphibolites has been mapped separately in this member, but, because the structural relationships are complex and these rocks are similar to the amphibolites that occur in far greater amount in the upper schist member of the formation, it seems best to describe all the amphibolites in connection with the upper member. This upper schist member consists of quartz schists, phyllites, and granulites interlayered with thick flows and sills of various kinds of amphibolite. A unit of predominant amphibolites has been mapped separately in this member.

The total thickness of the Vadito formation is estimated to be about 4,500 feet.

CONGLOMERATE MEMBER

Quartz Conglomerate and Quartzite

Distribution. Coarse quartz conglomerate and quartzite occur at the base of the Vadito formation in the southwestern part of the range. Very coarse conglomerate outcrops for 7 miles in an east-west belt 1/4 mile wide from the area near Apodaca to the mouth of Picuris canyon. Outcrops become sparser east of Picuris canyon, where the conglomerate is less coarse. Thin, discontinuous beds of moderately coarse conglomerate also occur south of the Harding mine, near the granite contact, and along the mountain front east of Picuris canyon.

Lithology. Good outcrops a mile northwest of the Harding mine show a sharp change northward across the strike from quartz-muscovite schist to coarse conglomerate containing boulders as much as 2 feet in size. A traverse for about 1,500 feet northward from here, as far as the contact with muscovite-garnet phyllite of the Rinconada schist member of the Ortega formation, supplies the folloowing lithologic data:

Lithology	*Distance traversed in feet*
Coarse conglomerate (cobbles averaging 3-10 cm. in size)	300
Pebbly conglomerate (pebbles averaging 3-5 cm. in size)	200
Fine-grained quartzite (gray-white, gritty, with rare pebbles, containing microscopic thinly-disseminated flakes of muscovite and a few black iron-oxide bands up to 0.5 cm. wide)	500
Pebbly conglomerate (pebbles averaging 3-5 cm. in size)	200
Coarse conglomerate (cobbles averaging 6-8 cm. in size)	200
Pebbly conglomerate and fine-grained micaceous quartzite	100-200

TABLE II.
ESTIMATED MODES OF THE VADITO FORMATION

	CONGLOMERATE MEMBER				SCHIST MEMBER				
	1	2	3	4	5	6	7	8	9
Phenocrysts									
Quartz	5	5							
Microcline	1								
Albite-oligoclase	1		20						
Andesine								27	6
Porphyroblasts									
Biotite-chlorite					8				
Garnet							2		
Staurolite							1		
Andalusite							18		
Cordierite					5		18		
Biotite				20					
Muscovite	20	15							
Hornblende				20				43	40
Epidote-clinozoisite									
Groundmass									
Quartz	40	40	28	5	40	60	53	6	6
Albite-oligoclase	15	10	34		10	24			
Oligoclase-andesine				50					
Andesine								20	40
Potash feldspar	15	30							
Biotite	3		15			5			
Muscovite			3		35	10	tr		
Sillimanite							tr		
Chlorite						tr	2		
Epidote-clinozoisite		tr	tr	5				tr	tr
Sphene			tr	tr		tr		tr	tr
Ilmenite Magnetite	tr	tr	tr	tr	1	1	6	4	8
Apatite			tr	tr	tr	tr		tr	
Zircon			tr			tr			
Tourmaline					1	tr			
Grain size in mm.									
Phenocrysts	.1-1	.5-2	1-2					2-10	
Porphyroblasts	.05-.1	.05-.1		.2-10	5-100		1-50	.1-1	.1-.2
Groundmass	.02-.04	.03-.06	.03	.05-1	.05-.1	.04-.5	.5-1		.04-.1
Texture[1]	G	G	G	G	S	Gr	G	G	G

1. Meta-rhyolite
2. Meta-rhyolite
3. Meta-quartz-latite
4. Meta-dacite
5. Quartz-muscovite phyllite
6. Quartz-biotite granulite
7. Andalusite-biotite hornfels
8. Porphyritic plagioclase amphibolite
9. Fine-grained plagioclase amphibolite

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[1] G—granoblastic; S—schistose; Gr—granulitic

This traverse, approaching the base of the Vadito formation, shows that the coarse conglomerate does not here lie directly at the base of the formation, but is underlain by pebbly conglomerate and fine-grained micaceous quartzite. In these outcrops there is a gradation upward in the stratigraphy from fine-grained micaceous quartzite to medium-coarse conglomerate, and from medium-coarse conglomerate to very coarse conglomerate. Such a gradation is not observable elsewhere in the conglomerate member of the formation, and areas or belts of any one of the three lithologic types alone, interbedded with various types of metavolcanics, seem to be the rule.

The matrix of the conglomerate is gray-white micaceous quartzite, rather fine-grained and showing a sparkle due to reflections from minute flakes of muscovite. Pebbles and cobbles are 90% coarse-grained quartzite, mainly gray-white to gray and rarely black. Some show dark banding not parallel to micaceous foliation of the quartzite. Some pebbles and cobbles of softer rocks have been reduced to flattened and streaked-out patchy shapes interstitial to the quartzite cobbles. Such masses consist largely of gray-green to silvery-white muscovite phyllite with abundant rounded, stubby, greenish-black porphyroblasts of biotite that is largely altered to chlorite. These porphyroblasts are 0.5 to 1 cm. in diameter. Flattened masses of a pink-and-white felsitic rock with rounded quartz phenocrysts occur also, and streaky patches of dark, slaty material are scarce.

The pebbles, cobbles, and boulders are of crudely ellipsoidal shape, with marked flattening and various degrees of elongation in the plane of foliation (P1. 9, A). The average ratio of axial lengths is 1: 2: 3, but at some localities it ranges to 1: 2: 6 and, in extreme cases, to 1: 8: 16. In places where the rock is densely packed with pebbles and cobbles, their flattened and elongated shapes are highly irregular, owing in part to the pressing of one pebble or cobble against another. Many pebbles and cobbles show a glossy coating of matted, tiny flakes of muscovite.

As viewed under the microscope, the quartzitic matrix is finergrained than the fabric of the cobbles; the equigranular mosaic of the matrix averages 0.1 to 0.2 mm. in contrast to 0.25 to 2 mm. for the quartzite fragments. Clean-cut muscovite plates, 0.04 to 0.1 mm. long, are interstitial to quartz grains and outline them. These plates, which are not well orientated, generally constitute 10% to 20% of the rock. Where it is more micaceous, the rock has a crude schistosity and commonly shows minutely knobby surfaces due to scattered quartz grains of 2 to 3 mm. size. Tiny, rounded grains of iron-oxide, largely ilmenite and 0.05 to 0.1 mm. in size, are sparsely disseminated through the matrix. Black layers several millimeters thick consist of densely-strewn trains of magnetite, ilmenite, and hematite in grains with 0.1 mm. average diameter. Small rounded zircon prisms are sparsely associated with the iron-oxide bands, as are garnet fragments and rough, stubby, bluish prisms of tourmaline 0.2 to 0.5 mm. long.

The conglomerate southwest of Picuris peak has a similar matrix of micaceous quartzite with rounded, angular, and flattened pebbles of micaceous, feldspathic, and quartzitic material 2 cm. in maximum length. The softer pebbles have been streaked out, and many fade, ghost-like, into the quartzitic matrix. South of the Harding mine and near the granite contact, thin conglomerate beds are interlayered with meta-rhyolite, and contain abundant ellipsoidal quartzite pebbles 3 to 5 cm. in length. Streaky patches of dark greenish-black biotite are abundant in the micaceous-quartzitic matrix, and some coarse chlorite flakes, granular epidote, and abundant iron-oxide grains also are present.

Thickness. The maximum thickness of the lower conglomerate member of the Vadito formation is estimated to be about 2,000 feet. Quartz conglomerate and quartzite, making up all of this member in the area north of the Harding mine and westward from Copper mountain road, are estimated there to have a highly variable total thickness of 500 to 1,000 feet. East of Picuris canyon and south of the Harding mine and the Rio Pueblo, this member is unusually thick because of much interlayering with metavolcanic rocks.

Felsites

Distribution. Dense, light-colored meta-igneous rocks are inter-layered with quartzite and quartz conglomerate near the base of the Vadito formation north of the granite contact south and east of the Harding mine; they occur similarly both east and west of Picuris canyon in contact with the lower quartzite of the Ortega formation and farther west in contact with Pilar phyllite and Rinconada schist. These rocks pinch out entirely still farther west along the contact between the Ortega and Vadito formations at a point 1½ miles north of the Harding mine. Much of the rock is meta-rhyolite, and some of it represents metavolcanic types of quartz-latite or dacite affinities. Much of the meta-rhyolite grades into coarser granite-like rock and appears to represent partial replacement by granite. A minor part of the rock mapped as felsite near the granite may be metamorphosed and finely-granulated granite.

Lithology. The meta-rhyolites have a dense, felsitic texture, and are gray-white, white, or flesh-pink and white in color. Some are gneissic because of the parallel orientation of abundant biotite flakes, and some of these rocks show a platy structure parallel to the micaceous foliation; some types are muscovite-rich and highly schistose. Thinly scattered, rounded quartz phenocrysts I to 2 mm. in size occur, but are rare.

Thin sections commonly show a hypidiomorphic-granular mosaic of quartz and feldspar grains 0.02 to 0.05 mm. in size (P1. 7, A). The texture of this groundmass generally is extremely equigranular. The minute feldspars are largely microcline and albite; orthoclase is present in some of the rocks. Many groups of microcline grains extinguish in unison and may represent a partial replacement by granite; scattered larger grains of microcline as much as 0.25 mm. in size have irregular shapes and are interstitial to quartz and albite. Abundant thin muscovite plates 0.05 to 0.1 mm. long are scattered in parallel orientation; thin trains of these give the rock a faint foliation. Rounded or lenticular quartzose areas 0.1 to 0.5 mm. in diameter contain quartz grains 0.1 to 0.3 mm. in diameter. Quartzose bands or lenses 10 mm. in maximum length are parallel to the micaceous foliation. The wider quartzose bodies are granulated at the ends, and most of the large quartz grains show undulatory extinction. Patchy feldspar phenocrysts 0.5 to 1 mm. in size occur also, but are rare; these commonly have ragged edges and a crude rectangular shape. Most are albite (Ab_{90}), or microcline and orthoclase. Small patches of quartz and clear microcline are present in some of these phenocrysts, as are a few coarse, patchy muscovite plates. There has been very little sericitization of fine-grained feldspar. Biotite locally occurs as small parallel-orientated flakes instead of muscovite. A very few small grains of iron-oxide are present. Modal estimates for two meta-rhyolites are given in Table II, Nos. I and 2.

Similar rocks of slightly coarser grain size show thin streaks or patchy aggregates of coarse, stubby biotite flakes, as well as numerous iron-oxide grains of all sizes. A few skeletal garnet crystals occur as strung-out porphyroblasts 1 mm. or more long, and coarse, granular epidote and aggregates of ilmenite and sphene are rare. The quartzose areas are likely to have a vein-like or tongue-like shape, and these are invariably parallel to the micaceous foliation.

Light gray and gray- and white-banded felsitic rock types occur. The darker color is caused by an abundance of small biotite flakes and granules of iron-oxide and epidote minerals. Minute patchy grains of albite-oligoclase commonly are dominant over potash feldspar, and locally are the only feldspar present. Such rocks commonly show megascopic veinlets and tongue-like masses of coarse-grained granitic-appearing material that is rich in biotite.

A light- to dark-gray felsitic rock type that is common south of the Harding mine shows silvery reflections from squarish mica patches. Under the microscope, the groundmass is a microgranular mosaic of quartz and feldspar, in which albite-oligoclase grains of irregular shape predominate over quartz. Very little microcline is present except as rare interstitial grains of relatively large size. Biotite flakes, 0.02 to 0.1 mm. in size, are thickly disseminated, show perfect parallel orientation, and comprise 20% of the rock. The reflecting crystals are thick porphyroblasts of muscovite, 0.25 to 0.5 mm. in diameter. These appear to represent individual crystals, but consist of aggregates of small widely-scattered, patchy areas that reflect in unison and are separated by fine-grained areas of other minerals. Granules of epidote and clinozoisite, 0.02 mm. in average diameter, are thickly scattered about; rarely they form crude clusters associated with coarser granulated epidote, large magnetite grains of 0.5 mm. size, minor granular sphene, and coarse-grained calcite. The rock approximates a dacite or quartz-latite.

Another thin section of a similar gray rock, which is interbedded with amphibolite south of the Harding mine, shows an identical fine-grained equigranular-granoblastic groundmass. The rock comprises perhaps 20% of quartz, 40% oligoclase, 10% of biotite plates, and 10% of vein-like streaks and lenticular clots of coarse, stubby biotite, together with granulated epidote and sphene, and prisms of apatite. The small plates of biotite are in almost perfect parallel orientation in the groundmass, but change direction and veer about somewhat near the vein-like streaks and clots. These streaks and clots consist of granitic material, and are believed to have been injected into the volcanic rock, which they replaced in part. Nearly all of this grayish meta-dacite or meta-quartz-latite shows some spotting or veining by lighter-colored granitic material, and all gradations occur up to a coarse-grained, semi-granitic rock in which coarse-grained poikilitic microcline becomes predominant. The results of this process have been complicated, however, by later granulation and metamorphism, which clearly have further modified the fabric.

A similar light-gray rock south of the Rio Pueblo and the Harding mine shows abundant whitish phenocrysts of rounded-rectangular shape and 1 to 2 mm. length. These constitute 20% of the rock. They are partly lined up in parallelism and some are streaked out. A few tongue-like veinlets of granitic material 1 to 2 mm. thick cross the rock haphazardly. Under the microscope, quartz and albite-oligoclase form a granoblastic groundmass averaging 0.03 mm. in grain size. Scattered biotite flakes show random orientation. The phenocrysts are rounded, frayed-appearing crystals of untwinned albite-oligoclase, which contain small plates of sericite and, rarely, large skeletal muscovite crystals. The usual lens-shaped patches of coarse biotite and granulated sphene, zircon, epidote, clinozoisite, and apatite are present, and are associated with sparse coarse crystals of magnetite. Some rounded and lenticular patches of coarse-grained quartz, 0.5 mm. in average diameter, also are present. A modal estimate of this rock is given in Table II, No. 3.

Thickness. South of the Harding mine and north of the Rio Pueblo, individual beds or sills of felsite are 50 to 100 feet thick. The thickness of the felsitic rocks increases greatly eastward from Picuris canyon and southward from the Rio Pueblo south of the Harding mine area.

Meta-andesite

General Statement. Associated with quartzites and amphibolites of theVadito formation are various gray, dark gray, greenish-gray and gray-black rocks, mostly believed to be metavolcanic types of andesitic composition. Many of these are bedded, and may well represent original tuffaceous types. Such rocks are abundant south and east of the Harding mine. Hornblende in large or small prisms is an essential constituent in all of these rocks, and its quantity is roughly proportional to the darkness of color in the rock. Thin sections of finely-banded, light gray and greenish-black types show biotite-rich layers with a fine-grained matrix of sodic plagioclase and quartz alternating with hornblende-rich layers that contain patchy oligoclase. A small amount of bleached biotite is associated with the hornblende, which occurs as small- to medium-large, partly granulated, poikilitic prisms or as sprays of tiny, slender prisms. It shows strong pleochroism, from pale yellow to brownish-green to blue-green. Such rock types probably represent thinly layered volcanic material of dacitic and andesitic composition.

SCHIST MEMBER

Quartz-muscovite Schist, Quartz-muscovite Phyllite and Quartz-biotite Granulite

Distribution. Several hundred feet of quartz-muscovite schist lie south of and stratigraphically above the conglomerate and micaceous quartzite north of the Harding mine. There is a gradation stratigraphically upward from micaceous quartzite of the conglomerate member to quartz-muscovite schist of the schist member, and thence to quartz-muscovite phyllite. Still higher up in the formation, and well exposed in an east-west belt just north of the Harding mine, are alternating beds, 10 to 50 feet thick, of muscovite phyllite and quartz-biotite granulite, with associated minor thin layers of micaceous quartzite. Schist and phyllite form good outcrops as far east as the mouth of Picuris canyon, beyond which they largely disappear or are unrecognizable. Exposures of schist and phyllite also occur south of the Harding mine, where there is much interbedding with metavolcanic rocks.

Lithology. The quartz-muscovite schist north of the Harding mine, and south of and stratigraphically above the coarse conglomerate of the conglomerate member, is similar to the quartzite of the conglomerate matrix already described, but contains minute flakes of muscovite that are more densely disseminated and in part felted together into continuous parallel layers. The mica constitutes 20% to 50% of the rock, and the felted layers give the rock a crude to fair schistosity.

Occurrences of the quartz-muscovite phyllite north and east of the Harding mine show a lustrous silvery-gray phyllite, generally hard and gritty to the touch, that contains scattered, poorly-orientated, stubby biotite porphyroblasts. These are 0.5 cm. in average diameter, and are largely altered to gray-green chlorite. Crudely rounded porphyroblasts of cordierite or andalusite, or rarely of chloritoid, 1 to 10 cm. in size, are common in some areas, where they form as much as 10% of the rock. Some of the andalusite forms dark stubby-rectangular crystals 2 to 4 cm. in size, and some occurs as longer, rounded-rectangular prisms that are largely altered to coarse muscovite. Cordierite crystals are numerous in certain beds near the Harding mine as flattened cigar-shaped prisms 2 by 4 by 6 cm. in size or as rounded-stubby, barrel-shaped and tapering crystal masses 1 to 10 cm. in maximum dimension. Most of these crystals are in part altered to muscovite and chlorite (P1. 8, C). In the arroyo east of the Harding mine such cordierite prisms consist partly of dense, fresh, gray-black material showing broad reflection planes on freshly-broken surfaces.

Under the microscope the phyllite shows abundant muscovite flakes of rather irregular, shreddy shape and about 0.1 mm. in maximum length. Part of these are interstitial to quartz grains and lack parallel orientation, and the remainder occur in thin, parallel, densely-felted trains. Quartz, which predominates over the muscovite, forms irregular, angular grains 0.05 to 0.1 mm. in size. These show poor sorting for size and do not lie in distinct equigranular layers. Coarse biotite porphyroblasts occur in random orientation, and are largely altered to pale green chlorite. Small, patchy, pale-brownish grains and partly-indefinable masses of sodic feldspar, mainly albite-oligoclase, are fairly abundant, as are small, randomly-orientated plates and grains of ilmenite and tiny bluish-green rods of tourmaline. A few small, rounded grains of apatite also occur.

Thin sections of fresher andalusite and cordierite porphyroblasts show relics of slaty structures, with layers, 0.02 to 0.04 mm. thick, of carbonaceous matter and of aligned grains of quartz and iron-oxide that are 0.02 to 0.05 mm. in diameter. Some andalusite porphyroblasts contain minute garnet crystals, unaltered stubby biotite plates, and rounded masses of cordierite of 0.05 mm. size enclosing dark layers of carbonaceous specks that are not parallel to the surrounding thin layers of quartz and iron-oxide grains. Neither are these carbonaceous layers parallel to the micaceous foliation of the surrounding phyllite, and they commonly show small-scale folding. Some andalusite crystals enclose crenulated layers of greenish tourmaline rods, 0.1 by 0.02 mm. in size, that are diversely orientated across the layering (P1. 7, B). Some fresh cordierite prisms enclose perfectly regular layers, 0.04 mm. thick, of lenticular quartz grains alternating with equally thin layers of cordierite of the host crystal in crystallographic orientation. Thin sections must be cut at precise orientation to expose such layering.

The quartz-biotite granulite is commonly a fine-grained, sandy, crudely-foliated rock showing irregular, silvery-white, micaceous surfaces on which tiny black flakes of biotite stand out sharply. With less muscovite the rock becomes a biotite-specked quartzose gneiss or quartzite. With more muscovite it grades into the quartz-muscovite phyllite already described. As seen in thin section, quartz grains 0.04 to 0.25 mm. in size make up at least 50% of the rock. They are angular and highly irregular in shape. Sodic feldspar constitutes 20% to 30% of the rock, and occurs as interstitial murky-brown patches 0.2 mm. in size; these are crowded with kaolin and iron-oxide dust but show very little sericite. Muscovite plates 0.1 by 0.05 to 0.2 by 0.1 mm. in size and partly of stubby habit amount to 10% of the rock; they are well orientated in parallelism, but cross the feldspathic patches and are not interstitial to the quartz grains. Scattered irregular patches of biotite, 0.25 to 0.5 mm. in size, are haphazard in their orientation. Some of the fresh ones have a brownish-black color, with a tinge of olive-green, but most are partly altered to pale grass-green chlorite. Some biotite crystals show alteration to streaky iron-oxide and wisps of leucoxene. Abundant platy grains of ilmenite, 0.1 by 0.04 mm. in size, are well orientated in parallelism and are associated mainly with the feldspar and biotite. A few small grains of apatite, zircon, and granular sphene are present.

Thickness. The combined thickness of interbedded quartz schist, phyllite, and granulite of the schist member, as exposed throughout the upper part of the Vadito formation, is difficult to estimate because of close folding and intercalation with associated meta-igneous rocks, but it is at least 1,250 feet and does not exceed 2,500 feet. Bedded amphibolitic metavolcanic rocks make up a considerable part of the maximum figure of 2,500 feet.

Minor Metasedimentary Rock Types Occurring in the Schist Member

General Statement. Associated with the schists in the schist member of the Vadito formation are one or two spotty occurrences of andalusite- and staurolite-bearing rocks that resemble in part the andalusite-biotite hornfels of the Rinconada schist member of the Ortega formation.

Such rocks are exposed at the mouth of Picuris canyon, and extend westward along the strike of the formation. They contain knobby andalusite grains and stubby, rounded porphyroblasts of biotite in a crudely-foliated matrix of quartz-muscovite phyllite. A few small relics of brownish staurolite grains also are present. Both the andalusite and biotite are about 0.5 cm. in average dimension. This rock simulates in general appearance the knobby andalusite hornfels occurring near Copper hill.

A second occurrence 50 to 100 feet wide, forms a part of a narrow east-west belt of schist and gneiss exposed 1½ miles south of Picuris peak between granite to the north and amphibolite to the south. This rock, a very coarse hornfels of dark gray color, contains irregular masses of andalusite as much as 5 cm. in diameter. The matrix is mainly an intergrowth of quartz and cordierite. Some knobby masses contain a dark spotting of magnetite in crude octahedra 2 to 3 mm. in diameter; others contain sharp crystals of brownish-red almandite that are of similar size. Flakes of black biotite are abundant in much of the quartzose matrix, and a few irregular, corroded-looking masses of brownish staurolite are as much as 1 cm. in size. Thin sections show poikilitic, sieve-like crystals of fresh andalusite and staurolite several millimeters in size in a matrix of coarse anhedral quartz and cordierite. Some of the cordierite also forms large, crude, poikilitic crystals. Stubby biotite porphyroblasts of pale brown color and 2 mm. maximum size are intergrown with all the other minerals; they are in small part altered to pale green chlorite. Some chlorite also occurs as coarse, spray-like clusters. Acicular sillimanite is abundant in parallel intergrowth with some of the andalusite. Magnetite crystals, ranging from very small up to 2 mm. in size, form 10% of the rock in some places. The habits of the andalusite, staurolite, biotite, and sillimanite are similar to those of these same minerals in the andalusite hornfels of the Rinconada schist in Hondo canyon.

Associated with amphibolite and quartz-muscovite schist, at points half a mile north and a mile northeast of the Harding mine, are outcrops of a bed, 1 foot or less thick, of massive pink thulite and pale green epidote. A good outcrop occurs just north of the Dixon-Harding mine road half a mile north of the mine, and spotty outcrops also are present westward along the strike. Pegmatites are in part closely associated with this layer of almost pure epidote minerals, which is believed to represent original calcareous beds that contained some manganese.

Amphibolites

General Statement. It is impractical to map or describe separately the various types of amphibolites in the Vadito formation, as the field relationships and origin of many types remain obscure. It has been possible, however, to map two separate zones of amphibolites on the basis of structure and lithologic association. One of these zones occurs in the lower conglomerate member where the amphibolites are associated with felsites, quartzite, and conglomerate; the other occurs in the upper schist member, where the association is with schists and phyllites.

Amphibolites of the Vadito formation can be grouped into several principal types. Of these the porphyritic type is the most distinctive, but gradations exist between coarse porphyritic amphibolite and fine-grained amphibolite in which remnants of feldspar phenocrysts are barely discernible. These porphyritic types may represent original sills of diabase and diabase porphyry. Some of the amphibolites are fine-grained, and a few show traces of irregular cavities that may be relics of original vesicular structure. These fine-grained types probably represent original basaltic flows and tuffaceous sediments of mafic character. Thin layers of garnet amphibolite are another distinctive type, but occur in minor quantity. Still another type contains abundant fragmental, sub-angular or lenticular inclusions of quartzite and other rocks in a fine-grained amphibolitic groundmass. This rock may represent an original mafic breccia or agglomerate, or some type of sheared basaltic conglomerate. Many of the amphibolites, especially those near the mouth of Picuris canyon and in the area to the east, show effects of intrusion by, or reaction with, granitic and pegmatitic magma.

The maximum thickness of amphibolites in the lower conglomerate member of the Vadito formation is estimated to be 750 feet, and the maximum thickness of those in the upper schist member is estimated to be 1,250 feet.

Distribution. An east-west belt of amphibolites, 750 feet wide, is associated with felsites and conglomerate in the conglomerate member; this belt extends westward from Picuris canyon, as well as eastward from there to points about a mile south of the southwest ridge of Picuris peak. Farther west this same belt has narrowed to a thickness of from 100 to 200 feet in the area half a mile south of Copper mountain ridge. This belt of amphibolites will be referred to as *the north belt.* South of the Rio Pueblo and 1½ miles southeast of the Harding mine are several small areas of amphibolites that are associated with felsites; these amphibolites also have been mapped as a part of the conglomerate member.

An east-west belt of amphibolites is interbedded with quartz- muscovite schists in the schist member. This belt is 1 mile wide, and can be followed sporadically for 10 miles along the strike from the area just west of the Harding mine to the vicinity of Telephone canyon. It will be referred to as *the south belt.* Several miles east of the Harding mine this south belt of amphibolite contains much interbedded felsite. A few widely scattered amphibolite layers also occur in the schist member, where they range in thickness from several centimeters to tens of feet. They are interbedded with schist, phyllite, and quartzite in the area northeast of the Harding mine.

Excellent outcrops of amphibolite porphyry occur in the south belt at the mouth of Picuris canyon and in the area to the east; good outcrops also occur at scattered points along the north belt. No amphibolites with identifiable porphyritic texture are known from the south belt west of Picuris canyon. Some thin layers of garnet amphibolite are associated with conglomerate on the west side of Picuris canyon, and also occur 1½ miles farther to the west. Amphibolite layers less than an inch thick are intercalated with lighter-colored felsitic layers several miles east of the Harding mine. In the vicinity of the mine, and southwest of it, are extensive outcrops of fine-grained amphibolite that contain many angular inclusions of quartzite and other rocks.

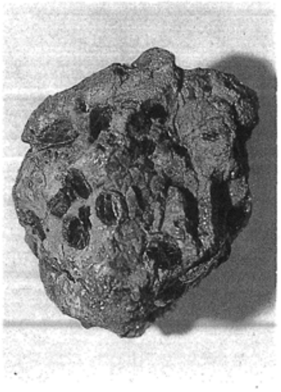
Lithology. The freshest of the porphyritic types of amphibolite are medium-grained to coarse-grained, gray to greenish-black, and contain abundant large, grayish phenocrysts of plagioclase (P1. 8, D), which appear as whitish patches on weathered surfaces. These phenocrysts make up 20% to 50% of the rock. Their shape is lath-like. Some have clean-cut outlines, whereas others are skeletal and irregular. Their size averages 1 cm. by 2 or 3 mm., but they range from very small, ragged plates to huge, stubby crystals 2 by 0.75 cm. in dimension. Some fine-grained amphibolites contain rounded, frayed-appearing phenocrysts 1 to 2 mm. in size; various amphibolites of the Harding mine area locally show a few such shapes. In all the amphibolites of the Picuris range black hornblende crystals are megascopically visible in the groundmass, where they range from coarse, stubby or lath-like prisms of 0.25 cm. size down to dense aggregates of minute needles.

Microscopically, the fresher porphyries show a coarsely granoblastic, porphyritic texture. Most of the phenocrysts are andesine (An_{35} to An_{50}), which forms large laths surrounding interstitial aggregates of hornblende and small, crisscrossing laths of andesine or surrounding granoblastic aggregates of plagioclase alone (P1. 7, C). The small phenocrysts are typically more sodic (An_{30} to An_{40}) than the large ones. Small, slender laths of andesine range from 0.1 to 1 mm. in length. The plagioclase is only slightly altered, and dense, brownish, saussuritized patches occur only sparsely in the larger phenocrysts. Fine, sharp albite twinning characterizes the clear and unaltered areas of the phenocrysts. Fresh anhedral grains of andesine, 0.1 mm. in size, also occur with minor anhedral quartz. Larger quartz grains, 0.5 mm. in size, are commonly in vein-like aggregates.

B

D

C



A

PLATE 8. Metamorphic rocks.

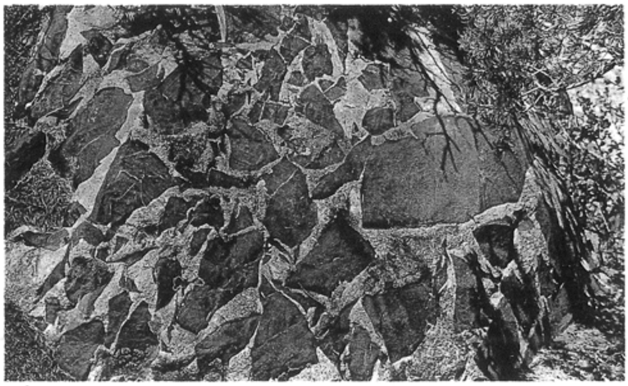
A. ANDALU5ITE KNOT SURROUNDED BY QUARTZ-BIOTITE-MUSCOVITE GNEISS WITH LARGE BIOTITE CRYSTALS FROM RINCONADA SCHIST IN HONDO CANYON. LONGEST DIMENSION, *4* INCHES.

B. STAUROLITE GNEISS OF THE RINCONADA SCHIST FROM EAST OF HONDO CANYON. TINY BLACK BIOTITE CRYSTALS STAND OUT IN THE QUARTZ-MUSCOVITE MATRIX. LONGEST DIMENSION 8 INCHES.

C. CIGAR-SHAPED PSEUDOMORPHS OF MUSCOVITE AND CHLORITE AFTER CORDIERITE IN PHYLLITE OF VADITO FORMATION ½ MILE WEST OF HARDING MINE. PSEUDOHEXAGONAL SYMMETRY OF ORIGINAL CORDIERITE CRYSTALS SHOWN IN CROSS SECTIONS. SMALL DARK BIOTITE PORPHYROBLASTS ARE LARGELY ALTERED TO CHLORITE. LONGEST DIMENSION, 10 INCHES.

D. COARSELY-PORPHYRITIC PLAGIOCLASE AMPHIBOLITE OF THE VADITO FORMATION FROM THE MOUTH OF PICURIS CANYON. LARGE PHENOCRYSTS ARE ANDESINE. ORIGINAL ROCK WAS A DIABASE PORPHYRY OR QUARTZDIABASE PORPHYRY. LONGEST DIMENSION, 4 INCHES.

A. COARSE QUARTZ CONGLOMERATE IN OUTCROP 1 MILE NORTH OF THE HARDING MINE. VIEW IS NORMAL TO PLANE OF FOLIATION. PEBBLES AND COBBLES ARE FLATTENED IN PLANE OF FOLIATION AND ALSO SHOW ROUGHLY PARALLEL ELONGATION. QUARTZITIC MATRIX IS FINE-GRAINED AND MICACEOUS.



B. BRECCIA OF FINE-GRAINED AMPHIBOLITE INTRUDED AND CEMENTED BY COARSEGRAINED GRANITE FROM POINT MILE NORTHEAST OF MOUTH OF PICuRIS CANYON. ADJOINING BLOCKS OF DARK AMPHIBOLITE ARE VARIABLY DISPLACED.

Plate 9. Outcrops of conglomerates and breccia.

The hornblende is idiomorphic against plagioclase and either occurs as small prisms, 0.2 by 0.06 mm. in size, that are lined up in crude trains parallel to boundaries of plagioclase phenocrysts and also are partly intergrown with small plagioclase grains, or occurs as coarse, stubby, poikiloblastic prisms, 2 to 3 mm. in maximum dimension, that in part are matted together into fibrous aggregates. This hornblende exhibits fairly constant optical properties throughout all the amphibolites pf the Vadito formation [$\alpha = 1.668$, $\beta = 1.680$, $\gamma = 1.685$; optically negative; $2V = 60°\text{-}70°$; $Z\Lambda c = 12°$; X = light brown, Y = brownish olive-green, Z deep blue-green]. The coarse hornblende masses generally are cut off sharply against the andesine phenocrysts, or else they occupy irregular wedge-shaped spaces. These wedge-shaped spaces are relics of an original ophitic texture. Small crisscrossing laths of andesine partly surround V-shaped aggregates of small hornblende prisms and interstitial andesine grains to form a clean-cut diabasic texture. Scattered apatite prisms 0.04 mm. long are common, and iron-oxide may be abundant as ilmenite and magnetite granules or as rare grains and crystals of these as large as 0.5 mm. The groundmass contains 50% to 80% of hornblende, 10% to 50% of andesine, 1% to 10% of quartz, 0% to 5% of iron-oxides and 0.1% to 1% of apatite. The larger andesine phenocrysts commonly form about 25% of the rock. A mode of a very fresh porphyritic amphibolite from the area east of the mouth of Picuris canyon is given in Table II, No. 8. The original rock is believed to have been a diabase porphyry or quartz-diabase porphyry.

Amphibolites of the Picuris range are rarely as unaltered and as lithologically definable as the porphyritic types described above. Altered porphyritic types that occur near the mouth of Picuris canyon show microscopically an advanced alteration of plagioclase to dense, brownish masses of sericite, clinozoisite, calcite and kaolin. Granoblastic aggregates of oligoclase-andesine appear, ghost-like, through these masses. Where clearer areas of large andesine phenocrysts remain, they are crowded with minute prisms of hornblende, clear needles of apatite, and flakes of sericite that are partly orientated in trains following cleavage directions. Some wide cracks in these phenocrysts are filled with clear, granoblastic oligoclase and quartz; others are filled with coarsely felted sericite or coarse-grained calcite. Calcite in grains 0.1 to 0.25 mm. in size occupies some areas interstitial to patches of coarse hornblende. The hornblende masses contain streaks and granules of iron-oxide.

Crudely foliated amphibolites that occur near the mouth of Picuris canyon contain coarse, streaked-out layers of saussuritized plagioclase alternating with broad trains of parallel-orientated prisms and crude layers of fibrous, matted hornblende. Much patchy and streaky, reddish-brown biotite appears to be intergrown with the hornblende. Coarse ilmenite grains occur with the biotite, and are surrounded in part by knobby sphene; such ilmenite-sphene clusters are as much as 0.5 mm. in diameter, and locally are abundant. At contacts with granite or aplite in Picuris canyon, altered porphyritic amphibolites show large andesine phenocrysts reduced in part to sieve-like myrmekitic masses. Minute quartz lenses which constitute 25% to 50% of the phenocrysts, are lined up parallel to one of the feldspar cleavage directions (010) . In the same rock, corroded-appearing patches of oligoclase are invaded and even cut up into similar sieve-like masses by small round grains of quartz, 0.01 to 0.02 mm. in size. The feldspar grains have an over-all dusty, murky appearance, apparently due to minute specks of impurities, but contain clear areas here and there as if being cleared of impurities. Small hornblende prisms are strung out in train-like aggregates that are surrounded by tongue-shaped masses of coarse-grained quartz. Ilmenite and apatite grains are abundant. Coarse grains of brownish almandite garnet, 0.5 mm. in diameter, occur sparingly in some amphibolites near granite contacts in Picuris canyon.

Garnet amphibolite which occurs 1½ miles west of the mouth of Picuris canyon, is a coarse-grained, gray-black rock rich in matted aggregates of hornblende. It contains a thin scattering of crudely-rounded porphyroblasts of brownish almandite that range from several millimeters up to 4 cm. in diameter. Thin sections reveal equal amounts of somewhat pale-colored hornblende in coarse, bladed aggregates and a fine- to medium-coarse granoblastic aggregate of bytownite and quartz. Some quartzose areas have grains 0.5 mm. in maximum size. The garnet crystals are poikilitic, rough, and partly granulated. Some stubby zoisite prisms are as much as 0.3 mm. long, abundant plates of ilmenite are lined up in crude trains, and a few small patches of pale brown biotite are intergrown with the hornblende.

Amphibolites south and west of the Harding mine contain abundant coarse inclusions of other rocks in a fine-grained groundmass. Angular, irregular, and streaked-out shapes of foreign inclusions are as much as 8 cm. in size; quartzitic and epidotic rock types are most abundant, and a hornblende-bytownite rock, described farther on, also is abundant. Small fragmental phenocrysts of plagioclase occur very sparsely in this rock. Thin sections show the groundmass to be almost wholly a finely granoblastic aggregate of hornblende, epidote, and andesine in equal amounts. Quartzitic inclusions are highly variable in grain size, and tiny hornblende prisms are scattered among the quartz grains.

Many amphibolites in the Harding mine area are very fine-grained. The amphibolites near the mine commonly show abundant epidote, and some fine-grained amphibolites southwest of the mine contain equal amounts of hornblende, epidote, and plagioclase; others contain perhaps 75% of hornblende and 25% of andesine. Solid masses of coarse, granoblastic epidote 3 mm. in maximum size occur in some of these rocks. Other amphibolites close to the mine show a layering caused by alternating light and dark layers, or by strung-out, flattened, lenticular, whitish masses of quartzose or feldspathic material, Under the microscope, thin alternating bands consist largely of small, densely-packed hornblende prisms, of fine-grained granoblastic quartz and andesine, or of granulitized epidote and clinozoisite; coarser-grained quartz-rich layers are associated, as well.

Except for the distinctive types already described, the amphibolites generally occur as fine-grained to coarse-grained, dark greenish-black to gray-black, hornblende-rich rocks. The hornblende, ranging from microscopic needles to coarse sheaf-like, bladed aggregates, invariably has optical properties similar to those already described, but the usual pleochroic colors vary from weak to intense. Stronger colors are likely to typify the hornblende in amphibolites near masses of granite. Much of the associated plagioclase, which is either andesine or oligoclase-andesine, occurs as rather fresh granoblastic aggregates, but some small patches that are interstitial to coarse hornblende masses are strongly sausseritized.

Gneissic amphibolitic rock types comprise irregular layers, 1 to 5 mm. thick, of nearly pure hornblende, which occurs either as coarse patchy aggregates or as small grains and stubby prisms, alternating with streaky layers of granoblastic plagioclase. Thin trains and scattered granules of epidote and clinozoisite are in part associated with the hornblende; some amphibolites contain fully as much epidote as hornblende. In most of the amphibolitic types, hornblende and plagioclase are equally abundant; such rocks are simply nondescript plagioclase amphibolites. Ilmenite and magnetite commonly occur with the hornblende as small platy or rounded grains, and amount to 5% or 10% of the rock. Equal amounts of anhedral quartz are associated with the plagioclase in some places.

PLUTONIC ROCKS

BYTOWNITE-HORNBLENDE META-INTRUSIVE

A light-gray bytownite-hornblende rock is associated with schists of the schist member of the Vadito formation, and is very similar in mineralogy to the bytownite-hornblende granulite described in association with the muscovite phyllite of the Rinconada schist member of the Ortega formation. It occurs as a widespread sill, 10 feet in maximum thickness, along the north margin of the south amphibolite belt, and also is present south of the southern contact of conglomerate in the area west of Copper mountain road and north of the Dixon-Peñasco road. Coarse, gray-black blades of hornblende, in sprays as much as several centimeters long, are thickly scattered through a light-colored quartzo-feldspathic groundmass. Thin sections reveal a fine-grained to coarse-grained granoblastic matrix of quartz and bytownite (An_{80}); large, ghost-like, skeletal phenocrysts of labradorite (An_{54}) fade almost indistinguishably into the granoblastic matrix or are in part sharply cut off by it. Some of the broad albite twin lamellae in these phenocrysts are very fuzzy, partly bent, and show wavy outlines. The sharp hornblende blades which form 10% to 50% of the rock, show optical properties similar to those of the hornblende in the bytownite-hornblende granulite of the Rinconada schist. Abundant iron-oxide grains, 0.1 mm. in maximum size, are partly arranged in crude bands. They make up nearly 10% of the rock.

A similar hornblende-bytownite rock occurs in the lower quartzite of the Ortega formation along the west slope and adjacent to the mouth of Alamo canyon. Here several groups of 8- to 10-foot layers are partly conformable to bedding in the quartzite, but seem to be in part crosscutting. Dark, coarse aggregates of bladed hornblende form 25% to 50% of the rock, and occur in a grayish, coarse-grained quartzo-feldspathic groundmass. Quartz lenses and thin quartz layers parallel to bedding are abundant in some of the rock. A thin section shows sharply-bladed, poikilitic hornblende crystals that are 1 to 10 mm. in size and possess pale pleochroic colors. Coarse bytownite grains, strongly saussuritized, are intergrown granoblastically with quartz grains 0.1 to 0.2 mm. in size. Ilmenite makes up 10% of the rock as platy grains 0.5 mm. in maximum length; some of these are of "sandwich" shape, with brownish leucoxene in the center. Stubby prisms of apatite, 0.2 mm. long, also are common.

META-INTRUSIVE AMPHIBOLITE

A 50- to 200-foot zone of sheared, coarse-grained amphibolite extends for a distance of 4 miles along the granite ridge west of Arroyo Miranda from north to south. The zone branches and widens to 500 feet at the northwest end. Some of the rocks are not severely metamorphosed, and apparently represent an original diorite or quartz-diorite that has been much sheared and altered by granitic and pegmatitic magma. Many pegmatites are closely associated with the amphibolitic rocks, some of which are hybrid gneisses possessing fine light-and-dark banding. The dark bands are hornblende-rich and the light ones are aplitic. The hornblende is in aggregates of stubby prisms 1 by 0.5 mm. in size. They are lined up in crude bands, and are not poikilitic. The lighter-colored bands are chiefly subhedral andesine (An_{35}), partly saussuritized and intergrown with minor anhedral quartz grains 0.1 to 0.2 mm. in size. Small prisms of apatite, as well as crystals of zircon and sphene, are common accessory constituents. Some coarse fragmental epidote also occurs locally. Shearing has in some cases granulated and streaked out the larger grains of hornblende. Some of the granulated hornblende is altered in part to chlorite. Pleochroic colors of the hornblende increase in intensity with increasing degrees of the alteration.

Much fine- to coarse-grained microcline and quartz have been introduced into the mafic bands of the hybrid gneisses, in addition to making up the interlaminated pegmatitic and aplitic bands. At the north end of the amphibolite zone west of Arroyo Miranda many thin amphibolite layers are surrounded and infiltrated by pegmatitic material. Some layers consist almost wholly of hornblende in coarse, densely-matted, stubby crystals. Several veins of iceland spar, a foot and more thick, are closely associated with these hybrid gneisses.

D1ORITE, QUARTZ-DIORITE, AND GRANODIORITE

Near the contact of granite and Pennsylvanian sediments 3 miles south of Talpa, some small areas of gray-black dioritic rocks occur within the area of granite One small mass of this sort, several hundred feet across, consists of medium-grained, weakly-gneissic rock that is rich in coarse, platy biotite and granular hornblende, and contains scattered patchy streaks of quartz. Study of a thin section reveals a hypidiomorphic-granular texture, somewhat granoblastic and granulated Coarse, stubby laths of plagioclase (oligoclase and oligoclase andesine) make up nearly 50% of the rock. Coarse granoblastic hornblende is conspicuous, as is much intergrown platy biotite of dark brown color. Small grains of quartz are thinly scattered about, and some coarse-grained, lenticular quartzose masses also are present. Prisms of apatite, some of them 2 mm. long, granules and knobby crystals of ilmenite-sphene, and coarse grains of magnetite are abundant. The biotite flakes are orientated in crude parallelism, and the apatite prisms also show some orientation. Tiny plates of ilmenite and streaky patches of biotite occur along cleavages or fractures in much of the hornblende, and also occur in some of the plagioclase. The sphene is partly strung out in trains of granules.

A thin section of the same rock closer to the granite contact reveals effects of hydrothermal alteration, with strong sericitization and saussuritization of plagioclase and chloritization of biotite. Some small, fresh, rounded grains of oligoclase are peppered through areas of altered oligoclase-andesine, and fine-grained aggregates of fresh microcline are commonly associated with scattered quartzose areas. The fresher rock is of dioritic composition, or contains barely enough quartz to permit classification as a quartz-diorite. A mode is given for the fresher rock in Table III, No, 2.

Some grayish, porphyritic, granodioritic rocks with very abundant biotite are associated with these occurrences of dioritic rocks.

EMBUDO GRANITE

General Statement

The Embudo granite borders the Picuris range on the south and on the east. This rock was called by Just (1937, p. 24) the Dixon granite, but this name has priority elsewhere. The new name, Embudo, is taken from the town of Embudo, located 2 miles west of Dixon and 4 miles west of extensive outcrops of the granite.

The Embudo granite occurs in the range as several rather distinctive rock types, but all seem related to a single magma source, as suggested by similarities in mineralogy and chemical composition as well as by general field relations. The variability in rock types is largely a function of 1) the degree of assimilation of foreign material by the granite and the type of rock assimilated, and 2) the degree of shearing and metamorphism in the granite. All granite exposures bordering upon and within the Picuris range represent the upper edges and stock-like apophyses of a great underlying granitic mass. All pre-Cambrian rocks of the Picuris range apart from granite have undergone hydrothermal metamorphism and have been injected by abundant pegmatites and quartz veins; these effects are presumably related to the intrusion of the Embudo granite, now hidden as an underlying batholith in the northern part of the range, but partly exposed in the southern and far-eastern parts.

All occurrences of this rock show a microcline-rich granite that is relatively rich in potash and soda, Modal analyses of thin sections from various occurrences show the following percentage ranges: quartz, 26-50; microcline, 20-35; albite-oligoclase, 26-33; biotite, etc., 0-10. Some typical modes are given in Table III and four chemical analyses are given in Table IV.[1] Plagioclase commonly is slightly dominant over potash feldspar, and the rock thus is strictly a quartz monzonite or granodiorite, but the general appearance and the appreciable variation in composition of the rock favor applying to it the more convenient term, granite. It seems best to distinguish three main granite types: 1) coarse-grained, partly-porphyritic biotite granite, 2) light-colored, partly-porphyritic gneissic granite, and 3) flesh-colored, coarse-grained to pegmatitic leucogranite.

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1. The principal purpose of these chemical analyses was to have a basis of comparison for the TiO, contents of the various granite types in making a study of the geochemistry of tantalum in the Harding pegmatite (Montgomery, 1950).

Biotite Granite

Distribution: A biotite granite is exposed over a limited area near Cañoncito, and also forms the entire granite mass wherever exposed along the front of the range from a point 1½ miles east of the Harding mine for a distance of 6 miles eastward and northeastward past the Picuris pueblo. The granite of this type occurring east of Picuris canyon is partly porphyritic.

Lithology. This rock has the appearance of a typical coarse-grained biotite granite, and for convenience will be called a granite, although chemical analyses and modal estimates based on thin-section study show it to be strictly a quartz monzonite. The groundmass shows patches, 0.5 cm. wide, of milky-white plagioclase that is inter-grown with flesh-pink microcline as well as rounded quartzose areas of equal size. Black biotite, in flaky aggregates 0.5 cm. long, is dispersed fairly evenly through the rock with enough parallelism to impart a crude foliation, and also forms a vein-like network around the other minerals. The microcline, in coarse, flesh-pink or grayish areas, ranges from finely granular to single, rounded crystals as much as 2 cm. in size. Crudely rectangular phenocrysts of microcline 3 cm. in maximum length are abundant in some outcrops of granite near Peñasco and north of Vadito; they consist of 10% to 20% of the rock, and rarely show some elongation roughly parallel to the micaceous foliation. This porphyritic type, a true granite, appears to be gradational into non-porphyritic granite. All the biotite granite east of the Harding mine contains a scattering of flat, cinnamon-brown crystals of sphene, commonly whitish from leucoxenic alteration. Most of the crystals are 1 to 3 mm. long.

Thin sections reveal a very coarse hypidiomorphic-inequigranular texture. Scattered clusters of coarse biotite plates are bent and altered in part to granules of ilmenite and magnetite, and to spindles of leucoxene. Some pale green patches of chlorite and coarse, granular epidote are associated. Where large magnetite grains are intergrown with biotite, the biotite flakes are bent against them. A few coarse plates of muscovite are intergrown with the biotite clusters. Small, rounded crystals of zircon, apatite and sphene of about 0.1 mm. in size are sparsely associated with the above minerals, as are large, pale brown, pleochroic sphene crystals with flattened wedge-shaped habit (P1. 7, D). Square-shaped allanite crystals, of 1 by 0.5 mm. size and very pale-brown color, are rare. The sphene crystals commonly show fringes of leucoxenic alteration and broken irregular edges; some actual breaking apart of these crystals has occurred (P1. 7, D). Some large sphene crystals are so intimately intergrown with apatite and zircon crystals and biotite plates as to assure contemporaneous formation.

Most of the quartz grains are large, anhedral, and show some fracturing and slight undulatory extinction; the interstices between some grains are filled with very late and clear microcline grains, which form clean-cut patches and veinlets. Plagioclase forms aggregates of large, stubby, lath-like grains, which are partly altered to kaolin dust and minute specks and small plates of sericite, but also show some clear areas with albite twinning. The range of composition is from oligoclase to oligoclase-andesine (Ab_{75} to Ab_{70}). Most of the large individuals show a fringe of untwinned oligoclase of more sodic composition; this is almost invariably developed against microcline. Against microcline are also developed some coarse myrmekitic growths of the usual quartz-plagioclase type, in which the plagioclase host is identical with the fringe-oligoclase. Rare myrmekitic growths were noted in which the dendritic or skeletal-shaped guest is microcline instead of quartz, and extinguishes in parallelism with the surrounding microcline. Some plagioclase shows partial replacement by microcline, the latter forming included, parallel-orientated blebs or streaks in antiperthitic textures or occurring as numerous clear inclusions of pellucid quality and sharp outlines. Microcline occurs both as large anhedral grains and as aggregated small grains 0.1 to 0.25 mm. in size. A few large grains show traces of crude perthitic textures, but many microcline grains also enclose small irregular patches and streaks of oligoclase. Small microcline grains tend to cluster about large plagioclase or quartz grains or to form tongues and veinlets interstitial to them. No orthoclase could be identified.

The estimated mode and the chemical analysis are given for this rock in Tables III and IV (Tal2a), and they represent a large sample taken across an exposure 1,500 feet wide north of Vadito. The rock is porphyritic in part. The sphene content of 0.3% listed in the mode is believed to be a conservative figure for the entire easterly occurrence of this sphene-bearing biotite granite; some masses of the rock contain as much as 4% of sphene. The biotite granite near Cañoncito (Ta15 in Tables III and IV) is similar in every respect to the easterly granite or quartz-monzonite type already described, except that sphene is absent.

Xenoliths are present throughout most of the outcrops of this rock in the area several miles east of the Harding mine; they were not observed in the Cañoncito occurrence or in those of biotite granite occurring east of Picuris canyon. These xenoliths generally are ovoid or disc-like bodies, but the shape of some is highly angular and irregular; the flattened ones are roughly parallel to regional foliation. The usual size

TABLE III. ESTIMATED MODES OF PLUTONIC ROCKS AND XENOLITHS

					EMBUDO GRANITE									
					BIOTITE GRANITE				FOLIATED GRANITE			LEUCOGRANITE		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
			820	819	2122	Ta12a	Ta8	Ta15	2350	Ta16	4-G	316a	393	315a
Phenocrysts														
Microcline											10			
Oligoclase-andesine			5	5										
Labradorite	5													
Porphyroblasts														
Hornblende	20													
Groundmass														
Quartz	20	5	21	22	31	27	33	30	26	33	32	40	50	35
Microcline			8	17	26	35	20	27	32	28	23	26	23	33
Albite-oligoclase					32	29	31	33	29	30	26	31	26	31
Oligoclase-andesine		45	28	17										
Bytownite	41													
Biotite		21	35	35	10	8	10	8	6	3	2	3	.1	tr
Muscovite			tr	tr	tr	tr	tr	tr	6	2	3	tr	tr	tr
Hornblende		22		1										
Garnet														.1
Epidote			2	2	tr	tr	tr	2	tr	2	2	tr		
Chlorite								tr	tr	tr	tr			
Sericite					tr	tr	tr	tr	1	2	2	tr	tr	tr
Magnetite }	14		tr	tr	tr	tr	2	tr	tr	tr	tr			
Ilmenite }														
Sphene		3	.3	.3	.3	.3	4	tr		tr	tr		tr	
Apatite		4	.3	.3	tr	tr	tr	tr		tr	tr			
Zircon			tr	tr	tr	tr	tr	tr		tr	tr			
Allanite					tr	tr				tr	tr			
Pyrite						tr				tr	tr			

TABLE III. ESTIMATED MODES OF PLUTONIC ROCKS AND XENOLITHS

Grain size in mm.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Phenocrysts	.5-2										5-20			
Porphyroblasts	1-20	.5-1	.5-1	.5										
Groundmass	.1-.5	.05-2	.1-.5	.1	.1-10	.1-10	.1-10	.1-10	.1-5	.1-5	.02-5	.5-10	.5-10	.1-2
Texture 1	G	Gt	Gr	Gr	Gr-Pg			Gr-Pg	Gr-F	Gr-F-P	Gr-F-P	Gr-Pg	Gr-Pg	Gr-A

1. Bytownite-hornblende meta-intrusive 2 miles north of Vadito
2. Quartz-diorite, 3 miles south of Talpa
3. Meta-dacite xenolith, 10′x10′, in Embudo granite 1½ miles east of the Harding mine
4. Meta-dacite xenolith, 6″x6″, in Embudo granite 1½ miles east of the Harding mine
5. Biotite granite 1½ miles north of Vadito
6. Biotite granite 1½ miles north of Vadito (average of 5 sections; sample partly porphyritic)
7. Biotite granite near contact with amphibolites 1½ miles east of the Harding mine
8. Biotite granite ½ mile east of Cañoncito
9. Foliated granite 1½ miles south of the Harding mine
10. Foliated granite ¾ mile southeast of the Harding mine
11. Foliated porphyritic granite ¾ mile west of the Harding mine
12. Leucogranite ¾ mile east of White caves
13. Leucogranite 3 miles south of Talpa
14. Leucogranite 4 miles south of Talpa

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1 G—granoblastic; Gt—granitoid; Gr—granulitic; Pg—pegmatitic; F—foliated; P—porphyritic; A—aplitic

range is from 2 to 10 cm., but some xenoliths are as much as 10 or even 20 feet across. The color is typically a light gray to dark gray, but xenoliths can be observed in all stages of fading almost indistinguishably into the surrounding granitic groundmass. The outer surfaces generally are fairly smooth, and outer parts of some xenoliths can be broken out of the granite quite cleanly.

TABLE IV. CHEMICAL ANALYSES OF EMBUDO GRANITE
(See Table III **for modal estimates)**

		1 Tal2a	**2** Ta15	**3** Tal6	**4** 316
Si02		71.11	72.06	73.70	*76.21)*
TiO,		.41	**.55**	**.29**	**.06**
Al,O,		14.14	14.16	14.42	14.01
Fe,O,		1.23	1.48	1.73	.47
FeO		1.28	1.27	.42	.16
MnO		.05	.09	.13	
MgO		.89	.37	.29	.06
CaO		1.63	1.76	1.30	1.12
Na,O		2.89	3.40	3.22	4.66
K,O		5.12	3.44	3.52	2.65
H,O		.77	.88	.67	.56
CO,			.09		
P2O5		.15	.06	.14	
ZrO,		.01			
S		.01	.03		
BaO		.07	.08	.07	
		99.76	99.72	99.90	99.95

1. Typical biotite granite 11/2 miles north of Vadito. (Composite sample, porphyritic in part). L. C. Peck, analyst.
2. Biotite granite ½ mile east of Cañoncito. F. A. Gonyer, analyst.
3. Light-colored foliated granite 3/4 mile southeast of the Harding mine. F. A. Gonyer, analyst.
4. Composite sample of leucogranite (316a, 393, 315a) from west and east ridges of Arroyo Miranda. F. A. Gonyer, analyst.

When broken open, the typical xenolith reveals an interior mass that is medium-grained, gray-black, and has a pepper-and-salt texture formed by black flakes of biotite with light gray plagioclase specks between. A few scattered patchy phenocrysts of white plagioclase 1 mm. in size also are present. Some xenoliths show still larger plagioclase phenocrysts, and much coarse altered hornblende; others rarely reveal traces of gneissic banding not parallel to the regional foliation. Several large masses of pale gray color and blocky shape, many tens of feet in size, were observed in the granite south of the Rio Pueblo, Such blocks may be roof pendants dislodged from overlying masses of older rock.

A thin section from a typical xenolith 10 by 10 feet in size shows a fine-grained hypidiomorphic-equigranular texture in the ground- mass, with grains 0.1 to 0.2 mm. in size. Sharp flakes of biotite, of similar size and with a dark olive-green tinge, are thickly scattered through this groundmass and have an orientation roughly parallel to the regional foliation. Numerous angular and highly irregular grains of quartz are intergrown with clear, clean-cut grains of oligoclase-andesine (Ab_{80}-Ab_{70}) of still greater abundance. The few larger plagioclase phenocrysts are of similar composition. Some interstitial grains of clear microcline also are present. Some large fragments of sphene appear to have been broken from large crystals, and abundant small granules of sphene occur in close association with the biotite flakes; these sphene granules show bare traces of brownish color. Epidote is also abundant as large broken grains and small granules. Tiny grains of zircon are rare, but small prisms of clear apatite are abundant.

A thin section from an adjacent xenolith of similar lithology, but only of 10 cm. size, reveals a much smaller grain size. Sphene and epidote occur as tiny granules, and flakes of biotite, 0.1 mm. in size, are strung out in parallel orientation. Microcline grains are larger, and make up from 10% to 15% of the rock. Many of the larger plagioclase and quartz grains have been fractured. Some coarse hornblende prisms of pale bluish color also are associated with a few clusters of coarse biotite. The modes of these two xenoliths are given in Table III, Nos. 3 and 4. The xenoliths are believed to represent a granulated, pre-assimilation metamorphosed rock of dacitic or quartz-dioritic type.

Gneissic Granite

Distribution. The gneissic granite includes all of the granitic rock south, west, and northwest of the Harding mine, except for the biotite granite half a mile east of Cañoncito. Much of the southerly rock is a metamorphosed and deformed biotite granite essentially similar to the type already described, but it shows a lighter color and sphene is conspicuously absent. Due west and northwest of the mine, however, the rock is distinctive for its porphyritic texture and even lighter color.

Lithology. The less metamorphosed granite of this type shows a coarsely-granitoid, gray-white to pinkish-white, bleached-appearing groundmass in which parallel-streaky patches of brownish-black or grayish mica impart a crude gneissic structure or foliation. The more metamorphosed types are finer-grained and strongly gneissic. The porphyritic granite of this type is studded with abundant microcline phenocrysts of 0.5 cm average size and square-stubby to rounded- rectangular shape. They generally constitute 10% to 20% of the rock. They are mainly of random orientation, although to a minor degree the long axes tend towards a rough parallelism with the micaceous foliation

In thin sections, the coarser non-porphyritic rock exhibits granoblastic textures and much granulation, with large plagioclase masses partly broken up into a coarse patchwork of frayed oligoclase grains, 0.05 to O.1 mm. in size, through which are scattered large, poikilitic porphyroblasts of muscovite, abundant tiny shreds of sericite, and small corroded prisms of epidote. Some remnants of large phenocrysts of twinned plagioclase show an oligoclase-andesine composition. Traces of myrmekitic oligoclase occur near the edges of these patchworks. The surrounding quartz grains have been broken down from a larger size to jagged masses showing mortar structure. Some large grains of microcline are bent and broken apart, but smaller grains which are mainly interstitial to the fragmental quartz grains, are fresh and undeformed. Clusters of large biotite flakes and coarse fragmental crystals of magnetite and epidote are partly disrupted and strung out in streaks. Small grains of sphene and zircon are scarce, and clusters of intergrown allanite and epidote are very rare constituents.

The more highly metamorphosed types of granite show extreme granulation, and may be very gneissic with a spotty foliation caused by streaked-out patches of biotite or muscovite. They are largely fine-grained granoblastic rocks, in which the grain size has been reduced to about one-fourth of that in the metamorphosed granite types already described. The oligoclase patchworks have been reduced here to finely-crenulated laceworks. Small, clean-cut muscovite plates, 0.1 mm. long, form a densely-studded network through these laceworks, and abundant small prisms of epidote with corroded edges and dark inclusions of iron-oxide also are associated.

Biotite occurs in these strongly metamorphosed granite types as streaky masses that contain large plates near their centers and are marked towards their ends by a wispy stringing-out of small flakes. This biotite is partly bleached and stained with limonite, and is associated with large, fresh plates of muscovite. Rare granules of sphene and leucoxene are present also, as are abundant granular masses of epidote and broken fragments of coarse magnetite crystals. Allanite crystals, 0.5 to 1 mm. in size, are sparsely intergrown with epidote around their edges and are stained dark in their interiors.

A few large, slabby rock masses, several feet in maximum length, are included in the strongly metamorphosed granite west of the Harding mine, and probably represent metasedimentary xenoliths of phyllitic type. Thin sections of these xenoliths exhibit continuous bands of coarse muscovite plates alternating with bands of metamorphosed granitic material; the muscovite comprises nearly 50% of the rock. Much of the granite west of the Harding mine is porphyritic, and contains the usual abundant phenocrysts of microcline. The phenocrysts are much deformed, are rounded and very irregular in shape, and many of them fade almost indistinguishably into the light-colored groundmass

Leucogranite

Distribution. A third distinctive granitic rock type is a leucogranite that underlies both ridges bordering Arroyo Miranda at the eastern end of the range and also forms much of the granite of the interior highland east of Picuris canyon.

Lithology. The leucogranite is whitish to flesh-pink, and is distinguished by its low content of dark minerals, which average less than 1% of the rock. Krieger (1932, p. 357) has described a similar leucogranite that is associated with amphibolite at the Pecos mine, 30 miles south of the Picuris range. The general appearance of this rock is similar to that of some meta-rhyolites already described, except that its grain size is very large. An abundance of microcline is the cause of the flesh-pink color. Weathered surfaces commonly show a grayish spotted effect caused by rounded quartz grains, 0.5 cm. in size, that are scattered evenly through the feldspathic matrix; local deformation in the leucogranite east of Picuris canyon has elongated these quartz grains and given the rock a coarsely gneissic appearance. Much of the Miranda leucogranite also shows some deformation.

The average Miranda leucogranite is a coarse-grained, hypidiomorphic-granular rock averaging 2 to 3 mm, in grain size; much of it is pegmatitic. Quartz is abundant as anhedral grains of various sizes. Large subhedral grains of albite-oligoclase and oligoclase (Ab_{90}-Ab_{75}) generally slightly outnumber the associated microcline grains; all the feldspar masses show very slight sericitization. Some of the larger plagioclase grains are partly fragmented, as are many of the larger quartz grains. A thin fringe of oligoclase of a more sodic composition surrounds many of the plagioclase grains, and abundant myrmekitic growths occur in association with adjacent microcline. Much plagioclase shows some signs of intergrowth with, or replacement by, microcline, which commonly forms included, parallel-orientated, lenticular blebs or wedge-shaped streaks occurring in antiperthitic intergrowths.

Some large grains of microcline are comparable in size to the coarser quartz and oligoclase, and may be slightly perthitic. Most of the microcline includes irregular patches and streaks of kaolinized oligoclase and much of the coarser material shows slight granulation. Many of the small microcline grains occupy interstices between grains of quartz. Associated minerals are mainly a few coarse flakes of bleached biotite, which are in part streaked out between fractured grains of quartz and feldspar, limonitic masses derived from the alteration of the biotite, broken pieces of large epidote prisms, rare plates of muscovite associated with altered biotite, and a few small scattered zircon crystals. An aplitic leucogranite also is present, and is similar in all respects to the rock described, except for smaller grain size, more abundant microcline, and a sprinkling of tiny, pale red garnet crystals.

Southwest of Picuris peak, occurrences of this leucogranite (strictly a leucomonzonite) commonly show a metamorphosed and deformed pegmatitic rock in which patches of feldspar and quartz have been strung out into lenticular shapes.

Age. The Embudo granite has invaded all rocks of the Ortega and Vadito formations, and thus is of more recent age. Pegmatites of the Picuris range are genetically related to the Embudo granite, as shown by field relationships and by similarities in mineralogy, and hence are of an age comparable to that of the granite.

The Harding pegmatite has been dated by Ahrens (1949, p 255) at 800 million years, by means of the strontium-rubidium method of age determination. This is in part corroborated by Muench's (1938, pp 2661-2662) lead-uranium age determination of 800-900 million years for a pegmatite associated with similar pre-Cambrian rocks 30 miles southward in the Sangre de Cristo range. This dating of the Harding pegmatite places the intrusion of the genetically-related Embudo granite in late pre-Cambrian time.

DIKES AND VEINS

Pegmatites

Distribution. Pegmatites are abundant in certain parts of the area only. Plate 2 shows their general distribution, which clearly is controlled by proximity to granite. The areal relations corroborate this in the southern and eastern parts of the range, and pegmatites in the northern part, where granite is not exposed, almost invariably occur in rocks of relatively low stratigraphic position or in rocks that show strong effects of hydrothermal metamorphism.

Size. Pegmatites of the Picuris range range in size from threadlike veinlets a few inches long to large dikes several feet thick and hundreds to thousands of feet long. A thickness of more than 10 feet is very unusual. Some pegmatites 3 to 4 feet in thickness can be traced for distances of nearly a mile along the strike of bedding and regional foliation. Such pegmatites are characteristic of the south amphibolite belt east of the Harding mine. The main flat-lying mass of the Harding pegmatite (P1. 5, B), unique in size for the Picuris range, is many hundreds of feet in breadth, 55 feet thick on the average, and thousands of feet in down-dip extent.

Mineralogy. Pegmatites of the Picuris range are of the common coarse-grained granitic type and, with one or two exceptions, are simple[1] in mineral composition. Coarse aggregates of flesh-pink microcline and white to pale smoky quartz form 90% of most masses. Partly perthitic microcline occurs as coarser, blocky masses near the centers and locally along the sides of the thicker dikes; quartz alone, however, is likely to occupy the cores of these. Coarse books of silvery-gray to grayish-green muscovite occur near the centers and also along the borders of many pegmatites. Platy to sugary and fine-grained white albite commonly is present as a partial replacement of microcline. Thin sprinklings of tiny brownish-red spessartite crystals also are common.

Many small pegmatites of the Picuris range contain rough prisms or knobby crystals of white beryl several centimeters or larger in maximum dimension. A little of this beryl has a faint tinge of bluish or greenish color. Small platy crystals of black columbite-tantalite are sparingly present in many pegmatites also, Cleavelandite, the platy variety of albite, is a common associate of this beryl and columbite. The Harding pegmatite is characterized by immense concentrations of lithium, tantalum, and beryllium, but only one other complex pegmatite is known in the Picuris range. This occurrence is in the lower quartzite of the Ortega formation, about a mile up Fletcher canyon south of Pilar. This small pegmatite is regarded as complex because it contains fairly abundant lepidolite as coarse platy aggregates. There is evidence of a late-stage hydrothermal mineralization following prominent shear fractures in this dike. The beryl- and columbite-bearing pegmatites of the range are regarded as simple rather than complex, despite minor albitization and the presence of small amounts of columbium, tantalum, and beryllium.

Coarse black tourmaline is common in some pegmatites along the southern edge of the range. Prisms of this tourmaline are as much as 10 cm. long, but their average length is about 2 cm. Both large and small crystals of tourmaline are very abundant also in schistose rocks adjacent to pegmatites and granite. The crystals are sparsely distributed within the pegmatites, or are concentrated along their outer edges against the bounding schist. A small pegmatite apophysis, half a foot to a foot thick, transects amphibolite about a foot above the top of the Harding dike at the west end of the mine quarry, and contains many dense aggregates of fibrous tourmaline. Tourmaline is also abundant in much of the amphibolite and mica schist adjacent to the Harding pegmatite, but except for the stringer already described, no tourmaline was observed within the Harding pegmatite itself. Some late bismuth mineralization, largely represented by the mineral bismutite, and some minor late copper mineralization, largely represented by chalcocite, malachite and azurite, are present in this large pegmatite mass.

No tourmaline-bearing pegmatites were found in the northern or far-eastern parts of the range.

Pegmatites associated with the leucogranite that borders Arroyo Miranda and occurs southwest of Picuris peak are distinctive in two respects. They do not appear to contain rare-element minerals, and they are rich in magnetite where they are associated with hybrid amphibolite gneisses. This magnetite forms crude octahedra as much as 7 cm. in diameter, and some dikes contain as much as 5% to 10% of it.

[1] The term “simple” pegmatites, as here used, refers to those pegmatites lacking an abundance of rare-element minerals, whereas “complex” pegmatites refers to those containing an abundance of such minerals.

Genetic relations of pegmatites and Embudo granite. The pegmatites of the Picuris range are believed to be genetically related to the Embudo granite because of suggestive field relations and similarities in mineralogy Abundant pegmatites are most characteristic of those terranes that lie close to masses of granite and in which well developed schistosity and foliation furnished easy paths of access (P1. 2). In the northern part of the range, where there are no granite exposures, pegmatites are largely confined to rocks of lowest stratigraphic position. The pegmatites themselves, except for those dikes associated with the leucogranite bordering Arroyo Miranda, can be interrelated by means of rare-element mineralogy; many of them in widely separated areas contain very small quantities of white caesium beryl and minute crystals of columbite. Black tourmaline is present in many pegmatites adjacent to granite contacts, and is abundant in schistose rocks close to granite; thus it suggests a connecting mineralogical link between granite and pegmatites.

Aplites

Many aplite dikes or stringers cut across the granite south and southeast of the Harding mine; they also are abundant near the mouth of Picuris canyon and along the granite ridge west of Arroyo Miranda, where granitic magma has intruded and reacted with mafic rocks. The aplites of the Picuris range are fine-grained, flesh-pink to gray-white rocks that form dikes only a few centimeters in average thickness. Thin sections show a fine-grained, equigranular-allotriomorphic mosaic of microcline and quartz.

Quartz Veins

General description. Quartz veins of varied sizes, types, and age relations are abundant in the Picuris range. Many pegmatites grade into, or are cut by, vein-like masses of quartz. The quartz masses range in size from microscopic veinlets to lenticular bodies 10 to 20 feet thick, but the length of even the larger veins rarely exceeds 100 feet. Many small veinlets in the Rinconada schists of the Ortega formation contain concentrations of coarsely-crystallized metamorphic minerals, chiefly kyanite, andalustite, sillimanite, and staurolite. Many of the quartz veins contain an abundance of black tourmaline in small or minute crystals.

Ore-bearing quartz veins. Ore-bearing quartz veins of several types are common in the range, and the areal distribution of the more important ones is roughly shown in Plate 2. The following main types of ore mineralization are represented in the range (the principal metal of each occurrence is *italicized)* : *copper,* gold, at Copper hill; *tungsten,* copper on Copper mountain; *lead,* silver, near the head of Hondo canyon; *bismuth,* above the highway 2 miles southwest of Pilar; *gold,* small amounts are present in quartz veins throughout much of the area.

Genetic relations between quartz veins and Embudo granite. The ore-bearing quartz veins, as well as most of the other quartz veins in the range, are believed to be genetically related to the Embudo granite. They are most abundant in areas close to granite exposures, or in rocks of lowest stratigraphic position. Their mineralogy is chiefly of hypothermal character, as indicated by tourmaline and ore minerals of tungsten, bismuth, copper and gold; such mineralogy ordinarily reflects a close relation to granitic rocks. Bismuth and copper minerals also are present in the Harding pegmatite Tourmaline is present in many quartz veins, ore-bearing or otherwise, and suggests a further connecting link with the granite, as already described in the case of pegmatites.

Diabase Dikes

A few scattered outcrops of diabase dikes lie east and west of the strip of Picuris tuft that crosses the range from Pilar to Vadito. These dikes generally can he traced along a general N. 50°W. trend for hundreds of feet only, but some dikes that outcrop west of Agua Caliente canyon may be continuous for several thousand feet, even though partly hidden beneath recent talus on the tops of ridges. Some dikes definitely pinch out abruptly after short exposures, and reappear beyond barren intervals of hundreds of feet. On the geologic map, therefore, these dikes are shown as scattered, isolated outcrops.

Most of the dikes are 50 to 75 feet thick. Their attitude is vertical or nearly so. One small outcrop far up Agua Caliente canyon shows a dip of 75°NE., and the dike that outcrops southwest of Picuris peak dips 88°NE. A characteristic reddish-brown color, caused by weathering, and small gaps in the tops of ridges where more resistant rocks surround the diabase, are aids in locating outcrops of these dikes in the field.

The rock has the typical appearance of a diabase; it is coarse-grained and dark olive-green to brownish-black in color, exhibits closely-spaced, square-set, blocky jointing, and breaks down rapidly on weathering to cobble-sized nodular masses. A few outcrops are marked by shearing effects, strong hydrothermal alteration, and brownish staining by iron oxides, but much of the diabase looks rather fresh. A finer-grained rock commonly forms the outer parts of the dikes, whereas a much coarser grain size characterizes the central parts, where ophitic textures are megascopically evident. A few joints in the diabase are filled with calcite.

Thin sections of the coarser-grained diabase reveal the usual ophitic texture, with crisscrossing narrow laths of plagioclase 1 to 2 mm. long, and interstitial patches and coarse rounded grains of augite. The coarsest material consists of plagioclase laths 1 cm. long and pyroxene grains several millimeters across. The large laths are labradorite (An_{52}), and the smaller ones range from such labradorite to andesine (An_{38}). Even the fresh-looking diabase shows some saussuritization of the plagiociase, and the sheared rock shows stronger saussuritization and granulation of feldspar laths, as well, In this sheared rock, the usually fresh, rounded grains of augite show frayed edges, are broken apart, are rimmed with limonite and iron-oxide granules, and are partly altered to thick-prismatic, pale green uralitic hornblende that is much chloritized. Coarse crystals and plates of magnetite and ilmenite, partly of skeletal form, make up 5% to 10% of the rock. Small apatite prisms are widespread. Small interstitial patches of micropegmatite also are present, and comprise clear quartz surrounding skeletal shapes of much-kaolinized albite. Small flakes of frayed and chloritized biotite are rarely associated with large, partly-altered grains of the iron ores.

Paleozoic and Cenozoic Rocks

INTRODUCTION

A lithologic study of the pre-Cambrian rocks of the Picuris range forms the major part of this report, but a brief lithologic description of the Paleozoic and Cenozoic rocks of the range is given below. Without such a description the border faults of the range, involving the pre-Cambrian and the Paleozoic and Cenozoic rocks, could not be discussed adequately in the section on structure.

PENNSYLVANIAN ROCKS

Folded but relatively unmetamorphosed Pennsylvanian sedimentary beds of the Magdalena group overlap the pre-Cambrian crystalline rocks unconformably or are faulted against these rocks along the far-eastern boundary of the Picuris range. The Paleozoic beds also occupy the area around U. S. hill, at the southeastern corner of the range, and extend northward from there as far as the pass between Alamo and Telephone canyons, just east of Picuris peak. These Pennsylvanian rocks have been described in detail by Young (1945, pp. 28-40) in their occurrence near the mouth of the Rio Grande del Rancho canyon. He assigned them to the Cortado formation, which belongs in the Des Moines series (Young, 1945, pp. 23-25)

The beds consist mainly of arkose, quartzite, conglomerate, shale, and limestone. A thin bed of fine-grained resistant quartzite, 15 to 25 feet thick, occurs along the pre-Cambrian-Pennsylvanian contact that follows the ridge bordering the Rio Grande del Rancho canyon on the west. Directly above the quartzite and stratigraphically higher is a distinctive bed, 50 to 100 feet thick, of grayish, fine-grained, non-fossiliferous limestone, certain layers of which are rich in chert nodules up to fist size. Above this limestone are several hundred feet of rusty, coarse-grained quartzite, arkose, and arkosic conglomerate, together with some thin beds of black shale or argillite. Still higher in the stratigraphy are beds of dark gray limestone and limy shale, 100 feet thick, that contain abundant marine fossils, and above these are thick beds of arkose, quartzite and blocky, olive-green argillite.

The Pennsylvanian rocks around U. S. hill and to the north comprise hundreds of feet of very coarse quartz conglomerate, quartzite, and arkose, In the field it is very difficult to distinguish some of these rocks from the underlying pre-Cambrian quartzite, and it is almost impossible to determine bedding in them. Much of the material present in the coarse quartz conglomerate and arkose appears to have been derived from the underlying pre-Cambrian quartzite and granite. The fine-grained quartzite bed and the non-fossiliferous limestone, found along the pre-Cambrian-Pennsylvanian contact above Rio Grande del Rancho canyon, were not observed in the U. S. hill area, where there are some beds of fossiliferous limestone and limy shale that are identifiable with the distinctive strata above the quartzite and chert-bearing limestone of the Rio Grande del Rancho canyon.

TERTIARY AND QUATERNARY ROCKS

PICURIS TUFF

Downfaulted blocks of tilted Tertiary beds of coarse conglomerate and water-laid volcanic tuft, the Picuris tuft1 of probable Miocene age, form a nearly continuous border along the northeast and southeast to south-central edges of the range. Most of the broad valley of Arroyo Miranda is occupied by a downfaulted block of similar material, and the same beds occur also in scattered outcrops along Rio Grande del Rancho canyon at the far eastern end of the range. A strip of coarse conglomerate, half a mile wide and believed to be a part of the Picuris tuft, extends southeastward across the range from Agua Caliente canyon to a point half a mile north of Vadito.

The Arroyo Miranda exposures supply the most complete stratigraphic data for the Picuris tuft. A basal conglomerate contains coarse fragments that are largely pre-Cambrian sillimanite-bearing quartzite and Pennsylvanian rocks, and above this are some thin layers of brick-red, yellow, olive-green, or white clay. Above the clay layers are thick boulder beds with a clayey or tuftaceous matrix, and overlying beds of coarse, hard, pinkish volcanic breccia that is associated with soft, white volcanic ash, thin beds of shale and compact marl, and also with some thin, highly altered basalt flows. Higher in the sequence are thick strata of gray-white water-laid tuft interbedded with coarse and fine gravels and some very coarse boulder beds. Towards the top of the sequence the pebbles, cobbles, and boulders of these strata consist largely of volcanic rocks, whereas near the base of the formation they consist largely, if not wholly, of pre-Cambrian rocks or of a mixture of pre-Cambrian and Pennsylvanian rocks.

Many of the fragments of pre-Cambrian rocks higher in the stratigraphy can be correlated with various pre-Cambrian rocks of the Picuris range. Boulders of giant dimensions, measuring as much as 10 by 20 feet in size, occur in some of the lower boulder beds of the formation, and are especially characteristic of the strip of coarse conglomerate crossing the range between the mouth of Agua Caliente canyon and Vadito. Near the summit of several small hills adjacent to Vadito and the Picuris pueblo are beds of pinkish sand and silt interbedded with Picuris tuft beds of fine white ash and coarse, grayish tuft that contains thin layers of gravel; the pinkish material because of color and sandy character, is believed to be a part of the Santa Fe formation here interbedded with the predominantly volcanic material of the Picuris tuft. Many of the tuft and boulder beds of the Picuris tuft contain a calcareous cement, and calcite is also abundant as fracture fillings Maximum thickness of the Picuris tuft is estimated to be from 1,250 to 1,750 feet.

1, The Picuris tuff, named by Cabot (1938, p. 91), is believed to be the equivalent of the Abiquiu tuff (Smith, 1935, pp. 32-50) and of part of the Los Pinos formation (Butler, 1946, pp. 45-92).

SANTA FE FORMATION

Tilted alluvial beds of the late Miocene or early Pliocene Santa Fe formation (Denny, 1940) border much of the western half of the range. This unit can be recognized in the area of the Picuris range by its usual pale pink to buff color and its extremely fine sandy or clayey texture Thin layers of gravel are present to a minor degree, and in some of these layers are many pebbles of volcanic material. Along the southeastern border of the Picuris range, Santa Fe beds conformably overlie Picuris tuft beds, and apparently there is much interfingering of the two formations. The predominant sandy material of the Santa Fe formation has been derived from a mountainous area to the east and south, whereas the predominant volcanic material of the Picuris tuft has been derived from volcanic centers to the north. Total thickness of the Santa Fe formation in the area adjacent to the Picuris range is unknown, but a thickness of several thousand feet is certain to exist.

SERVILLETA FORMATION

Unconformably overlying both Picuris and Santa Fe beds north of the northeasterly and north-central borders of the range are nearly horizontal alluvial beds with prominent interlayered flows of basalt of the late Pliocene or earliest Pleistocene Servilleta formation (Butler, 1946, p. 133). Gravels and basalt flows of this formation also are downfaulted against Santa Fe beds north of the northeast border of the range and near Pilar; near Rinconada and Embudo thick beds of buff-colored sand and clay of the Servilleta formation are faulted against Santa Fe beds. An isolated patch of nearly horizontal basalt, interlayered with sand and gravel, unconformably overlies the Picuris tuft north of Vadito and the village of Rio Pueblo, and almost certainly represents the Servilleta formation.

The flows of basalt in this formation adjacent to the Picuris range are typically about 50 feet thick. Only one such flow is evident northeast of Pilar in exposures of Servilleta beds closest to the range, but several such flows are exposed along the gorge of the Rio Grande slightly to the north. Gravels of the Servilleta formation are distinguished by abundant layers of micaceous sand and by much limonite. In the area north of the Picuris range a thickness of at least 1,500 feet of these beds is present along the Rio Grande and near Embudo,

GRAVEL DEPOSITS OF UNCERTAIN AGE

Several small deposits of partly consolidated gravel occur within the range. They rest upon pre-Cambrian rocks, and are of uncertain correlation.

Structure

INTRODUCTION

Bedded pre-Cambrian rocks of the Picuris range in general show an east-west strike and steep southward dips. Such an apparently homoclinal structure is due to isoclinal folding. Great pressure along a north-south direction has produced a system of tightly compressed east-west trending folds, the axial planes and limbs of which are essentially parallel, are overturned slightly to the north, and dip southward at an average inclination of 60° to 70°. Two major anticlines and two major synclines are exposed, with wave lengths of 1 to 2 miles; in the vicinity of the main ridge fold axes bend around sharply almost due southward, Folds are doubly plunging, and angles of plunge, on the average 20° to 30°, change direction both along the strike and across the strike. Very numerous small folds, several hundred feet in average wave length, are associated with the major folds, but are rarely well exposed. Their axial plunges conform to those of the larger folds, and the axial planes of both are parallel. The small-scale folding, much like the bellows of an accordion, has served to spread out fairly thin beds over a wide horizontal expanse, giving a false impression of great thicknesses for the rocks of the Picuris range

A major unconformity, or a great fault, exists between the Ortega and Vadito formations. Evidence favors an unconformity because of the stratigraphic relations, whereby conglomerate of the Vadito formation lies close above and stratigraphically higher than much of the contact between the formations, but farther east an increasing thickness of felsites and amphibolites separates the conglomerate from the contact and confuses the relations. Abundant quartz veins and some transverse faults further obscure the contact between the two formations. The later folding imposed upon such a contact, whether unconformity or fault, makes it almost impossible to determine its true nature.

Faults are of two generations, those associated either with Laramide or late pre-Cambrian orogenies and those of Tertiary or later age which largely represent the normal border faults of the range.

That part of the Embudo granite bordering the range on the south bears clear-cut intrusive relations with the associated bedded rocks, but the granite also exhibits some metamorphism and deformation and has a foliation parallel to regional foliation. This granite is believed to have been injected during the later stages of the main orogeny affecting these rocks, so that it is a syntectonic body. Its intrusion has been partly accomplished by assimilation and replacement of the invaded rocks, but much evidence points to forceful injection. The granite at the far-eastern end of the range, bordering Arroyo Miranda, owes its present position to faulting, and its origin and manner of emplacement remain obscure. Regional foliation is largely lacking in this granite.

Evidence suggests that a main, late pre-Cambrian orogeny affected the rocks of the Picuris range over a long period of time and along the same north-south direction of compressional stress. A sudden change to an east-west direction of stress may have occurred as a final episode of the same orogeny after the folding, or this may have occurred long afterward as a part of the Laramide orogeny. Such a change in the direction of stress is believed responsible for the abrupt change in the trend of regional structure from east-west to nearly north-south at the eastern end of the range. Such an east-west stress may have caused also the great Pilar-Vadito and Alamo canyon tear faults.

FOLDS

GENERAL STATEMENT

The four major folds will be discussed separately and treated from north to south as the following: Pilar anticline, Hondo syncline, Copper hill anticline and Harding syncline. Another major anticline may be partly exposed south of the Harding mine and the Rio Pueblo. Minor folds will be treated under a separate heading.

PILAR ANTICLINE

The Pilar anticline is exposed along the northern border of the range, both south of Pilar where its axis trends east-northeast, and also eastward from Hondo canyon where its axis trends due eastward for 5 miles as far as the west ridge of Alamo canyon, at which point the trend suddenly bends around almost due southward. These two large-scale exposures of the same anticline have been widely displaced by the Pilar-Vadito tear fault. The core of the anticline is occupied by the lower quartzite of the Ortega formation. The southern limb is occupied by the Rinconada schist; the northern is unexposed. Banding in the quartzite, presumed to be parallel to bedding, is so variable in trend as to suggest that small folds exist throughout the major anticlinal structure. The attitude of bedding, shown by thin layers of kyanite-sillimanite gneiss contained in the quartzite, shows this anticline to be overturned slightly to the north with its axial plane dipping southward at an angle of about 60°. Outcrops southeast of Pilar show that the anticlinal axis plunges about 18° to the east in that area. The anticlinal axis farther northeast plunges about 35° westward. It is clear, therefore, that this great anticline is a doubly-plunging fold.

HONDO SYNCLINE

The Hondo syncline is the best exposed major fold of the area. The Pilar-Vadito fault has widely offset the synclinal axis. Northeast of the fault the fold axis trends due west for 5 miles along Rito Cieneguilla and the head of Hondo canyon, as far as the ridge west of Alamo canyon where a sharp southward bend occurs; southwest of the fault the axis trends west-southwest for another 5 miles. The core of the syncline is occupied by the Pilar phyllite, with the Rinconada schist occurring on both limbs. Exposures northeast of the fault show two wide belts of Pilar phyllite; the syncline there is a syncline double at its base with Rinconada schist at the center. Exposures southwest of the fault show a single wide belt of Pilar phyllite, tapering, however, to a band only 200 feet wide at the western end. A small outcrop of Rinconada schist occurs near the central part of this single belt near its east end; this may define the start of the same double syncline that lies east of the Pilar-Vadito fault. The single western belt of Pilar phyllite may represent an exposure of the syncline at a higher level than that of the double fold farther east. The eastward plunge of the western segment of this syncline accounts for a greater erosion of the belt of Pilar phyllite there and its westward-tapering effect. Slaty cleavage throughout the Pilar phyllite is inclined at an average angle of about 60° to 70° to the south, and this is believed to represent the dip of the axial plane of the Hondo syncline. Axial planes of small folds in the Rinconada schist, just south of the tapering end of the western belt of Pilar phyllite, dip steeply southward and corroborate the 60° to 70° angle mentioned. The predominantly eastward plunge of the axis of the western fold segment is between 10° and 20°, based on observations of axial plunges of the same small folds mentioned above; the predominantly westward plunge of the western part of the eastern segment of the syncline is 30° to 40°. It is likely that axial plunges of all major folds change direction in many places along their east-west trends. Some small folds definitely change direction of axial plunge within relatively short distances, as those near the head of Piedra Lumbre canyon. Without such changes of axial plunge for major and minor folds, the thin beds occurring in these plunging folds would not persist as they do for many miles along the east-west strike, without wrapping around the noses of the major folds. The general uniformity of thickness for such thin beds as those of the Rinconada schist, shown on the geologic map for many miles along the strike, does not conform to the pattern expected for the outcrops of beds occurring in doubly-plunging minor folds; a thinning and a thickening of the beds occupying the cores of those folds would be expected. Such a discrepancy, however, may be due to the impossibility of mapping accurately the contacts of these thin beds along the strike in a region where only scattered outcrops can be found, and it is quite possible that the expected thinning and thickening of the beds really does occur. With one exception, small folds are not directly observable in the Pilar phyllite, owing mainly to its uniform lithology, but they undoubtedly exist; the exception was a chance observation of compositional banding perpendicular to slaty cleavage made during the study of a single thin section of the phyllite.

COPPER HILL ANTICLINE

The Copper hill anticline can be traced for a distance of 9 miles eastward from the area just west of Copper hill as far as Picuris peak. Its core is occupied by the lower quartzite of the Ortega formation, which first appears as a narrow strip half a mile west of Copper hill, but eastward becomes a zone 1 mile in width extending from Copper mountain to Picuris peak. The anticlinal axis trends slightly south of east around Copper hill, thence east-northeast as far as the Pilar-Vadito fault, where it is offset to the north; east of the fault it trends due east as far as Picuris peak, at which point the axis bends sharply southward. The Rinconada schist occupies both limbs of the anticline throughout most of the exposures, but half a mile west of Copper hill these younger overlying schists close in about the nose of the fold and take the place of the older, underlying quartzite, which disappears westward. A steep westward plunge of the anticlinal axis is responsible for this disappearance of the quartzite. Observations on the plunge of the axes of small folds in the Rinconada schist 1½ miles west of Copper hill give 30° to 35° for the plunge. The axial planes of these small folds strike N 85°W and dip 50° southwest. Detailed structural relations are extremely complex along Copper mountain ridge. Rinconada schists occupy the north anticlinal limb for 2 miles northeastward from Copper mountain road; farther northeastward the surface is covered by talus and there are no rock outcrops. The plunge of the anticlinal axis near Copper mountain is believed to be about 40° east-northeast as observed in a minor anticline half a mile to the north. A mile and a half east-southeast of Copper mountain, however, where the Pilar phyllite occupies the core of a small syncline, the axial plunge is reversed, and is westward. The Rinconada schist has a wide exposure north of Copper mountain on the northern flank of the anticline, but is largely absent on the southern flank. Near the tungsten mine on Copper mountain some thin bands of knobby andalusite gneiss occur in the quartzite; these bands are not in continuity along the strike and are in the form of widely separated lenticular bands. East of the Pilar-Vadito fault the axial plunge of the anticline is believed to be to the west, although the axial plunges of small folds around the head of Piedra Lumbre canyon reverse from a westward inclination near the fault to an eastern one within less than a mile east of there. The width of the east-west zone of lower quartzite increases towards Picuris peak in the area east of the Pilar-Vadito fault. The Rinconada schist has a very slight thickness on the northern anticlinal limb in this area; to the south it is missing completely, presumably because it has been cut off by outcrops of the unconformably-overlying Vadito formation.

HARDING SYNCLINE

Detailed structural relations in the Harding syncline are very obscure, The Pilar phyllite is exposed in a minor syncline of some size south of Copper hill and Copper mountain. Beds of Rinconada schist on the south limb of this syncline are followed southward by overlying beds of quartzite and coarse conglomerate at the base of the Vadito formation, occupying an east-west belt a third of a mile wide and occurring in a minor anticline. A zone of quartz-muscovite schists, half a mile to 1 mile in width, follows southward, and is believed to occupy the core of the Harding syncline. Amphibolites are interbedded with the schists and largely supersede them in the syncline east of Picuris canyon. In addition to the conglomerate on the north flank, there is an increasing thickness of interbedded felsites and amphibolites eastward from the zone of Pilar phyllite just south of Copper mountain ridge. In the area southwest of Copper mountain road the south limb of the syncline is occupied by interbedded quartz- muscovite schists and amphibolites underlain by a considerable thickness of interbedded meta-andesites and felsites, quartzite and conglomerate. East of Picuris canyon relations are obscure in the core and in the south limb of the syncline, and much granite appears in the fold. Amphibolites occupy a wide east-west belt in that area. Small folds just north of the Rio Pueblo and south of the Harding mine, showing interbedded felsites and conglomerate, have an axial plunge of about 25° to the northeast. South of the Rio Pueblo in this same area the axial plunge of some small folds is about 17° northeast. A predominantly eastward-plunging anticline seems likely in this area south of the Rio Pueblo.

MINOR FOLDS

Numerous small folds are associated with the major folds. Most of these average from 200 to 500 feet in wave length. They rarely are well exposed, but evidence for them is clear-cut wherever thin, distinctive beds are repeated across the strike, or where dark banding in quartzite, commonly parallel to bedding, is found deviating widely from the strike of regional foliation. These small folds are believed to characterize all of the folded pre-Cambrian rocks of the Picuris range. They are clearly observable only where thin, hard-and-soft layers are interbedded, as quartzite and schist. The attitudes of the axial planes of these minor folds are difficult to determine accurately, but wherever observable they dip steeply to the south, parallel to regional foliation. Their strikes in general are parallel to the axes of the associated major folds, but small local variations occur.

Highly complex small-scale folds are observable in some areas where thin, alternating, hard-and-soft beds occur in the Rinconada schist. Certain soft layers in these folds are found squeezed out of shape or pulled apart into lenticular streaks. Very small drag folds are common in such areas. The attitudes of these drag folds are not everywhere consistent with the shape and plunge of the adjacent major folds. As cross-bedding was also found to be inconsistent in determining the attitude of the beds associated with major folds of known character, it is probable that both structures apply only to the minor folds with which they are associated. It is suggested also that the drag folds may have formed by later shearing during the orogeny, perhaps related to an upward push of granitic magma, and thus they are not consistent with the earlier major folds.

POST-PALEOZOIC FOLDING

Pennsylvanian beds in the area are folded, mainly along north-south axes. Near most contacts with pre-Cambrian rocks the beds dip away very steeply, and recent faulting apparently has affected such attitudes. This obscures any interpretation of their original folded structures. Although minor folds occur in these beds, in general the folds in them are broad-scale, in contrast to the tight isoclinal folds of the pre-Cambrian rocks. Such folding of the Pennsylvanian rocks undoubtedly is related to Laramide orogeny.

FAULTS

OLDER FAULTS

General Statement

Two major faults cut across the east-west structure of the range, the Pilar-Vadito fault and the fault paralleling Alamo canyon. These are believed to be older tear faults, but very recent movement almost certainly has occurred along the Pilar-Vadito fault. A third major fault may occur along the low alluvial area bordering Copper mountain road, but no direct evidence could be found for it and there has been no observable dislocation of beds, as in the case of the Pilar-Vadito tear fault. The two great faults for which good evidence exists may have formed originally in very late pre-Cambrian time, but evidence in support of this is very indirect. They could have been associated also with Laramide deformation.

Small faults can be observed at a few places in the range; they are both transverse and longitudinal. Some of them, such as the small longitudinal fault that offsets a thin quartize bed in the Rinconada schist half a mile northwest of the Copper mountain tungsten mine, are clearly observable. Many more of these small-scale longitudinal faults probably exist where thin beds of quartzite, alternating with soft schist layers in the Rinconada schist, have been intensely deformed on the limbs of major folds. The small transverse fault south of Copper mountain ridge has displaced an amphibolite layer, as well as quartzite and conglomerate, northward on the east side of the fault for about 700 feet. This fault nearly parallels the Pilar-Vadito fault. Faulting has occurred in the conglomerate of the Vadito formation 1 mile south of Copper hill, where a coarse breccia zone, 25 feet wide and trending N. 25°E., can be followed for several hundred feet before disappearing beneath talus. The direction of movement is unknown.

Several small faults, occurring in en echelon pattern and having a general N. 20°W. trend, have displaced the granite-Pennsylvanian contact 3 miles south of Talpa. They may be either thrust or strike faults. They are of post-Pennsylvanian age, but are believed to be older than the Tertiary and post-Tertiary border faults of the range.

Pilar-Vadito Tear Fault

Evidence for the Pilar-Vadito tear fault, a major fault that crosses the range between Pilar and Vadito, is clearly shown on the geologic map because of the large-scale displacement of beds on either side of the fault zone. The strike of the fault is N. 50°W. It crosses the entire range, and therefore extends for a known distance of at least 6 miles. The mile-wide re-entrant cutting into the northern front of the range east of Pilar is probably related to it. Beds east of the fault have been moved approximately 1½ miles northwest relative to those on the west side. The displacement of Pilar phyllite is well shown, but the differences in the width and character of the outcrops of this phyllite on either side of the fault complicate the data on strategraphic throw. Rotation of one fault block relative to the other may be the cause of the differences in the pattern of outcrops on either side of the fault (there is a marked change of strike on either side), or later movement, largely uplift in the east block, may be the cause of the differences. The position of the double syncline east of the northern part of the fault may be due to recent uplift of the eastern block exposing a deeper level in a syncline that is double near its base; the small exposure of Rinconada schist in the center of the western belt of Pilar phyllite near the fault suggests the beginnings of this same double fold there. It also is possible that such a double syncline simply changes to a single fold along the strike westward, regardless of the level of exposure. But uplift of the eastern block has been effective in any case, as will be shown. The zone of copper-stained quartzite extending along the central part of Copper mountain ridge is definitely offset more than a mile to the northwest on the east side of the fault, where this zone continues along the high quartzite ridge half a mile south of the head of Piedra Lumbre canyon. Farther southeast along the fault, the displacement of beds of the Vadito formation on either side of the fault, as shown by the displacement of the belt of coarse conglomerate and quartzite, is only about half a mile. The smaller offset along this part of the fault may be due to differential rotation of the fault blocks.

The original movement along the fault is believed to have been essentially of strike-slip nature. A zone one-third to one-half mile in width along the entire fault shows deep alluvial cover characterized by giant conglomerate, believed to be a part of the Picuris tuff formation of Tertiary age. Recent erosion has reached the base of this alluvial cover scarcely at all; thus there are no exposures of the actual fault plane. Patchy outcrops of Pilar phyllite and Rinconada schist near the center of this alluvial zone, where it borders Agua Caliente canyon, indicate that solid rock underlies much of this zone. The inferred location of the fault has been placed on the geologic map along the central part of the zone.

Compression along an east-west or a north-south direction may have caused this tear fault, but there is good evidence also for recent vertical movement along it. Such normal faulting probably is related to the recent border faults of the range. Indirect evidence for this recent uplift along the fault is found in the higher-level topography throughout the whole of the eastern fault block in contrast to the western. The pronounced "step" effect rising from west to east along the summit of the range and clearly observable from the south, has already been described. The final eastern "step" shows a general summit level nearly a thousand feet higher than that of the central "step." The Pilar-Vadito fault separates these two "steps," as they represent its eastern and western fault blocks. Still more direct evidence for the relatively recent uplift of the eastern fault block is the position of the basalt flow north of the village of Rio Pueblo. This nearly horizontal flow lies at an altitude of 8,300 feet, and rests unconformably upon southerly-dipping beds of the Picuris tuff, This unconformity is similar to the one that transects tilted Santa Fe beds along the north border of the range, and represents the erosion surface upon which the Servilleta formation of latest Pliocene or early Pleistocene age was deposited Basalt flows are prominent near the base of the Servilleta beds north of the range, but these flows lie at an average altitude of only 7,000 feet. An isolated flow, 40 to 60 feet thick, is prominent just northeast of Pilar. The flow near Rio Pueblo has a similar thickness, and it seems likely that the Rio Pueblo flow bears a common relationship to the widespread erosion surface upon which the Servilleta basalts were extruded north of the range. Still more striking evidence for the recent uplift comes from a small mass of basalt that lies at an altitude of 7,600 to 7,700 feet three-quarters of a mile east of the Picuris pueblo. This basalt is on the west side of the fault, and the rock is similar in appearance to the basalt near Rio Pueblo; it seems very likely that the two occurrences represent parts of the same widespread flow. Such evidence supports the belief that the basalt near Rio Pueblo has been uplifted 600 to 700 feet in post-Servilleta time. This is evidence also for an extension of the Pilar-Vadito fault for an additional 3 miles south of the range.

Alamo Canyon Tear Fault

The Alamo canyon tear fault is a major break that trends due north along Alamo canyon for a distance of 4 miles and separates the lower quartzite of the Ortega formation on the west from leucogranite on the east. At the pass between Alamo and Telephone canyons, arkosic and quartzitic Pennsylvanian rocks occur in a narrow north-south strip, half a mile wide, that pinches out north of the pass but widens southward. The fault is believed to continue along the eastern border of these Pennsylvanian rocks towards U. S. hill, as the quartzite-leucogranite contact continues over part of the distance. This would add another 3 or 4 miles to the known length of the fault, and would suggest a change in trend from due north to about N. 35°W. A southward continuation of the fault along the east slope of Picuris ridge also is likely; here it would separate both quartzite of the Ortega formation and rocks of the Vadito formation on the west from Pennsylvanian beds on the east. The bedding is exceptionally difficult to determine in the Pennsylvanian rocks in this area, owing to their coarsely arkosic and conglomeratic nature, but several reliable observations of bedding indicate that these rocks dip either steeply away from, or into, the possible fault.

Definite evidence of the fault is found in the quartzite of the Ortega formation around the White Caves at the mouth of Alamo canyon, and everywhere near the quartzite-granite contact in this area. Much of the quartzite for 500 feet west of the contact has been ground up to a loose, fine-granular material. At the White Caves a few hundred feet west of the fault, several pits have been dug into a soft, soapy, yellowish or grayish material that is used locally as a wall-finish or plastering agent. Scaly muscovite is present in this clayey material, but pyrophyllite and kaolin seem to be the main constituents. The material is thought to represent some thin layers of kyanite-sillimanite-muscovite gneiss that were caught up in the faulting along with the surrounding quartzite. Many slickensided vertical joint surfaces here strike N. 25°W. to N. 40°W., parallel to the bedding in the adjacent quartzite; small grooves plunge about 70° northwest on these surfaces. Relations are very obscure along the quartzite-granite contact, which appears to be highly irregular. Some granite along the contact is much weathered, but it has not been ground up as has the quartzite on the west side of the fault. No calcite was found in this fault zone, although it is a common associate of Tertiary and Recent faults in this region, but much hydrothermal leaching is in evidence.

This fault is believed to be a tear fault, somewhat similar to the Pilar-Vadito fault and very likely related to it in time. If the area between the two faults is regarded as a wedge-shaped block, with its apex orientated towards the south, and if this block were squeezed northward by great east-west pressure, a reasonable explanation is at hand for the abrupt southward bending of beds along the east side of this block. Such bending, regarded as tremendous fault drag, seems a valid explanation for this remarkable structure. Only the rocks close to the Alamo canyon fault show evidences of strong dislocation or shearing. This suggests that the rocks dragged southward along the fault were deformed in a very plastic state, perhaps during the latest stages of the pre-Cambrian orogeny that so profoundly affected the rocks of the Picuris range. The southeastern branch of the Alamo canyon fault may be related to the Pilar-Vadito fault; the trends are not dissimilar. Such evidence suggests that there are two major directions of tear faulting in the Picuris range, northwest-southeast and north-south. A fault system of this type could have been caused by east-west compression. Whether such faulting occurred in very late pre-Cambrian time or in Laramide time is not known.

TERTIARY AND POST-TERTIARY FAULTS

The border faults of the range are normal faults along which the ancient crystalline rocks have been uplifted to their present high levels above the flanking Tertiary beds. Most of this normal faulting occurred between middle and latest Tertiary time. Some is even post-Tertiary, as evidenced by the tilting of the Servilleta formation north of the range (Butler, 1946, pp. 122-123) and by the post-Servilleta uplift of the eastern-highland area of the Picuris range, as already described. Other investigators have described the regional Tertiary faulting in detail (Bryan and McCann, 1937; Bryan, 1938; Butler, 1946; Cabot, 1938; Smith, 1935; Upson, 1938), and the subject will be treated very briefly here.

The border faults are best shown along the northern front of the range. Southwest of Pilar the northwestern mountain front is a steep line of cliffs that rise a thousand feet above the Rio Grande, but in its recent downcutting the river has cut into the uplifted block of crystalline rocks to form the cliffs which thus do not represent a fault-line scarp. The border fault here must lie west of the Rio Grande, as several outcrops of pre-Cambrian rocks occur on the west bank of the river. From the Pilar re-entrant northeastward to the White Caves, much of the northern mountain front rises with moderate steepness as a fault-line scarp to levels many hundreds of feet above the basalt and gravel-capped plateau surface to the north. The trend of this fault- line scarp is not straight, but shows two main directions, roughly N. 50°E. and N. 50°W. North of the mountain front in this area, the beds of the Santa Fe and Picuris formations are tilted northward 20° to 40°. Near the White Caves the Alamo canyon fault is intersected by the border fault zone, and a spur of granite projects northward for a distance of half a mile. The steep northern mountain front ends here, to be followed eastward by a broad, low-level area at the mouth of Arroyo Miranda.

The Picuris tuff in Arroyo Miranda represents a large downfaulted block that is bounded by pre-Cambrian granite on either side. The contacts show both sedimentary and fault relations. On the west side of Arroyo Miranda, near its mouth and about a mile southeast of the White Caves, beds of the Picuris tuff dip nearly vertically near a contact with pre-Cambrian granite that is clearly of depositional nature. Where the fault actually can be located just south of this area, beds of the Picuris tuff are tilted eastward at an angle of about 50°. Still farther south, these same beds dip at much lesser angles. Such relationships show that the actual fault may be present in the hard pre-Cambrian rocks beneath, even though it is not observable in the overlying softer Tertiary beds. The contact between Picuris tuff and granite along the eastern side of Arroyo Miranda is similarly a part-fault, part-sedimentary contact. The fault there passes by the hot springs at the north end of the granite ridge that borders the arroyo on the east. Southward along this granite ridge and part-way down its slope to the east the contact extends between Pennsylvanian beds and pre-Cambrian granite. This contact has been described as an unconformity by Young (1945, p. 20). Pennsylvanian beds are steeply tilted away from it at angles ranging from 50° to 65°, but in one outcrop beds were observed dipping steeply towards the contact.

Along the southern and western borders of the range beds of the Picuris tuff and Santa Fe formations dip gently away from the mountain front at angles of 10°to 20°. Most of the contacts here between the older rocks and the Tertiary beds have been traced carefully in the field and show sedimentary relationships. Some faults may exist here, but they were not observed and are not inferred on the geologic map. From Peñasco to Apodaca the contact between granite and Santa Fe beds is almost certainly a sedimentary one, but faults are likely to exist from Apodaca northeastward around the Dixon re-entrant of alluvial beds. A small patch of pre-Cambrian rocks on both sides of the Rio Pueblo between Dixon and Embudo represents an isolated fault block.

JOINTS

Joints are abundant and show a wide variability of strike throughout most pre-Cambrian rocks of the range. More than a hundred measurements of the most prominent joints observed, however, indicate three predominant sets. These strike N. 10°W. to N. 10°E. (nearly vertical), N 50°W to N 70°W. (dipping steeply NE), and N. 20°E. to N 40°E (dipping steeply SE) The approximate mean values for all three ranges of strike are N. 60°W, N-S and N. 30°E. The first of these directions is nearly parallel to the strike of the Pilar-Vadito fault; the second is parallel to the Alamo canyon fault. In some areas, as around Picuris peak, strong joints strike in many different directions. In Pennsylvanian rocks and in the granite bordering Arroyo Miranda the three main joint sets are present, but they do not appear to predominate over other strong sets that are rarely, if ever, observed in the older pre-Cambrian rocks. The isolated areas of quartzite northwest of U. S. hill show similar jointing. The granite along the southern border of the range is strongly jointed parallel to the regional foliation, and contains some joint sets parallel to the three main types first mentioned. It also is cut by some horizontal sheeting. Diabase dikes show the three main sets, but in them the N-S joints are less common than the other two types.

It is useless to speculate too freely about possible directions of compressional stress in terms of the orientation of the three main joint sets described. The northwest and northeast sets could have been formed by forces operating along either a north-south or an east-west direction. But it is of real significance that the north-south joints, together with regional foliation and cleavage, have been almost exclusively followed in some areas by ore-bearing quartz veins. This is especially well shown in the outcrops of the lower quartzite of the Ortega formation that extend from Copper hill to Picuris peak. North-south joints are prominent (P1. 5, A) wherever copper mineralization is present in the quartzite throughout this area. Many north-trending, copper-bearing quartz veins were observed at Copper hill and near Copper mountain. This ore mineralization is believed to have followed closely after granitic intrusion on the basis of evidence already presented in the discussion of quartz veins. The age of the Harding pegmatite has been estimated as 800 million years by Ahrens (1949, p 255), who used the strontium-rubidium method. This pegmatite is genetically related to the Embudo granite, which therefore has a similar age. This dating is believed to apply also to the ore mineralization, which preferentially followed the N-S joints. These joints could have formed as tension fractures on release of east-west compression and thus offered an easy path for ore solutions and late hydrothermal mineralization in general. They could have formed also as extension fractures caused by north-south compression. Small fractures cutting perpendicularly across micro-structures of east-west orientation are observable in many thin sections. The N-S joints and these small N-S fractures could well have been caused by the same forces operating in very late pre-Cambrian time.

FOLIATION

Foliation is well developed in the pre-Cambrian rocks of the Picuris range. Richly micaceous rocks, like those of the Rinconada schist member of the Ortega formation or of the schist member of the Vadito formation, are markedly schistose; this is caused by the orientation and packing of mica flakes into parallel sheets or layers. The amphibolites and felsites show a very poor foliation dependent upon the parallel orientation of aggregated blades of hornblende or of strung-out mica flakes. Some of the quartzites have a slabby cleavage, which grades into a crude foliation wherever muscovite becomes abundant enough to form thin films or layers. The Embudo granite, excluding the leucogranite at the far-eastern end of the range, shows a more or less well developed gneissic structure, mainly because plates and flaky aggregates of biotite are orientated in parallel groups or are streaked out into discontinuous trains. All of these planar structures are parallel over very broad areas, and make the rocks appear to dip steeply southward in a huge, simple homocline.

Where true bedding can be checked against foliation, the two are generally parallel, but this parallelism does not persist in the troughs or crests of some small folds. In many such positions the foliation largely disappears in favor of a crude, irreguar cleavage whose surfaces are spaced 5 to 10 mm. apart and follow around the troughs or crests of the folds. These two planar features are distinctly different, and in some specimens both types are present, and lie nearly perpendicular to each other. Rarely, the foliation is observable on the crests of small anticlines as nothing more than a finely-spaced corrugation. Also observed on the crests of certain small anticlines is a crude, widely spaced, fan-shaped jointing roughly perpendicular to the crest of the fold. In many places, dark banding in quartzite, known to be bedding, is cut by foliation, which is parallel to the axial planes of the associated small folds.

The regional foliation is not everywhere parallel to the axial planes of small folds, and it was observed following around the noses of many small folds. Moreover, in many places the regional foliation changes from its usual steep southward dip to a vertical position or to a very steep northward inclination. It was found that such changes invariably are associated with the north limbs of anticlines; in fact, they. could be used as indicators of such structures where the folding was otherwise obscured. In these cases the foliation cannot be parallel to the axial planes of the associated folds, but must be parallel to the bedding.

Whether this regional foliation is an axial-plane or a bedding foliation, or a combination of both caused by two periods of deformation, is not known. In the majority of cases it appears to be bedding foliation.

LINEATION

Linear structures are poorly developed in the rocks of the Picuris range, and they have been little studied. Where developed upon or parallel to the foliation planes they generally are of three types: 1) a parallelism or lining-up of elongate minerals, 2) corrugation or crinkling effects, and 3) a crude parallelism of long axes of the stretched pebbles and cobbles in the conglomerate of the Vadito formation.

The first two types can be observed in some specimens of phyllites and schists of the Rinconada schist member of the Ortega formation. In a few places they occur together, and appear to be parallel. The crinkling is caused by the intersection of a slip-cleavage, caused by tiny dislocations at an angle across the foliation, with the plane of foliation; such crinkling must be due to shearing effects later than the development of the foliation. The lining-up of elongate minerals, best seen as parallel trains of minute, elongate biotite flakes in the phyllites, might be due to recrystallization of the mica during the folding. Where a few measurements were made of such lineation, its trend was found to be nearly down the dip of foliation. There is no parallelism between this lineation and axial plunges of the associated major folds. Observations, however, are too scanty to have much validity.

The third type of lineation is rarely shown by a rough parallelism of the more elongated pebbles and cobbles in the conglomerate of the Vadito formation. The trend of this lineation also, in the few cases observed, is steeply down the dip.

STRETCHED PEBBLES

The stretched pebbles and cobbles of the conglomerate of the Vadito formation already have been described. Their elongation is rarely great enough, as shown by pebbles having an axial ratio of 1:2:6, to form a well-defined lineation. The longest and intermediate axes of these ellipsoidal masses lie parallel to the foliation (P1. 9, A) the shortest axis is perpendicular to this foliation. Some elongated masses show a distinctive wedge-like shape, with the apex of the wedge generally pointing down the plunge of the lineation.

Much of the flattening of the pebbles and cobbles is dependent upon the degree of their close packing in the conglomerate. It was found in many places that the effect of the pressing of one pebble or cobble against another actually could be noted in terms of the shape and the depth of imprint of the smaller body upon the larger. Thinly scattered pebbles and cobbles in this conglomerate show very little flattening. The amount of flattening of the pebbles and cobbles of average size in this conglomerate can be computed; such data allow an estimation of the degree of compression and lengthening of these rocks during the folding. The average axial ratio for these ellipsoidal bodies is about 1:2:3. As computed in terms of an original spherical shape, this gives a value for their flattening of 45%, and a value for their lengthening of 65%.

INTRUSIVE ROCKS

EMBUDO GRANITE

General Statement

Large bodies of granite are exposed along the southwestern, southern and far-eastern borders of the range, and evidence has been presented to show that these bodies are related petrologically, even though having a somewhat variable appearance from place to place. Mapping suggests also that the scattered granite outcrops along the southwestern and southern edges of the range, at least as far east as Vadito, represent one continuous granite mass; much of the deeper erosion of alluvial beds in various parts of this area has exposed underlying granite. The leucogranite at the far-eastern end of the range, although separated from the rest of the range by a fault, is duplicated in rock type by the leucogranite exposures north of Vadito.

Those parts of the range in which pegmatites are abundant are restricted largely to areas adjacent to exposed masses of granite, or to belts of rocks of low stratigraphic position that occur in anticlinal folds. Excellent examples of the latter are the exposures of the lower quartzite of the Ortega formation near Pilar, and on the west side of the mouth of Alamo canyon (P1. 2). Pegmatites are strikingly absent from rocks in the Hondo syncline; yet similar schistose rocks in the Harding syncline, which is adjacent to granite outcrops, contain many masses of pegmatite. Such relations suggest that granite closely underlies some of the rocks of lower stratigraphic position in the northern part of the range.

Manner of Emplacement

The granite shows clear-cut intrusive relations in the southern part of the range, but there also is indirect evidence for much assimilation of country rock. Reaction has occurred between granite and mafic rocks throughout the south amphibolite belt near the mouth of Picuris canyon and eastward from there along the strike, as well as throughout the narrow zone of amphibolite gneiss along the ridge east of Alamo canyon, and in the several small areas of amphibolite 3 miles south of Talpa.

Many of the felsitic and andesitic metavolcanic rocks that occur along the southern border of the range contain tiny veinlets and tongues of coarse granitic material. In some places thin, irregular, dike-like masses of coarse-grained granite a foot or more thick cut across schistose metavolcanic rocks. Large-scale intrusive relations of the granite to the adjacent bedded rocks are equally convincing. One and a half miles southwest of the Harding mine the granite transects layers of amphibolite and various metavolcanic rocks. Apophyses of granite hundreds of feet in width project far into the country rock along the Rio Pueblo south and east of the Harding mine. Nearly all exposed contacts between the granite and country rock are sharp and clean-cut, but in some places they have been modified somewhat by shearing and small-scale faulting. Forceful intrusion by granite on a major scale is suggested by the pattern of some rocks shown on the geologic map, as well as by other lines of field evidence. West of the Harding mine a great mass of granite has been intruded into schists, and appears to have wedged apart the formations to the north and south. Tremendous shearing has occurred along foliation planes in the lower quartzite of the Ortega formation over a wide area near Pilar, and much pegmatitic material has been injected into the quartzite parallel to such surfaces. The effects of strong hydrothermal mineralization are present in all the areas where a forceful intrusion of granite is believed to have occurred.

Assimilation has modified the granite to some degree in accordance with the type of country rock assimilated. Where the granite cuts across amphibolites southwest of the Harding mine, it becomes appreciably darker and more mafic, but where it cuts across quartz-muscovite schists north of there, it is much lighter-colored, more felsic, and is rich in potash feldspar. Many inclusions are present in the granite east of the Harding mine; these are believed to represent some of the metavolcanic rocks adjacent to the granite in this area, and the smaller inclusions clearly have been altered to more felsic rock by reaction with granitic magma. Reaction between granitic magma and mafic rocks is shown in many exposures, and various types of hybrid amphibolitic gneisses have been formed by such reaction in the narrow amphibolite zone east of Alamo canyon.

The best examples of reaction between granite and amphibolite are found near the mouth of Picuris canyon where porphyritic amphibolites and dike-like bodies of leucogranite and biotite-rich granite are exposed in close association for more than a thousand feet across the strike. The granite has in part invaded the amphibolites, forming lit-par-lit masses within them in some places, cutting across them in others, and engulfing them by partial assimilation in still others. A result of such assimilation is a local hornblende-rich or biotite-rich granite, in some of which streaks and wisps of hornblende are strewn about. Angular chunks of amphibolite of widely varying size and appearance are completely surrounded by granite (P1. 9, B). Some of these have been forcibly moved about; others apparently lave been quietly surrounded and engulfed without any displacement. As evidence of the latter process, some polished specimens show distinctive banding and other structures that extend without interruption from the wall-rock amphibolite across amphibolitic inclusions that are widely separated by the surrounding granite.

Relation of Time of Intrusion to Folding

The development of gneissic structure in the granite varies considerably from one area to another. East of the Harding mine, for example, the granite is weakly foliated and only slightly granulated, but in many other areas the foliation is well developed. Flow structures are poorly developed in the granite, and have not been studied carefully. Data from such a study might supply important evidence for relating the time of granite intrusion to the folding and metamorphism. Some evidence presented in the section on metamorphism, suggests that the granitic intrusion and the folding were not far apart in time. Certainly the intrusion of granite was not younger than the folding, for regional foliation is well developed in many granite exposures This foliation is parallel to the regional foliation of intruded rocks, but, in most observed occurrences, the foliation in the granite also is parallel to adjacent contacts with the intruded rocks An exception to this is the attitude of foliation in the granite mass that cuts across amphibolites southwest of the Harding mine; the foliation in this mass is almost perpendicular to the contact.

Where inclusions are present in the granite, they are lined up roughly parallel to the granite contacts and to the regional foliation. The pegmatites that are genetically related to this granite do not show any foliation, although they do exhibit some structural deformation. If the intrusion of the granite were pre-folding, the genetically related pegmatites should be marked by some foliation or gneissic streaking parallel to the regional trend of planar structure in the surrounding rocks. All such structural evidence, however indirect, suggests that the Embudo granite is related in time to the folding, and is a syntectonic intrusion.

PEGMATITES

Most pegmatites of the area have followed pathways parallel to the planes of regional foliation, and they are most abundant where this planar structure is well developed, as in schists and foliated amphibolites, and where masses of granite are near by (P1. 2). Thus the schists and amphibolites along the southwestern border of the range are especially rich in pegmatites. In the granite itself, joints were in part occupied by pegmatites. Aplites in the granite do not follow joints but cut across the rock in many different directions.

QUARTZ VEINS

Many quartz veins, especially the ore-bearing ones, the ones with segregations of certain metamorphic minerals, and tourmaline-bearing ones, follow north-south joints in the lower quartzite of the Ortega formation. Pegmatites do not ocur in such joints, which may be of post-pegmatite and pre-quartz-vein formation.

DIABASE DIKES

The diabase dikes rigidly follow a N. 50°W. trend, and have almost vertical walls. This attitude coincides with that of one of the three principal joint sets in the pre-Cambrian rocks of the range. The dikes lie parallel to the trend of the Pilar-Vadito tear fault, and are clustered along its sides; they may well have been emplaced during or shortly after a major period of movement along the fault. The joints may have been shear fractures that were left relatively open after the faulting, and later were filled with diabase, The dikes are younger than the granite, which is cut by one of them east of Picuris canyon, but the age difference between these two rock types is not known. Joints of N. 50°W. trend also occur in the Pennsylvanian rocks of the range, although they are not as abundant as in the older rocks, and hence it is not possible to date the joints or the diabase as pre-Pennsylvanian. The diabase is not much metamorphosed, but its intrusion would have followed the time of main metamorphism in any case. On the basis of currently available data, these dikes can be dated only as late pre-Cambrian or younger.

Metamorphism

INTRODUCTION

The pre-Cambrian rocks of the Picuris range have been subjected to a regional metamorphism ranging from middle-grade to high-grade, and upon this regional metamorphism has been superimposed a widespread hydrothermal metamorphism related to granitic intrusion. The granite itself has undergone some degree of dynamic metamorphism, which suggests that regional compressive forces continued to operate after the period of intrusion. Rocks of the Ortega formation show only very slight retrograde metamorphism, whereas rocks of the Vadito formation have been moderately affected. There is no reason to believe that the two major metamorphic episodes were unrelated or far apart in time; on the contrary, evidence suggests that the hydrothermal metamorphism may have followed soon after regional metamorphism or even may have been a late phase of it, The two periods of metamorphism are believed to represent related parts of the same great orogeny of late pre-Cambrian time.

The term, regional metamorphism, used above for the earlier period of metamorphism affecting the rocks of the Picuris range, implies a metamorphism regionally effective and predominantly dynamo-thermal in character. The term, hydrothermal metamorphism, as used above, implies a later metamorphism, widely effective under lessened stress, but much more localized because of primary dependence upon the agency of hydrothermal solutions and associated metasomatism.

REGIONAL METAMORPHISM

GENERAL STATEMENT

The major episode of regional metamorphism was associated with the main folding, and was in part related to depth. The stratigraphically lowest rocks of the area alone contain high-grade metamorphic minerals, Composition of the rocks evidently was an essential modifying factor, so far as resultant assemblages of metamorphic minerals are concerned, throughout those rocks of the Ortega formation that were affected by metamorphism of middle grade. Isograds can be drawn on the geologic map (P1. 2) to show three zones of progressive metamorphism; a sillimanite zone, a kyanite zone, and a staurolite zone; for the argillaceous rocks of the Ortega formation, These isograds are more or less parallel to the trends of regional structure and stratigraphy. Sillimanite is the index mineral for metamorphism of highest grade, and kyanite is usually an index mineral for upper middle-grade metamorphism. Ordinarily kyanite is not separated from staurolite, another middle-grade index mineral, but such a separation seems desirable here because some of the stratigraphically lower rocks contain kyanite but do not contain staurolite. A complicating factor in the high-grade zone is the fact that some of the sillimanite apparently is of hydrothermal origin; much of it, however, was formed under strong regional stress, and in general its occurrence can be safely used in mapping the high-grade zone.

Rocks of the Vadito formation, some of them slightly argillaceous but most of them of different composition from the rocks of the Ortega formation, are regarded as belonging in the zone of middle-grade metamorphism. Staurolite is very rare in these argillaceous rocks. The amphibolites of the Vadito formation also are believed to represent a middle-grade metamorphism. Retrograde metamorphic effects partly obscure the evidence for grade of metamorphism in the rocks of the Vadito formation.

ZONES OF PROGRESSIVE REGIONAL METAMORPHISM

Sillimanite Zone

With two exceptions, sillimanite is entirely limited to the lower parts of the quartzite member of the Ortega formation. Included in the sillimanite zone are most of the quartzite exposures along the northwest border of the range near Pilar and a small area of quartzite around Picuris peak. In general, these areas represent central parts of the Pilar and Copper hill anticlines. The exceptions are two occurrences of andalusite-biotite hornfels, one crossing Hondo canyon, and the other exposed between granite and amphibolites in a narrow zone of schist 1½ miles south of Picuris peak. In both occurrences the sillimanite is a product of hydrothermal metamorphism caused by intrusion of the Embudo granite; the mineral has developed contemporaneously in parallel intergrowth with late-formed andalusite, an anti-stress mineral (Harker, 1932, pp. 23 1-232) typical of aureoles of thermal metamorphism.

The sillimanite-kyanite occurrences in Hondo canyon have been described in detail in connection with the lithologic description of the lower quartzite member of the Ortega formation. Petrographic evidence suggests two generations of sillimanite in these occurrences, fibrous haphazardly-orientated sillimanite of later age surrounding and replacing earlier stout, parallel-orientated prisms of sillimanite that appear to have formed under stress. Some blades of kyanite also have been partly replaced by the later sillimanite. The formation of such sillimanite is believed to have been caused by the action of hydrothermal solutions upon the earlier-formed sillimanite. The two occurrences of sillimanite-andalusite intergrowths already mentioned are further examples of late-stage sillimanite. Many occurrences of sillimanite like those south of Pilar, are closely associated with tourmaline-bearing quartz veins and pegmatites.

Kyanite Zone

Kyanite also is confined to the lower quartzite of the Ortega formation, but one exception was noted in a thin bed of quartzite closely associated with an occurrence of Pilar phyllite south of Copper mountain ridge and presumed to be a part of the Rinconada schist member of the Ortega formation Otherwise, kyanite is absent from the Rinconada schist member. The kyanite isograd is drawn, therefore, chiefly along the contact between the lower quartzite of the Ortega formation and the Rinconada schist member of that formation.

In the kyanite and sillimanite gneisses crossing Hondo canyon, part of the sillimanite may have been developed by replacement of kyanite, but where coarse sillimanite prisms are intergrown with kyanite blades in parallel orientation, the two minerals probably formed simultaneously. Some suggestion of a telescoping effect in the formation of some of this kyanite may help to explain its rather unusual association with sillimanite, Under the microscope, some grains of kyanite contain dark bands that comprise minute specks of carbonaceous matter and scattered parallel-orientated muscovite plates of almost sub-microscopic size (P1. 6, B). These bands also cross adjacent quartz grains; they are not continuous across these grains, but commonly stop before reaching the grain boundaries, from which they are separated by rims of clear quartz. Further, the bands are not strictly parallel from one grain to another. It seems clear that they represent original banding in a shaly layer affected by regional metamorphism. It is noteworthy that a metamorphic mineral of as high a grade as kyanite could have preserved such banding after the structure survived metamorphic changes of lower intensity. These rocks must have been subjected suddenly to high-grade metamorphic conditions, and it is possible that the conditions appropriate for sillimanite formation were reached so quickly after kyanite began to form, that equilibrium was not reached and the formation of the two minerals overlapped to some extent.

In many places large crystals or crystal-aggregates of kyanite, staurolite, andalusite, and sillimanite are present in, or clustered about, small quartz veins. The large individuals occur only in rocks characterized by an abundance of the same minerals; thus large staurolite crystals are clustered about quartz veins only in staurolite schists. Some of the andalusite and kyanite crystals adjacent to these quartz veins reach very large sizes. Such occurrences have been ascribed to metamorphic differentiation (Read, 1933; Turner, 1948, pp. 143445). Because many of the quartz veins that show such segregations of metamorphic minerals occur along north-south joints that are younger than the main folding, and because tourmaline-bearing quartz veins and pegmatites are in part closely associated with these veins, the occurrences are presumed to be unrelated to regional metamorphism and due instead to later hydrothermal metamorphism.

Staurolite Zone

Staurolite is limited to the Rinconada schist member of the Ortega formation, except for two isolated occurrences in schists of the Vadito formation, which are described farther on in connection with hydrothermal metamorphism. The associated metamorphic minerals are biotite and garnet in porphyroblasts of small to medium size. Staurolite is not present in the Pilar phyllite, perhaps because the composition of that rock is not suitable. One bed of schist and gneiss in the Rinconada member is especially rich in coarse staurolite, the crystals of which push aside parallel-orientated flakes of muscovite and biotite (P1. 8, B). Other crystals occur in muscovite phyllite adjacent to the Pilar phyllite, but they are of different habit and are much less abundant than those in the rich bed. This suggests, by proximity alone, that the Pilar phyllite belongs in the staurolite zone, although this quartz-rich, muscovite-bearing rock has the appearance and mineralogy characteristic of a slate or phyllite of much lower metamorphic rank. Deformation has strongly affected it, but no more so than the rocks of the Rinconada schist member of the Ortega formation. It seems likely that its very simple original composition (predominantly silica and very minor alumina, potash, and iron) was not appropriate for development of the aluminum-silicate minerals that are considered typical of middle-grade metamorphism. Relics of porphyroblasts, however, may represent some original garnet and biotite

Calcareous layers, associated with muscovite phyllite in the Rinconada schist member of the Vadito formation, have been changed in part to aggregates of calcite, actinolite, phlogopite, and quartz. Some layers, like those near the mouth of Agua Caliente canyon, have remained essentially simple marbles, and consist chiefly of calcite associated with minor amounts of phlogopite, muscovite and quartz; except for recrystallization of calcite, very little change has taken place in this rock. More impure dolomitic beds, like those exposed along Rito Cieneguilla, have been changed to coarse aggregates of tremolite and diopside. Associated thin beds of granulite, largely hornblende-calcic feldspar-quartz assemblages, may have resulted from metamorphism of original calcareous grits.

The thin bed of very coarse hornblende and almandite that is exposed adjacent to the Pilar phyllite in Hondo canyon and elsewhere, may represent a highly metamorphosed calcareous-arenaceous sediment of the hornblende-granulite type already described, or may represent an original thin diabase sill. The bytownite granulite locally exposed in upper Hondo canyon may represent an original mafic dike or sill of unusual lime-rich composition; metamorphism, perhaps more intense locally, must have liberated abundant CaO to permit development of the calcic plagioclase.

THE VADITO FORMATION AND ITS POSITION IN REGIONAL METAMORPHIC ZONING

Most of the schists in the Vadito formation are highly quartzose. Richly aluminous types do not occur, although cordierite and andalusite porphyroblasts are present in some beds of schist. There is hardly a trace of staurolite in these schists, and garnet is scarce. Large, sparsely scattered porphyroblasts of biotite in some beds have been largely altered to chlorite during retrograde metamorphism. Sillimanite and kyanite are absent from all rocks of the Vadito formation, except for the single sillimanite-andalusite occurrence already mentioned, Amphibolites of the Vadito formation are characterized by hornblende of a dark blue-green color and moderately high refractive indices. It is the usual aluminous hornblende characteristic of middle-grade amphibolites (Turner, 1948, P. 90). The associated feldspar is andesine. Chlorite does not occur in these amphibolites, except to a minor degree as an alteration product. Almandite garnet occurs in certain of the amphibolite types. It would seem reasonable to assume that the amphibolites are the product of a middle-grade metamorphism, and that such a category seems appropriate for rocks of the Vadito formation in general.

The metamorphism of the bytownite granulite in the Vadito formation is difficult to explain, as a great deal of lime had to be available for development of the richly calcareous feldspar in this rock. A limy sediment would seem a more likely source of the CaO than the mafic dike or sill this rock is presumed to be, but the presence of large, bent phenocrysts of labradorite in the rock precludes such a possibility. The hornblende in this granulite was found to have weaker pleochroic colors and lower refractive indices than the hornblende typical of the amphibolites. This rock must have been originally a mafic dike or sill of unusual composition. The bytownite granulite, found locally in Hondo canyon and occurring in the Ortega formation, is rather similar, except that it contains abundant prisms of zoisite and does not contain phenocrysts of plagioclase.

HYDROTHERMAL METAMORPHISM

GENERAL STATEMENT

Pre-Cambrian rocks of the Picuris range have been strongly affected by a hydrothermal metamorphism that apparently followed closely after, or was an end stage of, the regional metamorphism already described. Such metamorphism was related to granitic intrusion, for wherever evidence of it is strongest, widespread tourmalinization and tourmaline-bearing quartz veins generally are closely associated. The process must have been one during which the rocks were grossly permeable, following release of pressure from the main folding, so that circulating solutions could move through them with maximum effectiveness. Such metamorphism probably was operative over a long period of time, during which temperatures remained high while granitic magma was being intruded into the deeper rocks. Both the pegmatites and tourmaline-bearing ore veins seem related to it; yet these were sufficiently remote from each other in time to allow an entirely different structural control, that of the north-south joints, to affect the later vein deposition. As temperatures declined after magmatic activity, retrograde metamorphism affected the minerals formed under high-temperature conditions, and some of them were altered to more stable forms under conditions of declining temperatures. Rocks of the Vadito formation show such effects to a moderate degree.

The chemical changes in these rocks during the hydrothermal metamorphism involved chiefly the addition of boron and potash. Tourmaline and microcline are abundant in many of the rocks. A widespread resilicification has occurred also in the deeper areas of the quartzite member of the Ortega formation.

HYDROTHERMAL METAMORPHISM IN THE ORTEGA FORMATION

Coarse black tourmaline is abundant throughout rocks of lower stratigraphic position in the Ortega formation. The quartzite is in part dark because of the countless inclusions of minute prisms of black tourmaline. Such tourmaline generally is found in areas where quartz veins are abundant. Under the microscope it is pale bluish to bluish-green. Most of the schists and gneisses of the Rinconada schist member of the Ortega formation contain similar minute tourmaline crystals, which generally lie parallel to the foliation, but locally lie across it in random orientation. Such crystals have more or less the same size range and the same pale bluish-green color. They commonly compose 1 % or more of the host rock. Much of this tourmaline probably was formed by replacement; some coarse blades of kyanite and prisms and fibers of sillimanite are partly replaced by bluish tourmaline in the sillimanite-kyanite rocks of Hondo canyon. Tourmaline characterizes many of the quartz veins and pegmatites, as fully described elsewhere.

Iron-oxide, in the form of hematite, is especially abundant in the rocks of lower stratigraphic position. Dark bands in the quartzite member of the Ortega formation may be composed largely of minute plates of hematite. Some ilmenite is associated with the hematite, but magnetite is generally absent. Part of the hematite was developed by replacement of magnetite; octahedral martite pseudomorphs are abundant in the thin, iron-rich, gneissic bands that occur along the contact between the quartzite member of the Ortega formation and the andalusite-biotite hornfels. Thus a change towards a higher state of oxidation of iron has occurred.

Coarse-grained sillimanite, kyanite, and staurolite occur in quartz-vein segregations in rocks that contain the same minerals in abundance. Sillimanite, especially, is present in some areas in close association with quartz veins, tourmaline-bearing quartz veins, and pegmatites, and such sillimanite is believed to be a second generation of the mineral, formed under conditions of local hydrothermal metamorphism. Almost without exception, such hydrothermal sillimanite is associated with sillimanite and kyanite that clearly were formed under conditions of regional metamorphism.

The andalusite-biotite hornfels in the Rinconada schist member of the Ortega formation supplies the most important evidence for the superimposition of a local hydrothermal metamorphism upon rocks already affected by regional metamorphism. This rock has been fully described in the section on lithology. It is similar to the overlying staurolite schist bed, and is essentially a quartz-muscovite-biotite schist or gneiss that contains porphyroblasts of garnet and staurolite. The hornfels, however, contains only a few coarse staurolite crystals, has very large unorientated biotite porphyroblasts instead of the usual small, parallel-orientated biotite crystals and is full of large masses of porphyroblastic andalusite (P1. 8, A). The andalusite contains a few prisms of sillimanite in a crystallographically-orientated intergrowth. Quartz stringers are abundant in the rock. The andalusite apparently formed last in this rock, for it contains as haphazard inclusions all the other minerals, including the coarse biotite crystals (P1. 6, C) and some clean, sharp crystals of staurolite. Suzuki (1930) has described a similar association of andalusite and staurolite, and has ascribed it to polymetamorphism, or hydrothermal metamorphism following a regional metamorphism. The same explanation seems valid for the very rare association of staurolite and andalusite in this bed. It is remarkable that much of the staurolite has remained fresh and unaltered in this rock, although in some outcrops it is altered and is surrounded by an iron-oxide stain. Staurolite may have been more abundant in this rock at first, and may have broken down because of a lowering of stress and raising of temperature to form coarse biotite and andalusite. The equation used by Billings (1937, p. 552) to explain an alteration of sillimanite to staurolite and muscovite in New Hampshire rocks can be used effectively here by substituting andalusite for sillimanite:

$$\text{sillimanite} + \text{biotite} + \text{water} \leftrightarrow \text{staurolite and muscovite}$$

The left side is stable at higher temperatures. It is not known why andalusite formed abundantly in this bed and did not form in the overlying bed of staurolite schist which has rather similar mineralogic composition. Shaly inclusions may have been present in this bed.

An addition of potash to the rocks of the Ortega formation is suggested by the local occurrence of microcline gneiss in upper Hondo canyon. Microcline porphyroblasts comprise 60% of a rock of otherwise phyllitic type; the microcline contains as inclusions relic banding composed of carbonaceous specks and minute, parallel-orientated flakes of muscovite.

HYDROTHERMAL METAMORPHISM IN THE VADITO FORMATION

Hydrothermal metamorphism has strongly affected the rocks of the Vadito formation. Tourmaline is abundant, both as coarse prisms and as minute crystals, and is especially in evidence in rocks near granite contacts. Quartz veins are very abundant; pegmatites are numerous near granite contacts.

Changes due to hydrothermal or thermal metamorphism, in contrast to the earlier regional metamorphism, are best seen in certain thin schist beds near the Harding mine, where porphyroblasts of andalusite and cordierite are locally abundant. These two minerals are typical of thermal aureoles. Some of the porphyroblasts contain relic structures characterized by folding on a minute scale, indicative of an earlier metamorphism under stress. Cordierite is absent from rocks of the Ortega formation.

An andalusite-biotite-staurolite hornfels in the Vadito formation, similar to the hornfels in the Rinconada schist member of the Ortega formation, has been described in the section on lithology. Nothing remotely like it has been found elsewhere in the Vadito formation, and only one other minor occurrence of staurolite in the schists of the Vadito formation was observed. Such a similarity between certain beds of both formations is undoubtedly due to identical metamorphism of beds of analogous composition. As granite lies adjacent to the occurrence in the Vadito formation, and as some of the hornfels is penetrated by dikes of aplite, thermal metamorphism of special intensity may have been locally effective.

Such occurrences in rocks of the Vadito formation, of several metamorphic assemblages that are similar to assemblages typical of the Ortega formation, raise a question, as to whether schists of the Vadito formation might be identical with schists of the Rinconada schist member of the Ortega formation. Just (1937, p. 22) believed they were in part the same. If they were indeed identical, their entirely different mineralogic compositions necessarily would be due to the effects of hydrothermal metamorphism operating with such intensity upon earlier regionally-metamorphosed rocks of the Vadito formation that nearly all signs of such stress minerals as staurolite and garnet were completely destroyed. Because hydrothermal metamorphism also has strongly affected rocks of the Ortega formation, as shown by the andalusite-biotite hornfels, it cannot very well be designated as a special agent for transforming regionally-metamorphosed rocks of the Vadito formation into their present form, while leaving somewhat similar argillaceous rocks of the Ortega formation virtually unchanged and hence characterized by a wholly different mineralogy. It seems more reasonable to assume that in a few special instances, somewhat similar argillaceous rocks in two different formations have been metamorphosed in identical fashion, whereas most of the other schists of the Vadito formation are sufficiently different in original composition from schists of the Ortega formation to yield wholly unlike metamorphic assemblages. The presence of cordierite in argillaceous rocks of the Vadito formation, and its apparent absence from argillaceous rocks of the Ortega formation, is a case in point.

The amphibolites show various degrees of hydrothermal metamorphism. It is likely that all amphibolite types, despite original differences, were changed by earlier regional metamorphism to a common general mineral composition of dominant hornblende and andesine. Even those porphyritic types that appear almost fresh and that have retained clean-cut diabasic textures, show this same mineral assemblage. Only one rock was found in which any original pyroxene remains. In contrast, some types show drastic changes related to hydrothermal metamorphism, whereas others show little or no changes of this sort. Amphibolites that are foliated or banded, or show signs of shearing or deformation, contain abundant biotite flakes of reddish-brown color and patchy appearance, as well as coarse, knobby aggregates of ilmenite and sphene. Epidote also is locally abundant, especially in fine-grained amphibolites in the Harding mine area. Quartz is locally abundant in porphyritic amphibolites that are enveloped by granitic rocks at the mouth of Hondo canyon and eastward from there. This quartz may have been derived largely from an original quartz- diabase rock, but some of it appears to be due to injection or replacement by granitic material. In this area andesine in the amphibolites is partly replaced by patchy oligoclase.

RETROGRADE METAMORPHISM

Retrograde metamorphism has affected the rocks of the Ortega formation only slightly. Replacement of sillimanite and kyanite by coarse muscovite is perhaps the most striking change to be observed. The schists of the Rinconada schist member have been little affected, but the Pilar phyllite shows complete destruction of its original porphyroblasts to aggregates of iron-oxide.

Retrograde effects are somewhat more evident in the rocks of the Vadito formation. Most of these occur in sheared and deformed rocks, as in the strongly foliated amphibolites. The plagioclase has been much saussuritized, and late-stage calcite is locally abundant. Such processes, however, have not been sufficiently effective in the amphibolites to produce chlorite in appreciable quantity. On the other hand, large biotite crystals in some schists near the Harding mine have been largely altered to chlorite, and associated andalusite and cordierite porphyroblasts have been partly replaced by aggregates of sericite and sericite-chlorite (P1. 8, C). Abundant epidote in some of the amphibolites may be the result of retrograde metamorphism.

The more foliated Embudo granite shows strong effects of hydrothermal and retrograde metamorphism. Epidote, tourmaline, and pyrite are present, and a great deal of sericitization of the plagioclase has occurred. The biotite has been streaked out and altered to iron oxide; much new muscovite in coarse flakes has been formed from alteration of plagioclase and biotite. Some chlorite is present locally.

Geologic History

PRE-CAMBRIAN

Far back in pre-Cambrian time the area now occupied by the Picuris range was a region of shallow to moderately deep seas, in which the sediments that now compose the Ortega formation were laid down. Several thousand feet of nearly pure quartz sand were deposited first, followed by hundreds of feet of quartz sand mixed with argillaceous impurities, then again several hundred feet of fairly pure quartz sand. With deepening of the seas, the type of sediments changed, and several hundred feet of arenacous mud were deposited. A few thin layers of calcareous mud also were laid down in the upper part of the section of arenaceous mud. The sedimentation closed with deposition of several thousand feet of arenaceous mud that contained carbonaceous impurities. All of these sediments were later consolidated.

Subsequently these rocks were uplifted and eroded. This was followed by the deposition of the strata that now form the Vadito formation. Several hundred feet of quartz sand, containing small amounts of argillaceous impurities, were laid down, followed by an equal thickness of medium-coarse and coarse gravel. A land surface with high relief must have existed at this time, and served to supply many large boulders to the gravel. Igneous activity accompanied this deposition, and was responsible for the extrusion of flows and the intrusion of sills of rhyolite, quartz-lathe, and dacite. These flows and sills were intimately interlayered with the beds of sand and gravel. Crustal disturbances then became active and, as deposition of muddy arenaceous sediments continued, they were interlayered with considerable thicknesses of intrusive and extrusive igneous rocks of mafic character. These younger arenaceous sediments were poorly sorted, and were derived from the weathering of both felsitic and, to a minor degree, mafic igneous rocks.

In later pre-Cambrian time, deformational forces culminated in a great period of orogeny. All of the rocks were now deep within the crust, where high temperatures prevailed. Great lateral forces were exerted in a north-south direction, and the rocks were compressed and plastically deformed into folds with east-west axes. This was the period during which these rocks were drastically affected by regional metamorphism. Under the influence of heat, pressure, and pervasive solutions, they were transformed by recrystallization from quartz sandstone to quartzite, from sandstone and arenaceous shale to quartzose gneiss, schist, and phyllite, from coarse gravel to coarse quartz conglomerate, from rhyolitic and dacitic rocks to meta-rhyolites and meta-dacites, from mafic igneous rocks to amphibolites, and from poorly-sorted sandstone and arenaceous shale to granulites and arenaceous phyllite. New minerals were orientated in response to the compressional forces, so that they became lined up in planes perpendicular to the pressure and thus created an east-west trending foliation.

In general, the metamorphism was of upper middle-grade character. Such metamorphic minerals as staurolite and kyanite were developed in the aluminous rocks of appropriate composition, and hornblende and andesine were formed in the mafic rocks. Thin argillaceous beds and argillaceous impurities that were present in the oldest and deeper-lying quartzite of the Ortega formation, were characterized by an abundance of the high-intensity mineral, sillimanite, and must be regarded as belonging to the zone of high-grade metamorphism. After the first great period of deformation, the forces of compression were relaxed to some degree, and granitic magma was intruded. The resultant higher temperature, together with lessened stress, promoted the formation of such anti-stress minerals as andalusite and cordierite at the expense of earlier-formed stress minerals, such as staurolite and chlorite. As the granitic magma crystallized, its more volatile constituents migrated upward to form pegmatites in the overlying rocks. Compressive forces were renewed after the intrusion of pegmatites, and all of the rocks were fractured and sheared. The Harding pegmatite was similarly affected prior to the final phase of hydrothermal mineralization.

A high degree of permeability existed throughout the rocks at this time, and emanations from the magma below were able to move through them rather freely. This was the period of great hydrothermal metamorphism. Abundant quartz veins were deposited in the fractures by fluids escaping from the crystallizing magma. Minerals of the rare elements, lithium, beryllium and tantalum, became concentrated in the Harding pegmatite. Boron-bearing vapors caused the widespread formation of tourmaline. Ore-bearing minerals carrying copper, tungsten, bismuth, and gold were deposited in some of the quartz veins. Minerals of copper, bismuth, and lead, together with tourmaline, were deposited in the Harding pegmatite during the final phase of mineralization. It is evident that all of these events occurred over a protracted period while deformational forces continued to act, not continuously and at high intensity, but perhaps intermittently, with alternating culminations and relaxations. During the later part of this period, the granite itself was deformed and metamorphosed to variable degrees, and the upper, earliest-consolidated, and quickest-cooled parts of the intrusive were most strongly affected. The compressional forces were still being exerted along north-south lines, for the foliation formed in certain parts of the granite trends east-west.

Still later, possibly in a final episode of the same great orogeny, profound stresses were exerted along a N. 65°E. direction. Two major tear faults developed, one trending north-south and the other N. 50°W. A large, wedge-shaped block was squeezed about a mile northward between these faults. Large-scale drag ensued along the eastern side of the block, where the beds were pulled around plastically from an east-west to a north-south trend. Such deformation indicates that the rocks must have been at great depth and in an exceedingly plastic state. All of the rocks may have been slightly buckled along north-south axes at this time, in such a way that gentle folds were developed; where they crossed the earlier-formed east-west folds, the earlier folds became doubly-plunging within relatively short distances. During this same period well defined joints probably were developed in the rocks, principally along N. 50°W. and N. 30°E. directions; these may have formed as shear fractures. With relaxation of compressional stress some of these fractures, especially those neighboring and parallel to the major western tear fault, remained open and acted as pathways for the intrusion of diabase. If the relaxation from compressional forces were rather sudden, it might have led to widespread fracturing of all the rocks along north-south lines at this time. North-south fractures, both on a wide scale as joints, and on a very minute scale as fractures cutting across tiny individual porphyroblasts, are abundant throughout the pre-Cambrian rocks of the Picuris range.

PALEOZOIC

In early Paleozoic time this area stood above the sea. No Paleozoic sediments were deposited, or else were deposited and later eroded, until late Pennsylvanian time, when shallow seas encroached upon a surface of moderate relief. Thick deposits of sand, gravel, and arenaceous and calcareous mud were laid down, and subsequently were consolidated into the rocks of the Magdalena group. The land supplying these materials lay to the north (Young, 1945, p. 296).

TERTIARY AND QUATERNARY

During the period of the Laramide revolution, in late Cretaceous or early Tertiary time, great compressional forces were exerted upon the rocks in an east-west direction. The Pennsylvanian sediments covering the pre-Cambrian rocks of the Picuris range were folded along north-south axes, but the underlying crystalline rocks were only slightly affected by this folding. It is possible that the major tear faulting in the Picuris range occurred during this orogeny, rather than very late in the pre-Cambrian orogeny. Very strong thrust faulting and shearing, accompanied by intense hydrothermal alteration, occurred at this time in those rocks that occupy parts of the Sangre de Cristo range to the east and north. This type of alteration has not been found associated with any of the major faulting in the Picuris range. Some of the joints that occur in both the pre-Cambrian and Pennsylvanian rocks of the Picuris range undoubtedly were formed during the Laramide orogeny.

A great period of volcanic activity commenced in middle Tertiary time, perhaps during late Oligocene or early Miocene. Coarse gravel was laid down upon the irregular surface of a shallow basin cut into Pennsylvanian and pre-Cambrian rocks at the eastern end of the area of the Picuris range. At this time the Picuris range probably did not exist, for none of its most distinctive rocks occur in this conglomerate. Most of the volcanic activity followed the deposition of the coarse gravel, and led to the widespread accumulation of tuffaceous sediments. The rocks of the Picuris range then were uplifted along normal faults, and evidently were exposed to erosion, as most of them are represented by fragments in the gravel and boulder beds of the Picuris tuff, Volcanic activity increased rather than diminished during the period of deposition of this formation, and the uppermost beds are especially rich in volcanic material. An east-west, structurally-controlled drainage system then was developed in the range, and a rugged, mature topography began to form.

Layers of buff-colored sand and silt were interlaminated with the uppermost beds of the Picuris tuff. The volcanic materials in the beds were derived from centers to the north, while the buff-colored sand and silt layers, now considered a part of the Santa Fe formation, were being carried down from mountains to the east and south. Gradually the volcanic activity ceased, and in late Miocene and early Pliocene time the Picuris range was surrounded by great thicknesses of the alluvial Santa Fe beds. Higher ridges and peaks, however, still projected above these beds as residual hills of much older rocks.

In very late Pliocene or earliest Pleistocene time, sand and gravel layers of the Servilleta formation were deposited upon the Santa Fe beds, and some basalt flows were interlayered with this sand and gravel. Deformation and long-continued erosion during the preceding period had tilted the underlying Santa Fe beds away from the northern border of the Picuris range and then had planed many of them off prior to deposition of the Servilleta beds. Much of the range was subsequently covered by the Servilleta beds.

More recently, in post-Servilleta time, strong uplift affected the Picuris range once again. Normal faulting occurred along the ancient Pilar-Vadito tear fault, as well as along the northeastern border of the range. Much of the eastern part of the range was elevated many hundreds of feet to form the present-day, highland area. Recent erosion has stripped away most of the alluvial cover, but fragments of chalcedony and a few scattered cobbles attest the former presence of gravel beds on many of the higher ridges of the range.

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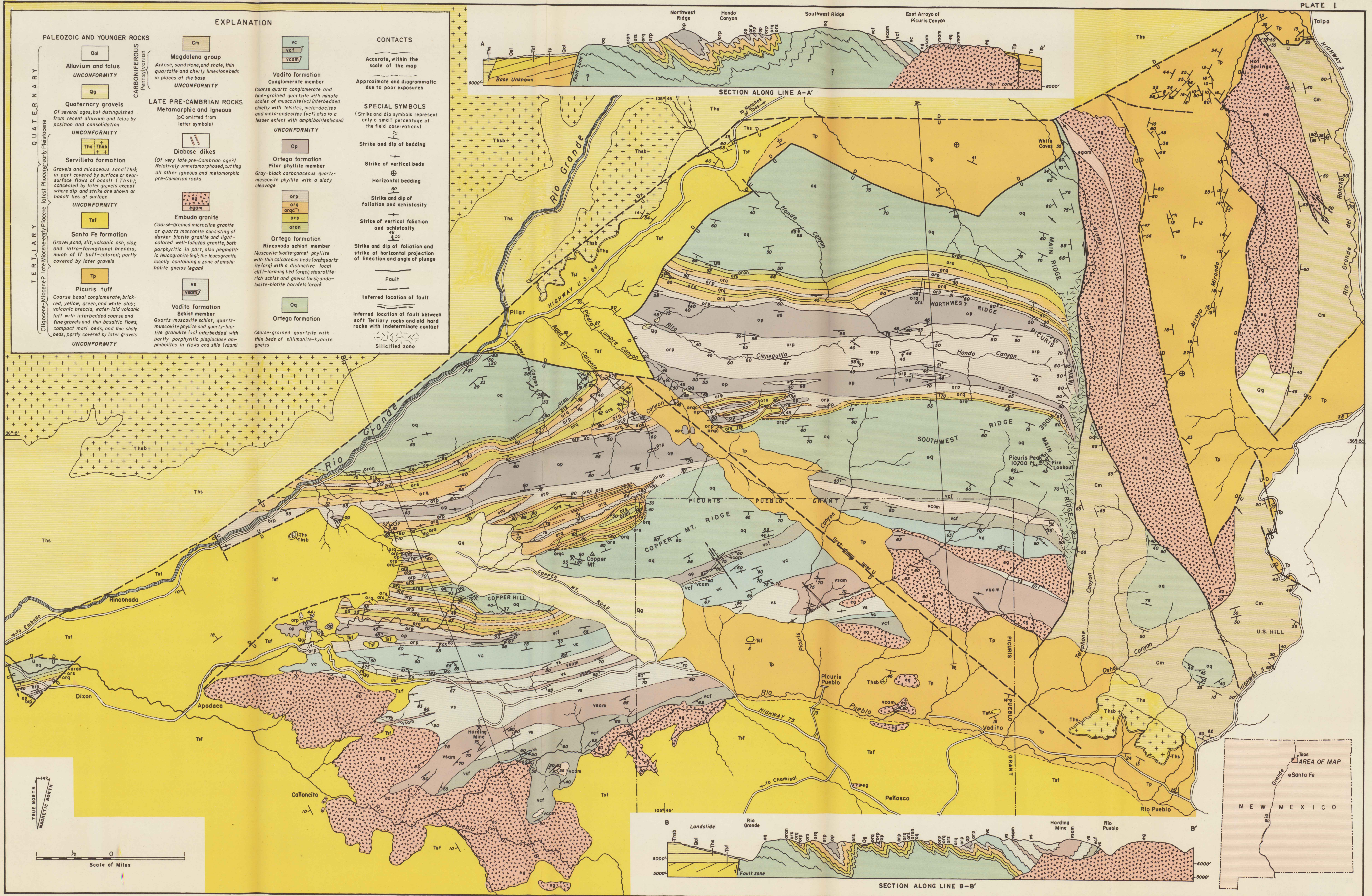


EXPLANATION

PALEOZOIC AND YOUNGER ROCKS

TERTIARY
QUATERNARY
Oligocene-Miocene? late Miocene-early Pliocene latest Pliocene-early Pleistocene

Qal
Alluvium and talus

UNCONFORMITY

Qg
Quaternary gravels

Of several ages, but distinguished from recent alluvium and talus by position and consolidation

UNCONFORMITY

Ths | Thsb
Servilleta formation

Gravels and micaceous sand (Ths); in part covered by surface or near-surface flows of basalt (Thsb); concealed by later gravels except where dip and strike are shown or basalt lies at surface

UNCONFORMITY

Tsf
Santa Fe formation

Gravel, sand, silt, volcanic ash, clay, and intra-formational breccia, much of it buff-colored; partly covered by later gravels

Tp
Picuris tuff

Coarse basal conglomerate; brick-red, yellow, green, and white clay; volcanic breccia; water-laid volcanic tuff with interbedded coarse and fine gravels and thin basaltic flows, compact marl beds, and thin shaly beds, partly covered by later gravels

UNCONFORMITY

CARBONIFEROUS
Pennsylvanian

Cm
Magdalena group

Arkose, sandstone, and shale, thin quartzite and cherty limestone beds in places at the base

UNCONFORMITY

LATE PRE-CAMBRIAN ROCKS
Metamorphic and Igneous

(p€ omitted from letter symbols)

Diabase dikes

(Of very late pre-Cambrian age?) Relatively unmetamorphosed, cutting all other igneous and metamorphic pre-Cambrian rocks

eg
egam
Embudo granite

Coarse-grained microcline granite or quartz monzonite consisting of darker biotite granite and light-colored well-foliated granite, both porphyritic in part, also pegmatitic leucogranite (eg); the leucogranite locally containing a zone of amphibolite gneiss (egam)

vs
vsam
Vadito formation
Schist member

Quartz-muscovite schist, quartz-muscovite phyllite and quartz-biotite granulite (vs) interbedded with partly porphyritic plagioclase amphibolites in flows and sills (vsam)

vc
vcf
vcam
Vadito formation
Conglomerate member

Coarse quartz conglomerate and fine-grained quartzite with minute scales of muscovite (vc) interbedded chiefly with felsites, meta-dacites and meta-andesites (vcf) also to a lesser extent with amphibolites (vcam)

UNCONFORMITY

Op
Ortega formation
Pilar phyllite member

Gray-black carbonaceous quartz-muscovite phyllite with a slaty cleavage

orp
orq
orqc
ors
oran
Ortega formation
Rinconada schist member

Muscovite-biotite-garnet phyllite with thin calcareous beds (orp); quartzite (orq) with a distinctive local cliff-forming bed (orqc); staurolite-rich schist and gneiss (ors); andalusite-biotite hornfels (oran)

Oq
Ortega formation

Coarse-grained quartzite with thin beds of sillimanite-kyanite gneiss

CONTACTS

Accurate, within the scale of the map

Approximate and diagrammatic due to poor exposures

SPECIAL SYMBOLS

(Strike and dip symbols represent only a small percentage of the field observations)

70
Strike and dip of bedding

Strike of vertical beds

⊕
Horizontal bedding

60
Strike and dip of foliation and schistosity

Strike of vertical foliation and schistosity

48
50
Strike and dip of foliation and strike of horizontal projection of lineation and angle of plunge

Fault

Inferred location of fault

Inferred location of fault between soft Tertiary rocks and old hard rocks with indeterminate contact

Silicified zone

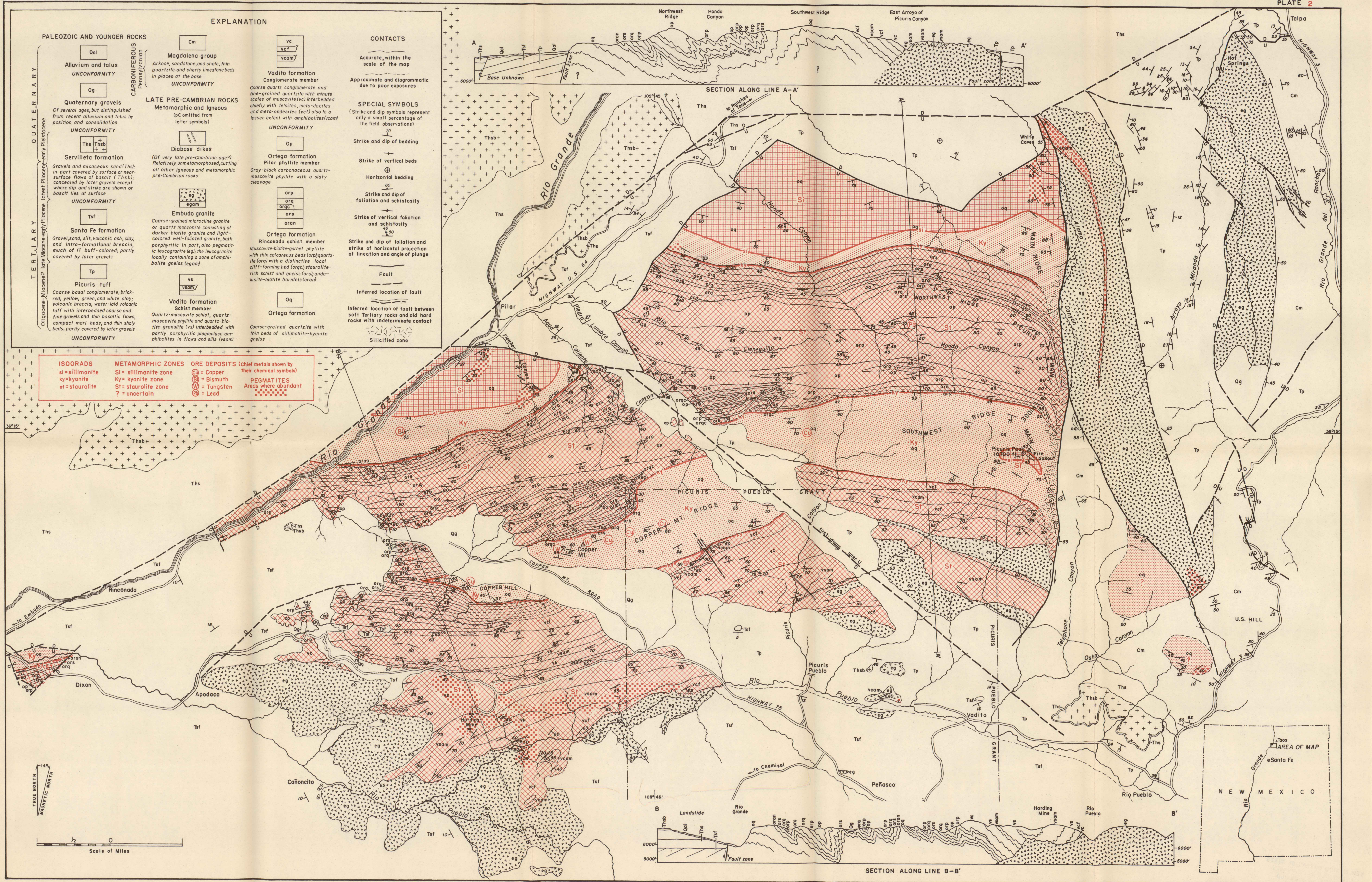
Base map from U.S. Soil Conservation Service planimetric sheets

GEOLOGIC MAP OF THE PICURIS RANGE, TAOS COUNTY, NEW MEXICO

Geology by A. Montgomery, surveyed 1947-49
Drafted by N. Allen

NEW MEXICO BUREAU OF MINES
AND MINERAL RESOURCES

BULLETIN 30
PLATE 2



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UNCONFORMITY

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ISOGRADS	METAMORPHIC ZONES	ORE DEPOSITS (Chief metals shown by their chemical symbols)
si = sillimanite	Si = sillimanite zone	Ⓒⓤ = Copper
ky = kyanite	Ky = kyanite zone	Ⓑⓘ = Bismuth
st = staurolite	St = staurolite zone	Ⓦ = Tungsten
	? = uncertain	Ⓟⓑ = Lead

PEGMATITES
Areas where abundant

Base map from U.S. Soil Conservation
Service planimetric sheets

GEOLOGIC MAP OF THE PICURIS RANGE, TAOS COUNTY, NEW MEXICO
SHOWING ISOGRADS AND METAMORPHIC ZONES AND DISTRIBUTION OF PEGMATITES AND ORE DEPOSITS

Geology by A. Montgomery, surveyed 1947–49
Drafted by N. Allen