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Geology and Mineral Resources of Rio Arriba County, New Mexico

by EDWARD C. BINGLER

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Abstract

Mineral production in Rio Arriba County since the 1880's has amounted to nearly $5 million. Sand and gravel and mica account for $3 million and $1 million of the production, respectively. Metal mining, principally gold, centered in the Hopewell and Bromide mining districts accounts for about $360,000. Crushed, dimension, and ornamental stone production represents about $250,000, and nearly $230,000 in copper and silver has been extracted from "red-bed" copper deposits.

The Hopewell and Bromide mining districts, most active during the late 1880's and early 1900's, include primary ore bodies in a Precambrian terrain and secondary placer deposits of Tertiary to Quaternary ages. Hydrothermal sulfide replacement veins in Precambrian schist and gneiss contain gold, silver, copper, lead, zinc, molybdenum, and a trace of fluorite. Secondary accumulations of alluvial gold in the Hopewell Lake area were the most valuable deposits of the district.

"Red-bed" copper deposits have been exploited near Cuba and in the Coyote–Youngsville area. Chalcocite nodules and replacements of carbonaceous trash in Triassic sandstone and conglomerate contain most of the copper and silver.

The Petaca pegmatite district is the leading mica-producing area in New Mexico. Mica occurs in distinct internal zones in pegmatite associated with the common pegmatite minerals, quartz, microcline, and albite, in addition to the accessory minerals, garnet, beryl, columbite-tantalite, samarskite, fluorite, monazite, bismuth, and magnetite-ilmenite.

Numerous nonmetallic commodities are scattered throughout the eastern part of the county in relatively small deposits. These include kyanite, fluorspar, kaolinite, diatomite, and bentonite. The county has very large reserves of the low-unit-value commodities, gypsum, limestone, pumice, stone, and sand and gravel.

Introduction

This report represents the sixth in a series of county studies, prepared by the State Bureau of Mines and Mineral Resources, designed to provide geological and mining information relating to the development of the mineral industry in various parts of the state of New Mexico.

The major subdivisions of this report include a summary of the geology of the county, described in the text and illustrated on a geologic map, and a description of known mineral commodities. The county geologic map (pl. 1) is published at a scale of one inch to two miles and, as such, is the only complete up-to-date geologic map of a New Mexico county. Both the map and the text are largely the result of compiling published and unpublished geologic maps from a variety of sources. The description of mineral commodities includes a detailed geologic study of the Hopewell–Bromide mining district, reconnaissance geologic maps of deposits and prospects not heretofore appearing in the literature, and a description of all known mines and mining prospects with available production figures and mining history. Thus, this report should serve as a catalog of what is known and as a stimulus to further studies in Rio Arriba County.

METHODS OF INVESTIGATION

The procedure followed consisted of four parts: (1) a preliminary literature search, (2) original investigations on both a regional and local scale, (3) examination of mines and prospects, (4) compilation of the county geologic map.

Original investigations included a geologic survey of the Hopewell and Bromide mining districts conducted during a five-week period in June and July 1966 by the writer and field assistant. The bedrock and surficial geology of these areas were mapped on enlarged aerial photographs and later transferred to a base suitable for publication. Pace and compass surveys of several mines and prospects were carried out when encountered during mapping or on trips to known properties. As a result of the preliminary literature search, several areas were discovered that either had not been mapped at all or were shown on very small-scale maps in insufficient detail for the county map compilation. The writer and one or more field assistants mapped these areas in reconnaissance on aerial photographs and 7½-minute topographical quadrangles.

Reconnaissance surveys of all known mineral commodities in the county were conducted as a check against published reports and to provide geologic data where none were available. Most of the mining districts in Rio Arriba County are or have been inactive, and mine workings are largely caved and inaccessible. In such areas, heavy reliance was placed upon older published reports.

The geologic map of Rio Arriba County is considered a major part of this report; consequently, its compilation and preparation was a major endeavor. It was compiled from published and unpublished maps, all more detailed than the resulting county map. Published maps were entirely from state and federal publications. Unpublished geologic maps were obtained from (1) the United States Geological Survey, (2) open-file reports of the New Mexico Bureau of Mines and Mineral Resources, including regional mapping by the writer (Bingler, 1968a,b), and (3) those included with theses and dissertations from the University of New Mexico, Harvard University, and the University of Texas. All base maps were photographed and reproduced on frosted plastic at the compilation scale of two inches to three miles. Base maps without topography were projected onto modern 7½-minute quadrangles and contacts adjusted to topography wherever possible prior to reproduction of the map on plastic.

Compilation of the county geologic map and field work during the summers of 1965 and 1966 required about four months each.

PREVIOUS WORK

The many papers relating to the geology and mineral resources of Rio Arriba County are listed under *References*. Most of these concern some aspect of the geology or mineralogy of the county; only a few describe mines or mineral deposits in detail. Among the best of the latter are Lindgren, Graton, and Gordon (1910) and Jahns (1946).

The writer's interest in Rio Arriba County dates from 1962 when he began field work in La Madera quadrangle. Familiarity with the La Madera area served as an invaluable base upon which to build a descriptive geologic report of the county.

GEOGRAPHY

Rio Arriba County is adjacent to the Colorado line in north-central New Mexico (fig. 1). The county is irregular in shape and occupies an area of 5855 square miles. Tierra Amarilla is the county seat, and Espanola, with a population of 1976 (1960 census), is the major city. Population of the county is 24,193 (1960 census).

Two U.S. Highways, 84 and 285, extend north from Espanola to the Colorado line, and six New Mexico highways serve principally the eastern part of the county. Other roads are sometimes impassable because of winter snow or summer rains. Much of the western part of the county and the high country of the Tusas Mountains is remote from centers of population and transportation. The projected east-west highway, U.S. 64, planned to link Taos with Farmington, will

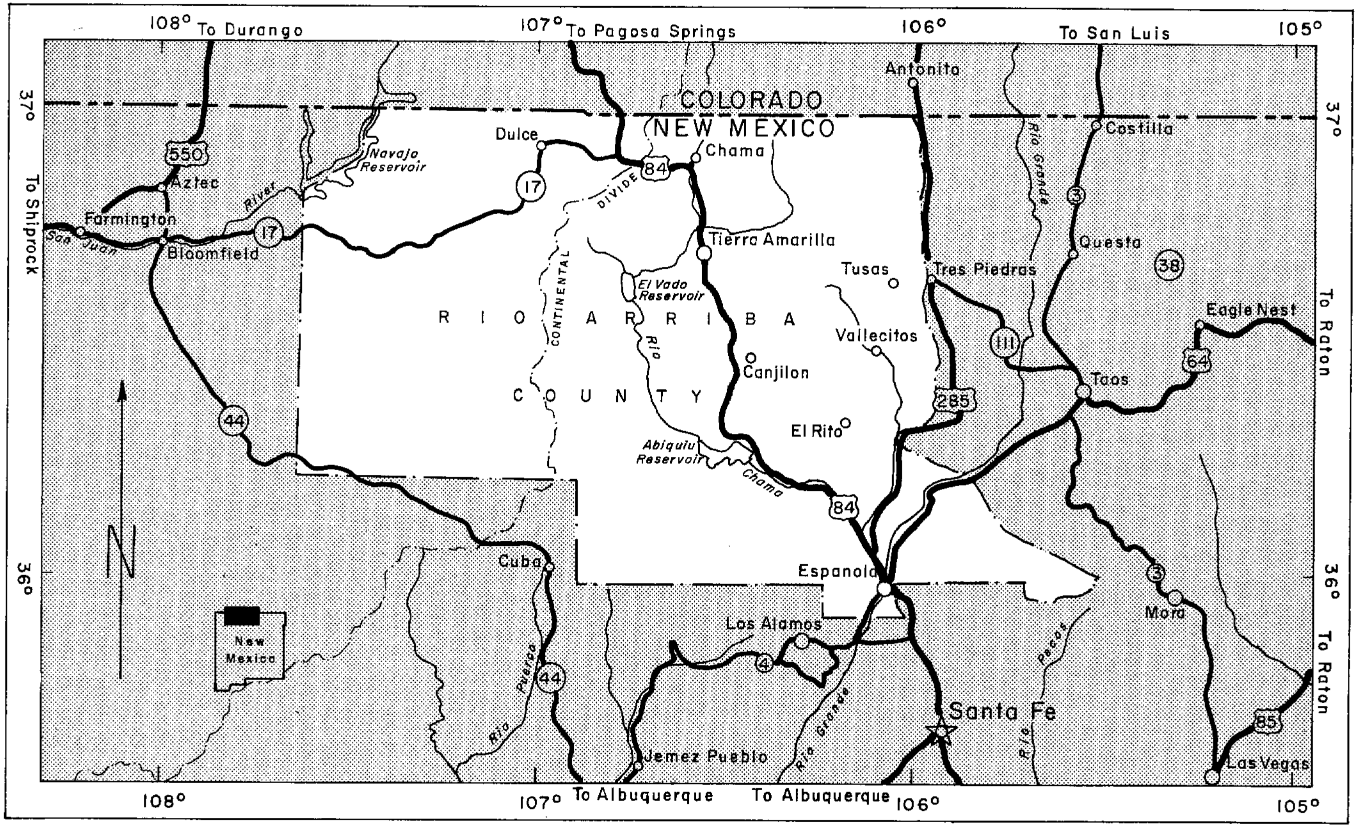


Figure 1
INDEX MAP OF RIO ARRIBA COUNTY

pass through Tres Piedras, Hopewell Lake, and Tierra Amarilla, thereby opening the most inaccessible part of the county to two-way traffic.

The only railroad is the Denver and Rio Grande, a narrow-gauge line that connects Durango and Antonito, Colorado, with Dulce, Lumberton, and Chama.

Rio Arriba County includes strongly contrasting physical features. The eastern and southern parts of the county are composed of moderately rugged, tree-covered, mountainous regions separated by broad brushy valleys. The western part of the county is principally semidesert, where gas pipelines criss-cross desolate badlands studded with pumping oil wells.

Mountain ranges in the county include the Tusas Mountains, sometimes referred to as the Brazos Mountains or southern San Juan Mountains, that trend diagonally northwestward across the eastern part of the county from Ojo Caliente to the Colorado–New Mexico line; the southern Sangre de Cristo Mountains in the extreme eastern part; the Jemez Mountains to the south; and the San Pedro Mountains in the south-central part. Peaks in these ranges soar to elevations above 10,000 feet.

The principal basin areas are the San Juan, which occupies the entire western half of the county; the Chama, which bridges the San Juan Basin and the Tusas Mountains; and the Rio Grande trough, marked north of Espanola by forest and plains of the Taos Plateau.

The variation in elevation within Rio Arriba County has led to the development of several floral zones and widely different climates. In the higher elevations of the Tusas, Sangre de Cristo, Jemez, and San Pedro mountains, winters are severe, cold, and wet; summers are cool and, through the rainy season of July and August, subject to sudden and severe thunderstorms. In the lower elevations, particularly in the western part of the county, the climate is semiarid. Climatological data for two parts of the county follow:

CLIMATOLOGICAL DATA FOR RIO ARRIBA COUNTY
(after *Climate and Man, U.S.D.A., 1941*)

	TEMPERATURE (°F)				PRECIPITATION (inches)		
TOWN	JANUARY AVERAGE	JULY AVERAGE	MAX.	MIN.	WETTEST MONTH	DRIEST MONTH	ANNUAL AVERAGE
Chama	21.5	63.0	99	–28	July	June	21.93
Espanola	29.1	72.1	106	–23	August	December	10.11

Vegetation ranges from spruce-aspen cover at the highest elevation through large areas of pinon-juniper to brush- and cacti-covered plains in the lowest basin areas.

ACKNOWLEDGMENTS

Several individuals greatly aided the preparation of this report by providing information regarding mines and mining districts. I wish to thank especially Mr. Rufus Little of Tesuque, who provided his camp facilities at Hopewell Lake for me and my field assistants. His personal experience in the Hopewell district saved me much time and effort in locating mines and prospects and his data in private reports concerning assay results and mine workings proved of inestimable value. Mr. John N. Eddy of Santa Fe very kindly provided a folio of records regarding the operation of the Bromide mine during the late 1950's.

Unpublished geologic maps of the northern Jemez Mountains and the Tierra Amarilla quadrangle were provided by the United States Geological Survey through the kind offices of Mr. Roy Bailey and Mr. Ed Landis. The county geologic map that accompanies this report would not have been possible without this co-operation, and I am most appreciative.

I am indebted to staff members of the New Mexico Bureau of Mines for friendly co-operation and advice during all stages of the preparation of this report. I especially appreciate the many helpful conversations with Dr. Frank E. Kottlowski and his continued interest in the report's progress. Discussions with Dr. Robert H. Weber and Mr. Max E. Willard helped in the clarification of regional and local geologic problems. Mr. Pat Hillard and Mr. Ken Mallon served as excellent field assistants. Both aided in the reconnaissance mapping of the El Rito and Valle Grande Peak quadrangles; Mr. Hillard also helped map the Hopewell and Bromide mining districts.

Dr. Kottlowski reviewed the manuscript; Dr. Weber read the commodities section and Mr. Roy W. Foster read the general geology section. Mr. William E. Arnold and his staff prepared the maps and illustrations; Mrs. Lois Devlin, Mrs. Wilma Nicholson, and Mrs. Cheryl LePlatt typed the manuscript, and Miss Teri Ray edited it.

Stratigraphy

Rio Arriba County includes four geologic provinces (fig. 2): the crystalline, basin, volcanic, and Rio Grande structural depression. The crystalline province comprises those areas of ancient and deformed crystalline rocks in the core of the Tusas Mountains, the San Pedro Mountains, and the southern Sangre de Cristo Mountains. These crystalline terrains consist for the most part of granite, granite gneiss, and quartz-rich, prominently foliated metamorphic rocks. Rocks of basic composition are sparsely distributed, and ultrabasic rocks are unknown. The basin province is in central and western Rio Arriba County where it consists of a large segment of both the San Juan Basin and the Chama Basin. These major structural depressions are separated by a faulted monoclinal warp that represents the northern extension of the Nacimiento uplift (pl. 2). Rocks in the basin province are largely shale, sandstone, and limestone, ranging in age from Mississippian through Tertiary. Brightly variegated sedimentary rocks of the Mesozoic succession are prominently displayed in the basin province.

The volcanic province includes a mantle of volcanic and volcanic sedimentary rocks exposed in the Tusas Mountains. Also in the Tusas Mountains, but underlying the volcanic sequence, is a thin but areally extensive mantle of conglomerate derived from the crystalline core of the Tusas Mountains. This once extensive accumulation of coarse detritus extends southeastward from the Tusas Mountains to south of Abiquiu, where it is overlain by the complex volcanic eruptive sequence in the northern Jemez Mountains. The fourth major geologic province is the Rio Grande depression, marked by a thick, much faulted accumulation of basin-fill sandstone, siltstone, and conglomerate.

Stratigraphic relationships in Rio Arriba County range from the relatively simple succession of diverse but areally uniform clastic rocks to complex Precambrian rocks in the Tusas Mountains. In the crystalline province, there is virtually no stratigraphy because the normal order of superposition is clouded by a complex polymetamorphic history of superposed deformation. Masses of quartzite, gneiss, and schist similar in texture and composition are exposed in many areas, but for the most part, original stratigraphic contiguity has been lost through the combined processes of folding, faulting, and erosion. Within the basin province, regional and local structural features are relatively simple, lithologic units extend uniformly over wide areas, and the stratigraphy is correspondingly well understood. Stratigraphic relationships in the volcanic province and Rio Grande depression are marked by intertongued fluviatile coarse clastics, containing few fossils. In these areas, several episodes of widespread faulting are the principal structural complexity.

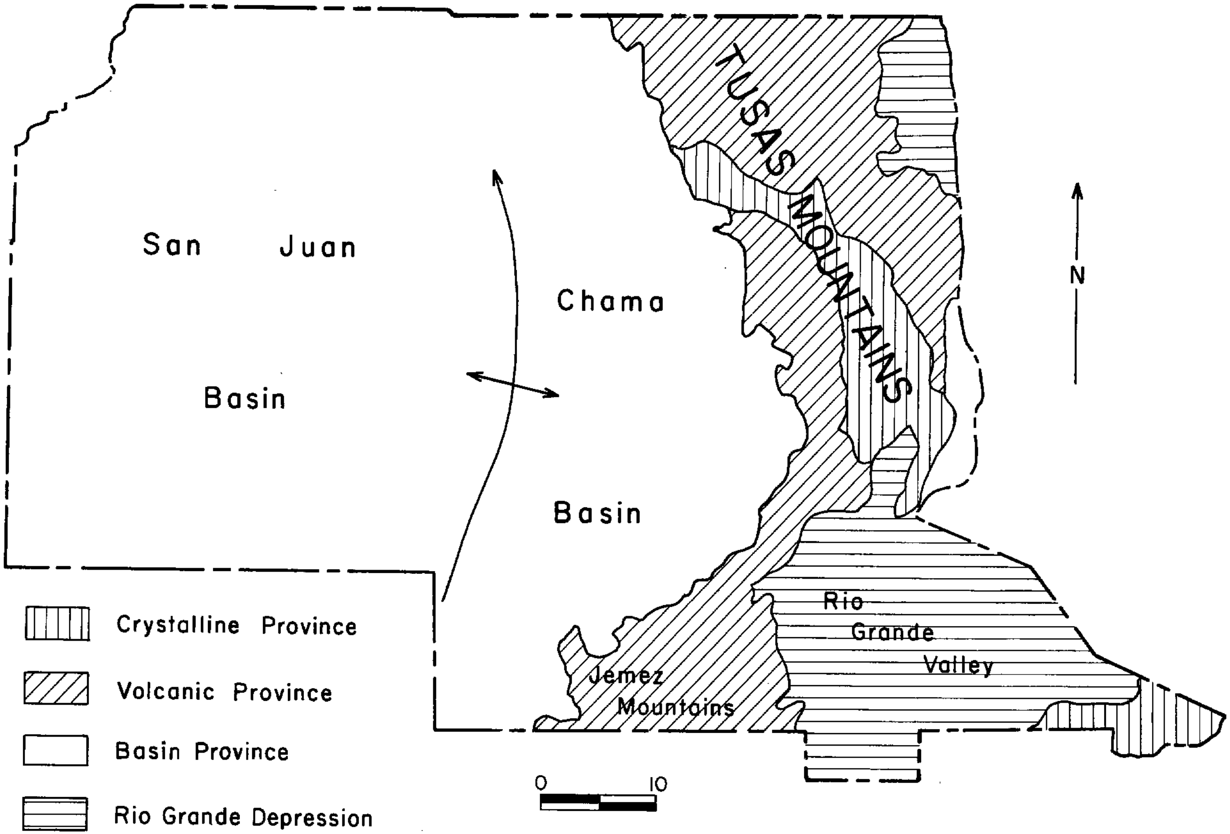


Figure 2
GEOLOGIC PROVINCES IN RIO ARRIBA COUNTY

PRECAMBRIAN ROCKS

Rocks of Precambrian age range in lithology from nearly monomineralic quartzite, in which the principal result of metamorphism has been simple recrystallization, through locally metasomatized schist and gneiss profoundly modified by circulating potash-rich fluids during the intrusion of pegmatite. Structurally, the rocks range from schist and phyllite, containing a penetrative and pervasive cleavage or schistosity that has completely transposed earlier planar structures, to unfoliated porphyritic granite.

Precambrian rocks are exposed in the south-central part of the county in the San Pedro Mountains south of Gallina, in the extreme southeastern corner of the county east of Truchas, in the vicinity of Truchas Peaks, and along the crest of the Tusas Mountains from Ojo Caliente northwestward to, and slightly beyond, the Rio Chaves.

Formal stratigraphic names have been used by other workers for the Precambrian of Rio Arriba County (Just, 1937; Montgomery, 1953; Barker, 1958; Muehlberger, 1960) and correlations based upon lithology but implying continuity have been made linking distant exposures, in particular from the Tusas Mountains to the southern Sangre de Cristo Mountains (Montgomery; Miller, Montgomery, and Sutherland, 1963). In this report, stratigraphic units are given lithologic names to avoid generalizations regarding the original continuity of rock masses.

Quartzite

Medium- to coarse-grained, blue-gray to grayish white, prominently laminated quartzite is the most widespread Precambrian map unit. It forms the precipitous cliffs in the Brazos and Chaves boxes and underlies Jawbone Mountain, Kiowa Mountain, Quartzite Peak, Ortega Mountains, and La Madera Mountain. In the southern Sangre de Cristo Mountains, it underlies a fifteen-mile-wide strip from Trampas Mountain to Truchas Peaks.

Quartzite within the county ranges in texture from even-grained, relatively homogeneous with a gray-white vitreous luster to granular, slabby, greenish gray with a dull matte luster. A prominent lamination due to the presence of specularite, kyanite, sphene, and zircon concentrated in laminae up to several millimeters thick is ubiquitous. Most of these laminae represent original bedding and cross-bedding that in some areas can be used to determine tops and bottoms of beds. However, in most quartzite exposures, particularly in the Ortega Mountains, intense shearing and plastic flow have so swirled and dislocated original bedding planes that they are no longer reliable indicators of normal or inverted beds. Pebble beds, composed of quartzite layers with a maximum thickness of several feet, are common in the quartzite. These beds consist of relict pebbles of milky quartz, fine-grained specularite quartzite, and red and black quartz in a medium-grained matrix of recrystallized quartz sand. Foliation is generally well developed and for the most part appears to be "welded" relict fracture cleavage or relict bedding. This foliation invariably contains a prominent lineation defined by the parallelism of kyanite blades or stretched pebbles. Lens-shaped segregations and veins of white, coarse-grained quartz are widely developed.

Gray quartz pebble conglomerate exposed near Big Rock and Hopewell Lake is included in the quartzite unit of Plate 1. Pebbles consist of light-gray, red and black quartz and range up to about one foot in diameter (Barker, p. 25); these pebbles are well rounded but, where deformation has been locally intense, tend to be flattened in the principal foliation plane. The pebbles are set in a matrix of gray to bluish-gray kyanite quartzite containing numerous specularite laminae.

Principal accessory minerals in quartzite are kyanite, sillimanite, and specular hematite. Kyanite laths from a few millimeters to several centimeters long are common on foliation planes in the matrix of the quartzite and also as rosettes in the quartz-kyanite vein. Kyanite is normally present up to 2 or 3 per cent, but in the Ortega Mountains and near Truchas Peaks, it is locally concentrated in schist and gneiss layers and constitutes up to 10 per cent of the rock. On La Jarita Mesa near Big Rock (T. 27 N., R. 8 E.), kyanite segregations contain up to 50 per cent kyanite (Corey, 1960, p. 60). Sillimanite is present in the quartzite of La Madera Mountain and Truchas Peaks as tufts generally less than one centimeter in diameter. These tufts commonly have a reddish tint produced by an iron-oxide film. Other accessory minerals in quartzite are zircon, epidote, tourmaline, sphene, and allanite.

Contacts between quartzite and other metamorphic rock types are generally sharp and well marked, except where quartzite grades into muscovitic quartzite by virtue of increased muscovite content. Greenish-black amphibolite is intercalated with quartzite near Kiowa Creek (T. 27 N., R. 8 E.) but individual layers are too small to appear on Plate 1. Near Truchas Peaks, granulite, amphibolite, and feldspathic gneiss interlayer with quartzite.

Quartzite as shown on Plate 1 includes the Ortega Quartzite of Just, the Ortega Quartzite and Kiowa Mountain Formation of Barker, and the Ortega Formation of Miller, Montgomery, and Sutherland.

Muscovitic Quartzite

Plate 1 shows a muscovite-rich variant of quartzite, leptite, and granitic gneiss as muscovitic quartzite. The bulk of this unit ranges in composition from muscovitic quartzite to quartz-mica schist with an increasing muscovite content. The muscovite is arranged in prominent laminae with an average thickness of 0.5 mm. These micaceous laminae alternate with layers of fine- to medium-grained quartz. Muscovite content averages about 30 per cent, ranging from 10 to 60 per cent. In exposures where the rock contains less than 10 per cent muscovite, it passes into gray to greenish-gray quartzite. The rock ranges in color from grayish white to pinkish gray, depending upon whether it grades into quartzite or a feldspathic rock such as leptite or granite gneiss. Common accessory minerals include specularite, epidote, chlorite, biotite, and garnet.

Muscovitic quartzite is exposed in a three- to four-mile-wide area extending from Poso Lake southward to Petaca and along the southwestern flank of Mesa de la Jarita from Vallecitos south to Ancones. In the area west of Las Tablas, several masses of muscovitic leptite and quartzite grade into muscovitic quartzite, but their boundaries are too indistinct to be shown on the map.

Muscovitic quartzite includes the Petaca Schist of Just and of Barker. Just believed the Petaca Schist resulted from metasomatism related to the Tusas Granite. Barker accepted the metasomatic hypothesis but held that the numerous pegmatites of the Petaca area constituted the source of the metasomatizing fluids. Bingler (1965) argued against pegmatitic metasomatism on the basis of detailed structural evidence and favored a sedimentary origin for the muscovite.

Quartz-Muscovite-Biotite Schist

Fine-grained, equigranular, quartz-rich schist composed of quartz, albite, muscovite, and biotite as essential minerals crops out in a one-half- to three-mile-wide northwest-trending belt along the eastern base of Mesa de la Jarita, in the Vallecitos valley two miles north of Ancones, and in a one-mile-wide west-trending belt supporting the north flank of Cerro Colorado two miles north of Ojo Caliente.

In the outcrop area between Petaca and Ancones, this unit is uniformly soft, fine- to medium-grained, gray to yellowish gray, and speckled with small flakes of biotite. The schistosity is well developed, and elongate plates of biotite in the plane of schistosity form a pronounced lineation. Poorly defined, widely spaced hematite laminae usually occur parallel to the schistosity. Common accessory minerals are garnet, epidote, specularite, and chlorite.

Jahns, Smith, and Muehlberger (1960) mapped quartz-muscovite-biotite schist exposed near Ojo Caliente Mountain. Although I have not made a detailed study of the schist in this area, it would appear from the brief description accompanying the map that the schist contains essential garnet, and hornblende and pyroxene are local additional phases.

Precambrian rock exposed in a fault block one mile west of Dixon and designated as quartz-muscovite-biotite schist on Plate 1 consists of thin, discontinuous layers of andalusite-biotite gneiss, quartz-muscovite-biotite phyllite, and quartzite.

HORNBLENDE–CHLORITE SCHIST

This map unit includes amphibolite and greenschist exposed as tabular masses intercalated with quartzite, muscovitic quartzite, and quartz-muscovite-biotite schist and as irregular bodies of considerable areal extent. Included are the Moppin Metavolcanics and Amphibolite Member of the Kiowa Mountain Formation of Barker and the Picuris Basalts of Just.

Hornblende-chlorite schist is exposed as irregular small masses adjacent to, and interlayered with, quartzite near Brazos Peak. It constitutes much of the bedrock north and east of Hopewell Lake and underlies most of Burned Mountain and Tusas Mountain, where it forms a nearly mile-wide outcrop belt and is prominently interlayered with quartz diorite gneiss. Under La Jarita Mesa, it consists largely of thin layers, often discontinuous, interfingered with quartzite and muscovitic quartzite. Granite porphyry completely surrounds an elongate exposure of hornblende-chlorite schist one and a half miles southeast of Truchas.

Between Hopewell Lake and Petaca, the map unit includes greenschist and amphibolite (Barker). The greenschists are fine-grained, dark-green schistose rocks composed of chlorite, albite, epidote, and calcite. Aggregates of chlorite that impart a streaked and spotted texture in outcrop are common. These clots are generally elongate and produce a pronounced lineation. Many of the chlorite aggregates represent retrograde replacement of hornblende crystals (Barker, p. 17). Biotite and sericite-chlorite-albite pseudomorphs of plagioclase are present locally.

Oligoclase-epidote-hornblende-biotite amphibolite containing a trace of apatite and several per cent of magnetite interlayers with quartzite and schist south of Tusas Mountain. Texture ranges from fine-grained and equigranular to coarse-grained and porphyritic. In general, grain size in the amphibolite masses increases eastward from Tusas Mountain.

Thin, discontinuous layers of conglomerate, phyllite, gneiss, and schist intercalated with hornblende-chlorite schist are present under Mesa de la Jarita (Barker, p. 21). These layers of metasediment, not differentiated on Plate 1, range in thickness from a few feet to several hundred feet. These rocks contain a well-developed schistosity and a pronounced lineation defined by the preferred orientation of tabular hornblende and stretched pebbles.

Farther south along Mesa de la Jarita, between Vallecitos and La Madera, thin, continuous layers of hornblende-chlorite schist with an average thickness of about 30 feet occur in muscovitic quartzite and quartz-muscovite-biotite schist. Most of the schist in this area is hard, compact, greenish black, and prominently porphyroblastic. Schistosity is well developed, and a mineralogic lineation produced by aligned hornblende crystals and elongate aggregates of fine-grained quartz and plagioclase is invariably present.

The hornblende-chlorite schist map unit on Plate 1 includes an isolated exposure of hornblende-andesine amphibolite near Truchas. This rock is massive, fine- to medium-grained, and gray-black and contains a crude schistosity produced by oriented hornblende needles (Miller, Montgomery, and Sutherland, p. 13). The amphibolites of this area are believed to be of metaigneous origin.

The conclusion that the amphibolites and greenschists of the crystalline province were originally igneous rocks, either intrusive sills and dikes or flows, is supported by all the geologists who have examined these rocks in detail (Barker; Miller, Montgomery, and Sutherland; Bingler, 1965). Evidence cited includes widespread occurrence of concordant contacts, relict porphyritic texture, and bulk composition.

Leptite

Areas designated *leptite* on Plate 1 are underlain by pinkish red to gray-white, flinty to schistose, granular and quartzofeldspathic, prominently laminated, and porphyritic rock termed *Vallecitos Rhyolites* by Just (p. 44), *Burned Mountain Metarhyolite* by Barker (p. 54), *Feldspathic Schist* by Bingler (1965, p. 29), and *Felsite* by Montgomery (*in* Miller, Montgomery, and Sutherland, p. 12).

Leptite is exposed along the entire length of the Tusas Mountains from north of Brazos Creek south to Ojo Caliente. Principal exposures are under Burned Mountain, under Mesa de la Jarita near Poso Lake, north of Canon Plaza, along the Rio Vallecitos from Vallecitos to Ancones, and along the north flank of Cerro Colorado.

There is considerable variability in the lithologic character of leptite. In general, it is pinkish red to reddish orange to greenish white, compact and flinty, with a marked fissility due to segregation of fine-grained muscovite into layers less than a millimeter thick. The principal identifying features of leptite include a fine-grained matrix of equant quartz and feldspar (average grain size, 0.01 mm); large, rounded, clear quartz grains (average diameter, about 1 mm); and large, pink to white, euhedral to subhedral grains of plagioclase (average grain diameter, about 3 mm). East and south of Vallecitos along the scarp that bounds the Rio Vallecitos on the east, Bingler (1965, p. 33-34) identified a gray-brown to brownish-black, biotite-rich phase and a mica-deficient, compact, gneissic variety of leptite.

Leptite becomes progressively more schistose from Jawbone Mountain south to La Madera. A sample collected from a thin layer in quartzite near the Jawbone Mine is compact and flinty with a nearly vitreous appearance. The matrix includes wispy, lenslike aggregates of quartz and feldspar that appear to represent an original texture of flattened lithic fragments similar to that found in some welded tuffs. This crude layering is transected by a penetrative fracture cleavage. A sample of leptite taken from near Petaca is markedly schitose with an average muscovite content of about 20 per cent and no apparent preschistosity structure.

Felsites in the Sangre de Cristo Range near Truchas are similar in composition, texture, and degree of variability to leptite in the Tusas Mountains (Miller, Montgomery, and Sutherland). Leptite interlayered with quartz-muscovite-biotite schist is similar in appearance to gneissic leptite exposed east of Vallecitos. It is pinkish red to reddish orange, slabby to massive, and readily identified by the presence of large quartz and feldspar grains.

Granitic Gneiss

Well-foliated, and for the most part nearly schistose, rock composed of quartz, microcline, albite, and mica crops out as relatively small masses strung along the eastern margin of the crystalline province in the Tusas Mountains. Although most of this rock has nearly the composition of average granite (Barker, p. 61), it is entirely recrystallized and few relicts of igneous texture survive. A penetrative schistosity and lineation produced by the preferred orientation of constituent micas is exhibited in nearly all outcrops. The contacts between granitic gneiss and other metamorphic rock units are both sharp, as along the Rio Tusas north of Las Tablas, and gradational, as in the Cribbenville district where the gneiss grades into muscovitic quartzite and leptite.

In outcrop, granite gneiss is pink to reddish orange to yellowish brown, schistose, fine- to medium-grained, and equigranular and consists of quartz, microcline, microcline microperthite, albite, muscovite, and biotite. Common accessory minerals include epidote, specularite, pink garnet, and myrmekite. Granitic gneiss exposed in Tusas Mountain is distinct from the bulk of the granitic gneiss unit of Plate 1 in that it is fine- to medium-grained, porphyritic, and unfoliated. This rock unit is described in more detail under the Bromide mining district.

Granitic gneiss as shown on Plate 1 includes the Tusas Granite (Just) and the Tres Piedras Granite (Barker).

Quartz Diorite Gneiss

Gray, foliated, quartz diorite gneiss was included in the Tusas Granite by Just and mapped separately as the Maquinita granodiorite by Barker in Las Tablas quadrangle. Barker described the lithology as follows:

> The Maquinita granodiorite is gray, homogeneous, well foliated, and strongly lineate. Both the foliation and lineation are defined by the distribution and orientation of biotite knots, 1/4-1 inch long. In some exposures the foliation is faint, but the lineation is well marked in all of the granodiorite. The granodiorite has been strongly sheared in the dikes that cut the Moppin series and in the plutons exposed in the area from Deer Trail Creek to American Creek. The feldspar and quartz are granulated, and locally the rock is essentially a flaser (lenticular) granodiorite.
>
> Under the microscope the Maquinita granodiorite is composed of moderately sericitized and saussuritized calcic oligoclase to calcic albite, altered orthoclase and microcline, quartz in grains of very irregular shapes and sutured boundaries, biotite and epidote in irregular lenses or clusters, and accessory magnetite-ilmenite, apatite, and calcite. The least sheared granodiorite is exposed along part of Duran creek, in secs. 32 and 33, T. 29 N., R. 7 E. This rock has been moderately sheared; plagioclase grains, which originally appear to have been subhedral and 1-5 mm in length, have been fractured and ground against neighboring grains so that they now are rounded to very irregular. Quartz occurs either as rounded to angular aggregates, 1-4 mm across, or as much finer interstitial grains. Biotite and epidote are associated in irregular clusters that are mostly intersertal to the larger grains of light-colored minerals.
>
> Alteration of the Maquinita granodiorite is very similar in all of the exposed bodies. Plagioclase and orthoclase have been moderately to thoroughly sericitized and slightly saussuritized. The markedly altered feldspar now appears as a thick network of sericite and saussurite, which contains epidote and rounded, interstitial grains of clear albite or oligoclase. Some of the altered plagioclase also is rimmed with clear albite or oligoclase. All of the albite-oligoclase present may well have been formed during the alteration. Similarly, the disseminated grains of epidote and biotite may be alteration products of hornblende.
>
> In the plutons from Deer Trail Creek to American Creek as much as two thirds of the granodiorite has been sheared to a fine-grained aggregate that is interstitial to the original grains. This aggregate consists largely of equant to irregular grains of quartz and untwinned feldspar, with lesser amounts of biotite, epidote, musco-

vite, and saussurite, all of which range from about 0.02 to 2 mm. Even in this highly granulated rock, which almost merits classification as a flaser-granodiorite, most of the biotite and epidote occurs as discrete, well-lineated knots. The amount of shearing is variable, even in the same pluton, and does not appear to increase toward the boundaries; however, too few specimens were gathered to warrant a definite conclusion.

Quartz diorite gneiss crops out along the ridge extending from Jawbone Mountain to Tusas Mountain. Near Tusas Mountain, it occurs as a wedge in hornblende-chlorite schist and in contact with granitic gneiss. It is well exposed in Maquinita Canyon northeast of Burned Mountain and crops out as a group of isolated small masses enclosed by hornblende-chlorite schist north of Hopewell Lake.

Granite Porphyry

This unit includes all the dominantly unfoliated granite in Rio Arriba County. Because of the lack of internal structure, these granite masses are considered postkinematic and probably represent the latest major Precambrian event.

Granite porphyry crops out in the extreme southeastern, south-central, and north-central regions of the county. The Embudo Granite (Miller, Montgomery, and Sutherland) is included in the granite porphyry map unit on Plate 1. It underlies about thirty square miles north and south of Rio de Truchas, largely west and south of the village of Truchas. The granite is in fault contact with quartzite along its eastern margin and is overlain by gravel along its northern edge. Isolated masses of this same granite form prominent hills near Ojo Sarco and east of Apodaca. In the Tusas Mountains, granite porphyry underlies Cerro Colorado and appears as an aggregate of irregular hills four miles north of Jawbone Mountain. A large triangular mass of granite porphyry underlies San Pedro Mountain south of Gallina. Rock in this area was examined in a brief reconnaissance that consisted of walking several forest trails across the southern flank of the mountain and examining recent stream gravels in drainage systems issuing from the northern and eastern flanks of the mountain.

Granite porphyry from these widespread exposures is very similar in texture and composition. At San Pedro Mountain, the rock is pink to reddish orange, massive to faintly foliated, largely porphyritic granite consisting of quartz, microcline, albite, and biotite. Local gneissic phases and compositional variants tending toward granodiorite are common. Dark-green, compact, weakly foliated, hornblende-plagioclase amphibolite dikes are widespread but are not shown on Plate 1. The granite north of Jawbone Mountain is coarsely porphyritic and contains large ovoid aggregates of quartz referred to as "quartz eyes" by Muehlberger (personal communication). He also noted the similarity between "quartz eye" granite and the rock underlying Cerro Colorado west of Ojo Caliente that Jahns, Muehlberger, and Smith (1960) referred to as porphyritic metarhyolite. The exposures of granite north of Truchas Peaks were studied in detail by Montgomery (Miller, Montgomery, and Sutherland). He described the granite porphyry in this area as follows:

> In the Truchas area and in the Santa Fe Range, much the same lithologic types of Embudo Granite are present. A first type, better termed microcline-biotite granite, is commonly medium- to coarse-grained and grayish in color, but also may be tan to flesh-pink. It is dominantly of quartz-monzonite or granodiorite composition, with about ten percent biotite and/or hornblende. Nearly equal parts of quartz, microcline, and albite-oligoclase are present. A second type, which is gradational into granodiorite, is a dark gray, in part distinctly gneissic, quartz diorite containing no microcline. Quartz is very minor; biotite and hornblende average about 20 percent each, while plagioclase (oligoclase-andesine) ranges from 40 to 50 percent. Apatite, magnetite-ilmenite, and sphene are very abundant accessory minerals; allanite and zircon are scarce accessories, as they are in all types of Embudo Granite. . . .A third type, termed leucogranite, may be either very coarse-grained or very fine-grained. It is usually pinkish to flesh-pink, or else tan, and is almost lacking in dark minerals which average less than one percent and never exceed three percent. Aside from this lack of dark minerals and the extreme variability in quartz content, the minerals contained are the same as those in the microcline-biotite granite. The rock has an unusually high silica and soda-potash content. . . .
>
> A variation of the first and third types of Embudo Granite is a light-colored, streaky, foliated granite, very spotty and localized in outcrop extent and comprising either a microcline-biotite granite or a pinkish leucogranite. In thinsections of such granite, small plates and patchy aggregates of muscovite are abundant, evidently derived in large part from alteration of feldspar. . . .

Metamorphism

The nature of metamorphism within the crystalline province of Rio Arriba County has been studied in detail by Barker, Bingler (1965), and Miller, Montgomery, and Sutherland. An examination of their reports reveals that the metamorphic processes active throughout Precambrian time have resulted in similar mineralogic changes throughout the metamorphic terrain of Rio Arriba County.

In the Truchas area (Miller, Montgomery, and Sutherland), quartzite, hornblende-chlorite schist, and quartz-muscovite-biotite schist were produced by dynamothermal metamorphism of regional extent. Original sediment in the form of quartz sandstone and shale were converted to quartzite and pelitic schist; rock of basic composition, possibly basalt, now is represented by hornblende-chlorite schist. Granite porphyry, which constitutes much of the Precambrian in this area, is only locally foliated and may represent local shearing effects during regional metamorphism, in which event the granite is partly synkinematic. The foliation may also represent a primary flow layering. A late period of hydrothermal metamorphism is marked by widespread occurrence of quartz veins spatially related to tourmalinized contact rocks. Other features related to late metamorphic effects are the introduction of feldspar locally, especially as microcline in leptite; resilicification of quartzite, resulting in a compact, white, vitreous-appearing rock; and the formation of sillimanite tufts.

In the Tusas Mountains, Precambrian rocks have been modified by an early period of regional metamorphism that converted all original rocks to quartzite, schist, gneiss, and phyllite. Subsequent hydrothermal and pegmatitic metasomatism was widespread but particularly severe near Petaca where numerous pegmatites were intruded.

Facies of regional metamorphism developed in the southern part of the Tusas Mountains include the Chlorite and Biotite subfacies of the Greenschist Facies and the Almandine Amphibolite Facies (fig. 3). Identification of these facies is based upon the presence of albite-chlorite-muscovite, muscovite-albite-biotite-epidote, and andesine-hornblende assemblages (Bingler, 1965). In the northern part of the Tusas Mountains, basic rocks were converted to chlorite-albite-epidote-sericite-carbonate and oligoclase-epidote-biotite-hornblende; pelitic assemblages are muscovite-oligoclase-staurolite-kyanite-magnetite and quartz-muscovite-biotite-plagioclase-almandine (Barker).

Hydrothermal metamorphism in the Tusas Mountains has resulted in the enlargement of pre-existing phases; for example, blades of kyanite in quartzite, growth of new phases such as andalusite filling fractures, retrograde hydration of anhydrous alumino silicates as in the replacement of kyanite by pyrophyllite, and the prograde crystallization of fibrous sillimanite. The association of these textural and mineralogic changes with obvious channelways such as schistosity and cleavage has led to their interpretation as hydrothermal features. However, no satisfactory source for the hydrothermal fluids has yet been postulated.

Pegmatitic metasomatism, striking at an outcrop scale, refers to the replacement of chlorite and hornblende by biotite, minor feldspathization, pronounced muscovitization, the formation of garnet in pelitic schist, and tourmalinization. All these effects are local, spatially related to intrusive pegmatites, and accompanied by a general coarsening of wall-rock textures.

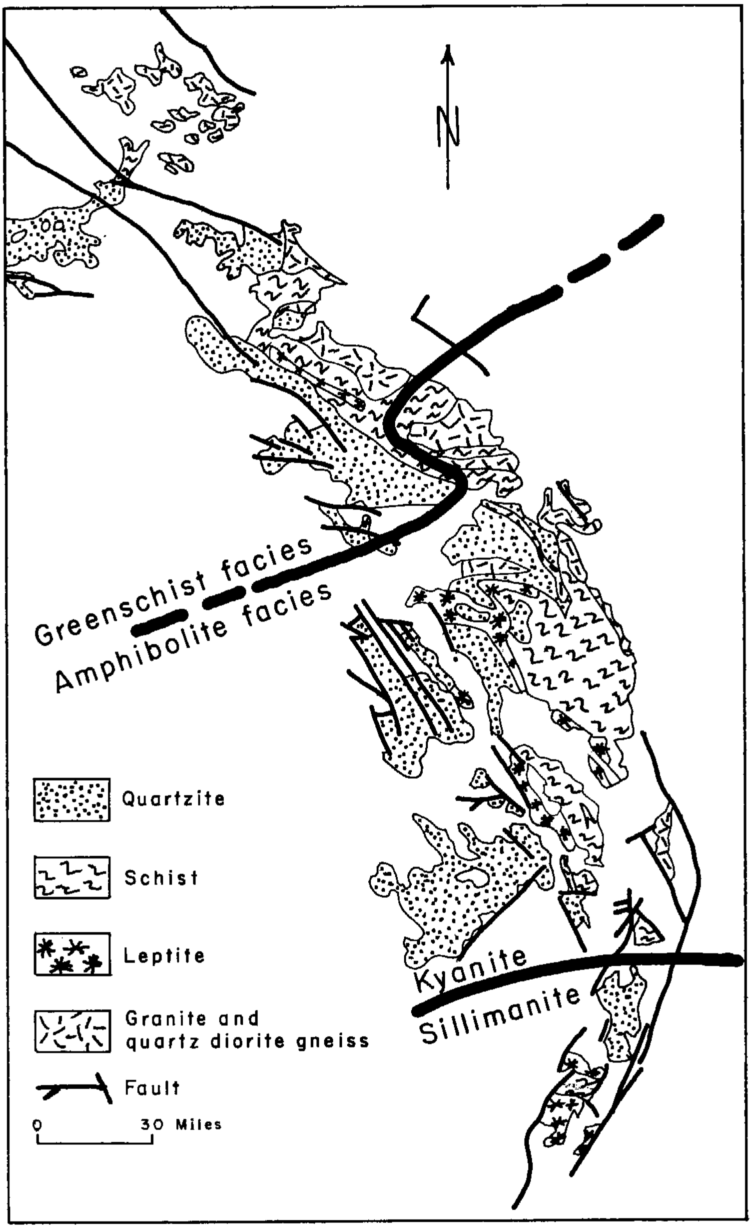


Figure 3

FACIES AND MINERALOGIC BOUNDARIES IN THE CRYSTALLINE PROVINCE, TUSAS MOUNTAINS

PALEOZOIC ROCKS

Mississippian System

Uniform, even-bedded, pale yellowish-brown to grayish-red quartz sandstone unconformably overlies Precambrian rocks north and east of Truchas Peaks (Miller, Montgomery, and Sutherland). This clastic sequence up to 75 feet thick (Armstrong, 1967) underlies limestone and sandstone of Pennsylvanian age.

Baltz and Read (1960) included these rocks as the basal sandstone member of the Espiritu Santo Formation and identified the strata as of possible Devonian age. However, its Mississippian age has now been established by the Meramec fauna collected by Armstrong. He also correlated these strata with the Arroyo Peñasco Formation in San Pedro Mountain. Miller, Montgomery, and Sutherland (p. 24) gave the name *Del Padre Formation* to these same rocks.

Pennsylvanian System

Rocks of Pennsylvanian age in Rio Arriba County consist of a thin-bedded sequence of alternating limestone, arkosic limestone, shale, and quartz sandstone. Most workers have recognized two major lithologic subdivisions, the basal Sandia Formation and the upper Madera Formation. Exposures of Pennsylvanian rocks extend over several square miles but in widely separated parts of the county.

In the rugged high country of the southern Sangre de Cristo Mountains along the East, Middle, and West forks of the Rio Santa Barbara, a little more than 1000 feet of limestone, sandstone, and shale overlie the thin Mississippian section. As described by Miller, Montgomery, and Sutherland (p. 30-38), the base of the sequence consists largely of dark-green siltstone and mudstone interbedded with thin sandstone. This lithology grades upward through a zone of interbedded clastic limestone and calcite-cemented quartz sandstone into thick-bedded, sandy, brownish gray limestone. An abundant fauna of crinoid fragments, bryozoa, brachiopods, pelecypods, gastropods, and fusulinids is present in the limestone beds. Overlying the dominantly limestone part of the section is a succession of interbedded sandstone, conglomerate, and arkosic limestone. Miller, Montgomery, and Sutherland named the lower part of the Pennsylvanian section *La Pasada Formation* (Flechado Formation farther north) and the upper arkosic rocks the *Alamitos Formation*. However, they did not indicate these formations on their geologic map; the formations are not shown on Plate 1 of this report.

Pennsylvanian sediments are exposed in three irregular areas along the southern, eastern, and northern flanks of San Pedro Mountain (Mining Mountain, Rio Puerco, and Rio Vequitas, respectively).

Wood and Northrop (1946) described the succession in these areas and subdivided the rocks into the Sandia and Madera Formations, first named in the Sandia Mountains. Nearly 300 feet of thin-bedded gray limestone interbedded with gray shale and grading upward into arkosic limestone, gray and red shale, and arkose have been assigned to the Madera Formation. These beds grade upward into red shale and sandstone of Permian age.

Three very small outcrop areas have been reported elsewhere in the county. Lookingbill (1953) located a small outcrop in sec. 20, T. 26 N., R. 2 E., that consisted of arkosic limestone. Muehlberger (1957) recorded the presence of fusulinid-rich gray limestone near the Chaves Box (six miles east and slightly north of Brazos). Smith, Budding, and Pitrat (1961, p. 5) record an outcrop of carbonaceous and gypsiferous siltstone in Arroyo del Cobre.

Permian System

Exposures of red shale and sandstone of Permian age assigned to the Cutler Formation are restricted to the south-central part of Rio Arriba County around the margins of San Pedro Mountain, the valley of the Rio Puerco, isolated areas from Gallina north to Gallina Peak, and north of Abiquiu in Arroyo del Cobre.

Wood and Northrop correlated brownish-gray to greenish-gray arkosic sandstone interbedded with brownish-red shale with the Permian Cutler Formation of Colorado. They indicated that these red beds exposed around the northeastern and southeastern flanks of San Pedro Mountain are the lateral equivalent of the San Andres, Yeso, and Abo Formations exposed farther south in the Nacimiento Mountains.

Northeast of San Pedro Mountain in the valley of the Rio Puerco, Bingler (1967) mapped a minimum thickness of 400 feet of red to reddish-brown shale with thin interbedded sandstone. Good exposures of Permian red beds in this area extend without interruption to the Rio Chama.

Smith, Budding, and Pitrat (p. 7) mapped the Permian rocks in Arroyo del Cobre, a prominent box canyon situated on the arch of a northeast-trending anticlinal warp. They describe in excess of 600 feet of alternating, cross-bedded, purple arkosic sandstone and purple to orange mudstone. They note that these lithologic units change rapidly along the strike. In this area, the red beds rest uncomformably upon Pennsylvanian rocks and are unconformable beneath thin-bedded sandstone of Triassic age.

Several exposures girdled by younger sediments are strung out along the prominent fault zone extending from south of Gallina to north of Gallina Peak. Permian rocks are now exposed in the cores of structures ranging from small anticlinal warps to breached, doubly plunging anticlines. Both Lookingbill and Fitter (1958) describe the Permian in this area as dark red to brown shale, siltstone, and thin-bedded sandstone.

Permian rocks are not present between Pennsylvanian limestone and Triassic sandstone in the Chaves Box (Muehlberger, 1968). It is not known whether Permian rocks are missing because of erosion or because of nondeposition.

MESOZOIC ROCKS

Triassic System

Extensive exposures of red shale and mudstone with interbedded gray to yellowish-brown, arkosic sandstone and conglomerate are referred to the Chinle Formation. This unit is divided into a lower sandstone member and an upper shale member. Good exposures occur in the middle reaches of El Rito Creek, along the rim of Arroyo del Cobre, adjacent to the structural margin of the Rio Grande depression, beneath Cerro Pedernal, beneath the dissected Llano del Vado, flanking the Rio Puerco along the rim of Mesa Prieta, in the canyon of the Rio Chama, and encircling the small upwarps along the northern extension of the Nacimiento fault zone. In the northern part of the county, thin, discontinuous exposures of Chinle sandstone and shale rest unconformably on Precambrian rocks from Brazos Creek to the Cañones Box.

The lower sandstone member of the Chinle Formation consists of gray-white to brown to yellowish-brown, fine- to medium-grained, massive to cross-bedded siltstone and discontinuous conglomerate layers.

Near Arroyo del Cobre, this member is about 250 feet thick (Smith, Budding, and Pitrat, p. 8) and locally rests with angular unconformity upon the underlying Cutler Formation. In the Coyote–Youngsville area, the unit contains more shale, and along the eastern flank of San Pedro Mountain, nearly a third of the formation is red shale concentrated in a medial zone and separating a lower and upper conglomeratic sandstone zone. Wood and Northrop named the basal sandstone sequence the *Agua Zarca Sandstone,* the medial shale the *Salitral Shale,* and the upper sandstone zone the *Poleo Sandstone.* These names are not used on Plate 1 because of the difficulty involved in identifying the lithic zones in areas other than San Pedro Mountain. In the Coyote–Youngsville area, the lower sandstone member is about 200 feet thick.

The upper shale member of the Chinle Formation is separated from the lower sandstone member by a gradational boundary involving the transition from thin-bedded shaly sandstone to even-bedded shale. Rocks of the upper member consist of interbedded siltstone and shale, complexly intercalated, that range in color from reddish brown to purplish red. Thin, discontinuous, light-green beds are common. The upper member has an average thickness of 300 feet but ranges up to 500 feet (Smith, Budding, and Pitrat, p. 9).

JURASSIC SYSTEM

Bright-colored sandstone, shale, siltstone, and gypsum of Jurassic age occupy an outcrop area similar to the Triassic rocks previously described. In general, these rocks form steep slopes or precipitous cliffs along major drainages such as El Rito Creek, Rio Chama, and Rio Puerco.

Rocks of this system are shown on Plate 1 as the combined Entrada–Todilto Formations and the Morrison Formation. These units crop out along the west side of El Rito Creek valley, along Mesa del Yeso, in Arroyo Seco, in the high-walled canyons of the Rio Chama and Rio Gallina, along the northern extension of the Nacimiento fault zone, and in the mesa tops between Capulin and the Cañon de Chama. The southeasternmost exposures occur in the canyon of Coyote Creek, beneath Cerro Pedernal, and north of Cañones. Scattered outcrops of Jurassic rocks in the northwestern part of the Tusas Mountains are situated between Brazos Creek and the New Mexico–Colorado line.

Entrada and Todilto Formations

The Entrada Formation consists of tan to pinkish-tan to white, well-sorted, cross-bedded sandstone with an average thickness of 200 to 250 feet. The contact between it and the underlying red shale of the Chinle Formation is everywhere sharp and represents a slight angular unconformity. Smith, Budding, and Pitrat (p. 11) describe the Entrada in the following terms:

> The Entrada consists for the most part of well-rounded, well-sorted quartz sand of fine to medium grain. Cross-bedding is present throughout, but the long, sweeping foresets so characteristic of aeolian beds are confined to the lower part. The color of the fresh material is generally tan or white, but the weathered cliff faces show more diversity in color. In the southern tier of quadrangles, where exposures are excellent, the lower 120 to 150 feet of the Entrada weathers red, the next 25 to 50 feet is white and the upper 50 to 75 feet weathers buff; the total thickness throughout these exposures ranges between 200 and 265 feet. . . .

This description applies to the Entrada Formation wherever I have observed it in Rio Arriba County.

The Todilto Formation is a thin, persistent sequence of limestone, calcareous shale, and gypsum. Thickness of this sequence ranges from nearly zero to slightly more than 100 feet. Thin-bedded, gray, medium-grained limestone and platy shale comprise the basal part of the formation. These beds rest upon and in part intertongue with the sandstone of the Entrada Formation, and grade upward into very pure gypsum that ranges from 0 to nearly 100 feet thick locally. For the most part, the Todilto Formation forms a thin, irregular, gray capping on varicolored Entrada sandstone; together, they form sheer cliffs in most exposures.

Morrison Formation

This unit includes gray to pinkish-white sandstone interbedded with green or red mudstone, banded green and orange mudstone, and red claystone. The over-all hue of the formation appears to grade from predominantly pinkish tan at the base to pinkish green at the top (Smith, Budding, and Pitrat, p. 14-15). The basal contact with the underlying Todilto Formation is sharp. The thickness of the Morrison Formation averages about 600 feet throughout the county.

Cretaceous System

In the central and northern parts of Rio Arriba County, about 4500 feet of tan and gray sandstone and shale of Late Cretaceous age crop out over an area of nearly 1000 square miles. These rocks lie within, and largely define, the Chama Basin and the eastern margin of the San Juan Basin. West of a line drawn through Gallina and Lumberton, Upper Cretaceous rocks grade into and pass beneath Tertiary sediments. East of Chama and Tierra Amarilla, along the edge of the Brazos high country, these same rocks are beveled and overlain by Tertiary volcanic and coarse clastic rocks.

Dane (1947); Smith, Budding, and Pitrat; Doney (1966), Muehlberger (1967) ; and Landis and Dane (1967) all have contributed to studies of the Cretaceous rocks in Rio Arriba County. Formal stratigraphic units used on Plate 1 include the Dakota Formation, Mancos Shale (including the Graneros, Greenhorn, and Upper Shale members), Mesaverde Formation, Lewis Shale, Pictured Cliffs Formation, and Upper Cretaceous rocks, undifferentiated.

Dakota Sandstone

The Dakota Sandstone includes from 180 to 400 feet of interbedded white to yellowish-tan sandstone and gray fissile shale. A basal zone and uppermost zone composed principally of cliff-forming sandstone, separated by a medial zone of dark-gray carbonaceous shale, form the basis for the tripartite lithology throughout the county. At large map scales, these subdivisions are mappable as members, but they have not been so designated on Plate 1.

Excellent outcrops of Dakota Sandstone encircle the Chama Basin from northeast of Chama, south along the west flank of the Tusas Mountains to the Rio Brazos. From the Rio Brazos south to El Rito Creek, the outcrops are obscured by younger rocks and landslide debris. The finest exposures in the county extend from Magote Ridge across the top of the high mesa country north of Ghost Ranch, then north along the canyon walls of the Rio Chama to Sawmill Mesa. Steeply dipping beds of Dakota Sandstone are present immediately west of the Gallina fault zone and in the resistant caprock of Mesa Prieta.

The age of the Dakota Sandstone in the county is generally regarded as earliest Late Cretaceous. Most workers recognize the presence of a thin, Lower Cretaceous sequence (Muehlberger, 1967; Smith, Budding, and Pitrat) but arbitrarily include these rocks, if present, in the Dakota Sandstone because of the similar lithology of the Lower and Upper Cretaceous rocks.

The basal sandstone part of the Dakota Sandstone consists of pale orange to yellowish-brown, in part cross-bedded, chert-bearing quartz sandstone. Individual sandstone beds are fine- to medium-grained and contain discontinuous quartz pebble conglomerate zones. Small fragments of coaly plant remains are common. The medial sequence is made up of dark-gray, fissile, carbonaceous shale. The upper sandstone is light gray, compact, silica-cemented in part, medium- to fine-grained, and prominently interbedded with shale both above and below the main sandstone mass.

The Dakota Sandstone rests unconformably upon the Morrison Formation throughout the Chama Basin and upon Precambrian quartzite in the northern Tusas Mountains (Muehlberger, 1967).

Mancos Shale

On Plate 1, the Mancos Shale is subdivided into the Graneros Shale Member, the Greenhorn Limestone Member, and the Upper Shale Member. The practice of separating the shale sequence above the Greenhorn Limestone Member into a Niobrara, Carlile, and an unnamed member (Dane, 1947) has not been followed in all areas. Also, it can be very difficult to recognize the paleontologic horizons necessary to identify these units. For these reasons, the Niobrara and Carlile subdivisions of the Mancos Shale have not been used in this report.

The basal part of the Mancos Shale is referred to the Graneros Shale Member. This unit consists of about 120 feet of dark-gray to black, thin-bedded, fissile sandy shale. Concretions composed of calcite and dolomite up to 5 feet in diameter occur in a thin zone near the base of the member. Thin beds of bentonite, brown calcareous siltstone, and shaly limestone are present throughout (Dane, 1947).

The Graneros Shale Member grades downward into the Dakota Sandstone through increase in the frequency of thin sandstone beds and upward into limestone of the Greenhorn Limestone Member.

The outcrop area of the Graneros Shale is more restricted than the Dakota Sandstone, particularly between El Rito and Gallina Peak, but the outcrop pattern is very similar.

Very thin-bedded, dark-gray limestone and calcareous shale are included in the Greenhorn Limestone Member. The limestone characteristically weathers to a gray-white color and is so thin-bedded, fissile, and densely jointed as to form a rubble of platy chips in most exposures. Thickness of the member varies from 40 to 60 feet in the western part of the Chama Basin (Dane, 1947) and from 12 to 26 feet along the eastern margin of the basin (Muehlberger, 1967). Doney notes the presence of thin bentonite beds.

The areal distribution of exposures is essentially the same as the Dakota Sandstone and Graneros Shale Member. Contacts with shale both above and below are intercalated and gradational.

The Upper Shale Member of the Mancos Formation includes the bulk of the unit with a thickness in excess of 1800 feet. It includes shale mapped as Carlile, Niobrara, and the Upper Shale Member of the Mancos Formation by Dane (1947), Muehlberger (1967), and Doney.

This unit is the surface rock throughout most of the Chama Basin. Exposures extend in a six- to eighteen-mile-wide, generally north-south strip along the axis of the basin. Tilted beds of this member form a wide outcrop belt from Gallina north to Tecolote Mesa.

The lithology of the Upper Shale Member includes dark-gray to light yellowish-tan shale, mudstone, and claystone. Numerous thin interbeds of calcareous sandstone, platy limestone, and bentonite are common throughout. Several workers have noted large septarian concretions. Near the top of this unit, shale is gradually replaced by thin sandstone beds until the rock is largely sandstone assigned to the Mesaverde Formation. The contact between the Mancos Formation and the overlying Mesaverde is arbitrarily drawn somewhere in the transitional horizon.

Mesaverde Formation

As used in this report, Mesaverde Formation refers to about 300 feet of gray to yellowish-tan sandstone and gray shale. These lithologies are concentrated into a basal sandstone sequence, a medial shale sequence, and an upper sandstone sequence. The basal sandstone beds have been referred to the Hosta Sandstone Member by Dane

(1947) and the Point Lookout Sandstone by Doney and by Muehlberger (1967). The medial shale was called the Gibson Coal Member by Dane (1947) and the Menefee Formation by Doney and by Muehlberger (1967). Dane referred to the upper sandstone as the *La Ventana Tongue* of the Pictured Cliffs Sandstone, and Doney and Muehlberger called it the *Cliff House Sandstone.*

The Mesaverde Formation crops out as a continuous north-south strip dividing the county into roughly east and west halves. The outcrop belt, narrow west of Gallina because of steep westerly dip, gradually widens northward as the beds become more horizontal. Near Tecolote Mesa, the outcrop area has a width of about three miles. Near Monero, the Mesaverde is much dissected and irregular in trend. Isolated areas of outcropping Mesaverde beds occur northwest of Chama and south of Tierra Amarilla. The southernmost exposures on the east side of the Chama Basin are near Canjilon Mountain, five miles east of Cebolla.

The basal sandstone beds of the Mesaverde Formation reach a maximum thickness of 240 feet (Dane, 1947) in the southern Chama Basin and thin to about 65 feet east and north of Cebolla (Doney). Thick-bedded, massive, fine- to medium-grained, olive-gray to tan, friable arkosic sandstone make up the basal beds. The medial unit consists of intimately interbedded gray, black, and purple siltstone and shale, coal, and gray-to-white cross-bedded sandstone. The coal beds mined at Monero lie in this middle unit. The interbedded shale and sandstone segment ranges in thickness from 250 feet (southern Chama Basin) to 100 feet (northern Chama Basin). The uppermost part of the Mesaverde Formation is composed of 30 to 80 feet of very fine-grained, thin-bedded, orange sandstone interbedded with gray shale.

Lewis Shale

Overlying the upper sandstone beds of the Mesaverde Formation are nearly 2000 feet of dark-gray, calcareous and arenaceous shale. Within 100 feet of the contact between this unit and the Mesaverde Formation is a zone of pale yellow-orange septarian concretions. Two or more gray, platy sandstone beds up to 10 feet thick crop out 700 to 1000 feet above the base of the formation.

The outcrop pattern of the Lewis Shale is essentially identical to that of the Mesaverde Formation.

Upper Cretaceous Rocks, Undifferentiated

Undifferentiated Upper Cretaceous rocks are present near the Colorado–New Mexico line and west of Gallina as thin wedges between the Lewis Shale and younger sediments of Cretaceous–Tertiary age. This sequence ranges in thickness from 0 to more than 100 feet.

The basal part consists of white, medium-grained quartz sandstone that grades laterally and downward into the Lewis Shale. The upper part is dark-green to black shale and interbedded brown and white sandstone. Dane (1947) and Baltz (1962) included the basal sandstone in the Pictured Cliffs Sandstone and the interbedded shale and sandstone in the Kirtland–Fruitland Formation.

Transitional Cretaceous–Tertiary Rocks

Formations in this category include the Ojo Alamo Sandstone, the Nacimiento Formation, and the Animas Formation. The first and second have been mapped and described by Baltz and the latter by Dane (1946). On Plate 1, the Ojo Alamo and Nacimiento Formations are shown as the equivalent of the Animas Formation south of the township line separating T. 26 N. and T. 27 N.

Ojo Alamo Sandstone

This unit crops out as a thin, westward-dipping layer between the undifferentiated Upper Cretaceous rocks and the Nacimiento Formation from the Rio Arriba–Sandoval county line north to T. 27 N. It ranges in thickness from 110 feet in the south to 200 feet in the north.

Lithology consists of pale yellowish-tan and brown, medium- to coarse-grained sandstone interlayered with thin lenses of olive-green shale. The sandstone is composed of quartz, feldspar, and red to gray-green chert. Cross-bedding is widespread, and the conglomeratic sandstones contain numerous pebbles of volcanic felsite.

According to Baltz, the Ojo Alamo Sandstone is unconformable upon the Kirtland-Fruitland sequence (Upper Cretaceous, undifferentiated of this report). The sequence contains Tertiary flora and possibly Late Cretaceous vertebrate remains, although this latter conclusion depends upon where the base of the formation is drawn.

Nacimiento Formation

This formation crops out between the Ojo Alamo Sandstone, with which it is conformable, and the San Jose Formation, from which it is separated by an angular uncomformity. The maximum thickness of 1750 feet is reached in T. 26 N.

The basal part of the Nacimiento Formation is made up of thick, fine- to coarse-grained sandstone and interbedded olive-green to gray carbonaceous shale. The middle part is dominantly shale with thin, lenticular, green shale beds. The upper part is a cliff-forming, conglomeratic, coarse-grained, arkosic sandstone interbedded with shale.

Baltz assigned a Paleocene age to this formation, based on dating of terrestrial vertebrates.

Animas Formation

From T. 27 N., the Animas Formation represents the Ojo Alamo–Nacimiento interval. The lithology of conglomeratic sandstones and green shale is similar to that described for the Ojo Alamo and Nacimiento Formations. The conglomerates contain clasts of chert, charcoal, quartzite, and, most frequently, andesite. Local thin coal beds interlayer with the shale. The Animas Formation ranges in thickness from 1200 feet in T. 25 N. to 3000 feet at the Colorado–New Mexico line. Dane (1946) stated that it is conformable upon the underlying Fruitland Formation and he assigned a Tertiary–Cretaceous age to it.

CENOZOIC ROCKS

Tertiary System

Rocks of Tertiary age are exposed in western Rio Arriba County within the San Juan Basin and in eastern Rio Arriba County from the Colorado–New Mexico line south along the Tusas Mountains to the Jemez Mountains. Taken together, they occupy about 70 per cent of the county area. In the San Juan Basin, the extensive cover of Tertiary sandstone and shale is similar in lithology to the older Mesozoic rocks. In the eastern part of the county, coarse conglomerate and much intercalated extrusive volcanic rock rest with great angular unconformity upon folded, faulted, and eroded Mesozoic rocks. In the older Paleozoic and Mesozoic sequences, thin laterally persistent formations are the rule, whereas the Tertiary deposits have much lateral variation in thickness and lithology. In general, the Tertiary rocks reflect widespread erosion and deposition related to Late Cretaceous orogeny and widespread concomitant volcanism.

The following discussion of Tertiary formations is divided broadly into rocks that crop out in western Rio Arriba County and those that crop out in eastern Rio Arriba County; the dividing line is drawn roughly between Gallina and Monero. The rocks of these regions are subdivided by sedimentary and volcanic origins. Volcanic clastic rocks are included in the sedimentary group.

Western Rio Arriba County

The San Jose Formation is the only formal stratigraphic unit of Tertiary age recognized in this area. Igneous rocks are subdivided on the basis of lithology and structure.

San Jose Formation. The sandstone-shale sequence overlying the Tertiary–Cretaceous transitional sediments is included within the San Jose Formation following Baltz's usage. These same beds were long referred to as the Wasatch Formation and were so described by Dane (1946).

The eastern limit of exposure of the San Jose Formation follows an irregular path north and northwest from a point several miles west and south of Gallina on the Rio Arriba–Sandoval county line to the Colorado state line in T. 32 N., R. 4 W. All rocks exposed west of this limit are in the San Jose Formation except for a small area of the Nacimiento Formation at Lybrooks and scattered basalt dikes southwest of Lumberton; thus, this formation occupies about 80 per cent of western Rio Arriba County and nearly a third of the entire county, or about 2000 square miles!

The San Jose Formation includes nearly 2000 feet of intertongued gray, tan, and reddish-brown sandstone and conglomerate and variegated gray and red shale. The basal beds consist principally of sandstone, are about 100 feet thick, and are conformable upon older rocks. These beds grade upward into from 800 to 900 feet of banded shale and interbedded thin sandstone beds. The shale-sandstone part of the sequence is transitional upward into sandstone with an observed thickness of about 1000 feet. Greenish-gray beds containing biotite flakes and andesite pebbles lie above the basal sandstone sequence in the northern part of the outcrop area (Dane, 1946).

Baltz subdivided the San Jose Formation into members in the southeastern part of the San Juan Basin, but his units are not used on Plate 1 because of the time required to delineate them throughout the rest of the basin.

Augite andesite. The eroded remnant of an augite andesite sill is exposed three miles north of Dulce over an area of about two square miles and forms the bulk of Archuleta Mesa. Dane's (1947) description is given below:

> The augite andesite sill of Archuleta Mesa is intruded into rocks of the Animas formation. The sill is more than 300 feet thick, and is generally concordant with the underlying beds. The beds of the Animas formation above the sill are present only in small areas near the southern edge of the mesa and are remarkable for the almost total absence of metamorphism. The sill is believed to be somewhat older than the lamprophyre dikes described below, which are probably of Miocene age, and it is cut by faults that are probably of late Miocene age. Like the dikes, the augite andesite of Archuleta Mesa is believed to have been intruded at some stage of the Miocene.

Lamprophyre dikes. A swarm of widely spaced lamprophyre dikes crops out in the northeastern part of the San Juan Basin west and south of Monero. Dane (1947) described the lithologic and structural features of these dikes as follows:

> The swarm of lamprophyre dikes that cut the rocks of the northwestern part of the area extends southward for nearly 40 miles from

the Colorado–New Mexico line and has a width of nearly 15 miles. The dikes range from 1 foot to nearly 30 feet wide. Typical dikes have a coarse-grained central phase about 2/3 the width of the dike, and dense or fine-grained chilled border phases. They are bordered by hard black baked shale and whitened siliceous sandstone. Most of the dikes are vertical or nearly so, but dips of 70° are not uncommon. Locally the tops of segments of the dikes mushroom, or spread out into flat sills, a few tens of feet in width. In the general vicinity of Archuleta Mesa there are several sills, locally as much as 10 feet thick and extending laterally for slightly more than a mile. The dikes are even more irregular than shown on the map. Discontinuity is typical; dikes split and fork; and double dikes, or short segments of dikes paralleling longer and more continuous segments, are common.

The dikes were intruded subsequent to the major period of folding of the rocks. They probably were later than the intrusion of the Archuleta Mesa sill, which they seem to avoid as if it had been a pre-existing rigid mass. On the other hand they preceded at least some of the faulting, as did the intrusion of the Archuleta Mesa sill. They are therefore believed to have been intruded at some stage of the Miocene. Under microscopic examination the dikes are seen to be chiefly biotite-hornblende lamprophyres having considerable range of mineralogical composition.

Eastern Rio Arriba County

El Rito Formation. The basal stratigraphic unit underlying the Tertiary succession in eastern Rio Arriba County is El Rito Formation. This unit was named by H. T. U. Smith (1938) from exposures along El Rito Creek and in the Ortega Mountains. Smith, Budding, and Pitrat mapped the formation south of El Rito but included the Ritito Formation between El Rito and Abiquiu. Doney, Bingler (1968a,b) and Muehlberger (1968) have mapped the unit north of El Rito.

El Rito Formation crops out as a narrow, irregular arc extending from Banco Largo two miles southeast of Coyote northeast to El Rito, then north along the Canjilon escarpment, ending north of Brazos Creek in a series of irregular erosional remnants. Scattered exposures of El Rito Formation in fault blocks are present in Arroyo Seco north of El Rito and in the western part of the Ortega Mountains in Cañon de la Madera and near Valle Grande Peak.

El Rito Formation includes breccia, boulder-to-cobble conglomerate, and medium-grained sandstone. The conglomerate matrix and sandstone consists of quartz sand with a silica and hematite cement. Clasts are almost entirely gray to bluish-gray specularite quartzite. Small amounts of other Precambrian rock types are present locally. The percentage of angular quartzite clasts is high near contacts with Precambrian rocks, but throughout most of the formation, the clasts are subrounded to rounded. Where the formation rests unconformably upon Precambrian rocks, it consists of a coarse breccia of the underlying crystalline rocks. Within a few tens of feet of the contact, however, the breccia grades into conglomerate that in turn grades westward into sandstone. The east-west transition from coarse to fine facies occurs from south of El Rito north to the Brazos high country, strongly supporting the conclusion that the Precambrian core of the Tusas Mountains provided most of the detritus. The formation ranges in thickness from 200 feet in the Ortega Mountains to 60 feet five miles west of Abiquiu.

Doney notes that El Rito Formation does not maintain its characteristic brick-red color where it rests upon Cretaceous yellow sandstone and gray shale. Instead, the formation in these areas is pale orange to pink to yellowish-gray and locally poorly cemented. These relations are best shown along the Canjilon escarpment east of Cebolla.

El Rito Formation rests unconformably on older rocks ranging in age from Precambrian to Late Cretaceous. The overlying Ritito conglomerate for the most part rests disconformably upon El Rito, but locally in Arroyo Seco and along the Canjilon escarpment, El Rito lithology grades laterally and vertically into unconsolidated Ritito gravel.

Long-distance correlations with Tertiary conglomerate in Colorado suggest a late Paleocene to early Eocene age for this El Rito Formation (Doney).

Blanco Basin Formation. Arkosic sandstone and conglomerate of the Blanco Basin Formation crop out as an irregular thin band and several isolated masses along the northwest flank of the Tusas Mountains from the Colorado–New Mexico line south to the Rio Chaves. This unit crops out entirely within the Chama 15-minute quadrangle and has been described in detail by Muehlberger (1967).

The Blanco Basin Formation consists of from 250 to 350 feet of well-cemented arkosic conglomerate interbedded with sandstone and siltstone. The fine-grained beds and conglomerate matrix range in color from reddish purple to light gray. Clasts in the conglomerate are pink granite, granitic gneiss, mica schist, and mica gneiss. The clasts are subangular to angular.

Muehlberger (1967) correlated the Blanco Basin Formation with part of the San Jose Formation, based upon lithologic similarity. He also noted that the Blanco Basin and El Rito Formations intertongue north of the Chaves Box.

Ritito Conglomerate. The Ritito Conglomerate was first defined by Barker in the Las Tablas quadrangle. Since then, it has been found to extend along the crest and western flank of the Tusas Mountains from north of the Rio Cañones to El Rito (Bingler, 1965; Doney; Muehlberger, 1967). South of El Rito, it has been mapped as part of El Rito Formation and the Abiquiu Tuff, which extend nearly to the Rio Arriba–Sandoval county line. Isolated exposures of Ritito Conglomerate occur along the axis of the Tusas Mountains, in La Madera Mountains, the Ortega Mountains, near Cañon Plaza, and west of Hopewell Lake. In these areas, the conglomerate is exposed in uplifted fault blocks or resting unconformably upon Precambrian rocks.

The Ritito Conglomerate consists of rounded to angular pebble-to-boulder-size clasts of Precambrian rock types, including predominantly quartzite, muscovitic quartzite, leptite, gneiss, and hornblende-chlorite schist. The conglomerate matrix comprises poorly sorted, angular to subangular quartz grains. Feldspar and mica are relatively rare as matrix constituents. The typical color of the formation is gray to brownish gray.

The distribution of various metamorphic rock types varies in the formation. Specularite quartzite is the principal clast type, and in areas where the conglomerate rests upon Precambrian quartzite, all the clasts are this rock type. Even accessory minerals in the quartzite clasts reflect local source areas; for example, at La Madera Mountain, fragments in the Ritito Conglomerate contain the prominent sillimanite tufts noticed in the bedrock of that area, whereas in the Ortega Mountains, only kyanite quartzite occurs as clasts. Wherever the lithology of the Precambrian changes, conplementary changes occur in the composition of adjacent Ritito Conglomerate. This kind of compositional variation results in a rather heterogeneous unit, yet the Ritito can everywhere be separated from younger volcanic conglomerates by the absence of volcanic detritus.

The Ritito Conglomerate is largely disconformable upon, and only locally gradational into, the underlying El Rito Formation. The gradational contact between these two units is best seen in exposures along the east flank of Arroyo Seco, three to four miles north of El Rito. In this area, dissected fault blocks expose characteristic red matrix, gray quartzite, clast El Rito grading upward and along the strike into weakly cemented, angular clast, gray Ritito Conglomerate. In general, gradational contacts between these two formations are prevalent in or very near the Precambrian source areas, and disconformable contacts are common along the fringe of the Tusas Mountains where the underlying El Rito Formation contains a higher percentage of fine-grained sediment.

Conejos Formation. The Conejos Formation, named by Larsen and Cross (1956) from localities in the extensive volcanic sequence in the San Juan Mountains of southern Colorado, consists of a lower part composed of tuff and conglomerate and an upper, thicker part composed of quartz latite flow breccia and agglomerate. It crops out in a roughly elliptical area extending from the New Mexico–Colorado line south to the Rio Brazos and from a few miles east of Chama east to San Miguel. Exposures tend to occur in polygonal segments because of the numerous faults in the area. Rock tentatively assigned to the Conejos Formation crops out in the Rio Tusas drainage four to five miles east of Hopewell Lake.

The lower part of the Conejos Formation is composed of from 150 to 250 feet of light orange to pinkish-white to grayish-white fine-grained tuff and graywacke interbedded with cobble conglomerate. The clasts in the conglomerate are principally granite and metamorphic rocks. The upper part, ranging in thickness from 1000 to 1300 feet, is made up of poorly sorted quartz latite to olivine latite flow breccia and agglomerate. Some basalt and rare tridymite latite are also present. The over-all color of the upper unit ranges from gray to grayish green to purplish gray to reddish purple. The dark-colored fragments of quartz latite contain prominent phenocrysts of plagioclase, biotite, pyroxene, and hornblende. Bedding planes are irregular throughout the formation and individual beds tend to be crudely intercalated and discontinuous.

The Conejos Formation intertongues with the Ritito Formation near Brazos Peak. It is believed to rest disconformably upon the Blanco Basin Formation (Muehlberger, 1967), but this contact has not been observed. A Miocene age has been assigned to the formation in Colorado (Larsen and Cross, 1956).

Treasure Mountain Formation. Ash fall tuff, welded tuff, flow rock, and fluviatile volcanic sandstone and conglomerate of the Treasure Mountain Formation, also named by Larsen and Cross (1956) from Colorado, disconformably overlies the Ritito and Conejos Formations in the northern Tusas Mountains. This formation has essentially the same distribution as the Conejos Formation but occupies less area.

Gray to black, vitreous, porphyritic quartz latite to andesite overlain by reddish brown porphyritic flow rock of similar composition makes up the basal part of the Treasure Mountain Formation. A medial sequence of ash fall tuff, tuff breccia, tuffaceous sandstone, and conglomerate and mudstone comprises the clastic, in part, fluviatile portion of the unit. These detrital rocks range in color from pale pink to dark gray and are about 150 feet thick. The uppermost beds are light gray to grayish red, fine-grained, porphyritic, glassy to fragmental welded tuff. The maximum thickness of these upper beds is 100 feet in Los Pinos Canyon.

The thickness of the formation ranges from 300 feet near San Miguel to 60 feet along the southern limit of exposures. The southward thinning results from the disappearance of the lower vitric beds and thinning of the clastic sequence and welded tuff. Butler (1946) remarked that if the welded tuff layer were not present, the clastic beds of the Treasure Mountain Formation would be indistinguishable from conglomerate of Los Piños Formation.

Los Piños Formation. Los Piños Formation, earlier referred to as

Los Piños Gravel (Atwood and Mather, 1932) and redefined by Butler from exposures in north-central Rio Arriba County, includes nearly all the volcanic and volcanic clastic rocks in the Tusas Mountains. The type area of Los Piños Formation lies east and north of the central Precambrian complex in the Tusas Mountains and has been described in detail by Butler; Los Piños Formation along the west flank of the Tusas Mountains has been described by Barker, Bingler (1965), Doney, and Smith, Budding, and Pitrat. Butler named four members, a basalt member and three based upon variation in the lithology of volcanic clasts. This report uses only the Jarita Basalt Member and includes all the conglomerate within Los Piños Formation.

Exposures of Los Piños Formation form a broad, though somewhat irregular, mantle about the crystalline core of the Tusas Mountains. Outcrops extend from Ojo Caliente north to the Colorado–New Mexico state line and from the Canjilon escarpment east to the Rio Arriba–Taos county line. This represents an outcrop area of about 1000 square miles.

Los Piños Formation is a markedly heterogeneous unit consisting of graywacke, tuffaceous graywacke and sandstone, siltstone, pebble-to-boulder conglomerate, breccia, basaltic-to-rhyolitic flow rock, and minor intrusive masses. The over-all color of the formation is light gray to grayish tan. Fine- to medium-grained tuff, graywacke, and arkose predominate, with conglomerate in the form of thin and discontinuous wedges, lenses, and individual beds forming less than 30 per cent of the formation. The distribution of rock types and textural changes indicate a source area for most of the formation centered near Tres Piedras or farther east under the present Taos Plateau. Conglomerate beds thicken and become more numerous from west to east across the Tusas Mountains, pyroclastic material and flow breccia are essentially limited to the Petaca–Tres Piedras area, and the maximum thickness of nearly 1700 feet is projected into this same area.

Stratigraphic relationships of Los Piños Formation are complex and vary locally. In the northern Tusas Mountains, Los Piños rocks rest disconformably upon the Treasure Mountain Formation. Farther south along the Canjilon escarpment, Los Piños rests upon and is gradational into the Ritito Formation. Around the west flank of the Ortega Mountains and from La Madera north to Vallecitos and Petaca, Los Piños Formation intertongues with Ritito Conglomerate and the Santa Fe Formation. In the northeastern Tusas Mountains, near San Antonio Peak, basalt of the Hinsdale Series unconformably overlies Los Piños Formation. The stratigraphic and sedimentologic features of the formation indicate that pyroclastic and extrusive rocks with a source along the eastern margin of the Tusas Mountains were rapidly eroded and transported westward to mingle with coarse detritus locally derived from a Precambrian terrain of subdued relief. The volcanic detritus spread south and west to the vicinity of the Jemez Mountains (upper part of the Abiquiu Tuff).

The age of Los Piños Formation is estimated as Oligocene to Miocene, based on stratigraphic relationships. A sample of intraformational rhyolite welded tuff collected west of Petaca yielded a potassium-argon age of 25.9 [$\pm$ 1.8] million years.

Jarita Basalt Member. A composite unit of basalt composed of several flow units exhibiting primary variation in the development of amygdaloids and marked variation in degree of secondary alteration occurs within Los Piños Formation and is referred to the Jarita Basalt Member (Butler). The type area occupies the western flank of Mesa de la Jarita east of Vallecitos where it reaches a thickness of about 30 feet. Butler noted 100 feet of basalt in the Tusas–Tres Piedras area and Bingler (1965) recorded 160 feet exposed in La Madera quadrangle.

The basalt ranges from dark, rusty brown to gray to greenish gray, is locally porphyritic and amygdaloidal, and is commonly vesicular.

Nearly all exposures of the member occur as isolated masses correlated on the basis of composition and stratigraphic position. The most extensive exposures are west of San Antonio Mountain, but individual remnants of flow rock extend south to Ojo Caliente.

Abiquiu Tuff. In 1938, H. T. U. Smith gave the name *Abiquiu Tuff* to exposures near Abiquiu of a thick sequence of water-laid tuffaceous conglomerate, minor intercalated flow rock, and conglomerate containing only Precambrian rock fragments. Subsequent geologic mapping (Butler; Barker) resulted in the naming of Los Piños and Ritito Formations for rocks of similar lithology in the Tusas Mountains. Reconnaissance mapping of the Valle Grande Peak and El Rito quadrangles (Bingler, 1968a,b) bridges these two areas. On the basis of this work, it is the writer's opinion that the lower 300 feet of Precambrian clast gravel included in the Abiquiu Tuff are the lateral equivalent of the Ritito Conglomerate and that the upper 1000 feet of conglomerate represent the southwestern extension of the volcanic Los Piños Formation. This correlation is based on composition and stratigraphic position. Also, Smith (1938) indicated outcrops in the Ortega Mountains, Ojo Caliente area, and La Madera–Petaca area as Abiquiu Tuff. In these areas, the volcanic conglomerate is directly traceble into the type area of Los Piños Formation.

Unfortunately, outcrops of Los Piños Formation east and north of El Rito Creek can not be traced into outcrops of Abiquiu Tuff west and south of El Rito Creek because of a broad apron of Quaternary gravels and faulting north of Sierra Negra (Bingler, 1968a). For this reason, the volcanic conglomerate and Precambrian clast conglomerate west of El Rito Creek are shown as Abiquiu Tuff on Plate 1.

Outcrops of this unit extend southwestward from El Rito in a narrow irregular strip along the western margin of the Rio Grande trough past Cerro Pedernal to south of Coyote.

The lower part of the Abiquiu Tuff is gray to grayish-pink conglomerate. Pebble-to-cobble-size clasts of porphyritic granite, granite gneiss, schist, quartzite, amphibolite, and leptite are set in a fine- to medium-grained matrix of quartz and feldspar. Smith (1938) noted that the lower gravel graded upward into water-laid tuff, but along the southeastern flank of Arroyo del Cobre north of Abiquiu, the grayish-pink Precambrian clast gravel changed upward to gray tuffaceous sandstone in a vertical stratigraphic interval of only a few feet.

The upper part of the Abiquiu Tuff is similar in every way to Los Piños Formation already described, except that it is finer grained and grayish white. Discontinuous thin beds of gray-brown limestone and jasper occur in the formation, with the limestone being restricted to the base of the unit (Smith, 1938).

Santa Fe Formation. The Santa Fe Formation consists of poorly consolidated pinkish-brown to yellowish-tan, fine-grained arkosic silt and sand; thin, discontinuous pebble beds are common, and much of the sand and silt are cross-bedded. Where the sediments are consolidated, the cement is generally calcium carbonate, but locally some faults are marked by elongate, planar, nearly vertical zones of silicification. Thin, interbedded basalt flows and gray to white tuff layers are prevalent in the southern part of the county.

Exposures of the Santa Fe Formation are restricted to the Rio Grande trough from south of Santa Clara Pueblo north and east to Servilleta Plaza. It extends from Abiquiu in the west to Truchas in the east. In all, the Santa Fe Formation occupies an outcrop area of about 300 square miles or about 5 per cent of the county area. The total thickness of the Santa Fe is not known but estimates range from 1000 to 7000 feet.

The Santa Fe Formation intertongues with Los Piños Formation over a large area from the badlands east of El Rito Creek through Ojo Caliente, La Madera, and Servilleta Plaza. In these areas, the pinkish-purple sandstone and conglomerate beds of Los Piños Formation are prominently intercalated with the buff siltstone of the Santa Fe. The contact zone represented by this interfingering appears to rise stratigraphically westward, although the absence of any key beds makes it very difficult to be certain of this conclusion.

The Santa Fe is relegated to formation status in Rio Arriba County because the Ancha Formation of the Santa Fe Group (Spiegel and Baldwin, 1963) has not been differentiated. Unconsolidated gravel, disconformable on the Santa Fe sediments has been included in the map unit, Quaternary–Tertiary gravel.

Dacite. Dacite and quartz latite flow rock occupies much of the northern Jemez Mountains in south-central Rio Arriba County. This unit is disconformable upon the Santa Fe Formation, the Abiquiu Tuff, and some of the basalt in the Quaternary–Tertiary Basalt unit and is disconformably overlain by the Bandelier Tuff. Ross, Smith, and Bailey (1961, p. 139) indicate a maximum thickness of 2000 feet of dacite, with individual flow units up to 800 feet thick.

Transitional Tertiary–Quaternary Rocks

Rocks included in this category range in age from Tertiary to Quaternary, including basalt found in the Jemez Mountains, basalt of the Hinsdale Series (Butler), and Recent basalt flows and cones in the Brazos high country (Doney; Muehlberger, 1967). The other major stratigraphic unit is gravel mapped as the Puye Gravel, the Ancha Formation, and the Servilleta Formation. No attempt was made to correlate widely scattered deposits, and no correlation is implied by inclusion within one map unit.

Basalt

Basalt flows and cinder cones, ranging in age from Late Tertiary to Recent, are included within this unit. Individual flows range from a few feet up to nearly 100 feet, depending upon the original thickness and the degree to which that thickness is reduced by erosion. In general, the basalt is gray to reddish black, dense, locally porphyritic, and vesicular and exhibits a wide range in weathering effects.

The most extensive outcrop of basalt occurs in the northeastern corner of Rio Arriba County near San Antonio Mountain and in several isolated masses south of Tres Piedras. Butler described these rocks and included them within the Hinsdale Series as the Cisneros, Dorado, and Servilleta Formations. These flows are part of the extensive basalt cover of the Taos Plateau. Farther south, between Espanola and Dixon, the southern edge of the Plateau is represented by the thin basalt cap of Black Mesa and smaller, unnamed peaks. In the Jemez Mountains, basalt flows are both younger and older than the dacite and quartz latite flow rock (Ross, Smith, and Bailey, 1961). These basalts, the result of coalescing flows, are distributed in an irregular mantle from west of Espanola to south and east of Coyote. Near Abiquiu, basalt overlies a major post-Santa Fe Formation fault. Isolated Recent flows and cinder cones are present along the west flank of the Tusas Mountains. These have been mapped by Doney and by Muehlberger (1967) and are most numerous near Brazos Canyon. Thin, scattered, near-vertical basalt dikes intrusive into the Santa Fe Formation are included in this map unit. They tend to occur in swarms of subparallel dikes and are commonly intruded along fault planes. These dikes are exposed west of Chili three to four miles from the Rio Chama, west of Abiquiu, and along El Rito Creek.

Gravel

Gravel of uncertain age that is disconformable on the Santa Fe Formation in the vicinity of Espanola is shown on Plate 1 as QT gravel. It includes the Ancha Formation, the gravel member of the Servilleta Formation, and the Puye Gravel (Miller, Montgomery, Sutherland; Ross, Smith, and Bailey, 1967).

Miller (Miller, Montgomery, Sutherland) described the gravel between Truchas and Dixon as crudely bedded conglomerate consisting of detritus ranging in size from silt to large boulders. Many of the clasts are composed of resistant Precambrian quartzite. The gravels are up to 300 feet thick and represent the eroded remnant of a once extensive alluvial fan complex developed along the fault border of the Sangre de Cristo Mountains. They are not regarded as Recent in age because of deep dissection, pronounced weathering of volcanic clasts, and development of a two-foot-thick caliche layer at the top of the gravels.

West of the Rio Chama and Rio Grande, Smith (1938) described 30 to 100 feet of dominantly gray, coarse gravel interbedded with lenses of silt, sand, and water-laid tuff. As in the Truchas–Dixon area, these gravels are calichified and dissected and now stand high above present stream level. They presumably represent volcanic detritus derived from the Jemez Mountains.

Quaternary System

Bandelier Tuff. The Bandelier Tuff includes up to 1000 feet of rhyolitic welded tuff that is unconformable on all older rocks in and around the Jemez Mountains. Its distribution has been mapped in detail by Ross, Smith, and Bailey (1967). The welded tuff crops out in steep-walled canyons in the northern Jemez Mountains and as isolated mesa caps from southwest of Espanola to Arroyo del Agua.

The Bandelier Tuff comprises an upper cliff-forming part and a lower part that weathers to more subdued forms. It is composed of pumice fragments throughout, but lithic inclusions tend to be more common in the lower part. It is gray white to grayish tan on a fresh surface and tends to weather to a light orange-tan color.

An age of 1.03 $\pm$ 0.1 million years has been determined by the potassium/argon method for the Bandelier Tuff in Sandoval County (Damon, 1963, p. 13).

Rhyolite. Four small masses of intrusive rhyolite crop out on the north flank of the Jemez Mountains. These are the youngest volcanic rocks in the Jemez Mountains and are believed to represent a ring dike complex (Ross, Smith, and Bailey, 1961, p. 141). A potassium/argon age of from 0.7 to 1.04 million years has been determined for these rocks (Doell and Dalrymple, 1966, p. 1061).

Andesite. This map unit (pl. 1) is limited to the extrusive andesite to quartz latite of San Antonio Peak, fourteen miles north of Tres Piedras. Butler described this rock as "two varieties of hypersthene-bearing rock. The more abundant rock is medium gray to slightly green-gray, aphanitic, sparsely porphyritic, somewhat vesicular. The other is a distinctive black, glassy slightly porphyritic rock that breaks with a good conchoidal fracture."

Glacial deposits. Isolated patches of glacial gravel, sand, and silt are present in the northern Tusas Mountains from Hopewell Lake north to the Colorado line. Most of these deposits represent terminal, lateral, recessional, and ground moraines related to alpine glaciers of probable Wisconsin age. Only Muehlberger (1967) has mapped glacial deposits in Rio Arriba County in any detail. Smith (1935) named the Canjilon Till in the Magote Peak area, but these gravels are almost certainly lag gravels resulting from the erosion of El Rito and Ritito Formations (Smith, Budding, and Pitrat).

The glacial deposits are characteristically poorly sorted and consist of bedrock clasts ranging in age from Precambrian through Tertiary, arkosic sand, and silt. Individual masses of till seldom exceed 50 feet in thickness.

Calcareous tufa. Calcareous tufa, the porous variety of travertine, forms a complex, multilayered deposit along the Rio Ojo Caliente at the west base of La Madera Mountain. The lithology and areal extent of this deposit are discussed in detail under *Ore Deposits.*

Landslide deposits. Extensive landslide deposits are exposed along the Canjilon escarpment and in the northwestern part of the Jemez Mountains. They have been mapped by Doney; Muehlberger (1967); and Ross, Smith, and Bailey (1967). In the northern Jemez Mountains, landslide debris is generally associated with mesa caps of basalt supported by the weakly indurated Abiquiu Tuff. A similar condition exists along the southeast flank of Black Mesa where basalt is poorly supported by sand and silt of the Santa Fe Formation.

The largest areas of landslide features are east of Cebolla and Tierra Amarilla. Doney described this area in detail and ascribed the landslides to earth flow and slump where Mancos Shale is the bedrock.

Muehlberger (1967) noted that in the Brazos high country, landslides involve glacial deposits, indicating a Pleistocene or Recent age for some of the slides.

Inasmuch as sliding can be expected to continue in the areas indicated on Plate 1, any construction in these areas is subject to extreme foundation-stability problems.

Alluvium. Alluvial sand, silt, and gravel form a thin veneer over bedrock in the middle and lower reaches of nearly all perennial and intermittent streams within the county. However, only alluvial fill of the larger streams and rivers in the county is shown on Plate 1. Where dissection reveals a vertical section through alluvial deposits, they are nearly always composed of lenticular beds of interlayered gravel and finer sediment. Within individual beds, the sediment is well sorted, but deposits as a whole are poorly sorted. Clasts in gravel are generally well rounded. Precambrian quartzite and Tertiary volcanic rocks tend to resist abrasion and therefore are the dominant rock types.

Structure

Rio Arriba County includes several major tectonic provinces and a large variety of structural features within its borders. Strike-slip, thrust, and normal faults are present, as are folds in both crystalline and sedimentary rocks. The age of these many structural elements ranges from Precambrian to Tertiary. Joints are ubiquitous but are not discussed in this report.

The discussion of the diverse structure displayed in Rio Arriba County is arranged by associated features of regional tectonic elements. These are, in approximate chronological order, the crystalline province, eastern San Juan Basin, Chama Basin, Gallina fault zone, Tusas uplift, and the Rio Grande trough, including western and eastern marginal features. Additional sections discuss structural trends and the structural control of ore deposits.

CRYSTALLINE PROVINCE

The crystalline province in Rio Arriba County includes the areas of Precambrian rock exposed along the axis of the Tusas Mountains and in the southern Sangre de Cristo Mountains. Internal structures, such as folds and metamorphic planar and linear structures, are discussed later, in addition to faults of possible Precambrian age. The internal structure of the Precambrian rocks in San Pedro Mountain has not been studied; consequently, this area is omitted from the discussion.

SMALL-SCALE STRUCTURES

Bedding, schistosity, fracture and slip cleavage, mineralogic and textural lineation, and drag folds are present in the Precambrian rocks of Rio Arriba County. Some, or all, of these structures have been mapped by Barker, Montgomery, Bingler (1965), and Muehlberger (1967).

Bedding and festoon cross-bedding have been identified locally in quartzite. Individual bedding planes are marked by thin, layered concentrations of specular hematite and rounded zircons that presumably represent heavy mineral concentrations in an original quartz sandstone. Thin, pebbly layers up to one foot thick are common indicators of bedding. These planar structures are well displayed in Jawbone Mountain and the large quartzite mass near Hopewell Lake. Farther south in the Ortega Mountains, the sedimentary structures are intensely deformed and accompanied by much pseudobedding of tectonic origin (Lindholm, 1964; Bingler, 1965).

Schistosity produced by the preferred orientation of small muscovite, biotite, and chlorite flakes is ubiquitous in the Precambrian rock types other than quartzite and granite prophyry. A mineralogic lineation is invariably present in the plane of schistosity. In La Madera–Vallecitos area of the southern Tusas Mountains, Bingler (1965) found this schistosity to be an axial-plane cleavage to southwest-trending isoclinal folds. The lineation paralleled the axis of the folds. In 1966, Bingler and Muehlberger (reconnaissance survey) found the same structural relationships exposed in the canyon of the Rio Brazos, in the northern Tusas Mountains. Whether or not this ancient fold system will be found throughout the Precambrian of the Tusas Mountains must await further detailed structural study.

Fracture cleavage in quartzite and slip cleavage in micaceous rocks are present throughout the Tusas Mountains. These cleavages are axial-plane structures of several fold systems and occur superimposed in numerous outcrops. They tend to occur in zones of closely spaced cleavage development, especially along the axial region of both small-scale and regional folds. Between zones of intense development, cleavage planes are widely spaced or absent. Lineation produced by the intersection of these axial-plane cleavages with bedding, schistosity, or another generation of cleavage identifies the orientation of regional fold axes.

Planar structures are concentrated into northwest and west trends in the Tusas Mountains. Schistosity, which is parallel to bedding except in the noses of isoclinal folds, generally dips to the southwest and strikes northwest. Axial-plane cleavage in northwest-trending folds has a similar orientation. In La Madera and Hopewell Lake areas, late fracture and slip cleavages strike west and have a steep dip.

Because of repeated deformation of regional extent in the Tusas Mountains, the relationship between various generations and orientations of cleavage and lineation is exceedingly complex. Bingler (1965) gives a detailed analysis of these structural features in the southern Tusas Mountains.

Three fold systems of regional extent have been recognized in the Tusas Mountains. The earliest system consists of isoclinal flow folds, much sheared and flattened, with northwest-striking axial planes and axes that bear and plunge to the south-southwest. The second system consists of nearly isoclinal folds overturned to the northeast and trending northwest (Bingler, 1965; Barker; Muehlberger, 1960). These folds change trend from northwest to west at La Madera Mountain, Kiowa Mountain, and Jawbone Mountain, producing a sinuous fold belt with prominent left-lateral offsets or "steps." The third system consists of broad warps and cleavage step folds (Bingler, 1965) mapped in La Madera area.

Metamorphic structures in the Precambrian rocks of the southern Sangre de Cristo Mountains include bedding, schistosity, mineralogic lineation and folds (Miller, Montgomery, and Sutherland). Bedding and cross-bedding marked by specular hematite and zircon have been reported in quartzite. Mineralogic lineation resulting from the preferred orientation of hornblende prisms is present in amphibolite. The principal fold system recognized in this area consists of tightly appressed, isoclinal, west-trending folds.

FAULTS

Several fault zones of uncertain age are discussed in this section. They include the Picuris–Pecos in the southern Sangre de Cristo Mountains and the Vallecitos and Hopewell in the Tusas Mountains.

The Picuris–Pecos fault described by Montgomery and by Miller, Montgomery, and Sutherland is interpreted as a major structural feature of the Sangre de Cristo Mountains, traceable for about 50 miles from Taos to near Santa Fe. It separates granite prophyry to the west from quartzite and Pennsylvanian rocks to the east. The fault trace trends a little east of north and is essentially vertical. First movement on this fault is believed to be right-handed strike-slip, evidenced by a prominent change in strike of thin metamorphic units and fold axes. Later normal separation of about 1500 feet is indicated by the dislocation of Pennsylvanian beds.

In the southern Tusas Mountains, the northwest-trending Vallecitos valley fault zone mapped by Barker and by Bingler (1965) is included here because of an extensive mylonite zone developed near the Ortega Mountains. This crush zone distinguishes the Vallecito valley fault zone from other numerous normal faults in the southern Tusas Mountains and may indicate a long history of movement.

In the northern Tusas Mountains, a similar crush zone is associated with the northwest-trending fault from Burned Mountain to Jawbone Mountain. Although the last movement has been down to the west on this fault, the wide shear zone does not seem in accord with the small dip displacement.

EASTERN SAN JUAN BASIN

The eastern part of the San Juan Basin province of the Colorado Plateau occupies the western third of Rio Arriba County. It is bounded on the southeast by the Gallina fault zone and on the northeast by the broad, and somewhat diffuse, southern extension of the Archuleta anticlinorium. Structural relief of the basin is estimated to be nearly 6000 feet (Kelley, 1955, p. 22).

Along the western flank of the Gallina fault zone, sedimentary rocks ranging in age from Permian to Tertiary dip westward, generally at steep angles, toward the central part of the basin. The strike of these beds changes from north to northeast around the flanks of the breached anticlines that occupy the axis of the fault zone. From Llaves Post Office north, the dip of the sediments decreases gradually northward to the Colorado–New Mexico line, where they dip very gently basinward. The axis of the basin trends north-northwest and lies a few miles west of the erosional edge of the San Jose Formation. Farther west, beds of the San Jose Formation dip gently east.

Along the east-central margin of the basin, from T. 26 N. to a few miles north of the Rio Chama, the basin boundary consists of a much faulted anticlinal warp. This structure bridges the Gallina fault zone and the Archuleta anticlinorium. Faults along the transitional arch are generally short, rarely more than three miles. They tend to strike north or west, parallel or transverse to the axis of the arch. Faults along the west flank have down-to-the-west separation and along the east flank, down-to-the-east separation. The average displacement on these faults is about 100 feet.

The trend of the basin margin is interrupted farther north by northwest-trending folds near Horse Lake and Tecolote Mesa. Two gently dipping limbs of these folds are separated by a sharply flexed limb transitional into a west-northwest-trending fault zone to the east. A similar but more subdued set of folds is exposed at Arroyo del Puerto Chiquito. The fold axes bear northwest and plunge gently in that direction. This northeastern limb of the anticline passes eastward into a normal fault with down-to-the-north separation.

The age of the structural depression forming the eastern margin of the San Juan Basin is given as latest Eocene by Dane (1946), who believes that the down-buckling preceded deposition of the Blanco Basin Formation. However, Muehlberger (1967) correlates the Blanco Basin with the San Jose Formation, and the San Jose Formation is folded along the flank of the basin. Baltz emphasized the speculative nature of the Blanco Basin–San Jose lithologic correlation and suggested that the Blanco Basin may be equivalent to only the uppermost part of the San Jose Formation. According to him, the main downwarp began in latest Paleocene or earliest Eocene and intermittent movement continued to late Eocene or early Oligocene.

CHAMA BASIN

The Chama Basin is an elongate, generally north-plunging and -trending, shallow structural and topographic depression. It is regarded as a subsidiary part of the San Juan Basin, being separated from that large structure by the Archuleta anticlinorium and the Gallina fault zone. The Tusas Mountains form the eastern boundary, the Rio Grande trough the southeastern boundary, and the San Pedro uplift the southwestern edge. A marked constriction in the basin occurs between Tierra Amarilla and Chama, resulting in a structural channel only about four miles wide. Maximum structural relief of the Chama Basin measured on the base of the Dakota Sandstone is about 1500 feet (Muehlberger, 1960).

Along the eastern margin of the basin, sedimentary rocks ranging in age from Pennsylvanian to Late Cretaceous are turned up more or less sharply against the crystalline core of the Tusas Mountains and are overlain unconformably by the Blanco Basin and El Rito Formations. Between the Rio Brazos and Magote Peak, Tertiary sediments extend well west of the base of the Mesozoic section and thus tend to obscure the structural margin of the basin. Farther north between Cañones Creek and the Rio Brazos, the eroded edge of the basin is exposed.

The southern margin of the basin is very broad and diffuse. It extends from the eroded edge of the Dakota Formation across the broad valleys of the Rio Chama and Rio Puerco. To the southeast, the basin edge is marked by the sinuous, gently north-northeast-plunging Arroyo del Cobre anticline. Directly south, the flank of the basin is penetrated by a broad arch trending parallel to the Rio Puerco. To the southwest, the southern edge of Mesa Alta marks the boundary of the basin. The southern margin of the Chama Basin as defined is somewhat unsatisfactory because of its irregularity and the complexity of the structural elements that comprise it. It would perhaps be better to restrict the southern boundary of the basin to the erosional edge of the Jurassic sequence along the north wall of the Rio Chama Canyon and the northwest edge of Arroyo del Cobre.

The slightly folded, but much faulted, western edge of the basin is marked by the Gallina fault zone in the south and the Archuleta anticlinorium in the north. The faulted arch linking these two uplifts includes numerous faults that trend north or west. A belt of northwest-trending normal faults extends from the Rio Chama about eight miles southwest of Tierra Amarilla to Archuleta Mesa near the Colorado–New Mexico line. This zone of faults marks the approximate trace of the Archuleta anticlinorium. The prominent west-northwest fault zone interrupts the zone of northwest-trending faults at Tecolote Mesa.

Folds within the basin are limited to numerous small domes and doubly plunging anticlines. The most prominent of these structures are El Cerro, North and South El Vado, Puente, and Lagunas domes and Azotea and Dos Lomas anticlines. These structurally high areas are isolated features that tend to cluster along the eastern flank of the Archuleta anticlinorium and in the basin constriction near Brazos. Anticlinal axes trend northwest parallel to the orientation of the overall basin axis. Structural relief varies from less than 100 feet to about

1000 feet. Dane (1947) and Muehlberger (1967) describe these structural features in detail.

The age of the Chama Basin is believed to be the same as the San Juan Basin. El Rito and Blanco Basin Formations truncate and overlie upwarped Mesozoic beds along the eastern margin of the basin. This is the only direct evidence bearing on the minimum age of the basin and suggests a Paleocene or Early Eocene age. Within the basin, the youngest folded rocks are part of the Late Cretaceous Lewis Formation.

GALLINA UPLIFT

The Gallina uplift refers to the northern extension of the Nacimiento fault in Rio Arriba County. It is a three- to five-mile-wide array of faulted domal structures extending from the Rio Arriba–Sandoval county line north-northeast to Gallina Peak, a length of approximately twenty-four miles. This linear zone of structurally high late Paleozoic and Mesozoic rocks separates the San Juan and Chama basins. A major fault, here termed the *Gallina fault,* parallels the axis of the uplift and splits three domal structures.

The uplift consists basically of three domes or doubly plunging anticlines, elongate in a north-northeast direction and connected by a single fault about eighteen miles long. The southernmost dome, exposed just north of Gallina, is about eight miles long and four miles wide. It is the largest dome in the uplift and includes rocks ranging in age from Permian to Jurassic. The eastern part of the dome is well exposed and structurally high with respect to rocks west of the bisecting Gallina fault. Down to the west, separation on the axial fault has juxtaposed Permian and Jurassic rocks. The medial dome, exposed in the canyon of the Rio Gallina, is the smallest of these three structures along the uplift. It is about two miles long and one mile wide. Beds of Permian, Triassic, and to a lesser extent Jurassic age dip away radially from the core of the dome. The Gallina fault splits this structural high, but in this area, separation on the fault is a few hundred feet down to the east. The northernmost structurally high area is an elongate, doubly plunging anticline slightly asymmetrical where the north-trending anticlinal nose changes to a northwest trend and becomes the Puerto Chiquito anticline. A small area of Pennsylvanian rocks is exposed in the core of the structure just west of the bisecting Gallina fault. Flanking beds disrupted by radial faults of minor separation are of Permian to Jurassic age. Separation on the Gallina fault in this area is minimal at the southern edge of the doubly plunging anticline and several hundred feet down to the west near Gallina Peak.

The Gallina fault is nearly vertical along its eighteen-mile length.

In the southern part near Gallina, the separation is down to the west; farther north, separation varies from down to the east to down to the west.

TUSAS UPLIFT

The Tusas uplift, now represented by the Tusas Mountains, is the topographically and structurally highest area in the county. It has a northwest trend and extends some fifty miles from the Colorado–New Mexico state line to the Taos–Rio Arriba county line near Ojo Caliente. With a structural relief of several thousand feet, it forms a major structural divide between the Chama Basin to the west and the Rio Grande trough to the east.

The Tusas uplift has been a positive area throughout a major part of geologic time. Muehlberger (1960) cites nine separate intervals ranging in age from Pennsylvanian to Quaternary during which the Tusas uplift was an active tectonic feature. These periods of uplift are indicated by stratigraphic thickening and thinning and by the presence of coarse clastic debris in formations along the flanks of the uplift. However, the major period of uplift occurred during the formation of the Chama and San Juan basins.

The uplift is marked by a central spine of Precambrian crystalline rocks now mantled and flanked by coarse clastic volcanic and terrigenous rocks. These younger sediments tend to mask the structural boundaries of the uplift and may conceal pre-Tertiary faults along which some, if not much, of the pre-Tertiary uplift took place. The western margin of the uplift is identical to the eastern boundary of the Chama Basin already described. In the south between El Rito and Ojo Caliente, the edge of the uplift is serrated and irregular where northeast- and northwest-trending normal faults delineate grabens of Tertiary rocks alternating with horsts of Precambrian rocks. The eastern boundary of the uplift is along and perhaps under the featheredge of the Taos Plateau basalts.

Faults and, to a much lesser extent, folds are the internal structural features of the uplift. Folds are limited to the Precambrian rocks. They trend northwest except where deflected in anomalous west-striking belts at Ojo Caliente, Kiowa Lake, and Jawbone Mountain. The distribution of Precambrian fold systems in space and time is complex, and no one has yet succeeded in establishing a causal relationship between Precambrian fold trends and the activity of the Tusas uplift. Faults are numerous and widespread and vary greatly in strike length and amount of separation. The major faults—that is, faults with greatest strike length—are aligned in a northwest direction, except between Ojo Caliente and Servilleta Plaza; here, nearly all the faults trend northeast. In the middle part of the Tusas uplift between Petaca and Hopewell Lake, northwest-trending faults with a strike length up to fifteen miles are connected by short faults nearly at right angles that trend northeast. Separation on these faults tends to average 500 feet with a maximum of 1000 feet. Direction of throw tends to be down to the west and has resulted in a generally eastward dip at 3 to 5 degrees in Tertiary sediments. In the northern part of the Tusas uplift from the Rio Brazos to the Colorado–New Mexico line, the fault trends are more irregular. The dominant trend is still northwest, but numerous arcuate to irregular north-trending faults link the northwest-trending faults. Separation on the faults in this area tends to be minimal and ranges up to several hundred feet.

Although the faults of the Tusas uplift generally have small separations, individual fault traces continue for many miles. The average length of some of the larger faults ranges from ten to twenty miles. One fault can be traced from Chama to Spring Creek, a distance of nearly thirty miles. Some of the present structural and topographic relief in this area is undoubtedly due to movement along the northwest-trending faults that parallel the uplift trend. However, the relatively minor separation on most of the faults, and the absence of any cumulative stepping of faults to produce a high crestal zone, suggests that most of the structural relief is inherited from Laramide crustal adjustments.

RIO GRANDE TROUGH

As the Tusas uplift dominates the northeastern part of Rio Arriba County, so the Rio Grande trough is the major tectonic element of the southeastern part of the county. This troughlike depression trends northeast from Los Alamos–Santa Fe–Rio Arriba county line near Espanola to the Rio Arriba–Taos county line east of Ojo Caliente. It is about thirty miles wide, reaching from west of Abiquiu to the southern Sangre de Cristo Mountains. The part of the Rio Grande trough included within the county boundaries is equivalent to the northern part of the Espanola Basin (Kelley, 1954). In general, the outcrop limits of the Santa Fe and Abiquiu Formations indicate the extent of the basin, except where the younger, overlying volcanics of the Jemez Mountains obscure these units.

The western margin of the trough is defined by an irregular zone of normal faults with dominantly down-to-the-east separation and northeast trend. These faults form a well-defined swarm west of Abiquiu. They emerge from beneath the late Tertiary volcanic rocks of the Jemez Mountains about five miles southeast of Coyote and extend northeastward along the eastern flank of Arroyo del Cobre to the extensive gravel apron southwest of El Rito. North and east of El Rito, the trough margin is very irregular, for northwest-trending faults of the Tusas uplift intermingle. Embayments of structurally depressed Tertiary rocks and elevated prongs of crystalline rocks project north and northeast. Between Ojo Caliente and Servilleta Plaza, in the Vallecitos valley, and in Arroyo Seco, elongate remnants of a once extensive cover of Santa Fe Formation are preserved on the downthrown side of normal faults.

To define the present Rio Grande trough by the erosional edge of Abiquiu and Santa Fe sediments is unsatisfactory. Such a boundary is no more regular than the somewhat tenuous fault boundary. Also, the presence of these sediments beyond the structural boundaries of the trough serves as a reminder that the depositional Rio Grande trough was more extensive than the structural trough defined by late Tertiary faulting.

The eastern margin of the Rio Grande trough parallels the exposed masses of Precambrian rock in the southern Sangre de Cristo Mountains. The actual fault boundary, however, is completely obscured by Quaternary–Tertiary fan gravel. The great differences in elevation of the Truchas Peaks and Santa Fe beds exposed at the foot of the mountains indicate a down-to-the-west separation of many thousand feet.

Numerous faults occur within the trough. Some of these are indicated by silicified zones, such as west of Black Mesa, and some by intrusions of basalt dikes along zones of weakness, as at Window Rock west of Espanola. Otherwise, the absence of extensive horizon markers in the Santa Fe Formation renders the identification and tracing of faults nearly impossible. It is quite likely that many faults have gone unrecognized in the central part of the trough.

STRUCTURAL CONTROL OF ORE DEPOSITS

Structural controls for several types of mineral deposits in Rio Arriba County include metamorphic planar structures, faults, and geologic contacts. These features control the orientation and localization of hydrothermal vein and replacement deposits, pegmatites, tufa, and red-bed copper deposits.

Schistosity and rock cleavage in the Precambrian rocks of the Tusas Mountains appear to control the orientation of mineralized quartz veins, planar zones of altered and mineralized schist, and pegmatites. In the Hopewell and Bromide mining districts, the northwest trend of planar mineralogical zones parallels the oldest and most extensively developed schistosity. Gold-bearing quartz veins in the Hopewell district parallel both northwest-trending schistosity and younger, west-trending fracture and slip cleavages. In the Petaca district, pegmatite lenses, dikes, and sills trend northwest with west dip and west with nearly vertical dip. These orientations parallel regional trends of schistosity and rock cleavage. Thus, in the Precambrian terrain, planar deposits tend to be localized by the regional structural grain. This is, however, a statistical conclusion, and some discordant masses are present locally.

Occurrences of fluorspar, manganese, and tufa are localized along normal faults in the Tusas Mountains. Purple, banded fluorite fills cavities in and near a normal fault south of El Rito near State Highway 96 (*see* detailed description, p. 132). North and west of Abiquiu, manganese seams and veinlets occur in a fault gouge separating the Santa Fe and Abiquiu Formations. North of Ojo Caliente near La Madera Mountain, an extensive deposit of tufa is directly related to hot-spring activity along a major north-south fault zone. All these occurrences appear related to crushing and fracturing effects along fault traces. Open spaces or channels created in this way then serve as conduits for the movement of percolating fluids.

Geologic contacts are an important structural control for red-bed copper occurrences. In these deposits, copper minerals are precipitated largely in oxidized form as carbonates and oxides in conglomerate beds closely associated with red shale and sandstone. Presumably fluids, from which the copper minerals precipitate, are able to circulate through relatively permeable conglomerate but not through impervious shale.

Mining History

Early mining activity in Rio Arriba County mirrors the mining history of New Mexico as a territory and as a province of Old Mexico. Early Spanish explorers passed through north-central New Mexico and noticed occurrences of red-bed copper. The Indian population probably knew of these copper occurrences, as well as of the sheet mica deposits of the Petaca region.

The earliest systematic mining operation centered around the Cribbenville area in the Petaca district, where large books of mica were split for windows in Santa Fe and Espanola (Jahns, p. 102). The earliest modern mining (Just) started about 1870 with the production of sheet mica for stove windows. In this same period, extending from 1865 to 1890, prospectors flooded New Mexico Territory searching for mineral deposits. Their activity resulted in the location of several copper claims east of Cuba and a silver strike in the central Tusas Mountains within what was to become the Bromide district.

By 1900, scrap mica demand accelerated prospecting, and many new mines were located south and north of the Cribbenville area. The market for sheet mica had been steadily declining when a new market in the form of electrical mica about 1912 created a new demand that persisted through the Second World War. Since 1945, most of the mica mined in the Petaca district has been ground and processed for scrap mica. Total mica production for the district is estimated at 850,000 pounds of selected mine-run mica for sheet stock from 1800 to 1946 (Jahns, p. 103). Scrap mica production is estimated at 18,000 tons between 1900 and 1942. For the period 1947 to 1965, total mica production reached 14,271 tons with a value of $807,045 (State Mine Inspector).

Discovery of silver at the Bromide mine prompted rapid expansion of prospecting throughout the Tusas Mountains. During the 1880's, several gold placers were located near the village of Hopewell. Search for lode gold in this area resulted in the posting of numerous lode claims in Placer Creek Gorge (formerly Eureka Creek). Rich pockets of oxidized gold-silver-copper ore soon depleted, however, and the more refractory unoxidized sulfide ores and very thin ore shoots encountered at depth led to a rapid decrease in lode mining about 1890. Small pockets of placer gold in the gorge were worked through 1903, at which time an extensive hydraulicking operation was instituted to wash gravels in a large meadow below the gorge. Within a year, this operation ceased because of low gold values, heavy runoff, and failure of dams near Hopewell. In 1935, the Amarillo Gold Company acquired most of the lode claims in the district and built a 30-ton mill. Thirty-five hundred tons of ore from the Mineral Point and Red Jacket mines were processed over a five-month period. The operation was unprofitable and closed in 1937, at which time the claims were acquired by Rufus Little of Tesuque. Except for an unsuccessful attempt to process gravel by dry-land dredge in 1964, and minor development work by Little, the district has been inactive. Farther south in the Bromide district, only the Bromide mine, owned by John Eddy of Santa Fe, has produced any ore in recent times. Benjovsky (1945) estimated production of placer gold from the Hopewell district at $285,000, most of which sold at $20 an ounce. Production records for lode mines are sketchy or nonexistent, but lode production from the district in gold, silver, copper, lead, and zinc probably totaled about $50,000.

Production of copper from red-bed deposits in the south-central part of the county has been very sporadic. During 1956-1957, 231 tons of copper and 841 ounces of silver were produced almost entirely from the Eureka mine. These metals had a value of $228,000.

MINERAL DEPOSITS

The mineral deposits of Rio Arriba County (pl. 3) exclusive of mineral fuels, are grouped into four categories based upon origin: hydrothermal, magmatic, metamorphic, and sedimentary. Ore deposits of the hydrothermal group include the Hopewell–Bromide gold-silver-copper-lead-zinc-fluorite and molybdenum-copper assemblages, fluorspar in El Rito district, red-bed copper deposits, manganese and hot-spring deposits. Magmatic deposits refer only to the pegmatites of the Petaca district, which are largely, if not entirely, of intrusive igneous origin. Metamorphic deposits refer to syngenetic segregations of iron and kyanite formed during regional metamorphism of Precambrian rocks. Sedimentary deposits include such diverse commodities as limestone, gypsum, kaolinite, expansible shale, diatomite, pumice, sand and gravel, and several types of placer deposits ranging in age from Cretaceous to Recent.

Several deposits could be placed in more than one category, depending upon the accepted mode of origin assigned to the mineral occurrence. Metamorphic deposits of iron, and particularly kyanite, are explained as the result of sedimentary accumulation of iron and alumina prior to metamorphism, as postmetamorphic hydrothermal deposits, and as metamorphic segregations. Thus, the classification of these deposits reflects individual preference regarding origin. Likewise, the secondary gold occurrence at Hopewell Lake is a sedimentary or residual deposit, depending upon a preference for alluvial or colluvial origin. This kind of ambiguity will decrease as future detailed work results in a clearer understanding of the genesis of individual deposits.

The following discussion and description of mineral deposits is subdivided into metallic and nonmetallic sections. Districts, mines, and prospects are arranged within this broad, twofold division. Important details of mining history associated with individual deposits are cited in the description of the deposit.

Metallic Deposits

Included in this section are descriptions of deposits and occurrences of gold, silver, copper, lead, zinc, iron, manganese, and titanium. For the most part, these are discussed under district headings. The Hopewell district includes complex epithermal gold-silver-copper-lead-zinc lodes, metamorphic iron dposits, and placer gold deposits. The Bromide district includes virtually only two mines, the Bromide and Tampa, which contain epithermal suites of gold-silver-copper-molybdenum. The Coyote–Youngsville–Abiquiu area and Senorito district include only red-bed copper deposits. Titanium, manganese, and gold occurrences not restricted to any of these districts are discussed under individual commodity headings. The principal mining districts are located in the Tusas Mountains and are shown in Figure 4.

HOPEWELL DISTRICT

The Hopewell mining district is in the central part of the Tusas Mountains, sixteen air miles west of Tres Piedras and eighteen air miles east of Tierra Amarilla. The district is approximately bounded on the west by the Rio Vallecitos, on the north by Jawbone Mountain, on the east by the Rio Tusas, and on the south by Burned Mountain. This represents an area of about twenty-five square miles, but most of the mines and prospects occupy less than one square mile along Placer Creek southwest of Hopewell Lake. The average elevation in the district is about 9500 feet, and maximum relief is slightly more than 1000 feet. For the most part, the terrain is one of gently rolling hills sparsely to densely covered with pine, spruce, and poplar. Winters at this elevation may be severe, with much snow; summers are cool and very pleasant. The central part of the district—that is, that part shown on the geologic map (pl. 4)—is drained by Placer Creek, which flows southwestward across the map area, and the Rio Vallecitos, which flows southeastward. Both are perennial streams with a moderate flow, except when charged with runoff from melting snowpack in the spring. Hopewell Lake is a man-made body of water formed by construction of an earth dam on Placer Creek. Modest camping facilities are maintained by the U. S. Forest Service, although no shelter is provided. The lake is stocked with fish by the State of New Mexico and draws many sportsmen during the summer months. Several cabins maintained on patented mining claims by Rufus Little constitute the only permanent housing in the area. These facilities are on private property and are not available to the general public.

The Hopewell district is accessible from Tres Piedras to the east and Vallecitos to the south via State Highway 111, which is paved from Tres Piedras to Tusas, and graded gravel roads maintained by the

U. S. Forest Service. Precarious jeep roads extend from Hopewell Lake southwest via Placer Creek Gorge to the lower flat placer area (private) and from Hopewell Lake south-southwest across the densely wooded northern slopes of Burned Mountain (public) to the lower flat placer area. The district is presently inaccessible from the Chama valley to the west.

The location and operation of the Fairview gold placer on Placer Creek in the late 1870's represents the earliest mining activity in the

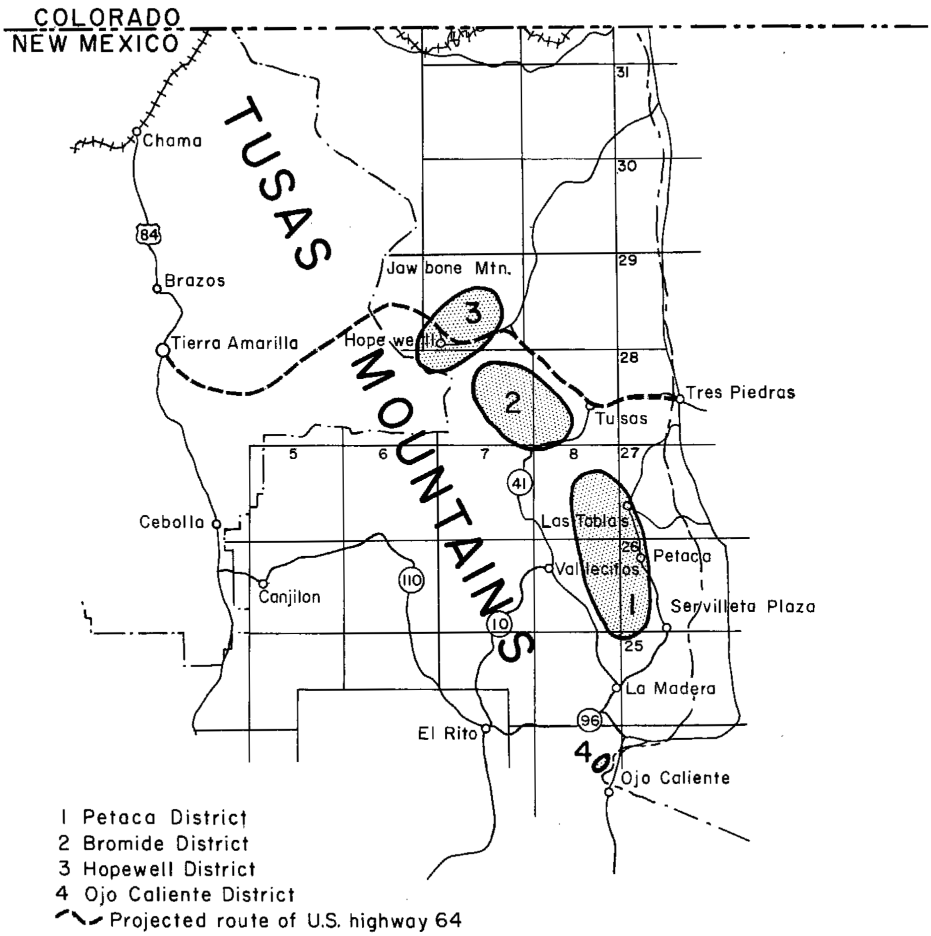


Figure 4

MINING DISTRICTS IN THE TUSAS MOUNTAINS

Hopewell district (Lindgren, Graton, and Gordon, p. 130). The claim was located in the valley of Placer Creek just west of the present site of Hopewell Lake. The richest gravel was found where the valley narrowed immediately above the gorge. The Fairview placer is reported to have produced $175,000 over a three-year period.

The discovery of alluvial gold prompted a search for lode deposits, culminating about 1881 with the location of the Croesus, Clara D., Mary E. Steele, Grand Mogul, and Little Casino claims on replacement veins and quartz veins in Precambrian schist. The upper, thoroughly oxidized, parts of these veins produced several thousand dollars in gold, silver, copper, and lead, but the rapid depletion of oxidized ore combined with narrow ore shoots and low values in the sulfide mineral suite resulted in diminished activity by 1890. Small-scale placer operations on local pockets of alluvial gold in Placer Creek Gorge continued during the period of active lode mining.

In 1903, an extensive hydraulicking operation was set up in the lower flat area southwest of Placer Creek Gorge. A natural lake, formed by talus and other debris that choked the narrow gorge at the southern end of the flat, was drained. Placer Creek was dammed near the Fairview placer claim and overflow was routed to the lower flat through a system of ditches and pipe. Within a year, the operation proved unsuccessful, however, because of the failure of dams on Placer Creek, heavy runoff, and disappointingly low gold values in the gravel. Only the upper 15 to 20 feet of gravel in a narrow strip along the axis of the meadow was washed.

Intermittent, largely one-man operations on lode and placer claims continued until 1935, when the Amarillo Gold Company acquired the Mineral Point claim. The company constructed a 30-ton mill and processed about 3500 tons of ore from the claim. At first, ore was brought by wagon to the mill site on the south side of Placer Creek; later, a trestle was constructed across the creek to connect the mill with the lower levels of the Mineral Point mine. The operation was unprofitable and closed in 1937. About this time, Rufus Little of Tesuque acquired most of the patented claims in the vicinity of the gorge. Little has conducted the only lode mining activity in the district since the late 1930's by minor exploration and development work.

Early in 1964, the Amistad Mining Company located four placer claims in the lower flat area and assembled a dry-land dredge on the site. A small amount of gravel was washed, probably less than 10,000 cubic yards, during the summer months before the project was abandoned. Very low gold values and illness of the principal investor are cited for the project's failure.

The oldest rocks in the Hopewell district are quartzite, schist, leptite, and quartz diorite gneiss of Precambrian age. In the western half of the district, quartzite, schist, and gneiss form a northwest-trending layered sequence. In the eastern part of the district, pink and gray, prominently foliated quartz diorite gneisses intimately intermingle. These ancient crystalline rocks are the host for all the replacement vein deposits in the district.

Younger conglomerate, part or all of which is of Tertiary age, obscures much of the Precambrian terrain. The lower part of the conglomerate sequence is locally derived and includes colluvial, talus, mudflow, and related deposits. Fluviatile volcanic clastic rocks derived from intrusive and extrusive volcanic rocks to the east overlie and grade into the locally derived conglomerates. Northwest-trending normal faults predate glacial deposits. Down-to-the-west separation on several of these faults is probably related to, if not responsible for, the gentle eastward tilt of the Precambrian–Tertiary unconformity and bedding in the volcanic clastic rocks. Quaternary deposits of glacial and alluvial origin now occupy many of the present stream courses and local depressions throughout the district.

Precambrian Rocks

Quartzite

Precambrian quartzite is exposed in a three-quarter-mile-wide belt bounded on the west by a fault contact with Los Piños Formation and on the east by a fault contact with phyllitic schist, leptite, and granular quartzite. in the southern part of this belt, quartzite is overlain by Ritito Conglomerate. Throughout most of the outcrop belt, quartzite is well exposed along ridges and spurs and in subsidiary peaks. In saddles and depressions between spurs and around the large tract of quartzite in general, a thin veneer of quartzite clast Ritito Conglomerate overlies the Precambrian bedrock.

Rock mapped as quartzite consists largely of quartz, is gray, pinkish and bluish gray, granular to vitreous, medium- to coarse-grained, laminated, and pebbly and contains up to 10 per cent specularite and kyanite. The rock contains a prominent slabby parting to weak fracture cleavage that transects gently curved, thin, specularite-rich laminae. A lineation trending about S. 50° W. is formed by the intersection of the slabby cleavage and specularite laminae. This lineation parallels aligned kyanite blades and specularite streaks in the rock cleavage. Bedding marked by pebbly zones and hematite laminae strikes about N. 40°-45° W. and dips from 75°-85° W throughout the quartzite exposures. A superposed fracture cleavage with an average strike of N. 60° E. and dip ranging from 45° NW to 80° SE is present in most outcrops.

Phyllitic Schist

Blue-gray, yellowish-cream to pinkish-brown, and tan phyllitic schist crops out in the gorge of Placer Creek three fourths of a mile southwest of Hopewell Lake. In the southwestern part of the gorge in the central part of sector 4E,* phyllitic schist is in contact with pink porphyritic leptite and in fault contact with Ritito Conglomerate. In sectors 5C and D, it interlayers with amphibolite and quartz diorite gneiss.

As a map unit, phyllitic schist includes two variants, a cream-to-pinkish-green and a blue-gray. Both varieties are very fine-grained with a platy to scaly cleavage and pearly luster. The pronounced platy texture of these rocks varies somewhat as a function of very fine-grained muscovite content. Under the microscope, these rocks are composed of fine-grained quartz, muscovite, and chlorite in about equal proportions. The ratio of chlorite to muscovite accounts for the light- and dark-colored variants prominent in outcrop. The average grain size of constituent mica flakes is about 0.02 mm. Accessory minerals are zircon, tourmaline, opaque iron oxides, siderite, and limonite. In most specimens examined, the mica flakes have a high degree of preferred orientation, producing a markedly lepidoblastic fabric. In some specimens, mica flakes have a more random orientation, resulting in a decussate fabric and a more homogeneous and tough rock in outcrop.

The marked platy texture of phyllitic schist along Placer Creek results from two periods of mica growth. The first generation of mica, both chlorite and muscovite, formed during regional metamorphism of the area and is now represented by a penetrative, regional phyllitic schistosity. A later period of mica growth accompanied the development of a very closely spaced slip cleavage locally transitional into a flow cleavage that in hand specimen completely obscures the older schistosity. This flow cleavage is so well developed in some layers that the rock has been converted to a phyllonite.

Several tabular masses of carbonate greenschist ranging in thickness from 5 to about 20 feet interlayer with the phyllitic schist. These layers consist of dense, compact, weakly foliated, tan schist composed of quartz, sericite, dolomite, chlorite, and siderite. Under the microscope, the rock has a matrix of fine-grained granoblastic quartz, calcite, and decussate sericite irregularly distributed in streamers and islands. Widely scattered poikiloblastic porphyroblasts of dolomite up to 3 mm in diameter, lacelike aggregates of siderite, and clots of chlorite are set in the fine-grained matrix.

Small lenses and augenlike masses of coarse-grained carbonate are irregularly distributed throughout the phyllitic schist. Individual lenses have an average thickness of about 2 inches and an average width of

* *Sector* refers to grid system used for locations on Plate 4.

about 6 inches and range in length up to about 3 feet. All such masses observed had their shortest dimension perpendicular to the schistosity of the enclosing phyllitic schist. The carbonate masses are gray-white to cream-white, are composed almost entirely of dolomite, and exhibit varying degrees of replacement by orange-brown limonite.

Limonite pseudomorphs after carbonate minerals, sulfides, and chlorite are widespread in the phyllitic schist. It is most frequently encountered as a cellular or spongy mat in the form of blebs or nearly spherical aggregates distributed evenly throughout the schistose rock, imparting a distinct, brown-spotted appearance. Similar-appearing limonite occurs as pseudomorphs after pyrite, carbonate porphyroblasts, siderite, and porphyroblastic aggregates of chlorite. In schist with more than one of these phases present, carbonate minerals are the first to be altered or replaced, then pyrite, and last chlorite. Throughout the Precambrian bedrock of Placer Creek Gorge, planar zones representing the site of sulfide replacement veins are now completely oxidized and consist of residual phases only. Interlayered with these zones are areas of schist bedrock containing unaltered pyrite. This distribution of pyritized rock adjacent to completely oxidized replacement vein material suggests that the zone of limonite development in the oxidized zone is very irregular at its base; in fact, irregular to the point of having thin planar "spikes" that project downward along highly sheared and mineralized zones.

Granular Quartzite

Rock mapped as granular quartzite ranges in texture from a coarse-grained quartzite to a metaconglomerate containing flattened fragments of white quartz, phyllite, and pink and black fine-grained quartzite. Thin, arcuate laminae composed of specularite segregations are sparsely developed. On a fresh surface, the rock is gray to pinkish gray, has a silky sheen imparted by sericitic mica, and weathers gray-black.

Outcrops of this unit are restricted to the northwest corner of the map area, where it interlayers with leptite porphyry. The best exposures of granular quartzite are along the west side of the small ridge in sector 2B. Granular quartzite float near the Hopewell fault in the central part of sector 4E suggests the existence of similar bedrock at this locality. However, the steep slopes along the valley wall of Bear Creek between Placer Creek and the central part of sector 2C are so obscured by talus and float from the overlying Ritito Formation that much of the bedrock may be interlayered with granular quartzite and leptite.

The most conspicuous feature of granular quartzite in outcrop and hand specimen is the penetrative phyllitic flow cleavage manifested by sericitic mica. This structural feature is present in all outcrops, has an average strike of N. 40° W., and includes a textural lineation that plunges south at about 50 degrees. The cleavage tends to swirl around equidimensional quartz fragments and flat clasts of phyllite. In some outcrops, a later east-west fracture cleavage is superimposed on the older flow cleavage.

Leptite

Rock mapped as leptite underlies a small part of the map area along the course of Bear Creek from sector 2A to sector 4E. Glacial gravels and colluvial material obscure most of this unit. Sparse outcrops protrude through the debris mantle along the north valley wall of Bear Creek near the common boundary of sectors 2A and B.

The inferred distribution of leptite is as layers several hundred feet wide intercalated with granular quartzite. These layers have an average trend of N. 35° W., and the contacts are transected at low angles by phyllitic schistosity with a more northerly trend. To the south, the leptite unit terminates against the Hopewell fault zone; to the north, it underlies Tertiary and Quaternary gravels.

Leptite is reddish orange to purplish tan, flinty and compact, and very fine-grained and contains from 5 to about 30 per cent rounded quartz grains and subhedral and euhedral pink feldspar crystals. The quartz and feldspar crystals range in diameter from about 1 to 5 mm, averaging about 2 mm. These large grains are set in a very fine-grained matrix of granoblastic quartz, untwinned potash feldspar, and sericite. The preferred orientation of sericitic mica flakes forms the phyllitic schistosity, and where the mica content is low, the planar structure in the rock is more aptly termed a penetrative fracture cleavage.

In some outcrops of leptite, the rock has a wispy color banding in which discontinuous areas, up to about 1/2 an inch wide and 2 to 3 inches long, of pinkish-red and light-tan matrix regularly alternate. This texture greatly resembles the fragmental texture in silicic tuffs and, together with the large quartz and feldspar grains and the quartzofeldspathic composition of the rock, suggests that the leptite of this area may have once been a rhyolitic volcanic rock (Barker).

Chlorite Schist and Amphibolite

Areally small and widely scattered exposures of chlorite schist and chloritic amphibolite occur within the outcrop area of quartz diorite gneiss. Exposures of these rocks tend to be tabular and either interlayer with phyllitic schist or parallel the regional northwest structural trend within the gneiss. No evidence of mineralization was noticed in these rocks.

In outcrop, chlorite schist and amphibolite range from schistose to granoblastic, and fine- to medium-grained and in places are porphyroblastic with hornblende laths 5 to 10 times the matrix grain size randomly distributed and oriented throughout the rock. Chlorite greenschist in the northeastern part of the area (sector 6A) contains thin laminae of magnetite and specularite, the former imparting a pronounced magnetism to the rock.

Quartz Diorite Gneiss

Fine- to medium-grained flaser gneiss with the composition of quartz diorite crops out in the eastern part of the map area where recent erosion has stripped away Tertiary and Quaternary conglomerate and gravel. The most extensive exposures are along the northeast margin of the map area from the Placer Creek fault in sectors 5 and 6A, and southeastward to the Hopewell Lake forest road in sectors 8C and D. Isolated outcrops of quartz diorite gneiss are exposed in sectors 6E and F, 5C and D, and 4A. No quartz diorite gneiss was found west of a line bearing N. 25° W. and passing through Placer Creek Gorge in sector 5D.

Two phases of quartz diorite gneiss recognized in the Hopewell mining district are subdivided on the geologic map. They are designated the grayish-green phase and pinkish-orange phase, this color distinction providing the basis for the map units. In some parts of the map area, these phases are distinct and readily separated, but for the most part they are gradational into each other and are separated on the geologic map by scratch boundaries.

The grayish-green phase of quartz diorite gneiss appears in outcrop as a fine- to medium-grained slightly knobby augen gneiss, ranging in color from a dark greenish gray to light gray and, in sectors 8B and C, containing a prominent lineation defined by streaky segregations of fine-grained biotite. In thinsection, the rock has a relict hypidiomorphic-granular fabric with subhedral oligoclase laths up to 3 mm in length enclosed in optically continuous, strained to granoblastic quartz. Decussate greenish-brown biotite and green chlorite are the ferromagnesium minerals. Plagioclase in all sections studied was partly altered to fine-grained sericite and epidote. The degree of alteration varies widely, however, from a mere dust to nearly complete replacement of the primary plagioclase crystals. A cataclastic fabric is overprinted on the hypidiomorphic texture and consists of irregular planar zones of crushed and recrystallized quartz and plagioclase. These zones of comminuted material form a weblike mortar texture ranging from incipient to well developed. Where the cataclastic fabric is moderately to well developed, the rock is a flaser gneiss. In the easternmost exposures of quartz diorite gneiss, the cataclastic fabric is absent and a crystalloblastic fabric instead is overprinted on the hypidiomorphic texture. It is in this type of rock that the biotite lineation is best developed.

The pink phase of quartz diorite gneiss is irregularly distributed throughout the eastern part of the map area. In outcrop, it tends to be somewhat massive with only a tenuous foliation, medium- to coarse-grained, with knobby segregations of gray-white quartz set in a fine-grained sericitic matrix. The over-all color of the rock is pinkish orange to grayish orange. The rock consists of oligoclase, quartz, sericite, and epidote. The light color of the rock results from the absence of chlorite and biotite and serves to distinguish it in the field from the grayish-green phase of quartz diorite gneiss. The fabric of this rock is identical to that of the grayish-green gneiss already described. In thin-section, relict patches of biotite (?) are marked by bleached and altered webs of sericite, opaque material, and limonitic staining.

Tertiary Rocks

Cobble-to-boulder conglomerate, coarse arkosic sandstone, and water-laid tuff of Tertiary age underlie about 60 per cent of the mapped part of the Hopewell mining district. They represent a mantle of varying thickness that accumulated as talus, mudflow, and fluviatile deposits. These clastic rocks are subdivided into a lower stratigraphic unit, the Ritito Formation, and an upper unit, Los Piños Formation. Together, they reach a maximum thickness of between 300 and 400 feet.

Ritito Conglomerate

Ritito Conglomerate shown on Plate 2 includes weakly cemented, pebble-to-boulder conglomerate consisting entirely of metamorphic rock fragments. This clastic unit occupies about 40 per cent of the map area, rests unconformably upon the crystalline rocks of Precambrian age, and is entirely of local derivation.

Ritito Conglomerate forms subdued outcrops, except along the west edge of the northwest-trending ridge in sectors A1 and B1. At this locality, cliffs of conglomerate stand 10 to 20 feet high and the composition and texture of the conglomerate are best shown. In most areas where Ritito Conglomerate forms the bedrock, its presence is indicated by a surface rubble of clasts derived from the weakly cemented conglomerate.

Where exposed, Ritito Conglomerate ranges in color from grayish white to pale yellowish brown. The over-all color of the conglomerate is the color of the dominant clast present; gray, where quartzite is the principal rock type, and tan, where quartz diorite gneiss predominates. Compositional facies based upon the type of clasts present are complex, for in every part of the map area the composition of the metamorphic conglomerate mirrors the composition of adjacent or subjacent metamorphic bedrock.

Grain size of the conglomerate ranges from clay- and silt-size material up to boulders 1 to 2 feet in diameter. For the most part, however, silt and sand-sized quartz, feldspar, and mica form the matrix, and cobbles 3 to 5 inches in diameter form the clasts. Boulder-sized material appears to be restricted to that part of the conglomerate nearest the bedrock surface. Sorting is very poor, and the clasts range from angular to subrounded.

The thickness of Ritito Conglomerate ranges from 0 to about 100 feet. The bedrock surface upon which it was deposited had moderate relief, as indicated by the irregular outcrop pattern in the quartzite belt between the Vallecitos and Hopewell faults. The eastward-dipping exhumed erosion surface developed on leptite in the southeast corner of sector A2 also suggests this. Ritito Conglomerate thins southward and eastward from Hopewell Lake, where its outcrop pattern is interrupted by several windows of crystalline rocks overlain in part by volcanic conglomerate. These windows of Precambrian rock may result from depositional or erosional thinning, or both combined with a bedrock surface of moderate relief, or bedrock relief of major proportions developed locally.

Ritito Conglomerate in the mapped area formed as a result of rapid erosion of bedrock and localized transport in the form of talus, mudflow, and alluvial gravel. These deposits grade into each other and form a complex of poorly sorted debris mantling most of the Precambrian terrain. This unit is presumed to be of Early to Middle Tertiary age, based upon correlation with similar conglomerate to the west and north overlying the Eocene (?) El Rito Formation, and its position beneath and partly correlative with the volcanic conglomerate of Late Oligocene to Early Miocene age.

Los Piños Formation

Irregular, isolated exposures of volcanic conglomerate are distributed throughout the northern, eastern, and southern parts of the map area. These areas of conglomerate are erosional remnants of eastward-tilted beds bounded partly by normal faults. Volcanic conglomerate in this area grades downward into metamorphic conglomerate and partly underlies glacial and alluvial deposits.

The map unit consists of gray to light purplish-tan tuffaceous sandstone and conglomerate. Most of the rock is poorly cemented and tends to weather into subdued low hills littered with clasts from the conglomerate beds. In rare outcrops, the rock is poorly sorted, coarse-grained arkose and graywacke containing numerous thin and discontinuous pebble-to-boulder conglomerate beds. Rare grayish-white tuff beds containing prominent bleached biotite flakes are present locally. Conglomerate clasts consist of gray to reddish-purple aphanitic rhyolite and rhyolite prophyry, gray to brown andesite porphyry, and reddish-brown basalt. The maximum exposed thickness of volcanic conglomerate is 280 feet in the valley of the Rio Vallecitos in sector 2F.

Los Piños Formation in the Hopewell district results from fluviatile deposition of volcanic extrusive and pyroclastic material derived from multiple source areas to the east (Butler). Stratigraphic relationships with the Santa Fe Group indicate a Late Oligocene–Early Miocene age for this unit.

Quaternary Deposits

Unconsolidated deposits of pebble-to-boulder gravel, lacustrine silts, terrace gravel, and stream alluvium are widely distributed throughout the Hopewell district. These deposits occupy only about 5 to 10 per cent of the map area, but an understanding of their distribution and origin is a necessary first step in any exploration program aimed at the recovery of valuable minerals from deposits of secondary origin.

Glacial Deposits

Cirques, hanging valleys, U-shaped valleys, and moraines are land forms characteristic of mountain glaciation in the map area. Several small cirques occur at the head of short tributary arms to Placer Creek and Bear Creek. These cirques are cut both in poorly consolidated Tertiary clastic rocks and resistant Precambrian rocks. They are now partly filled with a thin veneer of morainal gravels that extend downslope and mark the old glacial courses. The major hanging valley is near the western margin of sector 2C where the broad U-shaped valley across most of sector 1B drops into the valley of Bear Creek. Extensive, but thin, gravels form ground and lateral moraines in the hanging valley and along Bear Creek from sector 2B south to Placer Creek. Dissected moraines partly obscured by Quaternary lacustrine sediments overlie Tertiary conglomerate along the northwest margin of the lower flat.

Glacial deposits within the map area consist of medium-grained cobble gravel and poorly sorted till. These deposits represent all bedrock types in the map area, with local compositional facies in the gravel closely related to bedrock source areas.

Terrace Deposits

Terrace gravel deposits are mapped in two places along the course of Placer Creek. The easternmost deposits, in sectors 6 and 7B, rest unconformably upon volcanic and metamorphic conglomerate and obscure the location and southerly extent of the Placer Creek fault. The other area of terrace deposits lies west of Hopewell Lake in sector 5C. These gravels rest upon Ritito Conglomerate and Precambrian crystalline rocks. Much of the terrace gravel west of Hopewell Lake underlies the site of the old Fairview gold placer, and the deposits of gravel have been partly exposed by trenching and prospect pits. In prospect trenches north of Little's Cabin, terrace gravels overlie Ritito Conglomerate. A slight difference in color and the presence of rare volcanic clasts in the uppermost gravels mark the contact. All the terrace deposits are dissected by recent erosion along Placer Creek.

Alluvium

Deposits of silt, sand, and gravel along present stream courses were mapped as alluvium, along with clayey silt accumulations and relatively thick soil deposits in numerous shallow depressions throughout the map area. The lacustrine deposits, 1 to 5 feet thick, underlying most of the lower flat are also included as alluvium. Alluvial deposits represent the youngest mapped unit in the area. They are disconformable upon all older rocks and continue to accumulate at this writing.

STRUCTURE

Structural features in the Hopewell district range in age from Precambrian to Tertiary and range in scale from planar structures visible under the microscope to faults many miles long. The structures found in the Hopewell area represent only a small part of structural features found throughout the Tusas Mountains.

Precambrian Structural Features

Structures assigned to the Precambrian include planar structures such as flow, fracture, and slip cleavages, linear structures, and in part the spatial relationship of Precambrian rock masses as they now exist.

Rock cleavage occurs in all outcrops of Precambrian rock exposed in the Hopewell district. Slip cleavage and fracture cleavage are the most common types with a cataclastic variety of flow cleavage being developed in quartz diorite gneiss. Fracture cleavage and relict bedding are the only planar structures present in quartzite.

The orientation and distribution of measured cleavage planes in the district are shown on Plate 4 and in Figures 5 and 6 (lower hemisphere projection). As seen from the geologic map, most of the information regarding metamorphic structures was obtained from Placer Creek Gorge and the low hills of quartz diorite along the eastern margin of the map area.

The oldest recognizable rock cleavage (S_0) is a phyllitic schistosity preserved between slip cleavage planes (S_1) as microcorrugations in the phyllitic schist exposed in Placer Creek Gorge. The older phyllitic schistosity and the younger slip cleavage intersect at very low angles from about 5 to 20 degrees, and the result is a platy schistose rock that tends to split or weather out in thin and elongate diamond-shaped plates. The recognition of these planar structures is complicated by the sporadic development of the younger S_1 cleavage, which ranges from a slip cleavage in which individual planes are spaced from 1 to 3 mm to a phyllitic flow cleavage that entirely obscures any older rock cleavage. This range in intensity of development often occurs within individual outcrops, illustrating within a few yards the entire textural range from

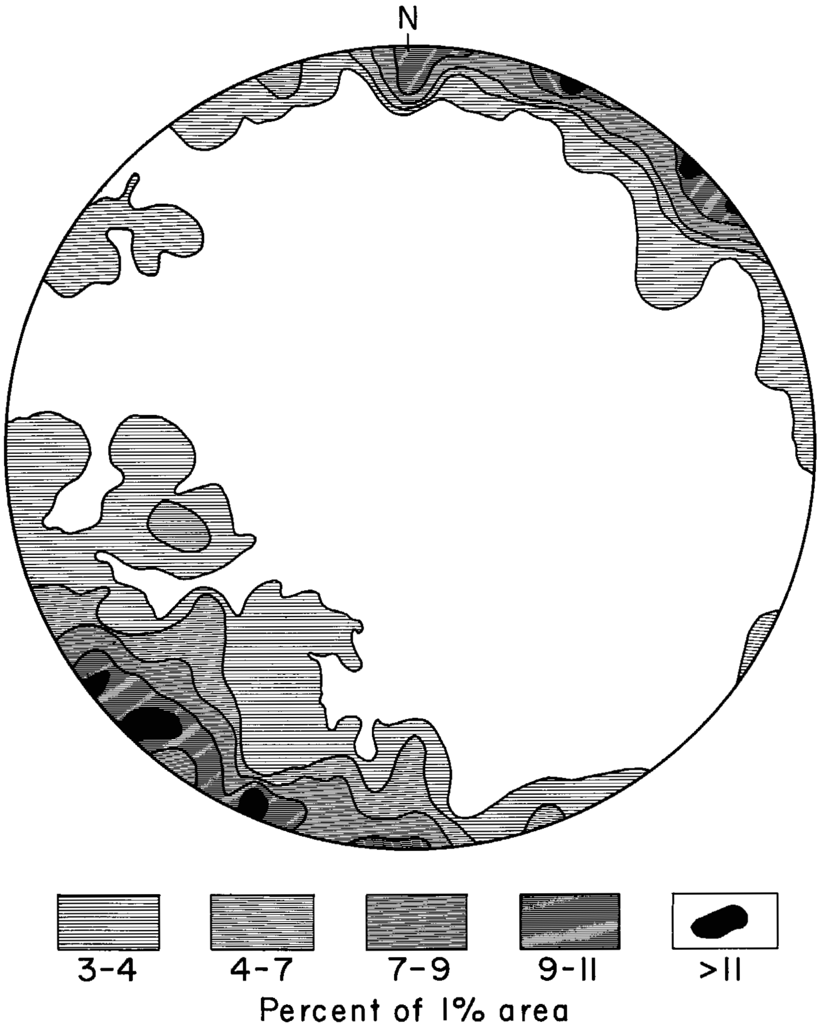


Figure 5

POLES TO FRACTURE AND SLIP CLEAVAGE IN THE HOPEWELL DISTRICT

(Lower hemisphere equal-area projection) rock with a single cleavage (S_0) to rock completely reconstituted by a superposed cleavage (S_1).

The two cleavages mentioned are nearly parallel, trend about N. 50°-55° W., and range in dip from vertical to about 60° NE within Placer Creek Gorge. The younger cleavage exposed in the gorge is the dominant and oldest recognizable rock cleavage in all other outcrops

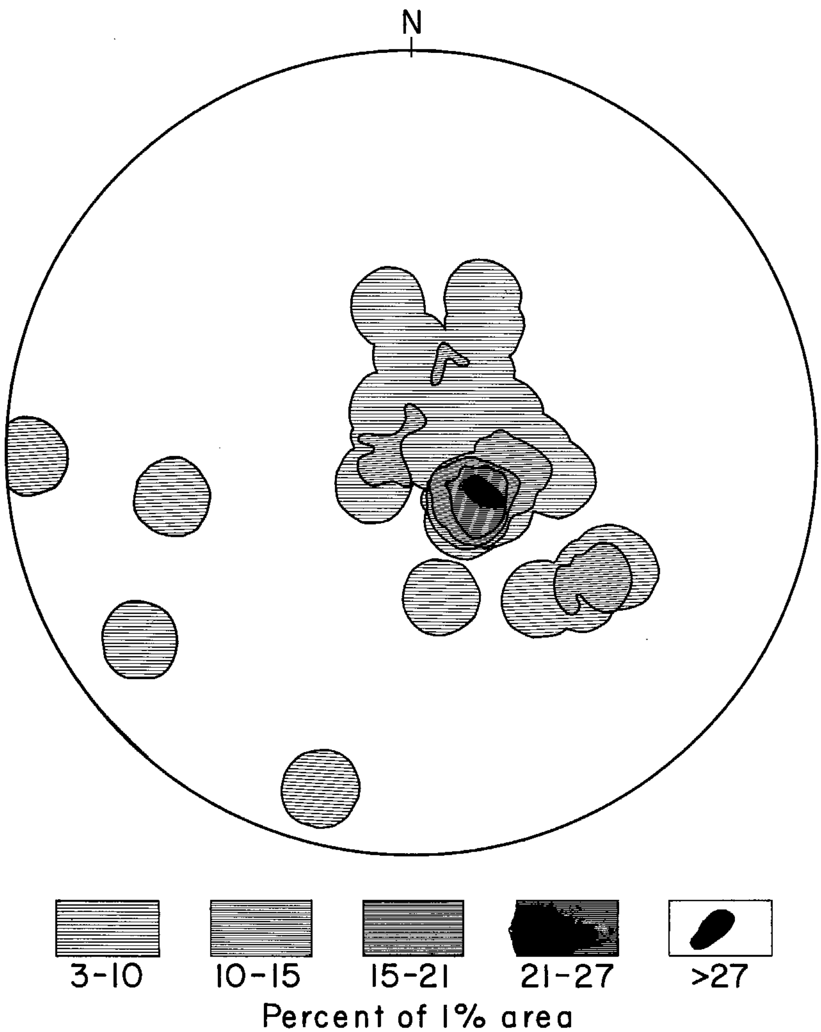


Figure 6

LINEATION IN THE HOPEWELL DISTRICT

shown on Plate 4. Throughout the quartz diorite gneiss, S_1 is the cataclastic cleavage superimposed on the older igneous texture of that unit. A prominent cleavage in quartzite, it parallels bedding as marked by thin pebble beds. This cleavage as exhibited in quartzite and quartz diorite gneiss is distributed in thin zones parallel to the strike and dip of the S_1 cleavage, but which internally show a wide range in intensity of development. Quartzite and quartz diorite gneiss within these planar zones ranges from nearly uncleaved rock to rock so intensely and penetratively cleaved as to be schistose. East of the Bear Creek fault, S_1 ranges in dip from about 60° NE in the eastern part of the map area to vertical near the Bear Creek fault. West of the fault in quartzite, S_1 dips uniformly to the west and ranges from 80° to 85° SW.

Two sets of fracture cleavage, S_2 and S_3, younger than S_1 cleavage are well developed in quartzite and sporadically distributed elsewhere in the map area. S_2 has an average strike of east-west and ranges in dip from 70° N through 80° S. It is prominently superposed on S_1 in quartzite and grades into flow cleavage in the schists of Placer Creek Gorge. S_3 is present throughout the quartzite outcrop area, but it is not so intensely developed as S_2 cleavage. Its average strike is N. 30° E. and the dip ranges from 45° S to 70° N with most cleavage planes being vertical. S_3 cleavage is rare east of the Bear Creek fault.

Linear structures consisting of mineralogic and textural lineation are present throughout the Precambrian rocks. Mineralogic lineation includes parallel-oriented kyanite blades and flaky aggregates of specularite in quartzite, elongate knots of chlorite and biotite in phyllitic schist and quartz diorite gneiss, and the preferred orientation of hornblende prisms in amphibolite. Textural lineation refers to micromullion structure in phyllitic schist, faint ribbing or ruling in the cleavage plane of quartzite, and the intersection of S planes.

L_1 lineation occurs in the plane of S_1 cleavage and is composed of all types of mineralogic lineation, micromullion structure, and faint ribbing or ruling in the cleavage plane. This lineation bears S. 60° E. and plunges between 70° and 75° SE (fig. 6). About 90 per cent of the lineation measured in the map area has this orientation. In phyllitic schist of Placer Creek Gorge, L_1 is produced by the intersection of S_0 schistosity and S_1 slip and fracture cleavages. In one hand specimen from this area, S_1 cleavage is an axial plane cleavage to a small fold. This fold was very obscure and became apparent only after the rock was stained for potash feldspar. It is also the only fold recognized within the map area.

Lineations produced by S-plane intersection tend to plunge steeply because of the steep dips on S_1, S_2, and S_3. Their orientation is shown in Figure 6.

Because of the large percentage of the map area underlain by Tertiary and younger rocks, the distribution and orientation of rock masses is not well known. Even the relatively few windows through which the basement rocks can be viewed are largely obscured by float and talus not shown on Plate 4. Admitting the inferential nature of any reconstruction of the bedrock configuration, the writer offers the following generalizations regarding the distribution of Precambrian rocks. Quartzite occupies all the area west of the Bear Creek fault, in which the strike of bedding, S_1 cleavage, and the fault contact are all parallel. East of the fault, a triangular-shaped mass of interlayered phyllitic schist, granular quartzite, and leptite is bounded on the west by the Bear Creek fault and on the east by a complex, in part interlayered, in part discordant, contact with quartz diorite gneiss. Tabular rock units within this wedge exhibit vertical or steeply northeast-dipping contacts that strike between N. 25° and 30° W. Thus these rock units are intersected at low angles by the regional N. 50°-44° W. S_1 cleavage.

The origin of the angular discordance between tabular rock masses east of the Bear Creek fault and the quartzite west of the Bear Creek fault is largely speculative. The simplest explanation is that the discordance resulted from separation on the Bear Creek fault cutting across the limb of a steeply plunging fold. The discordance may also represent an angular unconformity with quartzite the youngest rock. No direct evidence supporting this concept, such as expectable lithologic variation in the quartzite, was found. Or the discordance may be more apparent than real because of the large amount of float obscuring outcrops along the northeast valley wall of Bear Creek.

Tertiary Structural Features

Several faults of Late Tertiary age (post-Los Piños Formation) occur in the Hopewell district and are shown on Plate 4. The Bear Creek and Vallecitos faults are part of much larger, regional faults. Other faults in the map area have a short strike length and minimal separation. All the faults mapped except one have a northwest strike parallel to the structural "grain" of the Precambrian rocks.

Bear Creek fault. The Bear Creek fault underlies the stream of the same name in the central part of the map area and forms a major structural boundary in the district, separating quartzite from all other Precambrian rock types. The fault trace extends across the map area from northwest to southeast and is a segment of a regional fault with a strike length up to 20 miles long.

The fault has a strike of N. 50° W. with approximately vertical dip. Minimum down-to-the-west separation of about 600 feet is based upon the displacement of the Precambrian–Ritito Conglomerate contact at the mouth of Placer Creek Gorge in sector 4E. The minimum age of the fault is Late Tertiary, for it displaces the Ritito and Los Piños Formations of Tertiary age. However, there may have been movement along this zone during the Precambrian era. That the principal cleavage in the Precambrian rocks of the district (S_1) is of a cataclastic type, that it appears to become less intense away from the fault zone, as indicated by the change in texture of quartz diorite, and that it parallels the fault trace suggest a genetic relationship between these two structural features.

Placer Creek fault. The Placer Creek fault is a normal fault with down-to-the-west separation of about 500 feet located in the northeastern part of the map area in sectors 5A, 6A, and 6B. It has a strike of N. 50° W., a vertical dip, and a strike length of greater than 5000 feet. The northern end of the fault extends beyond the map area, and the southern end lies beneath terrace and alluvial gravel at Hopewell Lake. The fault is Late Tertiary in age and separates quartz diorite gneiss to the northeast and conglomerate of the Los Piños Formation to the southwest.

Other faults. The Vallecitos fault marks the southwestern boundary of the map area. It is similar in all respects to the Bear Creek and Placer Creek faults. Minor northwest-trending faults with a strike length of only a few thousand feet and minimal separation were mapped in the northern (sector 2A) and southern (sectors 5F, 6F, and 6G) parts of the district. A minor fault of east-west trend in sector 1C is the only fault mapped with that orientation. It is entirely within quartzite, where it is marked by intense brecciation and closely spaced jointing.

Mineral Deposits

Mineral deposits of the Hopewell district include hydrothermal sulfide replacement veins, gold-bearing quartz veins, metamorphic segregations of iron minerals, and placer deposits of alluvial gold. The principal products of mining in the district have been free gold and silver plus small amounts of copper, lead, and zinc. Alluvial gold was recovered from placers along Placer Creek, and lode gold and sulfide minerals from very narrow stopes in mines clustered around the northern end of Placer Creek Gorge. All mines in the district are caved and inaccessible.

Primary Deposits

Primary hydrothermal sulfide replacement and quartz fissure veins occurring in phyllitic schist and quartz diorite gneiss constitute the most extensively mined lode deposits in the district.

The replacement veins consist of tabular zones or veinlike masses of sericitic, sheared schist and gneiss impregnated with varying amounts of pyrite, auriferous pyrite, chalcopyrite, galena, sphalerite, and fluorite. These veins range in thickness from a few inches up to a maximum of about 2 feet. In many of the veins, disseminated sulfide minerals impregnate much sheared, altered, and limonite-stained schist, but in some, the host rock is compact, tough, and only weakly fissile schist or gneiss. The alteration observed in some veins largely results from the alteration of plagioclase feldspar in the metamorphic host rock. The boundaries of many of the veins are indistinct, for they consist of the gradual decrease in concentration of scattered pyrite or pyrite partly to completely altered to limonite. Many of the replacement veins proper represent thin zones of concentrated sulfides within a sheath of pyritized wall rock not necessarily symmetrically disposed with respect to the vein it encloses.

Hydrothermal quartz veins occur both intimately associated with the replacement veins and as distinct tabular masses enclosed by fresh, unaltered schist or gneiss. These quartz veins range in thickness from less than 1 inch up to about 3 feet and occur both concordant and discordant to the layering or cleavage in the host rock or replacement vein. Some veins are made up of lenticular masses that pinch and swell and are discontinuous along the strike; others are uniform in thickness and continuous within the limits of most exposures of bedrock. The quartz veins consist of quartz, massive aggregates and rhomboid crystals of brown siderite, limonite pseudomorphs after cubes of pyrite sometimes fringed with irregular specks of native gold, sheaves of chlorite, and clusters of black tourmaline. Although some areas of schist contain much disseminated and altered siderite, no genetic relationship between sideritic quartz veins and siderite-rich host rock was found.

There appears to be a minor variation in the distribution of some ore minerals in the district. Native gold occurs in most, if not all, of the mines in and around Placer Creek Gorge. However, Lindgren, Graton, and Gordon (p. 129) reported the most productive gold mine in the district as the Croesus mine, located in sector 5D (pl. 4) near the upper end of the gorge. Sphalerite and galena have been found on the dumps and are also reported from the Mineral Point and Hoover claims at opposite ends of the gorge. Fluorite, as finely divided disseminated crystals, was found on the dump of a northeast-trending adit driven near the Bear Creek fault in sector 4E.

Structural control of the replacement and quartz veins is obvious and well shown along the steep walls of Placer Creek Gorge. Here disseminated sulfides impregnate layers parallel to compositional layering and the northwest-trending, steeply east-dipping phyllitic cleavage (S_1). Some quartz veins parallel this plane of weakness and some parallel other cleavage directions (S_2, S_3). All the replacement veins parallel the northwest-trending S_1. The host rock in some of the replacement veins is considerably brecciated in addition to being already schistose. A sample taken from one vein on the Hoover group of claims consisted of a breccia of phyllitic schist fragments cemented by yellowish-brown limonite. This brecciation is restricted to zones parallel to the principal cleavage and replacement veins and, as such, appears to represent minor movement of bedrock after the period of mineralization.

The presence of disseminated grains of siderite appears to represent some part of the ore-forming process rather than a primary phase produced as part of the regional metamorphism. Unlike dolomite, which is present as augen and scattered porphyroblasts in the greenschists, siderite is present in all types of phyllitic schist and quartz diorite gneiss. Most of this siderite is now altered to a yellowish-brown limonite that either fills or lines cavities that once contained the siderite. Some parts of the phyllitic schist in the gorge are now largely composed of these vugs where alteration, through introduction of siderite, was intense.

An extensive oxidation mantle exists below the Tertiary–Precambrian unconformity in the gorge. This zone of oxidation is marked by the alteration of pyrite, dolomite, siderite, and chlorite, both in unmineralized schist and in replacement and quartz veins. This alteration by weathering takes the form of a replacement of these minerals by earthy, yellow to reddish-brown hydrous iron oxide identified as limonite. Nearly all the limonite is indigenous, having formed at sites determined by the presence of one of the primary minerals noted above. Only in rare brecciated veins does limonite form a cementing agent, providing evidence of local transport of iron. The lower surface of the oxidation zone is very irregular and extends downward in spike- or sheetlike projections parallel to shear zones and cleavage in the schist and gneiss wall rock. The presence of both weathered and unweathered rock in Placer Creek Gorge suggests that the lower boundary of oxidation has been exposed by erosion that cut the gorge and that the period of oxidation is related to exposure of Precambrian rocks prior to deposition of the Tertiary gravels. Thus, it is expected that the form of the oxidized surface will closely reflect the configuration of the buried Precambrian surface rather than any present surface of erosion or groundwater level.

The age of the hydrothermal mineralization in the Hopewell district has not been determined because of the lack of direct evidence. There is, however, some evidence that brackets a range of geologic time during which vein emplacement probably occurred. The presence of clasts of abraded, subrounded schist containing disseminated pyrite, limonite pseudomorphs after pyrite, and siderite in Ritito Conglomerate indicates that mineralized Precambrian rock was exposed to subaerial processes and eroded during early Tertiary time. Indicators of a maximum age, though, are more ambiguous. The presence of replacement veins parallel to S_1 cleavage in phyllitic schist and quartz diorite gneiss suggests that the transfer of material and the movement of mineralizing fluids was controlled by this structural feature and thus postdates it. The gold-pyrite-siderite quartz veins in the district are both conformable and discordant to S_1 and in addition appear to have been emplaced along cleavages (S_2, S_3) younger than S_1. This configuration indicates that the formation of the quartz veins may have been either a late feature of the replacement vein formation or a separate, younger event.

Secondary Deposits

Sedimentary deposits of free gold are located along and in Placer Creek west of Hopewell Lake. The largest deposit, the Fairview placer, was located in the northeast corner of the southeast quarter of sector 5C. Other small pockets of placer material were located in Placer Creek along the length of the gorge. The lower flat area in sector 3F, once the site of a lake, was worked for placer gold on at least two occasions, but no gold production was recorded.

The free gold recovered from the gravels of Placer Creek is of recent alluvial origin, no older than Placer Creek itself, which is a young, superposed stream that has pirated several subsidiary consequent streams in the area. Most of this alluvial gold has probably been washed into Placer Creek from colluvial debris along the mineralized bedrock flanks of Placer Creek Gorge. Some of the gold may also be reworked from the site of the Fairview placer. In any event, these young deposits of alluvial gold are small and low in gold values compared to the Fairview.

The origin of the rich Fairview placer is unfortunately very obscure, largely because of the complex, post-Precambrian geologic history of the district and the location of the placer at a point in the mapped area where it could have been produced by several geologic processes. Briefly, three acceptable hypotheses are (1) gold derived from bedrock north of the placer site, carried south by Placer Creek or its tributaries, and deposited along with alluvial sand and gravel in the bed of Placer Creek; (2) gold of colluvial origin occurring as an erosional and weathering residue along the Precambrian–Tertiary unconformity that has been exposed at the Fairview site by the downcutting of Placer Creek; (3) gold of early Tertiary age that formed in part of a drainage network having east-flowing streams that were eroding bedrock and depositing, in part, the clastic debris now represented by the Ritito Conglomerate.

The first hypothesis linking the placer gold with deposition from Placer Creek is the weakest of the three hypotheses of origin for the following reasons. First, Placer Creek north of the Fairview placer site drains a relatively small area south of Jawbone Mountain. This drainage area is underlain largely by Tertiary clastic rocks not known to be gold-bearing. Also, exposed Precambrian rocks within the drainage area contain little mineralization and no productive gold mines. Second, the site of the placer at the head of Placer Creek Gorge is very unusual if the gold-bearing gravel were transported and deposited by Placer Creek. Alluvial gold placers commonly form where the gradient of a stream suddenly decreases, only rarely, if ever, where the stream gradient *increases*. Third, the angularity of the gold (914 fine) grains panned from the placer site, together with the numerous grain imprints and adhering quartz grains, suggests only a short transport distance for the gold particles.

The colluvial origin of the placer gold is supported by the texturally immature form of the gold fragments, the presence of high gold values at the bedrock surface (Little, personal communication), and the tendency of the gold fragments to occur deep within cracks, joints, and cleavage planes in the bedrock surface. The latter two facts of the gold occurrence are equally likely if the gold is of alluvial origin because of the well-known riffle effect produced by prominently layered schist with an uneven upper surface.

The writer favors the third hypothesis for the origin of the Fairview placer and believes that it best fits the known facts. The placer deposit is envisioned as the result of fluviatile transport of sediment eastward and northeastward across the auriferous replacement veins and gold-bearing quartz dikes near the head of Placer Creek Gorge. These streams washed debris from the deeply weathered and mineralized Precambrian rocks, and native gold, freed from disintegrated schist and oxidized pyrite, was concentrated by natural stream action. Thus, the Fairview placer is viewed as an exhumed early Tertiary deposit, laid bare by the erosive action of Placer Creek which cut down to the base of the Tertiary conglomerate. This would explain the textural immaturity of the gold fragments as a natural consequence of limited transport of only a few hundred feet. Further, it would explain the meager placer gold occurrences elsewhere along Placer Creek.

Geologic History of the Hopewell District

The earliest geologic event recorded in the Hopewell area is the accumulation of pelitic and ferruginous quartz sand, and siliceous shale early in Precambrian time. Volcanic activity at about the same time resulted in the accumulation of silicic volcanic rocks, as flows or pyroclastic layers, and basalt. Regional metamorphism converted the sandstone to kyanite-specularite quartzite, the shale to greenschist, and the volcanic rocks to leptite and amphibolite. Subsequent to the regional metamorphism, the area was invaded by quartz diorite. Schist wall rock was locally granitized, complexly intruded by apophyses of quartz diorite, and converted to hornfels. A period of regional dislocation metamorphism followed the intrusive igneous activity. This metamorphism was largely dynamic and resulted in the regional formation of penetrative to widely spaced fracture and slip cleavages with a northwest trend and steep easterly to vertical dip. Intersection of this cleavage with the older schistosity in greenschist formed a steeply plunging, southeast-trending lineation. Quartz diorite converted to augen gneiss and schist to phyllonite by the regional dislocation metamorphism. Subsequent cataclastic metamorphism induced a widespread but non-penetrative east-west fracture and slip cleavage.

Hydrothermal mineralization later than these events but older than early Tertiary is marked by the formation of gold-silver-copper-lead-zinc replacement veins and gold-pyrite-siderite quartz veins. The sulfide replacement veins and quartz veins occur parallel to one or more cleavage directions produced during the two periods of cataclastic metamorphism. All the replacement veins parallel the northwest-trending regional fracture and slip cleavages, whereas the quartz veins trend both northwest and east-west. Extended erosion and deep weathering of the Precambrian terrain resulted in an irregular zone of oxidation locally extending downward along veins and crush zones.

Early in Tertiary time, east-flowing streams partly eroded and reworked residual deposits of Precambrian rocks in the form of talus, regolith, and mudflow deposits. Native gold, released from veins by oxidation and weathering, was concentrated in stream placers during this interval. Eruptive activity along the eastern front of the Tusas Mountains in Oligocene and Miocene time was the source for a thick blanket of fluviatile volcanic clastic and tuffaceous rocks that spread westward and completely covered the Hopewell area.

Down-to-the-west normal faulting resulted in eastward tilting of the Precambrian–Tertiary unconformity and bedded Tertiary clastic rocks. The formation of tilted fault blocks led to the establishment of a consequent drainage pattern in which the main trunk streams such as the Rio Vallecitos, Bear Creek, and the upper reaches of Placer Creek flowed south. Low-gradient dip slope and high-gradient fault scarp streams emptied into the northwest-trending trunk streams. Downcutting through the thin veneer of Tertiary rocks, the consequent stream network became locally superposed on Precambrian bedrock, thus forming the precipitous bedrock gorges common in the area. Placer Creek represents a high-gradient tributary of the Rio Vallecitos that cut through an elevated fault block and captured several southeast-flowing trunk streams.

Valley glaciers occupied many of the established stream valleys during the Quaternary period. Small cirques and thin veneers of till and ground moraine indicate that the glacial process was marginal at the elevation of the Hopewell district during the Pleistocene epoch. The deposits of till and moraine consist for the most part of gravel representing all bedrock types. Recent erosion along Placer Creek and its tributaries represents the youngest geologic event in the Hopewell area.

Mines and Prospects

This section describes mines, patented and unpatented claims, and prospects. With the exception of the Jawbone and Detroit claims, the Royal Purple group, and the iron prospects at Iron Hill, all properties described lie within the mapped area shown on Plate 4. All mine workings are now caved and inaccessible. Descriptions of workings, production figures, assays, tenor of ore, and geology of deposits are compiled from Lindgren, Graton, and Gordon (1910), a private report furnished by Mr. Rufus Little, Tesuque, and the writer's study of the bedrock geology during June and July 1966. Location of mining claims is shown in Figure 7.

Croesus Mine

The Croesus lode claim, located August 3, 1881, is the oldest bedrock property in the Hopewell district. It is the first of five claims, including the Clara D., Mary E. Steele, Grand Mogul, and Little Casino, filed by George T. Hope and Lord Sterling and patented April 8, 1890. The Croesus mine had the largest production of the district, estimated at $15,000 up to 1906, principally in gold. Gold values in replacement sulfide veins ranged up to $800 per ton with an average of $50 per ton. Ore was treated in a water-powered Chilian mill, later a stamp mill, at the mine site.

The Croesus mine is on the west canyon wall of Placer Creek Gorge, half a mile southwest of Hopewell Lake dam in sectors 4C, 4D, and 5D (pl. 5). The portal of the main adit is at the southern edge of the claim and is accessible by a private jeep road from Hopewell Lake. R. C. Little now owns the patented claim.

Figure 8 shows the mine workings. A 304-foot adit with several short crosscuts is driven about N. 20° W. An 80-foot shaft connects to the main adit by a 60-foot incline driven north. The main adit followed several shear zones containing disseminated pyrite and sideritic quartz veins. Most of the veins above the main adit and near the shaft and incline are stoped to the surface. Short winzes along the main adit reportedly followed rich pay streaks. Ore values decreased rapidly downward and the mine was abandoned by 1900.

The main adit of the Croesus mine is driven in grayish-blue phyllitic schist. This schist has a prominent layering and flow cleavage trending N. 60° W. and ranging in dip from vertical to about 80° SW. The back of the adit near the portal consists of sheared and pulverized phyllitic schist, partly bleached and stained with limonite. The shear zone is about 2 feet wide and parallel to the cleavage in the schist walls. Cleavage near the Croesus mine trends N. 60° W., N. 30° W., and north (pl. 5). The main adit paralleled these cleavage trends. Possibly

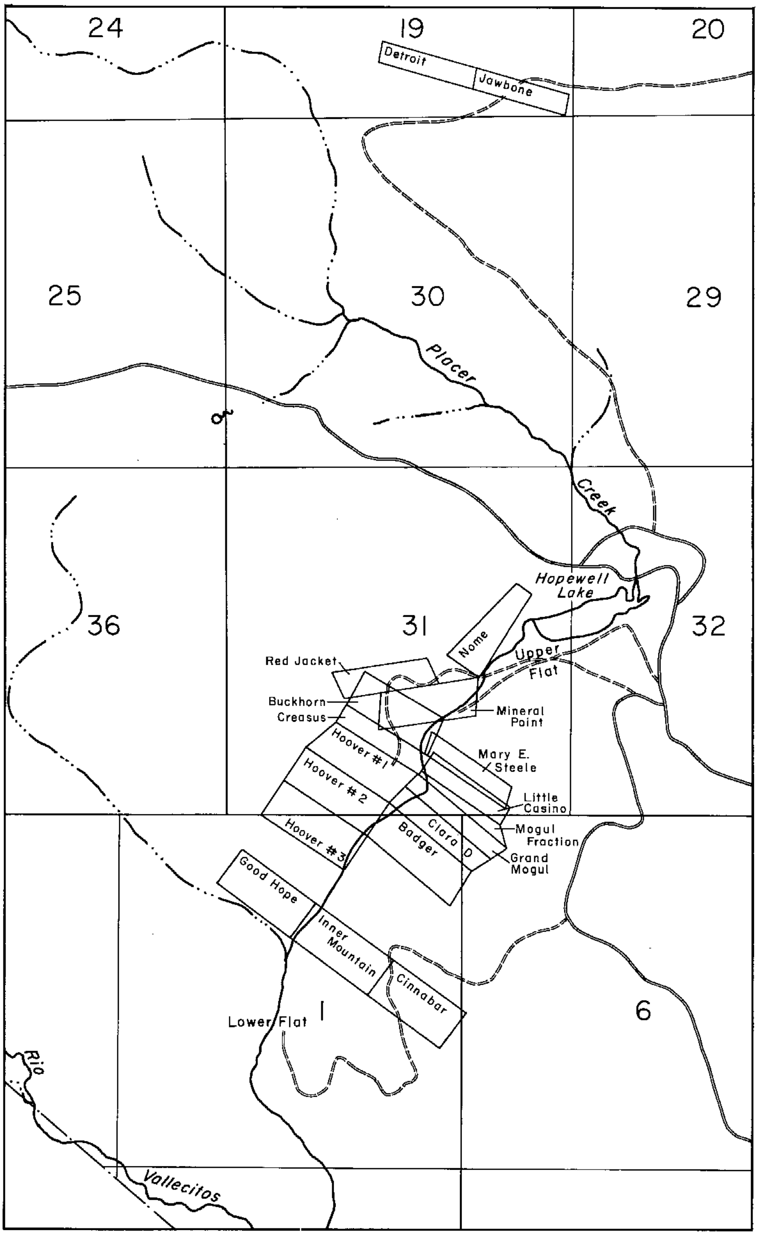
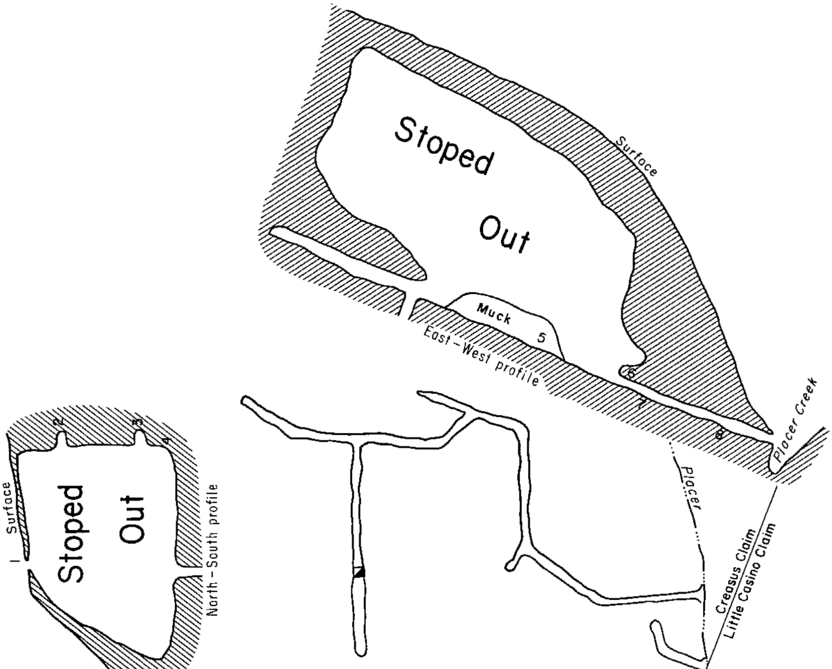


Figure 7
CLAIM MAP OF THE HOPEWELL DISTRICT



Sample Number	Gold, Oz/ton	Silver, Oz/ton
	4.87	–
1	2.13	0.39
	6.73	1.13
	1.78	5.82
2	0.31	–
	0.39	–
3	0.69	0.91
	0.29	–
4	0.89	2.16
	0.15	–
5	1.23	0.25
6	6.35	1.13
7	2.02	0.06
	1.00	2.04
	1.74	3.02
8	2.25	5.07
	2.05 Average	2.00 Average

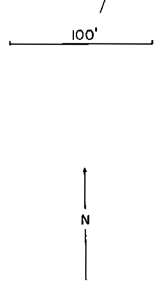


Figure 8

MINE AND SAMPLE MAP OF THE CROESUS MINE

the adit followed shear zones of irregular intensity and spacing parallel to the three cleavage directions recognizable in outcrop.

Sixteen chip, channel, and grab samples collected by R. C. Little from the old workings of the Croesus mine were assayed for gold and silver. The results of these assays, together with the sample sites, appear in Figure 7. The average gold and silver content agrees well with the reported average value of $50 per ton for Croesus ore.

Red Jacket Mine

The Red Jacket mine lies 2500 feet west-southwest of Hopewell Lake in the west-central part of sector 5C (pl. 5). The claim trends east-west and shows a common boundary with the Mineral Point claim adjoining it on the south. Nearly all the workings were in the eastern third of the claim, where Precambrian rocks project through Tertiary Ritito Conglomerate. The claim was located by the Atlantic Mining Company on May 11, 1889, and patented May 2, 1913. R. C. Little presently owns it.

The 120-foot shaft that developed the property intersected a 200-foot adit driven S. 70° W. The underground workings were described by Graton (Lindgren, Graton, and Gordon):

> From the bottom of the 120-foot shaft a crosscut to the north encounters small streaks of galena and limonite in the schist and parallel to its foliation, N. 60° W. and nearly vertical. The galena is said to carry good gold values and assays as high as $75 a ton have been obtained. It is possible that the gold is actually contained in the limonite, which resulted from the oxidation of pyrite. A zone of soft, much-foliated schist is next encountered. Beginning from this zone, a rather ill-defined band with streaks of limonite and carrying gold cuts across the schistosity in a northerly direction. A little pyrite is encountered in places. This ore is said to be of good grade.

Numerous shallow shafts and prospects dot the surface near the main shaft. A 32-foot by 36-foot warehouse built in 1945 is close to the main shaft. During the active period of mining, ore from the Red Jacket mine was amalgamated and concentrated at the site.

Plate 3 shows the surface geology at the Red Jacket mine. Interlayered gray and orange quartz diorite gneiss and schistose amphibolite trend N. 30° W. and dip vertically. Principal cleavage directions are N. 30°-50° W. and S. 70° W. The main adit followed the latter direction.

The ore minerals are native gold in limonite of the oxidized zone, auriferous pyrite, and galena. A grab sample collected by Little 60 feet north of the main shaft contained 0.39 ounce of gold a ton and 0.20 ounce of silver a ton. A selected galena-rich sample from the shaft dump assayed 1.26 ounces of gold a ton and 12.74 ounces of silver a ton. The high silver content of this sample suggests that silver in the veins occurred as argentiferous galena.

Mineral Point Mine

The Mineral Point mine is southeast of and adjacent to the Red Jacket (pl. 5). The claim was located by R. C. Moody on November 16, 1888, and patented September 16, 1914. Much exploration was conducted initially, both north and south of Placer Creek. A discovery shaft and several long adits explored interlayered schist and quartz diorite gneiss, but no substantial production is recorded. In 1935, the Amarillo Gold Company built a 30-ton mill on the south bank of Placer Creek and processed about 5500 tons of ore over a five-month period. The ore came from the Mineral Point mine, first hauled by wagon, later conveyed by a small trestle across Placer Creek. The operation was unprofitable and closed in 1937.

The workings consisted of 1500 feet in three adits driven north, south, and west. The discovery shaft, on a small, high point overlooking Placer Creek, connected with the adit driven north from creek level. Sulfide ore composed of galena, sphalerite, and quartz veins containing auriferous pyrite, chalcopyrite, and galena was encountered in the north-trending adit. Above the adit level, the ore was oxidized and consisted of limonite, hematite, malachite, and gold. A hand specimen of unoxidized ore collected by the writer from the shaft dump is prominently banded, fine-grained, quartz-chlorite schist. Pyrite as small (1 mm) cubes and irregular wormy grains is disseminated throughout the schist. Massive galena includes pyrite grains and small vuggy areas filled with an encrusted aggregate of honey-brown limonite grains.

The Mineral Point claim is on the southeastern projection of interlayered schist and gneiss exposed at the Red Jacket mine. Schistosity and fracture cleavage strike northwest and dip steeply northeast. The north- and south-trending adits cut obliquely across both cleavage and schistosity.

Clara D., Mary E. Steele, Grand Mogul, Little Casino, and Nome Patented Claims

These properties constitute the remainder of the patented claims within the mapped area of Plate 4. All were located during the late 1800's and have no recorded production.

The Clara D., Grand Mogul, Little Casino, and Mary E. Steele are nearly parallel and adjacent northwest-trending claims on the south side of Placer Creek Gorge (pl. 5). All were located by G. T. Hope and Lord Sterling in 1881-1882 and patented in 1890. Most of the workings on these claims included shallow shafts, prospect pits, and short adits. On the Grand Mogul claim, a 156-foot adit driven S. 50° E. intersected a 15-foot shaft. The workings and prospects explored thin, discontinuous shear zones in phyllitic schist, schistose amphibolite, and quartz diorite gneiss. The Mary E. Steele and Little Casino claims included the southeastern extension of interlayered schist worked in the Croesus mine. Gold values were low, and apparently no continuation of the Croesus ore shoots was located. Samples from this group of claims assayed 0.32 ounce of gold per ton and 0.91 ounce of silver per ton (Grand Mogul), 0.48 ounce of gold per ton and 0.20 ounce of silver per ton (Little Casino), and 0.03 ounce of gold per ton and 0.75 ounce of silver per ton (Clara D.).

The Nome claim, located by R. C. Moody and patented September 16, 1914, lies between the Mineral Point claim and Hopewell Lake dam. Very short adits near the dam and along Placer Creek expose pyritized schist and quartz diorite gneiss. From the meager workings, it is doubtful if the mine ever had a substantial production.

Hoover Nos. 1, 2, and 3, Badger, Buckhorn, and Grand Mogul Fraction Claims

These claims are unpatented but lie among or near the patented claims described above (pl. 5).

The Grand Mogul Fraction is a partial claim between the Grand Mogul and Little Casino claims. Workings consisted of an adit (50 feet long) driven S. 80° E. The portal is near creek level on the south side of Placer Creek. According to Little (unpublished report), the workings included three levels above the main adit, now caved. The adit and levels presumably followed a shear zone in phyllitic schist. Three samples collected by Little ranged from 0.18 to 0.85 ounce of gold per ton with an average of 0.42 ounce. Silver content ranged from 0.24 to 0.66 ounce a ton with an average of 0.31 ounce.

The Hoover Nos. 1, 2, and 3 claims trend northwest and lie southwest of the Croesus. No workings of consequence were found. Eight samples collected by R. C. Little had an average gold content of 0.05 ounce per ton and an average silver content of 0.20 ounce per ton.

The Buckhorn claim adjoins the Croesus on the northeast. The principal workings include two adits 50 and 80 feet long. The 80-foot adit had been stoped nearly to the surface. Six samples collected by Little from these workings averaged 0.97 ounce of gold per ton and 1.48 ounces of silver per ton. In 1935, 8 tons of ore shipped from the Buckhorn mine furnished 9.9 ounces of gold, 7 ounces of silver, and 100 pounds of lead for a total value of $356 (*Minerals Yearbook,* 1935). In 1932, 9 tons of ore shipped from the Buckhorn and Good Hope mines contained 17.9 ounces of gold and 14 ounces of silver.

The Badger claim adjoins the Clara D. and Hoover No. 2 claims. One caved adit driven southeast is the only evidence of activity on this claim. No production is recorded.

Good Hope, Inner Mountain, and Cinnabar Claims

These unpatented claims lie end to end along the Bear Creek fault (fig. 7 and pl. 4). Workings on these claims consisted of short adits driven northeast to intersect layers of pyritized schist and thin quartz veins.

A short adit on the southern end of the Good Hope claim intersected vein quartz, as indicated by samples from the dump, that contains chalcopyrite, tetrahedrite, and malachite. This is the only known occurrence of tetrahedrite in the district.

Hidden Treasure Group

The Hidden Treasure group of six unpatented claims is about half a mile south of Hopewell Lake. The claims lie within an area of table land supported by resistant Precambrian rocks, largely quartz diorite gneiss, obscured by a thin and discontinuous veneer of unconsolidated Tertiary conglomerate. Graton (Lindgren, Graton, and Gordon, p. 130) reported one 100-foot shaft in this area, but most of the workings were scattered prospect pits and shallow shafts 5 to 10 feet deep. The pits expose pyritized, intensely sheared quartz diorite gneiss, but gold values were apparently too low to support any substantial mining.

Royal Purple Group

Six claims of the Royal Purple Group and the Crown Point, Black Hawk, and Independence claims were located and patented between 1902 and 1904 by Lottie and Daisy Ashton. All lie within sec. 36, T. 29 N., R. 7 E., and sec. 31, T. 29 N., R. 8 E. (fig. 9) and several short adits and shallow shafts developed them. No production is recorded from this area.

The Royal Purple Group and adjacent claims are on an uplifted block of Precambrian schist and quartz diorite gneiss. The Precambrian rocks are bounded on the southwest by the Tusas Valley fault zone, and on the east by the eroded edge of the Treasure Mountain Tuff.

Jawbone and Detroit Patented Claims

The Jawbone mine, located on the claim of the same name, is in the SE¼SE¼ sec. 19, T. 29 N., R. 7 E. on the southern flank of Jawbone Mountain (fig. 7). Workings of the mine included an 86-foot discovery shaft with a 67-foot drift driven N. 70° W. and a second shaft, 30 feet deep with a 60-foot drift, north and west of the discovery shaft. The Jawbone claim was located in July 1889 and patented in March 1900. The collar of the shaft was in a zone of alternating thin-layered sericite schist and pink leptite porphyry. The layering trends east-west.

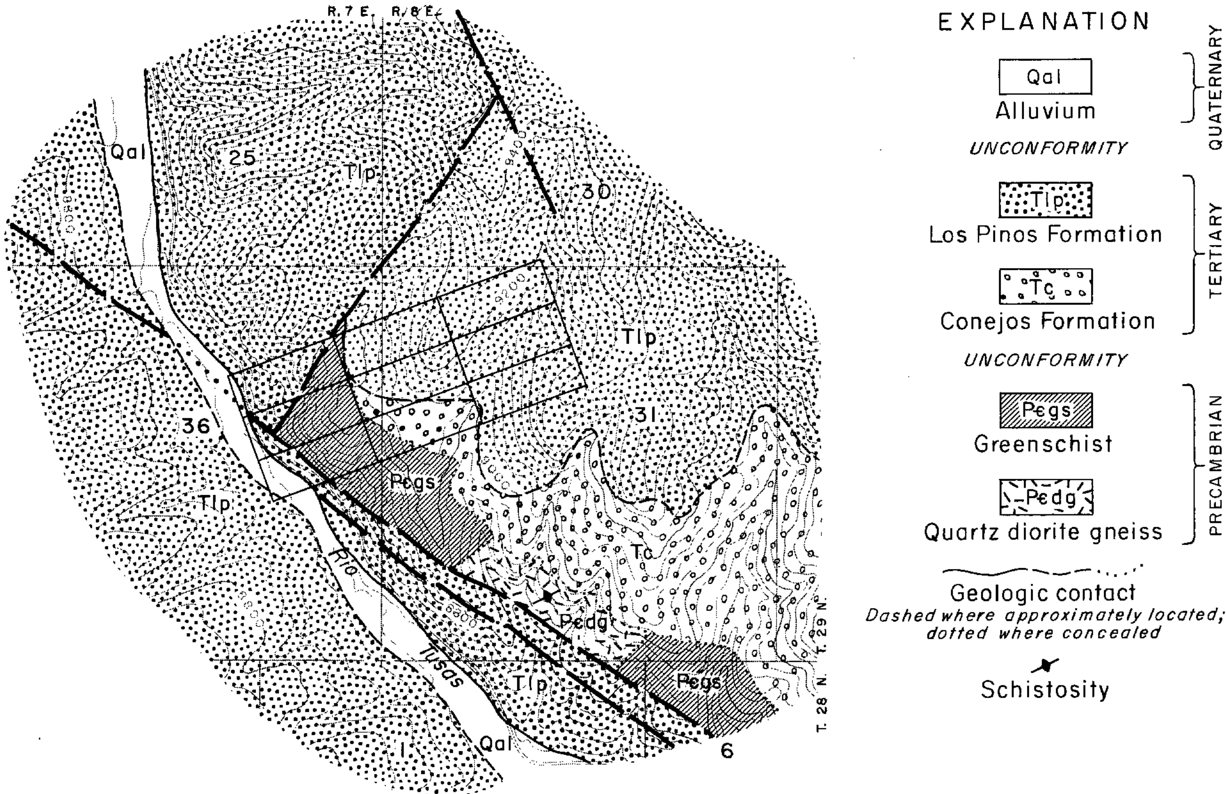


Figure 9

GEOLOGIC AND CLAIM MAP OF THE ROYAL PURPLE GROUP

(Modified from Barker, 1958)

Graton (Lindgren, Graton, and Gordon) describes the mineralization as follows:

> The vein, which does not appear prominently on the surface, is said to strike northwestward and to dip about 65° NE. Tourmaline is present in places; close to the quartz it completely replaces the schist with a felted aggregate of black needles. Siderite, associated with chlorite and muscovite derived from the wall rock, occurs at the borders of the vein in some places. Pyrite, chalcopyrite, and specular hematite are present in the vein. The ore body is said to have been a lens 8 feet wide, 30 feet long, and 45 feet deep. Beyond these limits the vein pinches. Some ore was shipped from this body. It is said that the total values ranged from $17 to $25 a ton, mostly in gold, but the copper content varied from 1 to 5 per cent. The diamond-drill holes are reported to have encountered no quartz nor ore, although sunk in the hanging wall of the vein. The property is now idle.

The Detroit Claim is adjacent to and northwest of the Jawbone, presumably on the extension of the Jawbone vein. Workings consisted of three shallow shafts, now caved. The claim was located in June 1900 by Peter McRae. No production is recorded.

Placer Claims

The location and operation of the upper flat placer ground (Fairview placer) for gold was the first mining activity in the Hopewell district. According to Graton (Lindgren, Graton, and Gordon, p. 130), $175,000 worth of gold was recovered during the first three years of operation. Total production is estimated at $300,000. By the late 1880's, the ground was worked out and the placer operation ceased.

Figure 7 shows the approximate location of the Fairview placer. The claim included much of the gravel along Placer Creek east of the Red Jacket and Mineral Point claims and west of the settlement of Hopewell. (The origin of the gold is uncertain, as explained previously.)

The lower flat placer ground refers to the broad meadow in sectors 3 and 4F. This area has been worked intermittently for gold but with little economic gain. Graton (Lindgren, Graton, and Gordon, p. 130) reports that the area was prospected by the King William Company, which sank a 40-foot shaft and brought in two hydraulic giants. The operation failed through heavy spring run-off that washed out dams and flumes. The small amount of gravel washed reportedly had low gold values. In 1964, the Amistad Mining Company attempted to recover gold by dry-land dredge in Placer Creek claims 1 through 4. Less than 10,000 cubic yards was worked before the project was abandoned.

BROMIDE MINING DISTRICT

The Bromide mining district is centered around Tusas Peak at the southern end of Burned Mountain. It takes its name from the Bromide mine and is generally regarded as a southern extension of the Hopewell district. The center of the Bromide district lies ten airline miles due west of Tres Piedras. The area is accessible from Hopewell Lake and State Highway 111 via the Burned Mountain road. Heavy summer rains may render this route temporarily impassable, effectively isolating the district. All land is within the Carson National Forest, except for patented mining claims. Climate, vegetation, and terrain are similar to the Hopewell district.

The earliest record of mining activity in the Bromide district is marked by the location of the Bromide mine May 31, 1884. During the next 20 years, 35 lode claims were located and eventually patented (table 1). The peak of mining activity was reached about 1890. Patented claims in the district form four clusters: at the head of Rock Creek, at Cunningham Gulch, at Cleveland Gulch, and along the lower reaches of Cow Creek (pl. 6). All these properties are located on sulfide replacement and quartz veins. Initial values were high enough in oxidized ore to support mining, but lower grade sulfides

TABLE 1. PATENTED CLAIMS IN THE BROMIDE DISTRICT

NAME	LOCATION	LOCATED	PATENTED	PATENT NUMBER
Bromide	Bromide Mining Co.	5/31/84	10/1/92	22021
Whole Group Whole	Bell Royal Copper Mining and Milling Co.	5/22/94	7/9/13	
Little Eunice	Daisy B. Ashton	6/12/97	2/25/04	
War Eagle	Mexican King Gold & Copper Mining Co.	4/11/98	11/9/03	
Copper Knob	Daisy B. Ashton	3/13/99	11/16/13	
Sumner	Daisy B. Ashton	2/13/99	10/10/10	156429
Providence	L. M. Ashton	3/14/99	5/1/05	
Virginia	Mexican King Gold & Copper Mining Co.	4/11/99	10/21/05	84932
Philadelphia	Lottie M. Ashton	4/18/99		
Denver	Daisy B. Ashton	4/18/99	11/9/03	
Ora	Daisy B. Ashton	4/18/99	11/9/03	
Payroll	Keystone Copper Mining Co.	4/22/99	6/20/04	
Admiral Group Blue Belle	Admiral Gold & Copper Mining Co.	5/20/99	12/29/04	
Lucky Boy	Daisy B. Ashton	5/27/99	10/31/04	
Butterfly Group Philadelphia	Mexican King Gold & Copper Mining Co.	6/22/99	7/6/11	214585
Last Hope	F. A. Lange	10/9/99		
Butterfly Group Horseshoe	Mexican King Gold & Copper Mining Co.	11/24/99	7/6/11	214585

TABLE 1. PATENTED CLAIMS IN THE BROMIDE DISTRICT (continued)

NAME	LOCATION	LOCATED	PATENTED	PATENT NUMBER
Pigeon	Lottie M. Ashton	1/1/00	2/25/04	
Dora No. 1	Lottie M. Ashton	1/1/00	1/29/04	
Dora No. 2	Lottie M. Ashton	1/1/00	12/20/05	
Jersey Cream	Daisy B. Ashton	1/1/00	10/31/04	
Butterfly Group	Mexican King Gold &			
Butterfly	Copper Mining Co.	1/1/00	7/6/11	214585
Copper Queen	Lottie M. Ashton	1/2/00	12/20/05	
Greenstone	Daisy B. Ashton	1/4/00	10/3/05	
Chicago	Daisy B. Ashton	1/12/00		
Ora Fino	Daisy B. Ashton	4/3/00	2/25/04	
Whole Group	Belle Royal Copper Mining			
Whole No. 1	& Milling Co.	5/28/00	7/9/13	
Admiral Group	Admiral Gold & Copper			
Sampson	Mining Co.	8/25/00	12/29/04	
Dewey	Admiral Gold & Copper			
	Mining Co.	8/25/00	12/29/04	
Red Fissure Group	Red Fissure Mining Co.			
Red Fissure Tunnel		10/4/00	10/13/10	157723
McKinley Group	Pennsylvania Mining &			
Elliot	Milling			
Billy Kennedy		1/3/01	6/28/05	
McKinley				
Red Fissure Group	Red Fissure Mining Co.			
Texas		2/9/01	10/13/10	157723
Red Fissure Group	Red Fissure Mining Co.			
Oregon		3/5/01	10/13/10	157723
Juniper	Daisy B. Ashton	3/13/01	10/31/04	
Jefferson	Daisy B. Ashton	3/31/01	7/9/13	346181
Red Fissure Group	Red Fissure Mining Co.			
Cowboy		5/15/01	10/13/10	157723
Butterfly Group	Mexican King Gold &			
McKinley	Copper Mining Co.	10/10/01	7/6/11	214585
Tusas Peak mill site	Tusas Peak Gold & Copper			
	Mining Co.	8/3/05	6/25/13	343384

encountered at shallow depth gradually forced the abandonment of many properties. By 1910, mining activity had ceased.

In 1956, Charles Besre, J. N. Eddy, and Sterling Lord reopened the Bromide mine. The old drift was opened and retimbered, and a shallow shaft and short crosscut were driven to intersect the vein. A 2-ton mine run of sulfide ore was shipped to the American Smelting and Refining Company in El Paso late in 1957. The pilot sample returned $34.67, mostly in silver. The Bromide mine has not been operated since 1957; John Eddy of Santa Fe now owns it.

The general geology of the Bromide district appears in Barker's report on Las Tablas quadrangle. Figure 10 shows the detailed geology of the central part of the district, including Tusas Peak and the Bromide mine. The following discussion of the geology of the Bromide district is based on the work done in the area shown in Figure 10.

The bedrock geology of the Bromide district closely resembles that of the Hopewell district. Rock types include greenschist, quartz diorite gneiss (both with and without biotite), and granitic gneiss. Schistosity and fracture cleavage in greenschist and quartz diorite gneiss trend from N. 30° W. to N. 60° W.; contacts between these units nearly parallel schistosity. Granitic gneiss has a nearly circular outcrop pattern within the area mapped around Tusas Peak. Cleavage within granitic gneiss trends N. 45° W., N. 30° E., and east-west. Mineral deposits include sulfide replacement and quartz veins, as in the Hopewell district. Ore minerals include gold, chalcopyrite, argentiferous tetrahedrite, native copper, copper carbonates, and molybdenite. Traces of fluorite, galena, and cuprite also are reported (Lindgren, Graton, and Gordon). Mineral deposits of the Bromide district differ from those of the Hopewell in having higher silver and copper and lower gold content. Molybdenite occurs only in the Bromide district at the Tampa mine.

Precambrian Rocks

Pale greenish-gray, platy to laminar greenschist comprises the bedrock throughout much of the central part of the Bromide district. Texturally, this rock ranges from a fine-grained phyllitic schist to a slabby augen schist. In thinsection, the rock consists of quartz, chlorite, muscovite, calcite, and albite with traces of zircon, rutile, and opaque iron oxide. The fabric of the rock ranges from lepidoblastic to protomylonitic, in which flattened phacoidal islands of chlorite-muscovite lie in a braided network of granoblastic and hiatal quartz-calcite. Biotite and hornblende (actinolite?) are present locally as porphyroblasts.

Quartz diorite gneiss, similar to gneiss of the same composition at Hopewell Lake, is exposed as a thin layer interfoliated with greenschist. In the western part of the map area (fig. 10), a light and a dark phase are present; in the eastern part of the map area, only the dark variant is present. Quartz diorite gneiss south of Tusas Mountain is pale greenish gray and weakly foliated and characterized by black streaks several millimeters in length composed of fresh biotite. In thinsection, the rock has a relict hypidiomorphic fabric of quartz and plagioclase overprinted by a crystalloblastic fabric that includes granoblastic quartz and epidote and clots of decussate biotite. Quartz diorite gneiss southwest of Tusas Mountain is schistose and in thinsection is marked by a protomylonitic fabric. The light-colored variant is free of biotite and contains only a trace of chlorite. The rock is silvery white to pale green and grades into the typical greenish-gray, biotite-rich gneiss along the strike.

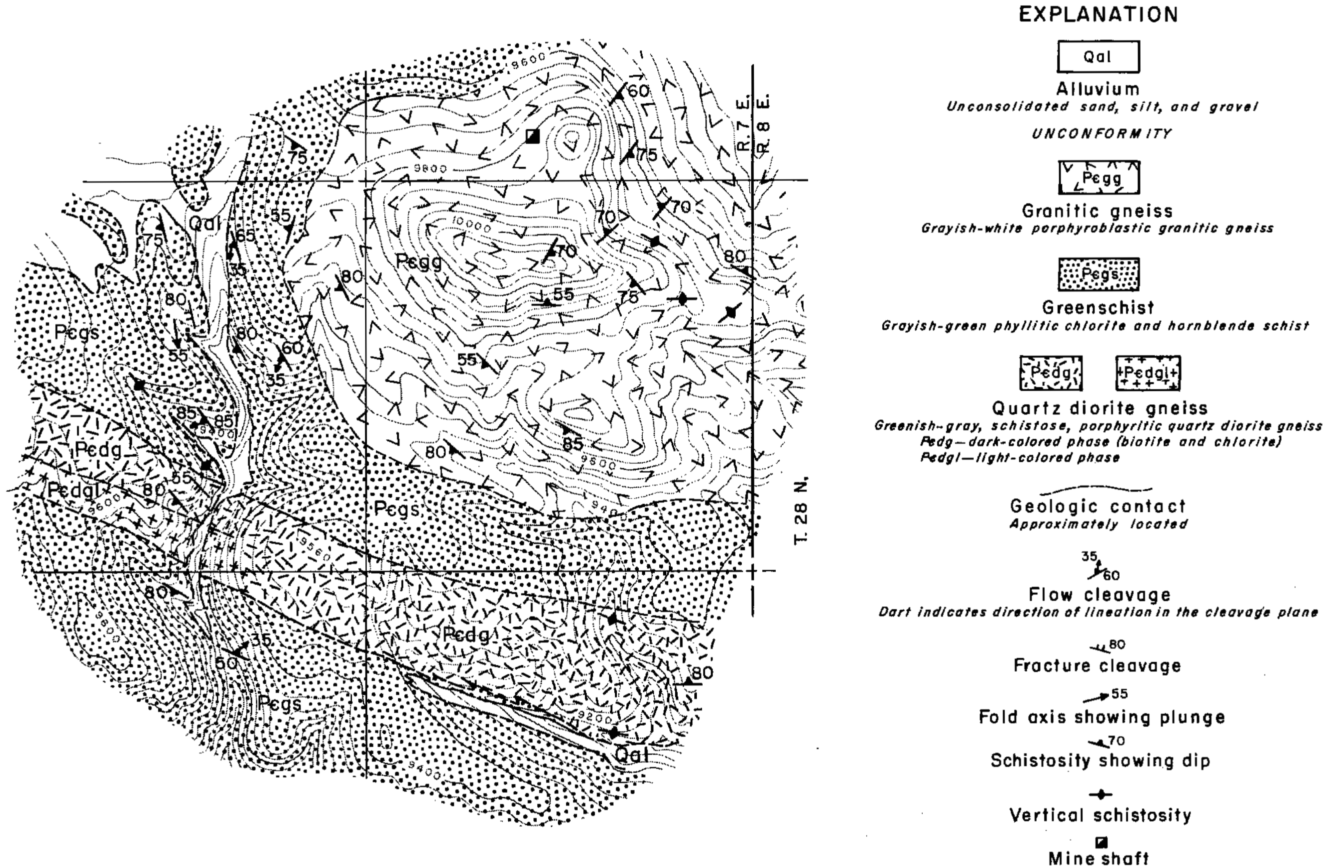


Figure 10

GEOLOGIC MAP OF THE CENTRAL PART OF THE BROMIDE DISTRICT

Granitic gneiss underlies Tusas Peak and occupies about one fourth of the map area (fig. 10). The rock is grayish white to cream-white with a lustrous sheen due to intergranular sericite. Gray-white quartz grains up to a centimeter in diameter stud the surface of the weathered rock. In thinsection, large, rounded, superindividuals of strained and fractured quartz are set in a matrix of fine- to medium-grained quartz, muscovite, and webs of very fine-grained colorless garnet. Irregular grains of microcline perthite range up to 3 mm in diameter. The fabric of the rock is entirely metamorphic, dominantly protomylonitic, with no remnant of igneous texture.

The only planar structure in granitic gneiss is a weak foliation resulting from the preferred orientation of matrix muscovite. In various parts of the outcrop area, this foliation has a west-northwest and a northeast trend. Along the southern and southwestern border of the Tusas Mountain mass, the foliation tends to follow the greenschist-granitic gneiss boundary.

Quaternary Deposits

Recent alluvium mapped in the central part of the Bromide district includes silt, sand, and gravel derived from the crystalline terrain and deposited along recent stream courses. Much coarse colluvial debris mantles the bedrock on the high tableland surface northwest of Tusas Peak. This material obscures the schist-granite contact in secs. 13 and 14, but it was not mapped.

Structure

The central part of the Bromide district shown in Figure 10 includes the roughly circular mass of granitic gneiss underlying Tusas Mountain to the northeast and the tabular mass of quartz diorite gneiss to the southwest, both lying within relatively homogeneous greenschist. The contacts between these different rock units are steep to vertical and, where exposed, sharp and easily recognized. In the central part of sec. 25, the contact between quartz diorite gneiss and greenschist is folded by left-handed, nearly isoclinal dragfolds. Northwest-trending contacts between quartz diorite gneiss and greenschist are parallel or at a slight angle to the principal rock cleavage.

Planar structures in this area include compositional layering, schistosity, and fracture and slip cleavages. Schistosity and compositional layering trend about N. 70° W. and range in dip from 50° NE to 70° SW in the southern part of the map area; in sec. 23, the strike changes to nearly north-south. In this same part of the map area, fracture and slip cleavages strike north-northeast and dip west. These cleavages are transitional into flow cleavage with a similar trend, and consequently, it is difficult to know whether the older schistosity tends to wrap around the mass of granitic gneiss or whether the change in trend of schistosity is due to the pervasive development of a new cleavage-schistosity with a north-northeast trend.

Linear structures include mineralogic and textural lineation in the plane of schistosity, intersections of schistosity and younger fracture and slip cleavages, and the axes of small-scale cleavage folds in which schistosity and compositional layering are the folded elements. Mineralogic lineation due to the parallel alignment of mica and hornblende crystals is present in the schistosity plane of greenschist and to a lesser degree in quartz diorite gneiss. Its plunge is to the east, but the bearing is highly variable because of the range in dip of the schistosity plane. Textural lineation produced by the intersection of schistosity and younger rock cleavage plunges to the west and southwest. This lineation parallels the axes of several dragfolds in which schistosity is folded and fracture or slip cleavage becomes the axial-plane cleavage.

The Precambrian of the central part of the Bromide district is polymetamorphic and includes evidence for the following events: An early period of penetrative deformation and recrystallization during regional metamorphism, resulting in the formation of schistosity containing a mineralogic lineation; a second period of deformation during which earlier formed schistosity was folded, accompanied by the formation of axial-plane fracture and slip cleavage.

Mineral Deposits

Mineral deposits of the Bromide district include sulfide replacement veins in Precambrian schist and gneiss and thin pyritiferous quartz veins. These deposits are similar to those in the Hopewell district. Mineralogy of the veins in both districts is the same except for the occurrence of molybdenite at the Tampa mine. Lindgren, Graton, and Gordon (p. 130) reported that chalcopyrite is more and pyrite less abundant than in the Hopewell district; gold values are lower and silver values higher. Also, tetrahedrite, a major constituent of the ore suite in the Bromide mine, is found in only trace amounts in the Hopewell district.

No placer deposits were located in the Bromide district.

Mines and Prospects

There is no mining activity at the present time in the Bromide district. All workings visited by the writer in 1966 were caved and inaccessible. Descriptions of individual mines and properties are taken largely from Graton (Lindgren, Graton, and Gordon) and examination of samples taken from mine dumps. J. N. Eddy supplied much unpublished data regarding the redevelopment of the Bromide mine during the 1950's.

Bromide Mine

The Bromide is the oldest mine in the district, having been located May 31, 1884, by the Bromide Mining Company. It is half a mile north of the Moppin Ranch (abandoned) and the Burned Mountain road. The patented claim lies on the boundary between secs. 23 and 26, T. 28 N., R. 7 E.

According to Graton (Lindgren, Graton, and Gordon, p. 132), inital high production values were obtained from a carload of oxidized silver ore believed to be silver bromide. A shaft was sunk to a depth of 140 feet, encountering sulfides at 50 to 60 feet. Exploration at the base of the shaft included a drift driven N. 20° W. for 212 feet and a 132-foot crosscut trending N. 30° E. An adit 760 feet long connected the main shaft with the main canyon east of the shaft. Low values and flooding closed the mine prior to 1929.

The mine was reopened between 1955 and 1958 by J. N. Eddy, Sterling Lord, and Charles Besre of Santa Fe. The main haulageway and a short winze were opened and retimbered and a 38-foot shaft sunk. In all, 30 tons of ore were mined. In the fall of 1957, a 2-ton shipment of mine-run ore was sent to the American Smelting and Refining Company smelter at El Paso, which reported 25.9 ounces per ton of silver and 2.05 per cent copper. There has been no further activity at the mine.

The bedrock exposed at the mine is grayish-green phyllitic schist composed of quartz, albite, muscovite, chlorite, and calcite. Schistosity parallels compositional layering and trends N. 60° W. and dips 70° SW. Samples of schist wall rock taken from the dump contain layers, pods, and stringers of milky vein quartz, segregations of carbonate minerals, and earthy aggregates of yellowish-brown limonite. Ore minerals are chalcopyrite, tetrahedrite, and malachite which occur intimately intergrown as stringers and veinlets, and also as disseminations in schist and vein quartz. Vuggy and porous lenses in the schist include incrustations of limonite that appears to represent altered siderite aggregates. Graton (Lindgren, Graton, and Gordon) gave the following description of the geology and mineralization in the workings:

> A quartz vein containing siderite and chalcopyrite is said to strike about N. 70° W., with almost vertical dip. Parallel to and near it the schist is impregnated with stringers and lenses of tetrahedrite, associated with calcite. This copper-antimony sulphide is in some places intergrown with chalcopyrite and associated with quartz, and it seems probable that it is a primary mineral. This mineral is probably the one which carries the silver. The ore is said to have followed a shoot in the vein. In the bottom of the shaft, at a depth of 140 feet, a 22-inch streak, running well in copper and silver, was left when

work was stopped. It is stated that the gold values are low, ranging from $1 to $4 a ton.

A parallel vein about 20 feet north of the Bromide vein furnished some good copper ore to lessees when water interfered with working on the main vein. The production of this mine is reported at $27,000.

Tampa Mine

The Tampa mine lies in the south-central part of sec. 13, T. 28 N., R. 7 E. about one fourth of a mile north of Tusas Peak. Access to the mine is by primitive road connecting with the Burned Mountain road.

During the period of active mining in the Bromide district, the Tampa was the largest mine in the district in terms of amount of workings. A 400-foot shaft served 800 to 1000 feet of drifting in five levels. Water problems were encountered below the 300-foot level. Samples taken from the dump indicate that bedrock in the mine is biotite and chlorite-rich quartz diorite gneiss and granite gneiss. Figure 10 shows the Tampa mine within the outcrop area of granitic gneiss. Therefore, the quartz diorite gneiss may represent part of a contact zone in roof pendant. Disseminated chalcopyrite, molybdenite, and cubes of pyrite occur in the dump material. The stringers and blebs of sulfide minerals commonly occur within or are intimately associated with segregations of chlorite and biotite.

Lindgren, Graton, and Gordon give the following detailed description of the mining geology:

> The vein strikes about N. 30° W. and dips steeply to the northeast. On the 45-foot level good ore was reached just north of the shaft. It consisted mainly of malachite, copper glance, and a little chalcopyrite. In a few places azurite, cuprite, and a little native copper were found. Some free gold was present in hematite, which probably resulted from pyrite. Little scales of molybdenite were occasionally found. On the 100-foot level a strong body of partly oxidized ore was reached, but the grade was lower than that of the ore above. The best ore is said to have been found on the 200-foot level. A crosscut extending 25 feet northward from the shaft reached the ore body, which was 14 feet wide. Specimens from this level show several narrow and coarsely spaced quartz veinlets, carrying along their borders a mixture of chlorite and chalcopyrite, and in some places considerable molybdenite. Two carloads shipped from this mine are said to have averaged about $15 a ton—one-eighth ounce of gold, 6 ounces of silver, and the rest copper. On the 300-foot level the vein cut on the levels above has not been sought, but a 300-foot crosscut has been run a little north of east to reach an ore body which is known on the surface. In this crosscut the country rock is granite with a few streaks of schist. Chalcopyrite and malachite are encountered in small bunches

here and there, but no ore body has yet been reached. A vein holding low-grade ore is said to have been cut on the 400-foot level, but whether it is the same as the one known on the 200-foot level is not certain.

Rock Creek Group

This group of claims located midway between Burned Mountain and Tusas Peak includes the Payroll, Whale, Whale No. 1, Denver, Lucky Bay, Ora, Philadelphia, and Chicago claims. The Payroll claim appears representative of the group and is described below.

Payroll mine. The Payroll mine is now marked at the surface only by a large dump and a caved shaft. The claim was located April 22, 1889, by the Keystone Copper Mining Company and was later acquired by the Keystone Bromide Mining Company. According to the patent map of this claim, workings included a 267-foot shaft with a 73-foot crosscut at the 250-foot level driven N. 20° E. and a 63-foot drift driven north. Bedrock samples in the dump are grayish-green phyllitic schist. A small amount of disseminated chalcopyrite occurring as thin stringers parallel to schistosity was found in some schist samples.

Graton's (Lindgren, Graton, and Gordon) description of the Payroll mine follows:

> The country rock is a sericite-chlorite schist, with foliation striking northwestward and dipping very steeply to the northeast. Along a zone of some width the rock is impregnated with chalcopyrite in stringers parallel to the foliation of the schist. Little lenses of calcite occur here and there along with the sulphide. A shaft 250 feet deep is sunk in the hanging wall of this sulphide zone or fahlband, and crosscuts are driven to it. The upper portion of the ore body is oxidized and consists of hematite and limonite streaks stained with copper, in the schist. At a depth of about 60 feet flakes of native copper are found, and below this depth sulphides appear. Chalcopyrite is the principal sulphide, pyrite being only sparingly present. A 50-foot crosscut to the south at the 150-foot level shows some ore in certain streaks. At the 250-foot level a crosscut to the south, after passing through a kaolin seam 4 feet from the shaft, reaches soft schist with stringers of chalcopyrite, said to average 4 per cent of copper and $6 to the ton in gold. It is said to be 20 feet wide, and the last 4 feet of the ore is harder, carrying 9 per cent copper and $30 a ton in gold. Beyond this is a kaolin streak, then a width of 70 feet of 2 to 3 per cent copper ore, gradually decreasing in value beyond a point 90 feet south of the shaft. Some of the chalcopyrite along fractures appears to be secondary.

Cleveland Gulch Claims

A group of twelve claims located in Cleveland Gulch (fig. 11) includes the Dora No. 1, Pigeon, Copper Queen, Jersey Cream, Dora No. 2, Little Eunice, Copper Knob, Ora Fino, Sumner, Greenstone, Juniper, and Jefferson. The claims are located along contacts between Precambrian amphibolite and quartzite and near several minor faults. Exploratory work consisted of numerous shallow shafts and short adits, except for the Sumner claim which included a 300-foot adit driven south, apparently along a fault trace. No production is recorded for any of the claims.

Cunningham Gulch Claims

The Butterfly and Admiral groups of patented claims lie in Cunningham Gulch near Butterfly Spring. Numerous shallow workings testify to considerable early development, but apparently little ore was produced.

SENORITO DISTRICT

The extreme northern part of the Senorito district extends into south-central Rio Arriba County at the southern edge of the San Pedro Mountains about seven miles east-southeast of Cuba. The only mine in this part of the district is the Eureka, which has produced copper and silver from a "red-bed copper" type of deposit.

Eureka Mine

The Eureka mine is at the southern edge of Eureka Mesa about one mile north of State Highway 126 (fig. 12). The mine can be reached via a poor jeep road from State Highway 126 or by a short climb down over the cliff edge from the primitive road along the top of the mesa. The mine lies on the Conglomerate Nos. 1 and 2 claims patented (No. 986449) October 2, 1926, by the Francisco Mining Company.

Old workings noted by Lindgren, Graton, and Gordon (1906) are now abandoned. Newer workings presumably driven in the middle 1950's included numerous 15-foot-wide adits driven north and northwest into copper-bearing conglomerate (fig. 13). The old workings are visible at several places but appear to be partly flooded and inaccessible.

Eureka Mesa is an erosional remnant of Triassic Agua Zarca Sandstone, one of the members of the Chinle Formation. At the Eureka mine, the Agua Zarca Sandstone consists of grayish-white to yellowish-tan interbedded sandstone and conglomerate. The conglomerate layers are prominently cross-bedded; numerous coaly plant remains lie in the plane of bedding, and cross-bedding. Clasts in the conglomerate and coarse sandstone ranging up to half an inch in diameter include milky quartz, gray quartzite, and lavender quartzite, all subrounded to well

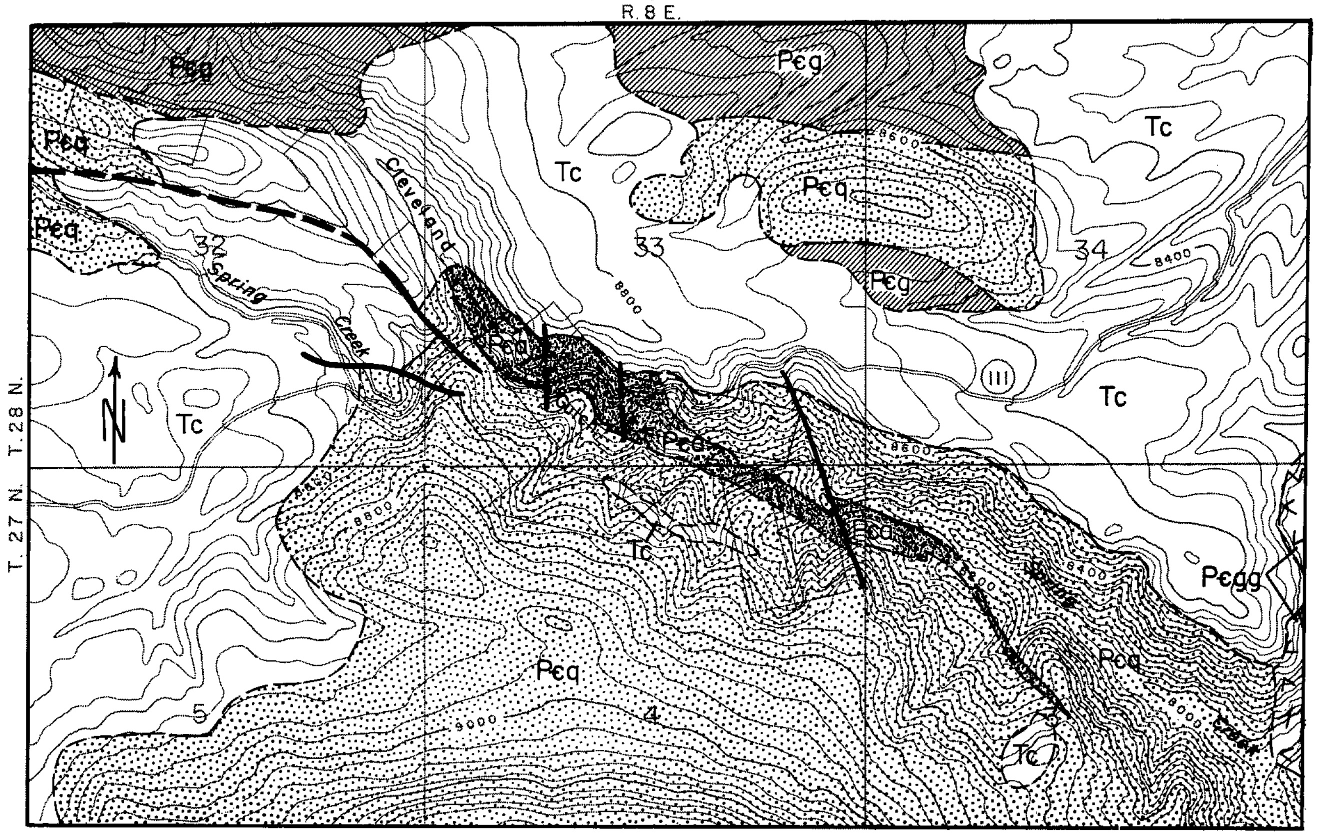


Figure 11

GEOLOGIC MAP OF THE CLEVELAND GULCH AREA

TERTIARY

Tc

Volcanic conglomerate

Grayish-tan conglomeratic sandstone composed of andesite, quartz latite, and rhyolite clasts in a tuffaceous matrix

UNCONFORMITY

PRECAMBRIAN

p€q

Quartzite

Gray laminated quartzite, muscovitic quartzite, and quartz-muscovite-biotite schist

p€a

Amphibolite

Interlayered greenish-black amphibolite and gray muscovitic quartzite

p€g

Greenschist

Greenish-gray to purplish-tan phyllitic schist

p€gg

Granitic gneiss

Purplish-orange, fine-grained granitic gneiss

Contact

Dashed where approximately located

Fault

Dashed where approximately located

Contour interval 40 feet

Datum is mean sea level

Figure 11 EXPLANATION

(Modified from Barker, 1958)

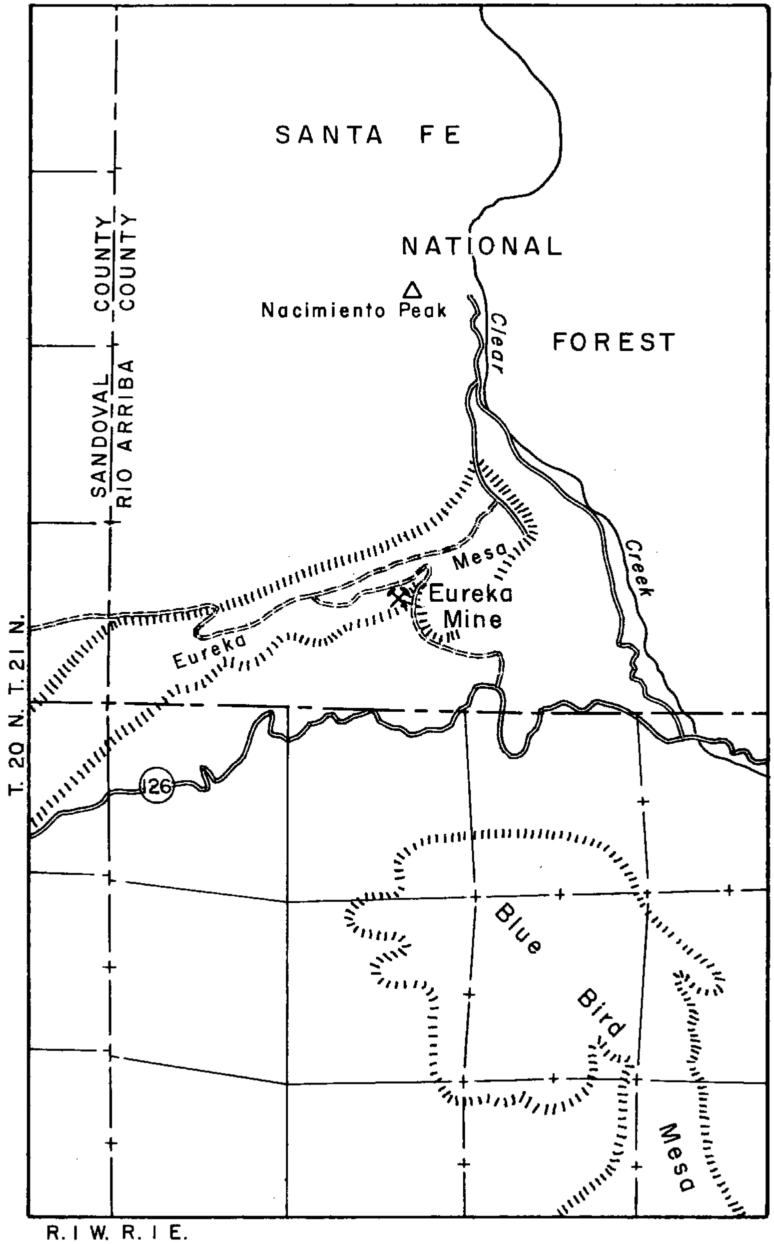


Figure 12
INDEX MAP SHOWING LOCATION OF THE EUREKA MINE

rounded. Irregular fragments of gray to pinkish-gray claystone or shale up to several inches in diameter are common in the conglomerate layers.

The mineralization consists of intergranular fibers of malachite and azurite that occur in discontinuous streaks throughout the conglomerate horizon, chalcocite replacing coaly plant remains as interstitial material. The sites of sulfide replacement are scattered throughout the conglomerate and constitute a very small percentage of the rock exposed in the main workings. One hand specimen selected from the dump as representative of the richest appearing ore consists of quartz, quartzite, and jasper fragments set in a quartz sand matrix. The specimen is pale greenish gray because of very thin films of malachite coating individual grains and occurring along grain boundaries in quartzite clasts. Chalcocite as interstitial material and as replacement sulfide in an organic host makes up a small percentage of the rock. A sample of this specimen assayed 19.4 per cent copper and 0.0126 per cent silver.

The Eureka mine is described by Graton (Lindgren, Graton, and Gordon) as follows:

> According to the reports of the mine operators the deposits are distributed through a thickness of about 25 feet of sandstone and

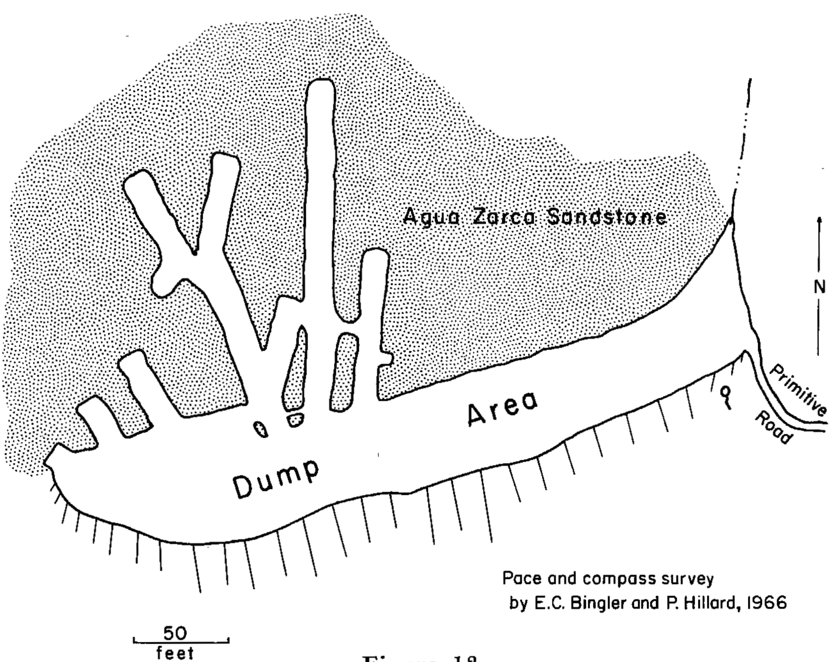


Figure 13
MINE MAP, EUREKA MINE

conglomerate, but the richer and most important part is contained in a bed of the copper-bearing fine conglomerate, 3 to 4 feet thick, that is said to average several per cent of metallic copper. Above this lie "low-grade" ore-bearing sandstone and conglomerate about 12 feet thick, which are thought to carry about 5 per cent of metallic copper. Considerable glance, much of it in the form of nodules, is present, especially in the lower conglomerate.

As seen in the ore bin at the Senorito smelter, the ore-bearing conglomerate is very siliceous. Its pebbles are essentially quartz, dense quartzite, some of which is schistose, some light-colored or buff aphanitic igneous rock, and yellowish-brown and slate-colored flint. The largest pebbles are those of quartz, some of them reaching 1½ inches in diameter. The quartz resembles that seen in granitic areas in different localities on the mountains. The cement is composed of detritus of igneous rocks, thoroughly impregnated with copper ore, chiefly the green carbonate. This has led mining engineers who have visited the deposit to report the cementing material to be copper ore.

The ore has mostly been quarried, but there has also been some underground development, consisting of tunnels or drifts aggregating about 600 feet in length, with crosscuts and raises. The Eureka tunnel, 500 feet long, extends through beneath the crest of the mountain to open air on the other side. These works and the croppings show the ore deposit to have a linear extent of about 400 feet on claim No. 1 and of more than 100 feet on claim No. 2. There is said to be about 1,000 tons of ore on the dump.

Copper and silver production in Rio Arriba County for 1956-1957 totaled 331 tons of copper and 841 ounces of silver. Most of this production probably came from the Eureka mine.

COYOTE–YOUNGSVILLE AREA

Considerable exploration for "red-bed" copper deposits has centered in the Mesozoic rocks of the Coyote–Youngsville area. Several prospects have been pursued but low grade and small tonnages have discouraged further work.

Smith, Budding, and Pitrat mapped a large area that includes the Coyote–Youngsville area, and they summarized the "red-bed" copper mineralization as follows:

Copper mineralization in sandstone about 150 to 200 feet below the top of the Cutler formation has been prospected in Arroyo del Cobre in the Canjilon SE quadrangle, but no other showings have been found in the Cutler outcrops to the west. The several occurrences are typical "red bed" copper deposits with carbonaceous plant fragments replaced by chalcocite, malachite, azurite, and various copper oxides; surrounding the fragments in the clean sandstone is usually an oxidation halo of malachite and azurite. Individual specimens may contain as much as 15% to 20% Cu, but the prospects usually expose only a few tons of material, which averages less than 1% Cu.

PROSPECTS

The writer examined Las Minas de Pedro (Pete's prospect) and Las Minas Jimmie (Jimmie's prospect) in Arroyo del Cobre north of Abiquiu (fig. 14). Both prospects occur in conglomerate or conglomeratic sandstone of the Lower Chinle, at or near the contact with the underlying Cutler Formation of Permian age.

Las Minas de Pedro consists of a 25-foot adit driven S. 70° E. along a seam of coaly trash. Eight to 10 feet of light-brown conglomeratic sandstone rest on and grade into the coaly zone, which rests upon bleached pink to purplish-green siltstone. Nodules of chalcocite rimmed and replaced with malachite occur in a ½- to 1-inch-thick zone within the layer of coaly material. Several prospect pits are scattered along the contact mineralized zone.

Las Minas Jimmie includes a prospect pit and two adits driven a few tens of feet S. 70° E. along the same contact zone as the Las Minas de Pedro. Malachite and azurite occur as tenuous fringes around coaly plant fragments scattered throughout the conglomeratic sandstone horizon.

EL RITO AREA

Earlier reports (Jones, 1904; Anderson, 1957) suggest the presence of alluvial gold deposits in El Rito Conglomerate north of El Rito. However, the writer found no evidence of mining or prospecting activity in this area during mapping of the Valle Grande and El Rito quadrangles. In the writer's opinion, there is little likelihood of locating alluvial gold deposits in El Rito Conglomerate.

IRON DEPOSITS

Iron-rich zones in Precambrian metamorphic rocks of the Tusas Mountains have been located and intermittently prospected in the past. Graton (Lindgren, Graton, and Gordon, p. 128) briefly described iron-rich greenschist underlying Iron Mountain in the northern part of the Hopewell district. Bertholf (1960), Harrer and Kelly (1963), and Harrer (1965) noted the presence of similar schist at Cleveland Gulch and reported the results of assays and metallurgical work done on several grab samples taken from prospect sites. Barker described the Moppin metavolcanic unit, which is the host rock for most of the iron occurrences, and Bingler (1965) described an occurrence of iron-rich quartzite at La Madera Mountain. There is no record of production

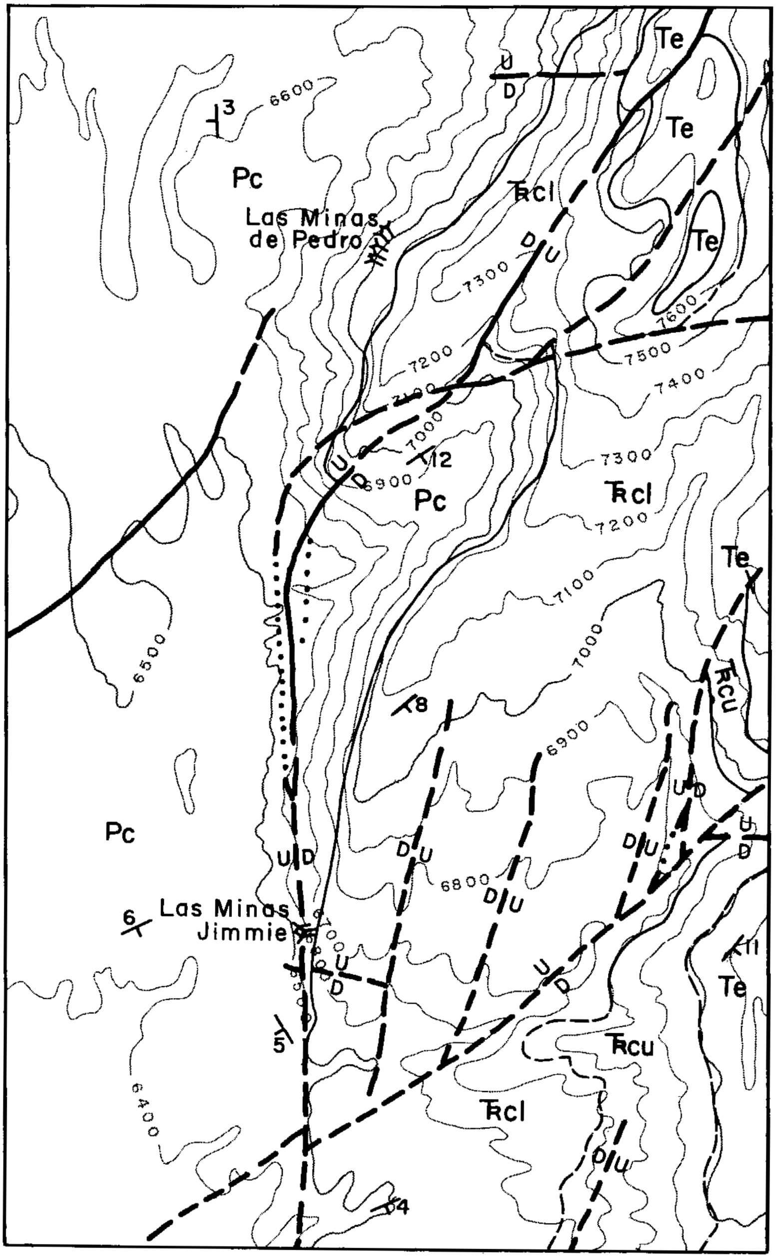


Figure 14

GEOLOGIC MAP SHOWING LOCATION OF COPPER PROSPECTS IN ARROYO DEL COBRE

(After Smith, Budding, and Pitrat, 1961) from any of the localities described, and iron-rich schist layers exposed in trenches and prospect pits are thin, intimately interlayered with normal schist, and discontinuous along the strike.

Iron Mountain Area

Iron-rich phyllitic schist crops out in several small workings on Iron Mountain in the northern part of the Hopewell mining district. Iron Mountain is the name given to a small prominence at the extreme southern margin of Jawbone Mountain. It is located 1⅓ miles north-northwest of Hopewell Lake in the NE¼, sec. 30, T. 29 N., R. 7 E. The area can be reached by primitive road from Hopewell Lake.

Figure 15 shows the geology of the area. Iron Mountain overlies grayish-green phyllitic schist composed of quartz, chlorite, muscovite, albite, and magnetite. The dominant schistosity (flow cleavage) trends about east-west and dips steeply to the north. In several outcrops, flow cleavage has a northwest or northeast trend that appears to result from overprinting rather than the varying trend of one cleavage. Compositional layering is marked by alternating layers of fine-grained, quartz-rich and mica-rich schist. Several layers of porphyroblastic schist were noted on the south flank of the hill, and one zone of magnetite-rich schist 12 to 14 feet wide was mapped near the crest of the ridge. All these types of compositional layering strike east-west and parallel the east-west flow cleavage. The approximate contact between phyllitic schist and quartz diorite gneiss also strikes east-west.

Several samples of iron-rich schist were taken from the layer that crops out near the west end of the ridge and from the portal of an inclined shaft on the south flank of the ridge. The shaft was sunk on a 2-foot-wide zone of reddish-brown to black iron-rich schist interlayered with greenish-brown quartzose schist and highly sheared greenschist. Within the iron-rich schist, 2- to 3-inch layers of pale green quartzite alternate with ¼-inch seams of magnetite and hematite. Under the microscope, the iron-rich schist is a very fine-grained (average grain size, about 50 microns) magnetite-quartz-chlorite phyllitic schist with a crystalloblastic and lepidoblastic fabric. Xenomorphic quartz and magnetite make up the bulk of the rock with interstitial, aligned flakes of chlorite defining the schistosity. Scattered porphyroblasts of muscovite up to 4 mm in diameter poikiloblasticly include quartz and magnetite. The grain size of magnetite averages 0.05 mm and ranges from 0.20 mm to a fine dust. Quartz and chlorite range from about 0.05 to 0.01 mm, with most grains near the average diameter of 0.03 mm. Nearly all quartz grains below 0.03 mm include smaller grains of magnetite. The modal composition of this rock based on a point count of 700 grains is magnetite, 59 per cent; quartz, 19 per cent; chlorite, 22 per cent.

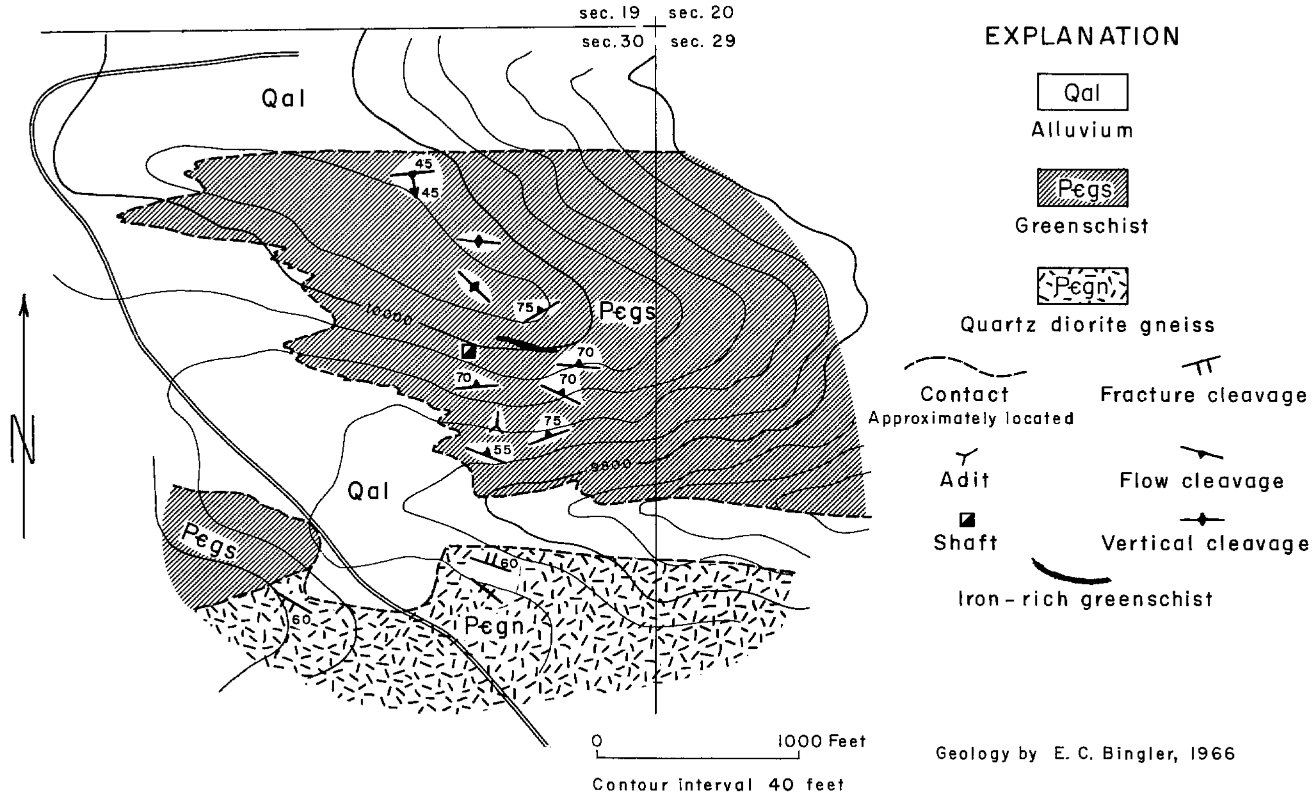


Figure 15

Geologic map of the Iron Mountain area

A character sample from this locality collected by the U.S. Bureau of Mines contained 40.1 per cent iron, 0.26 per cent phosphorus, 0.12 per cent sulfur, 0.1 per cent titania, less than 0.1 per cent manganese, and 38.4 per cent silica (Harrer and Kelly, p. 60).

A reliable estimate of reserves in the Iron Mountain area is difficult to obtain. Float mantles the bedrock surface and numerous fragments of ironstone in the colluvial debris may be derived from several thin, discontinuous layers rather than from a substantial thickness. Harrer and Kelly report tracing the Iron Mountain deposit for more than half a mile in a 100-foot-wide zone by dip-needle survey. However, the magnetite content of the greenschist unit is uniformly high, and this factor should be carefully considered in the evaluation of a dip-needle survey. A conservative estimate of the amount of iron-rich schist present would include at least two layers or zones of magnetite-rich greenschist, ranging in thickness from 10 to 20 feet with a strike length of at least several hundred feet.

Cleveland Gulch Area

Several prospect pits have revealed the presence of iron-rich schist in the Cleveland Gulch area. Bertholf constructed a magnetic profile across the strike of layered Moppin metavolcanic rocks, based on dip-needle measurements at 59 stations arranged in northeast-trending traverses along an east-west base line. Anomalies of several thousand gammas were recorded. Iron content of a composite channel sample collected at the highest anomaly was 35.6 per cent.

Harrer and Kelly (p. 62) traced iron-rich schist 3000 feet along an east-west outcrop belt; analyses of two iron-rich schist samples are shown below:

CHEMICAL ANALYSES (per cent)

Fe	P	S	TiO_2	Mn	SiO_2
29.7	0.15	0.12	0.1	0.2	53.2
37.7	0.10	0.04	0.16	0.2	44.4

La Madera Mountain

Bingler (1965) described a small lens of quartz-specularite-kyanite schist occurring in the quartzite that underlies La Madera Mountain:

> A lens of specularite-quartz schist with an exposed thickness of from three to four feet and a length of about forty feet crops out on the northwest flank of the western spur of La Madera Mountain. The outcrop trace of the lens strikes nearly west, parallel to the trend of the foliation in enclosing quartzite. In outcrop, it is grayish green to black, compact, and coarsely crystalline. The essential constituents

are kyanite, 36 per cent; specularite, 35 per cent; and quartz, 21 per cent. It contains accessory amounts of rutile, muscovite, and sillimanite. In thinsection, xenormorphic quartz with sharp extinction includes porphyroblastic kyanite idiomorphs and faint planar segregations of hematite. Most hematite occurs as large irregular patches of subhedral to anhedral grains. Numerous small orange anhedra of rutile are associated with the larger masses of hematite. Individual hematite grains range in size from submicroscopic to 0.7 mm, kyanite has an average prism cross-section diameter of 0.8 mm, and matrix quartz averages 0.35 mm in diameter.

Potential Reserves

Several writers have classified the Precambrian iron-rich greenschist in the Tusas Mountain as taconite—that is, the typical ferruginous chert of the Lake Superior iron districts (Bertholf; Harrer and Kelly; Harrer)—and have indicated potential reserves in excess of 100,000,000 tons. It is probable that such an estimate is grossly exaggerated, for at least two reasons. First, iron-rich schist is invariably interlayered with common greenschist as thin and discontinuous laminae. Second, the greenschist of the Moppin metavolcanic unit has a uniformly high iron-oxide content; for example, Barker reported analyses of greenschist in which the combined iron-oxide content ($FeO + Fe_2O_3$) ranged from 10 to 14 per cent. Any redistribution of this iron content during metamorphism, or its appearance as magnetite instead of in the minerals chlorite or hornblende, could result in locally developed layers of unusually high iron content. Such layers scattered over a large area of poorly exposed greenschist might well register as a large body of iron ore in a magnetic survey. At the very least, considerable caution should be observed when estimating iron reserves in the metamorphic terrain of the Tusas Mountains.

TITANIUM DEPOSITS

An airborne radiometric reconnaissance of the Jicarilla Apache Indian Reservation, conducted by the Atomic Energy Commission (Chenoweth, 1957, p. 216), located a deposit of titaniferous sandstone northeast of Stinking Lake during November and December 1955. Bingler mapped and sampled this deposit in June 1965. A second deposit in the Tierra Amarilla grant (NE corner, NE¼SE¼ sec. 2, T. 27 N., R. 1 E.) located during the same survey was not examined. According to Chenoweth, the latter deposit in the Point Lookout Sandstone is about 5 feet thick and is exposed along the rim of a mesa for about 1000 feet.

Stinking Lake Deposit

An occurrence of titaniferous sandstone of Late Cretaceous age referred to as the *Stinking Lake deposit* is located in sec. 3, T. 28 N., R. 1 E. 4½ miles northeast of Stinking Lake, just inside the eastern boundary of the Jicarilla Apache Reservation (fig. 16). Lenses of titaniferous sandstone are exposed along the north cliff edge of a 2- to 3-mile-long box canyon that opens to the southeast. Access to the area is via State Highway 95 to Hayden Lake, then 4.2 miles by primitive road. Caution must be exercised in wet weather, for much of State Highway 95 is in bentonitic shale, which quickly becomes impassable when wet.

This titaniferous sandstone occurs near the top of a sandstone sequence included within the Mesaverde Formation. The deposit lies on the eastern edge of the San Juan Basin, as indicated by the north-northeast strike and 8- to 10-degree west dip of bedding within the sequence. Erosion in this area has produced a prominent cuesta with a steep east front and a gentle westward dip slope.

The deposit consists of thin layers of heavy mineral concentrations interlayered with quartz sandstone (fig. 17). The over-all form of the deposit is lenslike. The lens strikes north-northeast, pinches out northwestward, and is truncated by erosion to the south-southeast. The strike length of the lens is about 3000 feet, and the width perpendicular to the strike is about 4000 feet. The thickness ranges from about 8 feet to 0, averaging about 5 feet. The lens was mapped by pace and compass methods, using a hand-held scintillometer. Background radiation for normal sandstone was 0.015 milliroentgen per hour, the lower limit for mapped lens material was 0.032 mr per hour, and the maximum radiation detected was 0.15 mr per hour.

The sequence that supports the cuesta and contains the heavy mineral lens consists of thin sandstone units. The lowermost sandstone is fine-grained, well sorted, light olive-green, and about 100 feet thick. It grades downward into gray Mancos Shale. The medial unit is fine- to medium-grained, yellowish tan to grayish white, and contains scattered thin laminae stained by yellowish-brown limonite. The uppermost unit is about 12 feet thick, prominently cross-bedded, grayish to yellowish-white, fine- to medium-grained quartz sandstone. Some cross-bedded laminae are defined by reddish-purple hematite staining. The heavy mineral accumulations occur entirely within and at the top of this uppermost sandstone.

The heavy mineral lens material consists of olive-brown to purple, fine-grained sandstone interlayered with barren cross-bedded quartz sandstone. Much of the lens material tends to have a poor to moderately well-developed desert varnish that helps to distinguish it from common sandstone. It is very well cemented with iron oxide, leucoxene, and a trace of secondary silica. The heavy mineral suite includes lavender and clear, angular to beadlike zircon, pink angular garnet, angular and beadlike black tourmaline, reddish-orange rutile and opaque minerals.

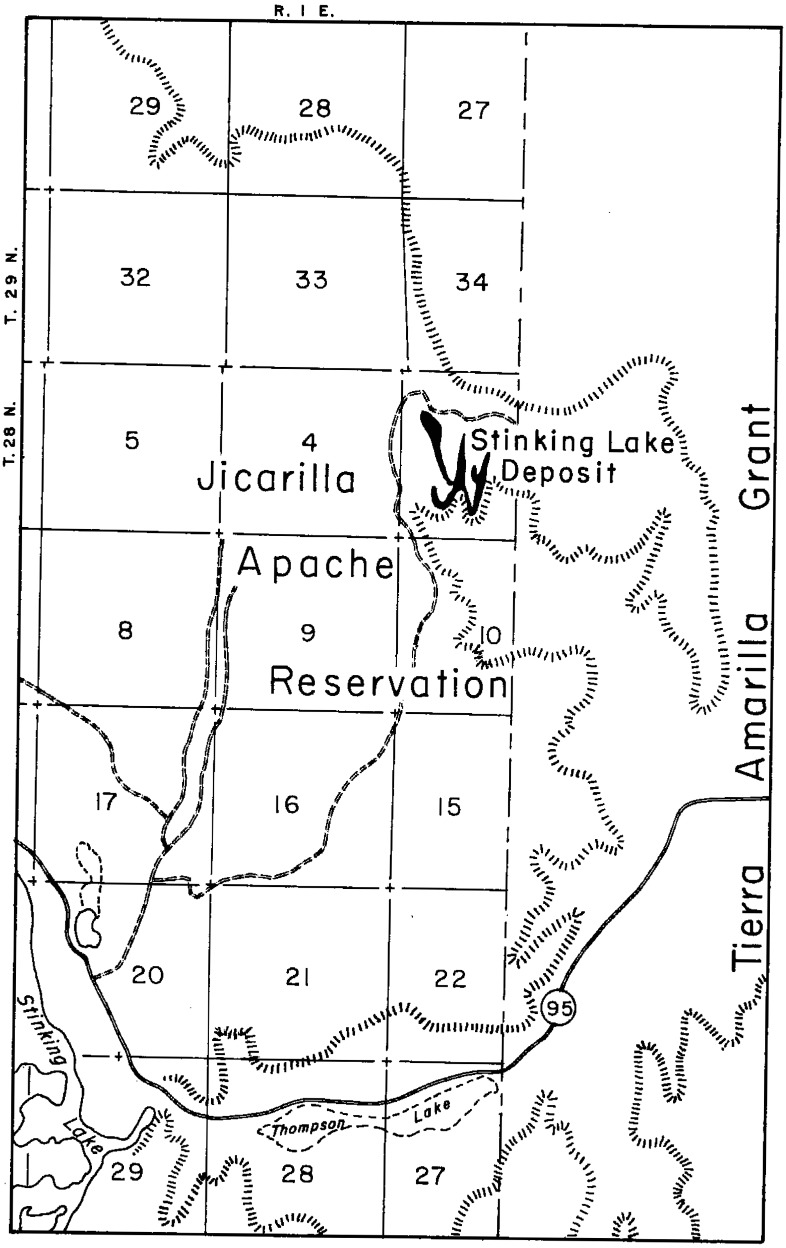


Figure 16
INDEX MAP SHOWING LOCATION OF THE STINKING LAKE DEPOSIT

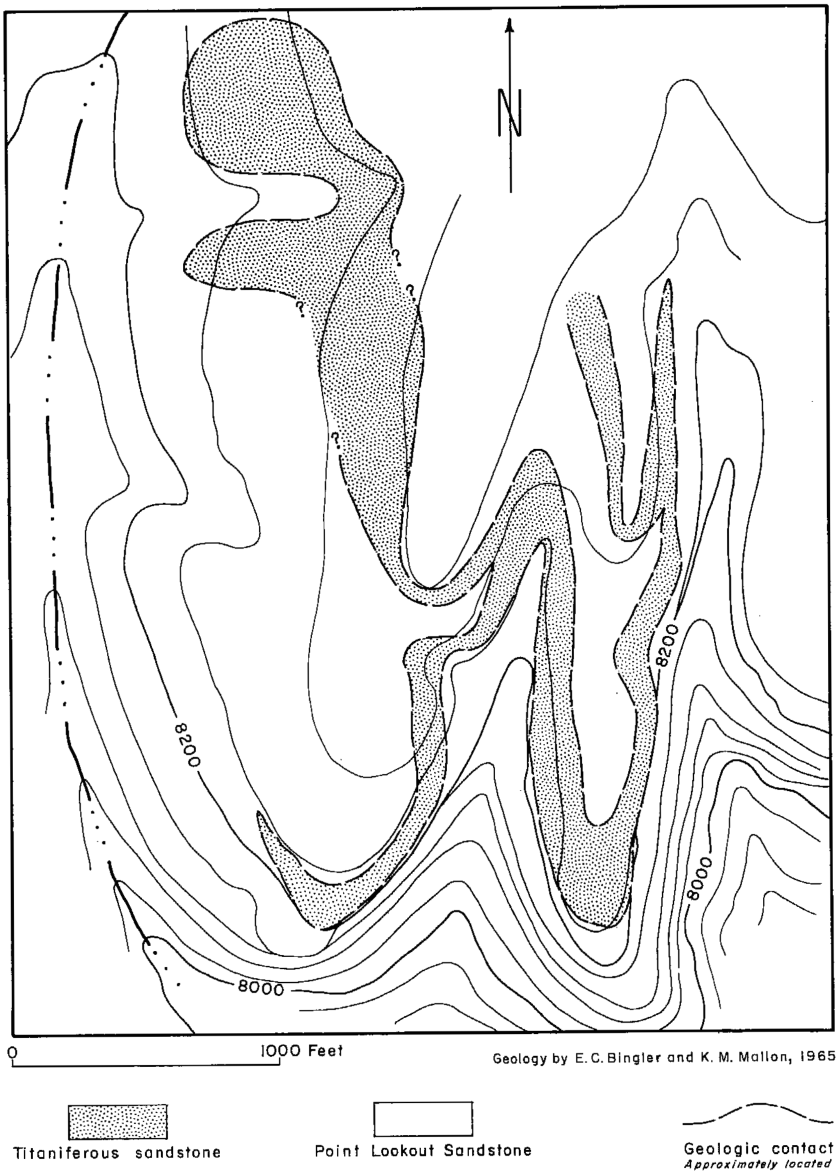


Figure 17
GEOLOGIC SKETCH MAP OF THE STINKING LAKE DEPOSIT

The opaque grains include magnetite and ilmenite in all stages of alteration and mixtures of limonite and leucoxene. The degree of alteration is marked by the color of the grains which ranges from white to brownish and reddish black, yellowish to cream-brown predominating. Unaltered primary iron-titanium oxides are rare, and judging from the degree of secondary titanium cement and alteration of primary oxides, the heavy mineral concentrations have been profoundly modified by diagenetic processes.

Reliable grade and tonnage estimates are impossible to make without detailed mapping, drilling, and sampling. A liberal first approximation based on the sketch map of the deposit suggests up to 5,000,000 tons of lens material. A sample of the best-looking lens material contains 5.73 per cent TiO_2.

In 1965, when the deposit was mapped, it did not appear that the area had been prospected or developed in any way.

MANGANESE DEPOSITS

A small amount of manganese mineralization occurs in a fault zone northwest of Abiquiu and in the Conejos flow breccia near the Colorado–New Mexico line southwest of Los Piños Canyon. The Abiquiu occurrence consists of manganese oxide as films and cavity fillings in a fault breccia. The mineralized fault breccia is exposed about halfway up the southwestern edge of Cerrito Blanca a few hundred feet northeast of the flume on the Abiquiu ditch.

Nonmetallic Deposits

At least eighteen nonmetallic commodities are produced or reported in Rio Arriba County. Most of the mining activity has centered in the Petaca district, an area of numerous large pegmatites and a major source area for mica in New Mexico. Other pegmatite products therein include quartz and feldspar, beryl, columbite-tantalite, and rare-earth minerals. Other nonmetallic products in the county include gypsum, fluorspar, kyanite, kaolinite, bentonite, pumice, travertine, diatomite, limestone, building stone, sand, and gravel.

PETACA DISTRICT

The Petaca district is in the southeastern Tusas Mountains between Ojo Caliente and Tres Piedras (fig. 18). The district is bounded on the north by Kiowa Mountain, on the east by the Rio Tusas, on the west by the Rio Vallecitos, and on the south by La Madera. Within these boundaries, the principal pegmatite areas occur at Kiowa Mountain, near Las Tablas–Persimmon Peak, La Jarita–Apache area, at Cribbenville, and in Alamos Canyon. Access to the district is via Tres Piedras (northern part) or Ojo Caliente (southern part) from U.S. Highway 285.

All pegmatites of the Petaca district occur in rocks of Precambrian age. The general geologic column and structural features of the Precambrian rocks in the Tusas Mountains have been described earlier and are only briefly reviewed below. Geologic maps of parts of the Petaca district appear in Just; Barker; and Bingler, 1965.

Precambrian bedrock in the Petaca district includes muscovitic quartzite, quartz-albite-muscovite-biotite schist, leptite, granitic gneiss, and amphibolite. Throughout the district, these units are complexly interlayered as the result of original stratification and large-scale flowage and rotation of planar structures during regional metamorphism. Pegmatites intrude all map units recognized and do not appear to cluster in a particular compositional unit.

Bingler summarized the complex structural history in an earlier paper (1965):

> The earliest deformation for which evidence now exists—the first deformation—involved major transport of material. Unrestricted flow, accompanied in later stages by flattening and penetrative shearing movements, resulted in the formation of isoclinal folds. These folds were probably recumbent and their axes were oriented southwest-northeast. Most of these folds were destroyed during the terminal phases of deformation by axial-plane shearing. These processes transposed an earlier planar element, probably bedding, into parallelism

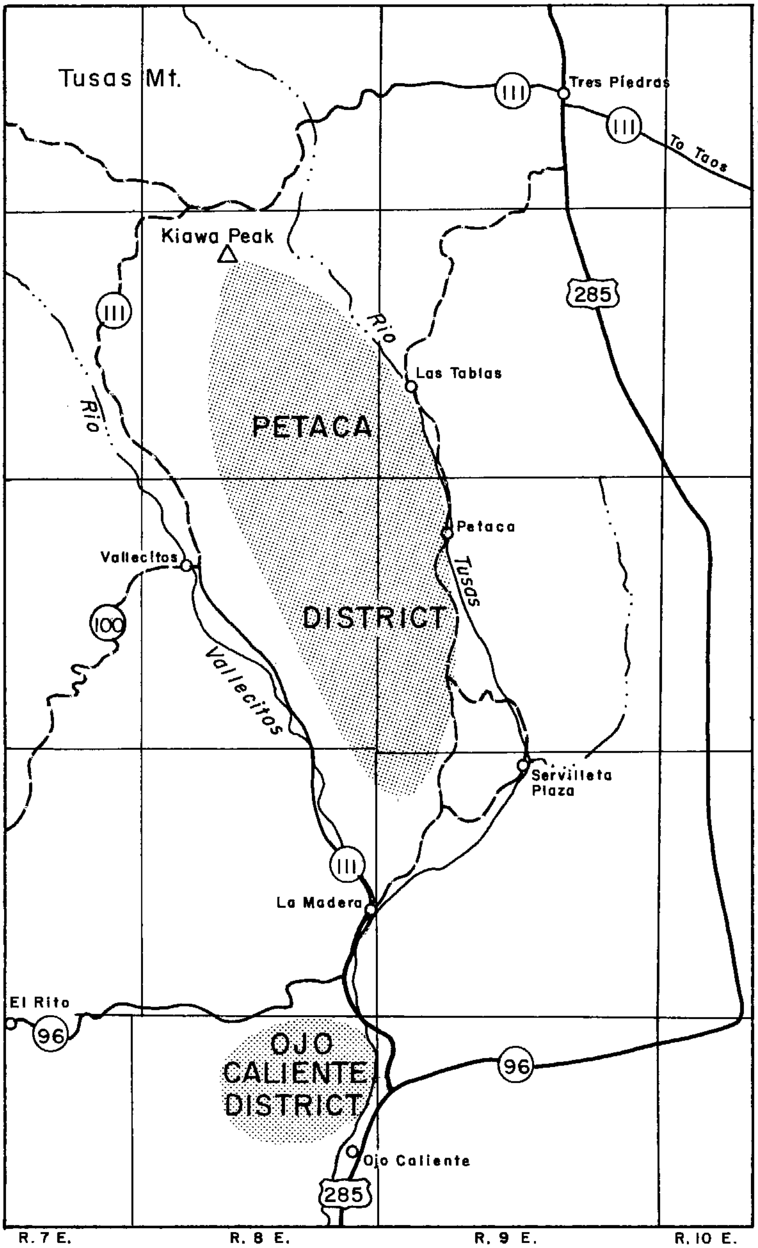


Figure 18

Index map showing locations and extent of the Petaca and Ojo Caliente districts with the fold axial planes. Shearing movements, internal rotation, and contemporaneous recrystallization resulted in well-defined axial-plane flow and fracture cleavage which contain prominent textural and mineralogical b-lineation. The mode and intensity of deformation resulted in the destruction of original stratigraphic continuity and contiguity. The end result of the first deformation process was a regularly interlayered sequence of mixed lithologies.

The second deformation resulted in the formation of a readily recognizable macroscopic fold system of generally nonplane cylindrical, asymmetric, nearly isoclinal, similar folds. The axial planes of these folds are overturned to the northeast. Fold axes trend northwest-southeast and are gently doubly plunging with a slight preferred orientation of axes plunging to the northwest. Congruent mesoscopic folds, similar in style in all rock types, indicate that Precambrian rocks behaved as a plastic or viscous medium during deformation. Earlier planar and linear structures were rotated nearly parallel with second deformation axial planes by the folding, and this process combined with the overturned attitude of the folds has produced the homoclinal, southwest-dipping layered sequence now exposed. Fracture and slip cleavages parallel to fold axial planes developed during the later stages of deformation and constitute a prominent structural parameter of the fold system. The form and attitude of this fold system are responsible for the promient northwest structural "grain" exhibited by exposed Precambrian rocks in the map area. Transport of material from southwest to northeast is suggested by the uniform eastward overturning of synforms and antiforms.

The third deformation consists largely of wide-spaced axial-plane fracture and slip cleavage ranging in strike from N. 70° W. to S. 70° W. and in dip from 60° S. to 60° N. The variation in strike and dip of axial-plane cleavage, combined with uniformly west-dipping older planar elements has produced variable fold axial trends. Mesoscopic folds are sparsely developed, yet widely distributed. The disposition of minor flexures in narrow, widely spaced zones suggests that the disposition of macroscopic plane cylindrical folds form a step-fold pattern with broad southerly flanks raised relative to steep northerly flanks. The low amplitude warps associated with this fold system have not effectively rotated earlier planar elements.

This complex regional pattern of structural elements appears to have exerted a control on the orientation of most of the pegmatites. Jahns divided the pegmatites into five classes based on external form, which included dikes, sills, pipes, elongate pods, trough-shaped (normal or inverted) bodies modified by spines, bends, warps or rolls, and protuberances. The average outcrop length is 410 feet, with a maximum of 1430 feet and a minimum of 75 feet. The average outcrop breadth is 30 to 35 feet. Many of the dikelike masses are best described as lenses plunging gently southwest to northwest.

Geology of the Pegmatites (after Jahns)

The pegmatites are aggregates of the principal minerals, microcline, quartz, plagioclase, and muscovite, arranged in one or more structural units including fracture fillings (youngest), replacement bodies, or zones arranged as successive layers in shells (oldest).

Zones may be completely or partly developed and ideally represent concentric shells about a core. From outermost to innermost, they are named the border zone, wall zone, intermediate zone, and core. Border zones range widely in thickness and grain size. Such zones have sharp contacts with wall rock, consist of fine- to medium-grained aggregates of microcline, quartz, and mica with or without garnet, fluorite, and beryl, and range in thickness from less than one inch up to several feet. Those having gradational contacts with wall rock are generally the broadest observed. Wall zones are for the most part well defined and range in thickness from a knife-edge to tens of feet; they consist of microcline and quartz with minor mica, garnet, fluorite, and beryl. Intermediate zones are irregular in form and often incomplete or absent. They exhibit a wide range in thickness, generally being thickest in the crest area of the pegmatite. They may be composed of coarse blocky microcline, coarse graphic granite, or quartz and large microcline crystals. The pegmatite cores are generally composed of massive quartz or quartz-microcline mixtures. The core zone commonly lies near the keel of the pegmatite mass.

Replacement bodies are aggregates of albite and mica that have replaced parts of the already crystallized pegmatites. They occur as fracture-controlled masses, as irregular rosettes or bursts of mica and albite particularly abundant along the margin of quartz cores, or as complete zone pseudomorphs when albite-mica has replaced one of the other zones.

Minerals in the Petaca pegmatites are classified as essential or accessory (less than 5 per cent). Essential minerals include feldspar, both microcline and plagioclase, quartz, and mica. Nearly 50 accessory minerals have been recorded, the most common including spessartite garnet, fluorite, beryl, columbite-tantalite, monazite, samarskite, and ilmenite-magnetite. Biotite, chalcedony, chlorite, hematite, kaolinite, limonite, manganese minerals, and sericite are widely distributed. Apatite, azurite, bismuth, bismuthinite, bornite, cassiterite, covellite, cuprite, fergusonite, gadolinite, galena, gummite, lepidolite, phenakite, phlogopite, pyrite, roscolite, scheelite, topaz, tourmaline, uraninite, and uranophane are only rarely present.

Potash feldspar in the form of microcline is the most abundant mineral in the pegmatites. It occurs in fine-grained, sugary aggregates and in individual crystals up to 12 feet in diameter. Its most common form is as irregular subhedral masses 6 inches to 5 feet in diameter. Microcline ranges in color from white to gray through pinkish red to pale green to greenish blue. Many microcline crystals exhibit a color zoning, and nearly all are perthitic, containing very fine spindle lamallae of albite.

Plagioclase in the form of albite (Ab_{96}-Ab_{99}) occurs as fine-grained, sugary aggregates and as groups of platy crystals (cleavelandite). Color ranges from lustrous white to deep red. Albite is present as fine-grained aggregates pseudomorphous after microcline, in cross-cutting veinlets, and as rosettes scattered throughout the pegmatite mass.

Milky white to light gray and smoky varieties of quartz occur principally in the core zones of pegmatites and as graphic granite.

Mica occurrence is in general related to the presence or absence of albite. When much albite is found in pegmatite, much mica is also found and *vice versa.* Jahns (p. 88-90) lists eleven modes of occurrence for mica in the pegmatites of the Petaca district:

> The following modes of occurrence are characteristic of the Petaca mica.
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> I. Pegmatite bodies in which zoning is not well developed.
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> A. Disseminations throughout the pegmatite. The proportion of mica in these deposits generally decreases from east to west or from bottom to top in westerly plunging pegmatite bodies. Most of the mica books are small and few of the concentrations are rich enough to be of commercial interest.
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> B. Well-defined concentrations along one or both borders of the pegmatite. These concentrations, which are generally thin, decrease in richness and taper out from east to west in most deposits. The mica books are characteristically small and so scattered that they cannot be recovered commercially.
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> C. Concentrations at the margins of small pods and lenses of massive quartz. Many of these have been prospected, but in general they are too discontinuous and contain too little mica to be mined at a profit.
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> D. Irregular concentrations in small pod-like portions of the pegmatite that are relatively rich in interstitial quartz. No concentration of this type has supported operations beyond the prospecting stage.
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> E. Poorly defined fringes around partly digested inclusions of country rock. These contain mica in books of moderate size, but the material is commonly soft and severely tangled. Few concentrations are sufficiently extensive for scrap-mica operations.
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> II. Deposits in well-zoned pegmatite bodies.
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> A. Concentrations along the borders of the pegmatite and around the margins of inclusions; similar to types A and B above. Neither of these appears to be of economic importance.

B. Concentrations flanking cores, especially where the cores consist of massive quartz with or without giant crystals of microcline. Such deposits are commonly rich and contain many large books, especially near their keels or east ends. They are of considerable commercial importance.

C. Concentrations in wall zones, especially along their inner margins. These also tend to be richest near the easterly ends or keels of most pegmatite bodies. They may flank more than one inner zone and may extend irregularly into such zones. They are characteristically rich, especially where the wall zone is relatively thin, and hence are commercially important, although they contain a higher proportion of scrap material than the concentrations adjacent to cores.

D. Fringes at the margins of rosettes and "bursts" of cleavelandite. These concentrations, which contain soft mica of scrap grade only, are generally small and of little economic interest.

E. Concentrations along major fractures. These also contain soft tangled mica of scrap grade, and are so small that they can be worked only where they are adjacent to other, richer concentrations of mica.

F. Disseminations in massive quartz and quartz-rich pegmatite, generally formed through intensive replacement controlled by a network of closely spaced fractures. Such concentrations are present at or near the keels of plunging pegmatite bodies and are generally extremely rich. The mica occurs as books too small to yield sheet and punch material.

Spessartite garnet is the commonest accessory mineral in the Petaca pegmatites. Individual crystals and aggregates range in diameter from 1/4 inch to 12 feet and in color from purplish red to reddish brown. Garnet is most often found in the wall zones of pegmatite masses.

Pale green aggregates of fluorite ranging in diameter from 1/4 inch to 7 feet are common. Fluorite altered and removed by solutions is marked by vuggy areas lined with an earthy yellow-brown residue often containing small fragments of fluorite.

Beryl, as milky white through yellowish brown and bluish green to deep blue aggregates and crystals, is present in several pegmatites of the district. The occurrence of beryl follows one of three patterns, as disseminated grains in mica—albite-rich concentrations, as related to zones, or as spindle-shaped crystals 1/2 inch to 6 feet long in altered country rock. Jahns (p. 96-97) divided the second category into six types of beryl occurrence:

A. Core beryl. Well-formed prismatic crystals a few inches to 8 feet long are present in quartz cores, and are related to the quartz in the same general way as the giant microcline crystals that occur in many cores and inner intermediate zones. None of these deposits has been mined for beryl (Sandoval, Nambe deposits).

B. Core-margin or intermediate-zone beryl. This is present as coarse rough to well-formed greenish crystals, and is most abundant in the inner parts of inner intermediate zones. It can be recovered by hand sorting, and some of these deposits are of economic importance (Lonesome, Kiawa, Werner, Hidden Treasure deposits).

C. Wall-zone beryl. Small ragged masses are scattered through the wall zones. The color is commonly more blue than green. Recovery generally necessitates milling, and hence such deposits are of little current economic interest (Kiawa, Globe, North Star deposits).

D. Border-zone beryl. In occurrence and characteristics this is similar to beryl present in the wall zones. In general the masses are even smaller (Kiawa deposit).

E. Pocket or pod beryl. Small rough masses occur in irregular pods of quartz-rich pegmatite that are exposed by coarse-grained microcline-quartz pegmatite. No deposits of commercial interest are known (Cribbenville deposit).

F. Beryl in pegmatites or parts of pegmatites in which zoning is not distinct. The size range of such material is great; some occurs in concentrations sufficiently rich and coarse to be of economic interest (Alma, Vestegard, Bluebird deposits).

Columbite-tantalite tends to be restricted to albite-rich parts of pegmatite. The mineral occurs in the form of tabular crystals $\frac{1}{2}$ inch to 4 inches, rounded masses up to 18 inches in diameter, as long feather-shaped crystals and crystal aggregates, and as intergrowths with samarskite, ilmenite, and magnetite. Tan and yellowish to rusty brown monazite is present in pegmatite as flattened crystals ($\frac{3}{4} \times \frac{1}{2} \times \frac{1}{2}$ inch) and equant crystals up to 5 inches in diameter. Samarskite, another common rare-earth accessory mineral, occurs in equant masses ranging in size from a fraction of an inch up to about one inch.

Mining History and Production

The earliest mining activity in the Petaca district was restricted to the Cribbenville area where large books of mica were split for use in windows in Espanola and Santa Fe. Modern mining began about 1870 when sheet mica was mined, split, and trimmed for stove doors. Mining operations expanded outside the Cribbenville area about 1900 when mines began to be opened for scrap-mica production. Demand for mica for electrical uses produced a spurt in mining activity about 1912. District production dropped after World War I, then rose to a peak from 1923 to 1930. Scrap- and sheet-mica production declined during the Depression and has remained low except for a short period from 1942 to 1944.

In 1953, the U.S. Government mica-buying program was broadened to include nonruby mica, at which time Continental Mines Products Company began to produce hand-cobbed mica from the Globe mine. Most mica produced in the district was marketed at the Custer, South Dakota, Government Purchasing Depot. In 1954, the Petaca Mining Corporation began construction on a $300,000 dry processing plant. The first shipment from the new mill was sent February 20, the last shipment in July. The Minerals Engineering Company subsequently took over the mill, which ceased operation in 1957. Principal mica-producing mines during the late 1950's were the Globe mine, the Apache mine, and the Kiawa Lode.

Scrap-mica production has steadily increased since 1963. Principal producers in 1965 were the Globe and Blowout mines (John W. Moran) and the Cribbenville mine (C. A. Morris and Co., Inc.). Ground mica is produced at the Los Compadres mill at Ojo Caliente from numerous small operations within the district.

Small amounts of pegmatite by-products were produced during the middle 1950's. Columbite-tantalite concentrates totaling 1626 pounds with a value of $1626 were produced during 1954-1955. Six tons of beryl with a value of $3150 were mined in 1955. From 1963 to 1965, 132 tons of quartz were sold for $1770.

Mines and Prospects

Jahns divided the mines and pegmatites of the Petaca district into five geographic groups. His report provided the data for the descriptions that follow.

Kiawa Group

This group of pegmatites, located about two miles east of Kiowa Lake, includes the Kiawa, South Kiawa, Buena Vista, and Green Peak deposits. Of these, Kiawa is the largest and has been the most productive. It includes two pegmatites located near the west edge of sec. 11, T. 27 N., R. 8 E. The main pegmatite mass is 1430 feet long and 275 feet wide in outcrop. A second pegmatite 200 to 300 feet north of the main mass is 38 feet wide and at least 1240 feet long. Both dikelike masses trend N. 75° E. and dip south. Jahns gives mineralogic details (p. 109-111) as follows:

> The north dike appears to have contained a discontinuous quartz core flanked by a wall zone of coarse microcline-quartz pegmatite and a border zone of fine- to medium-grained microcline-quartz-albite-oligoclase pegmatite. As widespread replacement by albite has obliterated all but local patches of the border zone and core, the precise distribution of primary pegmatite units can be determined only by

means of relict textures. The core was thickest and most continuous near the west end of the dike, but apparently was absent from much of the eastern part. The wall-zone pseudomorph, which contains minor quantities of garnet, green fluorite, and beryl, is present in the western three-fourths of the dike, where it is 1½ to 15 feet thick. The thin east end or tail of the dike consists wholly of albitized border-zone material.

The distribution of rock units in the main pegmatite body follows a broad general pattern, but is extremely irregular in detail. The border zone, which consists of sugary plagioclase-quartz-microcline pegmatite that is rich in partly digested country rock, is generally about ½ inch thick, but reaches thicknesses of 15 feet or more in the eastern part of the body. Some masses of this rock are within the body, but were clearly formed through the pegmatitization of country-rock inclusions of roof pendants. The wall zone, which ranges in thickness from a knife-edge to 25 feet, is a medium-grained intergrowth of microcline and quartz, with minor mica, albite, garnet, and fluorite, and rare beryl. It is most extensively developed in the western third of the body, where it forms the outermost mapped unit (Plate 6). The most widespread unit is the outer intermediate zone, which consists of very coarse-grained microcline-quartz pegmatite that is rich in graphic granite. Some of the largest graphic-granite masses are distinguished from the remainder of the unit in Plate 6. Where less rich in graphic granite, the zone contains irregular bodies of coarse blocky microcline and massive quartz. Some of the quartz pods, which are as much as 110 feet long and 18 feet in outcrop breadth, might be considered separate zones.

The inner intermediate zone, which is also rich in microcline, is best exposed in the vicinity of the Graphic Cliffs west of the New Lower pits. Coarse blocky microcline and graphic granite are its chief constituents. Irregular masses of very coarse-grained microcline-quartz pegmatite and pod-like bodies of massive quartz are also present. As in the outer intermediate zone, some of the quartz masses are relatively large. The core of the body is white to gray massive quartz that contains microcline crystals and crystal groups of giant size. The potash feldspar is most common in the area north of the Upper pit, where individual masses are as much as 40 feet in outcrop breadth. The core consists almost wholly of quartz where it is exposed north of the Lower pits, but large feldspar bodies are present in the most recent underground workings. No attempt has been made to indicate the distribution of zones in Plate 6, but individual rock types are shown instead. Many of the quartz or microcline bodies are merely parts of zones. Moreover, zone boundaries and locally the zones themselves have been transgressed and obscured by other units of later-stage development.

Albite is scattered throughout the main pegmatite body as sugary crystalline aggregates and groups of coarse cleavelandite blades. It is not abundant in the western third of the body, but is common farther east, especially along the flanks of quartz masses. Locally plagioclase has almost completely replaced microcline-quartz pegmatite. Some of the massive quartz has been penetrated and corroded by the albitizing solutions, and rosettes of coarse cleavelandite that were formed at its expense can be seen in the walls of the Old Lower pit, the Upper pit, and the Porcupine stopes. Near the east end of the body albitization is most common along country-rock contacts, the margins of partly digested inclusions, and throughgoing fractures.

The microcline ranges from white or greenish gray through flesh to brick red. In the coarse-grained pegmatite and blocky microcline units it occurs as crystals 4 inches to 7 feet in maximum dimension. Some contain irregular stringers and platy to pod-like masses of quartz, and in many the quartz occurs in graphic intergrowth. This material grades into irregular pods of massive quartz. Quartz masses are more abundant adjacent to graphic granite than to bodies of quartz-poor blocky microcline. Little of the rock mapped as graphic granite shows evidence of albitization, but some albite-rich units appear to have been formed from graphic material through selective replacement of the microcline, with preservation of the structure in the form of somewhat corroded but nonetheless clearly oriented quartz spindles.

Spessartite garnet, the most common accessory mineral, occurs in all parts of the deposit. It is especially abundant in the border zones and in albite-rich units. Many crystals 4 inches or more in diameter appear in albite-oligoclase-quartz-microcline pegmatite 70 feet east of the Twin stopes. Most of the fluorite, which is pale green and severely fractured, occurs near the walls of the pegmatite and in albite-rich material exposed in the mine workings. Alteration of this mineral and adjacent feldspars has formed irregular vugs ½ inch to 5 inches in diameter. These are especially common in the Twin and Porcupine stopes and in the workings that connect with the Espinosa shaft. Most are partly filled with a yellow to reddish-brown clay that contains small gritty particles of fluorite. A half-inch octahedron of clay, possibly a pseudomorph after fluorite, was observed in the Upper Twin stopes. Beryl is present in the border zone and wall zone as small pale waxy yellow to bright blue-green masses and locally along the margins of the quartz-rich core as well-formed prismatic crystals 2 inches or more in diameter. The border-zone beryl is well exposed at the mouth of the Hoyt adit, the wall-zone material in pegmatite north of the Graphic Cliffs and southwest of the Twin stopes, and the core-margin crystals in the Old Lower pit and Porcupine stopes.

Columbite, monazite, purple fluorite, and small pods of fine-grained green sericite occur in the albite-rich pegmatite exposed in most of the workings. Samarskite, magnetite, and bismutite are present along fractures in massive quartz, particularly in the Old Lower pit. Pyrite, chalcopyrite, chalcocite, and pale pink muscovite are rare accessory constituents that were observed in dump material only.

Production from both pegmatite masses prior to 1946 is estimated to exceed 2200 pounds of prepared sheet mica, 9000 pounds of plate mica, and 600 tons of scrap mica.

Persimmon Peak–Las Tablas Group

This group includes the Eureka, Silver Spur, Canary Bird, Meadow, and Alma deposits, which lie in a narrow northeast-trending zone two miles long centered about one mile west-southwest of Las Tablas. The Alma pegmatite is the largest of the group, with an outcrop length of 500 feet and width of 15 feet. This pegmatite produced 1265 pounds of beryl in addition to plate, sheet, and scrap mica.

La Jarita–Apache Group

This group of 27 pegmatite deposits is the largest of the Petaca district and includes the single largest producer of mica, the Apache mine. Other deposits are La Jarita, Lone Wolf, Vestegard, Vesely, El Contento, St. Joseph, Lonesome, Mica Lode, North Star, Mary, Etter, Werner, De Aragon, Conquistador, Wyoming, Keystone-Western, Maulsby, Silver Plate, Navajo, Coyote, Sandoval, Pinos Altos, Prima, Queen, Coats, and Bluebird. They occupy an area of about three square miles in the center of the Petaca district, extending from Big Rock to Petaca.

The Apache and Lonesome mines have been the largest producers. Jahns (p. 138 and 165) recorded a production of 85,000 pounds of sheet mica, a similar amount of pink mica, and at least 4000 tons of scrap mica from the Apache mine and 130 pounds of sheet mica, 30 tons of scrap mica, 4500 pounds of beryl, 375 pounds of columbite-tantalite, and 12 pounds of samarskite from the Lonesome mine.

The Apache mine is located in Apache Canyon in the NW¼ sec. 12, T. 26 N., R. 8 E. The main pegmatite mass is 8 to 27 feet in outcrop breadth and at least 450 feet long. It is dike-shaped, strikes approximately west, and dips to the north-northwest. Jahns (p. 168-169) gives details of structure and mineralogy:

> A thin, nearly continuous quartz core is present in the east half of the pegmatite body. It increases in width toward the west and is 5 to 7 feet thick in the vicinity of the vertical shaft. West of this the central part of the body is rich in coarse microcline. An inner intermediate zone consists of blocky microcline with large pod-like bodies of massive quartz, and an outer intermediate zone, which lies farther west, is virtually quartz-free. The wall zone, which now appears as an albite-rich pseudomorph, formed a nearly complete envelope around the inner zones and was itself surrounded by a finer-grained border ⅛ inch to 5 inches thick. Both outer zones appear to have consisted of typical microcline-quartz pegmatite. The wall-zone pseudomorph

is breached by the quartz-rich branch dike, which connects with the quartz core of the main body. Although shown on the map * * * as a quartz dike, the outer portions of this branch contain irregular masses of microcline and albite, as well as local concentrations of garnet and mica.

Albite has replaced most of the outer zones, and has also encroached upon the core and intermediate zones. Coarse cleavelandite has replaced quartz and some masses of microcline. Sugary albite is common elsewhere. Large rosettes of cleavelandite are exposed in the central parts of the pegmatite in many of the underground workings, particularly along the walls of Adit No. 1. Associated with the albite are irregular masses of purple fluorite and long thin blades of columbite and monazite. Garnet, pale green fluorite, and magnetite are present in the outer zones and show evidence of partial albitization. Samarskite and bismutite are common in quartz, especially in late-stage veinlets, but are also present in albite-rich pegmatite. Pod-like masses of pink muscovite and fine-grained green sericite are abundant on the dump beneath the stope in the eastern part of the dike. Apparently these occurred in the hanging-wall mica zone. Beryl was not observed in the main pegmatite, but occurs as well-formed crystals in the quartz core of a thin pegmatite dike 70 feet east of the portal of Adit No. 2.

Cribbenville Group

This group of 14 deposits lies in a half-square-mile area about two miles southwest of Petaca. Claims included in the group are the Gabaldone, Fridlund, Pino Verde, Freetland, Teddy No. 2, Bluebird No. 2, Teddy, Blanca, Capitan, Bonanza, North Cribbenville, Cribbenville, Pavo, and Nambe. The North Cribbenville, Cribbenville, and Fridlund have been the largest producers. The North Cribbenville is reputed to be the oldest mine in the Petaca district, with early production of stove mica being the initial interest. Forty thousand pounds of stove mica, 20,000 pounds of clear sheet mica, and 1500 pounds of scrap mica have come from this mine. Principal operation of the Cribbenville mine was during the Second World War; total production since 1900 is estimated at 5000 pounds of clear plate mica, 20,000 pounds of stained sheet mica, and 400 tons of scrap mica. The Fridlund mine produced several hundred pounds of bismutite and up to 5000 pounds of columbite, samarskite, and monazite, in addition to scrap and clear sheet mica. The Pino Verde mine supplied a few hundred pounds of monazite and bismutite along with operations for scrap mica.

Alamos Group

The Alamos Group, named for pegmatites exposed in and around Alamos Canyon, includes the Little Julia, Little Julia No. 1, Alto, Hillside, White, Alamos, Sunnyside, Triple EEE-A, Red, Globe, Big Boy No. 3, Carmelita, and Guadalupe deposits. Of this group, the Globe mine has been the principal producer, with an estimated production of 80,000 pounds of plate mica, 5000 tons of scrap mica, and 5000 pounds of columbite. This mine is the only patented property in the Petaca district.

The Sunnyside mine is unusual in that beryl-mica concentrations occur in mica schist rather than in pegmatite. The mine is in the NE¼SW¼ sec. 25, T. 26 N., R. 8 E. Jahns (p. 226-227) gives the geology of the deposit:

> The country rock is quartz-mica schist, in which a severely crumpled foliation trends N. 20° W. and dips 35° WSW. Much of this rock consists almost wholly of fine-grained pale green to colorless muscovite. Scattered through it, however, are thin lenses and larger irregular bodies of quartz, some of which are 10 feet or more in exposed length. These quartz masses and the mica-rich portions of the schist appear to be genetically related, inasmuch as many schist layers can be traced into beds of mica-poor quartzite from which vein quartz is absent.
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> Irregularly distributed through the schist are cigar-shaped crystals of beryl that taper to blunt ends. They are 1/2 inch to 6 feet long and 1/16 inch to 7 inches in diameter. Other, more sharply formed prismatic crystals occur in quartz, and a few extend from quartz into schist. Some are bent or broken, and most of the breaks have been healed with quartz. The mineral is pale to deep aquamarine in color and many specimens should have value as gem and ornamental material. Associated minerals in the schist are pale green to deep purple fluorite in irregular masses and crudely formed crystals 2 inches to more than 8 inches in diameter; white to pale yellow topaz in smaller, highly fractured lumps; ilmenite in well-developed tabular crystals 1/16 to 3/4 inch thick and as much as 7 inches in maximum dimension; and garnet in tiny scattered crystals. Fluorite, ilmenite, magnetite, and thin tablets of columbite are common in the quartz, and bismutite, sulfide minerals, and pale yellow apatite are rare constituents. A little microcline was enclosed in several of the large beryl crystals and crystal aggregates.
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> The rock from which the first production was obtained was remarkably rich, with an average beryl content of about 6 per cent. The occurrences are pockety, however, and the results of large-scale operations are likely to be disappointing. Some scrap mica of good quality was a by-product of the first mining, but the distribution of the mica-rich layers in the schist is also irregular. The high-grade material contains much vein quartz and tends to finger out into schist and quartzite relatively poor in mica.
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> About 150 feet southwest of the incline portal are two small pits that have been excavated in a lenticular body of mica schist. Quartz

pods 3 to 4 feet thick contain scattered tabular crystals of ilmenite. These range from 1/16 to 3/8 inch in thickness and from 1 inch to 6 inches in length. Qualitative chemical tests demonstrate an appreciable content of columbium, which may occur in intergrown columbite. Other occurrences of platy ilmenite in massive quartz have been found on the hill slope north of the Sunnyside workings, and many float blocks of this material are present in the bottoms of adjacent gullies.

The Globe mine is located east of Alamos Canyon in the NE¼ NE¼ sec. 36, T. 26 N., R. 8 E. and is accessible by graded gravel road from State Highway 111. Jahns (p. 237-239) gives details of the pegmatite:

Though most of the primary lithologic units in the dike have been partially or wholly replaced by albite and associated minerals, a well-defined zonal structure can be recognized. Remnants of a massive quartz core, which was 5 to 25 feet wide and more than 300 feet long, are exposed between the Long cut and the east end of the dike. Immediately north of the cut the long thin west end of the core is flanked by an intermediate zone in which aggregates of microcline crystals 6 inches to 12 feet in diameter are separated by irregular bodies of massive quartz 5 to 20 feet in maximum dimension. This unit extends westward to points beyond the portal of the New incline and forms the central portion of the pegmatite in all the underground workings * * *. Its average thickness is about 12 feet, with a maximum of 20 feet, and it plunges gently to moderately west. A second intermediate zone, which consists of extremely coarse-grained microcline-quartz pegmatite, occupies an interior position in the central prong of the dike west of the Upper pit.

Medium- to coarse-grained microcline-quartz pegmatite occurs as a nearly continuous wall zone 6 inches to 15 feet thick. It is absent from the poorly exposed margins of the central prong, and may be in part sheared out and in part obscured by two masses of late-stage quartz that appear to have been injected along or near the walls of the pegmatite * * *. A discontinuous border zone, which consists of fine- to medium-grained microcline-quartz-mica pegmatite with abundant partially digested country-rock material, is too thin to be shown on the map.

Albite is scattered throughout the wall and border zones, but is most abundant along contacts between the wall zone and inner zones, chiefly the inner intermediate zone. The primary minerals in the inner parts of the wall zone have been almost completely replaced by fine-grained sugary albite and by aggregates of coarse cleavelandite. Albitization in the core evidently was guided by fractures. In some places the entire thickness of quartz has been replaced, so that in plan the large remnants of massive quartz are like beads on a string.

Microcline crystals have been replaced along cleavage cracks and other fractures, and all stages in this process can be seen in the walls of the mine workings and in pegmatite blocks on the dumps. They range from microcline masses with tiny crosscutting veinlets of albite to large plagioclase aggregates in which only scattered residual masses of microcline are present. In the lower part of the New incline are several 1- to 4-inch albite-mica dikes. These cross-cutting bodies consist of coarse cleavelandite, whose lamellae lie normal to the dike walls, and small books of yellowish green mica. Large rosettes of coarse cleavelandite that appear to have formed through replacement of blocky microcline and massive quartz are well exposed near the portal of the New incline and along the north wall of the Long cut. Pseudomorphs of sugary albite after microcline occur in massive quartz in the North pit and in the Upper incline. They clearly show the crystal faces of the replaced potash feldspar.

The microcline ranges from white through flesh to brick red. Coarse perthitic structure is widespread, particularly in the large crystals. The albite is lustrous and white, and hence contrasts sharply with most of the potash feldspar. Much of it is cleavelandite, with strongly curved lamellae as much as 2 inches long and 1/8 inch thick. Most of the quartz is milky white to light smoky gray, although several late-stage veinlets consist of very dark smoky material. Small irregular masses of garnet are present in the wall zone and in albite-rich pegmatite, but are not common. Apple-green fluorite is abundant in quartz-rich pegmatite, especially near the portal of the New incline * * * and near the southeast corner of the North pit. It occurs as irregular masses 6 inches to more than 5 feet in diameter, and is commonly corroded by albite along fractures. Small masses of deep purple fluorite are scattered through albite-rich pegmatite in all the workings. This material forms rims around crystals of green fluorite and fills fractures within them.

Columbite, a widespread and abundant constituent of the albite-rich portions of the deposit, occurs in several forms. Well-developed equant crystals, an inch in maximum dimension, occur in deep flesh-colored albite, commonly with monazite and purple fluorite. Many appear to be slightly altered, and all have a dull earthy luster. Large "niggerheads" of columbite, several of which weighted 75 pounds or more, were found during the sinking of the New incline. Evidently their occurrence and associations were similar to those of the smaller crystals. Much of the columbite is present as long feather-like aggregates that consist of thin tabular crystals arranged in imbricate pattern. Most of the crystals are in contact with one another, but in some "feathers" they are separated by thin plates of albite. The aggregates generally are 3 to 5 inches long and less than an inch wide, but maximum known dimensions are 22 inches and 3-1/2 inches, respectively. Some are scattered very irregularly through albite-rich pegmatite and others are arranged radially, particularly near the cores of large cleavelandite rosettes. Monazite occurs as yellowish brown to mahogany red crystals with resinous luster, and more commonly as small feather-like aggregates similar in habit to much of the columbite. Rough crystals a half inch or less in diameter are common as inclusions in the columbite "feathers". Both minerals generally are coated with tiny scales of yellowish green mica, and much of the albite that surrounds them is stained flesh colored to dark red.

Small dark brown to black masses of samarskite and somewhat larger pods of yellowish to gray bismutite are present locally in quartz-platy albite pegmatite. Pale green beryl is a minor constituent of the wall zone, and a few small crystals of yellowish green apatite were observed on the dump in material that may have been mined from the wall zone. Ilmenite and sulfide minerals were observed in the North pit and the Upper incline, but are rare. Pale pink muscovite in aggregates of flakes 1/32 to 1/2 inch in diameter occur with quartz and albite near the top of the New incline and in dump material that was obtained from lower parts of the incline and from the North incline. Two small fragments of extremely fine-grained purple lepidolite were obtained from the North incline. On one of these is a cluster of coarse pink muscovite flakes. No lithium mineral is known to occur in any other deposit in the district.

Miscellaneous Deposits

Several scattered pegmatites in the La Madera–Paloma Canyon area have been mined, including La Paloma, El Floto, Aztec, Peno Blanco, Laura Crystal, Quartzite, Hidden Treasure, Big Boy, Ancen, Salt Lick, Paloma Canyon, and Lower Alamos Canyon deposits. La Paloma deposit has apparently been the largest, with production estimated at about 2500 pounds of sheet mica and at least 75 tons of scrap mica. Production from the other deposits has been minor.

Mining Activity Since 1945

Mica mining in the Petaca district has largely been directed toward increasing scrap-mica production. Scrap-mica output increased from 1955 to 1958, and the construction of the dry-processing plant at South Petaca was an important economic and technological factor in the district. With the failure of the mill, mica output declined; no production is recorded for the district in 1960. Scrap mica has been produced again from 1963 to the present largely from mica dump material processed at Ojo Caliente.

Accessory minerals in the pegmatites have been of sporadic interest, especially for columbite-tantalite and beryl. It is possible that space-age uses of rare earths may increase the market value to the point where recovery as by-products may constitute a substantial factor in the economic structure of pegmatite mining.

A small amount of quartz, 132 tons for 1963-1965, has been mined and some feldspar is still being stockpiled.

OJO CALIENTE DISTRICT

The Ojo Caliente mining district includes an area of pegmatites clustered in a northwest-trending elliptical zone within an area of about one square mile. The pegmatite zone is centered about four miles south of La Madera and a little more than one mile north of Ojo Caliente, flanking the eastern edge of Cerro Colorado (fig. 18). The district can be reached by primitive road from U.S. Highway 285 through the Ojo Caliente hot springs.

Jahns (p. 265) describes the geology of the Precambrian rocks that include the pegmatites:

> Ojo Caliente Mountain (Cerro Colorado) and several of the lower hills to the southeast are underlain by fine-grained gneissic granite. This rock is distinctly pinkish and consists of quartz, orthoclase, and microcline, with minor quantities of albite, muscovite, and biotite. The mica flakes are oriented in distinct foliation that in general trends northeast. In the north half of the district is an older complex of metamorphic rocks. Thinly foliated dark green to bluish black amphibole schist and pale greenish gray to buff quartz-mica schist are the principal rock types. Interlayered with them are vitreous quartzite, buff to dark gray quartz-staurolite and quartz-andalusite schists, and minor kyanite-bearing schist. The foliation of these rocks, much of which is markedly crenulated, trends northeast to east-northeast and dips steeply in the area immediately west of the Caliente River. Farther west its trend swings through north to west-northwest, and moderate to gently north-northeast dips prevail in the western part of the district. Local variations in attitude are common.

Pegmatites in the Ojo Caliente district include the Joseph, Star, and scattered smaller or less developed deposits.

The Joseph deposit has been the principal producer. Scrap mica was quarried up to 1932, by which time several thousand tons of scrap were produced (Jahns, p. 268). The mine was inactive until August 1961 when Alaska International Corporation placed a mobile plant at the quarry site. Several hundred tons of scrap mica were quarried and processed by it to April 1963, when M.I.C.A. purchased the property and mica obtained from the Joseph deposit was dry-ground at M.I.C.A.'s Pojoaque plant for paint and roofing products. Quarrying and scrap mica production ended in 1965 during a title dispute. The property was still inactive during the summers of 1966 and 1967.

Other pegmatites in the district have barely been developed past the prospecting stage, and no production is recorded.

KYANITE

Kyanite, a silicate of aluminum utilized in the manufacture of refractory products, occurs as a common accessory mineral in much of the Precambrian quartzite exposed in the Tusas Mountains. In a few areas, kyanite is present in thin and discontinuous quartz-kyanite veins in quartzite. In the Ortega Mountains kyanite is also present in quartz-kyanite-sericite schist (Bingler, 1965). The only deposits of kyanite that have excited economic interest are on La Jarita Mesa where podlike masses of quartz-kyanite rock and kyanite schist protrude above the gently rolling mesa surface. Many writers have noted these deposits (Talmadge and Wootton, 1937; Jahns, among others) and Corey described them in detail and referred to them as the *Big Rock* and *Kiowa View* deposits. The description given below comes principally from Corey.

Big Rock Kyanite Deposits

A group of six kyanite deposits located in secs. 22, 23, 27, and 28, T. 27 N., R. 8 E. are named for Big Rock, a rocky prominence in sec. 23. "Big Rock group" refers to the six deposits; "Big Rock *deposit*" refers specifically to the deposit in the NW¼SE¼ sec. 27, T. 27 N., R. 8 E. All lie within a northeast-trending zone about two miles long and thirteen airline miles northwest of Petaca (fig. 19). Access to the group of deposits is provided by graded gravel road from State Highway 111 (five miles) to the west or from Petaca (six and a half miles) to the east.

All mining activity has centered on the Big Rock deposit near the southern end of the group. In 1928, P. S. Hoyt of Van Horn, Texas, mined and shipped 1500 tons of kyanite ore to a St. Louis firm for use in the manufacture of high-grade refractories. Most of this material reputedly was obtained from large float boulders and from the large central knob. There is one caved 8 $\times$ 8 $\times$ 128-foot shaft on the property. There was no further mining activity until 1950 when Ray V. Mizunuma located three claims on the Big Rock property (McMillan, 1950) and collected samples to determine grade and physical properties. Below are the test results obtained by the U.S. Bureau of Mines:

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Ign loss	Total
71.74	26.17	0.29	0.15	1.13	99.48
62.24	36.30	0.25	0.45	0.64	99.88

Both samples below core 33 fusion

No kyanite was mined, and the deposit has remained inactive.

The kyanite deposits occur within a terrain of metamorphic rocks that includes quartzite, muscovitic quartzite, sericite schist, and small

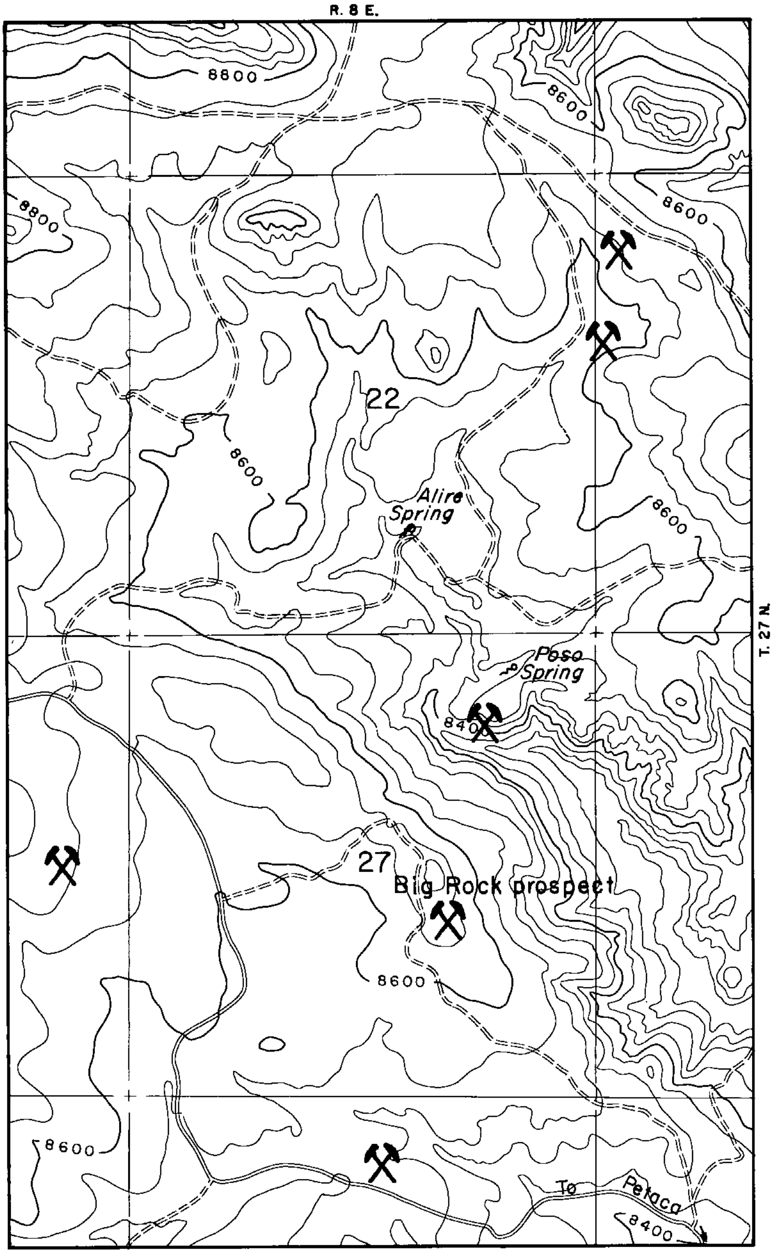

Figure 19
INDEX MAP OF KYANITE DEPOSITS, LA JARITA MESA

areas of metaconglomerate, garnet schist, biotite schist, and amphibolite. These rocks are isoclinally folded and overturned to the northeast. Regional fold axes trend N. 30°-60° W., with an average plunge of about 33° NW.

The six deposits include 25 lenses of quartz-kyanite rock and kyanite schist. The kyanite-bearing rock forms thick, stubby masses that are oval, crescentic, or rectangular in plan with a long dimension that ranges from 15 to 400 feet and an outcrop width of from 10 to 200 feet. Differential weathering of the resistant kyanite-rich rock has produced knobs and ridges that project up to 115 feet above the surrounding terrain.

All the deposits mapped by Corey are similar to the Big Rock deposit, which he describes in detail:

> Three large and eight small pods of kyanite-bearing rocks constitute the deposit. They are irregular in plan and have characteristic uneven, angular surface profiles. The largest pod is approximately 130 feet long, 60 feet wide, and 110 feet high . . . The smallest pod is 15 feet long, 12 feet wide, and 10 feet high. The entire deposit trends northward, but most of the individual pods trend north-northwest and dip west-southwest at moderately steep angles. The attitude of the lenses conforms to that of the schistosity in both the constituent kyanite schist and the surrounding metamorphic rocks.
>
> Within the kyanite schist three prominent joint sets strike northwest, west-northwest, and northeast, and dip steeply northeast, north-northeast, and northwest or southeast, respectively. In a lens at the north end of the deposit, two nearly isoclinal folds are overturned at a moderate angle to the northeast. Their axes trend northwest and plunge 14° and 20° NW. Other folds are present in the deposit, but their attitudes are obscure. Crenulations, with axes that trend and plunge west-northwest, are common in micaceous parts of both the kyanite schist and the quartz schist.
>
> Large hydrothermal quartz veins are more abundant in this deposit than in any other within the district. Their attitudes coincide with those of the three main joint sets. A few of these veins contain kyanite in blades as much as 8 inches long. Minerals within the kyanite schist are much enlarged adjacent to about half of the quartz vein, but this effect dies out a few inches away from the contacts.
>
> All the kyanite schist is rich in quartz, in most places so much so that planar structure is faint to absent. Widely distributed is fine- to medium-grained rock that consists of little but quartz; it is very hard and compact, and typically forms angular spires, blocks, and cliffs whose surfaces are smooth in detail. Tiny flakes of muscovite and shreds and blades of kyanite are present in many places, but rarely do these minerals constitute as much as 5 per cent of the rock. . . .
>
> Characteristically present in all the metamorphic rocks are segregations composed of large anhedral grains of quartz. In places the

texture of surrounding kyanite schist has been coarsened for a distance of an inch or two away from contacts with these segregations.

The pods of kyanite schist and associated quartz-rich rocks are enclosed by envelopes of sericite schist, which in turn give way successively to quartz schist and quartzite. Most of the sericite schist is concealed by a thin layer of soil, but numerous prospect pits and a few natural exposures show that the width of this unit ranges from 10 feet to 40 feet.

Three estimates of grade and reserves have been made of the Big Rock deposit. Corey (p. 59) divided kyanite-rich material into quartz-kyanite rock with an average kyanite content of 45 per cent, and kyanite schist with an average kyanite content of 26 per cent. The total tonnage of kyanite-bearing rock is estimated at 277,620. Corey quotes a report by Jahns as follows:

> Estimates of reserves were based upon measured areas of exposure, including reasonably inferred exposure in intervening areas where no outcrops are present, of rocks containing at least 5 percent kyanite. If it is assumed that the aggregate area of such material remains constant at successively lower levels beneath the outcrop, approximately 5,250 tons of potential kyanite ore is present per 10 feet of depth. The kyanite content of this ore ranges from 5 to about 75 percent by weight, and its average grade is near 18 percent. The grade undoubtedly could be held at a minimum of 25 percent kyanite by selective mining, with attendant reduction in output and reserves.

The U.S. Bureau of Mines (McMillan) estimated measured reserves at 1750 tons of 85 per cent kyanite rock, indicated reserves at 10,000 tons of 85 per cent kyanite rock, and inferred reserves at 100,000 tons of 50 per cent kyanite rock.

FLUORSPAR

Minor amounts of fluorite occur in hydrothermal veins in the Hopewell mining district and El Rito area and in pegmatites of the Petaca district. No production has been reported from the Hopewell or Petaca districts.

Two occurrences of fluorspar in the Tertiary Santa Fe Formation have been developed and mined in Rio Arriba County. Talmadge and Wootton (p. 78) noted an occurrence about three miles north of La Madera. Van Alstine (1965, p. 26C) mentioned a similar occurrence south of El Rito and, in discussing these Tertiary fluorspar deposits, remarked that

> The fluorspar occurs mainly as crusts and veinlets and as small irregular-shaped bodies in brecciated and altered zones along faults. . . . About 1,000 tons of hand-picked fluorspar containing more than 65% CaF_2 was shipped from these deposits to a flotation mill at Los Lunas, New Mexico.

Figure 20 shows a sketch geologic map of the deposit south of El Rito. Pale purple fluorite in concretionary and botryoidal crusts occurs as cavity fillings in the northernmost part of the fault zone and in closely spaced joints west of the fault in the volcanic facies of the Santa Fe Formation. The deposit is fifty yards west of State Highway 111 and four and one-tenth miles north of the bridge over the Chama River. Two claims on this property, the Small Fry Nos. 1 and 2, are held by Dotson Mineral Corporation of Socorro.

It is probable that minor fluorspar cavity fillings related to normal faults in the Santa Fe Formation are present in the badlands south of Ojo Caliente, east of State Highway 111 and west of U.S. Highway 285 (pl. 1).

KAOLINITE

High-grade kaolinite of exceptional purity and whiteness has been reported and described (Leopold, 1943; Kerr, Kulp, and Hamilton, 1949; Reeves, 1963; and Patterson, 1965a) from Mesa Alta, north of Youngsville. Mesa Alta is a prominent, dissected cuesta supported by gently north-dipping sediments along the southern margin of the San Juan Basin (pl. 1). The highest elevations along the southern edge of the cuesta are supported by Dakota Sandstone of Late Cretaceous age. The uniformly thick formation has been carved into a group of elongate spurs or mesas by deep dissection along the crest of the cuesta. Older Mesozoic rocks, including the Chinle, Entrada, Todilto, and Morrison Formations underlie the Dakota Sandstone and are exposed in an excellent section that forms the steep scarp of Mesa Alta. Kaolinite on Mesa Alta occurs at the contact between the Dakota Sandstone and the underlying Morrison Formation of Jurassic age. This contact, which rims Mesa Corral and Mesa del Camino (pl. 1) is marked by numerous chips and fragments of gray and white kaolinite along the mesa walls. Prospecting by drillhole and trenching has established the presence of a kaolinite-rich horizon under Mesa Corral and Mesa del Camino (Reeves; W. Hawks, personal communication). The zone, however, is very complex in detail and consists of thin layers of gray and white kaolinite intercalated with kaolinite sandstone and conglomerate. Individual kaolinite layers are more nearly pods and lenses, discontinuous along strike, and very irregular in plan. Efforts to delineate individual kaolinite layers have met with little success.

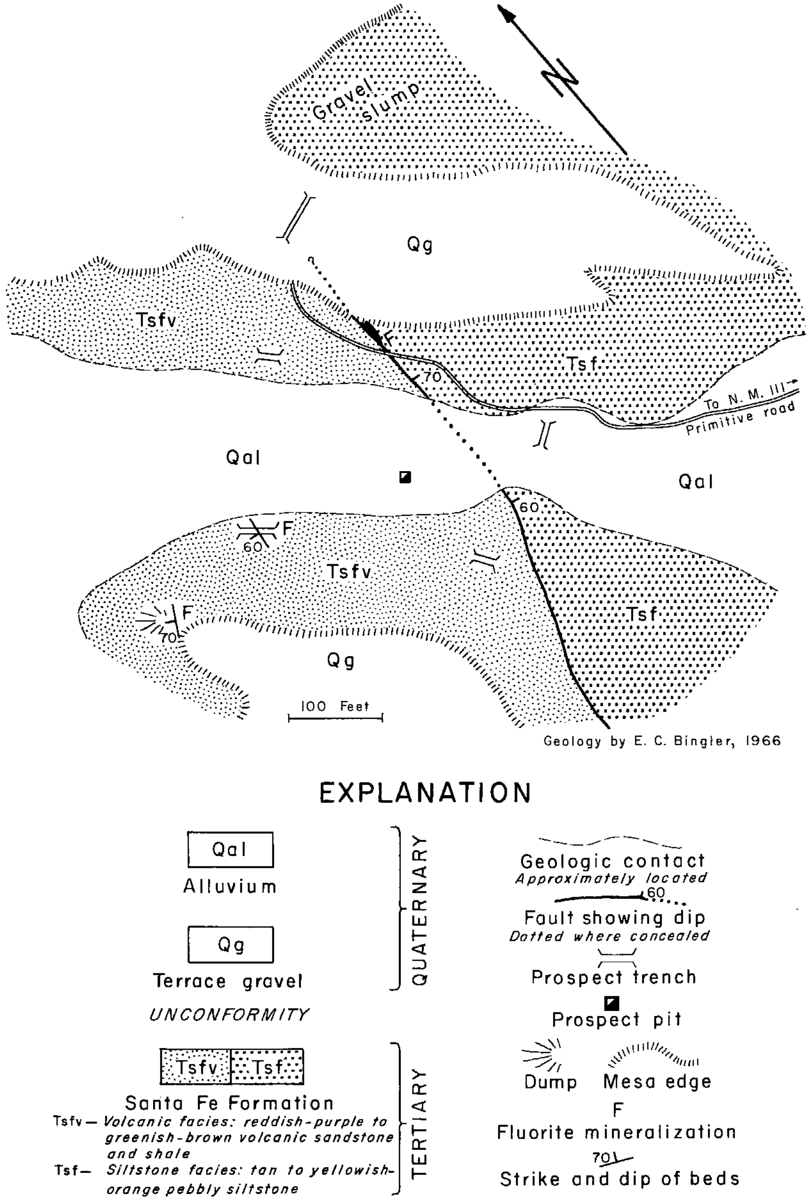

Figure 20

Geologic map of the Small Fry fluorite prospect

Myers Kaolinite Deposit (Ensign Claim)

The best exposure of kaolinite on Mesa Alta occurs in a small quarry on the Myers claim. It is from this pit that the American Petroleum Institute reference standard kaolinite was obtained. The claim is situated in secs. 2 and 11, T. 23 N., R. 2 E. about six airline miles northwest of Arroyo del Agua on the east flank of Mesa Corral (fig. 21). Access to the claim is by primitive road up the steep face of the cuesta, four and two-tenths miles from State Highway 96.

There is no record of production from the Myers claim. Prospecting and development work consists of several shallow pits and trenches that expose interlayered kaolinite and kaolinitic-standstone. A patented claim on the property, the Ensign Lode, lists Richard E. Myers, Verne Bryne, Alice C. Myers, and Evaline C. Myers as owners.

Kerr, Kulp, and Hamilton give the stratigraphic section exposed in the main Myers pit:

20.0 feet	Cross-bedded brown sandstone and conglomerates containing kaolinite pebbles
3.0 feet	Light gray sandstone with clay cement, grading downward into
1.5 feet	Gray kaolinite
2.0 feet	White porcellaneous kaolinite with conchoidal fracture
1.5 feet	Soft clay
	White sandstone

Other Prospects

Individuals of the Southwestern Kaolinite Corporation, formed in 1962, had begun prospecting the Dakota–Morrison contact in 1960. Backhole trenching and a modest drilling program enlarged the known area of kaolinite-rich rock, but no substantial amount of kaolinite was discovered.

DIATOMITE

Diatomite, a sedimentary rock composed largely of siliceous diatoms, has been quarried at the James H. Rhodes' diatomite property west of Espanola. The pit is located in the NE¼ sec. 22, T. 21 N., R. 7 E., four and four-tenths miles by poor primitive road west of U.S. Highway 84-285. According to Patterson (1965a, p. 323), only a few thousand tons of diatomite were mined during several months in 1953 and 1954. The diatomite was calcined and ground for use as an oil absorbant at the J. H. Rhodes Pumice Company, Inc., plant at Santa Fe.

The diatomite occurs as a lens interlayered with orangish-tan siltstone of the Santa Fe Formation and overlain by about 30 feet of basalt.

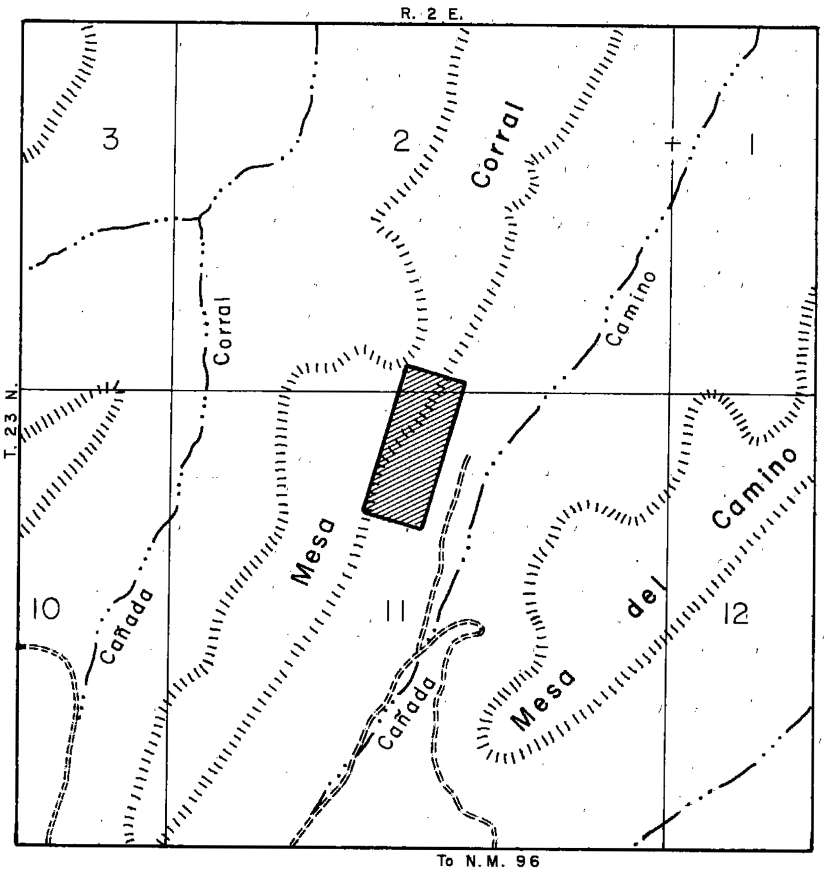

Figure 21

INDEX MAP SHOWING LOCATION OF THE ENSIGN PATENTED CLAIM

The deposit is prominently bedded and includes numerous thin layers of sandstone and claystone. The lens is best exposed on the west face of a small cuesta that slopes eastward and is supported by a thin basalt cap. Bedding in the diatomite strikes about north-south and dips between 8° and 10° E. The deposit is truncated on the north and west by erosion, bounded on the south by normal faults (down to the south), and grades into normal Santa Fe siltstone to the east.

The diatomite is gray to grayish white, medium- to fine-grained, and massive in hand specimen. All samples were found to be a mixture of siliceous diatoms, pumice fragments, calcium carbonate, and minor amounts of clay. With increasing content of pumice fragments, the diatomite grades into diatomaceous pumicite, both laterally and vertically. Total thickness of diatomite rock is estimated at 150 feet by Mr. Roy W. Foster of the State Bureau of Mines and Mineral Resources, who provided the measured section, lithologic column, and accompanying data shown on Plate 7.

GYPSUM

Gypsum constitutes a major part of the Todilto Formation which is exposed over a large part of south-central Rio Arriba County (pl. 1). Thin-bedded to massive gypsum and gypsite up to about 60 feet thick form the upper part of the Todilto Formation and are characteristically exposed as subdued cliffs atop the precipitous outcrops of the underlying Entrada Formation. The Entrada–Todilto outcrop belt forms a thin ribbon that extends northeastward from Gallina to Gallina Peak, girdles Mesa Alta, forms the northwestern flank of Cerro Pedernal, and extends up both sides of the Chama River Canyon to the Rio Cebolla.

This outcrop belt constitutes a major reserve of gypsum which to this date has remained virtually untouched. Factors contributing to the lack of exploitation include distance from consumers, poor transportation facilities, virtual wilderness conditions of some outcrop areas, location of much of the gypsum in cliffs rather than easily strippable benches, and low unit value. According to Weber and Kottlowski (1959, p. 19), a small amount of gypsum has been recovered from Cerro Blanco near Gallina for local use as an interior plaster.

LIMESTONE

Limestone occurs in four distinct geologic environments in Rio Arriba County: marine limestone of Pennsylvanian and Mississippian age, nonmarine limestone in the lower part of the Jurassic Todilto

Formation, Cretaceous limestone in the Greenhorn Limestone, and calcareous tufa related to Quaternary springs.

Marine limestone of Paleozoic age is exposed on the crest of the southern Sangre de Cristo Mountains near Truchas Peaks and along the southern and eastern flanks of San Pedro Mountain. The limestone sequence in these areas ranges in thickness from a few feet up to 300 feet (San Pedro Mountain), is highly fossiliferous, and tends toward complex intertonguing with thin shale and sandstone beds.

Limestone forms the lower part of the Todilto Formation; Smith, Budding, and Pitrat (p. 12) described it as

> dark-colored, fetid, fissile, calcareous shales at the base, grading upward into very thin-bedded, gray, medium crystalline limestone and finally into more massive gray limestone. Locally the limestone contains blebs of gypsiferous material.

The outcrop pattern of these limestone beds is identical to that of the overlying gypsum just described.

The Greenhorn Limestone is exposed throughout much of the Chama Basin (pl. 1). It includes about 30 feet of light gray, closely jointed, fossiliferous limestone with much argillaceous material.

Calcareous tufa of hot-spring origin is present in the Ojo Caliente–La Madera area at Owl Cliffs, Statue Spring, and Ojo Caliente. The largest deposit of tufa is at Owl Cliffs (Jahns, Smith, and Muehlberger, 1960), west of La Madera Mountain in secs. 25, 26, 35, and 36, T. 25 N., R. 8 E. (pl. 1 and fig. 22). Light-gray through yellowish-tan, porous, and vuggy to massive tufa forms a tiered constructional bench about one mile long and a quarter of a mile wide at the base of La Madera Mountain. Maximum thickness of this bench reaches about 200 feet. An erosional remnant of similar material caps a small mesa just north of State Highway 96 in the northern part of sec. 35, T. 25 N., R. 8 E. The writer suggests, from his brief examination of the tufa deposits, that internal stratification may be complex with thin layers of windborne silt accumulation alternating with irregular lenses of carbonate rock.

BENTONITE

Bentonite derived from the alteration of volcanic ash interbedded in the Santa Fe Formation is reported by Talmadge and Wootton, Davis and Vacher (1940), Reynolds (1952), and Patterson (1965a). Approximate locations of bentonite shown on Talmadge and Wootton's resource map are in sec. 5, T. 22 N., R. 9 E., west of Velarde, and sec. 24, T. 28 N., R. 6 E., about five miles southwest of Burned Mountain. The latter locality is underlain by Los Piños Formation, a Tertiary volcanic con-

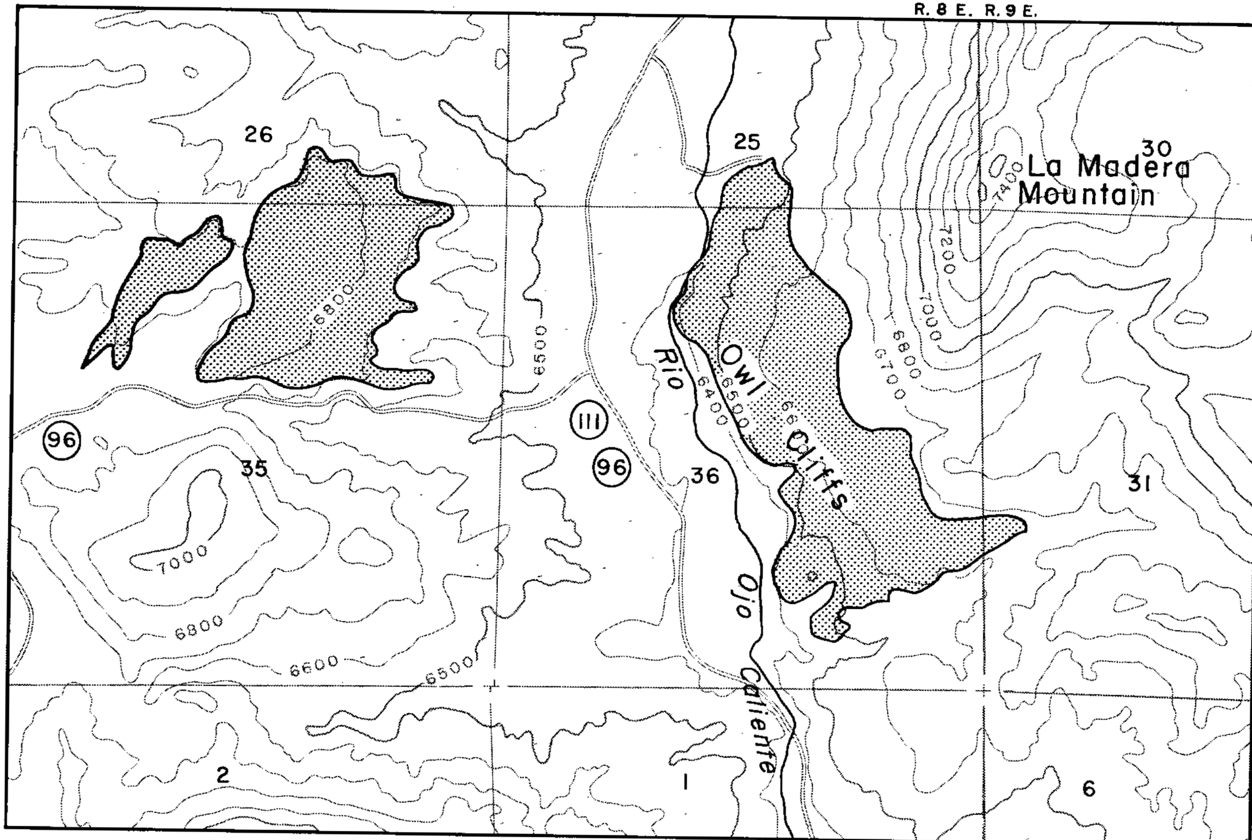

Figure 22
LOCATION AND DISTRIBUTION MAP OF THE OWL CLIFFS TUFA DEPOSIT

glomerate and sandstone unit containing numerous ash beds. No production is recorded from Rio Arriba County bentonite occurrences nor have reserves been evaluated. Table 2 shows a chemical analysis of

TABLE 2. CHEMICAL ANALYSIS OF BENTONITE FROM LOS PIÑOS FORMATION, RIO ARRIBA COUNTY

CONSTITUENT OXIDES	PER CENT CONTAINED
SiO_2	51.56
Al_2O_3	13.42
Fe_2O_3	3.22
CaO	2.04
MgO	4.94
K_2O	0.38
Na_2O	0.24
H_2O	23.46
	99.26

purified bentonite from Los Piños Formation reported by Ross and Shannon (1926).

PUMICE

Pumice in lapilli tuff at the base of the Bandelier Tuff of Pleistocene age forms a large outcrop area on the southeastern flank of the Jemez Mountains. Most of the pumice is exposed and has been mined in Sandoval and Santa Fe counties. A small part of this large pumice reserve lies within Rio Arriba County in T. 20 N., R. 7 E., about seven miles west and slightly south of Espanola. Pumice, produced continuously since 1951, has an aggregate production of 1,674,625 cubic yards with a value of $3,024,851 (State Mine Inspector). Most of this production has come from the General Pumice Company's Cullum mine in sec. 17, T. 20 N., R. 7 E. Most of the pumice mined is processed for lightweight building blocks, with lesser amounts used for concrete aggregate, railroad ballast, and scouring compounds.

STONE

Enormous reserves of stone are readily available in the county, but little have been utilized. Flagstone has been quarried from the thin sandstone sequence in the Lower Chinle west of Abiquiu. Blocks of welded tuff from the Bandelier Tuff were utilized in the construction of the old mission at San Juan Pueblo. A small amount of crushed stone is quarried and processed for highway construction, principally as ballast. An indication of production appears below:

YEAR	PRODUCTION (TONS)	VALUE ($)
1965	17,278	26,247
1964	120	4,000
1963	2,166	41,573
1962	155,925	157,500
1961	—	—
1960	—	—
1959	16,123	9,674
1958	10,400	9,900

SAND AND GRAVEL

Reserves of sand and gravel in Rio Arriba County are very large and widely distributed. In fact, so widespread are suitable deposits of these materials that temporary pits opened near construction sites have proved more than adequate. The largest known reserves are in Quaternary deposits of alluvium and terrace gravel along the main drainages in the county and in the Santa Fe Formation of Tertiary age that underlies much of the southeastern part of the county. Apparently, all sand and gravel produced in Rio Arriba County is utilized in the manufacture of concrete for the building trades and in highway construction. Table 3 shows the production of sand and gravel from Rio Arriba County for the period 1956 to 1965.

TABLE 3. PRODUCTION OF SAND AND GRAVEL FROM RIO ARRIBA COUNTY

YEAR	SHORT TONS	VALUE ($)
1965	689,000	465,000
1964	111,000	137,000
1963	366,000	453,000
1962	146,000	220,000
1961	697,000	901,000
1960	395,000	338,000
1959	815,000	589,000
1958	243,000	352,000
1957	299,000	373,000
1956	298,500	295,000

Table 4 shows known and potential sources of sand and gravel classified by age and formations. Relevant geologic features of each unit, which include grain size distribution, degree of cementation, geographic distribution, reactivity (related to the content of feldspar and volcanic ash or their alteration products), and mineralogic composition are also listed. Plate 1 shows the distribution of each formation or geologic unit.

TABLE 4. FEATURES OF SAND AND GRAVEL SOURCES

FORMATION	GRAIN SIZE	CEMENTATION	GEOGRAPHIC DISTRIBUTION	REACTIVITY	COMPOSITION
Alluvium	Boulders to clay, interlayered sand, sandy gravel	Weak	Widespread	Low to moderate	Quartz, feldspar, all rock types
Quaternary–Tertiary gravel	Boulder-to-pebble gravel, ferrous thin aprons along stream drainages	Weak	Widespread	Low to moderate	Quartz, feldspar, all rock types
Glacial deposits	Largely boulder to pebble gravel; some till	Weak	Restricted to highest elevation in Tusas and Sangre de Cristo mountains	Low	Quartz, feldspar, metamorphic rocks
Santa Fe	Fine to medium sand, thin conglomerate beds	Weak	Restricted to Rio Grande province in southeastern part of county	Low to moderate	Quartz, feldspar, montmorillonite, all rock types
Los Piños and Abiquiu Tuff	Boulder conglomerate to medium sand; conglomerate largely in district horizons	Moderate	Restricted to flanks of Tusas Mountains	Moderate to high	Quartz, feldspar, volcanic rock, volcanic ash
Ritito Conglomerate	Cobble-to-pebble conglomerate; poorly sorted	Weak to moderate	Restricted to western flank of Tusas Mountains	Low	Quartz, feldspathic quartzite; metamorphic rocks locally

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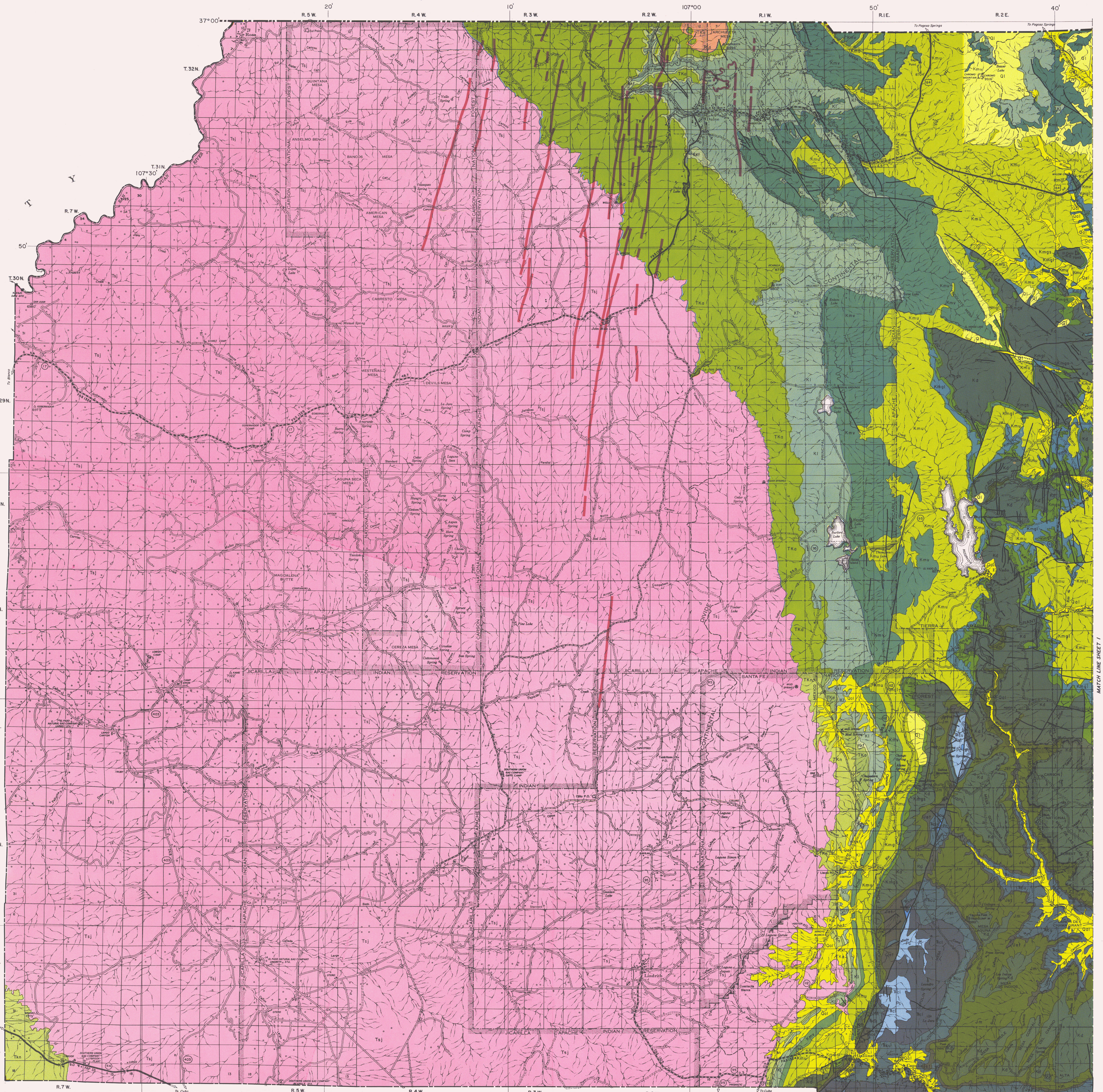
NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, BUREAU OF MINES AND MINERAL RESOURCES DIVISION

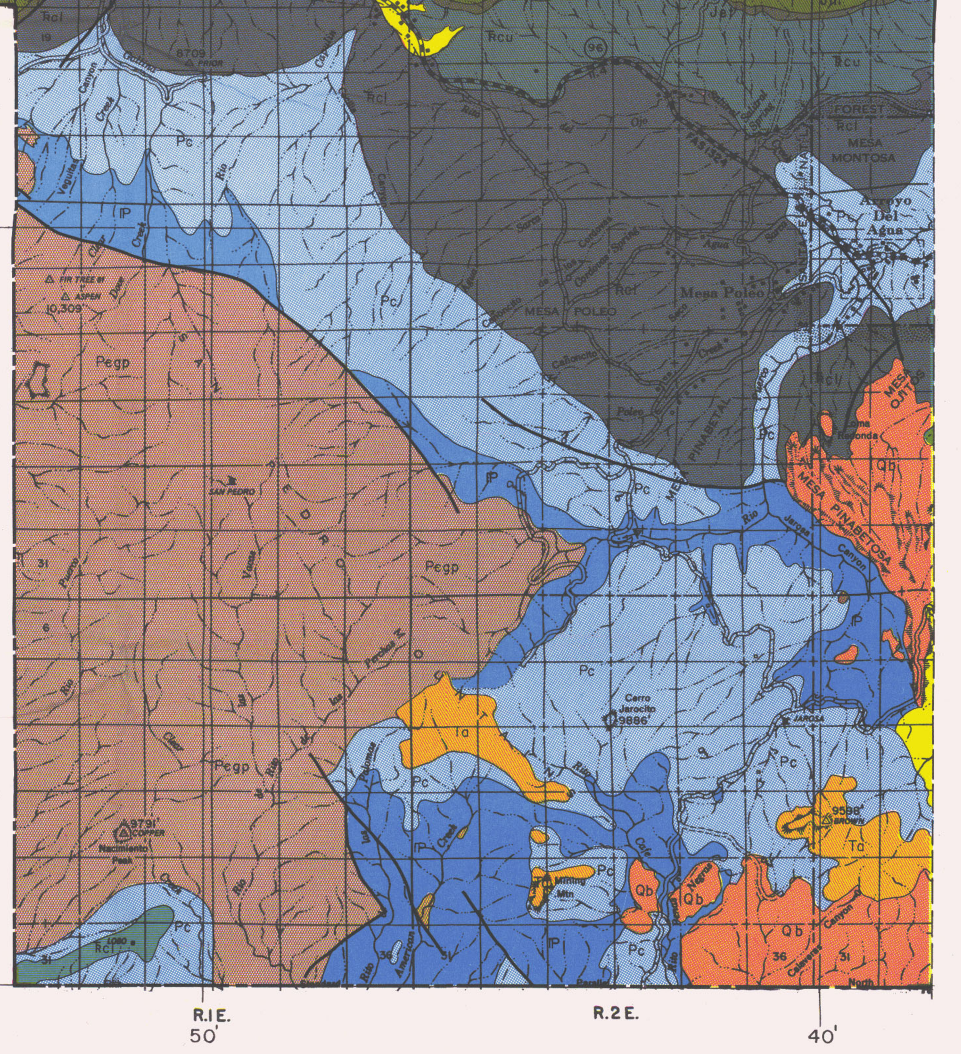
BULLETIN 91 PLATE Ia

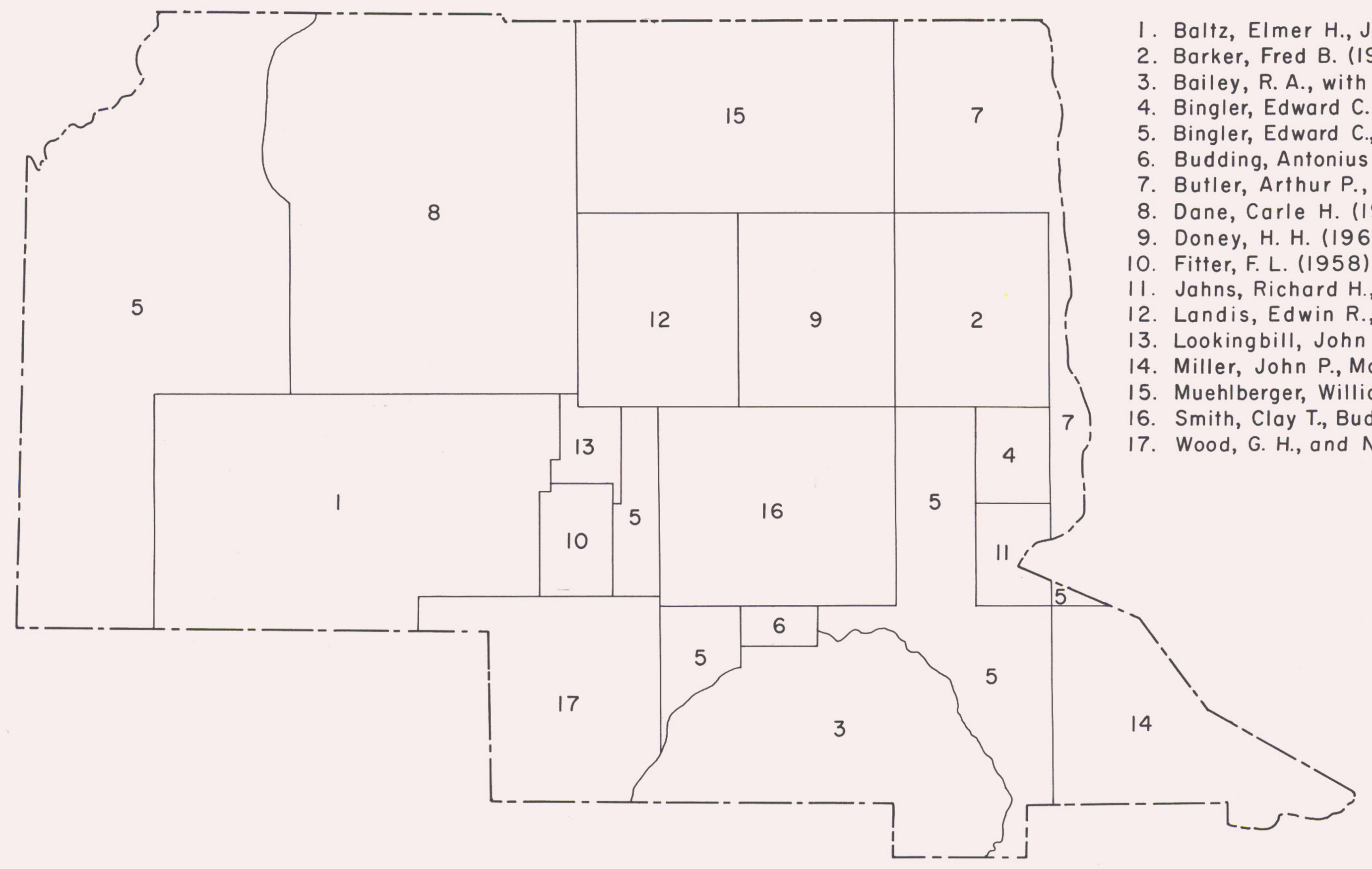


Base map from New Mexico State Highway Department

Geology compiled by Edward C. Bingler, 1967

SANDOVAL COUNTY





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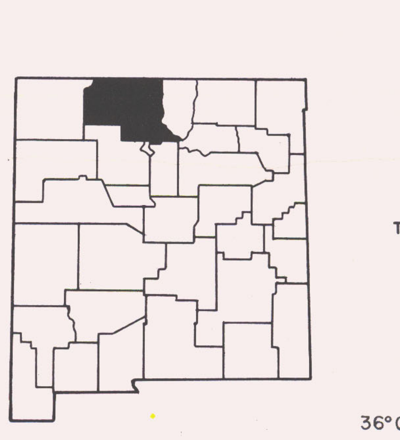
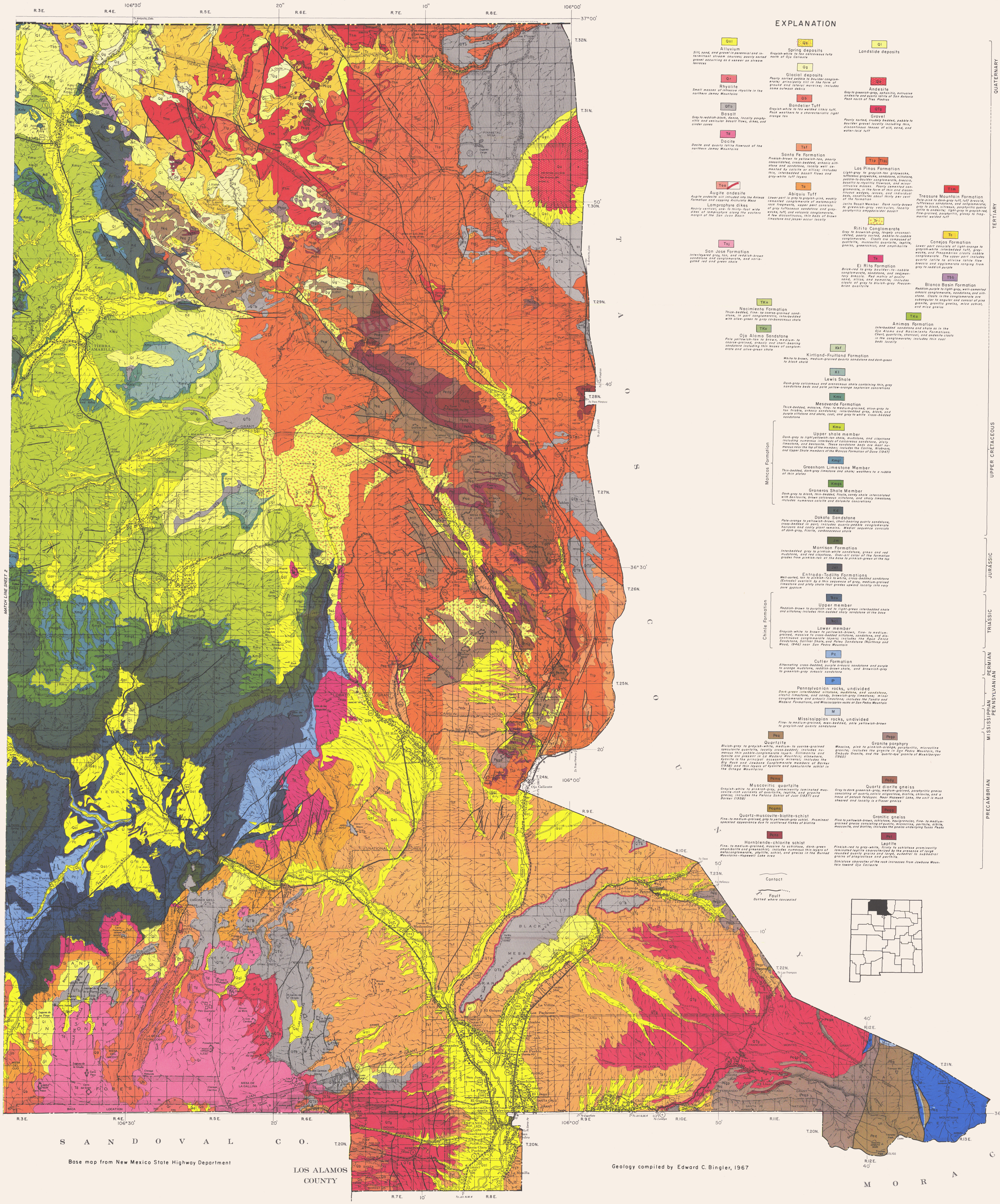


Sources of Geologic Mapping

SANDOVAL COUNTY

GEOLOGIC MAP OF RIO ARRIBA COUNTY, WEST HALF



EXPLANATION

QUATERNARY

Qal — Alluvium
Silt, sand, and gravel in perennial and intermittent stream courses; poorly sorted gravel occurring as a veneer on stream terraces

Qs — Spring deposits
Grayish-white to tan calcareous tufa north of Ojo Caliente

Ql — Landslide deposits

Qg — Glacial deposits
Poorly sorted pebble to boulder conglomerate; principally till in the form of ground and lateral moraine; includes some outwash debris

Qr — Rhyolite
Small masses of intrusive rhyolite in the northern Jemez Mountains

Qa — Andesite
Gray to greenish-gray, aphanitic, extrusive andesite and quartz latite of San Antonio Peak north of Tres Piedras

Qb — Bandelier Tuff
Grayish-white to tan welded lithic tuff. Rock weathers to a characteristic light orange tan

QTb — Basalt
Gray to reddish-black, dense, locally porphyritic and vesicular basalt flows, dikes, and cinder cones

QTg — Gravel
Poorly sorted, crudely bedded, pebble to boulder gravel locally including thin, discontinuous lenses of silt, sand, and water-laid tuff

TERTIARY

Td — Dacite
Dacite and quartz latite flowrock of the northern Jemez Mountains

Tsf — Santa Fe Formation
Pinkish-brown to yellowish-tan, poorly consolidated, cross-bedded, arkosic siltstone and sandstone, locally well cemented by calcite or silica; includes thin, interbedded basalt flows and gray-white tuff layers

Tlp, Tlpj — Los Pinos Formation
Light-gray to grayish-tan graywacke, tuffaceous graywacke, sandstone, siltstone, pebble-to-boulder conglomerate, breccia, basaltic to rhyolitic flowrock, and minor intrusive masses. Poorly cemented conglomerate, in the form of thin and discontinuous wedges, lenses, and individual beds, constitutes about thirty per cent of the formation

Jarita Basalt Member *Dark rusty-brown to greenish-gray vesicular, locally porphyritic amygdaloidal basalt*

Taa — Augite andesite
Augite andesite sill intruded into the Animas Formation and capping Archuleta Mesa

Lamprophyre dikes
Nearly vertical, one- to thirty-foot wide dikes of lamprophyre along the eastern margin of the San Juan Basin

Ta — Abiquiu Tuff
Lower part is gray to grayish-pink, weakly cemented conglomerate of metamorphic rock fragments, upper part consists of gray tuffaceous sandstone and graywacke, tuff, and volcanic conglomerate. A few discontinuous, thin beds of brown limestone and jasper occur locally

Ttm — Treasure Mountain Formation
Pale-pink to dark-gray tuff, tuff breccia, tuffaceous sandstone, and conglomerate; gray to black, vitreous, porphyritic quartz latite to andesite; light-gray to grayish-red, fine-grained, porphyritic, glassy to fragmental welded tuff

Tr — Ritito Conglomerate
Gray to brownish-gray, largely unconsolidated, poorly sorted, pebble-to-cobble conglomerate. Clasts are composed of quartzite, muscovitic quartzite, leptite, gneiss, greenschist, and amphibolite

Tsj — San Jose Formation
Interlayered gray, tan, and reddish-brown sandstone and conglomerate, and variegated red and green shale

Tc — Conejos Formation
Lower part consists of light-orange to grayish-white interbedded tuff, graywacke, and Precambrian clasts cobble conglomerate. The upper part includes quartz latite to olivine latite flow breccia and agglomerate ranging from gray to reddish purple

Te — El Rito Formation
Brick-red to gray boulder-to-cobble conglomerate, sandstone, and sedimentary breccia. Red matrix of quartz sand, silica, and hematite; includes clasts of gray to bluish-gray Precambrian quartzite

Tbb — Blanco Basin Formation
Reddish-purple to light-gray, well-cemented arkosic conglomerate, sandstone, and siltstone. Clasts in the conglomerate are subangular to angular and consist of pink granite, granitic gneiss, mica schist, and mica gneiss

TKn — Nacimiento Formation
Thick-bedded, fine- to coarse-grained sandstone, in part conglomeratic, interbedded with olive-green to gray carbonaceous shale

TKa — Animas Formation
Interbedded sandstone and shale as in the Ojo Alamo and Nacimiento Formations. Chert, quartzite, charcoal, and andesite clasts in the conglomerate; includes thin coal beds locally

TKo — Ojo Alamo Sandstone
Pale yellowish-tan to brown, medium- to coarse-grained, arkosic and chert-bearing sandstone including thin lenses of conglomerate and olive-green shale

UPPER CRETACEOUS

Kkf — Kirtland-Fruitland Formation
White to brown, medium-grained quartz sandstone and dark-green to black shale

Kl — Lewis Shale
Dark-gray calcareous and arenaceous shale containing thin, gray sandstone beds and pale yellow-orange septarian concretions

Kmv — Mesaverde Formation
Thick-bedded, massive, fine- to medium-grained, olive-gray to tan friable, arkosic sandstone; interbedded gray, black, and purple siltstone and shale, coal, and gray to white cross-bedded sandstone

Mancos Formation

Kmu — Upper shale member
Dark-gray to light yellowish-tan shale, mudstone, and claystone including numerous interbeds of calcareous sandstone, platy limestone, and bentonite. These sandstone beds are most numerous near the top of the member; includes the Carlile, Niobrara, and Upper Shale members of the Mancos Formation of Dane (1947)

Kmgl — Greenhorn Limestone Member
Thin-bedded, dark-gray limestone and shale; weathers to a rubble of thin plates

Kmgs — Graneros Shale Member
Dark-gray to black, thin-bedded, fissile, sandy shale intercalated with bentonite, brown calcareous siltstone, and shaly limestone; includes numerous calcite and dolomite concretions

Kd — Dakota Sandstone
Pale-orange to yellowish-brown, chert-bearing quartz sandstone, cross-bedded in part; includes quartz-pebble conglomerate horizons and coaly plant remains. Medial sequence consists of dark-gray, fissile, carbonaceous shale

JURASSIC

Jm — Morrison Formation
Interbedded gray to pinkish-white sandstone, green and red mudstone, and red claystone. Over-all color of the formation grades from pinkish-tan at the base to pinkish-green at the top

Jet — Entrada-Todilto Formations
Well-sorted, tan to pinkish-tan to white, cross-bedded sandstone (Entrada) overlain by a thin sequence of gray, medium-grained limestone and platy shale that grades upward locally into very pure gypsum

TRIASSIC

Chinle Formation

Ꞧcu — Upper member
Reddish-brown to purplish-red to light-green interbedded shale and siltstone; includes thin-bedded shaly sandstone at the base

Ꞧcl — Lower member
Grayish-white to brown to yellowish-brown, fine- to medium-grained, massive to cross-bedded siltstone, sandstone, and discontinuous conglomerate layers; includes the Agua Zarca Sandstone, Salitral Shale, and Poleo Sandstone (Northrop and Wood, 1946) near San Pedro Mountain

PERMIAN

Pc — Cutler Formation
Alternating cross-bedded, purple arkosic sandstone and purple to orange mudstone, reddish-brown shale, and brownish-gray to greenish-gray arkosic sandstone

PENNSYLVANIAN

IP — Pennsylvanian rocks, undivided
Dark-green interbedded siltstone, mudstone, and sandstone, clastic limestone, and sandy, brownish-gray limestone; minor conglomerate and arkosic limestone; includes the Sandia and Madera Formations, and Mississippian rocks at San Pedro Mountain

MISSISSIPPIAN

M — Mississippian rocks, undivided
Fine- to medium-grained, even-bedded, pale yellowish-brown to grayish-red quartz sandstone

PRECAMBRIAN

p€q — Quartzite
Bluish-gray to grayish-white, medium- to coarse-grained specularite quartzite, locally cross-bedded; includes numerous thin pebble-conglomerate layers. Sillimanite and kyanite are present in La Madera Mountain; elsewhere, kyanite is the principal accessory mineral; includes the Big Rock and Jawbone Conglomerate members of Barker (1958) and thin layers of kyanite and specularite schist in the Ortega Mountains

p€gp — Granite porphyry
Massive, pink to pinkish-orange, porphyritic, microcline granite; includes the granite in San Pedro Mountain, the Embudo Granite, and the "quartz-eye" granite of Muehlberger (1960)

p€mq — Muscovitic quartzite
Grayish-white to pinkish-gray, prominently laminated muscovite-rich variants of quartzite, leptite, and granite gneiss; includes the Petaca Schist of Just (1937) and Barker (1958)

p€dg — Quartz diorite gneiss
Gray to dark greenish-gray, medium-grained, porphyritic gneiss consisting of quartz, calcic oligoclase, biotite, chlorite, and a trace of potash feldspar. Near Hopewell Lake, the unit is much sheared and locally is a flaser gneiss

p€qms — Quartz-muscovite-biotite-schist
Fine- to medium-grained, gray to yellowish-gray schist. Prominent speckled appearance due to scattered flakes of biotite

p€gg — Granitic gneiss
Pink to yellowish-brown, schistose, equigranular, fine- to medium-grained gneiss consisting of quartz, microcline, perthite, albite, muscovite, and biotite; includes the gneiss underlying Tusas Peaks

p€hs — Hornblende-chlorite schist
Fine- to medium-grained, massive to schistose, dark-green amphibolite and greenschist; includes numerous thin layers of metaconglomerate, phyllite, schist, and gneiss in the Burned Mountains—Hopewell Lake area

p€l — Leptite
Pinkish-red to gray-white, flinty to schistose prominently laminated leptite characterized by the presence of large rounded quartz grains and large, euhedral to subhedral grains of plagioclase and perthite.

Schistose character of the rock increases from Jawbone Mountain toward Ojo Caliente

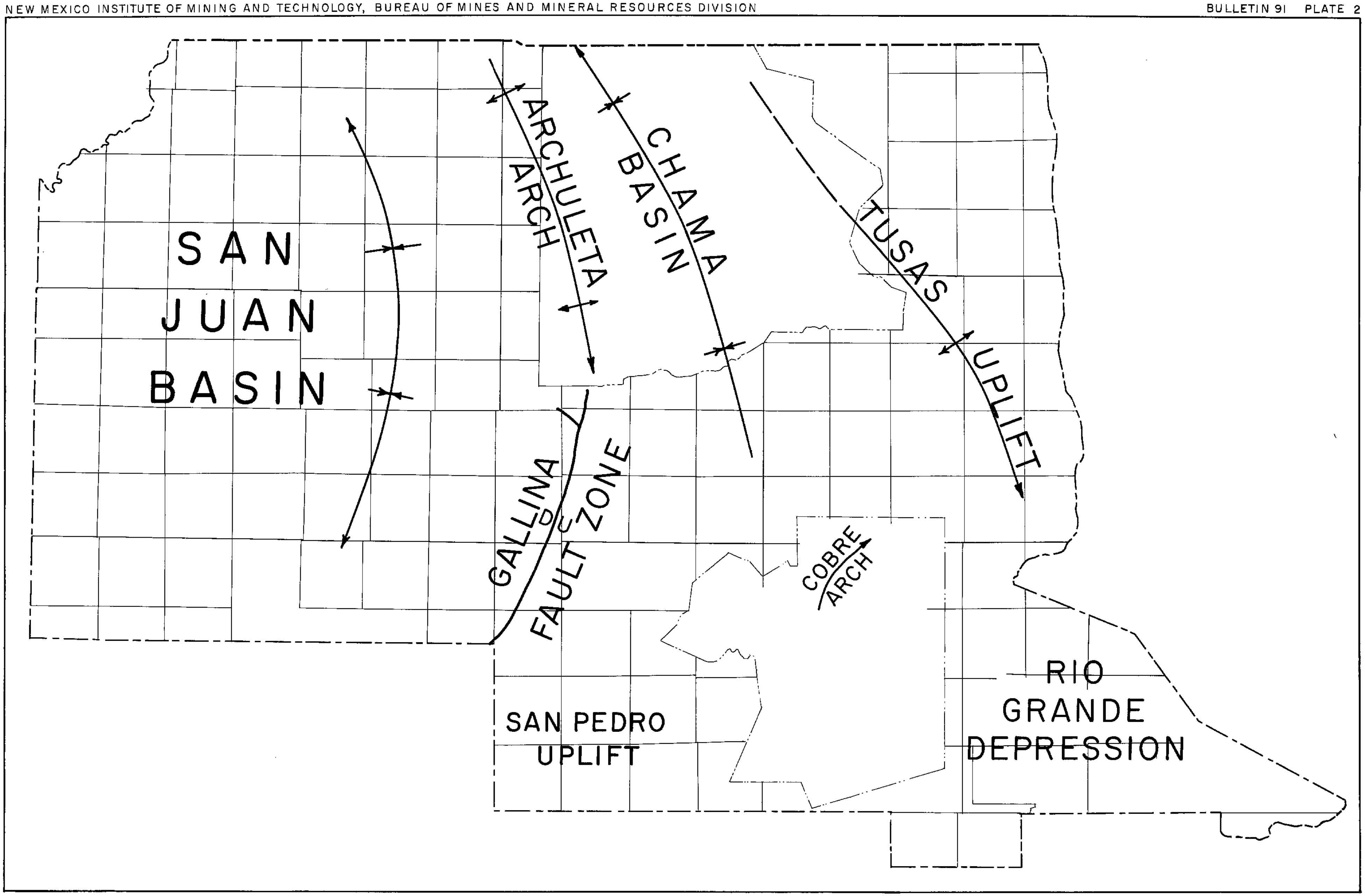
Contact

Fault
Dotted where concealed

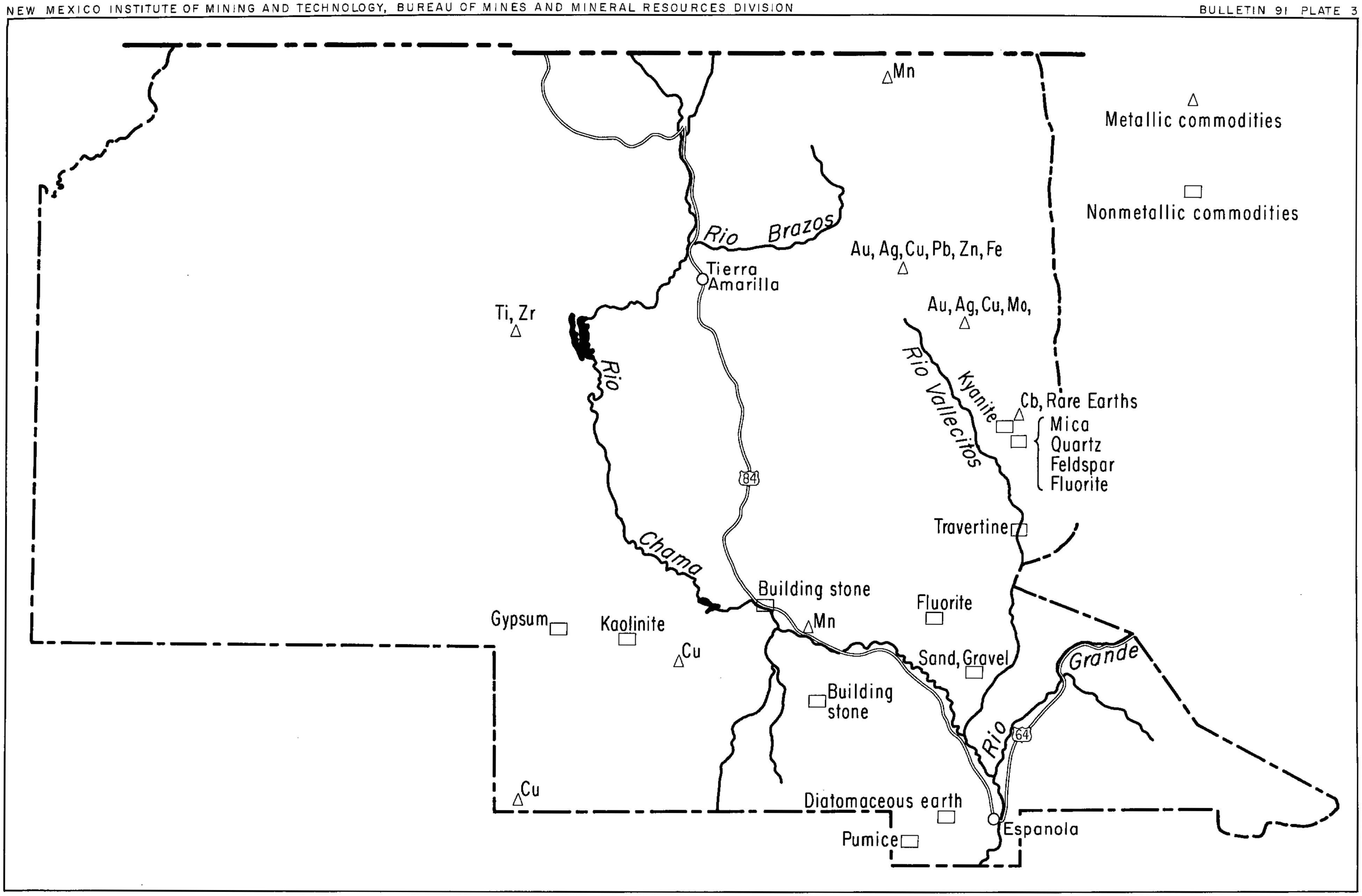
Base map from New Mexico State Highway Department

Geology compiled by Edward C. Bingler, 1967

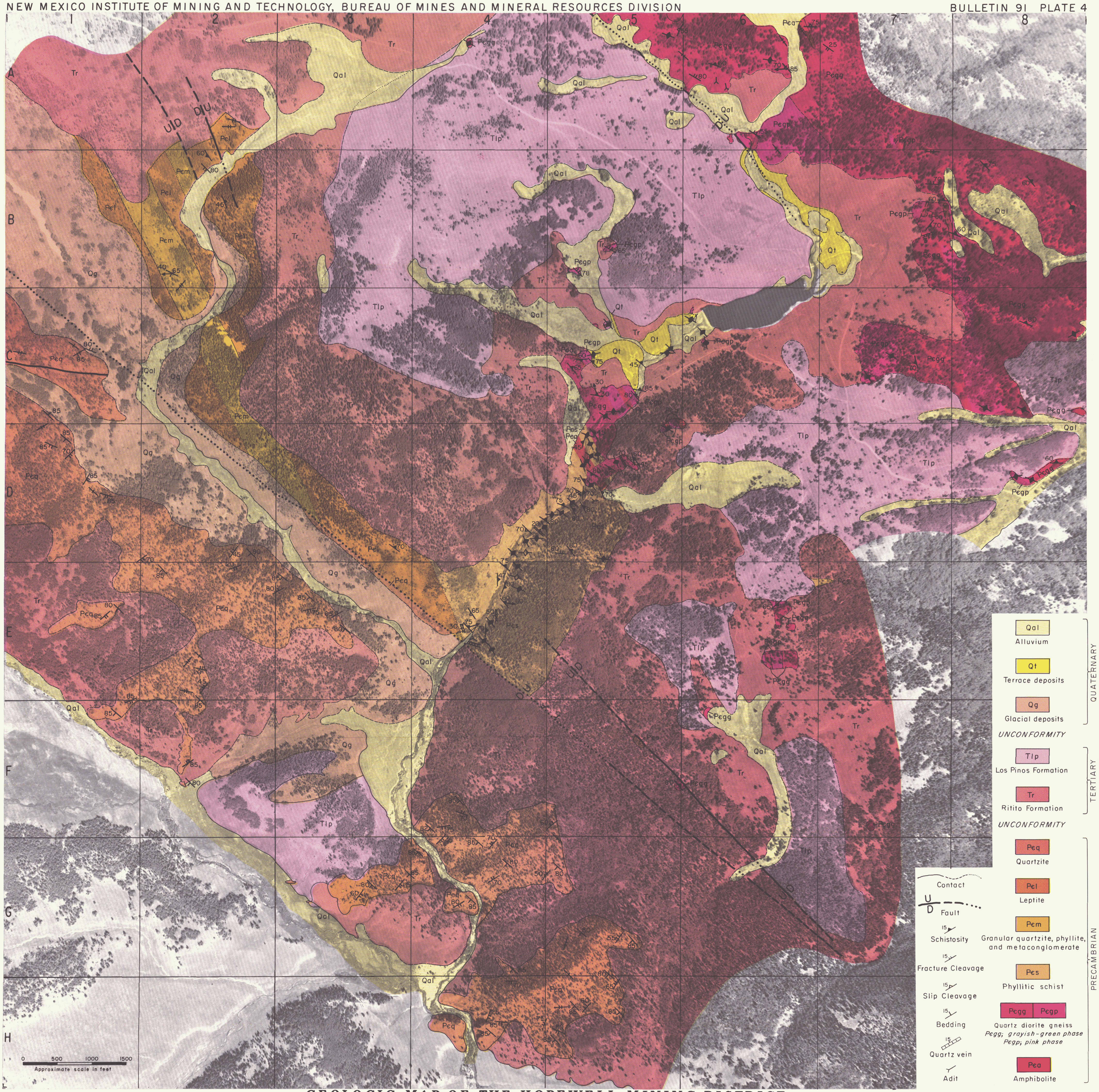
GEOLOGIC MAP OF RIO ARRIBA COUNTY, EAST HALF



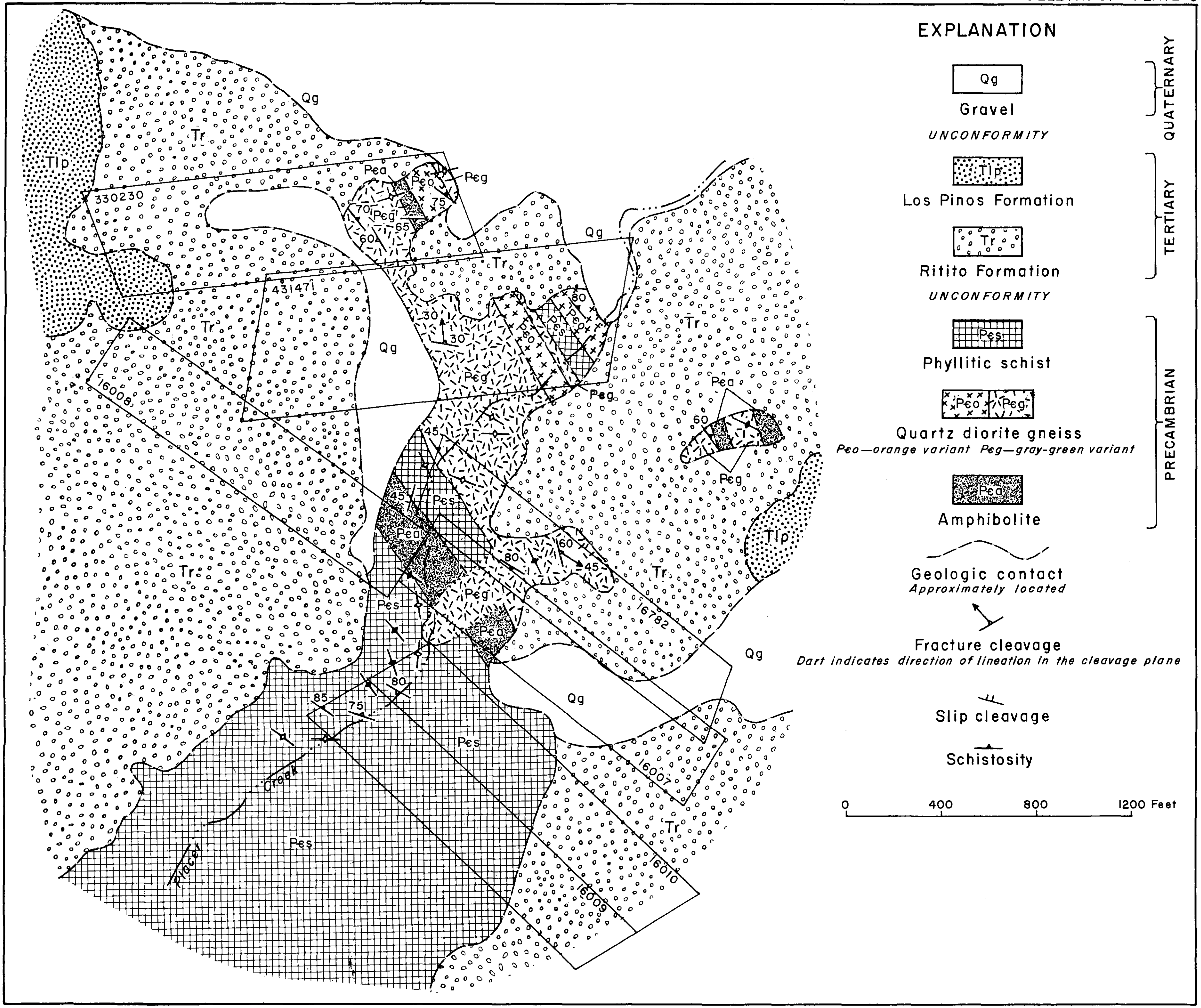
TECTONIC MAP OF RIO ARRIBA COUNTY



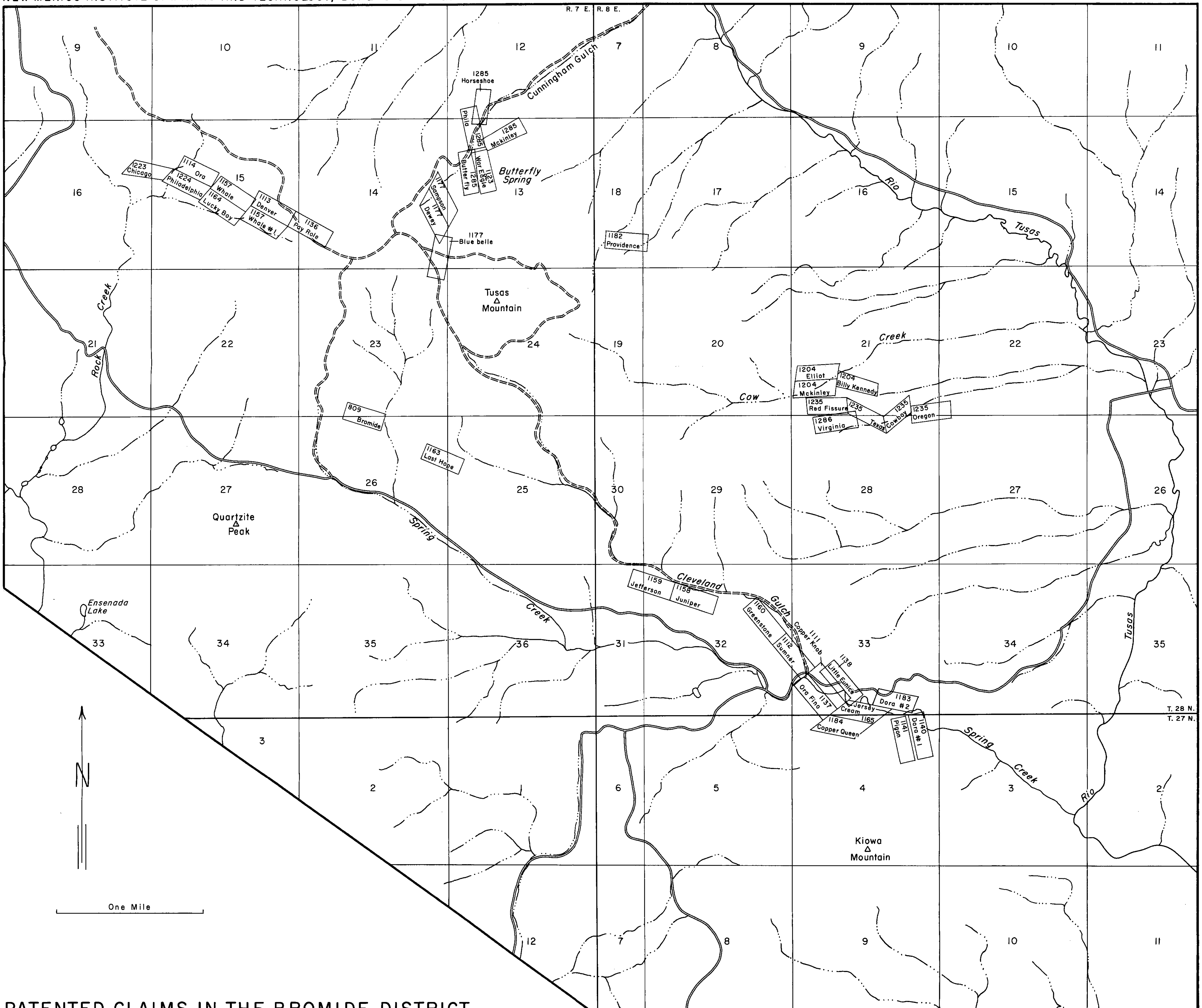
MINERAL COMMODITIES IN RIO ARRIBA COUNTY



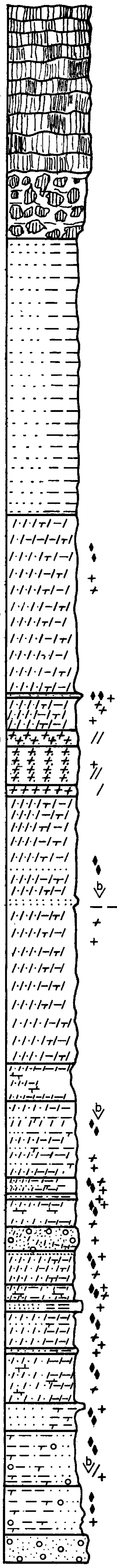
GEOLOGIC MAP OF THE HOPEWELL MINING DISTRICT



GEOLOGIC MAP OF THE RED JACKET, MINERAL POINT, CREASUS, CLARA D., GRAND MOGUL, LITTLE CASINO, AND MARY E. STEELE PATENTED CLAIMS IN THE HOPEWELL DISTRICT



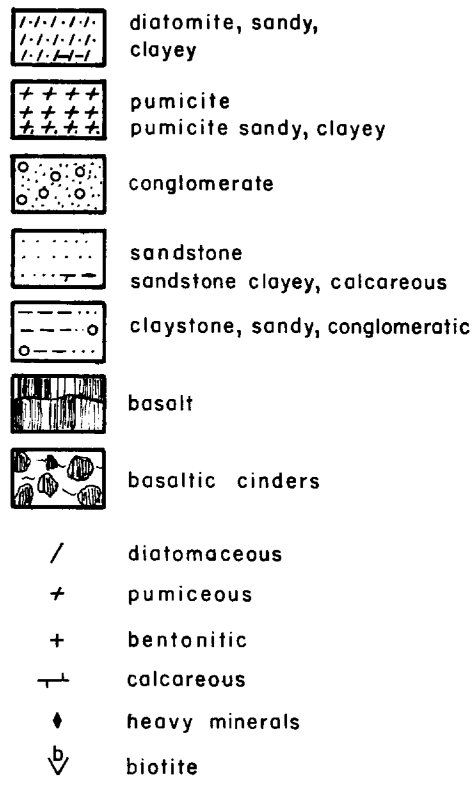
PATENTED CLAIMS IN THE BROMIDE DISTRICT



UNIT	THICKNESS	MISCELLANEOUS	MOISTURE %	UNIT	CARBONATE %
26	30'0"				
25	12'0"				
24	50'0"				
23	32'6"	Similar to 17; less sand	9.8		46.6
			14.0		34.1
			22.0		38.2
			18.6		43.0
			13.7	23	31.7
			14.0		44.1
			17.1		37.3
			14.5		51.1
22	0'6"				
21	6'0"	pale yellowish orange	5.2	21	26.1
20	3'0"	white	5.0	20	3.6
19	7'0"		34.6	19	10.6
18	2'0"	medium light gray	5.3	18	3.6
17	48'6"	similar to 15; almost white	4.2		36.2
			25.6		19.7
			10.0		34.8
		road			
			9.7	17	17.0
			16.3		33.6
			14.4		33.2
			4.9		35.8
			4.1		44.0
			5.4		35.1
16	7'0"	poorly exposed			
15	14'0"	very pale orange; very fine – fine sand	4.9	15	32.0
14	3'0"				
13	0'10"	light gray; coarse			
12	5'0"				
11	4'6"				
10	6'0"	similar to 5	4.2	10	39.6
9	3'0"	very pale orange; very fine sand; laminated	21.6	9	40.3
8	2'0"	with grains of brown calcite			
7	6'6"	diatomite as in 5			
6	1'2"	dark yellowish brown; fine–coarse			
5	9'0"	very pale orange; very fine– fine sand	11.7	5	36.2
4	5'0"				
3	10'0"	very pale orange; very fine–fine sand; few weathered volcanic boulders			
2	9'0"	yellowish gray; weathered volcanic boulders; fine–coarse, subrounded, frosted quartz grains			
1	5'0"	dark yellowish brown; discontinous ledge			

282'6" Total thickness measured

140'6" Thickness of diatomite



Data collected by Roy Foster, 1966

STRATIGRAPHIC SECTION OF THE RHODES DIATOMITE DEPOSIT