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Geology of Lordsburg Quadrangle, Hidalgo County, New Mexico

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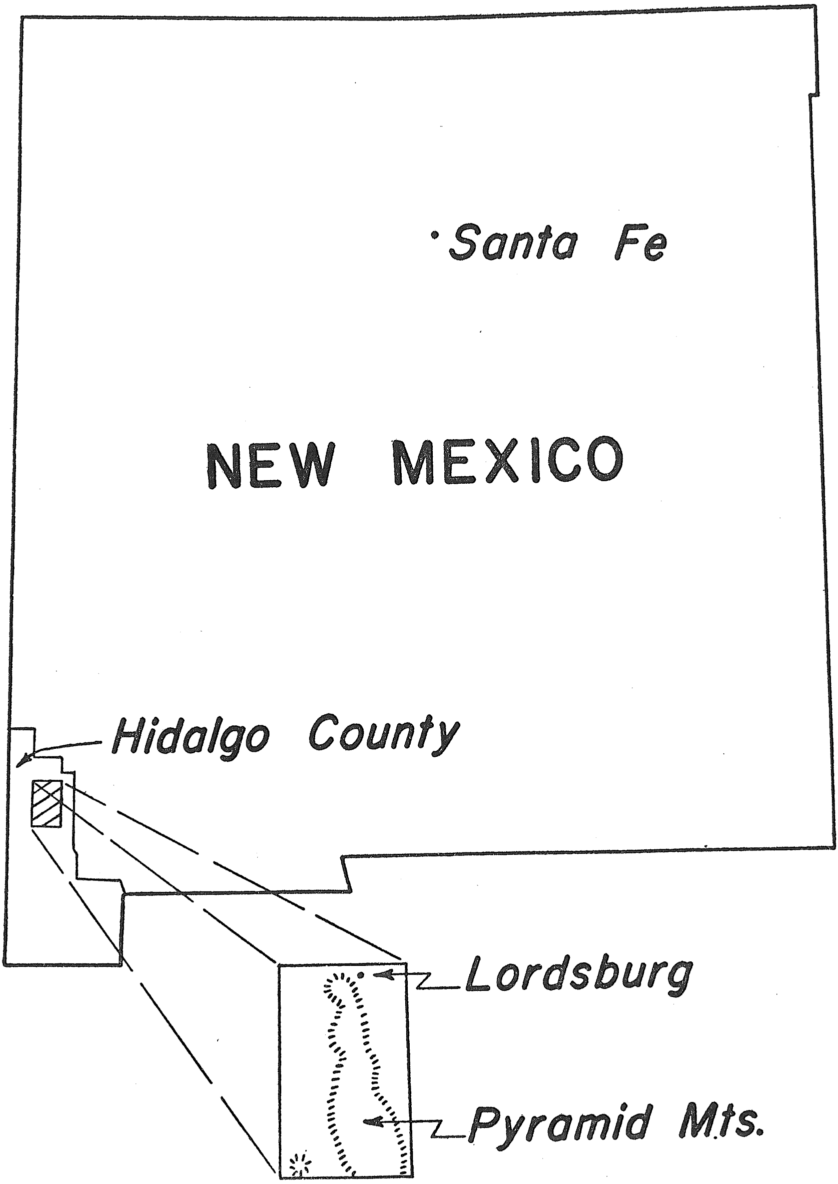

Figure 1

SKETCH MAP OF NEW MEXICO, SHOWING LOCATION OF LORDSBURG QUADRANGLE.

Introduction

NATURE OF THE INVESTIGATION

Surface geologic mapping of Lordsburg quadrangle was accomplished during the summers of 1953 and 1954; laboratory work on the rock samples was performed at Washington University, St. Louis, in 1954 and 1955. The project was carried out in cooperation with the New Mexico Bureau of Mines and Mineral Resources.

The geology of the quadrangle was mapped on a scale of 1:48,000 and transferred to the excellent topographic sheet of Lordsburg quadrangle (scale 1:62,500). Aerial photographs (scale 1:31,250), furnished by the State Bureau of Mines, provided full coverage of the quadrangle.

LOCATION AND ACCESSIBILITY

Lordsburg quadrangle lies in Hidalgo County in extreme southwestern New Mexico (fig. 1). It is bounded by the parallels 32°22′30″ and 32°02′30″ N. and the meridians 108°37′30″ and 108°52′30″ W. The length, which is 5 minutes greater than that of the standard 15-minute quadrangle, was increased in order to include the whole of the Pyramid Mountains. The area thus enclosed covers approximately 333 square miles.

Lordsburg, a town of about 4,000 population and the county seat of Hidalgo County, is the principal settlement within the quadrangle. Although numerous ranches are scattered throughout the area, the greatest part of the population is centered in Lordsburg. The town is supported mainly by the few operating mines in the Lordsburg mining district and by tourist business, farming, and cattle raising.

U. S. Highways 70 and 80 pass through Lordsburg, Highway 80 crossing the northern quarter of the quadrangle in an east-west direction, and Highway 70 entering Lordsburg from the east and then turning due north. A secondary gravel road, the Animas Road, leads southward from Lordsburg, cuts north of the Leitendorf Hills, and thence runs due south along the western side of the Pyramid Range. This road has been called the Old Animas Road since the construction of a new paved road to Animas a few miles to the west in the flat basin.

Although many of the unimproved farm and mine roads shown on the map are now unfit for travel because of washouts, most of the Pyramid Range is reasonably accessible by automobile.

The main line of the Southern Pacific Railroad passes through Lordsburg, traversing the northern part of the quadrangle in an east-west direction.

PHYSIOGRAPHY AND TOPOGRAPHY

Lordsburg quadrangle is situated in that part of the Basin and Range physiographic province which Fenneman (1931, p. 380) calls the Mexican Highland. The quadrangle may be divided into three main topographic units: Lower Animas Valley on the west, Lordsburg Valley on the east, and the Pyramid Mountains, which are between the two valleys.

Lower Animas Valley, bounded 15 miles to the west by the Peloncillo Mountains, is a typical desert basin filled with detritus from the bordering mountain ranges. It is flat in its axial portion and slopes gently upward toward the mountains. An alkali flat, which has a total area of about 15 square miles, is located in the northern part of the valley.

Shore features of ancient Lake Animas, a pluvial lake which was contemporaneous with glacial conditions in North America (Flint, 1949, p. 469), have been studied and mapped by Schwenessen (1918, p. 86-88). These features include beach ridges, beach slopes, and alternating light and dark bands marking strand lines formed as the lake level fell. On the east side of Lower Animas Valley, the old beach is fairly distinct for the whole length of the quadrangle at about the 4,200-foot altitude. (See geologic map, pl. 1). A well-defined, though somewhat discontinuous, wave-cut terrace not described by Schwenessen was found approximately three-fourths of a mile east of this beach line, at about 4,240 feet altitude. The terrace averages only a few feet in height, but the break in slope is sharp and the feature may be detected easily on aerial photographs. The terrace probably marks the highest level of ancient Lake Animas and suggests that the maximum depth of the lake was of the order of 65 feet.

Lordsburg Valley to the east of the Pyramid Mountains is similar to Lower Animas Valley. A small arm of ancient Lake Animas that once extended around the northern end of the Pyramid Range is now manifested as a dry lake bed in Lordsburg Draw near the northeast corner of the map.

The Pyramid Mountains are a linear north-south range about 22 miles long. The width, which ranges from 3 to 7 miles, averages about 5 miles; the total area is approximately 90 square miles. The range is divided by two low passes into a northern, a middle, and a southern part. The northern part, including the Lordsburg and Pyramid mining districts, consists of bare, pyramidal hills extending from just west of Lordsburg southward to the low pass just north of the Leitendorf Hills. The highest peaks in this part are Lee Peak, Aberdeen Peak, 85 Hill, and Lookout Hill, all of which range between 5,000 and 5,100 feet in altitude. The topography of this part has been etched into the oldest lavas and intrusives in the quadrangle, and intervening gullies tend to follow contacts between different formations. The drainage pattern is very irregular. Resistant quartz "dikes" constitute a prominent feature of the topography.

The middle part of the Pyramid Mountains, which is centered around North Pyramid Peak, the Leitendorf Hills, and Rim Rock Mountain, extends southward from the low pass north of the Leitendorf Hills to another low pass in the vicinity of the boundary between T. 24 S. and T. 25 S. The topography is formed in part by the original surfaces of middle- to late-Tertiary welded tuffs and pyroclastic deposits, and in part by the maturely dissected surfaces of older basalt flows. Most of the welded tuffs and pyroclastic rocks dip strongly to the northeast.

The most prominent landmarks of the southern part are South Pyramid Peak, Kirk Peak, Lightning Dock Mountain, and Goat Mountain. The most highly dissected topography is in this part of the range, and both constructional and destructional landforms are represented.

The two highest peaks in the Pyramid Mountains are North Pyramid Peak (6,002 feet) and South Pyramid Peak (5,910 feet). (See pl. 3A, B.) Both peaks are volcanic necks of rhyolitic composition. The maximum relief of the quadrangle, measured from the average elevation of the alluvial contact on the flanks of the range to the highest peak, is 1,600 feet. Within the range itself, the average relief is about 500 feet, and the maximum relief is 1,200 feet (at North Pyramid Peak).

The range is bordered everywhere by gently sloping pediments. The bedrock on which the pediment is cut appears either as low spurs (separated by gravel-filled arroyos which extend well back into the hills) or as isolated remnants surrounded by alluvium and cropping out less than three-fourths of a mile from the edge of the alluvium.

CLIMATE AND VEGETATION

Lordsburg quadrangle is characterized by desert climate and vegetation. The normal annual temperature at Lordsburg is about 60 degrees; summer temperatures average 75 to 80 degrees, and winter temperatures average 40 to 45 degrees. In the summer, daytime temperatures of well above 100 degrees are common, but the heat is bearable because of the low humidity, and the nights are usually comfortable. In the winter, snowfalls are infrequent and short lived.

The normal annual precipitation at Lordsburg is 9.51 inches. Most of the rain falls in the months of July and August in thunderstorms of short duration; a minor wet season occurs in the winter months. The following table shows annual precipitation at Lordsburg since 1934 (data furnished by the U. S. Weather Bureau, St. Louis, Missouri):

The quadrangle has no permanent lakes or streams, although water may remain for long periods in the shallow playas and in cattle ponds built in the mountains. The arroyos become raging torrents immediately after rains but dry up within a few hours.

The ground-water table lies at variable depths in the valleys adjacent to the Pyramid Mountains. Water can be obtained from depths as shallow as 15 feet in Lower Animas Valley, but the best supplies for irriga-

TABLE 1. ANNUAL PRECIPITATION AT LORDSBURG, NEW MEXICO, SINCE 1934

YEAR	INCHES	YEAR	INCHES
1935	10.66	1945	9.17
1936	10.18	1946	9.69
1937	13.43	1947	5.43
1938	5.71	1948	8.07
1939	9.05	1949	11.32
1940	12.26	1950	incomplete
1941	18.81	1951	10.52
1942	10.75	1952	11.19
1943	10.00	1953	8.03
1944	13.84	1954	5.98

tion are commonly found at depths of from 150 to 250 feet. In Lordsburg Draw, the ground-water table lies at depths ranging from 80 to 100 feet. Water for domestic use in Lordsburg is brought from wells near the town.

In the mountains, the depths to good water supplies are extremely variable. In some places, water of good quality for sheep or cattle has been obtained from dug wells only 20 to 25 feet deep; in other places, drilled wells have not encountered adequate water supplies at depths of less than 150 to 200 feet. South of the Lordsburg mining district, the water from drilled wells is generally of good quality, but a few wells yield water that is strongly mineralized.

The vegetation of the Lordsburg district is typical of the arid regions of the southwestern United States. Common plants are mesquite, greasewood, and numerous varieties of cactus. Juniper trees are exceedingly rare in the northern part of the range, but toward the south they become much more abundant. Cottonwood trees are scattered sparsely along the larger arroyos or at the confluence of several arroyos, where the ground-water level is somewhat closer to the surface. Grama grass of several species grows sparsely throughout the range, where it supports cattle, goats, and sheep.

PREVIOUS WORK

The Pyramid Mountains were so named by Antisell (1856, p. 153) because of the pyramidal shapes of the principal peaks in the range. This first allusion to the area is found in the report of Lt. John G. Parke of his explorations for a railroad route from the Mississippi River to the Pacific Ocean; Antisell was the geologist with the party. Little mention was made of the rocks other than to record that they were of plutonic origin. In conjunction with the Wheeler surveys west of the 100th meridian, Gilbert (1875, p. 514, 518) recorded the presence of eruptive rocks at the northern end of the Pyramid Mountains and noted the presence of the resistant quartz veins containing argentiferous ores of lead and copper in the Virginia (Ralston) mining district.

Brief summaries of the history, development, geology, and ore deposits of the Lordsburg mining district have been published by Jones (1904, p. 58-61; 1907, p. 444-445), Wells (1909, p. 890), Fry (1910, p. 820), Lindgren et al. (1910, p. 332-335), Darton (1933, p. 145), Lasky and Wootton (1933, p. 71-74), and Lasky (1935a, p. 337-341). Schwenessen (1918) gives a complete study of the ground-water supplies in the bolsons surrounding the Pyramid Mountains and a complete description of the Quaternary deposits, but mentions only casually the pre-Quaternary rocks of the Pyramid Mountains. A detailed description of igneous assimilation and contact metamorphism around the granodiorite stock in the Lordsburg mining district, and discussion of hydrothermal leaching of the ore deposits in the district, have been published by Lasky (1935b, 1936). In the most complete paper to date, Lasky (1938) has published a comprehensive account of the geology, ore deposits, and underground workings of the mines of the Lordsburg mining district. The production, history, and mining methods at the Eighty-Five mine in the Lordsburg district have been described by Youtz (1931). Huntington (1947) and Storms (1949) have described the geology, history, and mining methods at the Atwood group of claims.

ACKNOWLEDGMENTS

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The writer is indebted to the many hospitable residents of the Lordsburg area who helped make his stay in the area a pleasant one. All the ranchers in the district generously allowed free access to their property. Appreciation is expressed in particular to Mr. and Mrs. Pat Ewing, Mr. Joe Rouse, Mr. Rex Kipp, and Mrs. Eva Holtkamp.

Stratigraphy and Petrography

SEDIMENTARY ROCKS

No indurated sedimentary rocks crop out within the limits of Lordsburg quadrangle. Fusulinids of genus *Triticites* from outcrops of Pennsylvanian Magdalena limestone discovered by S. G. Lasky "about 8 or 9 miles south of Lordsburg and about 2 miles east of the Lordsburg-Animas highway" have been identified by Needham (1937, p. 13). However, these fusulinids are now known to be from included blocks of the limestone in a volcanic agglomerate.

Outcrops of Paleozoic and Mesozoic sediments are common just outside the limits of Lordsburg quadrangle, and these sediments are probably present at depth throughout the whole length of the Pyramid Mountains. Outcrops of Cretaceous limestone were found within 2 to 6 miles of the southwestern and southern limits of the quadrangle. Generally, the limestone crops out as small isolated hills or low mounds projecting up through the valley fill. About 5½ miles south of the quadrangle, where the Animas Road crosses a group of small hills, an outcrop of Cretaceous limestone is overlain by volcanic breccia that is probably a correlative of the middle- to late-Tertiary sequence in the Pyramid Mountains. Cretaceous limestone also crops out on the El Paso Natural Gas Company pipeline road about 2 miles south of the quadrangle, but this outcrop is isolated and surrounded by valley fill.

Three wildcat wells have been drilled just south of Lordsburg quadrangle in order to test petroleum possibilities. All were dry holes. The wells were located in sec. 17, T. 27 S., R. 19 W., and secs. 2 and 12, T. 27 S., R. 18 W., and had total depths of 410, 1,400, and 1,085 feet respectively. Completion dates were March 17, 1951; April 14, 1954; and September 5, 1950 (Umbach and Barnes, 1951, 1952; Umbach, 1955). Published data are not available regarding the formations encountered, but a cursory examination of some samples left at the well site in sec. 2, T. 27 S., R. 18 W., indicated that volcanic rocks were found throughout most of the depth of the hole.

INTRUSIVE AND EXTRUSIVE IGNEOUS ROCKS

Cretaceous Rocks

Basalt

The oldest rocks exposed in Lordsburg quadrangle are basalt flows of Lower Cretaceous age. Correlatives of these older basalts (the Hidalgo volcanic rocks) have been found interbedded with Lower Cretaceous (Trinity) sedimentary rocks in the Little Hatchet Mountains, 35 miles to the south (Lasky, 1947, p. 21).

Although the base is not exposed, the thickness of the Cretaceous basalt is at least 2,000 feet, as the workings of the Eighty-Five mine penetrated the basalt vertically to a depth of 2,050 feet.

Exposed basalt is confined largely to the northern part of the Pyramid Mountains, where it is the host rock for many of the mineral veins of the Lordsburg district, and to the vicinity of the Leitendorf Hills. The basalt forms a distinctive dark reddish-brown soil which contrasts with the lighter soils formed from the Tertiary pyroclastic rocks. Weathered surfaces of the basalt are commonly dark brown or gray, although some, as in the vicinity of the Leitendorf mine, are maroon rubbly exposures.

Megascopically, the basalt is commonly aphanitic, although locally it contains laths of feldspar 0.5 to 2 mm long. A typical specimen from the mining district consists of a few phenocrysts of augite less than 1 mm long in a felty groundmass of labradorite laths, among which are scattered minute grains of augite and iron-ore dust in a residuum of glass. The composition is estimated to be about 50 percent feldspar and 35 percent augite, with nearly equal amounts of glass and magnetite.

West of the Leitendorf Hills, one sample of the basalt contained olivine phenocrysts (10 percent) as much as 2 mm in diameter and seamed with iddingsite, and scarce granular aggregates of epidote, all set in an intergranular matrix of plagioclase microlites (55 percent), small green rods of interstitial augite (25 percent), iron oxide grains, and glass (pl. 7A). Small rods of accessory apatite were also present.

Another sample from west of the Leitendorf Hills showed phenocrysts of plagioclase with corroded borders (calcic andesine to sodic labradorite, 40 percent), small euhedral grains of hornblende (10 percent), and scarce grains of altered pyroxene (3 percent), all set in a dense groundmass of tiny feldspar laths, iron oxide dust, patches of amorphous silica, and glass. Each hornblende grain has an alteration rim of magnetite, and most are altered completely to carbonate and chlorite, as are the pyroxenes (pl. 7B).

Some specimens of the Cretaceous basalt contain a few phenocrysts of quartz having reaction rims of augite rods. The reaction rims suggest that these are xenocrysts, the source of which is not known.

At the north side of the mining district, a minor unconformity within the Cretaceous basalt is marked by 30 to 40 feet of bedded rhyolitic tuff, fine-grained rhyolitic breccia, and thin flows of rhyolite. Above the unconformity, about 300 feet of dense shiny-black basalt is easily recognized by the rounded boulders into which it weathers, and by the skin of soft rust on the weathered surface. The rock contains a few altered olivine phenocrysts, 1 to 2 mm in diameter, in a matrix consisting of nearly equal amounts of labradorite laths and tiny augite rods in a dark glassy base, which also contains a few grains of magnetite.

The Cretaceous basalt is characterized by an advanced degree of alteration. Nearly all the feldspar is altered to carbonate, clay, and sericite, and the ferromagnesian minerals are altered to carbonate, chlorite, chlorophaeite, and iron oxide. Secondary quartz and carbonate occur in irregular patches, and epidote grains are common. Some ferromagnesian minerals are altered to a central core of magnetite, surrounded by chlorite, which is in turn surrounded by epidote.

The basalt has been intruded by a large granodiorite stock, and a narrow contact aureole ranging from a fraction of an inch to 25 feet wide surrounds the stock. Within this aureole, the basalt has undergone varying degrees of alteration. At some places, metamorphism by solutions from the granodiorite stock has tended to change the basalt into a rock much like the granodiorite. The basalt is more crystalline than the average rock in these places and contains minute crystals of biotite in a very fine grained mosaic of orthoclase, oligoclase, and quartz; the original augite is altered to fibrous uralite. In other places, the contact alteration is simply marked by a cryptocrystalline, hard, black hornfels, which has the appearance of flint.

Intrusive Breccia

Small plugs of intrusive breccia intrude the Cretaceous basalt at several places in the Lordsburg mining district. The largest outcrop, which is about a mile long and 1,000 feet wide, forms Atwood Hill and a small hill to the southeast; just across the old railroad to the west is a smaller mass that probably has a subsurface connection with the plug at Atwood Hill. A mile and a half to the southwest, in secs. 11 and 14, T. 23 S., R. 19 W., are several other outcrops that may have been parts of another large plug. Two large masses also occur in secs. 28, 33, and 34, T. 23 S., R. 19 W., and smaller masses crop out at several other places. The Atwood Hill plug and the plugs in secs. 28, 33, and 34 contain included masses of basalt as much as 200 feet in length.

The finely granular matrix of the breccia is composed in some places of dark-gray to greenish basalt and in other places of white rhyolite. Small fragments of the Cretaceous basalt, averaging about one-half inch in length, and of flow-structured felsite are set in the matrix. The matrix of the breccia at several of the plugs has been replaced partially by silica.

Extrusive rhyolitic breccia interbedded with thin rhyolite flows caps Aberdeen Peak and the small hill to the northeast; this rhyolitic material is extrusive and presumably has been derived from one of the breccia-filled plugs.

Intrusive Rhyolite

The intrusive rhyolite is a chalky-white porcelaneous rock that has been sericitized and almost completely replaced by silica, probably as a result of hydrothermal activity. It is thought to represent the latest episode of the earliest volcanic period. The largest outcropping mass is located in secs. 11 and 14, T. 23 S., R. 19 W.; other outcrops that may originally have been part of the same mass crop out to the northwest in sec. 10. The rhyolite intrudes both the Cretaceous basalt and intrusive breccias and is intricately flow structured. Most of the small group of hills projecting through the valley fill south of Gary siding, as well as the rather large mass located a mile and a half due west of Lordsburg, consist of brecciated rhyolite.

The present outcropping bodies of intrusive rhyolite are believed to be remnants of volcanic necks. The general association of the intrusive rhyolite with the intrusive breccia, as shown on the geologic map, indicates that the lava erupted through the same vents that were open during the preceding volcanic period (Lasky, 1938, p. 14).

Cretaceous or Tertiary Rocks

Granodiorite

All the rocks thus far described are intruded by a horseshoe-shaped granodiorite stock thought to be of late-Cretaceous or possibly early-Tertiary age. The exposed length of the stock is about 6½ miles, and the width is 1½ miles, giving an area of about 10 square miles. The stock is probably appreciably larger at a depth of a few hundred feet, for many apophyses, doubtless connected to the main mass, are found just south and east of the north extension of the stock. The basalt-granodiorite contact is fairly regular along the southern part of the stock, but toward the north it is deeply embayed and the contact is locally indefinite, as numerous irregular apophyses of granodiorite project into the basalt and huge blocks of basalt as much as 1,000 feet across are surrounded by granodiorite. This change in the contact from south to north suggests that erosion has truncated the stock at a greater depth in the south, and that the top of the stock was irregular.

The granodiorite is fairly uniform in texture and composition throughout the main part of the mass, but is locally darker and finer grained in a narrow zone bordering the contact. Megascopically, the typical granodiorite is decidedly porphyritic, and fresh surfaces are pink. It consists of phenocrysts of plagioclase (oligoclase-andesine) 1 to 5 mm long, which constitute about 40 percent of the rock, quartz grains (10 percent), orthoclase (5 percent), green hornblende (5 percent), and scarce biotite, all in a fine-grained groundmass of intergrown orthoclase and quartz. Apatite, sphene, zircon, and magnetite are accessory minerals. Hornblende and biotite are almost completely chloritized and altered to iron oxide. Isolated granular aggregates of epidote are scattered throughout the granodiorite.

The darker granodiorite in the border zone differs mineralogically from the typical granodiorite in that its plagioclase is somewhat more calcic, augite is abundant, and magnetite is more common. These departures from the mineralogy of the typical granodiorite have been cited by Lasky (1935b, p. 558) as evidence of partial assimilation of the Cretaceous basalt by the granodiorite.

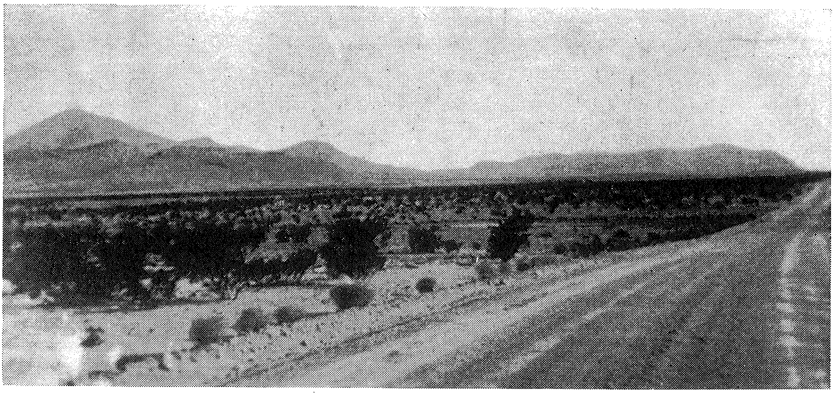
Tertiary Rocks

Pyroxene Andesite

Pyroxene andesite of early-Tertiary age crops out in the southern portion of the Pyramid Mountains over a nearly circular area of about 25 square miles. The base of the pyroxene andesite sequence is well exposed at the old goat camp known as Mexican Joe's, a place not named on the map, but located about three-fourths of a mile S. 84° E. of the southeast corner of sec. 36, T. 24 S., R. 19 W., at the junction of three roads that are shown on the map. The base of the sequence is marked by 200 feet of agglomerate containing rounded boulders of the Cretaceous basalt as much as 3 feet in diameter, blocks of pink Precambrian granite as much as 10 feet long (pl. 3C), and scattered blocks of Pennsylvanian Magdalena limestone ranging in size from pieces a few inches long to great blocks as much as 50 feet long and 6 to 8 feet wide. One of these blocks evidently was mistaken for a sedimentary outcrop by Lasky, but the fragmental nature of the block is definitely established by the igneous matrix in which it is set, and by the association of the granite and Cretaceous basalt boulders. The zone of limestone blocks and boulders can be traced for nearly 4 miles in a semicircle east and south of Mexican Joe's. The limestone is dense, black, petroliferous, and intricately veined by calcite. Silicified horn corals and brachiopods can be seen on the weathered surface of the limestone. The matrix of the breccia is characteristically light gray, and the texture is ashy; upon weathering, the matrix splits into slabby fragments.

Much of the southern part of the Pyramid Mountains, including such prominences as Lightning Dock Mountain, Goat Mountain, and Able Seep, is composed of nearly 1,000 feet of andesite flows and breccias overlying the basal agglomerate. Weathered andesitic rocks are typically purplish, maroon, or gray and form a dark-brown residual soil. The andesitic flows are commonly flow banded and are so extensively jointed that on weathering they break into small fragments.

The flows consist of zoned, corroded plagioclase phenocrysts (calcic andesine, 40 percent) and smaller grains of augite (10 percent), set in a glassy base containing tiny feldspar microlites, iron oxide dust, chlorite, and carbonate. The texture may be described as hyalo-ophitic (pl. 8A). The index of refraction of the glass is 1.535, which indicates 58 percent silica (George, 1924, p. 365). Augite is the dominant ferromagnesian mineral, but hypersthene was identified from one sample, and partially resorbed phenocrysts of hornblende as much as 1½ mm long (pleochroic from dark brown to light yellowish brown) were found in another. Most of the plagioclase ranges from calcic to sodic andesine, but one specimen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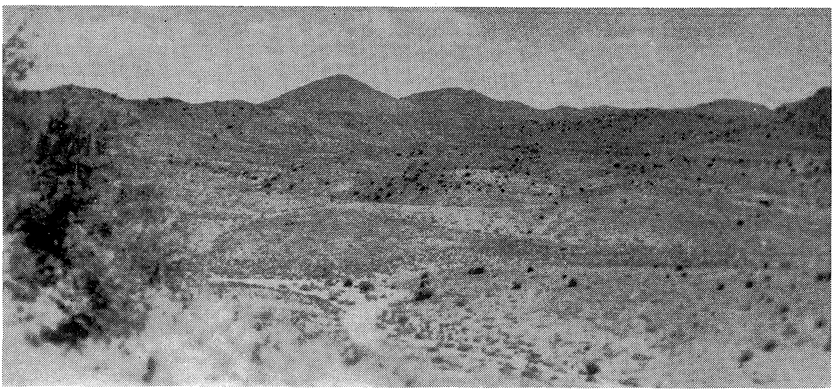
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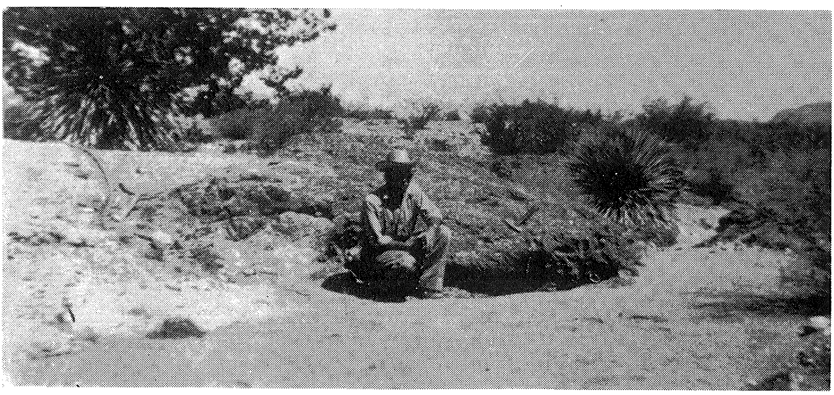
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Plate 3

A. North Pyramid Peak and Leitendorf Hills, from the north

B. South Pyramid Peak, from the west

C. Precambrian granite block in basal agglomerate of the pyroxene andesite sequence

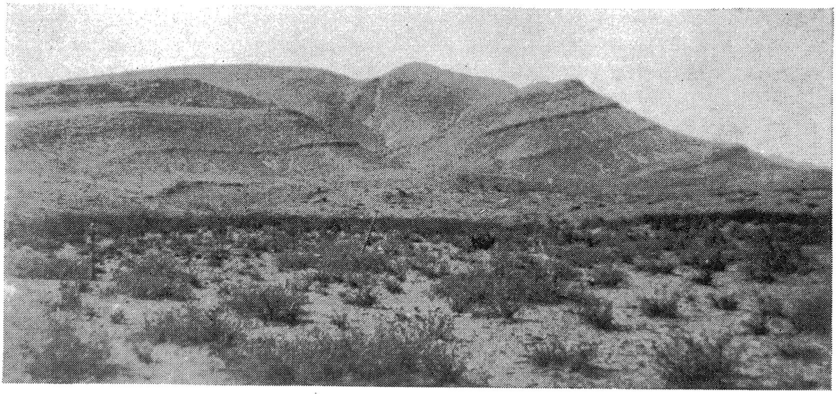
A

B

Plate 4

A. Bedded vitric tuff 3 miles south of Linn ranch

B. Bedded tuff near Dime-a-Day ranch dam



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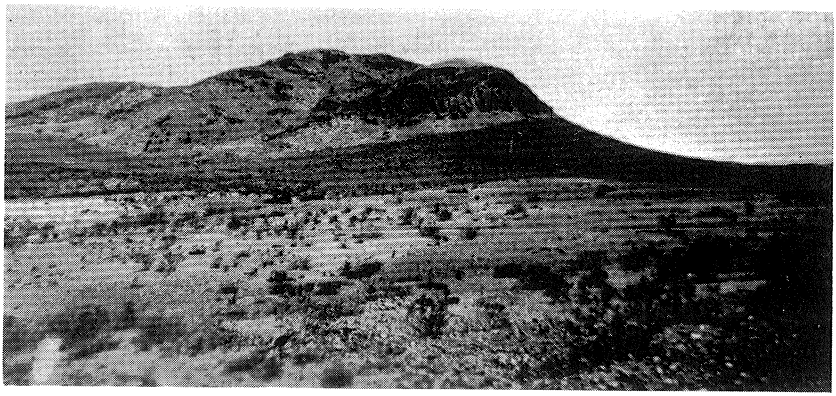

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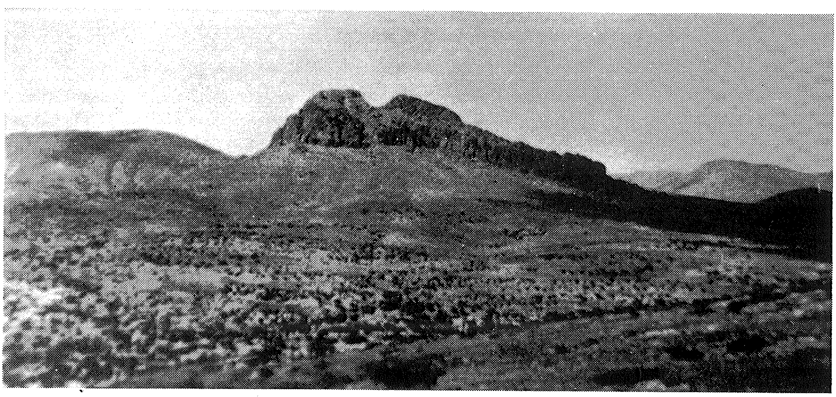

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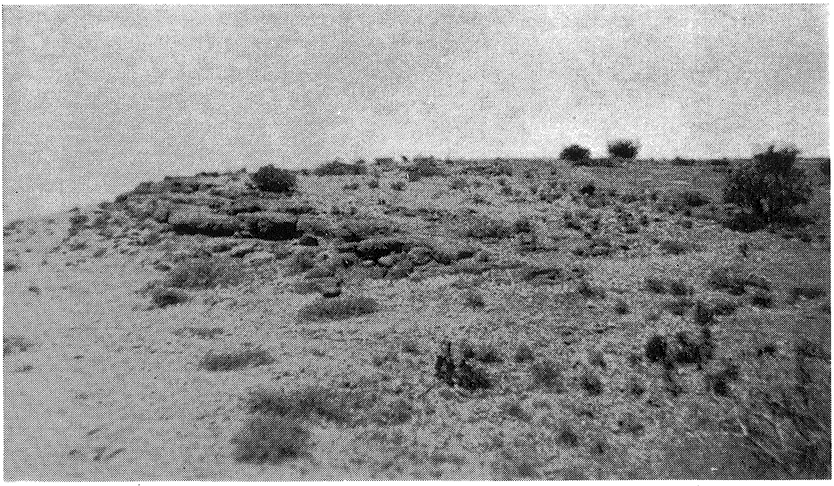
Plate 5

A. Rim Rock Mountain, capped by rhyolitic welded tuff, from the west
B. West face of Leitendorf Hills, from the northwest
C. Swallow Fork Peak, with resistant capping of North Pyramid rhyolite

A



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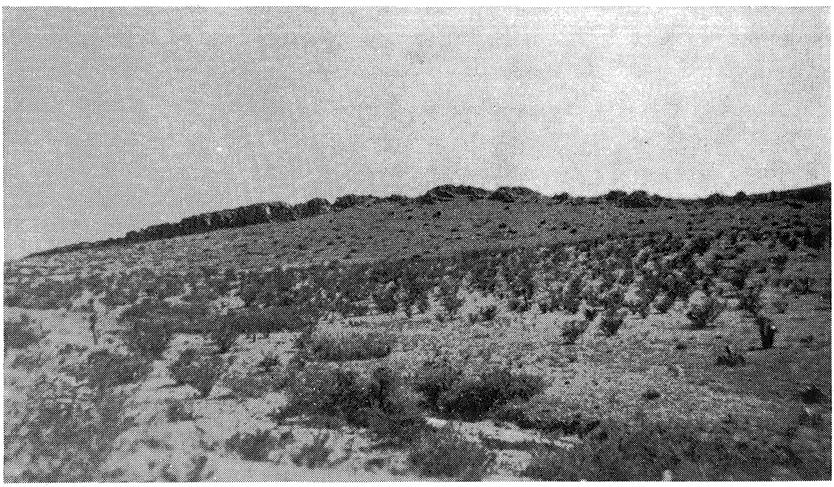


Plate 6

A. Pitchstone at base of South Pyramid rhyolite breccia

B. Resistant quartz vein of Atwood group contained phenocrysts of both calcic oligoclase and calcic labradorite. Nearly all the flows are distinctly porphyritic and are characterized by chlorite, carbonate, and some chlorophaeite as alteration products. Iron oxide is common as grains, patches, and fine dust in the matrix, and it often forms reaction rims around the ferromagnesian minerals. Veinlets and patches of secondary quartz are common; many of the irregular patches fill small amygdules and show faint banding. Many of the altered ferromagnesian minerals show a rim of iron oxide and a core of silica.

Many flows of steeply dipping brown andesitic breccia crop out north of Lightning Dock Mountain. Some of the individual layers appear to be 30 to 40 feet thick. Most lithic fragments in the breccia are of Cretaceous basalt; these fragments are generally one-half inch or less in diameter and are rounded and partly assimilated. Borders of the partly assimilated fragments are commonly marked by a rim of quartz. Much streaky brown glass is present in the groundmass, along with microlites of sodic andesine, patches of chlorite and carbonate, scarce augite grains, and dusty ore minerals.

A few thin flows of rhyolite are found throughout the sequence, mainly in the area east and southeast of Lightning Dock Mountain. Lightning Dock and Goat Mountains may represent volcanic necks marking the centers from which the andesite was erupted.

Monzonite

A small monzonite stock of early- to middle-Tertiary age, about 1 square mile in area, intrudes the pyroxene andesite in secs. 10, 11, 14, and 15, T. 25 S., R. 19 W. The stock probably has a much greater subsurface extension, as small apophyses of the monzonite crop out as much as 2 miles from the main mass. The monzonite weathers to a light tan, but fresh surfaces are light greenish gray and speckled with many green flecks of epidote, augite, and chlorite.

Ghosts of subhedral pyroxene phenocrysts 1 to 2 mm long can be seen in thinsection; the pyroxene has been entirely altered to a granular aggregate of carbonate, chlorite, and chlorophaeite. The altered pyroxene phenocrysts constitute 20 percent of the rock and are embedded in a diabasic groundmass of sericitized plagioclase (sodic andesine) and orthoclase present in subequal amounts; tiny augite grains are interstitial to the feldspars. Quartz is present in amounts of less than 5 percent. Near the margins of the intrusive, epidote, chlorite, and abundant iron oxide appear between the feldspar laths. Biotite is present in minor amounts.

Just east of Goat Canyon, on the hill of 5,240 feet elevation in sec. 11, T. 25 S., R. 19 W., contact alteration has caused the andesite to appear hornfelsic, but it nevertheless retains the texture and mineralogy of the original andesite. Augite phenocrysts as much as 2 mm long (10 percent), small hornblende crystals pleochroic from light to dark brown (3 percent), embayed and corroded calcic oligoclase and calcic labradorite phenocrysts (20 percent), and some fresh chlorite flakes are embedded in a dense matrix composed of tiny feldspar microliths, small magnetite grains, and some glass (pl. 8B). The hill on which this rock is exposed probably has a core of monzonite.

Unlike the granodiorite stock to the north, this southern stock of monzonite has very little associated mineralization. One fluorspar mine, the Animas mine, is located near the southern end of the stock, and two old silver mines, part of the Silver Tree claim 2½ miles east of the stock, may represent mineralization from this intrusion.

There is no evidence bearing on the age of this stock relative to the larger granodiorite stock in the Lordsburg mining district. Although they are rather dissimilar lithologically, it is possible that they both are early Tertiary in age. Quartz is definitely subsidiary in the monzonite, being present in amounts of less than 5 percent. The monzonite is nonporphyritic, and the plagioclase-orthoclase ratio is about 1:1. In the granodiorite to the north, quartz is present in amounts of 10 to 15 percent, the rock is porphyritic, and plagioclase greatly predominates over orthoclase. These lithologic dissimilarities suggest that the two intrusions belong to two distinct times of intrusive igneous activity.

Pyroclastic Rocks

Middle- or late-Tertiary pyroclastic rocks are exposed over an area of some 25 square miles in Lordsburg quadrangle and probably covered almost the entire quadrangle originally. The sequence is characterized by nearly 2,000 to 2,500 feet of rhyolitic tuff-breccias, rhyolitic volcanic breccias, rhyolite flows and tuffs, glassy material, and some welded material toward the top. The center of eruption for this pile of pyroclastic material is believed to have been in the near vicinity of the Leitendorf Hills.

The base of the sequence is exposed in a semicircle extending from secs. 27, 34, and 35, T. 24 S., R. 19 W., eastward to Mexican Joe's, thence southeastward and southward. The base is best exposed at Mexican Joe's, where the sequence begins with a thin series of chalky-white to very pale greenish rhyolite flows which are banded and have a dense, cryptofelsitic texture. The rhyolite is overlain by 500 to 600 feet of light-colored tuff-breccia interbedded with black discontinuous layers of vitrophyre and some bedded tuff. The layers of vitrophyre range from 5 to 20 feet in thickness, and at least 6 different layers were distinguished in the lower 400 feet of the section. The vitrophyre is a good marker and appears from place to place along the east edge of the outcrop area (that is, for 4 or 5 miles due south of Cedar Knob), in the low hills north and northeast of Mexican Joe's, and in the low hills south of Swallow Fork Peak. The vitrophyre is black, has a vitreous luster, and contains about 20 percent sodic oligoclase phenocrysts as much as 2 mm long.

The glassy base is crowded with trichites, and the index of refraction of the glass (1.496) indicates 72 percent silica (George, 1924, p. 365). In other places, this glassy material shows a hyalopilitic texture formed by broken phenocrysts of zoned and resorbed sodic oligoclase (20 percent), euhedral to subhedral augite phenocrysts (10 percent), scarce hornblende pleochroic from light to dark brown, and iron oxide grains, all set in a matrix of glass and finely crystalline devitrification products. The pyroxenes show iron oxide rims, and some have partly altered to chlorite.

Several layers of unfossiliferous bedded vitric tuff and crystal-vitric tuff are found scattered throughout the sequence. Total thickness of these tuff layers is as little as 4 feet in some places, and as much as 20 feet in others; individual layers have a distinctly bedded structure, which is due to minor textural differences. The tuff is usually white or cream colored and varies in hardness from place to place, some specimens being soft and others so indurated as to appear porcelaneous. Thinly bedded vitric tuff has been quarried at a locality just northwest of the hill of 4,907 feet elevation (about 3 miles south of the Linn ranch), where the tuff overlies Cretaceous basalt (pl. 4A). Beds of crystal-vitric tuff also crop out at localities northeast of the Dime-a-Day ranch dam at the southeastern end of the Pyramid Range, northeast of the Leitendorf Hills, and east of North Pyramid Peak.

The volcanic breccias of the pyroclastic sequence are generally massive and cliff forming. Breccias close to the middle of the sequence, exposed in the rugged hills south of Rim Rock Mountain, weather dark brown but are light brown when unweathered. They contain angular fragments (generally less than an inch in diameter) of Cretaceous basalt, andesite, and felsitic material in a dense felsitic matrix. A few agglomerate layers (containing boulders as much as 1 foot in diameter) appear from place to place in this part of the section.

Toward the top of the pyroclastic sequence, tuff-breccias that weather white to light gray to reddish are common; these are best exposed in the Leitendorf Hills (where they are locally called the Leitendorf breccia), and at Dogs Head, east of North Pyramid Peak. They contain generally small, angular fragments (less than 1 inch in length) of basalt, andesite, and felsitic material, but the matrix, unlike that of the breccias in the middle of the sequence, is tuffaceous and contains spangles of biotite and sparse crystals of feldspar and quartz. A few layers of welded tuff appear in this upper part of the sequence.

The uppermost layers of the sequence, which are best exposed on the south and southwest face of Rim Rock Mountain beneath the Tertiary basalt, consist of 75 to 100 feet of soft, white or cream tuff-breccia. Although the layers consist mainly of tuff, lithic fragments are present in sufficient quantity to justify the name tuff-breccia. The fragments average less than three-fourths of an inch in length.

Pyroclastic rocks belonging to the middle or upper part of the sequence are also exposed at the southern and southeastern edge of the quadrangle, where they consist of light-colored tuffs and tuff-breccias and a few layers of medium-brown welded tuff; erosion has not cut deep enough to expose the vitrophyre layers in the lower part of the section. Bedded tuff, which crops out near the Dime-a-Day dam (in sec. 2, T. 26 S., R. 18 W.) is pictured in Plate 4B.

A small outlier of the thin white basal rhyolite flows overlaps unconformably on the Cretaceous basalt and pyroxene andesite at a locality 3 miles southwest of the Linn ranch (just west of a patch of Cretaceous basalt shown on the geologic map). Other small outcrops of the pyroclastic rocks appear on the group of hills north of Gary siding, a few miles west of Lordsburg.

Basalt

Middle- to late-Tertiary augite-basalt and olivine-augite basalt overlie the Tertiary pyroclastic rocks and crop out over an area of about 8 to 10 square miles. The basalt is best exposed on the south face of Rim Rock Mountain and in the hills south of that mountain, where it underlies the welded-tuff sequence; it is also well exposed in the southern part of the quadrangle. Probably this basalt formed a continuous cover from Rim Rock southward and wrapped around the east side of the range, but erosion has left only isolated remnants on the east flank of the range. The most northerly outcrop appears on the southwest side of Rim Rock Mountain, where the front of the flow pinches out. The maximum thickness of the Tertiary basalt is about 150 to 200 feet. The basalt may have come from sources in the western or southern part of the Pyramid Mountains, or it might have been erupted from some source farther to the east or west.

The basalt is nearly homogeneous throughout its areal and vertical extent. A coarse breccia containing boulders of the basalt up to 1 foot in diameter (autobreccia?) is generally at the base. The basalt above the basal breccia is generally vesicular, and fresh surfaces are black to dark gray; weathered surfaces are brown to dark red and are commonly coated with iron oxide. It is crowded with nodules and veins of gnarled and banded chalcedony, which weathers out to form abundant float on the surface. Under the microscope, the basalt shows phenocrysts of augite and hypersthene as much as 2 mm long (10 percent), small laths of labradorite (40 percent), and sparse small grains of olivine (3 percent) in a hyalopilitic, vesicular matrix of clear brown glass and iron oxide dust (pl. 9A).

Rhyolitic Welded Tuff

Exposed above the Tertiary basalt is approximately 700 feet of pyroclastic rocks composed mainly of rhyolitic welded tuff. It now occupies an area of about 8 square miles but probably once covered most or all of the quadrangle, as outcrops have been observed at widely separated localities in many parts of the quadrangle. These localities include small hills in the Lordsburg Valley several miles east of the quadrangle limit; the hill of 4,435 feet elevation in sec. 16, T. 24 S., R. 19 W., on the west side of the quadrangle; the hill of 4,637 feet elevation north of Pyra siding, 4 miles west of Lordsburg; and areas in the southern part of the quadrangle.

The welded tuff is best exposed on Rim Rock Mountain, where it forms the resistant capping for that striking landform (pl. 5A). On the nose just east of the hill of 5,336 feet elevation, about 1 mile northeast of the top of Rim Rock Mountain, there is approximately 40 feet of thinly bedded, finely laminated crystal-vitric tuff between the Tertiary basalt and the welded tuff. This basal crystal-vitric tuff contains abundant quartz grains (about 30 percent) averaging 0.5 mm in size, and a few small lithic fragments. The overlying welded tuff is very massive, cliff forming, and resistant to erosion. It tends to weather spheroidally in places, as at Rock House Canyon and southward, where large parts of the surface are covered with tall pinnacles and great rounded boulders of the material. Although the medium-brown color of the weathered tuff is not uncommon, the pinkish tint of fresh surfaces is very distinctive. Fresh surfaces are decidedly "grainy" in appearance, and glittering grains of quartz, sanidine, pumice fragments, shiny biotite plates, and dark-brown hornblende crystals can be seen megascopically. Many outcrops show elongated and flattened vesicles several inches long that lie horizontally. Very few lithic fragments are present in the tuff.

The welded tuff contains fractured and broken grains of partly resorbed quartz and sanidine; resorbed sodic oligoclase containing glass inclusions; biotite altering to iron oxide; some magnetite grains and chlorophaeite; and a little hornblende, with accessory sphene and apatite. Glassy material makes up at least 30 percent of the rock, and the shards are flattened and squeezed between crystal grains; a few collapsed pumice fragments were observed (pl. 9B). Molding of the shards about crystals is not as extensive as in some of the welded tuff described by Gilbert (1938), nor are the shards squeezed into embayments in resorbed crystals. The designation welded tuff is appropriate, however, because shards are appressed between grains and the flattened shards are distinctly alined parallel to the plane of deposition. Minute quantities of tridymite have crystallized within some of the shards. Distortion and welding of the vitric fragments without fracturing is cited by Gilbert (1938, p. 1851) as evidence that the material was hot and viscous at the time of its emplacement. The welded tuff may have been deposited from nuées ardentes, or "burning clouds," filled with molten fragments of viscous magma, which rolled down the volcanic slopes and left a deposit of hot pyroclastic material, the fragments of which welded together. The location of the source of this pyroclastic material is not positively known, but the vent may have been located in the vicinity of the Leitendorf Hills.

Light-colored tuffs and tuff breccias are interbedded with the welded tuffs; some are rather soft, whereas others are well indurated.

Near the top of the welded-tuff sequence, a few thin, flow-structured, dense, dark-gray flows of andesite are interbedded with the pyroclastic rocks. A typical specimen, from the top of a hill just south of Rock House Canyon, contains corroded phenocrysts of zoned andesine (as much as 2 mm long) having thick resorption borders, set in a dense, hyalo-ophitic groundmass of tiny, subparallel feldspar microliths, specks of augite, and iron-ore dust, all in a matrix of clear glass (pl. 10A). The index of the glass is 1.530, which indicates 59 percent silica (George, 1924, p. 365). Some andesitic flows crop out on the hill of 4,637 feet elevation north of Pyra siding, west of Lordsburg. Isolated occurrences appear also in the vicinity of Wirter Canyon, east of Rim Rock Mountain, and about 1¼ miles north of the Dime-a-Day ranch dam.

The welded-tuff sequence in the south is similar to the sequence already described. Overlying the Tertiary basalt in this area is at least 800 feet of mainly rhyolitic welded tuff and tuff-breccias, having interbedded thin vitric and crystal-vitric tuff beds and thin andesitic flows. Good exposures of this welded tuff may be seen in secs. 2, 3, and 4, T. 26 S., R. 18 W.

Perlite

After the explosive outbursts that formed the pyroclastic sequence above the Tertiary basalt, the volcanic vent or vents, presumably located on the site of the Leitendorf Hills, were plugged with an intrusion of perlite. The resulting landform has several structural and physiographic features that are cited by Williams (1932) as characteristic of volcanic domes.

The perlite is exposed in a northwest-southeast band nearly 2 miles long and ranging from one-half mile to a few hundred yards in width. Two or three vents may have been alined in this zone. These exposures produce a more or less isolated ridge, rising nearly 500 feet above the surrounding countryside (pl. 5B). Remnants of the intruded material occur as isolated blocks of tuff-breccia scattered over the surface of the perlite. The presence of this material on the northeast slope of the Leitendorf Hills suggests that the structure may have been in part laccolithic. The center or centers of perlite intrusions may have been localized along the crest of the Leitendorf Hills, and some of the perlite may have broken through its confining walls and flowed southward and eastward for a short distance on the surface. Slickensides are common along fissures and joints in the perlite and indicate considerable movement after solidification. No slickensides on the margins of the dome which might indicate the formation of a spine or protrusion were seen. Evidence of autobrecciation on a small scale was seen near the southeastern part of the outcrop area.

The perlite is crossed intricately by lenses, pods, and stringers of devitrification products; some stringers show a central core of quartz. Much "stony" rhyolite is present. Some parts of the perlite show intricate and distorted flow banding. Flow structure is obscure over a large part of the area, but appears to dip generally southward from the crest of the ridge.

The perlite is typically a reddish brown to green and has a resinous luster. The index of refraction of the glass is 1.490, which indicates 75 percent silica (George, 1924, p. 365).

Quartz Latite Dikes and Plugs

Quartz latite dikes and plugs of middle- or late-Tertiary age are prominent in parts of the Lordsburg mining district; a fan-shaped swarm of these dikes is also found in the low hills south of Swallow Fork Peak. Small plugs appear in sec. 13, T. 23 S., R. 19 W., and in sec. 3, T. 24 S., R. 19 W. The dikes are generally long and narrow, and many of them extend without a break for nearly a mile. A few of the dikes are pronged, but most are simple tabular masses which at some places are strongly sheeted at the borders. Some of the dikes have been bleached white, but most are gray or medium brown. The quartz latite dikes cut all the rocks exposed in the Lordsburg mining district, and one dike (probably an extension of the swarm south of Swallow Fork Peak) crosses the perlite.

A typical specimen consists of phenocrysts of sodic plagioclase ranging from 1 to 3 mm in length, orthoclase, and numerous plates of biotite, all set in a dense, holocrystalline groundmass of quartz, orthoclase, and plagioclase. Biotite laths are altered to chlorite or carbonate, and commonly are surrounded by an envelope of amorphous silica. A few magnetite grains are present, and rare apatite and sphene are accessory. Quartz phenocrysts showing strong resorption are common in places.

North Pyramid Rhyolite Flows at North Pyramid Peak

Following the eruption of the welded tuff and the intrusion of the perlite, but prior to the rhyolite flows from North Pyramid Peak, the Pyramid Mountains were tilted to the northeast. The middle- to late-Tertiary pyroclastic breccias and welded tuffs now show a prominent dip toward the northeast, averaging about 25 degrees. During the tilting, the welded-tuff sequence on Rim Rock Mountain was broken by numerous north-south high-angle faults.

Rhyolite flows of late-Tertiary age from the volcanic neck at North Pyramid Peak cover an area of 3 or 4 square miles in the central part of the quadrangle. The flows extend for a distance of only 3 or 4 miles from North Pyramid Peak (testifying to the viscosity of the lava) and overlap the Tertiary pyroclastic rocks and Cretaceous basalt. Field relations suggest that most of the flows were funneled down between Rim Rock Mountain and the Leitendorf Hills, and then spread out to the southwest, as the rhyolite now forms a thin but resistant capping on many of the smaller hills west of Rim Rock Mountain. (See pl. 5C.) A similar resistant capping is seen on the low hill north of North Pyramid Peak.

Rhyolite forming the neck and associated flows is medium brown on the weathered surface and light tan on the fresh surface, and has phenocrysts of feldspar in an aphanitic groundmass. Outcrops weather to low rounded forms and characteristically have a hackly surface. A typical specimen contains zoned, corroded sodic to intermediate andesine phenocrysts (1 to 2 mm long), having undulatory extinction, rare, tiny euhedral pyroxene grains, and small laths of biotite altering to iron oxide, all set in a dense holocrystalline base of quartz and orthoclase. Glomeroporphyritic groups of feldspars are common. Subordinate magnetite grains, apatite, and rare zircon are accessory. The rhyolite contains small veinlets and irregular patches of quartz.

South Pyramid Rhyolite Breccia at South Pyramid Peak

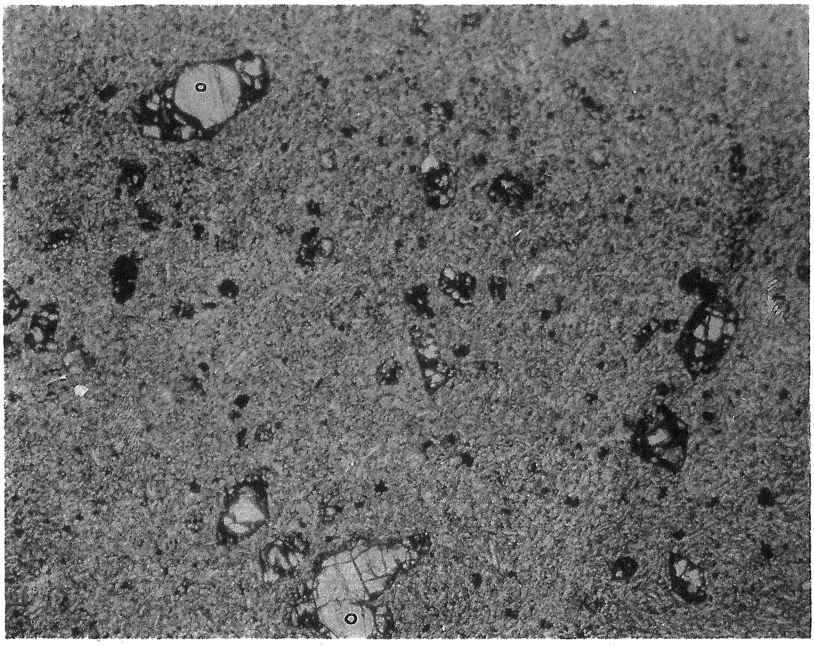
Rhyolite breccias of late-Tertiary age, probably derived from the neck at South Pyramid Peak, crop out east and west of that peak over an area of 6 square miles and overlap the late-Tertiary pyroxene andesite. This light-tan breccia is recognized very easily because it has a distinct hackly weathered surface and appears as low rounded topographic forms. The lithic fragments are generally small (about one-half inch in average diameter) and include angular pieces of basalt, andesite, and felsite. The thickness of the breccia is estimated to be 500 feet, on the basis of measurements of poorly exposed sections.

Nearly everywhere the base of the breccia is marked by a layer of pitchstone ranging from 8 to 15 feet in thickness (pl. 6A). The pitchstone contains phenocrysts of sodic oligoclase and is cut by many thin veinlets of devitrified glass; some of the veinlets and stringers have a quartz center. The index of refraction of the glass (1.495) indicates 73 percent silica (George, 1924, p. 365).

A typical specimen of rhyolite breccia contains lithic fragments (mainly of basalt and andesite) up to one-half inch long in a streaky groundmass composed almost entirely of glass containing phenocrysts of quartz, sodic oligoclase, and biotite. The glassy matrix is strongly flow banded and spherulitic (pl. 10B). Near the base, the breccia appears to be welded, for shards are flattened and slightly molded around lithic fragments and mineral grains. Many of the lithic fragments are embayed, and some are enclosed in a sheath of quartz. Scattered patches of tridymite, formed by devitrification of glass, appear in the matrix.

The relations between the breccia in the vicinity of South Pyramid

A



B

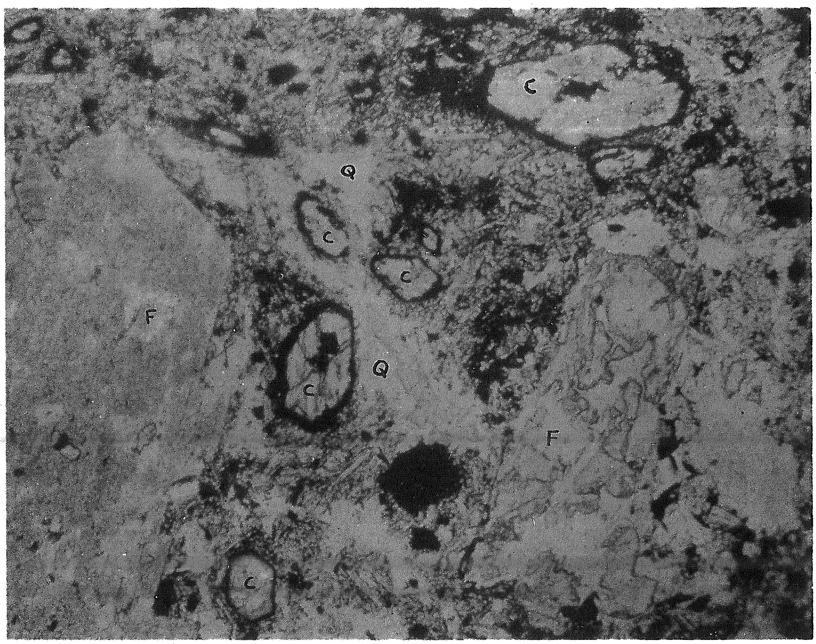
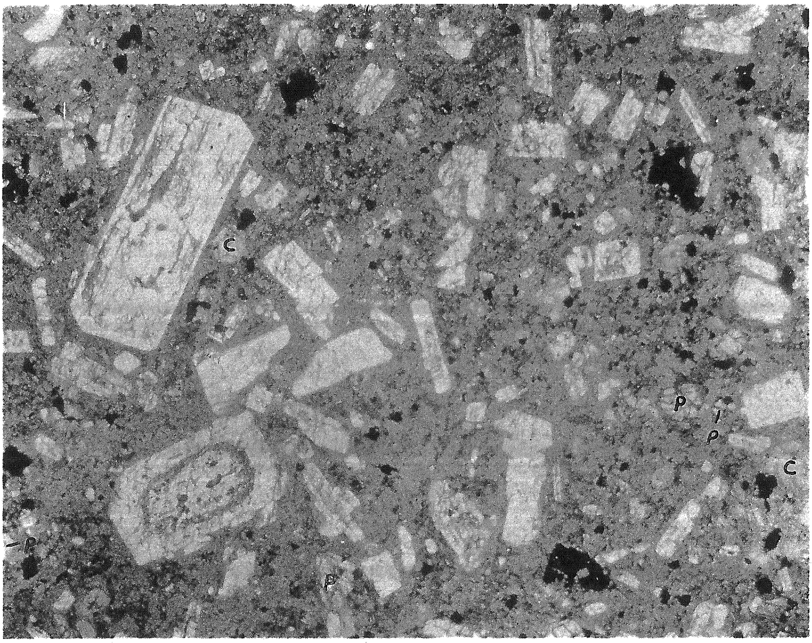


Plate 7. Photomicrographs of Cretaceous basalt.

A



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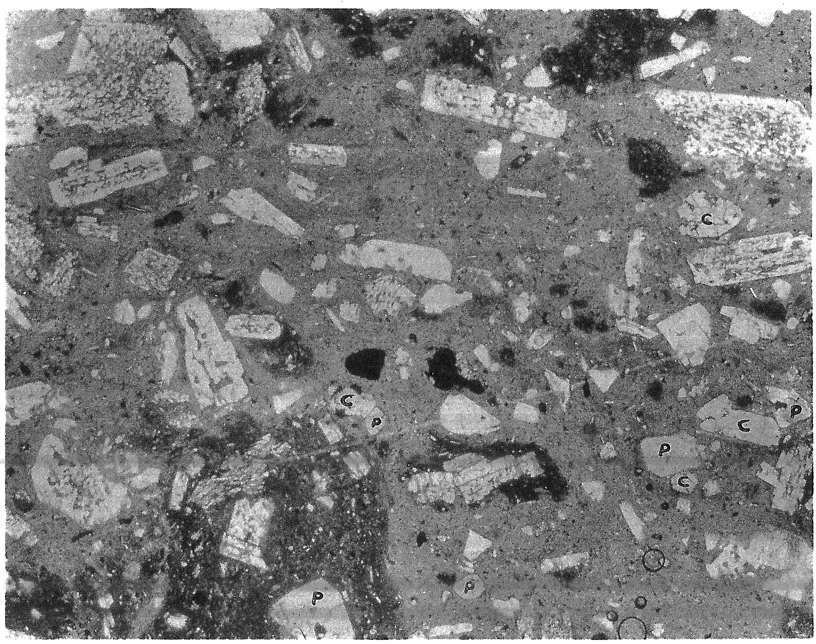
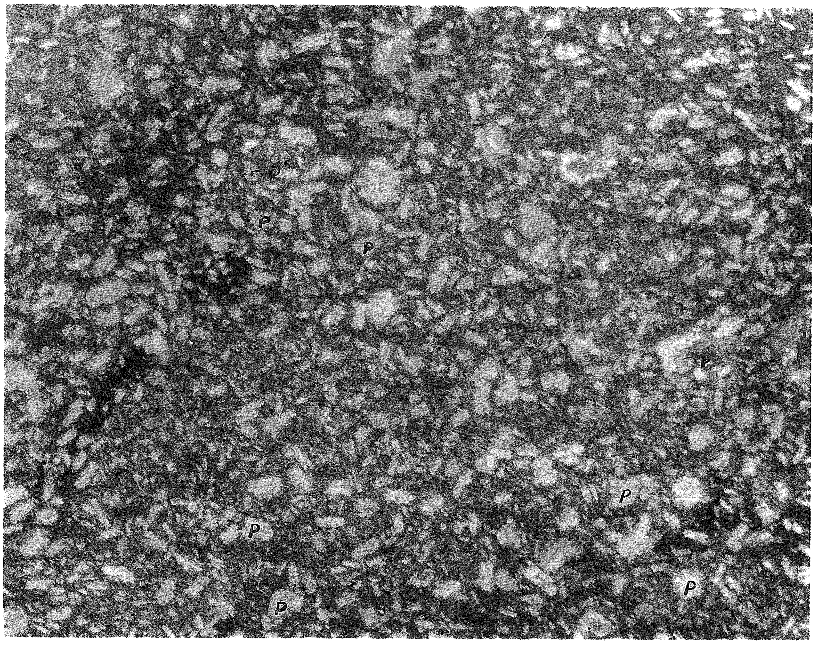


Plate 8. Photomicrographs of Tertiary pyroxene andesite.

A



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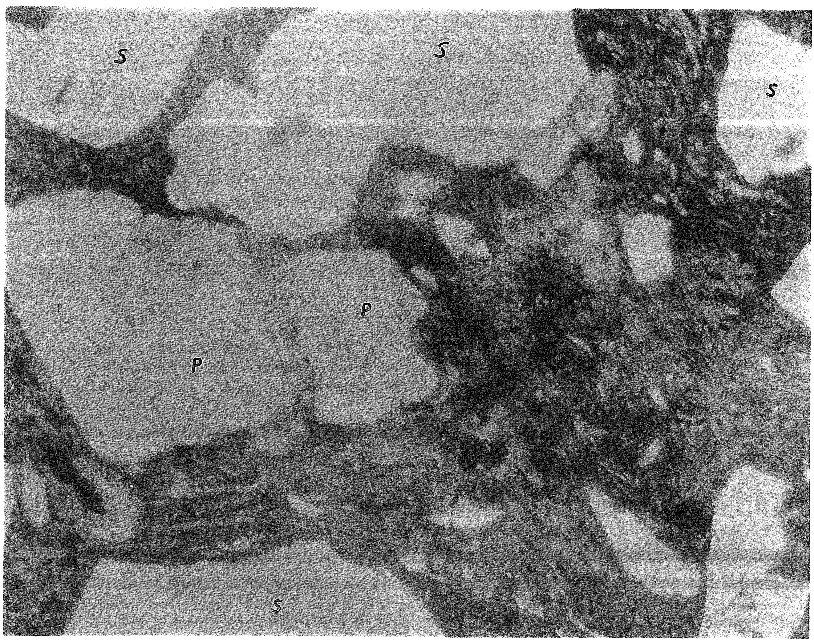
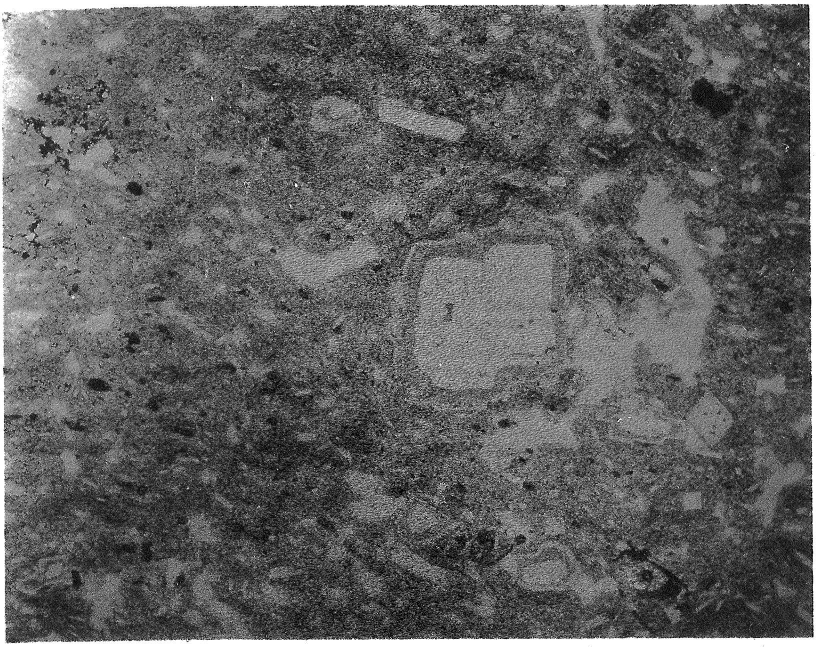


Plate 9. Photomicrographs of (A) Tertiary basalt and (B) rhyolitic welded tuff.

A



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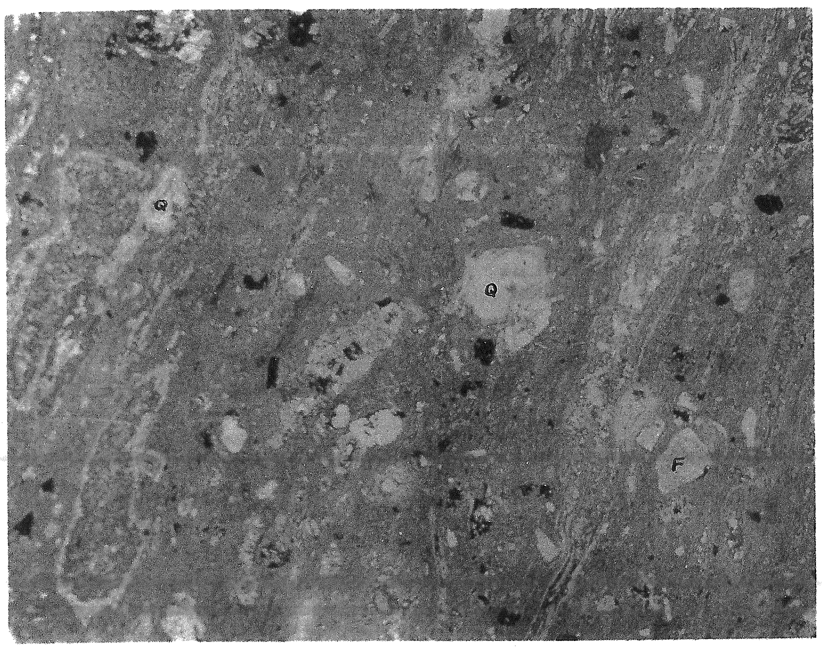


Plate 10. Photomicrographs of (A) andesite interbedded in rhyolitic welded tuff sequence and (B) South Pyramid rhyolite breccia.

Peak and the rhyolite at North Pyramid Peak are obscure. It is possible that they are nearly contemporaneous.

Rhyolite Dikes and Plugs

Late-Tertiary rhyolite dikes and plugs intrude all older rocks exposed in Lordsburg quadrangle. Because all these dikes and plugs are very similar lithologically, they are believed to represent a single intrusive episode. The dikes and plugs are pure white and commonly silicified, and some show mild autobrecciation at the borders. The dikes are commonly more resistant than the host rocks; they often rise several feet above the surface as low narrow ridges. Outcrops characteristically weather into a mass of small platy fragments. The rock is typically a cryptofelsite; feldspar phenocrysts are lacking or definitely subsidiary.

One east-west string of dikes, nearly 4 miles long and made up of 9 different segments, extends across the Pyramid Mountains west of South Pyramid Peak. A swarm comprising 12 to 15 dikes is seen 3 miles east of Lightning Dock Mountain, and several rhyolite dikes are exposed farther northward in the Lordsburg mining district. Small plugs of rhyolite are scattered over the mining district, and one conical hill of rhyolite nearly one-fourth mile in diameter is surrounded by valley fill in secs. 12 and 13, T. 26 S., R. 20 W. The rhyolite on this hill contains small grains of quartz and plates of biotite in a cryptofelsitic matrix.

Quaternary Rocks

Stream Gravel and Valley Fill

Stream gravel and valley fill, ranging in thickness from a feather edge to at least 250 feet, are found in the desert basins surrounding the Pyramid Mountains. In general, the thickness increases gradually from the mountains toward the central part of the basins. In the Lower Animas Valley, the thickness of the alluvium is variable because of the great topographic irregularity of the underlying bedrock surface; bedrock outcrops projecting up through the valley fill are common in the axial portion of the south part of the Lower Animas Valley.

In general, the shallow alluvial material becomes progressively finer grained toward the central part of the basins. Near the mountains, the alluvium consists of a heterogeneous mixture of boulders, gravel, sand, and some fine-grained material; in the axial portion of the basins, however, fine-grained detritus is prevalent at the surface. An alkali flat with an area of 15 square miles occurs in the northern part of the Lower Animas Valley.

The alluvial contact on the flanks of the Pyramid Mountains ranges in elevation from 4,400 to 4,700 feet. Gravel-filled arroyos project well back into the hills, however, and the range appears to have been nearly buried by alluvium in the vicinity of the low pass west of the Linn ranch.

Summary of Geologic History

The geologic history of the Pyramid Mountains is recorded by intrusive and extrusive igneous rocks emplaced during 4 main periods of volcanic activity and 2 main periods of intrusive activity. Although the general sequence of igneous events is known, it should be emphasized that the dates applied to these events are at best only estimates.

The earliest period of volcanic activity is recorded by about 2,000 feet of dark-gray to red basalt flows which are presumed to be Lower Cretaceous. The intrusion of plugs of breccia and rhyolite into the basalt probably marked the close of the earliest period of volcanic activity. In late-Cretaceous or early-Tertiary time, these Cretaceous basalts were intruded by a stock of granodiorite (which represented the first main period of intrusive activity), and the mineral veins of the Lordsburg mining district were formed.

Following a period of erosion, a sequence of about 1,000 feet of andesitic flows and breccias was erupted in early-Tertiary time. A basal agglomerate of this sequence contains large boulders of the Cretaceous basalt, blocks of Precambrian granite, and huge blocks of Pennsylvanian Magdalena limestone. Following the eruption of this sequence, the andesites were intruded by a small monzonite stock in early-Tertiary time, which represented the second main period of intrusive activity.

After a rather long period of erosion, an episode of violent explosive activity resulted in the accumulation of from 2,000 to 2,500 feet of rhyolite flows, tuffs, tuff-breccias, welded tuffs, basalt, and several layers of vitrophyre. This activity probably took place during middle- or late-Tertiary time. Toward the close of this episode, the glass-cored volcanic dome of the Leitendorf Hills was formed. Quartz latite dikes and plugs were then emplaced.

After regional tilting to the northeast, the latest period of volcanic activity ensued, with the formation of about 500 to 600 feet of rhyolitic flows and breccias, probably derived from the volcanic necks of North and South Pyramid Peaks. Following the extrusion of these flows and breccias, rhyolite dikes and plugs were injected into the country rock.

Recent basalt flows are not exposed in Lordsburg quadrangle, but Quaternary basalt resting on valley fill has been described by Schwenessen (1918, p. 85) in the Lower Animas Valley a few miles west and south of the quadrangle.

Moderate compression, with the formation of a broad low anticline, and extensive high-angle block faulting took place in the area in late-Tertiary time.

Petrogenesis

The general sequence of lavas erupted in Lordsburg quadrangle is as follows: (1) Cretaceous basalts, (2) pyroxene andesite, (3) rhyolitic pyroclastic rocks, (4) Tertiary basalt, (5) rhyolitic welded-tuff sequence, and (6) rhyolitic flows and breccias of North and South Pyramid Peaks.

Thin flows of rhyolite are interbedded in the Cretaceous basalt and Tertiary andesite, and thin flows of andesite are interbedded in the welded-tuff sequence. The total thickness of the volcanic sequence, about 7,000 feet, is distributed as follows: Cretaceous basalt, 2,000 feet; pyroxene andesite, 1,000 feet; rhyolitic pyroclastic rocks (volcanic breccia, tuff-breccia, tuff, rhyolite flows, and vitrophyre), 2,500 feet; Tertiary basalt, 200 feet; rhyolitic welded-tuff sequence, 800 feet; rhyolitic flows and breccias of North and South Pyramid Peaks, 500 feet.

The volumes of the various sequences, based on their probable original distribution in the quadrangle, are estimated as follows: Cretaceous basalt, 15 cubic miles; pyroxene andesite, 3 cubic miles; Tertiary basalt, 0.5 cubic mile; middle- to late-Tertiary pyroclastic rocks (rhyolitic pyroclastic sequence and welded-tuff sequence), 18 cubic miles; rhyolitic flows and breccias of North and South Pyramid Peaks, 1.5 cubic miles. The volume of andesitic and rhyolitic material exceeds the volume of basalt, and in all the volcanic rocks above the Cretaceous basalt, the volume of andesitic and rhyolitic material, as compared to the volume of accompanying basalt, is excessive.

Without chemical analyses, it is impossible to determine whether the Cretaceous basalt is of tholeiitic or olivine basaltic type. Kennedy (1933, p. 241) has listed the following criteria as characteristic of the olivine basaltic type: The essential minerals are olivine, augite, basic plagioclase, and iron ore, the pyroxene being a diopsidic or basaltic augite; residual quartz-free interstitial material of alkaline nature may be present. The essential minerals of basalt of the tholeiitic type (op. cit., p. 241) are pyroxene (enstatite-augite or pigeonites of small axial angles), basic plagioclase, and iron ore; olivine is absent or subordinate, and the interstitial acid residuum may be glassy but is dominantly quartzo-feldspathic.

Tholeiitic basalt may contain in many instances an abundance of zeolites, chlorophaeite, chlorite, carbonates, and chalcedony, testifying to the activity of late magmatic solutions that were charged with silica, carbon dioxide, soda, and lime. Primary quartz may be present. On the other hand, olivine basalt rarely contains primary quartz; when present, it is rounded and embayed and surrounded by reaction rims of glass, tridymite, and augite.

Some features of the Cretaceous basalt may be diagnostic in determining its type. Quartz is commonly found as phenocrysts, and Lasky

(1938, p. 11) has found quartz in the basalt "surrounded by a 'fence' of closely packed grains of augite"; olivine is present, but is definitely subordinate; much chlorite, carbonate, and brown chlorophaeite is present; amorphous silica is common; residual glass is present densely charged with iron oxide; the pyroxene present is augite with large 2V; feldspathoids are absent. As can be seen, there are mineralogical properties characteristic of both the tholeiitic and olivine basaltic types. However, on the basis of the scarcity of olivine, the absence of feldspathoids, and the presence of much chlorite, carbonate, amorphous silica, and chorophaeite, the Cretaceous basalt is assigned tentatively to the tholeiitic type of basalt.

Whether or not the volcanic sequence of Lordsburg quadrangle was derived by differentiation from a parent basaltic magma is open to question. As stated before, the volume of andesitic and rhyolitic material is excessive. It is surprising that such great quantities of rhyolitic and andesitic material have been erupted with but little accompanying basalt. Furthermore, widely different types of flows are intimately associated and interbedded; e. g., andesite flows appear within the welded-tuff sequence, thin rhyolites are interbedded with the Tertiary pyroxene andesite and Cretaceous basalt, and basalt is found in the middle- to late-Tertiary pyroclastic sequence.

Larsen et al. (1936, 1937, 1938) have listed the following mineralogical peculiarities of the San Juan rocks which cannot be correlated with simple magmatic differentiation, but rather indicate mixing of magmas in the course of the evolution of that volcanic sequence: (1) The presence of markedly different varieties of plagioclase phenocrysts mutually associated in any one flow; (2) corroded quartz and sanidine are present in many of the basalts and andesites and are mantled with pyroxene or plagioclase; and (3) the composition of plagioclase phenocrysts shows little relation to the chemical composition of the rocks in which they occur.

Several of the mineralogical peculiarities described by Larsen et al. for the San Juan rocks were observed in the volcanic rocks of Lordsburg quadrangle. Augite-rimmed quartz phenocrysts are found in the Cretaceous basalt; sodic to intermediate andesine phenocrysts are found in the North Pyramid rhyolite; plagioclase phenocrysts of calcic oligoclase and calcic labradorite are found mutually associated in the Tertiary pyroxene andesite.

The petrogenesis of the volcanic rocks of Lordsburg quadrangle is not attributed to simple fractional crystallization of primary basaltic magma because: (1) The great volume of rhyolitic and andesitic material relative to the small volume of accompanying basalt is anomalous; (2) the intimate association of widely different types of flows, such as rhyolite interbedded in basalt or andesite, andesite interbedded in rhyolite, or basalt interbedded in rhyolite, suggests independent origin and uprise of two kinds of magma; and (3) the mineralogical peculiarities of the rocks suggest mixing of magmas, rather than simple differentiation of a primary basaltic magma.

The origin of the great volume of andesitic and rhyolitic material, the intimate association of varied types of flows, and the mineralogical peculiarities of the volcanic rocks of Lordsburg quadrangle are attributed tentatively to differential fusion of basaltic or other rocks beneath or within the sialic layer, where downward thickening of the sialic layer accompanies crustal folding. Such fusion may be accompanied by the development of andesitic and rhyolitic magmas either by complete or partial fusion of rocks of varied composition. If folding is active, segregation of the magmas and mixing and blending of the magmas en route to the surface are possible, thus accounting for the mineralogical peculiarities and the intimate association of varied types of flows. These processes, as pointed out by Turner and Verhoogen (1951, p. 223), modified by differentiation wherever magma temporarily is held in a closed reservoir, may be complex enough to account for the wide variations observed in the surface eruptive products.

The granodiorite and monzonite stocks, normally associated with the "plutonic" association of Kennedy (1938, p. 25-28), may be compared genetically to the volcanic sequence of Lordsburg quadrangle. Tyrell (1955, p. 419) has pointed out that in the basalt-pyroxene andesite-hornblende-mica-andesite-dacite-rhyolite series characteristic of some orogenic zones and times, basalt is subordinate in the series. Pyroxene andesites are dominant, and in some regions acid lavas and tuffs are nearly as abundant as the andesites. The lava series, ranging from pyroxene andesite to rhyolite, has the same chemical composition, the same geological and geographical distribution, and the same tectonic environment, and appears at the same stage of the tectono-igneous cycle as the plutonic series, ranging from quartz diorite to granite. If the latter are parts of a plutonic association, then it is logical that the andesite-dacite-rhyolite series is also. Tyrell (1955, p. 420) states:

> . . . if the volcanic association consists predominantly of basaltic lavas with their differentiates, together with subordinate coarse-grained intrusions of "plutonic" type, there is no reason why the predominatingly coarse-grained, more or less "acid," subjacent intrusions should not give rise to subordinate series of volcanic rocks corresponding to them in chemical range.

Structural Geology

The Cretaceous basalt flows and fragmental rocks and most of the Tertiary pyroxene andesites contain no features that indicate their structural attitude. Dips and strikes can be observed here and there, but they show no general trends and probably are only reflections of the underlying topography.

Some of the breccia layers in the Tertiary pyroxene-andesite sequence north of Able Seep show a change in strike from nearly east-west to northwest, with the dip remaining toward the north in all cases. Possibly this may be due to regional tilting or to the effect of underlying topography when the flows were extruded; no evidence of a fault origin for this feature is seen here.

Dips and strikes in the middle- or late-Tertiary pyroclastic rocks and welded tuffs show some general trends. On Rim Rock Mountain and in the low hills just to the south, the dip is generally northeastward. This attitude is thought to be the result of late-Tertiary tilting toward the northeast. On the east side of the range, toward the south, the Tertiary pyroclastic rocks have a general, uniform eastward dip toward Lordsburg Valley. This may be due in large part to the effect of underlying topography.

At the south end of the range, moderate compression in late-Tertiary time formed a broad, low anticline trending northwest-southeast. Dips on the flanks of the fold at the southwest and southeast corners of the Pyramid Range can be observed; they are on the order of 20 to 25 degrees on both limbs. Toward the axis of the fold, the dips are more obscure and unreliable, owing to faulting. Perhaps a possible extension of this fold may account for the drilling for oil a few miles southward.

The anticline is broken into a number of blocks by an intricate pattern of high-angle faults; the faulting probably resulted from collapse and settling of the arch after folding. It is difficult to determine whether the faults are normal or reverse. In general, it may be said that the faults fall into two main sets, one trending east and northeast, and the other trending northwest to nearly north. Probably both sets were nearly contemporaneous; north-south faults can be seen displacing east-west faults and vice versa. Sometimes it is impossible to determine which came first. When the fracturing and faulting took place, there must have been a jumble of blocks all moving independently; many of the faults show a so-called "scissor" movement in that the upthrow and downthrow sides change along the strike of the fault. Some faults are seen to decrease in displacement along the strike until they die out. Several of the faults are 2 or 3 miles long and have displacements of a few hundred feet, but the majority are of much smaller displacement.

The precise age of the faults in the southern part of the quadrangle is not known, but they certainly are later than the South Pyramid rhyolite breccia; probably they were formed in latest Tertiary time.

Another zone of principally north-south faults is found south and east of Kirk Peak and is probably an extension of the zone farther south. On Rim Rock Mountain, the welded-tuff sequence is broken by a number of north-south, high-angle faults which probably were incurred during the late-Tertiary tilting of the welded tuffs. One fault seen in cross-section was vertical; the others, from their relation to topography, seem nearly so. Displacements on most of the faults near Rim Rock Mountain are rather small (100 feet or less), but one fault nearly 3 miles long, about three-fourths of a mile east of the top of Rim Rock Mountain, has a displacement of nearly 500 feet.

Economic Geology

COPPER, GOLD, SILVER, LEAD, AND ZINC

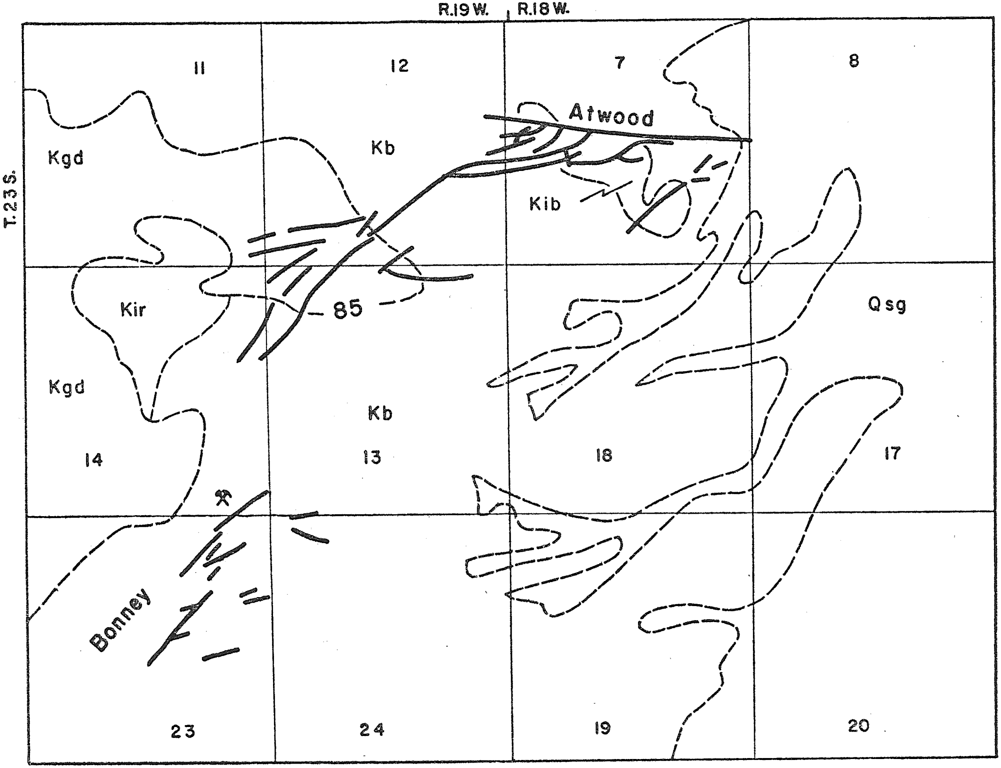
The history, development, and geology of the mines of the Lordsburg district up to 1935 has been discussed in detail by Lasky (1938). Since 1933, most of the mines in the district have been shut down; some sporadic activity has taken place subsequently, but the only mine that has produced continuously since 1935 is that owned by the Banner Mining Co. In the summers of 1953 and 1954, when surface mapping of Lordsburg quadrangle was carried on, the only mining in the district was at the Banner mine and on the Atwood group of veins (surface operations); all the other mines in the district were shut down and inaccessible and had been so for some time. Consequently, only a summary of the geology of the mines, much of which is taken from Lasky (1938), will be given here, together with a review of developments since 1935.

The ore deposits of Lordsburg quadrangle are located in two contiguous subdistricts, both of which lie in the northern part of the Pyramid Mountains. The Lordsburg mining district (formerly known as the Ralston, Shakespeare, or Virginia mining district) is situated in that part of the Pyramid Range lying north and west of the Animas Road. It covers approximately 20 square miles. The Pyramid (Leitendorf) district lies south of the Animas Road and just north of the Leitendorf Hills, and covers approximately 1½ square miles.

In general, it may be said that the Lordsburg district is a copper camp, and that the Pyramid (Leitendorf) district is a silver camp. Both districts, however, have produced some gold, lead, and zinc.

The veins of the Pyramid (Leitendorf) district occur in the Cretaceous basalt and are genetically related to those of the Lordsburg district. Shipments from most of the mines consisted of lead-silver-gold ore and silver ore low in copper and lead. Ore minerals were cerargyrite, argentite, native silver, chalcopyrite, and galena in a gangue of quartz, calcite, and wall rock. Prior to 1931, when the mines shut down, the value of total production from the district is thought to have been on the order of $1 million. Since 1931, operations have been intermittent and of small consequence. In the summer of 1954, a small shaft was opened on one of the veins near the Leitendorf mine, in the NW¼ sec. 1, T. 24 S., R. 19 W., and several truckloads of silver ore were shipped to a smelter at El Paso. The vein pinched out at a shallow depth, however, and operations were suspended after 2 months.

The copper deposits of the Lordsburg mining district are of the copper-tourmaline type; the veins lie along fault fissures. Most of the veins occur in the Cretaceous basalt, but those at the Eighty-Five mine are found in the granodiorite stock (fig. 2). Prior to 1932, when the



Qsg	Valley fill	Kib	Intrusive breccia	Kir	Intrusive rhyolite
Kgd	Granodiorite	Kb	Basalt	⚒	Banner mine

Figure 2

SKETCH MAP OF PART OF THE LORDSBURG MINING DISTRICT, SHOWING LOCATION OF THE BONNEY, EIGHTY-FIVE, AND ATWOOD GROUPS OF VEINS. (Modified after Lasky, 1938)

Eighty-Five mine was shut down, it had been the largest producer in the district and was the deepest in the state, with a total vertical depth of 2,250 feet.

The second largest producer in the district prior to 1935 was the Bonney mine. In June 1935, the Banner Mining Co. purchased the Bonney mine. A flotation plant was constructed, and milling began in August 1936. Since then the company has consolidated several other properties, including the Misers Chest, Manilla, Oro Alta, Anita, Mikesell, Last Chance, Goodsight, and Nellie Gray, all of which include over 2,000 acres. Production has been continuous since 1935, except for a short work stoppage in 1948.

The main vein on the Banner property is the Bonney vein, which is exposed at the surface for 3,000 feet. It averages 5 to 6 feet in width, but may become as wide as 30 feet. The strike of the vein is about N. 50° E., dipping 70 degrees northwest in the upper part of the Banner mine, but becoming nearly vertical with depth. The vein filling consists of massive quartz and altered quartz-seamed country rock containing stringers of chalcopyrite and pyrite. The percentage of copper is estimated at about 2.6 percent (E. S. Bowman, personal communication).

Since 1935, the mine has been deepened from 600 to 1,500 feet, and diamond drilling below this level indicates that ore is present to at least 1,600 feet (E. S. Bowman, personal communication). The vertical extent of the vein is confined to the Cretaceous basalt wall rock. The amount of gold and silver decreased rapidly from the upper levels, as did the percentage of silica gangue, which was 75 percent near the surface and 45 percent at the 1,500-foot level.

The mill uses a simple flotation circuit, and the recovery is good. The tails run 0.09 percent copper and 0.09 ounce of silver (Mining World, 1943). The concentrates, shipped to the smelter at El Paso, run 27 percent copper, 9 ounces of silver, and a trace of gold (Mining World, 1943). For a number of years, the Banner mine produced 350 tons of ore a day, but in 1954 production was about 200 tons a day. Since 1935, the Banner mine has produced about 1,750,000 tons of ore (E. S. Bowman, personal communication).

The veins of the Atwood set (fig. 2) tend to form prominent, wall-like outcrops that stand many feet above the surface (pl. 6B). In 1931, when the Atwood mine was shut down, development had been carried to a depth of 792 feet. The Atwood veins lie along the south side of the intrusive breccia which forms Atwood Hill. The veins trend east-west and are largely silicified rock containing copper, gold, silver, and lead; veins are localized either in the basalt or at the contact of the basalt and intrusive breccia.

A preliminary examination of the Lordsburg mining district in 1942 by C. H. Johnson (Huntington, 1947, p. 1), engineer with the U. S. Bureau of Mines, showed that a substantial tonnage of siliceous copper ore that could be mined and processed might be developed on the Atwood group of claims. Exploration of the district was begun by the Bureau in October 1942 and completed in June 1943 (Huntington, 1947). A substantial amount of new ore was discovered. The lessee of the Atwood group, C. H. McIntosh, drove a crosscut to a copper-lead-zinc vein found in the course of the exploration and began production. From 1943 through the first 11 months of 1947, this new ore body in the Atwood group produced 60,580 tons of ore, which contained 0.058 ounce of gold, 5.64 ounces of silver, 1.12 percent lead, and 2.2 percent copper per ton (Storms, 1949; figures quoted are average values).

In 1951, the Atwood mine of C. H. and S. A. McIntosh was leased by Ira L. Mosely, and crude copper, silver, gold, and lead ore was shipped to a smelter at El Paso. In July 1954, Ira L. Mosely started surface operations (by blasting and bulldozing) on the Wilson claim of the Atwood group. The Atwood vein at this locality forms a resistant ledge standing 4 to 8 feet high. The ore is shipped to El Paso and averages 0.70 to 0.80 percent copper, very little gold or silver, and small amounts of lead and zinc (Ira L. Mosely, personal communication).

The total value of copper, gold, silver, and lead from the Lordsburg mining district from 1904 through 1935 was $19,527,248 (Lasky, 1938, p. 28). From 1936 through 1951, the total value of copper, gold, silver, lead, and zinc from the district has been $12,894,662. Since 1904, when complete production figures were first available, the Lordsburg district has produced copper, gold, silver, lead, and zinc worth $32,421,910.

The following table shows the annual production of the district since 1935:

PERLITE

Commercial deposits of perlite in Lordsburg quadrangle are found in the Leitendorf Hills, 8 miles southwest of Lordsburg. This resistant material is largely responsible for the relief of the Leitendorf Hills, which stand about 500 to 600 feet above the surrounding country. The perlite crops out in a northwest-southeast band nearly 2 miles long and from one-half mile to a few hundred yards wide; the area of outcrop is approximately 1 square mile. The volume of perlite included in this area is estimated very conservatively at 30 million cubic yards.

The perlite is typically greenish to dark reddish brown, with a resinous luster. It shows distinct flow structure and is jointed and cut by thin devitrification bands and pods and stringers of "stony" rhyolite. The occurrence of this worthless stony rhyolite undoubtedly has contributed to the fact that the perlite has been developed only intermittently and for short periods of time. The operators are often faced with the necessity of blasting out the stony material before further shipments of perlite can be made. When too much of such material is encountered, the operations are suspended.

TABLE 2. PRODUCTION OF GOLD, SILVER, COPPER, LEAD, AND ZINC IN THE LORDSBURG MINING DISTRICT, HIDALGO COUNTY, N. MEX., 1936-1951 *

YEAR	ORE (short tons)	GOLD (fine oz)	SILVER (fine oz)	COPPER (pounds)	LEAD (pounds)	ZINC (pounds)	TOTAL VALUE
1936	21,279	1,306	28,612	816,150	52,900		$ 145,396
1937	74,752	2,143	75,196	3,807,890	53,200		597,077
1938	112,157	3,402	134,849	6,346,300	113,200		833,403
1939	116,331	4,230	131,471	6,367,900	6,000		899,835
1940	126,670	2,225	76,770	6,555,300	77,900		877,111
1941	121,145	1,270	63,886	7,467,300	48,000	12,000	974,657
1942	123,397	1,257	90,803	6,715,100	224,400	113,600	946,693
1943	110,963	1,440	82,350	4,991,900	113,800	41,500	770,924
1944	132,707	2,316	113,739	4,717,400	292,800	78,000	831,106
1945	84,773	1,411	90,336	2,292,800	337,200		452,151
1946	54,729	1,582	100,963	2,392,000	215,000		547,887
1947	70,893	1,845	185,561	3,539,300	530,400		1,052,139
1948	68,481	1,683	165,256	3,415,000	158,000	138,000	996,161
1949	81,640	1,981	149,312	3,868,000	683,000	51,000	1,080,704
1950	73,349	714	92,816	4,122,100	171,100	8,000	990,624
1951	72,107	755	89,610	3,041,000	287,300	31,000	898,794
Totals	1,445,373	29,560	1,671,530	70,455,440	3,364,200	473,100	$12,894,662

* Production figures compiled from the *Minerals Yearbook,* 1936-1951.

Desultory perlite quarrying was carried out in the Leitendorf Hills during the summer of 1953. One quarry, located toward the center of the outcrop band in sec. 12, T. 24 S., R. 19 W., was opened in the early summer, and operations were suspended (perhaps temporarily) in August. Another quarry, located in the eastern part of the outcrop area, was opened in June 1953. Roads were constructed to the locality, and a site was cleared for a loading dock on a railroad spur 1 mile southeast of Lordsburg. Operations, however, were suspended shortly thereafter; no perlite was ever mined or shipped. A third perlite quarry is located in sec. 1, T. 24 S., R. 19 W.; it was not in operation during the summers of 1953 and 1954.

FLUORSPAR

Several mines in the Pyramid Mountains have produced fluorspar, but they were shut down and inaccessible in 1953 and 1954. The Animas fluorspar mine located at the foot of Lightning Dock Mountain, in sec. 15, T. 25 S., R. 19 W., developed a fissure vein in the Tertiary pyroxene andesite to a depth of 300 feet. The vein contained fluorspar, quartz, and black calcite, and ranged from 4 to 10 feet in thickness. The ore averaged 63 percent fluorspar (Rothrock et al., 1946, p. 105). Work was discontinued at this mine in 1943.

The Fluorite Group prospects are situated northwest of the Leitendorf Hills, in sec. 34, T. 23 S., R. 19 W., and secs. 2 and 3, T. 24 S., R. 19 W. They explore a series of fissure veins in the Cretaceous basalt, composed mainly of fluorspar, quartz, and calcite. Ore removed from these veins averaged 60 percent fluorspar (Rothrock et al., 1946, p. 106). The veins varied in width from 3 inches to 3½ feet.

Smaller deposits of fluorspar have also been worked in the Lordsburg mining district.

AGATE

Agate "thunder eggs" from the Tertiary pyroxene andesite have been mined in the NW¼ sec. 5, T. 26 S., R. 18 W. There are no data available concerning this mining, but it is obvious that the site has been abandoned for many years. The operation must have been by simple stripping, for several shallow pits are found within a circle of 100 yards radius. The agate is found as nodules and geodes, and is gray and faintly banded.

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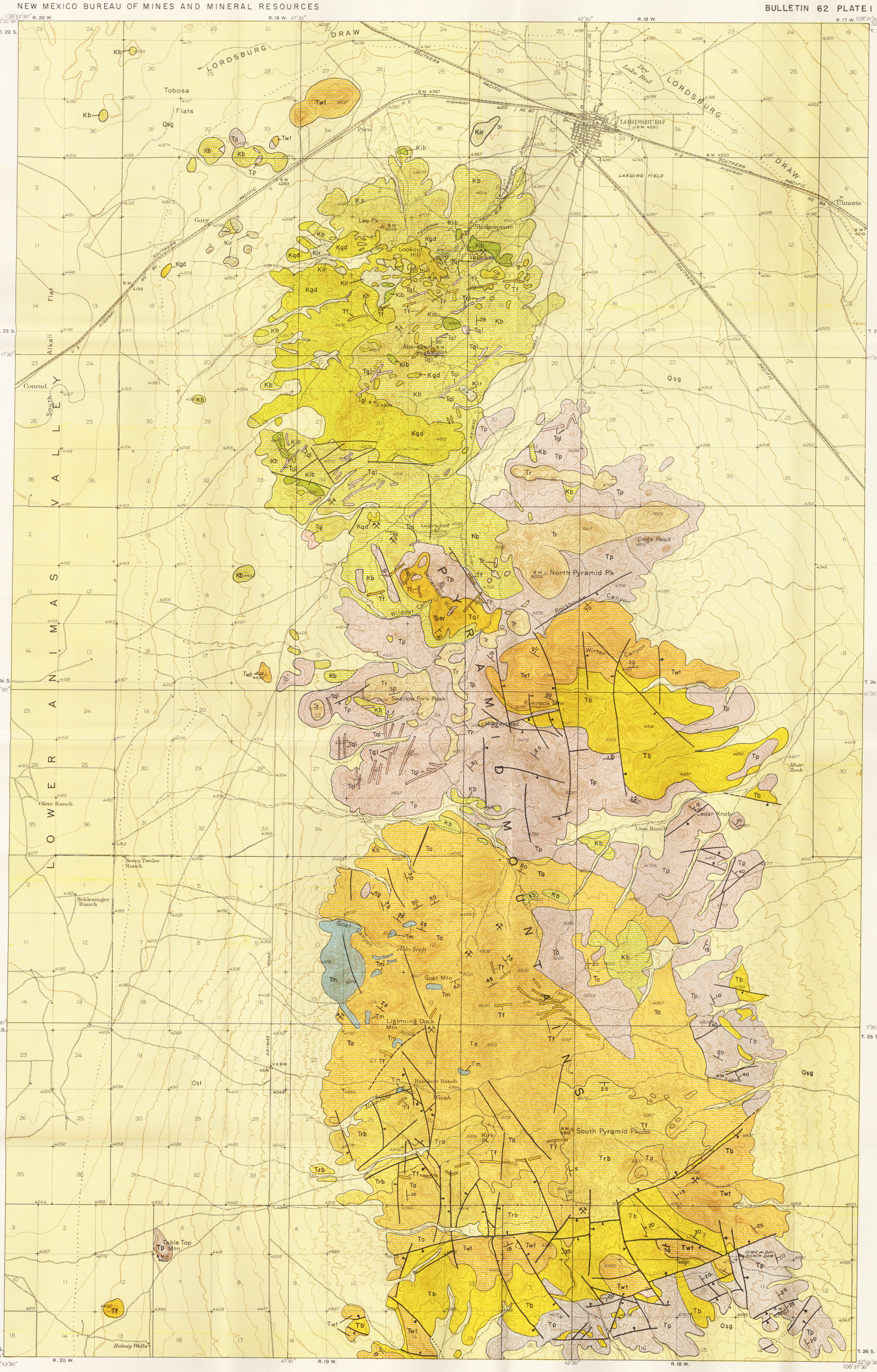


EXPLANATION

QUATERNARY

Pleistocene & Recent

- Qsg — Stream gravel and valley fill

TERTIARY

- Tf — Felsite (Rhyolite dikes and plugs)
- Trb — South Pyramid rhyolite breccia
- Tr — North Pyramid rhyolite
- Tql — Quartz latite dikes and plugs
- Tper — Perlite (With stony rhyolite)
- Twt — Rhyolitic welded tuff
- Tb — Augite and olivine-augite basalt
- Tp — Pyroclastic rocks (Breccia, tuff, rhyolite, and vitrophyre)
- Tm — Monzonite
- Ta — Pyroxene andesite

CRETACEOUS

Upper

- Kgd — Granodiorite

Lower

- Kir — Intrusive rhyolite
- Kib — Intrusive breccia
- Kb — Augite and olivine-augite basalt

Geologic contact

Fault, showing downthrown side

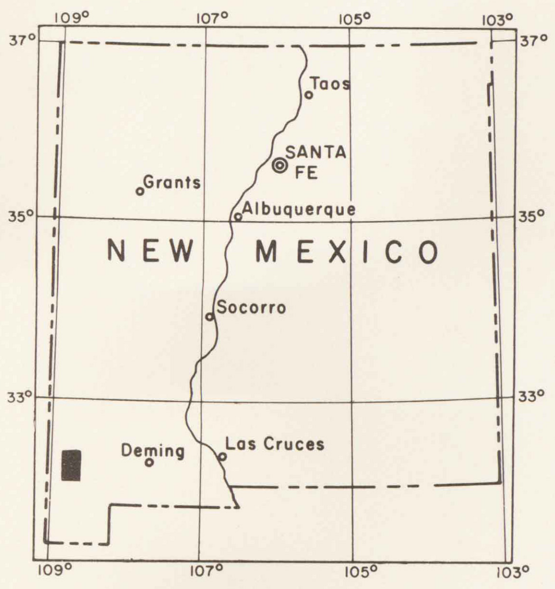
Shorelines of ancient Lake Animas

Strike and dip of beds

Mines or prospects

True North / Magnetic North

APPROXIMATE MEAN DECLINATION, 1952



Index map showing Lordsburg quadrangle

Base map from U.S. Geological Survey Lordsburg quadrangle, New Mexico

Geology by R. Fred Flege, Washington University. Surveyed 1953–54 as part of a Field Assistance Fellowship Program

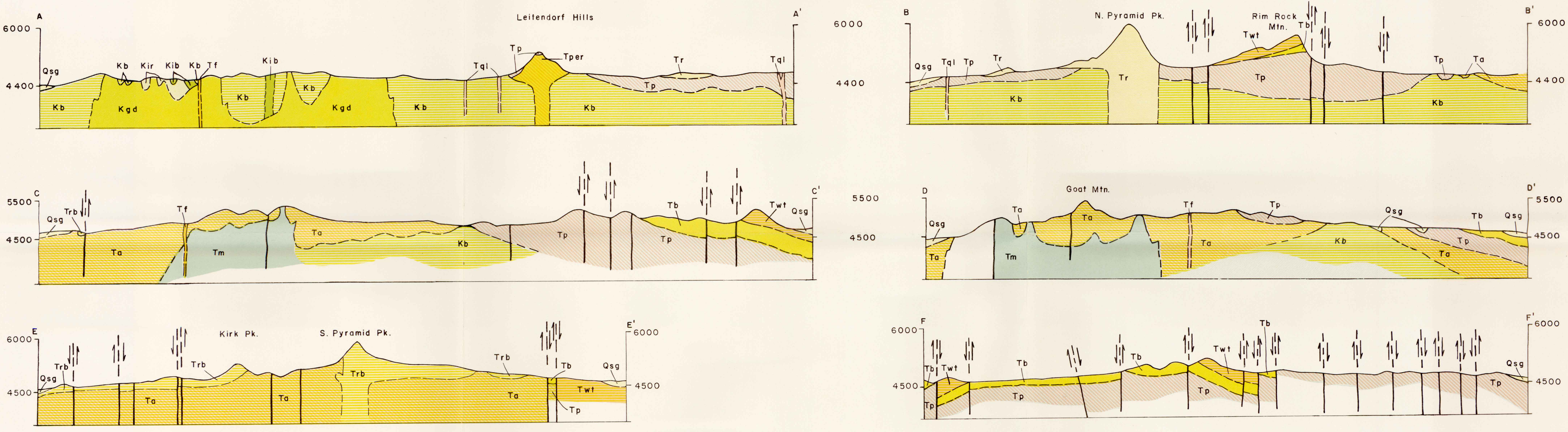
GEOLOGY OF LORDSBURG QUADRANGLE, HIDALGO COUNTY, NEW MEXICO

Scale $\frac{1}{62500}$

1 0 1 2 3 4 Miles

Contour interval 25 feet

Datum is mean sea level



FOR EXPLANATION SEE PLATE I

GEOLOGIC SECTIONS ACROSS LORDSBURG QUADRANGLE

Horizontal scale: I inch = I mile

Vertical scale: I inch = 2000 feet