GEOLOGIC AND GEOCHEMICAL INVESTIGATIONS OF GEOPHYSICAL ANOMALIES, SIERRA RICA HIDALGO COUNTY, NEW MEXICO

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by

Peter M. Van Der Spuy

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A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science. (Geology)

Signed: Peter M. Van Der Spuy
Peter M. Van Der Spuy

Golden, Colorado
Date: April 13th, 1970

Approved: Harold Bloom
Harold Bloom
Thesis Advisor

H. C. Kent
Head of Department

Golden, Colorado
Date: __________, 1970

ABSTRACT

The Sierra Rica is located on the United States-Mexico border in southwestern New Mexico. It is separated from the surrounding mountain ranges by alluvium-filled valleys. Lithologies range in age from Ordovician to Holocene. Paleozoic rocks exposed in the Sierra Rica are allochthonous and occur as klippen. Autochthonous rocks in the Sierra Rica are of lower Cretaceous age. The 8500-foot succession of Lower Cretaceous rocks consists of 3500 feet of predominantly carbonate rocks overlain by 5000 feet of quartz sandstones and siltstones; subdivided into the U-Bar Formation and Mojado Formation respectively. The Lower Cretaceous rocks are unconformably overlain by allochthonous Paleozoic limestones, Tertiary and Quaternary volcanics, or Quaternary alluvium.

The Sierra Rica was structurally deformed prior to the emplacement of igneous rocks. Compressive stresses operating in a southwest-northeast direction caused folding and thrusting. Tensional stress which post-dated the compressional stress caused high-angle normal faulting in the Sierra Rica.

Mafic volcanics occur in the northeastern part of the Sierra Rica. They are surrounded by alluvium and, apart from containing plugs of younger acidic volcanics, exhibit

no contact relationships. Granite outcrops in the southeastern part of the Sierra Rica are petrologically similar to early-Tertiary granites in the Little Hatchet mountains. The high-angle normal fault which transects the Sierra Rica has been intruded by a ridge-forming latite dike. Granite xenoliths in the latite dike establishes their relative ages. Rhyolite porphyry dikes and flows of indeterminate age occur to the north of the Sierra Rica and a number of rhyolite plugs and associated pyroclastics occur, principally along the southern flank of the range. The pyroclastics are partly covered by basalt which is petrologically similar to the Quarternary basalts common throughout southwestern New Mexico.

In the southeastern part of the Sierra Rica impure carbonate rocks have been metamorphosed to pyritic calc-silicate tactites which contain some molybdenite. The intrusive granite is responsible for the metamorphism. The clastic sediments of the Mojado Formation have been silicified to quartzites. The silification was probably caused by siliceous groundwaters rising from a buried intrusive.

Lead-zinc and minor copper mineralization occurs in the Sierra Rica as fracture filling and limestone replacement.

An airborne magnetic survey of the Sierra Rica delineated a northwesterly-trending magnetic anomaly. A gravity survey delineated an anomaly similar in shape and trend to the magnetic anomaly. An induced polarization survey conducted over the Sierra Rica resulted in a linear anomaly which has the same trend as the gravity and magnetic anomalies. All of these anomalies are sub-parallel to the strike of the sediments. They suggest that the Sierra Rica may be underlain by an intrusive with associated sulphide mineralization.

Rock samples from the Sierra Rica were analyzed for heavy metals and molybdenum. The data obtained from these samples verified the presence of exposed mineralization, but did not locate areas of mineralization or leakage which were not previously known. Residual soil samples were collected. No leakage halos were detected, however. Stream sediment samples were successful in outlining the areas of lead mineralization. A geobotanical anomaly was noted; ocotillos (Fouquiera family), which normally grown only on limestone or calcareous gravels, were observed growing in profusion on fractured quartzites.

This study was initiated and supported by Phelps Dodge Corporation, who undertook all the goephysical work. It was hoped that a geologic and geochemical investigation of the Sierra Rica would explain the causes of the geophysical anomalies. The geologic investigation led to the conclusion that the magnetic and gravity anomalies were probably caused by a large granitic intrusive underlying the Sierra Rica. The geochemical investigation did not detect leakage from possibly concealed heavy-metal sulphides. It therefore seems possible that the I.P. anomalies could have been caused by metamorphosed carbonaceous siltstones or contact metamorphic calc-silicates which may have some associated pyrometasomatic base-metal sulphides.

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INTRODUCTION AND ACKNOWLEDGMENTS

The Sierra Rica was first proposed as an area for thesis study by Prof. Harold Bloom of the Colorado School of Mines. Mr. George Rogers, Chief Geophysicist of Phelps Dodge Corporation, had brought the area to the attention of Prof. Bloom. As part of their continuing geological and geophysical reconnaissance in southwestern New Mexico, Phelps Dodge Corporation has gathered regional magnetic and gravity data over the last five years. The results of these data in the Sierra Rica area motivated the Corporation to undertake an induced polarization survey in 1968. This survey resulted in a number of anomalies which could not be explained by geologic data available at that time. The object of this study was to collect geologic and geochemical data over an area of 49 square miles in an attempt to establish the cause of geophysical anomalies. The study was sponsored by Phelps Dodge Corporation who supplied the necessary financial aid, field and laboratory equipment, and facilities.

Eleven weeks were spent in the field. After an initial visit to the area in December 1968, the writer spent 10 weeks in the area during June, July, and August 1969, during which time geologic mapping was completed and geochemical samples were collected. Four weeks were spent in the Phelps Dodge geochemical laboratory immediately following the field season. During this time petrographic work and geochemical analyses were undertaken.

Aerial photographs from the Soil and Conservation Service, U.S. Department of Agriculture, were used for mapping in the field. The photographs, flown in 1957-58, are 9 x 9-inch contact prints at an approximate scale of 1:20,000. Data plotted on individual photographs were transcribed to a controlled photo-mosaic at a scale of 1:24,000. A transparent topographic film at the same scale was then overlaid on the mosaic. In this manner data were transferred to the final map. The scale of the geologic map is 1:12,000. The base map is an enlargement of the 1:62,500 topographic map of the area, surveyed in 1917-18. Section corners, bench marks and U.S.A.-Mexico international boundary posts were used for control.

The writer wishes to express his sincere appreciation to Mr. Ray Ludden, Chief Geologist, and Mr. George Rogers, Chief Geophysicist, Phelps Dodge Corporation, for initiating and supporting this study. Thanks are due to Mr. Richard Geer for his continuous encouragement, and to Dr. S. A. Williams and his colleagues in the Phelps Dodge geochemical laboratory for providing information and cooperation during all stages of geochemical data handling.

The writer also wishes to thank those people whose assistance proved invaluable; Mahlon T. Everhart and family of the Hatchet Ranch, who provided accomodation, assistance, and much valuable information; Vivienne van der Spuy, without whose assistance this study would not have been possible; and to those people, too numerous to mention individually, connected with Phelps Dodge Corporation in Douglas, Arizona, who helped the writer in one way or another.

The writer is indebted to Professor Harold Bloom for suggesting this study and for his assistance in acting as liason between the writer and Phelps Dodge Corporation. Finally, the constructive criticism of Professors Bloom, Epis, and Dover are acknowledged as important contributions to this thesis.

PREVIOUS WORK

Little geologic work, other than reconnaissance has been carried out in the Sierra Rica. Lindgren (1910) described the mineralization in one of the mines within the area. Darton (1928) included the area in his geologic map of New Mexico. Lasky (1947) described the geology and ore deposits of the Little Hatchet Mountains, to the west of the Sierra Rica, and separated from the Sierra Rica by the Hatchet Valley. Some of his data are relevant to the area under review. Strongin (1958) described the geology and ore deposits of the Apache Hills and northern Sierra Rica. Although his work was concentrated in the Apache Hills, it provides useful information regarding the mines and prospects, contact metamorphism, and the possible mode of ore emplacement in the Sierra Rica. Zeller (1958) described the geology of the Big Hatchet Peak quadrangle, the northeasternmost corner of which includes part of the Sierra Rica. Zeller (1965) also described the stratigraphy of the Big Hatchet Mountains area. As regards the geology of this part of New Mexico, Zeller's latter paper is probably the most significant to date, having provided invaluable information concerning the stratigraphy and paleontology of the region. On the basis of his data, he has been able to describe the stratigraphy of the Big Hatchet Mountains area.

GEOGRAPHY

Location and Accessibility

The Sierra Rica forms a low group of hills in the eastern part of Hidalgo County, New Mexico. The range crosses the United States-Mexico international border where the border changes from an east-west to a southward direction (Fig. 1). The area may be reached from Interstate 10 by taking New Mexico State Route 81 which leaves the Interstate approximately midway between Deming and Lordsburg. This highway is paved as far south as Hachita, the nearest settlement to the area under review. According to a 1950 census, Hachita had a population of 250. At that time it still served as a station on the Southern Pacific Railroad and was an active shipping point for cattle. However, with the abandonment and removal of the railroad in 1964-65, the population decreased rapidly. At the present time the population is estimated at about 25 persons. A saloon, at which gasoline can be purchased, and a Post Office, are the only places of business. Highway 81 continues southward from Hachita, past the Apache Hills, Sierra Rica, Little Hatchet Mountains and Big Hatchet Mountains, to Antelope Wells, on the Mexican border, approximately 35 miles south of Hachita. From Hachita southward the road is unpaved,

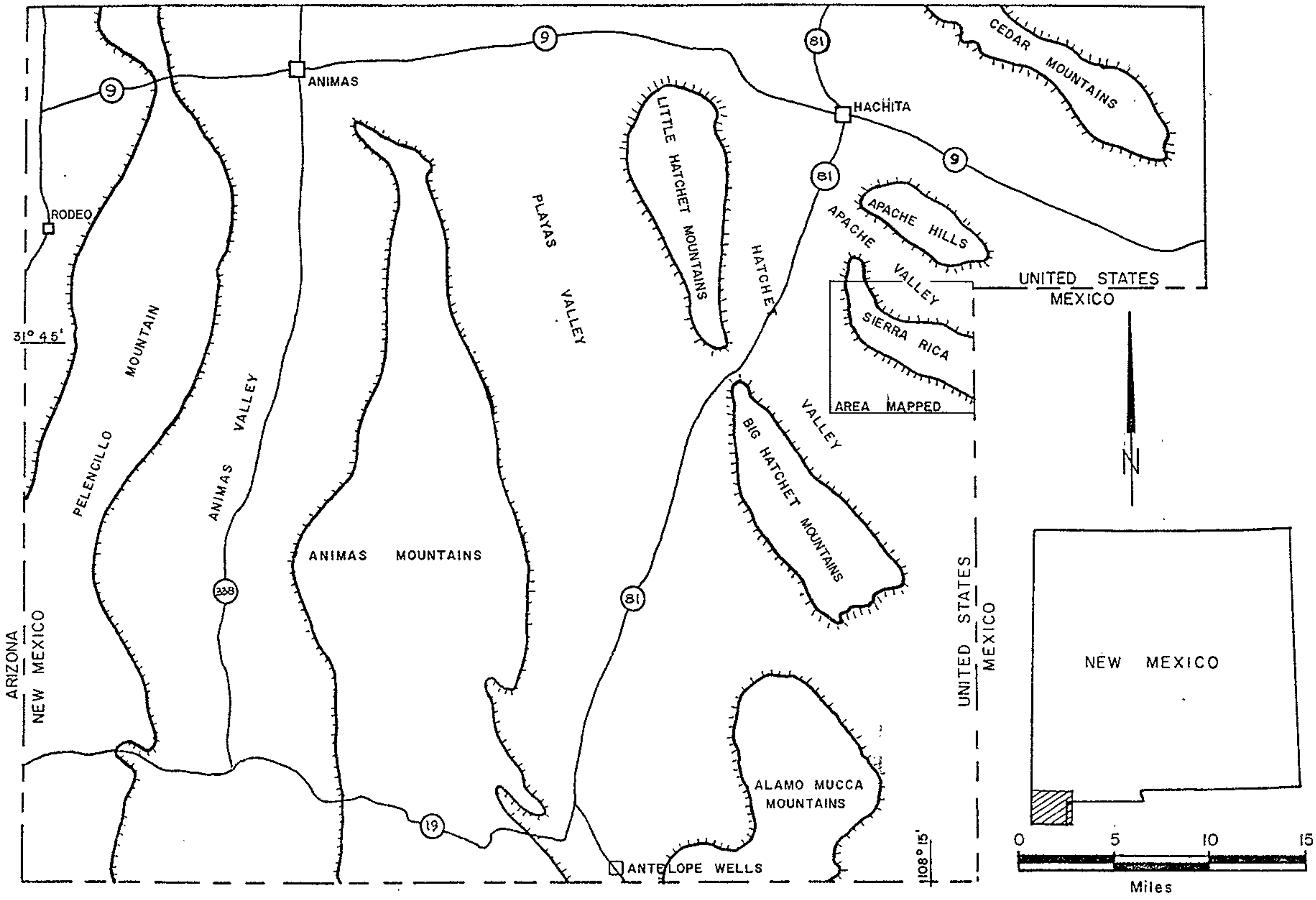

Fig. 1 Location map of the Sierra Rica, and main geographic features of southwestern New Mexico

but is maintained in very good condition by the New Mexico State Highway Department.

The Sierra Rica, which is the northeastern part of the Hatchet Ranch, may be reached by a ranch road leading east from highway 81 South, 12 miles south of Hachita. Roads and trails within the area under investigation have been updated and plotted on the geologic map (pl. 1). Excepting for the eastern part of the area, in the proximity of the international border, the roads are in good condition and a normal vehicle can traverse them with ease. Due to washouts and steep gradients, a four-wheel-drive vehicle is required in the eastern part of the area. The possibility of flash floods causing washouts during the summer makes it advisable for vehicles to carry equipment such as shovels and jacks at all times. Furthermore, during the summer months, a good supply of drinking water should be carried.

Relief and Elevations

The Sierra Rica forms a low range of hills about nine miles long and one to three miles wide. The range trends north-northwest in the northwest part of the area mapped, and west-northwest in the eastern part. The southwestern flank of the range consists of ridge-and-valley topography, with streams incised perpendicular to the strike of the sedimentary formations. The remainder of the range consists of rounded hills for the most part, giving an impression of gentle topography. The mean elevation of the range is about 5100 feet. This portion of New Mexico lies within the Basin and Range Province of the western United States. Middle to late Tertiary taphrogenic adjustments have resulted in young block mountains separated by alluvium-filled grabens. The Hatchet Valley, which separates the Sierra Rica topographically and geologically from both the Big Hatchet and Little Hatchet Mountains, is probably the trace of a major "Basin and Range"-age fault plane. Figures 1 and 2 illustrate the physiography of the area.

The maximum relief in the Sierra Rica is 1200 feet with respect to the Hatchet Valley, and 800 feet with respect to the Apache Valley. This is in sharp contrast to the Big Hatchet Mountains, a few miles to the southwest of the Sierra Rica, which have a topographic relief in excess of 4000 feet.

Drainage

The Hatchet Draw, which runs to the west and south of the area mapped, is the principal drainage of the area. It follows the Hatchet Valley and is typical of the playa drainages in the southwestern United States. The main drainage in the area mapped is Doyle Creek which drains the Apache Valley, rising in Mexico and draining westwards into

Figure 2. Panoramic view of the Sierra Rica, looking northwards from south of the Hatchet Draw near the United States-Mexico border. 1 = Doyle's Peak, 2 = high peak in sec. 36, T.29S., R.14W.

the Hatchet Draw. The northern slopes of the Sierra Rica drain into Doyle Creek, and the southern slopes into the Hatchet Draw. Except for the Hatchet Draw and Doyle Creek, all the drainages exhibit flood-wash characteristics; unsorted detrital material with a negatively skewed particle size distribution. The size of boulders in many of these small drainages testifies to the high energy conditions which must prevail for short periods of time.

Climate

Physiographically this part of New Mexico lies within the Sonoran Desert. The annual precipitation measured at the Hatchet Ranch over a number of years averages about 11 inches. However, individual years show wide variation, from 1 inch to 18 inches having been recorded. The rains normally commence in mid-July, lasting until early September; precipitation takes the form of late-afternoon and evening thunderstorms, frequently violent in nature. A local resident described one such storm in which eight inches of rain fell in a half-hour. Storms such as this would, no doubt, be responsible for the mass-transportation of material observed in the drainages. The thunderstorms are usually localized, favoring the higher elevations. Precipitation at Doyle's Well is significantly greater than at the Hatchet Ranch, although the former is only about

400 feet higher than the latter.

During the summer months afternoon temperatures frequently rise above 100°F, but generally fall below 80°F at night. Incipient thunderstorm clouds and gentle breezes often reduce the intensity of the heat in the afternoons. Winters are dry and cool, with daytime temperatures around 65°F and often falling below freezing point at night. The low annual precipitation, coupled with the high summer temperatures has led to the development of a calcareous environment. Residual soils are usually slightly to moderately calcareous, while valley-fill alluvial gravels and pediments are very calcareous. A caliche crust has developed in the gravels and pediments. This caliche varies in thickness from a few inches to tens of feet.

Flora and Fauna

The low mean annual precipitation supports an arid-climate vegetation. Grass cover is generally sparse. Greasewood (*Larrea tridentata*) is the most common shrub and does not appear to be selective with respect to geology, water-availability or soil type. Mesquite bushes are scattered in a random fashion, but seem to favor thick alluvium and sand. Dense thickets of mesquite occur on alluvial gravels in the southwestern part of the area mapped. Wild Walnut and Chinaberry trees grow in the larger flood-wash drainages close to the international boundary. Occasional stunted pinon pines occur in the hills. They do not grow on the alluvial gravels. Ocotillos (Fouquieria family) characteristically grow on limestone bedrock, although they occur on alluvial gravels and pediments with an apparently random distribution. Anomalous concentrations of ocotillo were noted over fractured quartzites in a few localities.

Fauna includes species common to the Southwest: rattlesnakes, packrats, buzzards, scorpions, solipugids, tarantulas, lizards, coyotes, rabbits, deer and javalinas.

Economy

Owing to the scarcity of water and the calcareous nature of the environment, the region is not suited to crop farming. Cattle ranching is the sole form of agricultural economy. Mining in the region was sporadic between the late 1890's and the early 1950's. Mines in the Little Hatchet Mountains, Apache Hills and Sierra Rica exploited base metals with associated silver and gold. Metallization took the form of hydrothermal veins, massive replacement in limestones and contact metasomatic deposits. None of the properties have been operated since 1953.

Considerable interest has been shown in the area by both petroleum companies and mining companies in the last decade. Two wildcat wells were drilled, one to a depth of 12000 feet (sec. 25, T.32S., R.16W.) and the other to a depth of 3000 feet (sec. 12, T.30S., R.15W.). The latter well adjoins the area mapped. Much seismic work has been undertaken in addition to gravity, magnetic and induced polarization surveys. The mapped area lies in a region which appears favorable both from the point of view of its petroleum potential and the possibility of porphyry-type copper deposits.

Electric power is supplied to the area by the Rural Electrification Administration. Power in the form of natural gas is available from the El Paso Natural Gas Company pipeline which runs east-west, 10 miles north of Hachita.

ROCK UNITS

General Features

Of 49 square miles investigated, about 24 square miles are covered by alluvium. The Sierra Rica forms a belt of continuous outcrop whereas outcrops in the Apache Valley occur as irregular windows in the alluvium. On the southeastern and western sides of the Sierra Rica a few windows in the alluvium expose bedrock. The alluvium, which is partly pediment and partly valley-fill gravel, becomes very thick as one proceeds southward from the hills toward the Hatchet Valley. This is indicated by the gravity values (see pl. 4). The alluvium in the Apache Valley consists mostly of outwash material from the Sierra Rica and the Apache Hills and probably does not exceed a thickness of more than a few hundred feet.

The rocks exposed in the mapped area range in age from Ordovician to Recent. Ordovician, Mississippian, Pennsylvanian and Permian rocks occur as allochthonous thrusts and klippen. Thrusting appears to have been from the south and southwest where these rocks are autochthonous. The predominant lithologic units in the area are carbonates and terrigenous sediments forming a sedimentary succession about 8500 feet thick. On the basis of paleontologic evidence, these sediments have been dated as early Cretaceous. They constitute the bulk of the Sierra Rica. Apart from alluvium, no sediments younger than early Cretaceous in age were observed in the area mapped.

Igneous rocks, both intrusive and extrusive, have invaded the sediments. The igneous rocks range in composition from basaltic to rhyolitic. Intermediate to acidic varieties predominate, however. Intrusive rocks include granite, quartz latite, latite porphyry, felsite, lamprophyre, and rhyolite porphyry. Except for the granite, these rocks occur as dikes, sills and plugs. Extrusive igneous rocks include basalt and andesite-porphyry flows, latite and dacite flows, rhyolite flows, and rhyolite tuffs and breccias. Very few data are available for the relative age dating of these igneous rocks. They are younger than the early Cretaceous sediments which they intrude, and older than the recent alluvium. Composition and texture, field relations both from within and outside the area mapped, xenoliths, and topographic expression of the igneous rocks were factors used in differentiating and assigning relative ages to these rocks.

A contact-metamorphic aureole is exposed in the southeastern part of the Sierra Rica. Calcareous rocks have been metamorphosed to lime-silicate tactites, and quartzose rocks have been silicified. Outcrops of granite are exposed within the metamorphic aureole and are probably responsible for the metamorphism. The quartzose rocks of the Mojado formation have been silicified throughout the Sierra Rica, probably by heated groundwaters rising from unexposed intrusives (aero-magnetic and gravity data presented later in this report support the idea that the area is underlain by intrusives).

Table 1 is a summary of the rock units in the area described in this report, following Zeller's (1965) formally proposed nomenclature. Table 2 illustrates the correlation of stratigraphic units pertaining to this portion of New Mexico.

Ordovician

El Paso and Montoya Formations

Rocks of the El Paso and Montoya Formations are exposed as klippen, principally in secs. 31 and 32, T.29S., R.14W., in the low hills about one mile north of the Dishpan Tank. No Precambrian or Cambrian rocks were found in the Sierra Rica.

Other exposures occur in secs. 10 and 15, T.30S., R.14W., in the vicinity of the Badger Tank.

Imbricate thrusting and incomplete exposures have precluded the separation of the rocks into individually mappable units and they have therefore been mapped as one unit. The unit consists predominantly of limestone and dolomite, with interbedded quartz sandstone and quartzite.

Table 1

SUMMARY OF THE LITHOLOGIC SEQUENCE IN THE SIERRA RICA

GEOLOGIC AGE	MAP UNITS		THICKNESS, FT	DESCRIPTION	INTRUSIVE IGNEOUS ROCKS
QUATERNARY	ALLUVIUM		0-1000+	Unconsolidated pediment & valley-fill gravels	
	UNCONFORMITY				
	BASALT		0-50+	Flows	
	UNCONFORMITY				
LATE TERTIARY	RHYOLITE		0-50+	Plugs, flows, tuffs, breccias	QUARTZ-LATITE, FELSITE
EARLY TO MIDDLE TERTIARY	UNCONFORMITY				
	RHYOLITE PORPHYRY		0-200+	Flows and plugs (?)	LATITE, LAMPROPHYRE, GRANITE
	UNCONFORMITY				
LATE CRETACEOUS TO EARLY TERTIARY	LATITE-DACITE		0-200+	Flows	
	BASALT-ANDESITE		0-300+	Flows	
	UNCONFORMITY				
EARLY CRETACEOUS	MOJADO FM.	UPPER MEMBER	950+	Fossiliferous quartzite, interbedded limestone	
		LOWER MEMBER	4000	Fossiliferous quartzite, interbedded siltstone and limestone	
	U-BAR FORMATION	SUPRAREEF LS. MEMBER	250-300	Blue ls., fossiliferous, ss. in upper part	
		REEF LS. MEMBER	400-500	Blue-gray ls., fossiliferous, cliff former	
		LIMESTONE SHALE MEMBER	350-450	Gray ls. interbedded with gray calc. shale	
		OYSTER LS. MEMBER	1200-1800	Blue-gray ls., massive, abundant oyster fossils	
		BROWN LS. MEMBER	1200+	Tan ls., lithographic, interbedded calc. ss.	
	FAULT CONTACT				
PERMIAN	EARP FM.		200+	Tan siltstones, fissile, dolomitic, red dolomite	
	FAULT CONTACT				
PENNSYLVANIAN	HORQUILLA FM.		600+	Blue-gray ls., massive, fossiliferous	
	FAULT CONTACT				
MISSISSIPPIAN	ESCABROSA & PARADISE FMS.		1500+	Blue-gray ls., crinoidal, abundant chert nodules	ALLOCHTHONOUS ROCKS
	FAULT CONTACT				
ORDOVICIAN	EL PASO & MONTOYA FMS.		0-700+	Gray to black ls., dolomite, and black chert	

Table 2. Correlation of nomenclature pertaining to stratigraphic units common to the Big Hatchet Mts (Zeller, 1965), Sierra Rica (this report), Little Hatchet Mts (Lasky, 1947), Apache Hills and northern Sierra Rica (Strongin, 1958).

	Zeller (1965)	This report	Lasky (1947)	Strongin (1958)
	Mojado fm.	Mojado fm.	Corbett fm.	Corbett fm.
LOWER	Upper member	Upper member		
	Lower member	Lower member		
	U-Bar fm.	U-Bar fm.	Howell's Ridge fm.	Howell's Ridge fm.
CRETA-	Suprareef ls. member	Suprareef ls. member		Ls.-ss. member
	Reef ls. member	Reef ls. member		Rudistid ls. member
CEOUS	Ls.-shale member	Ls.-shale member	Hidalgo Volcanics	Orbitolina ls. member
	Oyster ls. member	Oyster ls. member	Ringbone Shale	Oyster ls. member
	Brown ls. member	Brown ls. member	Broken-Jug Limestone	Red beds member
PERMIAN	Earp fm.	Earp fm.	--	Abo fm.
PENNSYL- VANIAN	Horquilla fm.	Horquilla fm.	Magdalena fm.	Magdalena fm.

A distinctive lithology encountered in this unit is a 40-foot sequence of thinly stratified dark gray dolomitic limestone with interbedded 3- to 6-inch bands of brown-weathering black chert (see Figure 3). Irregular nodules of the chert also occur in the dolomitic beds. Zeller (1965, p. 14) has described this lithology in the Big Hatchet Mountains.

> A characteristic feature of the Sierrite Member of the El Paso Formation here as in most places is the rhythmic alteration [alternation] of reticulated laminae of brown-weathered chert with laminae of carbonate rocks...The laminae of chert average one-half inch in thickness, are wavy and irregular, are interconnected, and weather in relief. Often they are concentrated in such numbers as to produce conspicuous dark brown bands on hill slopes. In some zones, the proportion of chert exceeds dolomite...

The limestones are usually light-gray, fine grained and massive. Brachiopod, gastropod and bryozoan fossils occur, but are not common. The dolomitized carbonates are usually dark-gray and more resistant than the limestones. No fossils were found in the dolomitic beds. The quartz sandstones and quartzites occur both within the limestones and the dolomites, the transition is gradational from arenaceous carbonate beds to calcareous quartz sandstone and quartzite beds. The arenaceous beds are from two to eight feet thick and occur as lenses. The lateral extent of arenaceous lenses could not be determined due to limited outcrop.

The stratigraphy of the El Paso and Montoya formations has been described by Zeller (1965, p. 12-22) from exposures

Figure 3. Thinly bedded black chert and gray limestone, overlain by nodular black chert in massive gray limestone, El Paso formation, sec. 32, T.29S., R.14W.

of the relatively undisturbed strata in the Big Hatchet Mountains. The combined thickness of the two formations in the Big Hatchet Mountains is about 1300 feet. Zeller (1965, p. 119) has identified these formations in a lithologic log from a wildcat well drilled in sec. 12, T.30S., R.15W., about four miles southwest of the nearest outcrop in the Sierra Rica. The combined thickness of the El Paso and Montoya formations, as determined by Zeller from his interpretation of the lithologic log, is 1195 feet. This is an apparent thickness which has not been corrected for dip. Exposures in the Sierra Rica are erosional remnants which were subjected to complex imbrication during thrusting and post-thrust faulting. The thickness of the exposed section, as determined by dip and topography measurements, is about 700 feet, whereas the thickness of the thrust plate appears to be less than 300 feet.

Mississippian

Escabrosa and Paradise Formations

Carbonate rocks of Mississippian age are exposed in the form of allochthonous thrust blocks in secs. 29 and 30, T.29S., R.14W., and as windows in alluvium at the center of sec. 25 and the west side of sec. 24, T.29S., R.15W. Identification of these outcrops is based on lithologic similarities to well-exposed, paleontologically-dated outcrops in the Big Hatchet Mountains. Although lithologies typical of both the Escabrosa and Paradise formations are present in this area, the two formations were mapped as one unit. The allochthonous nature of these rocks is proved by fault contacts with the underlying Cretaceous sedimentary rocks. Incomplete stratigraphic sections of the Escabrosa and Paradise formations suggest the presence of faulting within the allochthonous units. The absence of Silurian klippen can also be explained by such faulting.

The lithologies identified as typical of Escabrosa consist of light- to dark-gray weathering limestones which are dark gray on a fresh fracture and have a fetid odor. The limestones are evenly stratified in one-foot beds. The most characteristic feature of these rocks is the presence of gray-brown weathering gray-black chert (see Figure 4). The chert is present both as irregular stringers two to six inches thick, conformable with the bedding, and as irregular nodules up to nine inches in diameter.

Fossils, although not abundant, do occur in the limestone. Brachiopods, crinoids, bryozoans and occasional corals were encountered. None of the fossils were specifically identified. Apart from some coarse crinoidal limestone beds, the carbonates are fine grained, often exhibiting a lithologic texture on a fresh fracture.

The Paradise Formation was recognized from an irregular area of outcrop in S.W.¼, sec. 29, T.29S., R.14W.

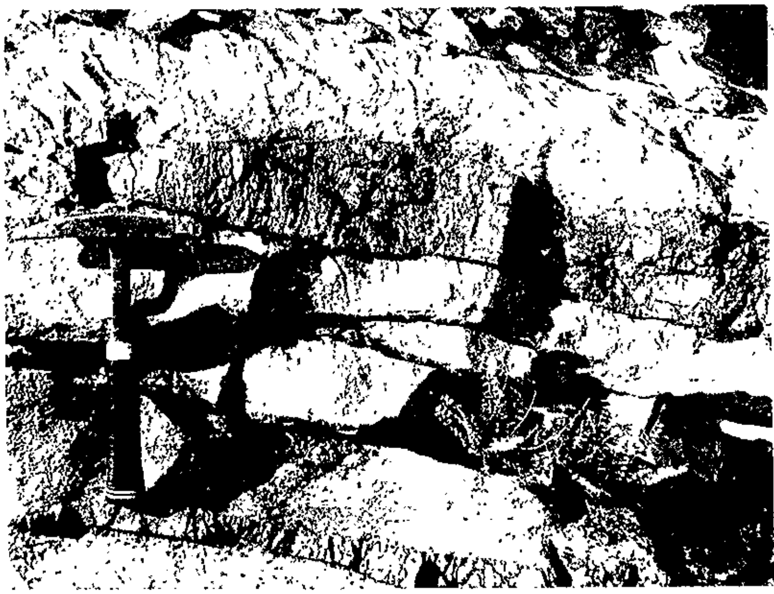

Figure 4. Lenses of dark gray chert in massive Escabrosa limestone, sec. 30, T.29S., R.14W.

Fossiliferous orange-brown weathering, thinly stratified and cross-stratified gray limestones are typical of this formation. Common marine fossils include brachiopods, pelecypods, gastropods, corals and bryozoans.

No thicknesses were measured within these overthrust sheets. However, the attitude and outcrop pattern indicate an anomalous thickness in excess of 3500 feet. The total thickness of the Escabrosa and Paradise formations in the Big Hatchet Mountains is in the order of 1500 feet. The anomalous thickness of the Sierra Rica is most likely the result of imbrication within thrust plates.

Pennsylvanian

Horquilla Formation

The most prominent outcrop of the Horquilla Formation is in Doyle's Peak, secs. 20 and 21, T.29S., R.14W., where it forms the upper 700 feet of a conical peak. Four other exposures of the same formation crop out as windows in valley-fill material in secs. 17 and 18, T.29S., R.14W. All five outcrops (see pl. 1) are erosional remnants of a large overthrust.

The klippen of Horquilla Formation rocks are composed entirely of blue-gray weathering recrystallized limestones which are dark gray, and often have a fetid odor on a fresh fracture. The texture varies from aphanitic to coarsely crystalline, the coarsely crystalline patches representing crystal overgrowths around crinoidal debris. Occasional tetracoral stems, not in growth position, were observed on the north side of Doyle's Peak. Although the limestones are massive, giving no indication of their attitude, a fairly well developed horizontal jointing pattern suggests the presence of horizontal bedding. The lithology in Doyle's Peak is identical to the upper third of the massive Horquilla limestone cliffs in the Big Hatchet Mountains, identified as Horquilla by Zeller (1958, p. 65), on the basis of paleontological evidence.

Permian

Earp Formation

On the western, southern and eastern slopes of Doyle's Peak a distinctive lithology crops out. These rocks differ in lithology from the overlying rocks (Horquilla Formation limestones) and the underlying rocks (Mojado Formation quartzites). They were mapped as Earp Formation (Permian) because of their lithologic similarity to Earp Formation rocks exposed in the southwestern part of the Big Hatchet Mountains. This inverted sequence, Pennsylvanian overlying Permian which in turn overlies Lower Cretaceous, may be explained by imbricate thrusting. Zeller (1958) has recorded similar imbrication in the Big Hatchet Mountains, where the relatively competent Horquilla limestones were sheared and thrust over the less competent Earp Formation rocks. Although the writer found no fossils, Zeller (oral communication, 1969) found paleontologic evidence in the windows exposed on the east side of Doyle's Peak which indicates that these rocks are definitely of Permian age.

Outcrops of the Earp Formation are very poorly exposed, owing to the nonresistant nature of the rocks. On the western and southern slopes of Doyle's Peak these rocks are exposed in gulleys only and consist of brown-weathering, tan siltstones interbedded with cream mudstones and tan dolomitic limestones. The siltstones and limestones are fissile and break into ¼- to 2-inch slabs. A few thin beds of very fissile red shale are also present. All of the lithologies described above are calcareous, but it was not possible to determine whether this was a primary or secondary feature in these rocks. Although the Earp Formation is present over a vertical interval of 100 feet, poor exposures precluded the measurement of a section. The attitude of the rocks appears to be horizontal, but the deeply-weathered outcrop has undergone some deformation through slumping and locally very anomalous apparent attitudes may be observed.

Lower Cretaceous

General Description

The Lower Cretaceous sedimentary rocks in the Sierra Rica consist of an 8500-foot succession of conformable carbonate and clastic rocks which are divided into mappable units on the basis of lithology and paleontology. Table 2 illustrates the nomenclature formally proposed by Lasky (1947) and Zeller (1965). Because the rocks in the Sierra Rica closely resemble those described by Zeller in type-sections, a number of which were visited by the writer, Zeller's nomenclature is used in describing these rocks in the Sierra Rica. Three Lower Cretaceous formations are recognized in the Big Hatchet Mountains; the Hell-to-Finish Formation, U-Bar Formation, and Mojado Formation. Neither the bottom nor the top of the Lower Cretaceous sequence is exposed in the Sierra Rica; the Hell-to-Finish Formation crops out in Mexico, to the east of the area mapped, and the very uppermost part of the Mojado Formation is covered by either Paleozoic klippen, Tertiary volcanic rocks, or alluvium. Fossils occur throughout this sedimentary succession. Zeller (1965) has recognized sufficient index fossils to allow dating of the rocks as early Cretaceous in age.

U-Bar Formation

The U-Bar Formation rocks are exposed in two north-westerly-trending bands in the eastern part of the Sierra Rica. About 6 square miles of the formation crop out. Although these outcrops have been much affected by either faulting or metamorphism, or both, lithologic units are still distinguishable and therefore mappable. The least tectonically disturbed complete U-Bar section is to the north of the Border Tank, in secs. 1 and 2, T.30S., R.14W.

The U-Bar Formation has been subdivided into five members on the basis of lithology and paleontology. They are as follows, from oldest to youngest: Brown Limestone Member, Oyster Limestone Member, Limestone-shale Member, Reef Limestone Member, and Suprareef Limestone Member.

Brown Limestone Member. Exposed in a narrow band extending north-northwest from border post no. 42, the Brown Limestone Member has been altered by metamorphism. However, as determined by thin-section examination, the original texture must have been thinly-stratified sandy limestones, with occasional 1- to 2-foot beds of quartz sandstone. No fossils were observed in this exposure. The metamorphosed carbonate is light gray on a fresh fracture, weathering dark brown, and is a resistant ridge-forming rock. The thinly-stratified sandy limestone has been metamorphosed to scapolite and diopside layers which weather differentially, resulting in a fluted outcrop appearance. The thickness of the Brown Limestone Member in the type section is in the order of 400 feet (Zeller, 1965, p. 60). The thickness in the Sierra Rica, calculated from one dip measurement and outcrop width is about 2500 feet. This apparent thickness may be due to one of three factors:

repetition by faulting, change in dip, or transition from lower U-Bar Formation to upper Hell-to-Finish Formation near the international boundary. Poor exposure prevents the determination of which explanation is the most likely.

Oyster Limestone Member. Exposed in normal sequence north of the Border Tank, and in three faulted outcrops in the southeastern portion of T.29S., R.14W., this member takes its name from the abundant oyster fossils which it contains. The dominant lithology is gray-weathering gray limestone, massive in the upper part, but thinly stratified in 2-foot beds in the lower part. The texture of the limestone varies from lithographic to coarsely bioclastic. The most distinctive lithologies occur in the lower part where lenses of *Exogyra* coquina are abundant. The lenses are from 6 inches to three feet thick and may be followed for many hundreds of feet along strike. These brown-weathering bioclastic beds occur within calcareous quartz sandstones and arkoses, and quartzose, fossil-rich limestones. Cross-stratification is ubiquitous in the lower part of this member. Because of the quartz silt and sand content of the lower beds in the member, these beds have a distinctive brown weathered surface which is in contrast to the color of the higher massive gray limestone beds. In the vicinity of the Occidental mines, SW¼, sec. 25, T.29S., R.14W., some of the bioclastic *Exogyra* shells have been selectively replaced by pyrite and pyrrhotite during periods of mineralization. Higher in the section, in the massive limestone, a few large *Pecten* shells are encountered. Gastropods varying in length between ½ and 3 inches are fairly common, and occasional specimens of *Orbitolina texana* occur throughout the member. The thickness of the Oyster Limestone Member in its undisturbed section north of the Border Tank, about 2000 feet, is in close agreement with the thickness measured by Zeller in the Big Hatchet Mountains.

Limestone-shale Member. Poorly exposed on the west side of the valley north of the Border Tank, but well exposed on the east flank of the peak in sec. 36, T.29S., R.14W., and sec. 1, T.30S., R.14W., this member takes its name from the interbedded nature of its lithologies. Dense, almost lithographic gray weathering, blue-gray limestone beds ranging in thickness between ½ and 20 feet alternate with calcareous, gray-weathering, cream quartz siltstones and shales. In some beds the shale parting is so poor as to warrant the name claystone. Occasional oysters and *Orbitolina texana* are found in the limestone intervals. Neither the base nor the top of this member is well defined and for mapping purposes the lowermost and uppermost shales or siltstones were arbitrarily chosen as the member boundaries. The thickness varies, but appears to range between 300 feet and 500 feet.

Reef Limestone Member. The Reef Limestone Member crops out in a normal sequence to the northwest of the Border Tank and in a faulted sequence around and to the northwest of the high peak in sec. 36, T.29S., R. 14W. (see Figure 5), and also in the extreme northeast corner of the area mapped. It is characterized by massive blue-gray limestone with a very rough weathered surface. Examination of a weathered surface with the aid of a handlens reveals a clastic texture with grain size ranging between fine- and very coarse-sand size. On a fresh surface this limestone is dark gray and appears crystalline. Fossils are not abundant; a few *Orbitolina texana* and some unidentified brachiopods were noted. Zeller (1958, p. 126) suggests that the Reef Limestone Member is biohermal. One of his points of evidence is that its thickness in the Big Hatchet Mountains is very variable, ranging from 20 feet to 500 feet. This variation was not noted in the Sierra Rica, although no detailed sections were measured. However, the coarse texture would seem to indicate a bioclastic limestone, possibly a reef-mound type analagous to the west coast of Grand Bahama Island.

Suprareef Limestone Member. The Suprareef Limestone Member is the uppermost member of the U-Bar Formation. It crops out in conformable stratigraphic sequence to the northwest of the Border Tank and in a faulted sequence at the summit of the high peak in sec. 36, and in sec. 35, T.29S., R.14W. The lower part of the member consists of gray-weathering limestone which is dark blue-gray on a fresh fracture. The texture is bioclastic, but not as coarse as that of the underlying Reef Limestone Member. The limestone is evenly stratified in 5- to 10-foot beds. Calcareous siltstones up to 6 inches thick usually occur along the bedding planes. Although fossil shell fragments are fairly common in this member, identifiable fossils are rare. Zeller (1965, p. 64) tentatively identified rudistids as _Toucasia_. The writer tentatively identified a rudistid as _Planocaprina trapezoides_. The upper part of the Suprareef Limestone Member contains fine-grained quartz sandstones interbedded with the limestones. Proceeding up section the quartz sandstone beds begin to predominate. Where this takes place is defined as the uppermost limit of the Suprareef Limestone Member and therefore the contact between the U-Bar Formation and the Mojado Formation. The contact is conformable and gradational and its stratigraphic position was arbitrarily defined by Zeller (1965, p. 108) in type-sections. The following stratigraphic section was measured by the writer across the U-Bar Formation-Mojado Formation contact in the Sierra Rica:

Section measured along cross-section line D-D' (see pl. 1), on the west side of sec. 36, T.29S., R.14W., starting in the Suprareef Limestone Member of the U-Bar Formation and ending in the Lower Member of the Mojado Formation:

Lithology	Unit thickness	Cumulative thickness
Limestone, blue, small dark brown fossils	64 feet	64 feet
Shale, calcareous, gray-green	11	75
Limestone, blue, shaly parting	15	90
Covered	40	130
Shale, olive, breaks into 2-inch blocks	5	135
Sandstone, quartz, buff, calcareous, fine-grained, ripple-marked, 6-inch beds	2	137
Sandstone, quartz, green, very fine grained, poorly sorted, contains purple mudstone clasts, calcareous cement	2	139
Limestone, blue-gray, occasional detrital shell fragments	3	142
Limestone, blue-gray, thin beds of small black fossils	12	154
Shale, gray, calcareous	6	160
Limestone, blue, thin-bedded	12	172
Dolomite, brown, sandy	8	180
Limestone, blue, 6-inch beds	9	189
Limestone, gray, shaly	6	195
Shale, brown, fissile	15	210
Limestone, blue, 6- to 12-inch beds	26	236
Sandstone, quartz, brown, calcareous	24	260
Limestone, brown, very fossiliferous	20	280
Sandstone, brown, calcareous	10	290
Limestone, blue-gray, bioclastic	3	293
Covered	9	302
Orthoquartzite	9	311
Limestone, blue, massive, fossiliferous	14	325
Covered	6	331
Siltstone, brown, calcareous	3	334
Limestone, blue-gray	3	337
Covered	3	340
Limestone, blue-gray	3	343
***** U-Bar Formation--Mojado Formation contact *****		
Sandstone, quartz, brown, calcareous, thinly stratified	6	349
Shale, ochre, fissile	2	351
Sandstone, quartz, brown, calcareous	9	360
Sandstone, quartz, brown, calcareous, thin-bedded	40	400
Shale, brown, calcareous	54	454

Lithology	Unit thickness	Cumulative thickness
Shale, red-brown, blocky	8 feet	462 feet
Sandstone, quartz, white	16	478
Covered, limestone float	18	496
Sandstone, quartz, white, medium grained, well sorted, rounded, in trough and tabular cross-sets, interbedded brown shales	92	588
Limestone, gray, in 6-inch beds	6	594
Sandstone, quartz, white	45	639

The approximate thickness of the U-Bar Formation in an apparently unfaulted section in the Sierra Rica north of the Border Tank is 3500 feet. This thickness compares favorably with the thickness in the Big Hatchet Mountains, about 3500 feet, as reported by Zeller (1965, p. 64).

Mojado Formation

Extending across the mapped area from northwest to southeast in an almost continuous 1-1½ mile wide outcrop-band, the Mojado Formation constitutes one of the most prominent lithologies in the Sierra Rica. It crops out over an area of about 10 square miles, mainly along the northwestern and southwestern flanks of the Sierra Rica, with a narrow strip repeated by high-angle faulting in the center of the range. The Mojado Formation consists of slightly less than 5000 feet of terrigenous sediments; interbedded quartz sandstones, shales and mudstones with occasional carbonate beds, and conformably overlies the U-Bar Formation carbonate rocks. The top of the Mojado

Formation is nowhere exposed in the Sierra Rica as it is covered either by klippen, volcanics, or alluvium.

The formation may be conveniently subdivided both paleontologically and lithologically, for mapping purposes, into a Lower Member and an Upper Member.

Lower Member. The lower contact of the Lower Member, arbitrarily chosen as a thick quartz sandstone unit above the limestones of the U-Bar Formation, can be traced for a distance of over three miles from a point ½-mile west-northwest of the Border Tank to the northeast corner of sec. 33, T.29S., R.14W. The Lower Member of the formation is comprised of a monotonous 4000-foot sequence of inter-bedded quartz sandstones and claystones. Throughout most of the Sierra Rica, the rocks have been silicified to quartzites and hornfelses. The cause of the silicification is not known, but some possibilities have been suggested (see p. 15). The thickness of the quartz sandstone and siltstone bodies ranges from a few feet to many hundreds of feet, but averages about 100 feet for the quartz sandstone beds and about 30 feet for the claystone beds. Near the lower contact the quartz sandstones are medium- to fine-grained, poorly sorted, subangular, stratified and cross-stratified in 1- to 4-foot sets. Cut-and-fill scouring and channeling is ubiquitous, and many transport-direction reversals were noted. Feldspar is a common constituent in these rocks, but seldom exceeds 10 volume-percent. Occasional biotite flakes and allogenic chert grains were observed in thin sections. The color of the quartz sandstones is tan on a weathered surface and gray to cream on a fresh fracture. Locally, staining by iron oxides from the adjacent claystones gives the quartz sandstones a reddish tint. The variegated claystones, now hornfelses, range in color from black to maroon. They sometimes exhibit a shaly parting, but are for the most part massive, with a conchoidal or blocky fracture. Some specimens, when observed in thin section, show as much as 20 volume-percent silt-sized detrital quartz, and warrant the name silty claystone or mudstone. Occasional fossil plant material, in the form of carbonaceous debris and silicified wood, was observed. Locally, some of the quartz sandstone beds contain an abundance of carbonaceous debris, and some well-preserved leaf impressions were observed. Fossil wood fragments occur throughout the Lower Member, but seem to become more common towards the top of the member. In the northeast corner of sec. 30 a complete fossil tree was found. It measured 35 feet in length and had been compressed to give a rhombic cross-section measuring 15 x 22 inches. The silicified fossil wood is dark gray in color and almost no cell structure can be seen.

Marine animal fossils are rare in this member, and like the fossil wood, appear to be more abundant towards the top of the member. A gastropod, _Turritella_, and pelecypods not identified but resembling _Lucina occidentalis ventricosa_ and <u>Arca ponderosa</u> are the most frequently encountered fossils.

Distinctive lithologies were found within the Lower Member and were used as marker beds for stratigraphic and tectonic interpretation. These beds are clastic limestones which occur 800 feet and 1000 feet stratigraphically above the base of the Mojado Formation. They are separated by quartz sandstone. In the type locality of the Mojado Formation in the Big Hatchet Mountains, Zeller (1965, p. 103) has recorded these beds in the same stratigraphic position. The beds are between 2 and 3 feet thick, and can be followed for many thousands of feet along strike. They are composed of gray limestone granules, ¼- to 3/4-inch in diameter, well rounded and set in a matrix of calcareous brown quartz sandstone. On a weathered surface the limestone has been differentially etched out, resulting in a deeply pitted surface.

<u>Upper Member</u>. The Upper Member of the Mojado Formation crops out along the northwestern flank of the Sierra Rica, and in isolated localities along the southwestern flank of the Sierra Rica and at the base of Doyle's Peak. It is differentiated from the Lower Member by the presence of a rich faunal assemblage and change in lithology. Although this member consists predominantly of silicified quartz sandstone, it contains less claystone and more limestone than the Lower Member. It also contains an irregular

lensoid marker bed of chert-quartz-pebble conglomerate about 100 feet stratigraphically above the contact with the Lower Member. The contact is arbitrarily chosen at the first appearance of a dark-brown bed of pelecypod-limestone coquina (see Figure 6). Above this bed, claystone is less frequently encountered than fossiliferous limestone, as intercalated beds in the quartz sandstone. Because of the nonresistant nature of the pelecypod-limestone coquina, this bed cannot be accurately traced along strike. The contact is therefore indicated on the geologic map (pl. 1) as an approximate one.

The chert-quartz-pebble conglomerate is characterized by well rounded ½- to 2-inch granules and pebbles of cream-colored quartz and gray-colored chert set in a matrix of silicified quartz siltstone. The beds vary in thickness between a few inches and 4 feet over distances of about 1000 feet along strike. The conglomerates are exposed in SW¼, sec. 27, T.29S., R.14W., and NW¼, sec. 10, T.30S., R.14W.

Higher in the section, some 2-foot beds of quartz sandstone containing abundant marine fossils occur. Figure 7 illustrates an outcrop of these rocks in the SW¼ of section 19, T.29S., R.14W. The following fossils within these outcrops were tentatively identified by the writer:

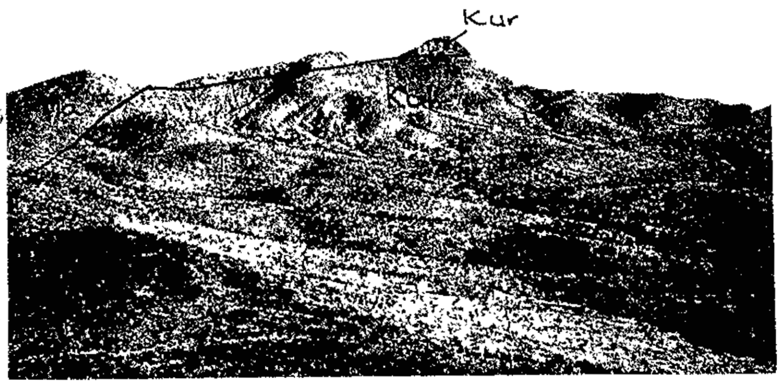

Figure 5. High peak in sec. 36, T.29S., R. 14W., viewed from the east side of sec. 1, T. 30S., R. 14W. Reef Limestone Member (Kur) overlying Limestone-Shale Member (Kul) of U-Bar Formation. Latite (Tla) forms rounded hill visible on left side of photo.

Figure 6. Pelecypod limestone coquina bed chosen as the lowest unit of the Upper Member of the Mojado Formation.

Figure 7. Brachiopod and pelecypod fossils in quartzites of the Upper Member of the Mojado Formation, exposed in SW¼, sec. 19, T.29S., R.14W.

Pelecypods; Arca sp., Brachydontes sp., Neithea texana (Roemer), Nucula sp., Protocardia texana (Conrad), Yoldia sp., Gastropods; Cassiope sp., Lunatia, and various species of Turitella, not specifically identified. Zeller (1965, p. 71) has identified Haplostiche texana (Conrad), as well as many other fossils from these same outcrops.

Pyrite molds and limonite pseudomorphs after pyrite are encountered, through not abundant, in the quartz sandstones. The top of the Mojado Formation is nowhere exposed in the Sierra Rica because it is covered either by allochthonous thrust plates or by alluvium. The maximum thickness of the exposed part of the Upper Member, calculated from dip and outcrop width, is approximately 1000 feet. The total thickness of Mojado Formation exposed in the Sierra Rica is therefore about 5000 feet. Zeller's (1965, p. 103) measurement in the type locality gave a thickness of 5295 feet, which indicates that only the very uppermost portion of the formation is not exposed in the Sierra Rica.

Correlation of Lower Cretaceous Rocks

The U-Bar and Mojado formations as exposed in the Sierra Rica correlate both lithologically and paleontologically with the type formations described in the Big Hatchet Mountains. Detailed paleontological studies of the faunal assemblages undertaken by Zeller (1965) indicate that the U-Bar and Mojado formations are of Trinity-Fredericksburg-

Washita age. The overall pattern of terrigenous sedimentation followed by carbonates which are in turn followed by terrigenous clastics has been well established for the Lower Cretaceous rocks of southwestern New Mexico and southeastern Arizona. The lithologies are the expression of a basin of deposition, perhaps geosynclinal, which developed in late Jurassic-early Cretaceous time. The basin probably ceased to exist towards the end of early Cretaceous time as there is little evidence of Late Cretaceous sediments in this part of southwestern New Mexico or southeastern Arizona. The U-Bar Formation is the expression of a warm, marine environment, whereas the Mojado Formation is the expression of a regressive shoreline and neritic-tidal flat-fluviatile environment.

The thickness of Early Cretaceous rocks in the Big Hatchet Mountains is slightly less than 10,000 feet. This is in great contrast to the thickness of Early Cretaceous rocks in the Little Hatchet Mountains, 17,000-21,000 feet, as reported by Lasky (1947). Although good correlation exists between the Sierra Rica and the Big Hatchet Mountains, no correlation can be made with the Little Hatchet Mountains although the Sierra Rica is equidistant from these two ranges. Furthermore, Lasky (1947, p. 13), on the basis of paleontologic evidence, dates his 17,000- to 21,000-foot succession as Trinity in age. In other words, while a 3000-foot succession of Hell-to-Finish Formation and lower U-Bar

Formation were being deposited in the Big Hatchet Mountains and to the east of the Sierra Rica, a succession thicker than 17,000 feet was being deposited less than 20 miles away, in the Little Hatchet Mountains. Lasky (1947) reports four cycles of terrigenous clastics-carbonates-terrigenous clastics in his sedimentary succession, with thick interbedded volcanic sequences. A more reasonable interpretation is that the normal Lower Cretaceous sequence for this area has been repeated by thrust faulting in the Little Hatchet Mountains. Zeller (oral communication, 1969) reports the presence of abundant and very complex thrusting in the Little Hatchet Mountains. The ancmalous thickness of Lower Cretaceous sediments in the Little Hatchet Mountains and the possibility of repetition by faulting are graphically expressed in five stratigraphic columns constructed for this portion of New Mexico and Arizona by Zeller (1965, p. 74).

Upper Cretaceous and Tertiary Igneous Rocks

General Description

No sedimentary rocks of Upper Cretaceous or Tertiary age are exposed in the area covered by this report. The Lower Cretaceous rocks are directly overlain by klippen of Paleozoic rocks; Tertiary or Quaternary volcanics; or Quaternary alluvium. The Skunk Ranch fanglomerate mapped by Strongin (1958, p. 32) to the east of Doyle's Peak does not appear to be anything other than caliche-cemented pediment.

Nine distinguishable igneous rock units of Tertiary age were mapped in the area covered by this report. Five of these units are intrusive and four are extrusive. The ages and sequence of the igneous rocks (see table 1) have been assigned on the basis of data both from within the area mapped and from regional published data for this portion of southwestern New Mexico (Lasky, 1947; Strongin, 1958). The writer's interpretation of the relationship between igneous events and tectonic events is discussed later.

Basalt-andesite

This unit is exposed over most of sec. 24, T.29S., R.14W., and extends northwestward into the adjoining sections and eastward into Mexico. Adjacent to the international border the unit forms low, rounded, dark-colored hills. The rock has been deeply weathered and much of the outcrop has broken down to form a black C-horizon soil. Within the area mapped, the unit is surrounded on all sides by alluvium. It is exposed over a vertical interval in excess of 300 feet.

In hand specimen the rock is melanocratic porphyritic-aphanitic, with 1- to 3-mm subhedral plagioclase phenocrysts. Phenocrysts comprise between 5 and 25 percent of the rock volume. Ferromagnesian phenocrysts are very rarely observed in hand specimen investigation. Two samples were examined in thin section. One is andesitic, containing 92 percent plagioclase altered to calcite and epidote, 5 percent basaltic hornblende altered to iron oxides, 2 percent magnetite, and a trace of augite and quartz. Some secondary veining of adularia is also present. The other sample is basaltic, containing 58 percent plagioclase, 25 percent glass, 6 percent pyroxene altered to iron oxides, 5 percent magnetite and 6 percent quartz. This sample might be termed a quartz basalt. Although not observed in these two thin sections, chloritization of the ferromagnesian minerals is ubiquitous, giving the weathering outcrop a dark green tint. The magnetite seen in the thin sections is probably secondary, and derived from the oxidizing ferromagnesian minerals. Zoned plagioclase phenocrysts were observed in thin section, and the composition estimated as ranging between that of labradorite and andesine.

Although the outcrop gives an impression of thick horizontally-bedded flows when viewed from a distance, no bedding could be determined on the outcrop. Flow structure was not visible in hand specimen, but traces of flow lamination were exhibited by the glassy material in one of the thin sections examined. It seems probable that these volcanics are composed of flows differing in composition. Such differentiation was not mappable, however, and the rocks have been grouped into one unit, mapped as basalt-andesite.

No contact relationships, other than a younger rhyolite plug in the NE¼, sec. 24, T.29S., R.14W., are available to establish the age of the volcanics. Lasky (1947, p. 21) has correlated these volcanics with the Hidalgo Volcanics mapped by him in the Little Hatchet Mountains. He considered the Hidalgo Volcanics to be of early Cretaceous age, and interbedded with Lower Cretaceous sediments. No evidence of interbedding was observed in the Sierra Rica, however. In summary, the basalt-andesite volcanics are younger than the Lower Cretaceous sediments and older than the intrusive rhyolite plug of probable late Tertiary age.

Latite-dacite

Exposed in a number of small outcrops in the center and the southeast portion of the Apache Valley, these rocks are distinguishable in hand specimen from the basalt-andesite unit, and are therefore mapped as a different unit. Outcrops are deeply weathered; the freshest outcrop and best exposure of these volcanics is around the base of the conical hill formed by an intrusive plug in sec. 15, T.29S., R.14W. In hand specimen a fresh sample is mesocratic-melanocratic, gray-brown porphyritic-aphanitic with ½- to 2-mm sodic plagioclase phenocrysts. The volume of phenocrysts seldom exceeds 15 percent, and is generally about 10 percent. One thin section cut from a sample of this rock contains 64 percent plagioclase altered to sericite and calcite, 15 percent orthoclase, 2 percent quartz, 16 percent hornblende altered to chlorite, iron oxides and calcite, 2 percent biotite and 1 percent magnetite. Outcrops are too weathered to exhibit flow layering, but fresh hand specimens show a poorly developed preferred orientation of the feldspar laths which suggests an essentially horizontal layering. It is possible that the latite-dacite unit is genetically related to the basalt-andesite unit. From its outcrop position the latite-dacite unit is inferred to be younger than the basalt-andesite unit. It is older than the rhyolite porphyry plug by which it is intruded in sec. 15, T.29S., R.14W.

Granite

Granite is exposed in four small outcrops in secs. 13 and 14, T.30S., R.14W., to the south and southwest of the Border Tank. More extensive outcrops occur in Mexico, adjacent to the international border.

The contact metamorphism and pyrometasomatic mineralization observed in the sediments adjacent to the granite outcrops extend throughout the area indicated as a metamorphic aureole on the geologic map (pl. 1). The exposed granite must be part of an intrusive that was large enough to have metamorphosed at least 5 square miles of outcrop. The monzonitic intrusive and associated mineralization in the Apache Hills, and the mineralization in the Sierra Rica, may be genetically related to the granite.

In outcrop, the granite is weathered and friable and has broken down to form gravel. Noteworthy is the high magnetite content of the sands and gravels in the washes draining the area of outcrop. In hand specimen a fresh surface of the granite is leucocratic pinkish-white and has a hypidiomorphic seriate texture with grain size ranging from 1 to 15 mm and averaging about 8 mm.

Granite exposures in Granite Pass, at the southern end of the Little Hatchet Mountains about 15 miles north of west of the granite exposed in the Sierra Rica were visited by the writer. These outcrops were described by Lasky (1947, p. 33):

> The granite weathers to friable gravel...The rock is porphyritic and consists essentially of grains of quartz reaching ¼ inch in diameter and crystals of pink orthoclase and microcline as much as an inch in length in a continuous graded series. A few zoned crystals of oligoclase-andesine are present with 5 to 10 percent of corroded book-like plates of brown biotite, 1 to 2 millimeters across. The accessory minerals are apatite, magnetite, and zircon. The alteration minerals are sericite, chlorite, and calcite.

Thin-section analyses of granite samples from the Sierra Rica and from Granite Pass in the Little Hatchet Mountains are compared below:

	Volume Percent	
	Sierra Rica	Granite Pass
Quartz	27	22
Orthoclase	48	46
Plagioclase	18	25
Biotite	5	6
Magnetite	Trace	Trace
Apatite	Trace	Trace
Sphene	Trace	Trace
Rutile	Trace	--
Zircon	Trace	--

In both samples of granite the plagioclases are slightly sericitized and the biotites are chloritized. Figure 8, a photomicrograph of the granite which occurs in the Sierra Rica, illustrates the alteration.

Petrographically these rocks are very similar. They also have a similar outcrop appearance and contact metamorphic aureole. Furthermore, a regional aeromagnetic survey, part of which is reproduced in plate 3, indicates that the granite exposed in the Sierra Rica extends in a west-northwesterly direction under the Sierra Rica and then swings westward under the Hatchet Valley to crop out again in Granite Pass.

Lasky (1947, p. 38, Fig. 4) suggests a Cretaceous-Eocene age for the Granite Pass granite, but indicates it as being of Tertiary age on his geologic map of the Little Hatchet Mountains. Zeller (oral communication, 1969) stated that the Granite Pass granite has been radiometrically dated as early Tertiary in age. The granite exposed in the Sierra

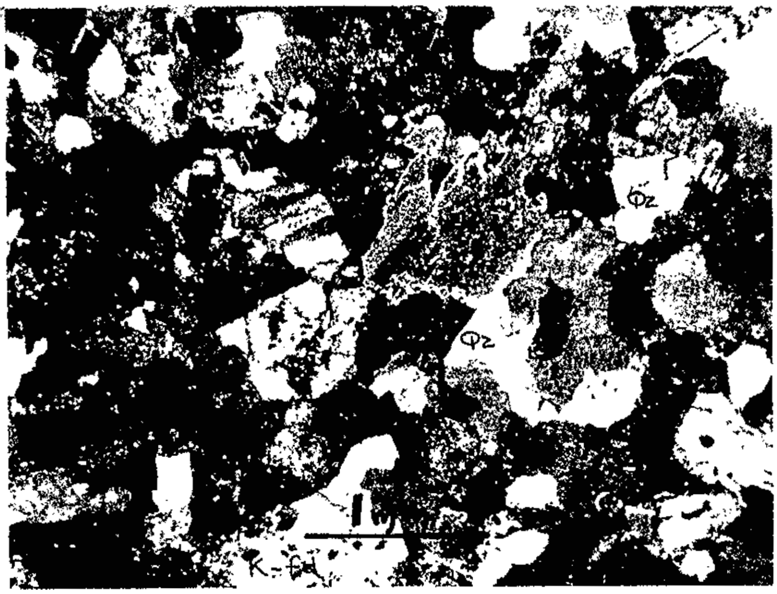

Figure 8. Biotite granite from outcrop in sec. 13, T.30S., R.14W. Crossed nichols. Qz = quartz, Bi = biotite, K-fd = orthoclase.

Rica would therefore appear to be of Early Tertiary age. It is at least younger than the Lower Cretaceous sediments which it intruded and older than the prominent latite dike which transects the Sierra Rica and which contains granite xenoliths.

Lamprophyre

Seven lamprophyre dikes were mapped in the eastern and southeastern Sierra Rica, in the proximity of the international border. The dikes have a random orientation and a random distribution. They vary in size from a few feet in width and a few tens of feet in length to tens of feet in width and hundreds of feet in length.

In the Sierra Rica, only Lower Cretaceous sediments have been intruded by the lamprophyre dikes, whereas in the Little Hatchet Mountains the Granite Pass granite is criss-crossed by lamprophyre dikes identical to those in the Sierra Rica. Lasky (1947, p. 33) reports these dikes as occurring throughout the Little Hatchet Mountains, and Strongin (1958, p. 73) has reported two such dikes from the Apache Hills. The lamprophyres of the Sierra Rica are dark-green to black, fine-grained to aphanitic rocks. In some samples needles of hornblende and flakes of biotite are visible, and in other samples zoned plagioclases are visible, although rare. One sample examined in thin section contained 67 percent plagioclase with saussuritized calcic cores and unaltered sodic rims, 28 percent hornblende, 4 percent biotite, and traces of sphene, magnetite, and orthoclase. The composition of this sample is dioritic, and represents the spessartite variety of lamprophyre.

The age of the lamprophyre dikes is bracketed between the age of the granite which it intrudes and the age of the prominent latite dike which transects the Sierra Rica and contains lamprophyre xenoliths.

Latite

Petrographically and topographically the most distinctive igneous rock unit in the Sierra Rica, the latite occurs as an unbroken sinuous dike between 300 and 1500 feet wide and extending from the international border in a northwesterly direction through the hills for 4¾ miles. Four isolated outcrops were mapped to the northwest of the point where the continuous dike disappears. Throughout most of its length the resistant latite dike forms a prominent ridge. The dike was emplaced along a major northwest-trending, high-angle normal fault.

The latite forms round-weathering, orange- to ochre-colored outcrops. In hand specimen a fresh surface is gray to ochre colored, porphyritic-aphanitic, with 1- to 4-mm feldspar phenocrysts. Euhedral orthoclase and sodic plagioclase crystals, sometimes zoned, are present in approximately equal proportions. Occasional euhedral sanidine crystals also occur. The phenocrysts make up between 5 and

30 percent of the rock volume. Visible crystals of pyrite are often present, though not abundant. Occasional xenoliths of granite and lamprophyre are encountered. The xenoliths seldom exceed 2 inches in diameter.

Six samples were examined in thin section. The average composition is as follows: Quartz 27 percent, sanidine 1 percent, orthoclase 38 percent, plagioclase 31 percent, biotite 1½ percent, hornblende 1½ percent, and trace amounts of pyrite, sphene, magnetite, zircon, apatite, and allanite. The quartz is often present as small β-quartz crystals. Well developed carlsbad twins of orthoclase are common. Alteration products are sericite, iron oxides, calcite, chlorite and epidote. Alteration is not abundant and the rock appears fresh both in hand specimen and in thin-section investigation. Figures 9, 10, and 11 are photomicrographs of the latite.

Although the quartz content of the rock is readily visible under the microscope, it is not visible in hand specimen. Therefore, although the rock should properly be termed a quartz latite, it is termed a latite for the purpose of mapping, so as to distinguish it from another quartz latite unit which contains abundant visible quartz.

The age of the latite is bracketed between the age of the lamprophyre which is contained within the latite as xenoliths, and felsite dikes which are intrusive into the latite. The fault along which the latite dike intruded sets

Figure 9. Orthoclase carlsbad twin crystal in latite from latite dike, sec. 29, T.29S., R.14W. Crossed nichols. Matrix of quartz, plagioclase and orthoclase.

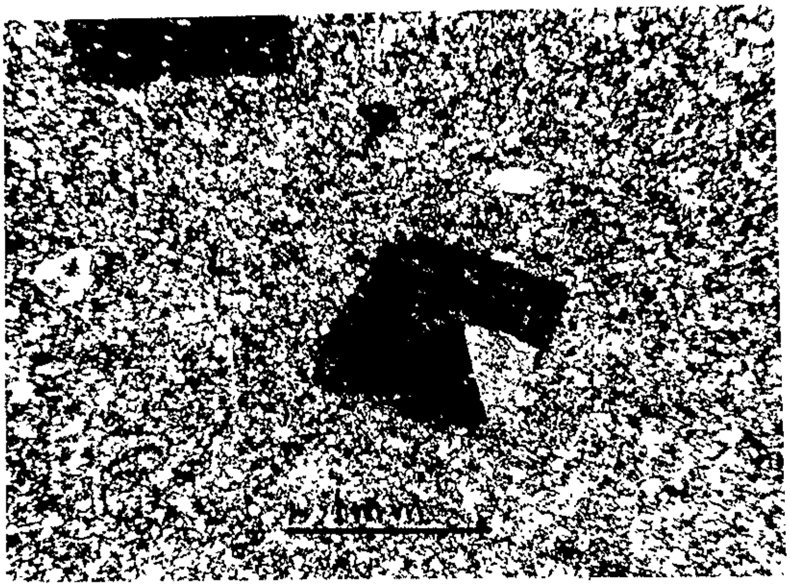

Figure 10. Orthoclase baveno twin crystal in latite from latite dike, sec. 19, T.29S., R.14W. Crossed nichols. Matrix of quartz, plagioclase and orthoclase.

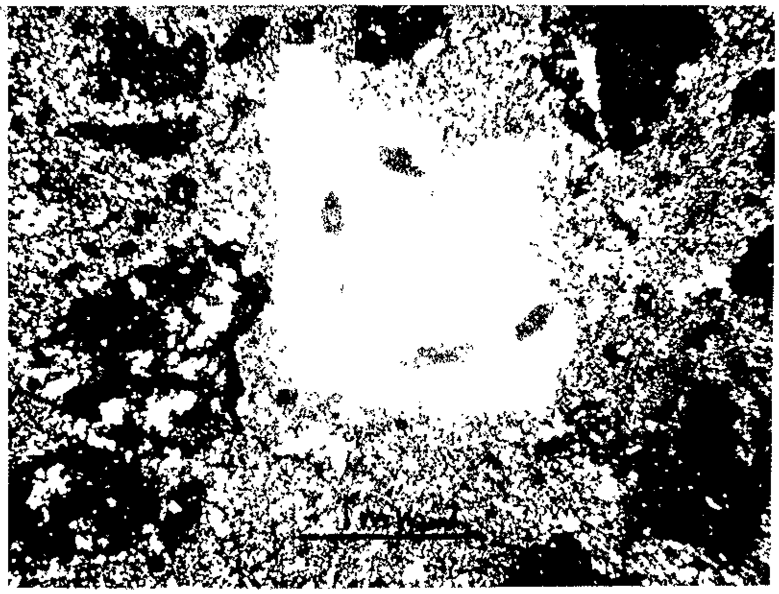

Figure 11. β-quartz phenocryst in micrographic latite from latite dike, sec. 1, T.30S., R.14W. Crossed nichols. Matrix of quartz and feldspar.

a maximum age for the latite in relation to tectonic events.

Rhyolite Porphyry

This rock unit is exposed as a plug forming the prominent conical peak in sec. 15, T.29S., R.14W., and as flows, for the most part horizontal, cropping out as windows in the alluvium in the Apache Valley. Except for the plug, the outcrops do not form prominent topographic features but usually occur as low rounded exposures. The rock is very hard, resistant to erosion, and the outcrops are not badly weathered.

The rhyolite porphyry is leucocratic porphyritic-aphanitic, with a color ranging from gray to purple. Weathered surfaces are usually purple and fresh surfaces are usually grayish. Phenocrysts of 1- to 3-mm-sized quartz, orthoclase, and plagioclase, hornblende and biotite occur in varying amounts. Quartz and feldspar are the most common phenocrysts and may constitute between 10 percent and 30 percent of the rock volume. In some outcrops the golden-brown weathering biotite books are more abundant than the quartz-feldspar phenocrysts. Devitrified glass is abundant, and the horizontal flow lines are readily visible in this material. Some beds of ash-flow tuff occur in the outcrops in NW¼, sec. 17, T.29S., R.14W.

In thin section the rhyolite porphyry contains quartz bipyramids, often corroded, occasional euhedral sanidine crystals, abundant orthoclase, twinned after the carlsbad and baveno laws, sodic plagioclase, biotite, hornblende, and accessory apatite and zircon, in a matrix of devitrified glass in which feathery feldspar is intergrown with silica. Chlorite and calcite are the principal alteration minerals.

The rhyolite porphyry is younger than the latite-dacite unit which it intrudes in sec. 15, T.29S., R.14W., and younger than the Horquilla Formation allochthonous thrust plate which it intrudes in sec. 18, T.29S., R.14W. The rhyolite porphyry appears to be older than the fault in the extreme northeast corner of the area mapped. However, two other possibilities also exist; 1) the rhyolite porphyry may only be older than the most recent movement of the fault, which may have been as late as in Pleistocene time, and 2) the rhyolite porphyry may have intruded along the fault and extruded downslope into the Apache Valley, implying that the fault may predate the rhyolite porphyry. The thickness of the flows was not determined, but their distribution suggests that they probably seldom exceed 200 feet in thickness.

Felsite

Forming a northeast-trending cluster of long sinuous outcrops in the center of the area mapped and exposed in a few isolated outcrops to the east of the Badger Tank and also in the proximity of the international border, the felsite dikes are very conspicuous because of their porcelain-like color and texture. The felsite dikes have no topographic expression, but stand out as white sinuous bands in the enclosing rocks. In the Sierra Rica they are intrusive into the Lower Cretaceous sediments and also the large latite dike. Strongin (1958, p. 65) has recorded numerous felsite dikes in the Apache Hills, and Lasky (1947, p. 35) has recorded a number of small felsite dikes and plugs in the northern part of the Little Hatchet Mountains. In Granite Pass, at the southern end of the Little Hatchet Mountains, the writer observed a great number of felsite dikes cutting the lamprophyre which is itself intrusive into the Granite Pass granite body.

In hand specimen the felsite is a cream to white colored aphanitic rock. Very rare quartz phenocrysts can sometimes be found. They never exceed 1 mm in diameter. Locally the felsite is speckled with small red-brown spots which under the handlens appear to be limonite pseudomorphs after pyrite. The dikes are very finely jointed and iron oxides in colloidal suspensions have percolated through the jointing fractures staining the joint surfaces of the felsite a red-brown color. A sample of felsite examined in thin section contained less than 5 percent quartz and orthoclase phenocrysts in a micrographic matrix.

In the Sierra Rica only a maximum age of not older than the latite unit can be assigned to the felsite unit.

Strongin (1958, p. 65) states that the felsites in the Apache Hills are older than late Tertiary pyroclastic rhyolites.

Quartz Latite

Ten small dikes of quartz latite crop out in the valley to the north of the Border Tank. The outcrops have no topographic expression and are best exposed in the sides of gulleys. In hand specimen the quartz latite is leucocratic, buff-colored, porphyritic-aphanitic, with 1- to 2-mm phenocrysts of subhedral quartz and orthoclase, and occasional sanidine crystals. The exposures are deeply weathered, and the plagioclase has decomposed to clay. No samples suitable for thin-section examination were obtained. In hand specimen the quartz latite does not resemble the lithology of the latite unit, the principle difference being the abundance of quartz phenocrysts. No data for determining the age of this unit are available, other than the fact that the quartz latite is younger than the Lower Cretaceous U-Bar Formation sediments into which it is intrusive.

Rhyolite

Rocks of this unit are exposed as plugs in secs. 24 and 25, T.29S., R.14W., and as plugs, dikes, ash flows and pyroclastic tuff breccias along the southern flank of the Sierra Rica. The plugs stand out as prominent light-colored, weathered outcrops. The light-colored dikes do not have any topographic expression and the dark-colored ash flows and tuff breccias are exposed as windows in alluvium in the vicinity of the Badger Tank.

In hand specimen, samples from the plugs and dikes are leucocratic, cream-colored, porphyritic-aphanitic. Subhedral to euhedral phenocrysts of quartz, orthoclase, sanidine, and occasionally plagioclase range in size between 1 and 4 mm, and comprise between 5 and 20 percent of the rock volume. The average phenocryst content is probably about 10 percent. Samples from the ash flows contain abundant vitreous material including some good quality obsidian and samples from the tuff breccias contain abundant dark-colored lithic fragments, pumice lapilli and ash, so that an accurate determination of mineralogical composition is not possible. Figures 12 through 14 illustrate textures observed in the tuffs.

Five samples of the dike and plug rhyolite were examined in thin section. The average compositional values are as follows: Quartz, present both as β-quartz phenocrysts and in the matrix, 38 percent, sanidine 11 percent, orthoclase 45 percent, plagioclase 4 percent, biotite 2 percent, and accessory magnetite, zircon, and lepidomelane. None of the samples deviate significantly in composition from these average values. In thin section the ash flows and tuff

Figure 12. Welded ash-flow rhyolite tuff, showing quartz (Qz), sanidine (S) and hornblende (Hb) in a matrix of shards with occasional collapsed pumice lapilli (P). From late Tertiary rhyolite breccia unit, sec. 3, T.30S., R.14W. Ordinary light.

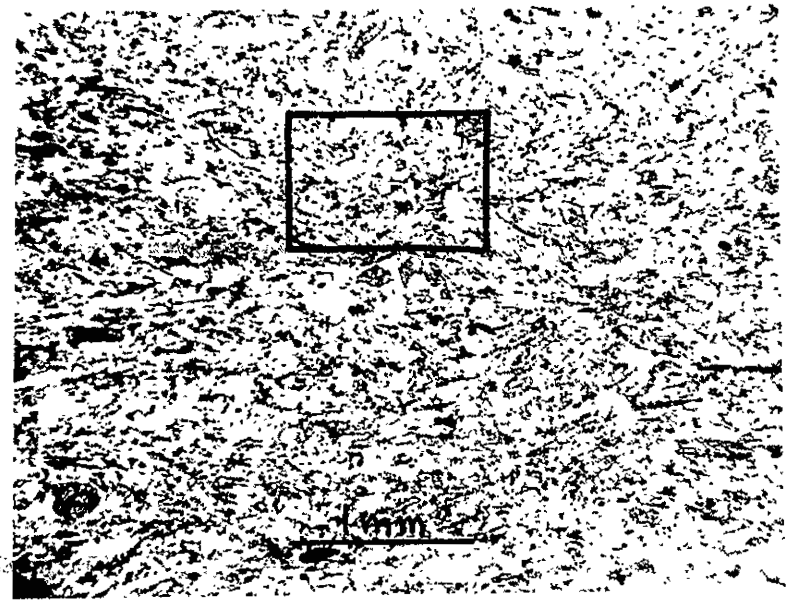

Figure 13. Hornblende ash-flow rhyolite tuff, showing orientation of shards. From late Tertiary rhyolite-breccia unit. Ordinary light. Rectangle enlarged in following figure.

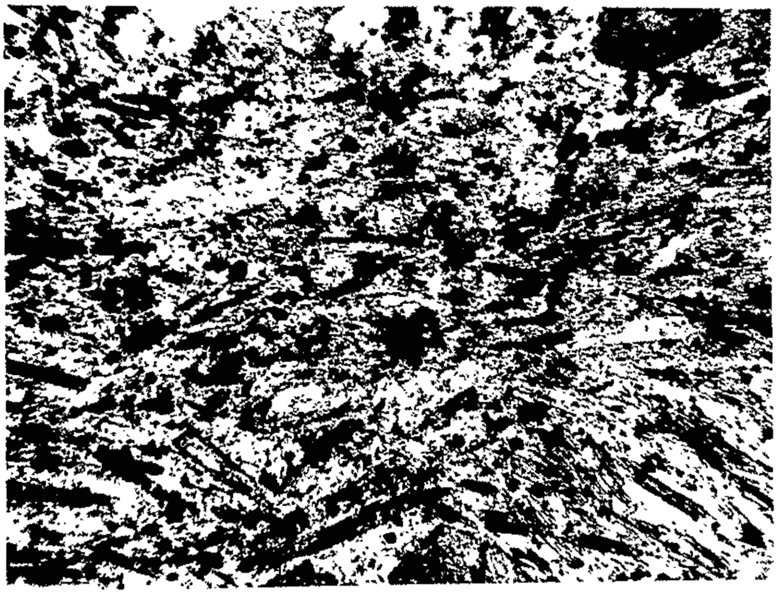

Figure 14. Enlargement of rectangle outlined in previous figure. Dark bladed-crystals are hornblende and biotite in a matrix of glass shards. Black blebs are magnetite. Ordinary light.

breccias are seen to contain phenocrysts of quartz, sanidine, and dark-colored unidentified lithic fragments in a micro-spherulitic trachitic matrix. Partial devitrification of the glassy material to orthoclase and silica is ubiquitous. In hand specimen the ash-flow tuffs and pyroclastics are red-brown to dark gray. Black, vitreous lithic fragments and pumice lapilli range in size between powder-sized material and 2-inch blocks.

Similar rhyolitic lithologies have been described by Lasky (1947, p. 35) in the Little Hatchet Mountains. Lasky assigns a Miocene age to these rocks. Strongin (1958, p. 66) has described rhyolite flows, tuffs, and breccias in the Apache Hills. These rocks appear to be lithologically equivalent to the rhyolite unit mapped in the Sierra Rica. Strongin (1958, p. 83) assigns an age of middle and upper Tertiary to the rhyolites of the Apache Hills, on the basis of regional relationships.

About 2000 feet due west of the Badger Tank the rhyolite unit is overlain by Quaternary basalt which establishes a minimum age for the rhyolite as not younger than Pleistocene. The rhyolite is intrusive into, and therefore not older than, the allochthonous limestone exposed to the north and east of the Badger Tank.

Quaternary Rocks

Basalt

Basalt outcrops occur in only two localities in the Sierra Rica, capping a hill of Lower Cretaceous Mojado Formation sediments in the northwest corner of sec. 3, T.30S., R.14W. (see Figure 15), and 2000 feet due west of the Badger Tank.

In hand specimen the basalt is dark-gray to black in color and is vesicular. The vesicles indicate a horizontal flow layering. Non-vesicular layers are black and aphanitic. One sample examined in thin section had the following composition; plagioclase 62 percent, augite 8 percent, magnetite 9 percent, olivine 20 percent, and traces of apatite, and calcite filling amygdules (see Figure 16). The plagioclase ranges in composition between labradorite and andesine and forms euhedral laths in a matrix of subhedral to anhedral augite and olivine. The olivine has been altered to deep red-brown pleochroic iddingsite but the feldspars and augite are unaltered.

The basalt is similar both in outcrop appearance and in composition and texture to the widespread Pleistocene basalt flows which are common throughout southwestern New Mexico, southeastern Arizona and northern Mexico. The basalt is the youngest igneous rock unit mapped in the area covered by this report. It is younger than the rhyolite pyroclastics which it overlies to the west of the Badger Tank (see pl. 1).

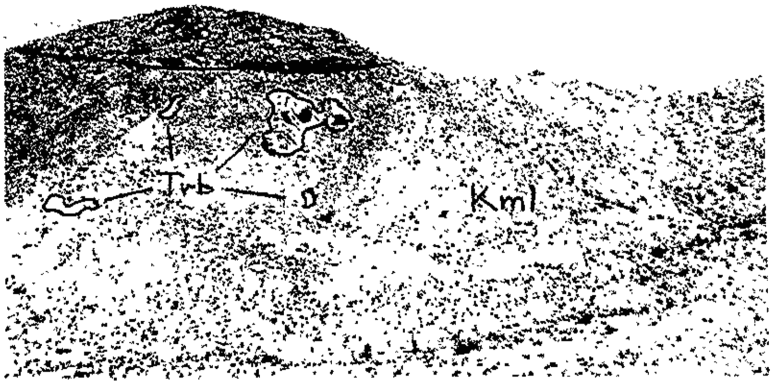

Figure 15. Hill in northwest corner of sec. 3, T.30S., R.14W. Quaternary basalt (Qb) capping hill of Mojado Formation quartzites and hornfelses (Kml), with plugs of rhyolite (Trb) exposed in the side of the hill.

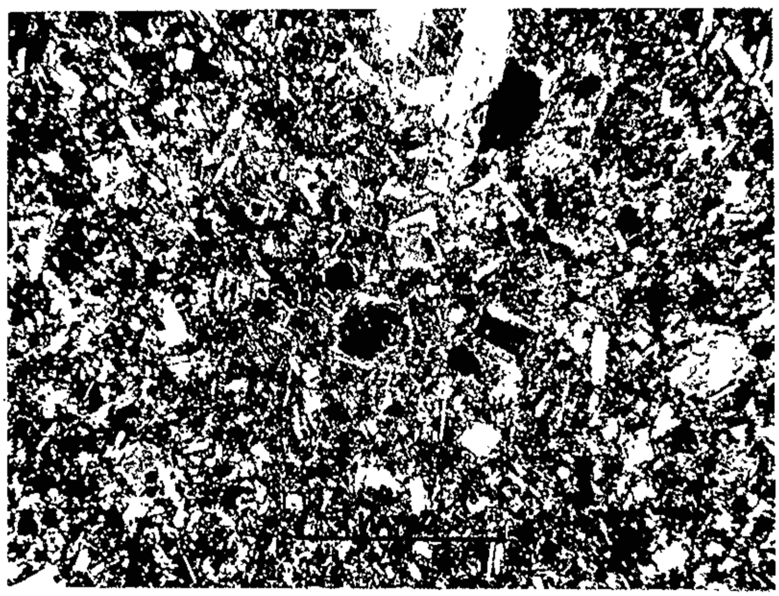

Figure 16. Quaternary basalt, showing rounded crystal of pleochroic iddingsite after olivine in center of field, surrounded by plagioclase laths and black magnetite grains.

Alluvium

About 25 square miles of the area mapped are covered by alluvium indicated on the geologic map (pl. 1) as Holocene alluvium. Although not differentiated on the map because of a lack of clearly defined boundaries, the alluvium can be separated into pediment, high valley alluvium and deep valley alluvium. The deep valley alluvium is nowhere exposed, being covered by high valley alluvium. Gravity data in the Hatchet Valley to the south of the area mapped indicate that the alluvium may be as much as 5000 feet thick (see pl. 4). In the area covered by this report the thickness probably does not exceed about 1000 feet.

In the Apache Valley, to the north of the Sierra Rica, the "alluvium" is a mixture of pediment and alluvial soil. Doyle Creek has incised into a slightly calcareous black soil which is at least 40 feet thick. The pediment is very calcareous and a zone of caliche up to 6 feet thick is encountered immediately below the surface in many prospect pits.

The alluvium along the western and southern flanks of the Sierra Rica consists mostly of high valley gravels, cemented by caliche. These gravels overlie the deep valley gravels which fill up the grabens of the Basin and Range Province. The very irregular magnetic pattern obtained over the southwestern flank of the Sierra Rica (see pl. 3) indicates that the alluvium is underlain by volcanics. These may be either late Tertiary rhyolites or Quaternary basalts, or both.

STRUCTURE

General Description

The structural fabric in the area covered by this report is compatible with the regional pattern for southwestern New Mexico and southeastern Arizona. The most striking structural features for the region are the northwest-trending mountain ranges and alluvium-filled valleys of the Basin and Range Province, and the thick allochthonous sheets thrust from the south. Folding, low-angle reverse faulting, and high-angle normal faulting form the most prominent structural features in the Sierra Rica. Locally low-angle reverse and high-angle normal faults, both with small displacements, occur. Small-scale drag folding associated with faulting also occurs.

The main tectonic events: Folding, thrusting, and high-angle faulting are discussed below, in chronological sequence.

Folding

The Sierra Rica and Apache Hills form part of a large faulted anticline. The Sierra Rica forms the southern limb of the anticline. In the area mapped the anticlinal axis trends northwest (see pl. 1). The crest of the anticline is exposed about 850 feet south of border post no. 41, where it crosses the international border into Mexico. In the northern part of the area mapped the anticlinal axis assumes a north-northwesterly trend. The outcrop pattern, abundant U-Bar Formation rocks exposed in the southeast, but not exposed in the northwest of the area mapped, suggests that the anticline plunges gently in a northwesterly direction. Strongin (1958, p. 84) has recorded minor folds in the Apache Hills which parallel the major fold in the area mapped by the writer.

Thrusting

Allochthonous rocks cover about 3 square miles of the area mapped, cropping out along the southwest flank of the Sierra Rica and in the Apache Valley. The dip of the sole of the thrusts in the southwestern Sierra Rica appears to vary between 5 and 25 degrees to the southwest, whereas the thrust soles exposed in Doyle's Peak are essentially horizontal. Some imbrication within the thrust plates was mapped, but more was inferred from the interrupted stratigraphic sequence within the Paleozoic rocks and the presence of gash-fractures (see Figure 17). The bedding in the thrust sheets along the southwest flank of the Sierra Rica dips to the northeast and northwest, implying that the sole of the thrusts cuts obliquely across the bedding.

A singular feature is the double thrust exposed in Doyle's Peak where Pennsylvanian rocks overlie Permian rocks. This is illustrated in Figure 18. Neither of the

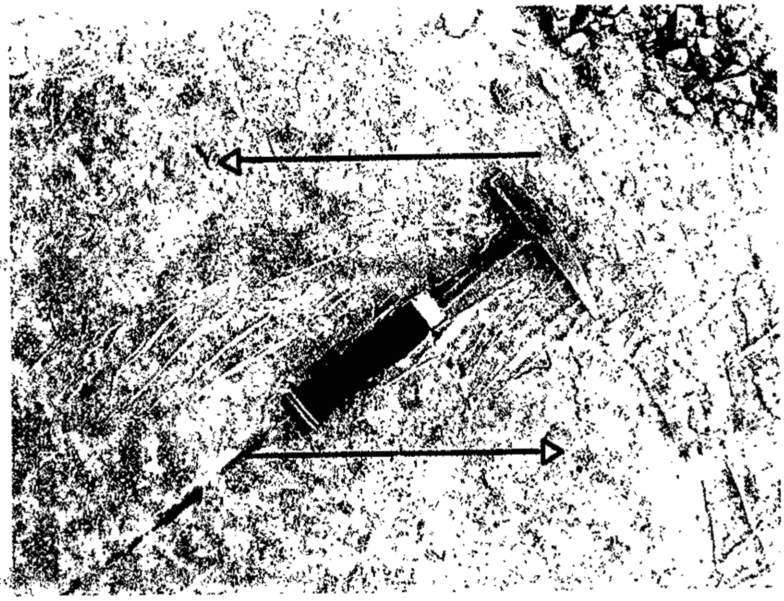

Figure 17. Calcite-filled gash fractures in Paleozoic limestone thrust sheet, suggesting the proximity of concealed imbricate faulting.

Figure 18. Double thrust exposed in Doyle's Peak. View from the southwest. Horquilla Formation (Ph) thrust over Earp Formation (Pe) which is thrust over the Upper Member of the Mojado Formation (Kmu). Latite (Tla) exposed in lower left foreground.

thrust soles are exposed, but this sequence of rocks is interpreted as an imbricate thrust in which the Pennsylvanian beds overrode the Permian beds which acted as a glide plane.

Spectacular drag folding and gouge is exposed locally at the base of the thrusts. The complex fault pattern in the Mojado Formation rocks exposed on the north and west slopes of Doyle's Peak is probably a result of rock fracture under the stress of the advancing thrust plates. Intense fracturing, drag folding, and thrust-fault breccia are exposed in sec. 32, T.29S., R.14W., and fracturing without drag folding is exposed in the southwest corner of sec. 33, T.29S., R.14W.

Locally, the lowermost 3 feet of the limestone thrust sheets have recrystallized to a white calcite spar with individual crystals as large as 8 inches in length (see Figure 19). For the most part, however, the rocks above the sole of the thrusts does not exhibit marked gouging. This is in sharp contrast to the sediments beneath the sole of the thrust. Locally, the Mojado Formation quartzite has been crushed to a depth of 4 feet below the fault contact. The crushed material ranges in size between powder-size and 2-inch angular blocks, and is cemented by silica (see Figure 20).

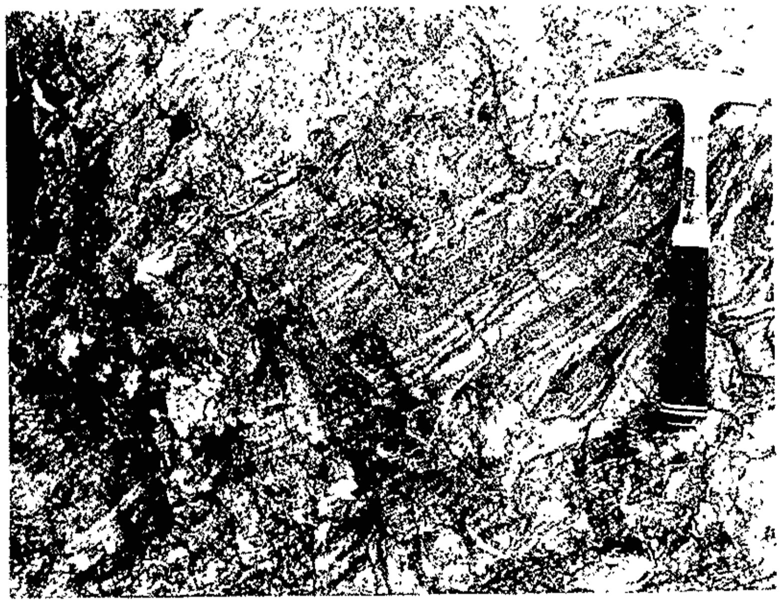

Figure 19. Bands of recrystallized calcite in Escabrosa limestone immediately above the base of the thrust in sec. 32, T.29S., R.14W.

Figure 20. Fault gouge and breccia in Mojado Formation quartzite below the base of the allochthonous limestone thrust sheet in sec. 32, T.29S., R.14W.

High-angle Normal Faulting

A zone of high-angle normal faulting extends diagonally across the area covered by this report. Entering the area about 1 mile north of border post no. 42 (see pl. 1), the fault zone extends in a west-northwesterly direction through the Sierra Rica, and changes to a northwesterly direction in the northwestern part of the area mapped. The fault zone parallels the trend of the anticlinal axis which runs through the Apache Valley. The following phenomena are presented as evidence for the fault zone: Drag folding and slickensides exposed in the eastern half of sec. 19, T.29S., R.14W.; repetition of the stratigraphic sequence at many localities within the Apache Valley and northern Sierra Rica; multiple subparallel slickensided, dragfolded shear zones in sec. 28, T.29S., R.14W.; a brecciated fault contact between U-Bar Formation limestones and Mojado Formation quartzites in the center of sec. 35, T.29S., R.14W.; and the sinuous latite dike which transects the rocks in the eastern half of the area mapped, and which, over much of its length, has intruded along the fault zone. Strongin (1958, pl. 1) does not show this fault. However, most of his mapping was conducted in the Apache Hills, and his map of the northern Sierra Rica should be considered to be a preliminary sketch map. Zeller (1958, pl. 7, section C-C') indicates the fault as a high-angle reverse fault with the Mojado Formation and upper

U-Bar Formation moved northwards, presumably as a decollement-type structure contemporaneous with the introduction of the allochthonous Paleozoic rocks during a compressional episode. However, Zeller (oral communication, 1969) stated that his evidence is based on a small area of outcrop exposed in a ravine in the southwestern portion of sec. 35, T.29S., R.14W. The writer had visited this area and had also recorded an apparent thrust relationship, but as this relationship was not compatible with the strong evidence for high-angle normal faulting, and as it is a feature too small to indicate on the geologic map, it is not dealt with any further.

Exposed slickensided fault planes in secs. 19, 28, and 35, T.29S., R.14W., have a dip of 60 degrees to 80 degrees in a northeasterly direction. The vertical displacement along the fault zone was calculated by using three independent sets of data. (It was assumed that the anticline was fairly symmetrical prior to faulting.) The data used for calculating the displacement were: a) a coquina marker horizon present in the Mojado Formation in the southwestern part of sec. 19, and repeated in the northeastern part of sec. 19, T.29S., R.14W., in the downfaulted Mojado Formation quartzite; b) the two limestone-granule marker horizons 850 and 1000 feet respectively above the U-Bar Formation-Mojado Formation contact, exposed in the southwestern part of sec. 34 and repeated in the faulted section in secs. 27 and 35, T.29S., R.14W.; and c) the prominent sandstone chosen as the contact between the Mojado Formation and the U-Bar Formation exposed in sec. 34 and repeated by faulting in sec. 35, T.29S., R.14W. Vertical displacement calculated from the above data gave the following three values; 2550 feet, 2700 feet, and 2600 feet. Strongin (1958, pl. 1) indicates a fault along the southern flank of the Apache Hills, the "Apache fault." This fault was located by the writer and is indicated on the geologic map (pl. 1) in the extreme northeastern part of the area mapped where Lower Cretaceous limestones are in contact with Tertiary rhyolite flows. Strongin's "Apache fault" is parallel to the fault which transects the Sierra Rica, and is also a high-angle normal fault. Strongin (1958, p. 89) suggests that the "Apache fault" was responsible for the uplifting of the Apache Hills and that it is a Basin and Range-type fault of Miocene age. It is possible that the "Apache fault" and the fault in the Sierra Rica may be of the same age. However, geophysical data presented later in this report suggest that the high-angle normal fault which transects the Sierra Rica may be older than the (dated) early Tertiary granite exposed in the southeastern part of the area mapped. These faults post-dated the compressive forces which caused the folding and thrusting in the Sierra Rica and are the expression of taphrogenic forces which caused the down faulting of the rocks in the Apache Valley.

An example of a high-angle normal fault with a very large vertical displacement is the Basin and Range-type fault which separates the Sierra Rica and Apache Hills from the Big Hatchet Mountains and Little Hatchet Mountains. Figure 21 illustrates the structural relief between the Big Hatchet Mountains and the Sierra Rica. This fault is nowhere exposed, except possibly in the Hatchet Gap, between the Little Hatchet and Big Hatchet Mountains, where allochthonous (?) Pennsylvanian limestones are in contact with Precambrian granite. The presence of the fault is inferred from the physiography of the Big Hatchet Mountains and the structural relief between the autochthonous (?) rocks in the Big Hatchet Mountains and the autochthonous rocks in the Sierra Rica. All of the above mentioned faults have a structural style typical of "Basin and Range" tectonics and it is possible that they are all of the same age.

Minor High-angle and Lateral Faults

High-angle normal faults in secs. 25, 26, 35, and 36, T.29S., R.14W., probably formed contemporaneous with the major high-angle normal fault which transects the Sierra Rica. Displacements along these faults appear to be small, the maximum displacement as inferred from a cross-section (pl. 2, section D-D') is less than 300 feet. This portion

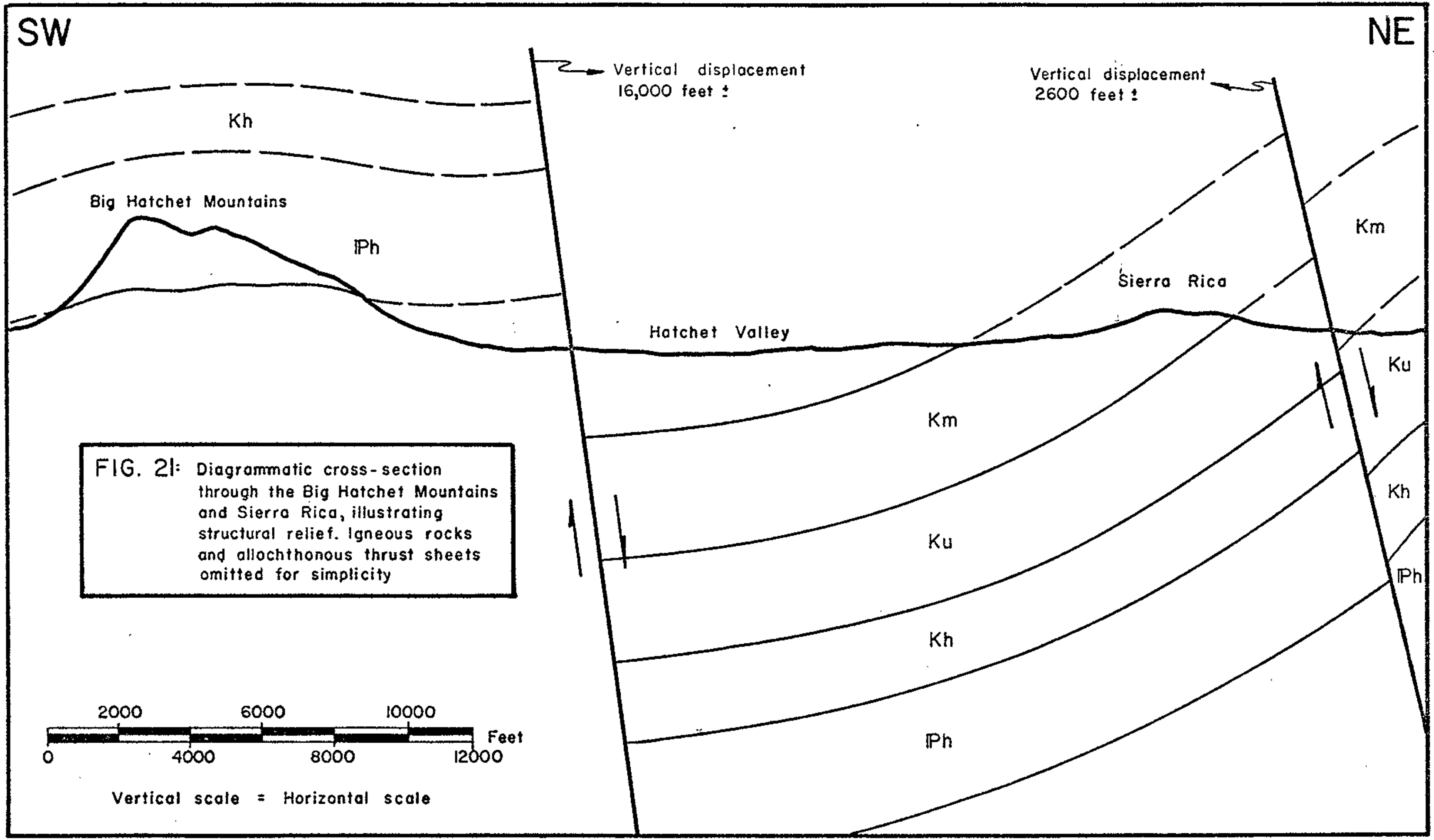

FIG. 21: Diagrammatic cross-section through the Big Hatchet Mountains and Sierra Rica, illustrating structural relief. Igneous rocks and allochthonous thrust sheets omitted for simplicity

of the Sierra Rica appears to have broken into blocks which were not downdropped as much as the rest of the rocks in the northern Sierra Rica and Apache Valley.

Numerous small faults with displacements probably less than 100 feet, both high-angle normal and reverse, and strike-slip, occur along the southwestern flank of the Sierra Rica in the Mojado Formation quartzites and hornfelses. No displacements could be determined on these faults. The sense of movement could be inferred only from slickensides. Many of the small dikes, such as the felsite dikes in the center of the area mapped (see pl. 1) have probably intruded along small fault or shear zones.

A rose diagram constructed from 83 measured orientations of faults and small dikes shows an apparent preferred orientation in a northeast direction (see Fig. 22). However, as this is the orientation of the very prominent felsite dikes, it is felt that a bias has been introduced into the rose diagram; many small shear zones or faults could have been missed because of poor geologic or topographic expression. Neglecting the apparent preferred orientation, the rose diagram shows an even distribution of faults and dikes throughout 360 degrees. An interesting observation however, is that many of the minor faults along the southwestern flank of the Sierra Rica are normal or sub-normal to the strike of the sediments. Horizontal compressive forces operating in a northeasterly direction, such as

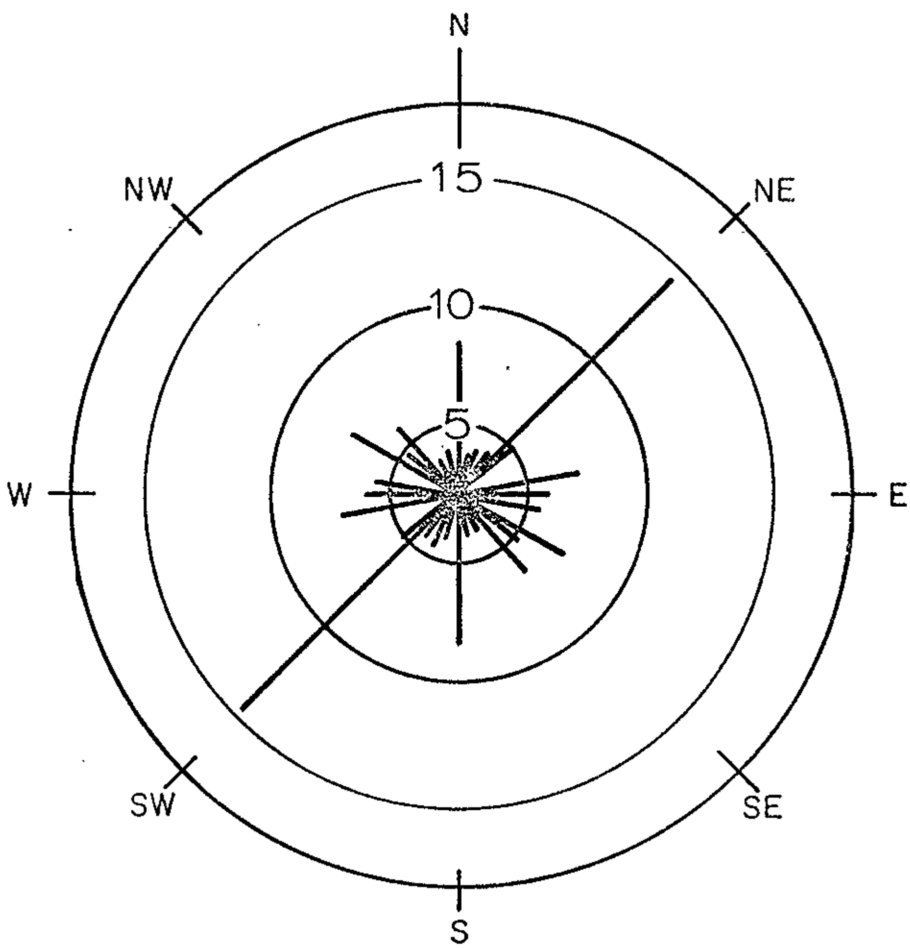

Figure 22. Rose diagram of fault orientations in the Sierra Rica. Eighty-three measurements plotted.

prevailed during the period of folding and thrusting, could be responsible for the attitude of these faults. However, the age of the faults is uncertain. They are at least older than the felsites which intruded along them.

METAMORPHISM

General Features

The Lower Cretaceous rocks in the Sierra Rica differ markedly from their lithologic equivalents in the type-sections described by Zeller (1965) in the Big Hatchet Mountains. Both contact metamorphism and silicification have affected these rocks in the Sierra Rica, whereas they are not metamorphosed in the type-sections. Silicification is included under the heading "Metamorphism" because it can, with some certainty, be related to intrusions of igneous rocks.

Silicification

The quartzose rocks of the Mojado Formation have been silicified throughout the Sierra Rica. Five samples of quartzite were examined in thin section. In all of these samples the cementing material is silica. Kaolin after allogenic feldspar has been partly changed to hydromicas, but the heavy minerals observed, tourmaline and zircon, have not been affected. Figure 23 is a photomicrograph illustrating the texture of the quartzites; some crushing and pressure solution can be seen. Iron oxides are present in most of the samples examined. Some is obviously derived

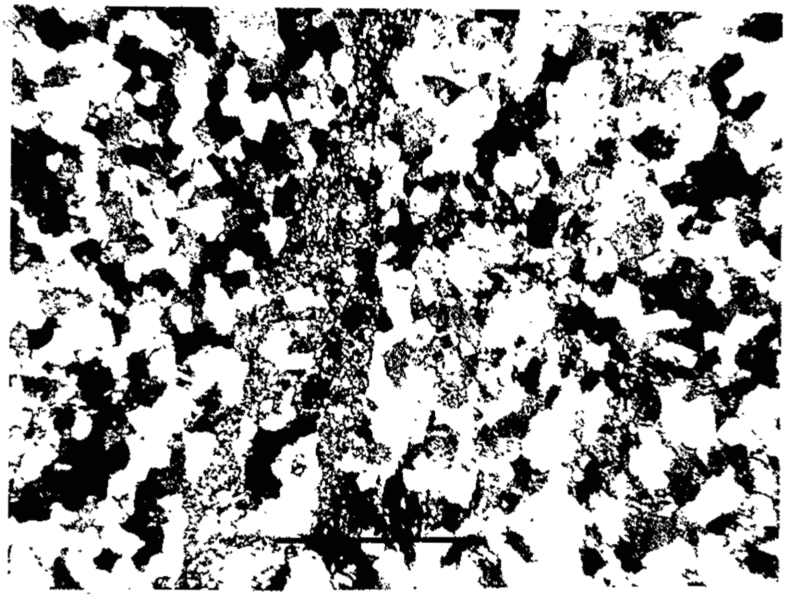

Figure 23. Quartzite, silica cemented, showing crushed zone crossing center of field. Mojado Formation, sec. 26, T.29S., R.14W. Crossed nichols.

from the oxidation of pyrite (see Fig. 24), but much of the iron oxides probably entered the rock through fractures.

The fact that carbonate rocks outside of the metamorphic aureole shown on plate 1 have not been affected by silicification suggests that primary porosity of the rocks (high in sandstones, low in carbonates) was an important control on silicification. Furthermore, apart from fracturing or crystallization of the carbonates in the vicinity of faulting, neither the Paleozoic nor the interbedded Lower Cretaceous limestones show evidence of fracturing which would have resulted during dynamic metamorphism. The pressure solution observed in the quartzites could, therefore, be local features caused by excessive stress during faulting, and not be related to dynamic metamorphism.

Granite outcrops in the southeastern part of the Sierra Rica are associated with contact metamorphism; geophysical data presented later in this report suggest that the Sierra Rica is underlain by a large intrusive. It therefore seems probable that heated siliceous groundwaters rising from an intrusive at depth caused the silicification of the previously-permeable quartz sandstones and siltstones. The carbonate rocks escaped reaction because of their low porosity and possibly because of the relatively low temperature of the rising groundwaters.

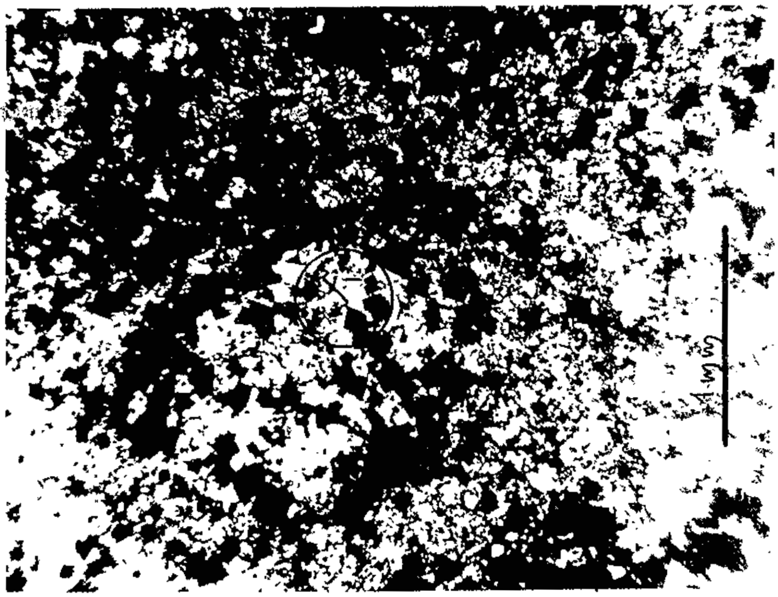

Figure 24. Quartzite with pyrite cubes (Py) oxidizing to hematite and limonite. Mojado Formation, sec. 26, T.29S., R.14W. Ordinary light.

Contact Metamorphism

Contact metamorphism is exposed in the southeastern Sierra Rica (see metamorphic aureole outlined on pl. 1), locally at the contact of the fault-intruding latite dike and the enclosing carbonate rocks, and in the Fremont Mining District, in sec. 25, T. 29S., R.14W. Along the latite dike the metamorphic zone in the carbonate rocks is restricted to a zone which seldom exceeds a few feet in thickness. Where the contact is well exposed a 2- to 8-inch zone of tremolite and diopside tactite borders the intrusive. Pyrite and pyrrhotite occur as disseminated blebs in this contact tactite. The zone of calc-silicates is locally bordered by a coarsely crystalline marble zone of irregular thickness, usually less than 4 feet. The extent of zoning appears to be determined by the pre-metamorphic texture and composition of the carbonate rocks. The calc-silicate tactite in the Fremont District (see pl. 1) does not appear to be related to the small dikes which crop out. Small faults which served as channelways for mineralization probably also served as channelways for heated, metamorphosing fluids emanating from an intrusive at no great depth, perhaps only a few hundred feet.

The contact metamorphic aureole outlined on plate 1 covers an area of 5 square miles, if the area underlain by shallow alluvium is included. The metamorphosed rocks within this aureole are exposed through a vertical interval of

650 feet. Rocks of the Lower Member of the Mojado Formation and all the members of the U-Bar Formation have been affected.

Relict bedding, best exemplified by metamorphosed impure carbonate rocks, and the presence of silicified quartz sandstone beds made mapping of the different units of Lower Cretaceous rocks possible.

Depositional textures and pre-metamorphic composition of the calcareous rocks determined the end-products of contact metamorphism; both in terms of texture and mineralogy. The most characteristic textural feature observed in the metamorphosed rocks is relict bedding, exemplified by mineral layering. Commonly, bands of coarsely crystalline subhedral grossularite alternate with massive diopside. Figure 25 illustrates the fluted appearance of the differentially weathering grossularite-diopside tactite. The same features can be observed on a fresh surface; brown vitreous grossularite contrasts in color and luster with the gray greasy diopside. Figures 26 and 27 illustrate relict stratification in tactite as seen in thin section examination.

No zoning into metamorphic facies was detected in the contact-metamorphic aureole. Alternation between marble and tactites of differing compositions appears to be random and controlled by the pre-metamorphic composition of the rock. On the northwestern side of the aureole, a brown-weathering black rock type crops out. It is characterized by white

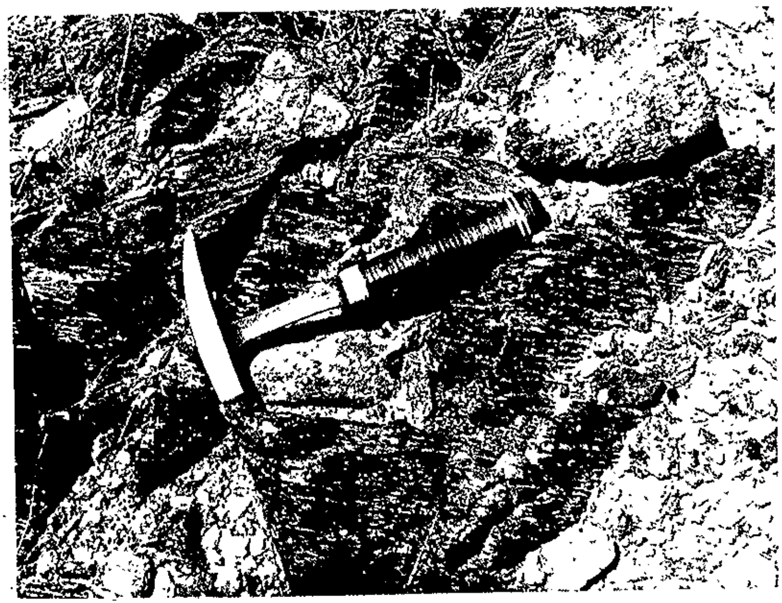

Figure 25. Differentially weathering grossularite-diopside tactite, sec. 13, T.30S., R.14W.

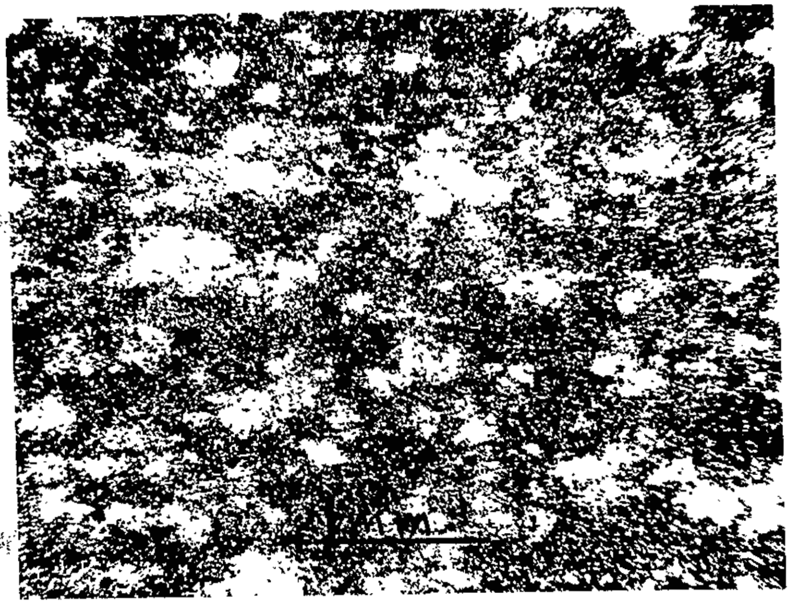

Figure 26. Diopside-scapolite-grossularite tactite, showing relict bedding. Dark areas are diopside and grossularite, light areas are incipient scapolite crystals. From metamorphosed Mojado Formation, sec. 14, T.30S., R.14W. Crossed nichols.

Figure 27. Pyritic diopside-scapolite-tactite, showing relict bedding. Dark bands of diopside alternate with light bands of scapolite. Black blebs are pyrite. From metamorphosed Mojado Formation, sec. 12, T.30S., R.14W. Ordinary light.

nodules with dark brown cores set in a black matrix. The nodules range in size between 1/16 inch and 3 inches. In thin section the brown cores are seen to consist of hornblende, diopside, and clinozoisite, with minor sphene, calcite, quartz, and actinolite. The white rims are sodic and potassic feldspar, and the black matrix is composed of minute biotite crystals and diopside grains in a carbonaceous (?) matrix. This rock is probably a metamorphosed argillaceous limestone. A thin section of a metamorphosed claystone from within the Mojado Formation showed the following mineralogy: Quartz 3 percent, orthoclase 12 percent, sericite 29 percent, biotite 18 percent, cordierite 25 percent, andalusite 10 percent, hematite 2 percent, and traces of leucoxene. This mineralogy indicates a thermally metamorphosed pelitic rock.

Eleven samples of metamorphic calc-silicate rocks collected in secs. 13 and 14, T.30S., R.14W., were examined in thin section. The major metamorphic minerals are diopside, grossularite, plagioclase, scapolite, tremolite, and wollastonite. Minor minerals, present in quantities usually less than 5 percent, are orthoclase, clinozoisite, hydromicas, calcite, quartz, sphene, apatite, goethite, pyrite, pyrrhotite, hornblende, epidote, vesuvianite, and molybdenite. It was noted that samples taken a few feet apart on the outcrop differed greatly in their mineralogy. The major metamorphic minerals fall within the hornblende-hornfels facies of contact metamorphism for this rock type (impure limestone), as defined by Winkler (1967, p. 68). In some specimens diopside ~~and grossularite~~ occur with chlorite, tremolite and clinozoisite. This mineralogy suggests a transition between the hornblende-hornfels facies and the albite-epidote-hornfels facies. These transitional mineral assemblages probably indicate localized conditions of lower temperature, water content or CO_2 pressure. Such localized conditions could have been controlled by differences in the porosity and permeability of the impure carbonate rocks. The presence of minerals such as scapolite, pyrrhotite, and molybdenite suggest that the system may not have been entirely closed, and that a limited amount of allochemical metamorphism may have taken place. Nevertheless, it is possible that the carbonate rocks contained sufficient chlorine (from minor amounts of minerals evaporated) and sulphides (from organic debris) to have formed these minerals. Molybdenite flakes in the tactite (see fig. 28) are not found far from exposures of granite and are probably of pyrometasomatic origin.

The similarity between the tactites of the Sierra Rica and those of the Apache Hills and Little Hatchet Mountains is striking. Furthermore, all three localities show evidence of pyrometasomatic metallization. Copper, lead, and zinc sulphides have been removed from disseminated and

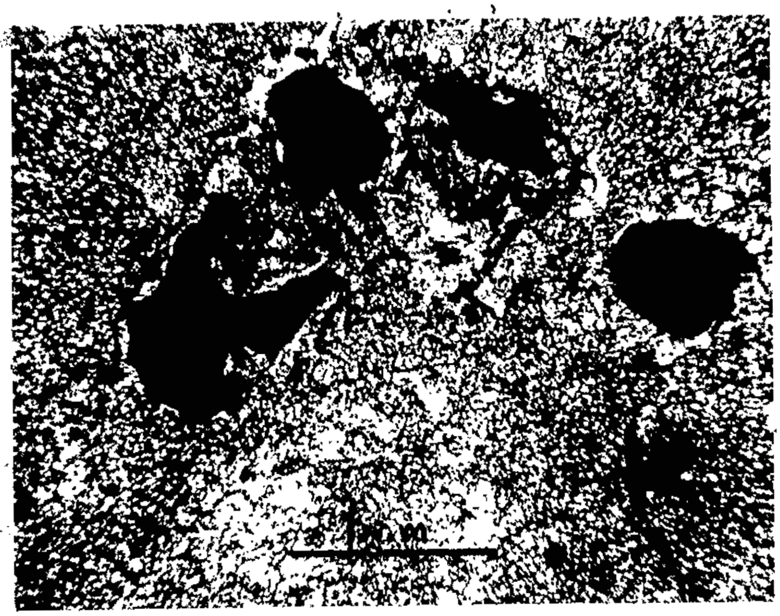

Figure 28. Molybdenite in diopside-grossularite-scapolite tactite, from metasomatized Mojado Formation in sec. 13, T.30S., R.14W. Ordinary light.

fracture-filling ore in the tactites in the Apache Hills. Prospects in the tactites at the southern end of the Little Hatchet Mountains have exposed copper-iron sulphides, molybdenite, and scheelite. Copper, lead, zinc, and silver minerals in tactites have been mined in the Sierra Rica in sec. 25, T.29S., R.14W., and from mines to the east of the international border, in Mexico.

The granite outcrops in secs. 13 and 14, T.30S., R.14W. are no doubt part of a large granitic intrusive which underlies the southeastern Sierra Rica at no great depth. Aeromagnetic and gravity data (see Geophysics) indicate an intrusive trending northwestward through the Sierra Rica. This intrusive is responsible for the contact metamorphism described above, and probably responsible for the silicification observed in the Sierra Rica outside of the metamorphic aureole, where the intrusive rocks are more deeply buried.

MINERALIZATION

General Features

Evidence of mineralization is present at numerous localities in the area covered by this report, and sporadic mineralization occurs throughout this part of southwestern New Mexico. Within a 20-mile radius of the Sierra Rica, base-metal and other mineralization is known in the Little Hatchet and Big Hatchet Mountains, the Apache Hills and in Mexico. Pyrometasomatic scheelite and sulphide deposits, as well as massive hydrothermal replacement and fracture filling base-metal sulphide deposits were worked in the first half of this century. In the Sierra Rica only one district, the Fremont district in sec. 25, T.29S., R.14W., has produced any ore.

Fremont District

This district was described by Lindgren (1910) and Strongin (1958). At the present time the four shafts shown on the geologic map (pl. 1) are inaccessible. However, a number of prospect pits and adits are accessible. The mines are within the Oyster Limestone Member of the U-Bar Formation, which in this locality contains a number of thin beds of calcareous quartz sandstone intruded by few lamprophyre and felsite dikes. The attitude of the rocks along the international border is nearly horizontal, being on the crest of the faulted anticline which runs through the Apache Valley. About 1000 feet west of border post no. 41, the rocks begin to dip steeply in a southerly direction, having been tilted by faulting. Mineralization occurs as massive replacement bands in the impure limestone and as fracture filling veins along minor fault zones. The limestones in the vicinity of the metallized veins and replacement deposits have been metamorphosed to diopside-grossularite tactite. The ore minerals are argentiferous galena, sphalerite, and some chalcopyrite, with oxidation products such as malachite, cuprite, and cerussite. The fracture-filling veins occur in a gangue of iron-oxide stained quartz and coarsely crystallized calcite. The surface expression of these veins is earthy and massive limonite and manganese oxides. Gossan, showing boxwork, if present, was destroyed during prospecting operations. The massive-replacement deposits occur in beds reported to be as much as 3 feet thick (Lindgren et al, 1910). Thin 3- to 6-inch bands of massive galena and sphalerite with minor calcite gangue were observed by the writer in one of the prospect pits. Lindgren et al (1910) has reported a 200 ton shipment of 40 percent lead with 20 ounces of silver per ton from one of the properties; values of 20 percent copper, 15 ounces of silver and 5 ounces of gold per ton from another property; and 4 percent copper and

10 ounces of silver per ton from a third property. Lindgren also reports an analysis of dump material from a fourth property as running 20 percent zinc, 10 percent lead, with some silver. Strongin (1958, p. 194) reports the shipping of an unknown amount of lead-zinc ore by a local resident in 1953. The writer was unable to trace any reliable records pertaining to the tenor of the ore and the amount shipped from the Fremont district. Major mining companies have renewed the interest in the Sierra Rica and Apache Hills, and several independent parties were actively prospecting in the Fremont district during the summer of 1969.

Prospects

Numerous prospect pits and trenches are scattered throughout the central and eastern part of the Sierra Rica. Only four of the prospects show signs of base-metal mineralization. A few prospect pits and one 50-foot shaft have been developed on metallized veins in secs. 27 and 28, T.29S., R.14W., about one mile and two miles southeast of Doyle's Peak, respectively (see pl. 1). The veins are fault and fracture-controlled, and have a steep dip. They are contained within highly-fractured quartzite. The surface expression of the veins is milky quartz accompanied by abundant iron and manganese oxides which stain the quartzite black. The veins contain malachite with traces of chrysocolla, cerussite, and abundant limonite, in a quartz gangue. Sulphide boxwork in limonite, and golden-colored turgite occurs in some of the veins. Cupriferous alunite, and epidote occur in both mineralized and non-mineralized fractures. No ore-grade material has been reported from these prospects, to the knowledge of the writer.

A short adit in the NW¼ of sec. 36, T.29S., R.14W., has exposed some small galena-calcite, massive replacement pockets, together with abundant massive iron oxides, in limestone. This prospect adit is in the proximity of two small high-angle faults, which could have served as channelways for a small lamprophyre dike and the mineralizing hydrothermal fluids. The galena pockets appear to have been exhausted and the ore minerals discarded on the dump.

In the northeastern corner of sec. 13, T.30S., R.14W., some large pits have exposed fractured tactite. The fracture surfaces of the rock are coated with malachite and azurite, but no primary sulphides are in evidence. Iron oxide staining is present, but not abundant.

Barren Veins

Numerous 2-inch to 3-foot iron and manganese oxide veins occur in the eastern part of the Sierra Rica. Prospect pits have been dug on a number of the veins, but no base-metal mineralization has been found. The veins have no preferred orientation and are exposed only over short distances, generally less than 10 feet. The oxides are massive to earthy and are colored red, brown and black. No sulphide boxwork texture was observed in the vein material. Banding within the veins suggests that the oxides were deposited in fractures from colloidal solution in upward-percolating groundwaters. Spectroscopic examination of the vein material shows that they are composed principally of iron oxides and hydroxides, but contain a significant amount of manganese oxides. Trace amounts of copper are detectable in this vein material.

Relation Between Mineralization and Intrusives

The mode and type of mineralization in the Sierra Rica is very similar to that in the Apache Hills and in the Little Hatchet Mountains. However, whereas the hydrothermal activity in the Apache Hills and Little Hatchet Mountains can be genetically related to monzonitic intrusives, the mineralization in the Sierra Rica is not demonstrably relatable to any particular intrusive. No intrusives, other than small lamprophyre and felsite dikes, are known in the Fremont district or near any of the other mineralized sites. Furthermore, in outcrop, none of the igneous rocks exhibit hydrothermal alteration products. Because of the widespread centers of mineralization, it seems probable that the intrusive to which the mineralization is genetically associated must underlie much of the eastern part of the Sierra Rica. It also seems probable that the hydrothermal mineralizing fluids followed permeable zones created by fractures and faults. All of the known centers of mineralization in the Sierra Rica are either on, or in close proximity to, fractures or faults. The most probable source of mineralizing fluids appears to be the granitic intrusive which probably underlies the Sierra Rica. The observed mineralization in the Sierra Rica is of the mesothermal type which suggests that it may have formed as apophyses to a larger hypothermal deposit at depth.

GEOLOGIC HISTORY

Although present in the Sierra Rica as allochthonous thrust sheets only, Paleozoic sedimentary rocks occur throughout southwestern New Mexico and southeastern Arizona, and Paleozoic rocks, in all probability, underlie the Lower Cretaceous rocks exposed in the area covered by this report.

In early Paleozoic time the southwestern part of the United States and the northern part of Mexico became a basin of deposition, an embayment of the Cordilleran geosyncline. In Cambrian and Ordovician time, near-shore shallow-water sedimentation of quartz sandstones and carbonate rocks took place. With deepening water conditions in the geosyncline, the terrigenous sedimentation gave way to marine carbonate deposition with the formation of reef-mound complexes. The Paleozoic history is essentially one of almost continuous carbonate deposition. No Mesozoic sedimentary rocks older than Cretaceous are exposed in southwestern New Mexico or southeastern Arizona. It appears that the basin of deposition may either have ceased to exist towards the end of Paleozoic time, or else the Triassic and Jurassic rocks could have been removed by erosion during an epoch of mountain building or epeirogeny.

In earliest Cretaceous time a new basin of deposition, possibly geosynclinal, developed in southeastern Arizona, southwestern New Mexico and northern Mexico. In the Sierra Rica the record of Lower Cretaceous rocks indicates a sequence of shallow water-deeper water-shallow water marine sedimentation. This sequence is well established in this part of the United States and Mexico (Zeller, 1965). The Hell-to-Finish Formation (not exposed in the Sierra Rica) and the Brown Limestone Member of the U-Bar Formation, composed of quartz sandstones and quartzose limestones, are evidence of near-shore, shallow-water sedimentation. The remainder of the U-Bar Formation, essentially pure fossiliferous limestones with minor amounts of quartz sandstone and shale, testifies to conditions of shallow- to deep-water sedimentation at some distance from the shoreline. Limestones of the U-Bar Formation show evidence of a reef-mound environment of deposition. The U-Bar Formation-Mojado Formation contact, chosen at the point of transition from carbonate sedimentation to terrigenous clastic sedimentation, reflects a regression of the Cretaceous sea. The lithologies, fauna, and sedimentary structures within the Mojado Formation rocks are evidence of near-shore marine, beach flat, and fluviatile environments of deposition. The youngest sedimentary rocks in the Sierra Rica, discounting Quaternary alluvium, have been dated as being of early Cretaceous Washita and Fredericksburg age (Zeller, 1965). Upper Cretaceous sedimentary rocks do not occur in the Sierra Rica or Big Hatchet Mountains, and are not known in this part of

New Mexico or Arizona. The thickness of an incomplete section of Lower Cretaceous rocks in the Sierra Rica is 8500 feet. In the Big Hatchet Mountains the complete Lower Cretaceous sequence is present, unconformably overlying Permian limestones, and is about 9500 feet thick. The 4-cycle sequence of shallow water-deep water-shallow water sedimentation recorded by Lasky (1947) in the Little Hatchet Mountains, and his 17,000- to 21,000-foot thick sequence of Lower Cretaceous rocks do not conform with the regional pattern. As has been previously stated, thrust faulting may have caused the anomalous sequence observed in the Little Hatchet Mountains.

Towards the end of Cretaceous time, or in earliest Tertiary time, the Sierra Rica was structurally deformed. The first phase of tectonism was tangential compression operating in a northerly and north-easterly direction. The anticline of which the Sierra Rica forms the southern limb was caused by this compression. Continued compression caused the development of large imbricate thrust faults. Thrusting in this part of southwestern New Mexico appears to have been from the south and southwest. The allochthonous rocks in the area covered by this report were emplaced during this episode of compression. Zeller (1958, pl. 7) has recorded very complex high-angle reverse faulting and thrust faulting in the Big Hatchet Mountains. The thrust plates which rode over the previously-formed anticline in the Sierra

Rica were probably very thick, possibly as much as 10,000 feet thick, as the allochthonous thrust sheets are not as broken up as would be expected from thin thrust sheets.

Lasky (1947, p. 51) has suggested an idea which is favored by the writer: "It seems safe to conclude that the Big Hatchet Mountains are part of a plate thrust against the younger rocks of the Little Hatchet Mountains."

High-angle normal faulting post-dated the thrusting, resulting in the development of Basin and Range-type block mountains and grabens. The high angle-normal fault which transects the Sierra Rica may be of early Tertiary age; geophysical data presented later in this report suggest that the (dated) early Tertiary granite intruded along this fault zone.

Igneous activity appears to have commenced towards the close of the period of tectonic activity, possibly soon after the high-angle normal faulting had taken place. Mafic and intermediate volcanics of basaltic, andesitic and dacitic-latitic composition were extruded over the eastern half of the Apache Valley. Their topographic position and their relation with respect to the sedimentary rocks suggests that they were extruded as flows over the eroded topography of the Apache Valley. Petrologically similar volcanics in the Lordsburg and Santa Rita mining districts have been dated as Late Cretaceous-early Tertiary.

In Tertiary time the Sierra Rica area was intruded by granite and lamprophyre and latite dikes. The latite and lamprophyre were emplaced as fracture-filling dikes. Rhyolites were extruded as flows and pyroclastics, possibly from fault-fracture channelways.

The contact metamorphism in the Sierra Rica probably took place during and soon after the emplacement of the granitic body. In the Apache Hills and Little Hatchet Mountains monzonitic and granodioritic stocks of Eocene-Miocene age were the precursors of mineralizing events. It seems probable that the granite exposed in the Sierra Rica could be genetically related to these more mafic intrusives. The mineralization in the Sierra Rica post-dated the intrusion of the latite dikes, as evidenced by the mineralized fracture-filling veins to the southeast of Doyle's Peak; mineralizing fluids have invaded those fractures not already filled by latite. Strongin (1958) and Lasky (1947) have presented evidence to show that hydrothermal activity in the Apache Hills and Little Hatchet Mountains occurred in pulses. Unfortunately no such evidence is readily detectable in the area covered by this report.

Minor quartz latite and felsite dikes of uncertain age, arbitrarily assigned to the upper Tertiary, and rhyolitic volcanics which are probably Miocene-Pliocene in age, conclude the Tertiary igneous activity in the Sierra Rica. Similar late-Tertiary post-mineral rhyolitic volcanics occur in the Apache Hills, Little Hatchet Mountains, and the Lordsburg and Santa Rita mining districts. The quartz latite, felsite, and rhyolite could be indicative of renewed pulses of magmatic activity in this part of New Mexico, and may be related to tectonic adjustments during the formation of the Basin and Range physiographic and structural province.

The youngest igneous event in the Sierra Rica was the extrusion of Quaternary-age basaltic lavas. Although present in only two small outcrops in the Sierra Rica, it is possible that these lavas could have covered much of the Sierra Rica and surrounding countryside. Extensive fields of Quaternary basalt are still present in the Alamo Hueco Mountains, to the south of the Big Hatchet Mountains, and in Mexico. A prominent mesa of this basalt can also be seen a few miles to the east of Hachita.

The Youngest unit mapped in the Sierra Rica is alluvium which fills the structural basins of the Basin and Range province.

GEOPHYSICS

General Statement

As part of a regional reconnaissance program in southwestern New Mexico, Phelps Dodge Corporation had undertaken gravity surveys and aeromagnetic surveys during the latter part of the 1960's. Gravity and magnetic anomalies obtained over the area covered by this report were followed up by induced polarization survey for the following reasons:

1) Gravity data showed substantial areas of shallow alluvium cover, and suggested the presence of intrusives.
2) Aeromagnetic data suggested the possible presence of buried intrusives.
3) Sporadic base-metal mineralization in the Sierra Rica and surrounding ranges suggested that large mineralized intrusives might underlie this area.

During 1968 and early 1969, 165 line-miles of induced polarization survey were run by Phelps Dodge in the area covered by this report. The presence of induced polarization anomalies delineated during the survey could not be explained by a superficial examination of surface geology. The chief geologist and chief geophysicist of the Corporation therefore presented this as a problem suitable for a thesis study, in the hopes that geology and geochemistry might throw some light on the cause of the induced polarization anomalies. The geochemical investigation of the Sierra Rica is discussed later in this report.

The geophysical data contained in this report were made available to the writer by Phelps Dodge Corporation.

Magnetic Data

Plate 3 shows the results of an aerial magnetic survey which includes the mapped area, outlined by a heavy line on the magnetic contour map.

A very prominent magnetic pattern occurs over this area; magnetic highs in the northwestern and southeastern corners of the mapped area are connected by a "saddle" of relatively high magnetic values. The highly irregular magnetic patterns in the southwestern and northeastern corners of the mapped areas are interpreted as indicating volcanic rocks, some of which can be observed in the field as windows in the alluvium.

The magnetic high in the southeastern corner of the mapped area coincides with the location of granite outcrops. As no other large intrusives are known in this area it seems safe to conclude that the northwesterly-trending magnetic belt is the reflection of a buried granitic intrusive which underlies the Sierra Rica.

Gravity Data

Plate 4 shows the results of a gravity survey which includes the mapped area. As in the case of the magnetic survey, the dominating feature is a northwesterly-trending belt of relatively high gravity values. A most interesting fact observed is that when the gravity and magnetic maps are superimposed, very close agreement between the contour trends is seen to exist, notwithstanding the fact that the contour lines represent completely different properties of the rocks. The gravity map substantiates the idea that the Sierra Rica is underlain by a large intrusive. From the trend of the gravity and magnetic contours (see Plates 3 and 4), it appears that the trend of the intrusive closely parallels the trend of the high-angle normal fault which transects the mapped area. It therefore seems probable that the intrusive invaded this fault zone at depth.

Induced Polarization Data

The induced polarization anomalies are shown as a shaded pattern on Plates 3, 4, and 5. The induced polarization data were gathered from north-south traverse lines at one mile separation, with stations at 12,000-foot centers along the traverse lines. Moveout distances along these lines were at 1000-foot intervals. Over the areas covered by the magnetic highs, an induced polarization grid was set up, with stations at 6000-foot intervals and readings were taken at 500-foot moveout intervals.

Three anomalous areas were outlined (see plate 5). The most prominent anomaly varies in width between 1000 and 7000 feet, and extends along a northwesterly trend through the Sierra Rica for a distance of over 7 miles. To the southeast of this anomaly a 1000-foot wide banana-shaped anomaly extends out of the area mapped. Part of this anomaly extends over the granite outcrop exposed in the southeastern part of sec. 13, T.30S., R.14W. The third anomaly, in the northeastern part of T.30S., R.14W., has not been outlined in detail. It is drawn on the basis of data gained from traverse lines which entered this area from the north and from the south.

The striking feature of the linear induced polarization anomalies is that they follow the belts of northwesterly-trending magnetic and gravity anomalies. At a superficial glance they appear to be subparallel to the geologic trend also. However, on closer inspection, the linear belts of induced polarization anomalies are seen to have a cross-cutting relationship with geologic features such as the strike of the sedimentary rocks, and faults. It should be noted that no anomalies occur over the areas of known mineralization. The following four possible causes for the anomalies are presented:

1) Water-rich fracture zones.
2) Syngenetic minerals such as carbon, or metamorphic graphite.

3) Contact metamorphic minerals such as tremolite and actinolite.

4) Sulphide mineralization, possibly localized in a pyrometasomatic contact zone.

In the northwestern part of the mapped area the induced polarization anomaly occurs over an area where apparently barren quartzites crop out. The depth to the top of the responsive body appears to be about 1100 feet, and the response is characterized by moderate to high resistivities and high polarization effects.

The anomaly in the southwestern part of sec. 11, T.30S., R.14W., is characterized by low resistivities and high polarization effects, and the depth to the top of the responsive body appears to be in the order of 300 feet. The outcrop over this area consists of faulted and fractured quartzites with interbedded claystone and occasional quartzose limestone beds. The low resistivities may be due to water-filled fractures.

The anomaly in the southern part of sec. 13, T.30S., R.14W., is characterized by high resistivities and moderate polarization effects. The depth to the top of the responsive body appears to be about 400 feet. Outcrop in the area consists of pyritic and molybdenitic grossularite-diopside-tremolite tactite, and granite.

The anomaly in the southeastern part of sec. 1, T.30S., R.14W., is characterized by moderate to high resistivities and moderate to high polarization effects. The depth to the top of the responsive body appears to be about 500 feet. Outcrop in the area consists of pyritic scapolite-diopside tactite.

Two of the areas contain tremolite and fractured quartzites respectively, and two of the areas contain pyritic tactite. These factors could have some influence on the induced polarization results. Although plant material is fairly common throughout the Mojado Formation, no carbonaceous or graphitic shales were observed in the outcrop.

Therefore, it seems reasonable to assume that the induced polarization anomalies may be a reflection of sulphides at depth. However, the possibility that the anomalies may be caused by contact metamorphic minerals such as tremolite and actinolite cannot be discounted.

GEOCHEMISTRY

General Discussion

Rock, soil, stream sediment, and plant samples were used in the geochemical investigation of the Sierra Rica. It was hoped that these geochemical samples would indicate traces of mineralization not visible on the outcrop, and possibly the presence of secondary dispersion halos emanating from concealed metallization. Lithologies, mineralization, soils, and vegetation have been discussed. A brief reiteration of soil types follows: Over areas of outcrop, soil cover is skeletal, calcareous, and seldom exceeds a thickness of more than 18 inches. In general, a veneer of windblown sand is admixed with the thin layer of organic-rich A-horizon soil, and is immediately underlain by C-horizon weathered bedrock material. In areas of alluvium (see Qal, pl. 1), the material consists generally of caliche-cemented gravels.

A limited amount of geochemical data has been collected in the southwestern United States (Bloom, 1966; Canney, 1963; Cooper and Huff, 1951; Erickson and Marranzino, 1960; Graf and Kerr, 1950; and Lovering, Huff, and Almond, 1950). These workers have shown that in general, the arid southwest poses problems in geochemical exploration; principally because of the restrictive effect of the calcareous environment on the secondary dispersion halo of heavy-metal mineralization.

During this study the writer collected 1125 samples. In addition to these, the writer had available the data from 592 samples which had been collected by Phelps Dodge Corporation. Determination of copper, lead, zinc, and molybdenum by different analytical methods from a total of 1717 samples resulted in slightly more than 7100 pieces of information. As the area of geochemical sampling does not exceed 25 square miles, the sample density is about 69 samples per square mile.

The geochemical information is presented under the following headings: Sample collection; sample analysis; and interpretation of geochemical data.

Sample Collection

Sample collection can be subdivided into the following five categories: Claim-validation drillchip samples; lithogeochemical samples; pedogeochemical samples; stream sediment samples; and biogeochemical samples.

Claim-validation Drillchip Samples

During the latter part of 1968 and early part of 1969, Phelps Dodge Corporation staked 592 claims in the area covered by this report. As required by New Mexico mining law, each claim had to be validated by excavation of a 10-foot prospect trench or a 10-foot drill hole. The drilling was done with a percussion-type shothole drill to a depth of 10 feet on either the east-central or west-central side of each claim. About 1 lb. of drillchip material was gathered up at the mouth of the drillhole on completion of the drilling. The location of each claim-validation drillhole is indicated on Plate 5. Unfortunately, no record of the material being drilled was available to the writer.

Lithogeochemical Samples

Of 200 lithogeochemical samples collected, 61 were collected on the geochemical grid in sec. 13, T.30S., R.14W. The locations of these 61 samples are shown on Plate 6. The remaining 139 lithogeochemical samples were collected over an area of about 25 square miles in the Sierra Rica and Apache Valley. Appendix 1 on page 140 shows the location, by section, of each sample, and the lithology. A great variety of samples was collected in order to establish trace-element background values for different lithologies. Vein material, fault gouge, and fractured samples were collected in order to determine their trace element content. About 1 lb. of chip samples were usually taken from each sample site. Care was taken to ensure that composite samples of fractured rocks contained as large a fracture-surface area as could be obtained by chip sampling methods. Weathered and fresh rock were sampled separately.

Pedogeochemical Samples

Two traverses were laid out to cross the induced polarization anomalies (see pl. 5). The reasons for sampling along these lines were twofold:

1. To conduct an orientation survey in order to evaluate the type of materials available for sampling and the heavy-metal background concentrations for different soil types, and
2. to see if the induced polarization anomaly had any geochemical expression in the overlying soils. Both residual and alluvial soils were sampled as part of the orientation survey. Line 1 ran from the top of the hill in the center of sec. 25, T.29S., R.15W., in a northeasterly direction to a point about 1000 feet southwest of the northeast corner of sec. 19, T.29S., R.14W. The traverse started on allochthonous limestone, crossed the alluvial material deposited by Doyle Creek, and continued over Mojado Formation quartzites and hornfelses with intrusive latite dikes. Soil samples were taken at 100-foot intervals. Sampling depth varied; over the quartzites and limestones, C-horizon soil was encountered at less than 6 inches depth. This material was sampled. In the alluvial material an arbitrary depth of 6 to 9 inches was chosen for sampling. In this manner surface windblown sand and organic matter were avoided. The alluvial soil is uniformly calcareous to a depth of at least

3 feet. Samples were screened to pass 40 mesh (Tyler) in the field. A steel kitchen sieve was used for the field screening.

Line 2 ran along the United States-Mexico border fence from the southeast corner of sec. 13, T.30S., R.14W., northward to the point in sec. 36, T.29S., R.14N. where the border road forks (this end of the traverse coincides with stream sediment sample station no. 40, see plate 5). Samples were taken at 100-foot intervals along this traverse as far as the northeast corner of sec. 13, T.30S., R.14W., and at 200-foot intervals to the north of this point. The sampling depth and screening methods used were essentially the same as those used on line 1. Appendix 2 records the distance from the start of each traverse, and soil and rock type.

In a separate study over the tactite on the isolated hill in sec. 13, T.30S., R.14W., 263 soil samples were collected on a 20 x 100-foot grid. The location of these samples is shown on the geochemical grid map, Plate 6. These samples were taken in C-horizon soil, below the pebbly caliche layer which forms a 3-inch thick blanket immediately below the surface of this admixed residual-transported soil. Depth to bedrock varied between 6 inches and 18 inches, and averaged about 9 inches. Samples were taken immediately above bedrock, and screened to pass 40 mesh.

Stream Sediment Samples

Plate 6, a drainage map of the Sierra Rica, shows the location of stream sediment sample stations. A total of 330 stream sediment samples were collected from 126 sample stations, averaging 2.6 samples per station. The actual number of samples taken at any one station ranged between one and eight. The number of samples taken at any one station was determined by (i) the type of drainage, and (ii) the type of material in any particular drainage. In ill-defined braided stream-type drainages, a number of samples were taken across the drainage; one for each of the main drainage channels. In drainages that contained both channel and floodplain-sediments, samples of each type of material were collected. All samples, with the exception of wet mud samples, were screened to pass 40 mesh at the sample site. Wet mud samples were dried, pulverized, and screened in the base camp. Appendix 3 lists the number of samples taken at each station.

Biogeochemical Samples

The flora within the mapped area has been described. Figure 2 illustrates the commonest flora in the area, greasewood scrub. Mesquite, which has been used in geochemical exploration in the southwestern United States (Huff, 1963) was not examined in this study because it is generally restricted to areas of thick alluvium. Plants growing on bedrock were examined. Of these, ocotillos (Fouquiera family), thin stemmed thorny xerophytic plants showed an apparently anomalous growth distribution. They characteristically grow only on limestones or very calcareous gravels. These plants grow in profusion on the limestones in southwestern New Mexico and southeastern Arizona (the hills around Tombstone and Bisbee are covered by dense growths of octillo, and locally, this species is planted along fence lines to form an impenetrable barrier to animals). It was noted in the Sierra Rica that anomalous concentrations of ocotillo grow on fractured quartzites in the least calcareous part of the mapped area. Very few specimens of ocotillo were encountered on unfractured quartzites. Figure 29 shows an anomalous concentration of ocotillo growing on fractured quartzite near the prospect pit in sec. 27, T.29S., R.14W.

Six specimens from sec. 27, T.29S., R.14W., and six specimens from the allochthonous limestone on the east slope of Doyle's Peak, sec. 21, T.29S., R.14W., were sampled. Six 3- to 4-inch cuttings of fresh-growth materials were taken from each specimen in such a manner that each side, as well as the center of the plant, had been sampled. The six samples cut from one specimen were composited and sun dried. In addition, composite soil and rock-chip samples were taken around the base of each specimen sampled. Root

Figure 29. Anomalous growths of ocotillo (_Fouquieria_ family) on fractured quartzites in SW¼, sec. 27, T.29S., R.14W.

material was not sampled because its heavy wood texture was not amenable to rapid ashing.

Sample Analysis

A number of different methods of sample preparation and sample analysis were tried; either singly, or in combination, for any particular sample. The different types of preparation and analysis procedures are described below. Atomic absorption and colorimetric analysis were done by the writer in the Phelps Dodge laboratories in Douglas, Arizona. All other analyses were done by the staff of the Phelps Dodge geochemical laboratory and by commercial laboratories.

Sample Preparation

All samples were sun-dried before entering the laboratory. Lithogeochemical samples were ground in a rotary-type ceramic-plate crusher after primary crushing in a manganese-steel jaw crusher. A minimum of 20 grams of -200 mesh powdered sample was collected from the ceramic crusher. One batch of 150 selected soil and stream sediment samples was crushed to pass 200 mesh by the above process.

Soil and stream sediment samples were screened to pass 80 mesh in stainless steel sieves. A number of samples were selected and screened to -80 mesh, -120 mesh, and -200 mesh, in addition to the -40 mesh field screening, so that four size fractions were obtained from each of these samples.

Except for the field screening, all samples were screened through stainless steel Tyler screens.

Weighing of biogeochemical samples was carried out on an analytical balance, and weights were recorded to the fourth decimal place. An accurate balance was used for these weighings to avoid the excessive error which could have resulted when weighing heavy nickel crucibles containing small quantities of plant ash on a single beam balance. All other samples were weighed on a single beam balance having a sensitivity of 10 mg. The weighing error was less than 10% at the 90% confidence level. Scooping of samples in a specially constructed 0.2 g scoop was attempted, but abandoned because variation in sample material caused significant variation in the weight of scooped samples.

Ashing of biogeochemical samples was done at 400°C in nickel crucibles in a muffle-furnace. Ashing time was approximately 8 hours. The samples were cooled in dessicators and weighed. Ashing was repeated until constant weight was achieved.

The following four methods of soil sample digestion for colorimetric and atomic-absorption analysis were tested on 0.2 g samples in 18 x 150mm test tubes:

(i) 5 ml 40% HF + 3 ml 95% H_2SO_4

(ii) 5 ml 60% $HClO_4$ + 5 ml 100% HNO_3

(iii) 5 ml 50% HNO_3

(iv) 5 ml 25% HNO_3

The samples were digested cold for 25 minutes, then simmered on a hotplate for 30 minutes, cooled, and diluted to 10 ml with demineralized water. Aliquots for metal determination were taken from the diluted digested samples. It was found that the perchloric acid-nitric acid digestion gave good reproducible results. This method was therefore used for most of the sample digestions as it was amenable to batch analysis, and it was not hazardous, providing that organic matter was eliminated from the samples by digestion with a few drops of nitric acid prior to the addition of the perchloric acid.

Experimental data gathered from the x-ray apparatus used in this study indicate that at the 95% confidence level the error is less than 15% in the following concentration ranges for copper, lead, zinc, and molybdenum: Cu 25-1000 ppm; Pb 25-1000 ppm; Zn 0-400 ppm; and Mo 50-1000 ppm.

Atomic Absorption Analysis

A Jarrel-Ash model 82 was used for atomic absorption analysis. Air was used as oxidant and hydrogen as fuel. The sensitivities for copper, lead, and zinc were as follows: Cu 1 ppm; Pb 5 ppm; Zn 1 ppm.

Colorimetric Analysis

Because molybdenum is not amenable to analysis by atomic absorption methods using air as oxidant and hydrogen as fuel, molybdenum in the digested samples was determined colorimetrically. The colorimetric method used was essentially the same as that described in U.S. Geological Survey Bulletin 1152 (Ward, Lakin, Canney, and others, 1963, p. 62). However, a 0.5 gm sample was used instead of a 0.1 gm sample, and acid volumes were increased from 1 ml to 2 ml of H_2SO_4, and from 1 drop to 3 drops of HNO_3. These modifications resulted in a sensitivity of 1 ppm.

Interpretation of Geochemical Data

Before reviewing the geochemical data as a whole, the interpretation and evaluation of the data obtained from the different types of samples will be discussed in the following order: Claim-validation drillhole data; lithogeochemical data; pedogeochemical data, and biogeochemical data.

Claim-validation Drillhole Data

Plate 5 shows the location of each drillhole, and the values of copper, lead, zinc, and molybdenum, where determined.

An inspection of the data shows that they can be divided into two sets; a northwestern set where the drillhole numbers are prefixed with a W, and a southeastern set where the drillhole numbers are prefixed with a C. The reason for this grouping is that each set was analyzed by different methods in different laboratories. The values from the W-prefixed drillholes were determined by atomic absorption methods in the case of copper, lead and zinc; and by colorimetric methods in the case of molybdenum. The values from the C-prefixed drillholes were determined by x-ray fluorescence.

The metal values from adjoining W-drillholes seldom differ by more than 50 percent, and 88 percent of the values differ by less than 25 percent. Assuming that adjoining drillholes were drilled into the same material, the variation of less than 25 percent indicates sound geochemical data. At this level of concentration of trace elements (copper averages 14 ppm, zinc averages 35 ppm, and molybdenum averages less than 1 ppm), a 25 percent variation between "identical" samples is minimal.

In sharp contrast to the W-drillhole data, the C-drillhole data are far less precise. Fewer than 10 percent of neighboring drillhole sample metal values differ by less than 25 percent, and 27 percent of the metal values differ by 100 percent or more. The non-reproducible nature of these data is attributable to the relatively poor sensitivity of the x-ray instrument.

Figure 30 illustrates the difference in distribution between the C- and W-drillhole data for copper. The other metals common to the two sets, zinc and molybdenum, show

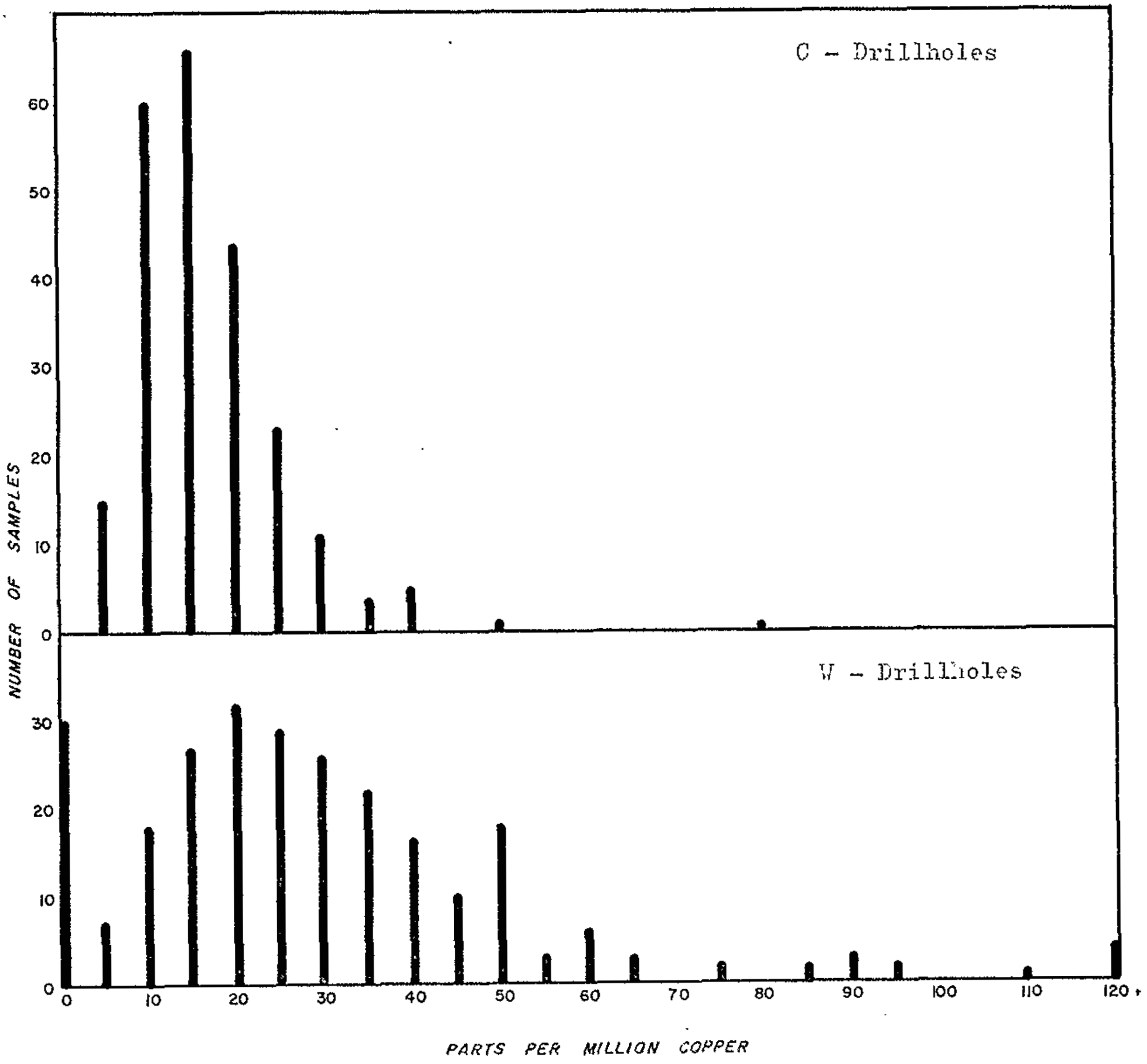

Figure 30. Frequency distribution of copper concentration in 494 drillchip samples from claim validation drillholes. Location of C- and W-drillholes shown on plate 5.

the same type of distribution.

From a geochemical exploration viewpoint, the data from the validation drillholes may be used for determining generalized regional backgrounds for copper, lead, zinc, and molybdenum. The anomalous value of 44 ppm molybdenum at W-359, on the southern border of sec. 25, T.29S., R.14W., is probably erroneous, as no validation hole could be found at this site.

Lithogeochemical Data

The data gathered from trace element analysis of rock chip samples are divided into two groups: the data from the geochemical grid over the isolated hill in sec. 13, T.30S., R.14W., and the data from the remainder of the area covered by this report.

Sixty-one lithogeochemical samples were taken on the geochemical grid (see pl. 6); a sample was taken wherever bedrock cropped out along the soil sample traverse lines. Except for the fractured quartzite on the western side of the hill, and a small area of granite outcrop and a few minor dikes, the hill consists of diopside-grossularite tactite. Pyrite and pyrrhotite blebs and flakes are disseminated throughout the metamorphosed limestone; the presence of minor amounts of chalcopyrite and molybdenite was the motivation for laying out a large-scale geochemical grid over this area.

The samples were analyzed by x-ray fluorescence and a number of replicate analyses by atomic absorption were undertaken, after sample digestion by the hydrofluoric acid-sulphuric acid method described on page 121. The latter, when compared with the x-ray analyses, showed poor correlation. However, as the nitric acid-perchloric acid digestion was not successful in taking the tactite into solution, and as the sulphuric acid-hydrofluoric acid digestion was too hazardous for batch analyses, no further chemical analyses were tried on these samples.

In the data reported on the geochemical grid, only values greater than 30 ppm are shown; only two samples contained more than 30 ppm molybdenum; line H, sample 6 east, and line F, sample 8 west. The reason for the 30 ppm cutoff is because of poor reproducibility of the x-ray method below 50 ppm.

Copper values range from 0 ppm to 740 ppm, lead values range from 0 ppm to 220 ppm, and zinc values range from 10 ppm to 350 ppm. An inspection of the plotted lithogeochemical data (see pl. 6) shows that the values are somewhat erratic. This is due to the fact that more than 60 percent of the values reported are close to the sensitivity of the instrument, and these values are therefore not reproducible.

Appendix 1 lists the location, lithology, and Cu, Pb, Zn, and Mo content of lithogeochemical samples as determined by x-ray fluoremetric analysis.

The geochemical analysis of rock chip samples for trace elements served two purposes: (1) An evaluation of trace metal background values, and (2) an assay of vein material, altered rock, and visible mineralization. Background values can be obtained by averaging the analyses for any particular rock type. For example, fractured quartzites with no visible alteration, veining, or oxide staining, have an average of 30 ppm Cu, 80 ppm Pb, 65 ppm Zn, and 10 ppm Mo (10 samples averaged). These data can be contrasted with the data obtained from fractured iron oxide-stained or mineralized quartzite. An average of the analytical data from 13 altered or mineralized samples, of which the localities are listed in Appendix 1, gave the following metal concentrations: 120 ppm Cu, 1100 ppm Pb, 190 ppm Zn, and 15 ppm Mo. An assay of mineralized rock by x-ray fluorescence generally gave reproducible results, as the metal values in such samples were usually greater than the sensitivity of the analytical method.

Pedogeochemical Data

The pedogeochemical data can be divided into two groups: soil sample traverse data (see Appendix 2), and geochemical grid data.

Appendix 2 shows the position along the soil sample traverse lines, soil type, rock type, and copper, lead, and zinc values, as determined by atomic absorption analysis, after sample digestion in 25% nitric acid.

Figure 31 shows the distribution of heavy metal concentrations in residual soils collected over limestone and quartzite along soil sample traverse lines 1 and 2. The residual soils over limestone have higher heavy-metal concentrations than those over quartzite, notwithstanding the fact that the limestone has a lower heavy-metal content than the quartzite. The following averaged values of copper, lead, and zinc from 10 unmineralized limestone samples are compared with the averaged values obtained from 10 unmineralized quartzite samples, shown in parentheses: Cu 15 (30) ppm, Pb 45 (80) ppm, and Zn 45 (65) ppm. These data viewed in conjunction with Figure 31 illustrate the restricting nature of calcareous soils on the mobility of heavy metals, and also the fact that the heavy metals have been leached out of the soils forming over quartzite.

The geochemical grid data are recorded on the geochemical grid map, Plate 6. Soil data from traverse lines A through G were obtained from atomic absorption analysis, performed by a commercial laboratory, for Cu, Pb, and Zn, after sample digestion in nitric and perchloric acids. The data from traverse lines H through M were obtained by the same methods, but analyses were conducted by the writer. In addition, from traverse lines H through M, samples were colorimetrically analyzed for molybdenum. Rock chip samples,

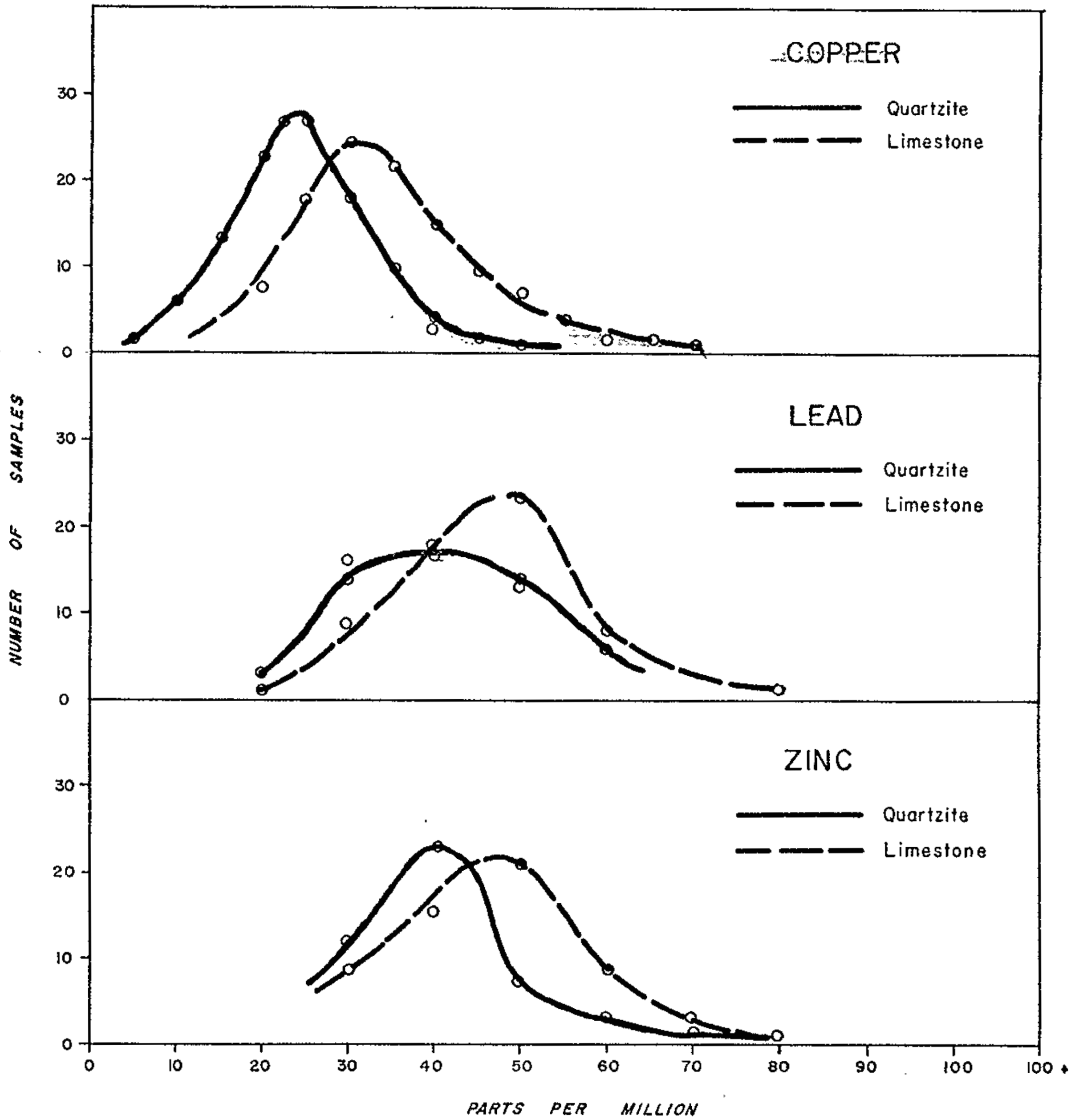

Figure 31. Contrast between heavy-metal concentrations in residual soil over limestone and over quartzite. Soil samples from traverse lines 1 and 2 (see appendix 2). Data from 51 soil samples over quartzite and 61 soil samples over limestone.

the location of which are shown on Plate 6, were analyzed by x-ray fluorescence.

The data, as recorded on the geochemical grid map, show a reasonably good correlation between high heavy metal values in rock samples and soil samples. However, sufficient data are not available to draw any valid conclusions concerning the manner in which the soil content of base metals reflects the parent material. In the eastern and southern part of the grid, molybdenum values of up to 5 ppm were obtained in residual soils. Of 104 determinations of molybdenum in soils, 77 percent have a value of 2 ppm or less. The remaining 23 percent contain between 3 and 5 ppm molybdenum. The average content of molybdenum in soils (background) is about 2 ppm (Bloom, 1966). The values greater than 2 ppm obtained from residual soils over the geochemical grid are a reflection of the pyrometasomatic molybdenite flakes which occur in the contact-metamorphic tactite. The molybdenum content of different soil-size fractions was determined for one sample, 11-east on line H, and the following results were obtained: -40 mesh, 4 ppm; -80 mesh, 5 ppm; -120 mesh, 4 ppm; and -200 mesh, 4 ppm. The conclusion drawn is that the molybdenum is present in the soil as a molybdate salt, and not as molybdenite flakes which, as determined from thin section examination of the soil parent material (tactite), are seldom less than 1/2 mm in diameter.

Stream Sediment Data

Appendix 3 lists the copper, lead, and zinc values obtained from each sample at each stream sediment sample station, and the averaged heavy metal values for each station. Determinations were made by atomic absorption, after digestion of the samples in nitric and perchloric acids. Plate 5, a drainage map of the Sierra Rica, shows the location of each station, and the averaged base metal values obtained from that station.

Figure 32 shows the distribution of heavy metals in the stream sediments. Comparison of these distributions with those of heavy metals in residual soils (Figure 31) shows that of the three metals determined in the stream sediments, lead appears to have the most erratic distribution. Lepeltier's (1969) statistical method for determing background and threshold values for the metal concentrations in stream sediment samples was attempted. However, this method was not successful, and further investigation showed that of the heavy metals, only zinc approximates the log-normal distribution required to fulfill Lepeltier's postulates.

The copper-mineralized fractured quartzites in sections 27 and 28, T.29S., R.14W. (see pl. 5), do not appear to reflect their copper content in the sediments from the streams draining this area; the calcareous environment probably witholds most of the copper as insoluble copper

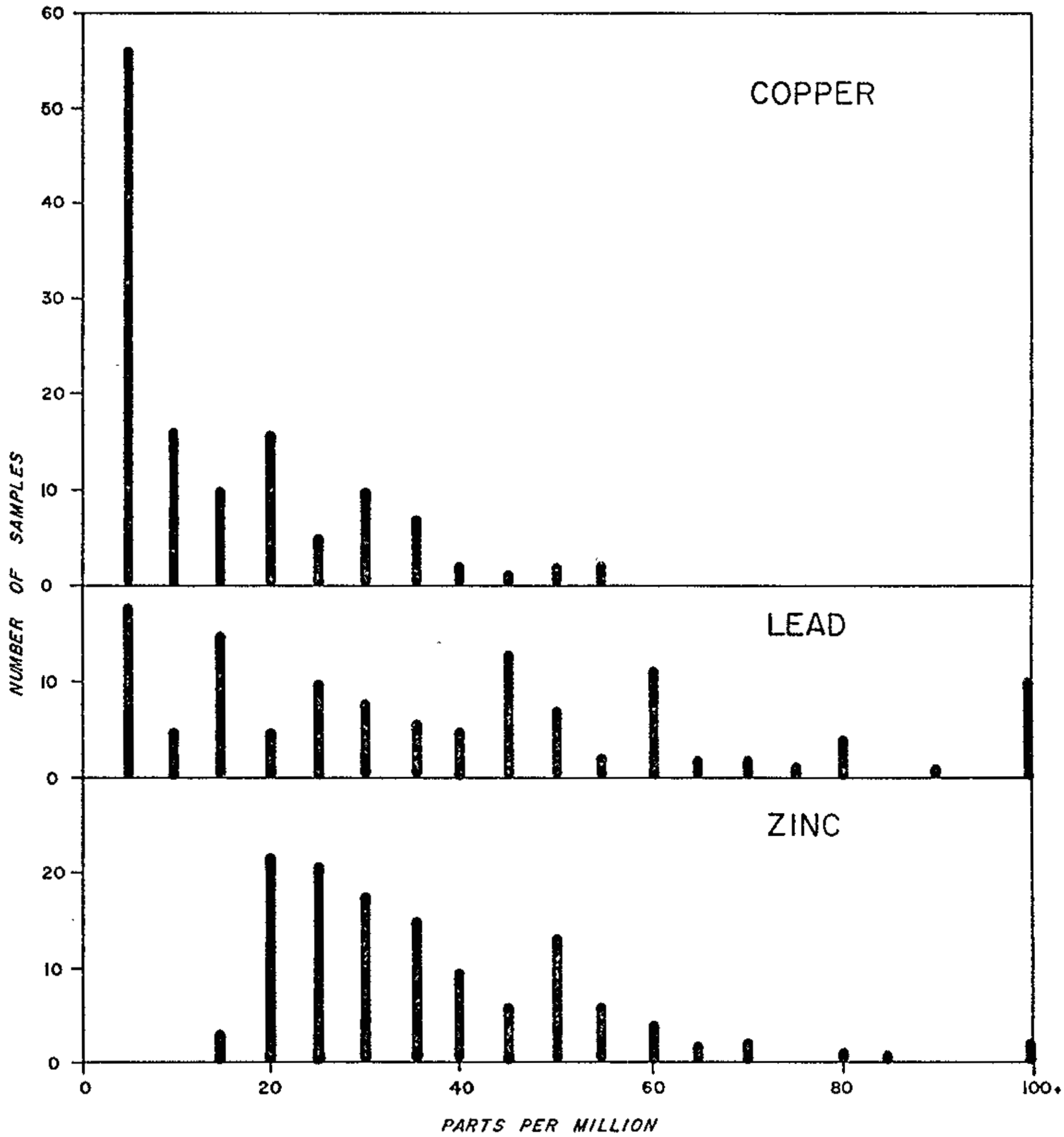

Figure 32. Frequency distribution of copper, lead, and zinc concentration in 126 averaged stream sediment samples (see appendix 3).

carbonates close to the point of origin in the mineralized fractures.

The log-normal distribution of zinc is attributable to the presence of zinc mineralization in the Sierra Rica coupled with the high mobility of zinc. Lead shows a much wider and more erratic distribution in stream sediments than it does in soils. An inspection of the data plotted on the drainage map of the Sierra Rica (pl. 5) shows that although individual sample values are slightly erratic, the lead being drained from known centers of mineralization is clearly reflected in the drainages. A 4-mile trend of high lead values extends downstream along Doyle's Creek from the mineralization in sec. 25, T.29S., R.14W. (see pl. 5, stations 24 through 28). Similar high-lead trends occur in the streams draining mineralization in sec. 36, T.29S., R.14W. The locally erratic values suggest that the lead may be transported as detrital galena grains. The difference between the lead concentration at station 24 (400 ppm) and at station 25 (45 ppm), 3000 feet downstream from station 24, is further evidence that the lead is probably present as detrital galena.

High lead values obtained from a number of samples between stations 100 and 110 cannot be correlated with known mineralization; these values may be indicating lead-mineralized veins which were not observed on the outcrop.

Biogeochemical Data

The results of the biogeochemical investigation are shown in Table 3.

TABLE 3. Results of Biogeochemical Investigation

Samples 1 through 6 collected from and around ocotillos growing on fractured quartzites in Sec. 27, T.29S., R.14W.; Samples 7 through 12 collected from and around ocotillos growing on allochthonous Paleozoic limestone in Sec. 21, T.29S., R.14W. Determination of heavy metals in plant ash made by atomic absorbtion after digestion in nitric acid, and soil samples after digestion in nitric and perchloric acids; determination of heavy metals in rock samples made by x-ray fluorescence after grinding of samples to -200 mesh.

Sample No.	Cu(ppm)			Pb (ppm)			Zn (ppm)		
	Plant Ash	Rock	Soil	Plant Ash	Rock	Soil	Plant Ash	Rock	Soil
1	70	30	35	5	30	30	250	15	55
2	75	20	45	5	10	50	165	15	70
3	85	15	50	5	35	60	205	10	70
4	85	10	35	5	20	35	130	35	65
5	130	15	30	5	20	30	175	5	50
6	200	10	25	35	25	30	210	5	45
Average	105	15	35	10	25	40	190	15	60
7	165	5	25	5	25	75	390	25	50
8	140	5	10	5	70	80	185	35	35
9	170	10	5	20	35	60	185	35	35
10	65	0	15	5	75	130	85	35	35
11	200	5	20	5	40	90	260	40	35
12	215	5	30	120	25	50	680	20	35
Average	160	5	15	25	45	85	250	35	35

These data indicate that ocotillos collect more heavy metals when growing on limestone than they do when growing on fractured quartzites. This is true even in the case of copper, notwithstanding the fact that the quartzite contains more copper than does the limestone. The conclusion drawn is that heavy metals do not influence the distribution of ocotillos, but that the anomalous geobotanical distribution of this plant is probably attributable to the presence of groundwaters in fractures and joints. Such fracture and joint control on the distribution of ocotillos on rocks other than limestones may be of value in exploration inasmuch as the plants may be indicating the presence of channelways which could have been mineralized during hydrothermal activity of concealed intrusives, or which could have served as leakage channels for buried mineralization.

CONCLUSIONS

Geologic data show that granitic intrusives are present in the Sierra Rica, thus strongly supporting the aeromagnetic and gravity indications of buried intrusives underlying the area. The absence of hydrothermal alteration and the strongly localized centers of mineralization suggest that the hydrothermal fluids responsible for mineralization were introduced along restricted fracture channelways. The absence of carbonaceous or pyritic shales in the outcrop would appear to preclude these materials from being a cause of the induced polarization anomalies. Contact metamorphic tremolite and actinolite, observed on the outcrop, or pyrometasomatic base-metal sulphides could have been the cause of the induced polarization anomalies. The similarity between the trends of the gravity, aeromagnetic and induced polarization anomalies suggests that the induced polarization effects are directly related to an intrusive, or its products.

The geochemical investigation confirmed the presence of base-metal mineralization in the Sierra Rica. Soil and rock samples collected in the contact-metamorphic aureole contained small amounts of disseminated pyrometasomatic base-metal sulphides. Residual soil samples collected on unmineralized rocks over which induced polarization anomalies were obtained did not indicate leakage from buried mineralization. This may indicate either that no mineralization is present, or that no leakage channelways are available for the secondary migration of the heavy metals or molybdenum. Stream sediment samples detected the secondary dispersion of lead better than that of copper or zinc. Anomalous growth density of ocotillos over fractured quartzites did not appear to be controlled by base-metal distribution, but may serve as a useful guide in locating areas of fractured rock which may contain evidence of concealed mineralization.

The geochemical investigation of the Sierra Rica did not explain the cause of the induced polarization anomalies.

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APPENDIX 1: Lithogeochemical sample record. Copper, lead, zinc, and molybdenum values determined by x-ray fluorometric analysis. This record does not include the 61 lithogeochemical samples collected on the geochemical grid in sec. 13, T.30S., R.14W.; they are recorded on the geochemical grid map, see Plate 6. Values in parts per million, or percentage as indicated. Samples collected by the writer and analyzed by Phelps Dodge Corp. in Douglas, Arizona.

Location T.29S., R.14W., Sec.	Lithology	Cu	Pb	Zn	Mo (ppm)
9	Rhyolite	185	40	275	0
15	Rhyolite	90	110	190	0
15	Dacite	90	45	180	0
15	Dacite	75	65	100	25
17	Rhyolite	40	35	105	0
18	Rhyolite	40	45	105	0
19	Quartzite, calcareous	40	25	65	0
19	Quartzite	30	20	30	0
19	Quartzite, FeO-stained	35	25	70	25
19	Quartzite, fractured	5	40	25	0
20	Fault breccia	45	2800	400	20
20	Chert	0	70	30	0
20	Quartzite, Feldspathic, calcareous	45	90	80	5
20	Coquina in upper Mojado Fm.	15	75	35	0
20	Quartzite, alunite on fractures	25	35	135	0
24	Limestone, fossiliferous	0	45	50	0
25	Fault gouge	20	1900	200	45
25	Fault gouge	0	12%	470	0
25	Limestone, dolomitized, tactite	90	180	185	0
25	Latite	15	60	45	20
25	Dacite	30	45	70	20
25	Dacite	50	45	100	0
25	Dacite	30	30	100	0
26	FeO-vein in limestone	80	50	40	0
27	Quartzite, FeO-stained	70	105	50	25
27	Limestone, FeO-stained	10	25	20	10
27	Quartzite, FeO-stained	155	50	5	0
27	Vein quartz, mineralized	4.1%	0.9%	990	0
27	Latite	570	120	60	0

APPENDIX 1: (cont.)

Location T.29S., R.14W., Sec.	Lithology	Cu	Pb	Zn	Mo(PPM)
27	Limestone at latite contact	185	80	60	0
27	Limestone	20	10	20	0
27	Latite	85	520	200	15
27	Limestone	35	100	50	10
27	Latite	205	120	60	0
27	Quartzite, alunite in fractures	115	50	100	0
28	Limestone	30	25	30	0
28	Quartzite with epidote and FeO	160	50	15	40
28	Quartzite with turgite and goethite	930	0.4%	380	0
28	Quartzite, FeO-stained	45	80	30	10
28	Quartzite, pyritic	115	70	60	0
29	Latite	30	45	45	10
29	Latite	45	55	100	60
29	Vein quartz	25	25	15	5
29	Latite	20	55	50	0
29	Quartzite, FeO-stained	25	35	25	0
30	Quartzite, FeO-stained	55	80	70	0
31	Limestone, dolomitized	0	35	25	60
32	Calcite spar in siltstone	0	75	50	0
33	Siltstone, FeO-stained	30	45	15	0
34	Quartzite, pyritic, calcareous	15	25	130	15
34	Dacite	20	35	70	0
34	Limestone-granule conglomerate	4	50	55	20
35	Limestone, arenaceous	0	45	40	0
35	Limestone	30	80	140	0
35	Limestone, sheared	5	120	245	0
35	Vein quartz, FeO-stained	195	7200	11.2%	5
36	Limestone, fractured	5	110	440	10
36	Chert	20	65	125	0
36	Limestone	0	15	60	0
36	Fault gouge	0	20	45	40
36	Limestone	0	20	30	0
36	Vein of FeO material	75	1700	3470	40
36	Fault gouge	30	90	1550	5
36	Tactite	0	70	125	40

APPENDIX 1: (cont.)

Location T.30S., R.14W., Sec.	Lithology	Cu	Pb	Zn	Mo (ppm)
1	Gossan with galena	1.95%	5.5%	2710	30
1	Tactite	1100	1.4%	235	15
1	Tactite, pyritic	105	930	165	10
1	Fractured limestone	170	190	160	0
1	Marble	65	210	65	20
1	Siltstone, calcareous	90	1300	215	5
1	Limestone, fractured	25	260	85	55
1	Quartz latite	75	135	80	0
1	Tactite, pyritic	15	105	70	0
1	Tactite, FeO-stained	10	55	80	15
1	Oxidized vein material	155	9100	4500	0
2	Lamprophyre	120	300	850	0
2	Latite, FeO-stained	30	105	50	0
2	Tactite, pyritic	35	60	50	0
3	Rhyolite porphyry	40	660	170	0
3	Quartzite, weathered	40	135	95	35
10	Rhyolite welded tuff	35	300	110	0
10	Tactite	20	30	60	0
11	Tactite	40	175	135	25
11	Quartzite, pyritic, weathered	25	280	75	15
11	FeO-vein material	55	30	190	60
11	Siltstone, carbonaceous	30	65	45	45
11	Siltstone, carbonaceous	30	70	75	0
11	Quartzite, FeO-stained	35	40	35	15
11	Cherty limestone	120	75	80	0
12	Limestone	15	40	35	10
12	Diorite(?), weathered	40	40	60	5
12	Calcite fracture filling	0	15	15	5
12	Tactite, pyritic	20	75	200	10
12	Quartz latite(?), weathered	10	35	25	0
12	Tactite	15	30	60	10
13	Felsite	15	40	35	0
13	Tactite	0	50	10	5
13	FeO-vein material	230	55	135	35
13	Felsite	25	35	40	0
13	Tactite, FeO-stained	5210	50	95	0
13	Granite, weathered	10	35	40	0
13	Lamprophyre	100	60	375	85
13	Tactite, pyritic	525	70	300	40
13	Tactite, pyritic	95	200	145	55
13	Tactite, molybdenitic	210	90	155	225
14	Tactite	10	30	40	5

APPENDIX 1: (Cont.)

Location T.30S., R.14W., Sec.	Lithology	Cu	Pb	Zn	Mo (ppm)
15	Quartzite breccia	45	30	20	35
24	Tactite, FeO-stained	10	50	15	0
24	Quartzite	5	55	170	0
24	Lamprophyre	340	90	125	0
24	Granite, float	30	45	65	0
24	FeO-vein material	10	25	55	50
24	Fault filling quartz	15	25	15	15
24	Tactite	10	25	50	15

APPENDIX 2: Pedogeochemical sample record. Copper, lead, and zinc values determined by atomic absorption spectrometry after sample digestion in 25% nitric acid. Location of lines 1 and 2 described under heading: Pedogeochemical samples. This record does not include the 263 pedogeochemical samples collected on the geochemical grid in sec. 13, T.30S., R.14W.; they are recorded on the geochemical grid map, see Plate 6. Samples collected and analyzed by the writer.

Line 1

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
0	Residual	Limestone	70	60	65
100	"	"	75	50	50
200	"	"	40	40	45
300	"	"	75	50	50
400	"	"	25	50	45
500	"	"	25	50	40
600	"	"	40	60	50
700	"	"	40	50	30
800	"	"	25	50	25
900	"	"	25	60	25
1000	Transported	Alluvium	45	60	65
1100	"	"	45	50	30
1200	"	"	25	50	50
1300	"	"	40	50	45
1400	"	"	45	40	40
1500	"	"	30	40	50
1600	"	"	40	60	55
1700	"	"	40	60	50
1800	"	"	30	50	40
1900	"	"	30	40	30
2000	"	"	15	30	25
2100	"	"	15	50	30
2200	"	"	55	50	45
2300	"	"	25	60	15
2400	"	"	15	40	30
2500	"	"	40	40	35
2600	"	"	45	60	40
2700	"	"	45	60	40
2800	"	"	30	30	30
2900	"	"	40	75	40
3000	"	"	20	50	45
3100	"	"	30	30	30
3200	"	"	25	30	40
3300	"	"	25	30	45
3400	"	"	15	50	50
3500	"	"	25	50	25
3600	"	"	55	60	55

APPENDIX 2: (Cont.)

Line 1

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
3700	Transported	Alluvium	45	40	60
3800	"	"	45	60	100
3900	"	"	45	50	105
4000	"	"	40	30	35
4100	"	"	40	50	60
4200	"	"	30	50	65
4300	"	"	60	75	75
4400	Sediment	"	60	40	70
4500	"	"	130	40	75
4600	"	"	25	40	60
4700	Transported	"	45	60	35
4800	"	"	20	50	35
4900	"	"	5	30	30
5000	"	"	30	40	35
5100	"	"	5	50	30
5200	"	"	25	30	30
5300	"	"	30	30	35
5400	Residual	Quartzite	15	30	30
5500	"	"	30	40	30
5600	"	"	15	30	25
5700	"	"	25	40	40
5800	"	"	30	40	35
5900	"	"	15	20	30
6000	"	"	40	50	40
6100	"	"	15	30	25
6200	"	"	15	30	25
6300	"	"	25	50	35
6400	"	"	5	40	35
6500	"	"	15	30	40
6600	"	"	30	60	35
6700	"	"	15	60	35
6800	"	"	15	50	35
6900	"	"	50	60	40
7000	"	"	20	30	45
7100	"	"	5	20	30
7200	"	"	15	20	35
7300	"	"	5	60	30
7400	"	"	15	40	35
7500	"	"	15	40	35
7600	"	"	15	30	40
7700	"	"	15	30	50
7800	"	"	20	40	70
7900	"	"	20	50	45
8000	"	"	30	60	90
8100	"	"	25	50	30
8200	"	"	Lost sample		

APPENDIX 2: (Cont.)

Line 1

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
8300	Residual	Quartzite	30	30	55
8400	"	"	25	40	40
8500	"	Latite	25	30	95
8600	"	"	25	50	30
8700	"	Quartzite	25	40	30
8800	"	"	15	50	40
8900	"	"	15	50	40
9000	"	"	25	50	30
9100	"	"	25	30	45
9200	"	"	5	30	30
9300	"	"	15	60	35
9400	"	"	15	40	30
9500	"	"	25	50	35
9600	"	"	25	30	40
9700	"	"	5	50	25
9800	"	"	30	50	35
9900	"	"	15	40	25
10000	"	"	15	30	35
10100	"	"	15	30	40
10200	"	Frac. Quartzite	30	50	35
10300	"	Quartzite	15	40	105
10400	"	"	20	50	60
10500	"	"	20	40	45
10600	"	"	20	40	45

End of Line 1

Line 2

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
0	Transported	Alluvium	25	50	25
100	"	"	15	50	25
200	"	"	15	50	25
300	"	"	15	40	25
400	"	"	15	50	30
500	"	"	5	30	25
600	"	"	15	30	30
700	"	"	30	50	30
800	"	"	5	20	25
900	"	"	15	30	25
1000	"	"	20	20	40
1100	"	"	15	30	25
1200	"	"	5	70	25
1300	"	"	15	20	30
1400	"	"	30	50	35
1500	"	"	30	60	35
1600	"	"	20	30	40
1700	"	"	25	40	30
1800	"	"	5	50	35
1900	"	"	5	30	35

APPENDIX 2: (Cont.)

Line 2

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
2000	Transported	Alluvium	45	40	40
2100	"	"	25	60	35
2200	"	"	5	30	25
2300	"	"	20	50	35
2400	"	"	25	60	35
2500	"	"	15	30	25
2600	"	"	20	30	30
2700	"	"	5	50	30
2800	"	"	5	40	35
2900	"	"	15	40	40
3000	"	"	5	30	30
3100	"	"	40	50	45
3200	"	"	5	50	30
3300	"	"	20	50	30
3400	"	"	25	40	40
3500	"	"	25	40	30
3600	"	"	5	30	30
3700	"	"	5	50	35
3800	"	"	50	60	35
3900	"	"	5	20	25
4000	"	"	5	80	70
4100	"	"	5	50	55
4200	"	"	30	85	55
4300	"	"	45	75	60
4400	"	"	45	40	60
4500	"	"	55	75	75
4600	"	"	40	50	60
4700	"	"	30	30	50
4800	"	"	25	20	45
4900	"	"	55	30	45
5000	"	"	35	40	40
5100	"	"	45	40	50
5200	"	"	45	30	35
5300	"	"	30	50	50
5400	"	"	25	40	30
5500	"	"	45	50	35
5600	"	"	50	30	50
5700	"	"	35	75	75
5800	"	"	15	50	30
5900	"	"	30	75	70
6000	"	"	30	60	60
6100	"	"	25	20	45
6200	"	"	25	50	55
6300	"	"	55	50	70
6400	"	"	55	30	40
6500	"	"	15	40	35

APPENDIX 2: (Cont.)

Line 2

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
6600	Transported	Alluvium	55	60	55
6700	"	"	5	30	40
6800	"	"	30	30	55
6900	"	"	5	30	50
7000	"	"	25	20	27
7100	"	"	40	75	90
7200	"	"	60	60	40
7300	Residual	Limestone	40	50	70
7400	"	"	20	40	40
7500	"	"	25	30	50
7600	"	"	25	50	25
7700	"	"	40	85	35
7800	"	"	40	50	35
7900	"	"	25	30	25
8000	"	"	30	50	45
8100	Transported	Alluvium	45	75	50
8200	"	"	55	30	50
8300	"	"	30	50	55
8400	"	"	25	30	35
8500	"	"	5	30	30
8600	"	"	25	40	45
8700	"	"	45	50	50
8800	"	"	5	30	30
8900	Residual	Felsite	25	30	40
9000	"	"	25	30	55
9100	"	"	55	50	100
9200	Transported	"	35	30	50
9400	"	"	70	30	90
9600	"	Limestone	25	50	75
9800	Residual	"	55	30	50
10000	"	"	40	30	60
10200	"	"	55	40	40
10400	"	"	45	30	10
10600	"	"	30	50	35
10800	"	"	40	30	30
11000	"	"	60	50	45
11200	"	"	35	50	45
11400	"	"	25	40	50
11600	"	"	15	40	30
11800	"	"	25	40	65
12000	"	"	25	40	30
12200	"	"	20	50	25
12400	"	"	30	20	40
12600	"	"	15	30	30
12800	"	"	45	75	40
13000	"	"	25	40	50

APPENDIX 2: (Cont.)

Line 2

Feet	Soil Type	Rock Type	Cu	Pb	Zn (ppm)
13200	Residual	Limestone	5	40	30
13400	"	"	25	30	35
13600	"	"	40	30	45
13800	"	"	55	50	30
14000	"	"	20	50	35
14200	"	"	60	50	45
14400	"	"	25	50	35
14600	"	"	45	30	35
14800	"	"	60	30	50
15000	Transported	Alluvium	60	30	55
15200	"	"	40	30	35
14500	"	"	25	50	55
15600	"	"	5	50	35
15800	"	"	45	30	100
16000	"	"	60	30	50
16200	"	"	30	50	55
16400	"	"	25	60	50
16600	"	"	45	40	45
16800	"	"	25	50	55
17000	"	"	25	50	45
17200	"	"	30	30	55
17400	"	"	30	60	45
17600	"	"	30	40	60
17800	Residual	Limestone	65	50	250
18000	"	"	30	50	75
18200	"	"	30	60	45
18400	"	"	40	50	55
18600	"	"	30	30	45
18800	"	"	20	40	60
19000	"	"	25	40	45
19200	"	"	15	50	50
19400	"	"	25	30	30
19600	"	"	40	30	10
19800	"	"	45	60	45
20000	"	"	5	30	50
20200	"	"	25	30	40
20400	"	"	40	40	40
20600	"	"	20	40	60
20800	"	"	30	60	55

End of Line 2.

APPENDIX 3: Stream sediment sample record. Copper, lead, and zinc values determined by atomic absorption spectrometry after sample digestion in perchloric and nitric acids. Stream sediment sample map, see Plate 5, shows average values for each station, as reported in right-hand column below. For example, average for A, B, and C at station 1 shown opposite 1A. Samples collected and analyzed by the writer.

	(ppm)			Avg. (ppm)		
Station	Cu	Pb	Zn	Cu	Pb	Zn
1A	40	25	45	15	10	40
1B	1	5	50			
1C	1	5	20			
2A	1	5	40	5	10	60
2B	1	5	60			
2C	20	20	80			
3A	10	20	95	20	15	90
3B	25	10	90			
4A	35	10	60	35	10	60
5A	1	20	60	5	25	55
5B	10	25	55			
6A	20	25	50	10	30	35
6B	1	25	20			
6C	10	35	40			
7A	20	25	25	20	25	25
8A	1	5	50	20	5	45
8B	40	5	40			
9A	10	5	40	5	15	35
9B	1	25	35			
10A	1	5	40	1	5	45
10B	1	5	45			
11A	5	5	20	20	5	15
11B	40	5	10			
11C	10	5	15			
11D	50	5	15			
11E	10	5	20			
11F	20	5	20			
11G	20	5	20			
11H	5	5	15			
12A	10	50	20	10	45	20
12B	10	60	35			
12C	10	25	15			
13A	20	5	5	35	20	20
13B	10	25	20			
13C	60	25	20			
13D	50	25	30			

APPENDIX 3: (Cont.)

	(ppm)			Avg. (ppm)		
Station	Cu	Pb	Zn	Cu	Pb	Zn
14A	60	20	40	35	35	35
14B	25	60	30			
14C	25	25	40			
15A	20	25	45	15	15	50
15B	5	5	55			
16A	5	25	20	5	10	20
16B	5	5	15			
16C	5	5	25			
Destroyed						
22B	10	5	40	10	5	40
23A	5	60	40	5	60	50
23B	5	60	60			
24A	25	250	375	30	400	480
24B	40	350	460			
24C	10	300	510			
24D	60	250	410			
24E	25	150	505			
24F	5	1050	600			
25A	5	60	45	15	45	55
25B	20	25	60			
26A	5	60	60	5	60	55
26B	5	60	55			
27A	5	25	85	5	45	85
27B	5	60	85			
28A	10	25	65	10	45	70
28B	5	60	75			
29A	10	60	60	5	50	30
29B	1	50	25			
29C	1	50	15			
29D	1	50	30			
30A	1	75	20	1	70	20
30B	1	60	20			
31A	1	100	120	1	185	70
31B	1	250	40			
31C	5	200	45			
32A	1	300	25	1	255	25
32B	1	150	25			
33A	5	100	50	5	125	65
33B	5	150	80			
34A	5	150	65	5	230	65
34B	5	150	65			
34C	5	200	60			
35A	5	150	35	5	130	40
35B	5	150	55			
35C	5	100	40			

APPENDIX 3: (Cont.)

Station	Cu (ppm)	Pb (ppm)	Zn (ppm)	Avg. (ppm) Cu	Avg. (ppm) Pb	Avg. (ppm) Zn
36A	5	100	45	5	65	55
36C	5	25	60			
37A	5	25	40	5	45	50
37B	5	60	60			
38A	5	60	65	5	60	50
38B	1	60	55			
39A	1	60	65	5	60	55
39B	5	60	45			
40A	5	25	55	5	45	50
40B	1	60	60			
40C	1	50	45			
41A	1	60	35	5	30	25
41B	10	5	15			
41C	5	25	20			
42A	5	50	35	5	40	30
42B	5	35	25			
43A	5	60	20	5	25	20
43B	5	5	20			
43C	5	25	35			
43D	5	25	15			
43E	5	10	15			
44A	5	25	35	10	55	20
44B	5	60	10			
44C	10	60	20			
44D	10	60	20			
44E	10	60	25			
44F	10	60	25			
44G	5	60	20			
45A	5	60	25	20	80	30
45B	25	60	30			
45C	40	100	40			
45D	20	100	35			
46A	5	10	20	5	30	35
46B	5	25	40			
47A	5	20	25	5	15	30
47B	1	10	40			
48A	1	5	25	1	5	35
48B	5	5	45			
49A	5	5	40	1	5	40
49B	1	5	40			
50A	1	5	40	1	5	35
50B	5	5	35			
51A	25	25	25	20	45	35
51B	10	60	45			

APPENDIX 3: (Cont.)

	(ppm)			Avg. (ppm)		
Station	Cu	Pb	Zn	Cu	Pb	Zn
52A	5	60	40	5	60	35
52B	5	60	30			
53A	1	25	40	1	25	40
54A	1	25	40	5	15	50
54B	5	10	60			
55A	5	50	60	5	65	50
55B	10	75	40			
56A	10	60	60	10	35	50
56B	5	5	35			
57A	5	25	65	5	30	60
57B	1	35	60			
58A	10	35	65	10	45	60
58B	10	50	55			
59A	5	50	60	5	35	35
59B	1	60	35			
59C	10	25	40			
59D	5	25	30			
59F	5	25	25			
60A	25	25	10	30	35	20
60B	20	35	25			
60C	35	50	20			
61A	10	50	20	20	50	20
61B	25	50	25			
62A	10	50	20	15	50	20
62B	20	50	25			
63A	5	50	30	5	35	25
63B	5	25	20			
63C	5	25	30			
64A	40	5	15	25	15	15
64B	10	25	20			
64C	25	10	20			
64D	25	25	15			
65A	20	10	20	20	5	30
65B	25	5	30			
65C	20	5	30			
66A	25	5	35	25	10	35
66B	10	25	35			
66C	40	5	30			
67A	5	5	25	5	5	25
67B	5	5	25			
68A	20	20	15	10	15	15
68B	1	5	20			
69A	10	5	30	10	5	25
69B	10	5	20			

APPENDIX 3: (Cont.)

Station	Cu (ppm)	Pb (ppm)	Zn (ppm)	Avg. Cu (ppm)	Avg. Pb (ppm)	Avg. Zn (ppm)
70A	5	25	35	5	25	30
70B	10	25	30			
71A	25	25	25	20	20	25
71B	20	10	40			
71C	10	25	5			
72A	40	60	35	25	45	25
72B	5	25	15			
73A	5	25	20	20	25	20
73B	35	25	15			
74A	20	25	20	10	25	20
74B	5	25	20			
75A	5	25	40	5	25	35
75B	5	25	35			
76A	5	25	35	20	15	30
76B	40	5	20			
77A	5	5	35	5	5	25
77B	1	5	20			
78A	1	5	20	10	5	15
78B	25	5	15			
78C	1	5	20			
79A	1	5	20	5	5	25
79B	5	5	30			
80A	1	25	35	1	25	30
80B	1	25	25			
81A	35	5	15	25	15	15
81B	20	25	15			
82A	25	25	15	35	40	20
82B	60	50	15			
82C	20	50	30			
83A	5	50	35	10	50	25
83B	20	50	25			
83C	5	50	20			
84A	20	100	20	30	125	20
84B	40	150	20			
85A	20	25	15	15	40	25
85B	10	60	35			
86A	35	100	25	35	80	20
86B	40	60	15			
87A	10	60	35	15	60	30
87B	20	60	30			
88A	5	75	20	10	75	25
88B	10	75	30			
89A	10	60	35	20	60	30
89B	25	60	30			

APPENDIX 3: (Cont.)

Station	Cu (ppm)	Pb (ppm)	Zn (ppm)	Avg. Cu (ppm)	Avg. Pb (ppm)	Avg. Zn (ppm)
90A	1	60	25	5	60	25
90B	10	60	25			
91A	50	60	25	40	45	25
91B	25	25	25			
92A	20	25	20	45	45	20
92B	75	60	20			
93A	60	60	20	55	60	20
93B	50	60	25			
94A	70	60	25	55	60	25
94B	35	60	25			
95A	10	5	15	20	40	25
95B	30	75	30			
96A	20	75	35	40	50	35
96B	55	25	35			
97A	35	25	30	35	25	30
97B	35	25	35			
98A	40	25	20	30	15	15
98B	35	5	25			
98C	35	5	20			
98D	20	25	20			
98E	20	25	20			
99A	5	100	15	10	100	20
99B	20	100	20			
99C	1	100	25			
100A	10	75	25	5	90	25
100B	1	100	30			
101A	10	5	20	10	5	25
101B	10	5	25			
102A	40	5	40	25	5	40
102B	5	5	40			
103A	5	5	20	5	5	20
103B	1	5	20			
104A	5	5	25	5	5	25
104B	1	5	20			
105A	5	60	25	5	80	25
105B	5	100	25			
106A	1	150	35	1	150	35
107A	1	60	35	1	30	35
107B	1	10	35			
107C	1	25	35	1	45	30
108A	1	25	25			
108B	1	60	35			
109A	1	5	25	1	5	20
109B	1	5	15			

APPENDIX 3: (Cont.)

	(ppm)			Avg. (ppm)		
Station	Cu	Pb	Zn	Cu	Pb	Zn
110A	5	50	25	5	55	25
110B	5	60	30			
111A	1	75	45	5	75	35
111B	10	75	25			
112A	5	60	40	10	60	45
112B	10	60	45			
113A	10	100	25	10	80	40
113B	10	60	50			
114A	5	60	35	5	45	30
114B	5	25	30			
115A	45	25	25	55	30	25
115B	65	35	30			
116A	25	35	40	50	35	40
116B	70	35	40			
117A	40	25	40	30	25	40
117B	20	25	35			
118A	20	5	40	30	5	50
118B	45	5	55			
119A	30	5	45	15	15	45
119B	1	25	40			
120A	5	25	40	25	15	45
120B	40	5	45			
121A	60	25	45	30	15	45
121B	1	5	40			
122A	1	5	40	15	15	50
122B	25	25	55			
123A	60	5	30	30	15	30
123B	1	25	30			
124A	60	25	20	30	50	25
124B	10	60	20			
124C	25	60	30			
125A	35	60	30	30	30	35
125B	40	25	15			
125C	20	5	20			
126A	30	5	20	35	25	25
126B	50	5	30			
126C	25	60	20			

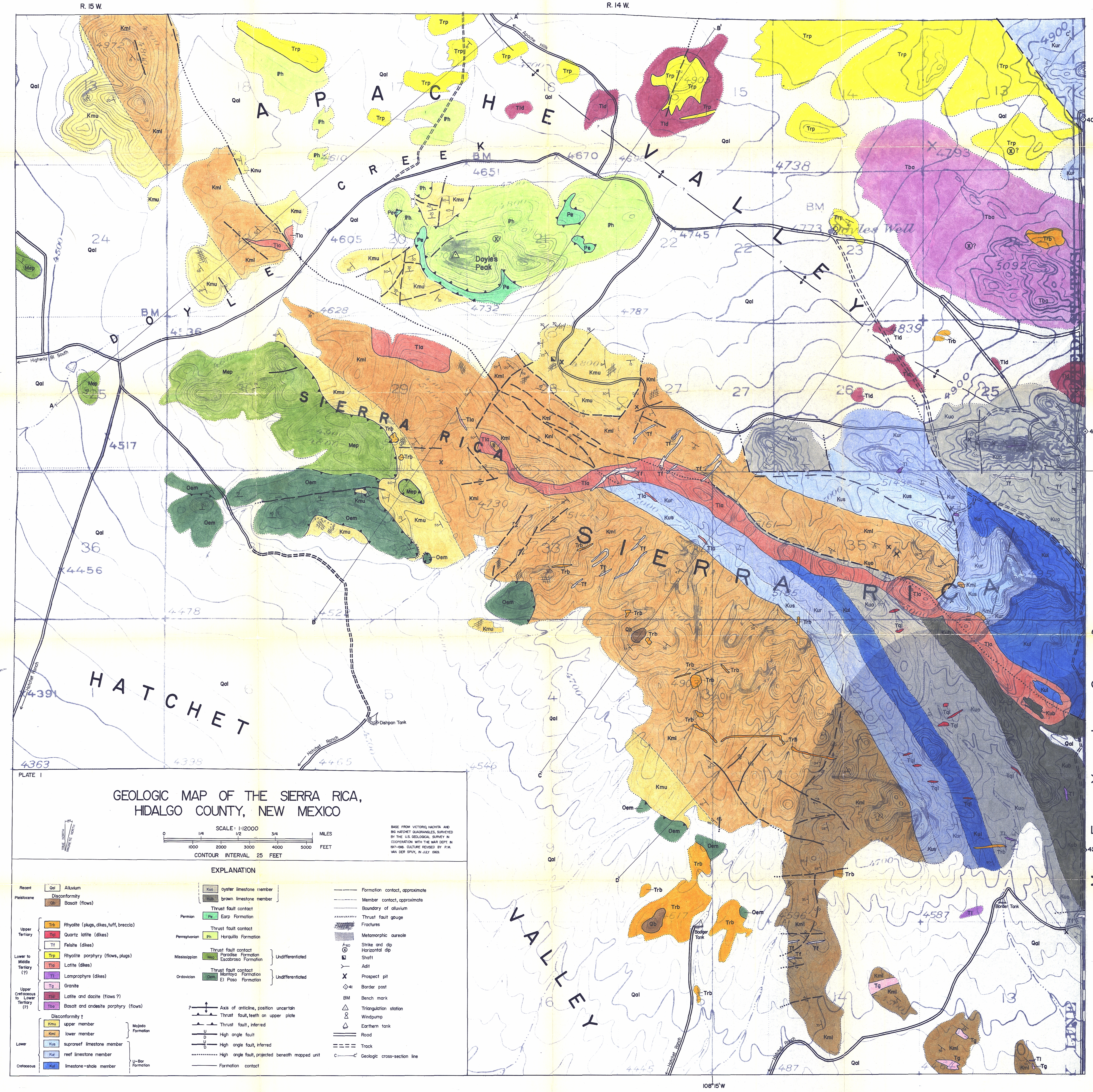


PLATE I
GEOLOGIC MAP OF THE SIERRA RICA, HIDALGO COUNTY, NEW MEXICO
SCALE: 1:12000
0 1/4 1/2 3/4 1 MILES
1000 2000 3000 4000 5000 FEET
CONTOUR INTERVAL 25 FEET
TRUE NORTH
MAGNETIC NORTH
13½°
BASE FROM VICTORIO, HACHITA AND BIG HATCHET QUADRANGLES, SURVEYED BY THE U.S. GEOLOGICAL SURVEY IN COOPERATION WITH THE WAR DEPT. IN 1917–1918. CULTURE REVISED BY P.M. VAN DER SPUY, IN JULY 1969.
EXPLANATION
Recent
Qal Alluvium
Disconformity
Pleistocene
Qb Basalt (flows)
Upper Tertiary
Trb Rhyolite (plugs, dikes, tuff, breccia)
Tql Quartz latite (dikes)
Tf Felsite (dikes)
Lower to Middle Tertiary (?)
Trp Rhyolite porphyry (flows, plugs)
Tla Latite (dikes)
Tl Lamprophyre (dikes)
Upper Cretaceous to Lower Tertiary (?)
Tg Granite
Tld Latite and dacite (flows ?)
Tba Basalt and andesite porphyry (flows)
Disconformity ?
Lower Cretaceous
Kmu upper member
Kml lower member
Mojado Formation
Kus suprareef limestone member
Kur reef limestone member
Kul limestone-shale member
Kuo oyster limestone member
Kub brown limestone member
U-Bar Formation
Thrust fault contact
Permian
Pe Earp Formation
Thrust fault contact
Pennsylvanian
IPh Horquilla Formation
Thrust fault contact
Mississippian
Mep Paradise Formation, Escabrosa Formation
Undifferentiated
Thrust fault contact
Ordovician
Oem Montoya Formation, El Paso Formation
Undifferentiated
Axis of anticline, position uncertain
Thrust fault, teeth on upper plate
Thrust fault, inferred
High angle fault
High angle fault, inferred
High angle fault, projected beneath mapped unit
Formation contact
Formation contact, approximate
Member contact, approximate
Boundary of alluvium
Thrust fault gouge
Fractures
Metamorphic aureole
Strike and dip
Horizontal dip
Shaft
Adit
Prospect pit
Border post
BM Bench mark
Triangulation station
Windpump
Earthern tank
Road
Track
Geologic cross-section line
R. 15 W.
R. 14 W.
T. 29 S.
T. 30 S.
31°45' N
108°15' W
APACHE VALLEY
DOYLE CREEK
SIERRA RICA
HATCHET VALLEY
MEXICO
Doyle's Peak
Doyles Well
Dishpan Tank
Badger Tank
Border Tank
Apache Hills
Highway 81 South
Hatchet Ranch

PLATE 2

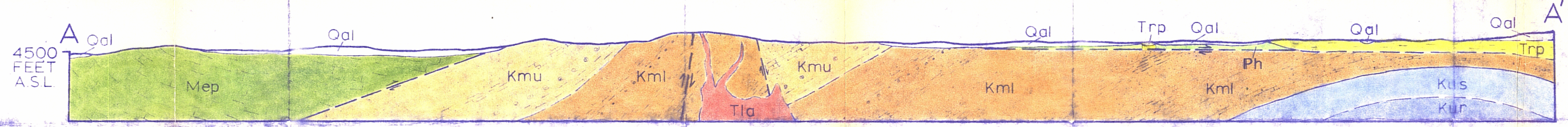
T 1292

GEOLOGIC CROSS-SECTIONS, SIERRA RICA, HIDALGO COUNTY, NEW MEXICO

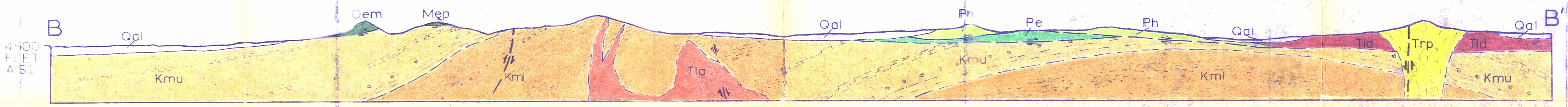
HORIZONTAL SCALE = VERTICAL SCALE

1:12000

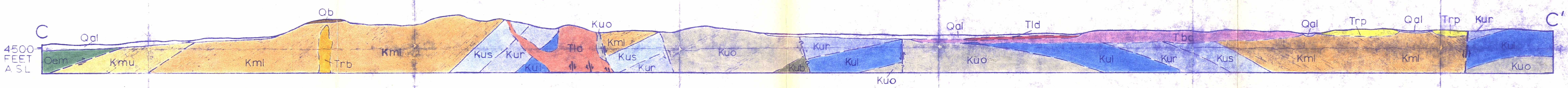
SECTION A - A'



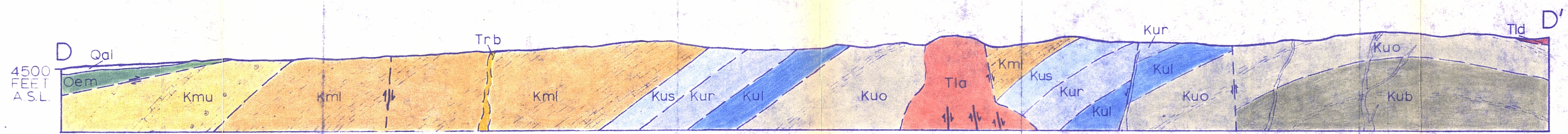
SECTION B - B'



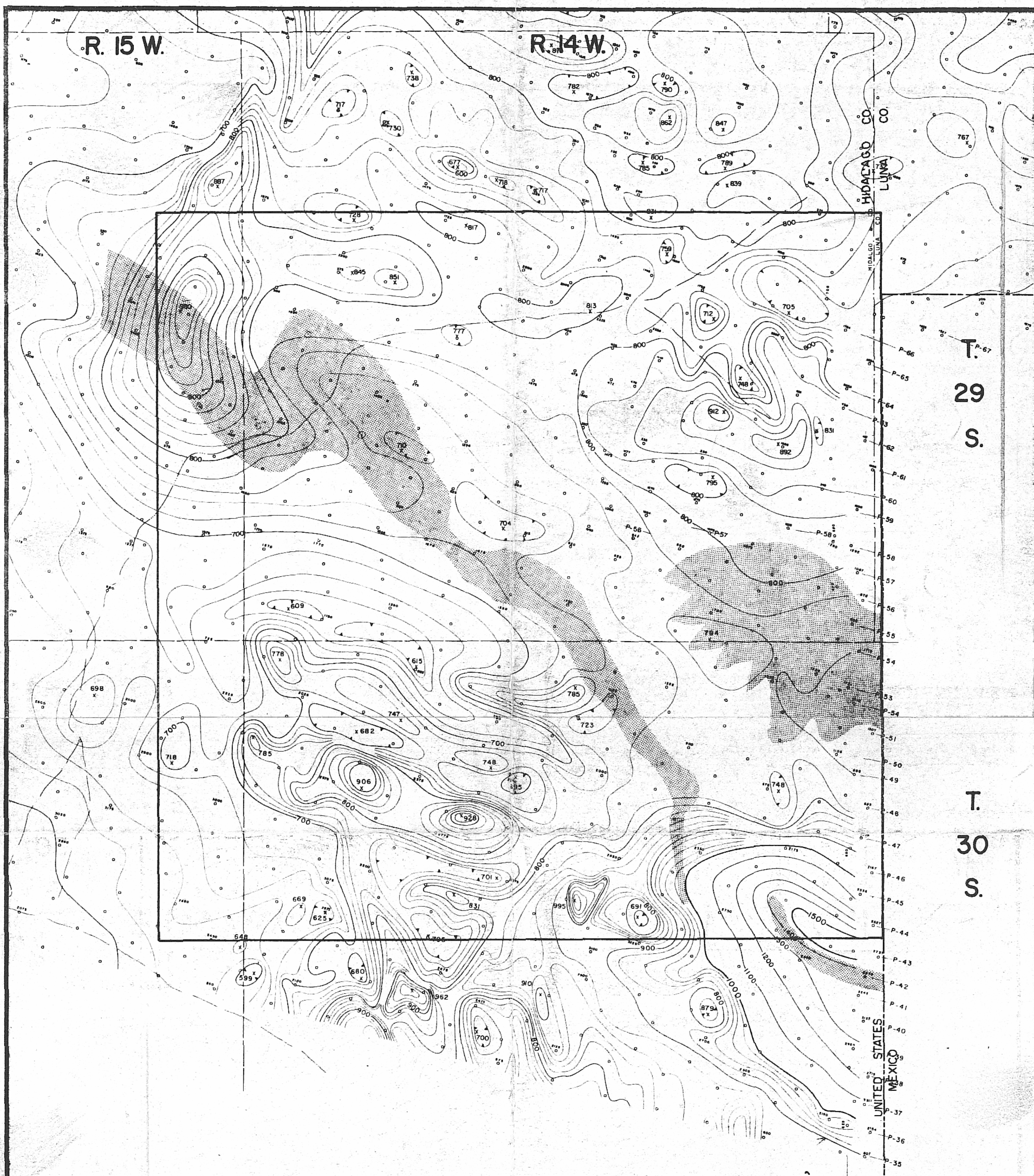
SECTION C - C'



SECTION D - D'



Peter M van der Spuy 1970



AERIAL MAGNETIC SURVEY

GRANT, HIDALGO AND LUNA COUNTIES, NEW MEXICO

CONTOUR INTERVAL 20 GAMMA

0 5000 10000 15000 20000 25000 FEET

SCALE 1:62,500

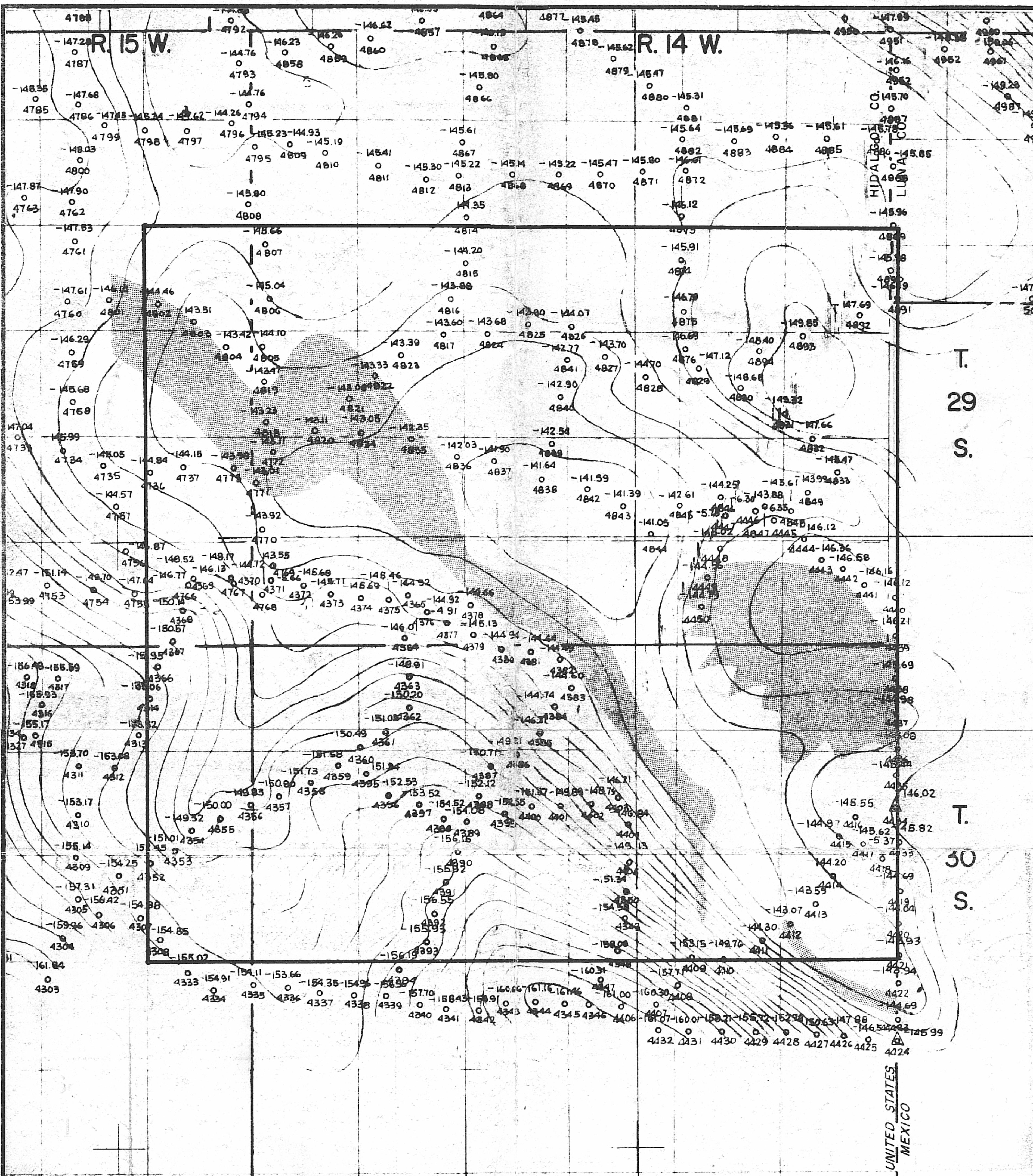
AREA OF PLATE 1

INDUCED POLARIZATION ANOMALY

TN MN 13°

Data supplied by
Phelps Dodge Corp.
Douglas Arizona
July, 1969

P.M. VAN DER SPUY



GRAVITY SURVEY
GRANT, HIDALGO AND LUNA COUNTIES, NEW MEXICO

CONTOUR INTERVAL 1 MILLIGAL

0 5000 10000 15000 20000 25000 Feet

SCALE 1:62,500

BORDER POST

4292 GRAVITY STATION

-155.66 RELATIVE GRAVITY

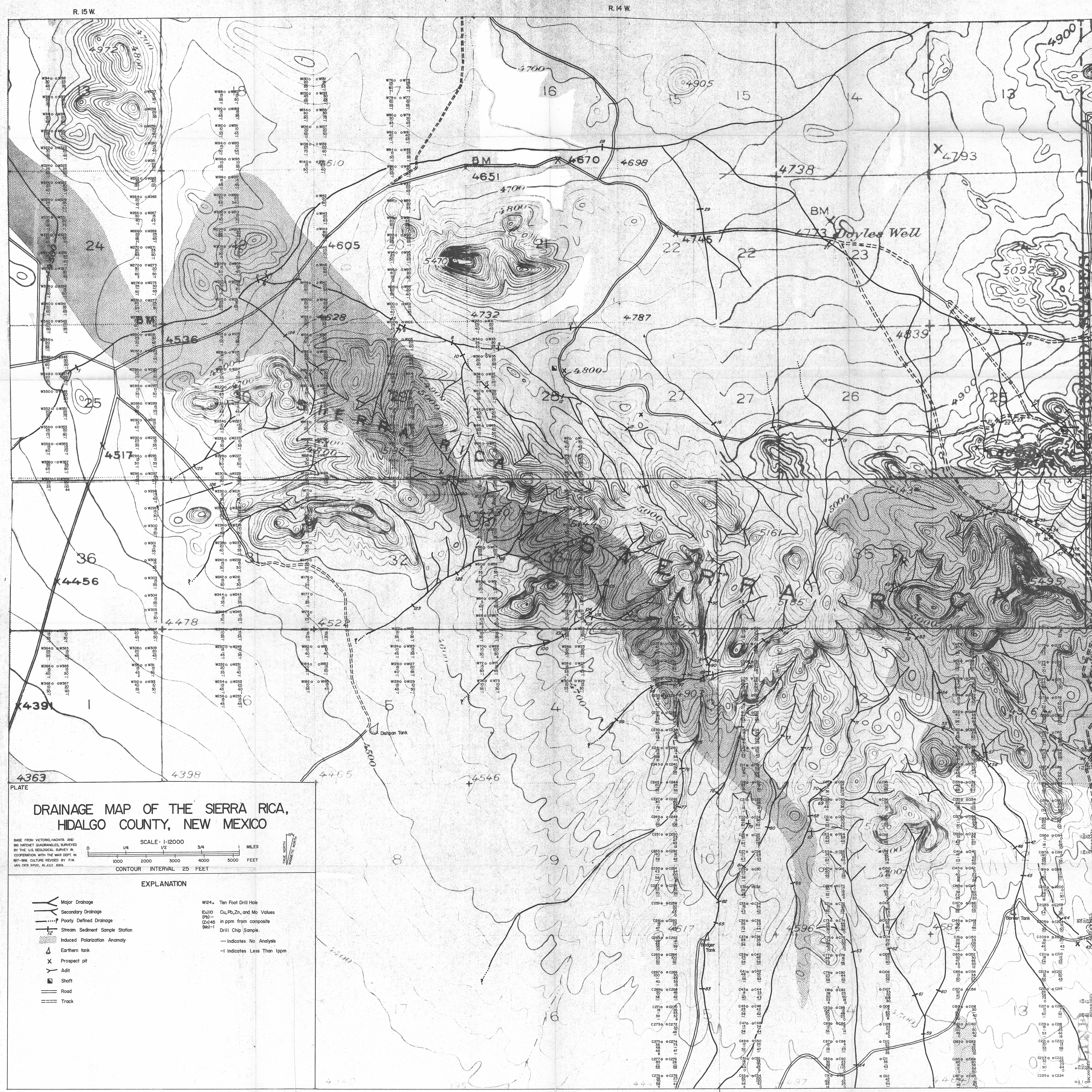
INDUCED POLARIZATION ANOMALY

AREA OF PLATE I

TN MN 13°

Data supplied by
Phelps Dodge Corp.
Douglas, Arizona
July, 1969

P. M. VAN DER SPUY



R. 15 W.
R. 14 W.
T. 29 S.
T. 30 S.
31°45'N
108°15'W
MEXICO
SIERRA RICA
Doyles Well
Dishpan Tank
Badger Tank
Border Tank
BM
PLATE
DRAINAGE MAP OF THE SIERRA RICA, HIDALGO COUNTY, NEW MEXICO
BASE FROM VICTORIO, HACHITA AND BIG HATCHET QUADRANGLES, SURVEYED BY THE U.S. GEOLOGICAL SURVEY IN COOPERATION WITH THE WAR DEPT. IN 1917–1918. CULTURE REVISED BY P.M. VAN DER SPUY, IN JULY 1969.
SCALE: 1:12000
0 1/4 1/2 3/4 1 MILES
1000 2000 3000 4000 5000 FEET
CONTOUR INTERVAL 25 FEET
TRUE NORTH
MAGNETIC NORTH
13°
EXPLANATION
Major Drainage
Secondary Drainage
Poorly Defined Drainage
Stream Sediment Sample Station
Induced Polarization Anomaly
Earthern tank
Prospect pit
Adit
Shaft
Road
Track
W124 Ten Foot Drill Hole
(Cu) 10 (Pb) — (Zn) 45 (Mo) -1 Cu, Pb, Zn, and Mo Values in ppm from composite Drill Chip Sample.
— Indicates No Analysis
-1 Indicates Less Than 1ppm


PLATE 6
GEOCHEMICAL SAMPLE GRID
SCALE: 1:600
TOPOGRAPHIC CONTOURS CONSTRUCTED BY BRUNTON AND PACING METHOD.
0 20 40 60 80 100 FEET
GRID LOCATION: SW 1/4, SE 1/4 SECTION 13, T 30 S, R14W, HIDALGO CO., NEW MEXICO.
Baseline Station
Soil Sample Station
Rock Chip Sample Station
Boundary Between Alluvium (Qal) And Bedrock
Topographic Contour, Qal Boundary Taken As Zero Datum
Road
TRUE NORTH
MAGNETIC NORTH
13°
BASELINE
Qal
A
B
C
D
E
F
G
H
I
J
K
L
M
10
20
30
40