GEOLOGY AND GROUND MAGNETIC SURVEY OF A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO

by

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ABSTRACT

Large-scale geologic mapping, ground magnetics, aeromagnetics, petrographic examination of thin sections, and jasperoid evaluation techniques were employed in the geologic examination of 1 1/2 sections of land near the Chino mine, New Mexico. The geologic mapping uncovered no indication of a hidden ore body in the area. The geologic mapping and the thin section examinations indicate that the hydrothermal solutions which produced the alteration and mineralization at the Chino mine had no obviously significant effect on the exposed rocks in the thesis area. Some secondary iron oxide boxworks after pyrite and one vein of hollandite and manganite are present in fault systems which trend into the Chino area. These features may reflect lateral migration of mineralizing solutions from the Cino stock system along fault systems into the thesis area, they may be related to other emanations from igneous activity in or near the study area, or they may be of low-temperature near-surface origin.

A regional aeromagnetic high exists in the area and was interpreted as a basement anomaly. The ground magnetic survey located several smaller magnetic highs that were not reflected in the results of the aeromagnetic survey. Through the geologic mapping, these anomalies were traced to pre-Chino mineralization igneous rocks and post-Chino mineralization igneous rocks that contain magnetite.

Extensive jasperoid deposits exist in the limestones north of the Nancy fault. Jasperoid evaluation techniques were employed to

determine if the jasperoid deposits are a surface expression of hydrothermal processes which might have also produced an undiscovered ore body. Based on the Young and Lovering classification, it was determined that the jasperoid deposits are probably not related to ore mineralization but that they may be genetically related to the hornblende quartz diorite sill.

The suitability of the land for use as a location for possible future leach dumps for the solution mining of copper-bearing waste rock from the Chino mine was investigated. A large portion of the area is suitable for this purpose.

INTRODUCTION

Purpose and Scope of Study

The purpose of this study was to investigate in detail the geology of a section and a half of land near Kennecott Copper Corporation's Chino mine, an open pit copper mine in southwestern New Mexico. The area is of scientific and possibly commercial value because of its proximity to the Chino ore deposit, the existence of major fault systems which trend into the Chino area, the occurrence of part of a large aeromagnetic anomaly, and the presence of partially covered sedimentary horizons which contain ore-grade tactite mineralization in the active mining areas of the district.

The economic potential of the area was to be evaluated since the possibility for the existence of an undiscovered ore body in this area was believed to be good. It was believed that ore solutions might have migrated into the area along the major fault systems from the Chino stock system or from another, but undiscovered, source and produced ore-grade tactite mineralization in the favorable horizons at depth along the fault systems. It was also believed that a small intrusive stock beneath the surface which was not encountered during the earlier aeromagnetic surveys might have produced a small- to medium-size ore deposit in the favorable horizons.

It was also the purpose of this study to ascertain whether or not the effects of the hydrothermal activity at Chino have produced a significant amount of alteration in the study area. It was hoped that the results

will increase the understanding of the regional geologic effects of the Chino stock system and that this study will help to define the spatial limits of these effects.

Methods of Study

Field mapping was done at a scale of 1 inch equals 200 feet on Ozalid prints of a topographic base map prepared from aerial photographs. Brunton compass and tape, and transit, plane table, and stadia rod were used to locate additional control stations for the ground magnetic survey and the geologic mapping. Mapping was performed between known points by Brunton compass and tape traverses, with Brunton compass and pacing used to map features located on either side of the traverses. Paced distances were kept below 200 feet. Outcrops were mapped, as were contacts and structures, with interpretation between outcrops done in the field where possible. Occasionally, interpretation of structure was performed on maps and cross sections in the office and then field checked. Field mapping and control required 129 days during the period April, 1969 through June, 1970.

Accuracy of the base map is 0.5 percent vertically and 5 percent horizontally. Prints will be less accurate due to paper stretch when they are run through the Ozalid machine. Total horizontal accuracy of the final geologic map, including original map accuracy, map stretch, and traverse variations, is on the order of 10 to 15 percent.

The vertical ground magnetic survey was run with an Askania torsion magnetometer Model Gfz. The precision of this instrument is one to three gammas. Twenty field days were required to run the magnetometer survey. A base point was established and all readings are relative

to that point. A grid system was laid out and readings were taken at 500-foot intervals throughout the area. Where one-point anomalies were encountered, the readings were checked. If they were found to be valid, readings were taken at 100-foot intervals radially away from the anomalous point for several hundred feet until the anomaly was outlined. All readings were corrected for diurnal variations and converted to gammas, plotted, and contoured at 10-gamma intervals.

Thirteen thin sections were examined to aid in the identification of rock types, the description of alteration and metamorphic effects, and to define mineralogic relationships. Two polished surfaces of opaque minerals were studied to aid in the definition of mineralization controls and in the search for trace amounts of ore minerals in areas where evidence of mineralization exists. X-ray analyses were used to identify the minerals in one polished surface.

Total spectrographic analyses were run on 10 jasperoid samples by the Geochemical Research and Laboratory Division of Kennecott Exploration, Inc., as an aid in the determination of the ore potential of the area.

Location and Accessibility

The Lampbright West area is located in southwestern New Mexico approximately 14 air miles east of Silver City, New Mexico, and about 2 air miles east of Kennecott Copper Corporation's Chino mine at Santa Rita, New Mexico (Fig. 1). The area is in the Santa Rita quadrangle, and the portion studied consists of slightly more than 1.5 square miles including sec. 30 and slightly more than the N1/2 sec. 31, T. 17 S., R. 11 W., Grant County, New Mexico. Meridians 108°0'34"

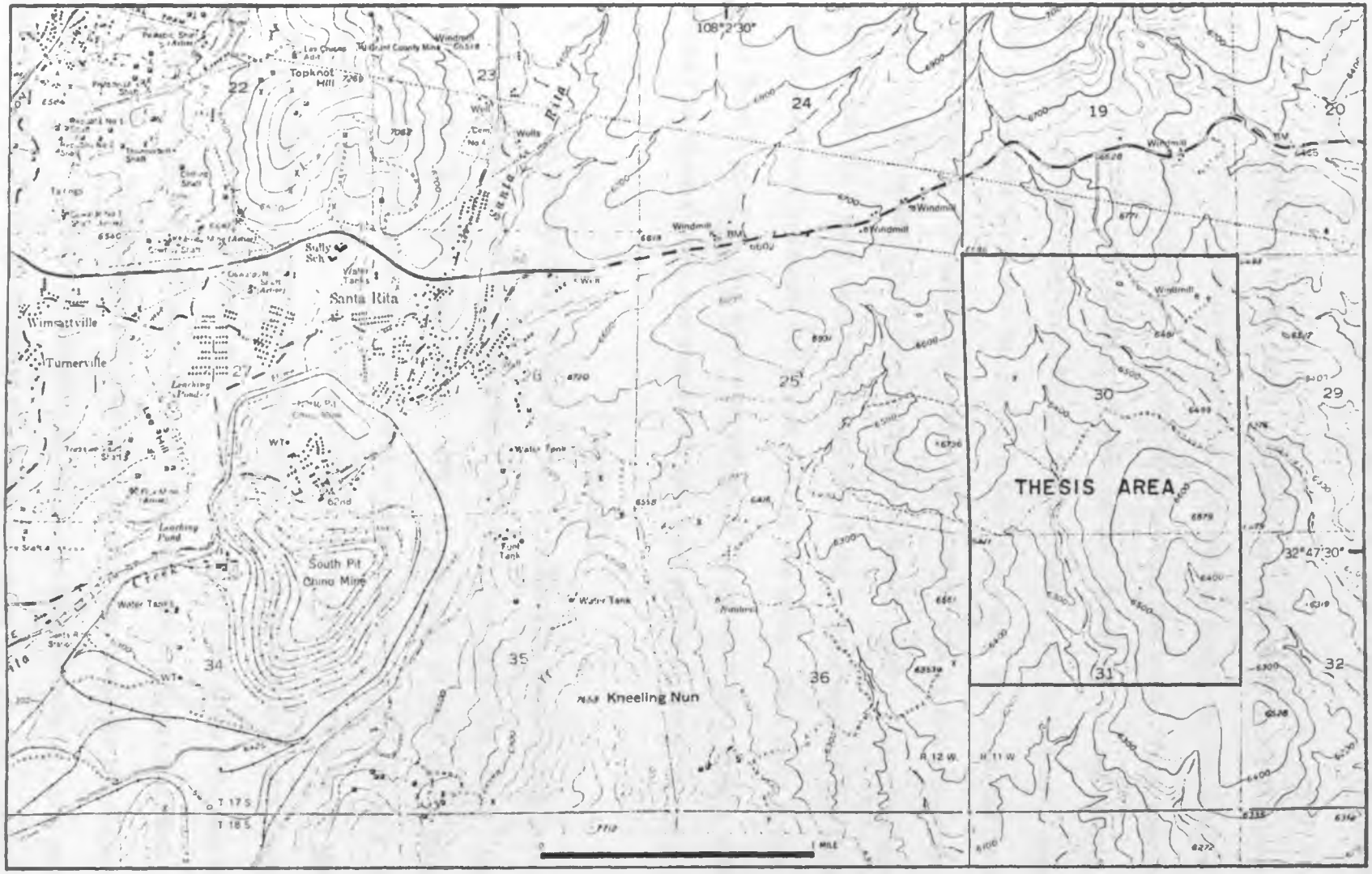


Figure 1. Index Map Showing Location of the Study Area.--Modified from U.S.Geological Survey Topographic Map of the Santa Rita Quadrangle (1951).

and 108°1'36" W. and parallels 32°47'6" and 32°48'26" N. bound the thesis area.

Access is most readily gained by following State Highway 90 for 4.3 miles east of Hanover Junction and turning south on the Delk Ranch road for 0.4 mile to the northern boundary of the area. This road traverses the northeast quarter of section 30. Most of the remaining area is accessible by field vehicle on roads joining the Delk Ranch road. One dirt road leads from the Chino mine into the area, but it is not open to public travel. The same area reached by this road is more readily accessible by the roads intersecting the Delk Ranch road. One other dirt road enters the area from State Highway 90 about 1 mile east of the Delk Ranch road and crosses the north half of the area. This road joins the Delk Ranch road at the east-central edge of section 30. Roads which cross the thesis area are shown on the geologic map (Fig. 2, in pocket).

Topography

The topography is one of gently rolling to moderately steep hills cut by generally narrow, steep-walled drainages and one broad, flat valley (Fig. 3). The topographic relief of the area is 560 feet. The maximum elevation is near the northwest corner of section 30 and is 6,710 feet above sea level. The minimum elevation of 6,150 feet is in the south-central portion of the study area. Slope gradients range from gentle to moderately steep with slope angles of less than 5 to more than 25 degrees; slope angles of 10 to 15 degrees are the most common.

Rock types that are resistant to erosion, such as the Beartooth Quartzite, the sandstone member of the Colorado Formation, and the quartz diorite sills, commonly cap hills and form dip slopes, cliffs, and

A

B

Figure 3. Topography of a Portion of the Lampbright West Area

A. View looking southeast from hill west of the northwest corner of sec. 30, T. 17 S., R. 11 W.

B. View looking east from hill west of the northwest corner of sec. 30, T. 17 S., R. 11 W. State Highway 90 in background.

ledges. The trachyte plug is erosion resistant and forms a vertical cliff some 50 feet high with steep slopes below the cliff (Fig. 4). The Abo Formation is quite susceptible to erosion but forms steep slopes where its cap of Beartooth Quartzite is present (Fig. 5). Where the Beartooth is absent, the Abo forms nearly flat slopes and is generally covered with colluvium or alluvium. The shale member of the Colorado Formation and the shales and argillaceous limestones of the Syrena and Oswaldo Formations are slope formers and form gentle to moderate slopes. The limestone beds in the Oswaldo and Syrena Formations tend to be ledge formers and to produce moderate to steep slopes.

Vegetation in the area consists of a moderately dense cover of juniper, oak, and piñon trees, wild grasses, catclaw, prickly pear, and plants of the yucca family. The tree cover becomes very dense on steep north slopes, thinner on low-angle and south slopes, and quite thin on alluvial areas.

Previous Work

The thesis area was mapped by Jones, Hernon, and Moore (1967). This map was published at a scale of 1:24,000 as part of the study of the general geology of the Santa Rita quadrangle. Jones, Case, and Pratt (1964) included the area in an aeromagnetic survey flown at an altitude of 1,000 feet. Their map was published at a scale of 1:63,360. The area is included as part of an unpublished Bear Creek Mining Company aeromagnetic survey (1954). A few prospect pits, all less than 5 feet deep, are in the area, but no records of prospecting attempts exist.

To my knowledge no other published work has been performed in the area.

Figure 4. Plug of Trachyte

Viewed from the west.

Figure 5. Beartooth Quartzite Underlain by Abo Formation

Viewed from the east. Kneeling Nun and Nun Ridge on skyline.

GEOLOGIC SETTING

The Santa Rita quadrangle lies in the broad transitional zone between the Datil section of the Colorado Plateau and the Basin and Range province near the southeastern tip of the Colorado Plateau (Jones et al., 1967) (Fig. 6). The Santa Rita area lies near the confluence of a northeast-trending lineament which can be drawn through Cananea, Bisbee, Lordsburg, Tyrone, Santa Rita, and probably through the Kingston and Hillsboro districts and the west-northwest-trending Deming axis or Texas lineament (Rose and Baltosser, 1966). The northeast-trending tectonic belt is characterized by faulting of northeast trend and intrusions of Late Cretaceous to early Tertiary age and the west-northwest-trending tectonic belt by intermittent uplift and thin sedimentation beginning in late Paleozoic time (Rose and Baltosser, 1966). An east-west trend characterized by faulting is present but less apparent and is of unknown age and importance (W. W. Baltosser, personal communication, 1970).

The structure in the region is more typical of Basin and Range than of Colorado Plateau and is characterized by broad open folds and steep north-trending or northwest-trending normal faults that bound horsts, grabens, and tilted blocks. The Santa Rita quadrangle lies on the northeast side of one of the prominent horsts that is bounded by northwest-striking faults in an area where the horst is cut by a set of northeast-striking transverse faults (Jones et al., 1967) (Fig. 7). This regional horst is bounded by the northwest-trending Mimbres fault about 5 miles northeast of Santa Rita and by the similarly trending Silver City

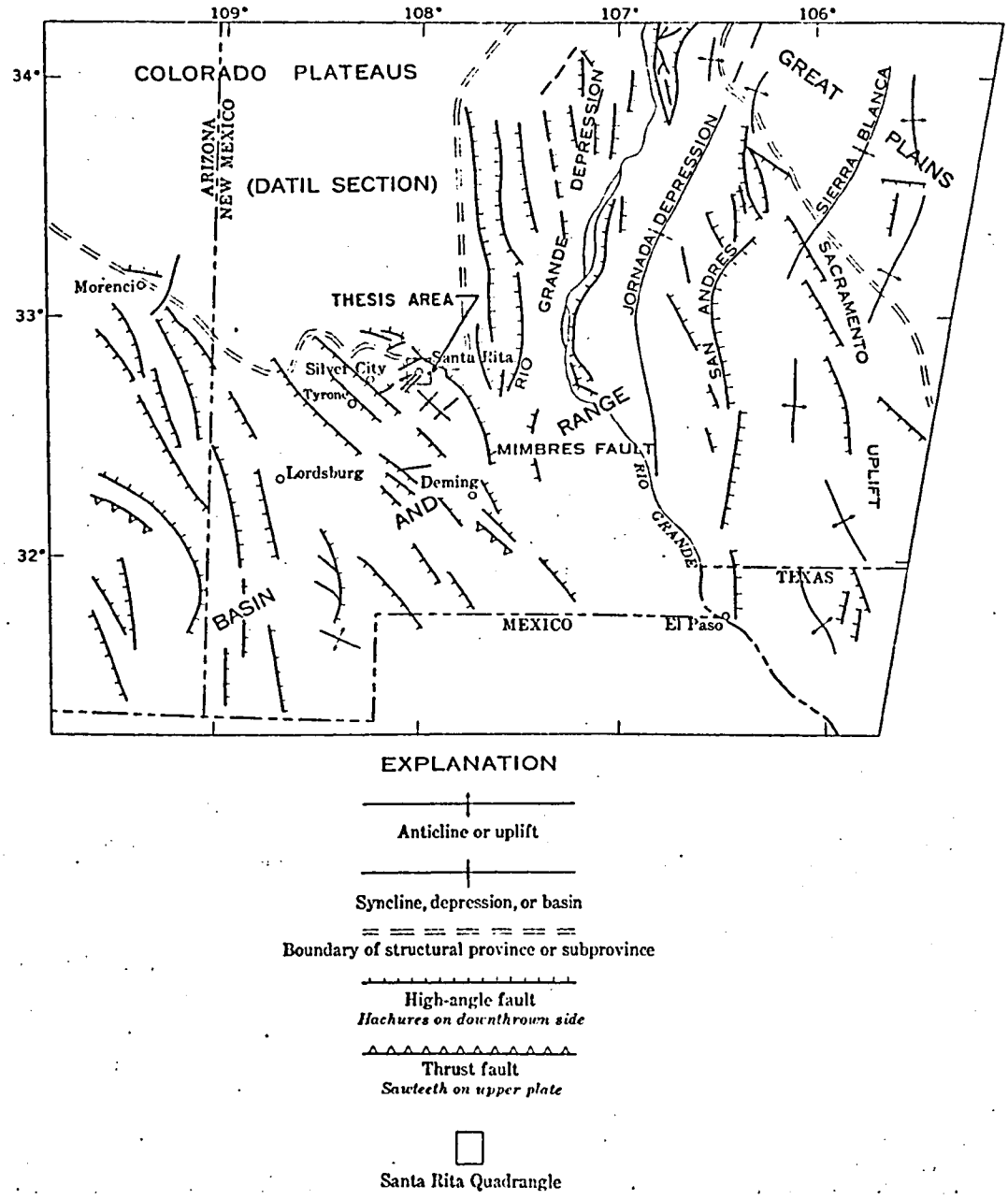


Figure 6. Laramide and Younger Tectonic Features of Southwestern New Mexico.--Modified from Jones et al. (1967), Fig. 40.

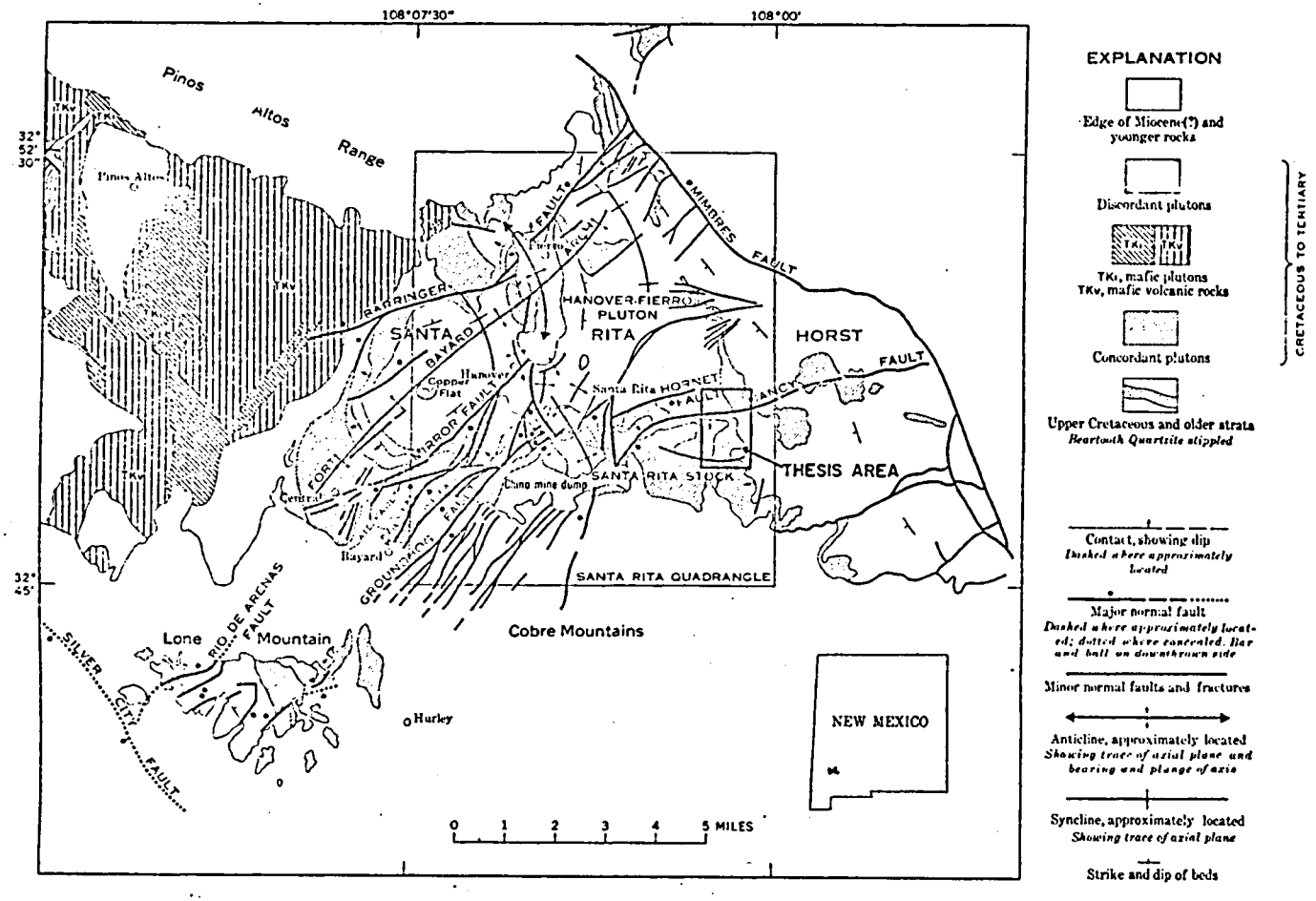
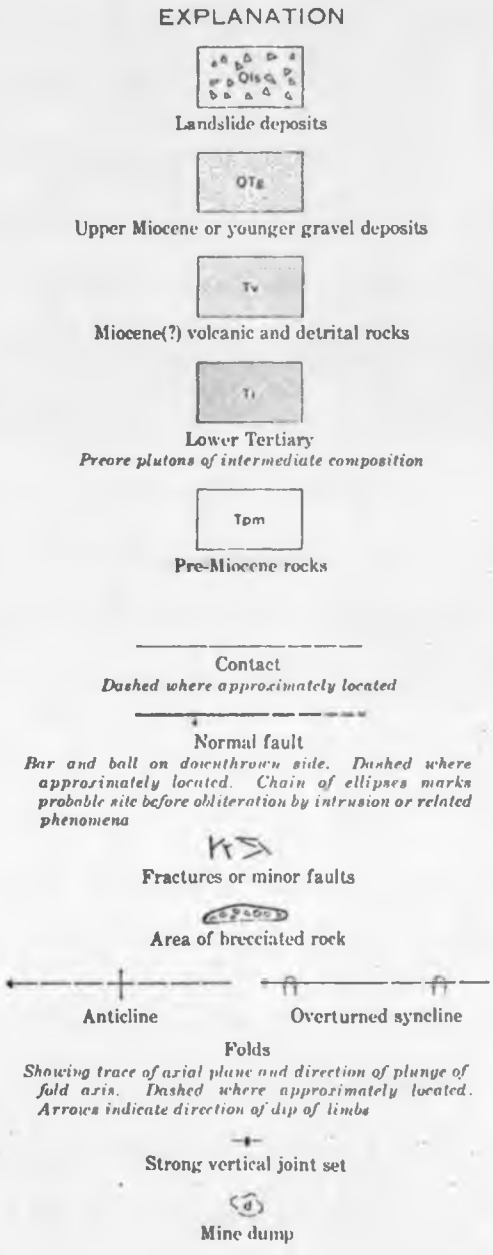


Figure 7. Structural Geologic Setting of the Santa Rita Quadrangle.--Modified from Jones et al. (1967), Fig. 42.

fault, inferred to lie under alluvium about 10 miles southwest of Santa Rita. Within this uplifted block, Mesozoic and Paleozoic rocks are exposed in an east-west-trending zone 5 to 10 miles wide and 25 miles long. Tertiary volcanic rocks cover the older rocks to the north and south (Rose and Baltosser, 1966). The strata within the horst form a broad shallow syncline which trends northwest (Rose and Baltosser, 1966) and is locally modified by domes, arches, and tight folds peripheral to several plutons. While the structural grain of the region reflects faulting in Miocene or more recent time, the fault pattern probably developed as early as Late Cretaceous or early Tertiary time (Jones et al., 1967).

On the east flank of the regional horst is a triangular-shaped subsidiary horst known as the Santa Rita horst. It is bounded on the northeast by the Mimbres fault, on the northwest by the Barringer fault, and on the south by a zone of discontinuous normal faults trending N. 75° E. (Jones et al., 1967) to which group the Nancy and Hornet faults belong (Fig. 8). Within this horst, the strata are flexed into elongate arches, domes, small synclines, and locally into tight folds. Subsidiary horsts and grabens exist within the Santa Rita horst. Major structural features include the Fort Bayard arch, the dome corresponding to the Hanover-Fierro pluton, a shallow downwarp paralleling the dome on the west and a similar shallow syncline on the east between the pluton and the Mimbres fault, the tilted fault blocks over the Santa Rita stock with correspondingly downwarped sediments east of the stock and south of the Nancy and Hornet faults, the Hanover Hole (a possible collapsed caldera), and several breccia pipes (Rose and Baltosser, 1966; Jones et al., 1967) (Fig. 8).

Figure 8. Major Structural Features in the Santa Rita Quadrangle.--Modified from Jones et al. (1967), Figure 43.



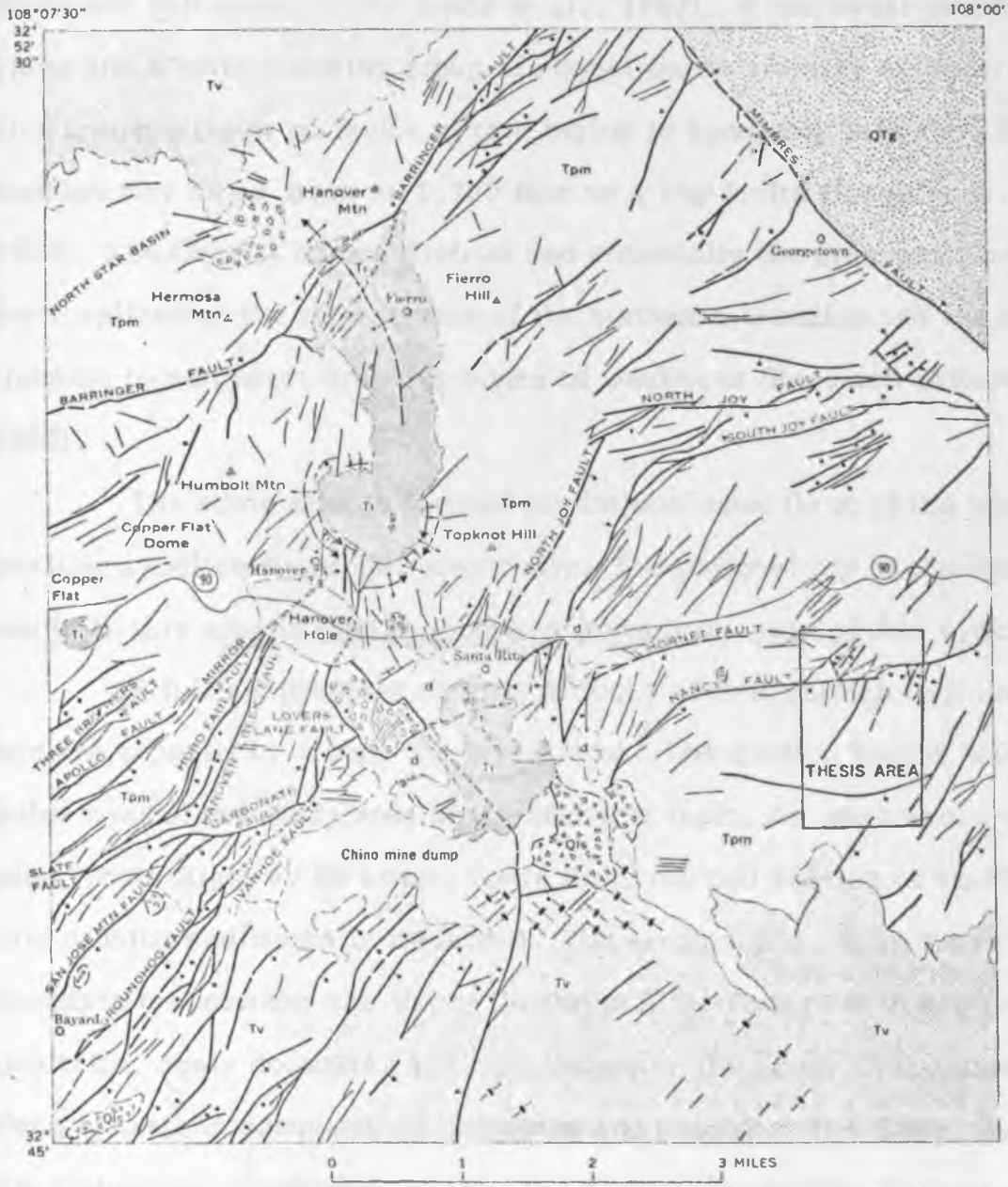


Figure 8. Major Structural Features in the Santa Rita Quadrangle.--Modified from Jones et al. (1967), Figure 43.

The most obvious district fault trend is northeast and includes two groups of normal faults of N. 30°-50° E. and N. 70°-85° E. trend (Rose and Baltosser, 1966; Jones et al., 1967). A northwest-trending group and a north-trending group of normal faults are also evident. The stratigraphic throw on faults in this region is commonly less than 300 feet but may be as much as 1,700 feet on a few faults (Jones et al., 1967). The Central mining district and especially the granodiorite stocks are localized at the intersection of the northeast-trending and the north-trending to northwest-trending zones of weakness (Rose and Baltosser, 1966).

The study area is located on the northeast flank of the broad shallow syncline mentioned previously. The regional dip of the sediments in this area is gently southwest toward the axis of this syncline.

A full sedimentary section of rocks of Precambrian to Holocene age are exposed in or near the thesis area. The section begins about 4.3 miles east of the study area at the Mimbres fault. As one travels west along State Highway 90 toward Santa Rita, the full section of southwesterly dipping sediments is traversed. The section (Fig. 9) includes Precambrian greenstone; the Upper Cambrian Bliss Formation consisting of quartzite, shaly dolomite, and conglomerate; the Lower Ordovician El Paso Limestone composed of limestone and dolomite; the Upper and Middle Ordovician Montoya Dolomite; the Silurian Fusselman Dolomite; the calcareous shale and black fissile shale of the Upper Devonian Percha Shale; the Lower Mississippian Lake Valley Limestone; the limestone of the Upper and Middle Pennsylvanian Oswaldo Formation; the argillaceous limestone and calcareous shale of the Upper Pennsylvanian Syrena

SYSTEM OR SERIES	FORMATION	APPROXIMATE RANGE IN THICKNESS (FEET)	LITHOLOGY
Recent and Pleistocene	Younger alluvium * Older alluvium		Unconsolidated alluvium and colluvium in valley floors, flat uplands, and on slopes. Includes sand, silt, and gravel.
Pliocene and Miocene(?)	Gravel deposits in Mimbres River system	0-800	Somewhat consolidated poorly sorted bolson deposits ranging from silt to boulder deposits. Similar and in part equivalent to Gila Conglomerate and Santa Fe Formation
Miocene(?)	Basaltic andesite flows and underlying gravel and boulder deposits	0-850	Dark gray finely crystalline porphyritic flows, weather reddish brown; contain phenocrysts of pyroxene, magnetite, and olivine in matrix of labradorite
	Pitchstone, sandstone, and indurated rhyolite tuff underlain by Kneeling Nun Tuff	0-600	Crystal fragments of quartz, sanidine, biotite, and oligoclase and rock fragments imbedded in compacted glass shards in part devitrified and in part replaced by chalcedony. Black pitchstone contains rock fragments and is locally vesicular.
	Sugarlump Tuff	0-600	Pumiceous tuff, gravel, and sandstone, locally replaced by clinoptilolite. Generally well stratified
	Rubio Peak Formation		Andesite breccia (See below)
		0-600	Conglomerate containing intercalated indurated tuffs and rhyodacite and andesite flows. (Rubio Peak Formation)
Lower Tertiary and Upper Cretaceous(?)	Andesite breccia	0-900	Andesite breccia and fine grained crystal tuff, volcanic sandstone and some nonvolcanic sandstone and mudstone
Upper Cretaceous	Colorado Formation *	0-1000	Upper 800 feet consists of tan, greenish brown, and white sandstone interbedded with dark green, brown, and black shale. Lower 225 feet is black limy shale except for 20 feet of quartzite about 80 feet above base. Thin beds of fossiliferous impure limestone conspicuous in lower part above the lower beds of black shale.
Upper(?) Cretaceous	Beartooth Quartzite *	55-142	Fine grained quartzite containing thin black shale partings locally. Conglomerate beds near top
Lower Permian	Abo Formation *	0-265	Red shale, mudstone, and limy mudstone containing lenses of algal conglomerate locally
Upper Pennsylvanian	Syrena Formation *	170-390	Impure limestone and limestone interbedded with irregular lenses of red calcareous shale and with shale beds particularly in lower 140 feet.
Upper and Middle Pennsylvanian	Osmaldo Formation *	330-420	Blue gray limestone, fairly pure except in upper part, interbedded with thin shale beds, gray to red siliceous shale or grit about 20 feet thick occurs at base, known locally as "Parting shale."
Lower Mississippian	Lake Valley Limestone	300-400	Limestone, pure crinoidal and massive in upper part, argillaceous and thin bedded in central part. Much nodular chert throughout.
Upper Devonian	Percha Shale	230-315	Upper member or Box Member, is gray calcareous shale containing abundant limestone nodules, lower member or Ready Pay Member, is black fissile shale, calcareous at base.
Silurian	Fusselman Dolomite	100-300	Gray cherty finely crystalline vuggy massive dolomite.
Upper and Middle Ordovician	Montoya Dolomite	300-350	Light gray to gray very finely crystalline massive dolomite containing interbedded dolomite and dark chert in central part and concentrations of opalescent quartz sandstone at base.
Lower Ordovician	El Paso Limestone	500-519	Thin to thick bedded light gray limestone and dolomite. Chert nodules in upper part, abundant fucoidal markings in lower part.
Upper Cambrian	Bliss Formation	140-198	Predominantly dark brown massive quartzite, locally hematitic and glauconitic. Grayish brown shaly dolomite and basal coarse conglomerate locally
Precambrian			Granite, granite gneiss, and greenstone

Figure 9. Columnar Section of Layered Rocks, Santa Rita Quadrangle.--Modified from Jones et al. (1967), Figure 2.

Formations marked by an asterisk (*) crop out in thesis area.

Formation; the calcareous mudstone and shale of the Lower Permian Abo Formation; the quartzite, thin shale, and conglomerate of the Upper(?) Cretaceous Beartooth Quartzite; the shale, sandy shale, and sandstone of the Upper Cretaceous Colorado Formation; and colluvium and alluvium of Quaternary age. The portion of the sedimentary section from above the base of the Oswaldo Formation through the Quaternary alluvium and colluvium is exposed in the study area. Early Cretaceous rocks are absent from the Santa Rita quadrangle but are present further to the south and southwest. Rocks of Triassic and Jurassic age are absent from southwestern New Mexico due either to erosion or nondeposition (Jones et al., 1967). The maximum thickness of the sedimentary section is nearly 4,300 feet, including about 3,150 feet of Paleozoic and about 1,150 feet of Mesozoic sediments. This thickness is quite variable because the Paleozoic rocks, with the exception of the continental red beds of the Abo Formation, were deposited in shallow seas, evidently on an intermittently submerged foreland shelf, and because of the nature of the upper surface of the Colorado Formation, which is everywhere an erosional surface (Jones et al., 1967).

Igneous rocks in the Santa Rita quadrangle are many and varied in characteristics. More than 30 types of igneous rocks have been identified in the quadrangle. They include Precambrian granite (penetrated in deep drill holes at Chino) and granite gneiss; Late Cretaceous(?) quartz diorite sills; Late Cretaceous(?) to early Tertiary andesite breccia and mafic intrusive rocks; early Tertiary syenodiorite to granodiorite sills, laccoliths, and dikes, and granodiorite, quartz monzonite, quartz latite, and rhyodacite stocks, plugs, and dikes; Miocene(?) rhyolite to quartz

latite plugs, dikes, and crystal and lithic tuffs; and Miocene(?) andesite to basalt dikes and flows interbedded with water-laid sand, tuff, and conglomerate (Jones et al., 1967). In the area examined, the exposed igneous section consists of Late Cretaceous(?) quartz diorite sills and Miocene(?) plugs and dikes of trachyte and dikes of basalt.

The following paragraphs on mineral deposits in the Central mining district are compiled, except where otherwise noted, from information presented by Hernon and Jones (1968).

The Central mining district is composed of mineral deposits located in and near the Santa Rita quadrangle and includes the subdistricts of Hanover, Fierro, Santa Rita or Chino, Copper Flat, and Georgetown. Primary ore deposits in the district include (1) disseminated copper deposits; (2) iron oxide replacement deposits in limestone, with minor copper; (3) sphalerite replacement deposits in limestone with nonuniform and smaller quantities of lead, copper, and silver minerals; (4) veins of sphalerite with smaller amounts of lead, copper, and silver minerals; and (5) argentiferous galena replacement deposits in limestone with minor zinc minerals. Location of these deposits and their spatial relationships to major structural features in the district are shown in Figure 10. Secondary enrichment of copper in vein and disseminated deposits has been substantial, and enrichment of silver and gold has probably been significant in some veins.

Disseminated copper deposits in the district include the porphyry copper deposit of the Chino mine with its disseminated and secondarily enriched copper mineralization in the Santa Rita stock and in the surrounding Cretaceous sedimentary rocks and quartz diorite sills, and

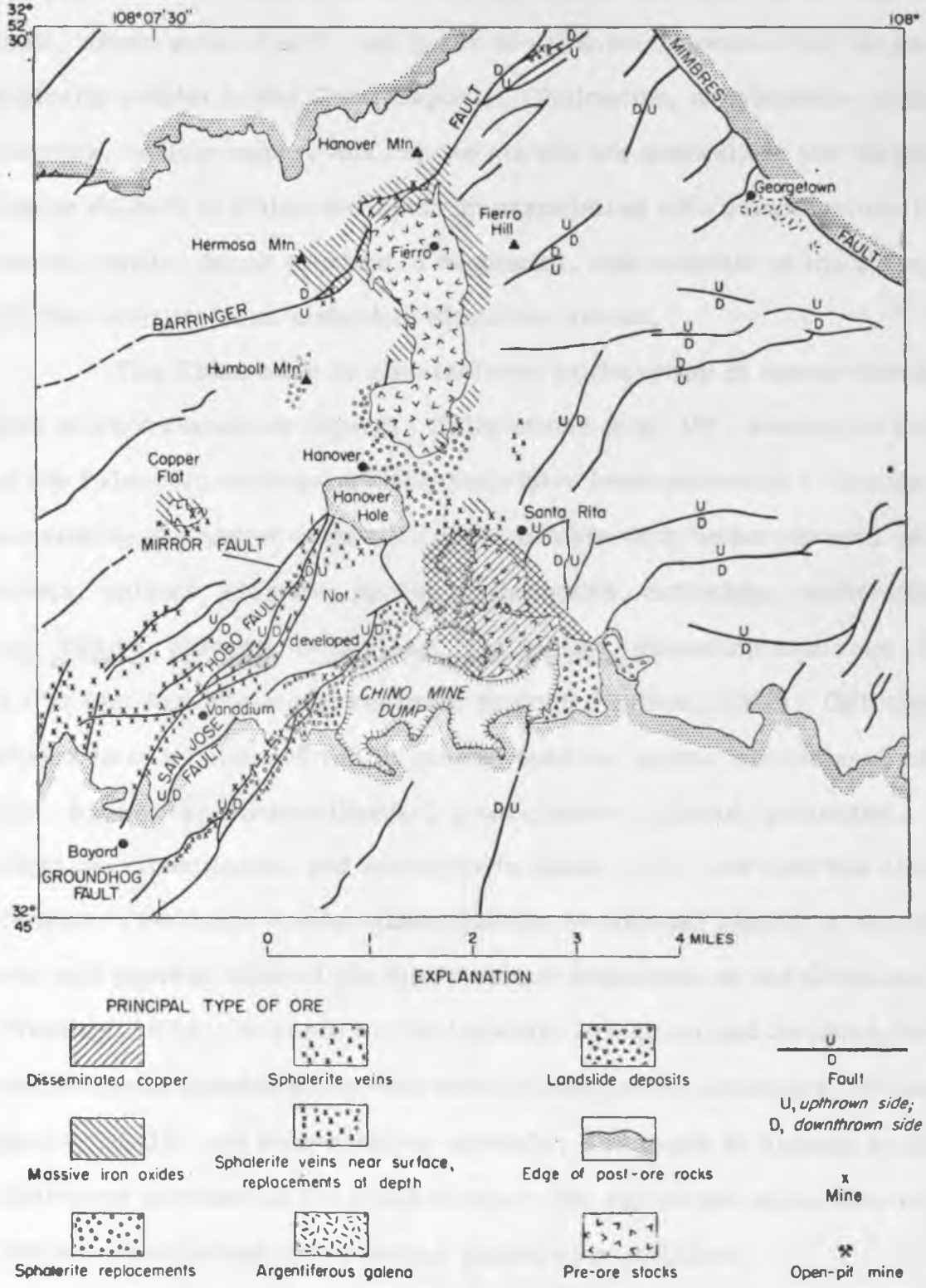


Figure 10. Ore Deposits of the Central Mining District, New Mexico.--From Hernon and Jones (1968, Figure 2).

a copper deposit north of Fierro on the hanging-wall side of the Barringer fault, whose size, shape, and grade is unknown but which may be geologically similar to the Chino deposit. Chalcocite, molybdenite, chalcopyrite, native copper, and cuprite are the ore minerals in the porphyry copper deposit at Chino and occur in association with gangue minerals of quartz, pyrite, minor amounts of magnetite, and minerals of the potassic, phyllic, argillic, and propylitic alteration suites.

The Chino mine is also included in the group of copper-bearing iron oxide replacement deposits in limestone (Fig. 10). Limestone beds of the Paleozoic sedimentary sequence have been converted to tactite, consisting of massive magnetite and andradite with lesser amounts of quartz, epidote, chlorite, pyrite, chalcopyrite, actinolite, montmorillonite, biotite, siderite, orthoclase, and zeolite, extending in places to 2,000 feet from the stock-sediment contact (Nielsen, 1970). Calcareous shales have been converted to quartz, epidote, pyrite, orthoclase, biotite, magnetite, montmorillonite, chalcopyrite, chlorite, actinolite, diopside, specularite, and andradite to about 2,000 feet from the stock contact. Ore-grade copper mineralization is attained locally in this zone and will provide much of the future copper production at the Chino mine (Nielsen, 1970). At depth in the dolomitic limestone and dolomite beds, serpentine is present along with massive magnetite, andradite, chalcopyrite, pyrite, and calc-silicate minerals. Ore grade is highest in the sediments adjacent to the stock contact. No sphalerite mineralization has been recognized in the active mining area at Chino.

Other massive iron oxide replacement deposits in the district are localized around the Hanover-Fierro stock and the Copper Flat stock.

The deposits are generally tabular to lenticular and are in all the Paleozoic calcareous formations. Most of the iron ore production has been from a favorably located cluster of magnetite replacement ore bodies in the El Paso Limestone and Montoya and Fusselman Dolomites of the Fierro area. The main ore minerals in the calcareous beds of the Fierro area are magnetite, hematite, chalcopyrite, and small amounts of sphalerite. Gangue minerals in the dolomite and dolomitic limestone beds include pyrite, quartz, serpentine, magnesite, idocrase(?), wollastonite, calcite, and apatite with lesser amounts of andradite, epidote, ilvaite, and hedenbergite. In pure limestones, the gangue assemblage is masive andradite with lesser amounts of pyrite, epidote, hedenbergite, ilvaite, rhondonite, calcite, and tremolite. Recrystallized limestone is common locally. Impure limestone and calcareous shales were converted to silicate-hornfels with a similar mineralogy to that reported at Chino. With respect to channelways, a general zoning pattern consists of the earlier formed minerals wollastonite, garnet, epidote, and magnetite close to the channelway with copper and zinc increasing with distance from the channelway. Production from the Copper Flat deposit was zinc and magnetite (Lasky and Hoagland, 1948). The massive iron oxide replacement deposits are controlled by their location in the pyrometasomatic envelopes around the Santa Rita, Hanover-Fierro, and Copper Flat stocks and to some degree by the attitudes of the bedding of the replaced sediments. Some deposits transgress bedding at small angles: others cut across bedding along fault zones and dikes. Some are related to sills, and still others have replaced purer limestone beds in a generally impure calcareous sequence.

Sphalerite replacement deposits (Fig. 10) are usually elongate bodies which may be tabular corresponding to the bedding or may be chimney-shaped and cut across bedding. Replacement bodies away from the stocks occur along fracture zones that in many places tend to follow the walls of granodiorite dikes. The largest bodies are in the limestone formations above the Percha Shale. Within the pyrometasomatic silicate zone around the stocks, sphalerite with small amounts of galena, chalcopyrite, and silver occur in a gangue of andradite, pyroxene, ilvaite, and small amounts of pyrite and magnetite. Proportions of galena and/or chalcopyrite increase with increasing distance from the stock. Zoning next to channelways, which may include a stock contact or a dike, comprises epidote on the igneous side of the channelway, andradite on the sediment side of the channelway followed by a band of salite, ilvaite, rhodochrosite, rhodonite, siderite, and sphalerite, then a zone of marble followed by limestone containing tremolite and actinolite. Replacement deposits of sphalerite are localized along the south lobe of the Hanover-Fierro stock which has forced the Paleozoic sediments into an overturned syncline that is overlapped by an asymmetrical anticline. Ore bodies are localized in the syncline, along the common limb of the syncline and the anticline, and in the anticline. Many ore bodies are at the interface between marble and calc-silicate rocks. Within the fracture systems, orebody shape has been determined both by fracture and bedding control. Favorable bedding replacement has also occurred, especially near the Hanover-Fierro stock where ore solutions favored the crinoidal member of the Lake Valley Limestone and the lower and upper beds of the Oswaldo Formation.

Sphalerite vein deposits occupy faults and fracture zones associated with faults (Fig. 10). Rotated breccia ore is a characteristic feature of fault veins, and crackle breccia and sheeting characterize stringer lode veins in fracture zones. A single vein may contain both types of ore. A typical vein contains silicified and pyritized rock or chloritized and calcitized rock with ore shoots distributed along it. The most productive veins occur in sills in Cretaceous sediments and in or along granodiorite dikes that cut these rocks. Sphalerite, galena, and chalcopyrite, with silver associated with the sulfides, are the primary ore minerals of the veins. Gangue and alteration minerals associated with the veins include quartz, pyrite, epidote, chlorite, albite, calcite, sericite, clay minerals, specularite, and magnetite. In places, bands of bleaching have been noted adjacent to ore as have sheaths of sericitized and pyritized rocks. Vein material has replaced the wall rocks in places. The veins occur in the pyrometasomatic halos of both the stocks and the granodiorite dikes and extend out of the stock halos along faults and fracture zones.

Argentiferous galena replacement deposits in the upper part of the Fusselman Dolomite were mined in the Georgetown area (Fig. 10) in the late 1800's. Enriched secondary ores contained cerargyrite, native silver, argentite, bromyrite, pyrargyrite, cerussite, vanadinite, and residual galena. Sphalerite and argentiferous galena were present in pockets of primary ore. Gangue minerals include calcite and quartz. The dolomite was extensively silicified in the Georgetown area, and jasperoid occurs along fractures and faults in the limestone to within a mile of the Chino mine.

GEOLOGY

Sedimentary Rocks

Paleozoic Rocks

Magdalena Group. Pennsylvanian rocks in central New Mexico were named the Magdalena Group by Gordon (Jones et al., 1967). However, Pennsylvanian rocks in southern New Mexico cannot be correlated on the basis of lithologies with those in central New Mexico, nor can strata be correlated throughout the Santa Rita quadrangle on this basis (Jones et al., 1967). The Magdalena Group totals some 800 feet thick in the Santa Rita area and contains Middle and Late Pennsylvanian fossils (Jones et al., 1967). In this region, the Magdalena Group is divided into a lower unit, the Oswaldo Formation, which is predominantly limestones, and an upper unit, the Syrena Formation which is predominantly argillaceous limestones and calcareous shales (Fig. 2, in pocket). The Magdalena Group can probably be correlated with part of the Naco Group, including the Horquilla Limestone and possibly part of the Earp Formation, in southern Arizona (Jones et al., 1967).

In the region, the lithology of the Magdalena Group is characteristic of sediments deposited on the edge of a geosyncline with fluctuating seas. Beds change lithology within a short distance, lenses are a common occurrence, and pinching out of beds within short distances is a common feature.

The Oswaldo Formation is the oldest sedimentary unit exposed in the thesis area (Fig. 2, in pocket). Fossil evidence suggests that

this formation ranges in age from Middle to Late Pennsylvanian (Jones et al., 1967). The Oswaldo Formation consists primarily of light-gray limestone beds with subordinate argillaceous limestone. The base of the Oswaldo is the base of a 20- to 40-foot-thick widespread shale unit known as the Parting shale (Jones et al., 1967). The top of the formation is arbitrarily set as the last light-gray limestone bed in a series of similar beds, above which is a thick sequence of light-brown argillaceous limestone beds. The beds typical of the Oswaldo Formation consist of limestones which are relatively pure, finely crystalline, light to dark gray on fresh surfaces, and light blue gray on weathered surfaces (Fig. 11). Light-brown argillaceous limestones are less commonly present here than in the Syrena Formation and occur as thin beds and irregular lenses within the light-gray limestones. Some dark-gray limestones are present as are beds containing nodules of light-gray limestone surrounded, in part, by thin coatings of light-brown argillaceous material. A few shale beds are present, but they are generally covered, and the limestones above and below the covered shale beds form benches. Black chert lenses and nodules of light-gray chert are common in the Oswaldo Formation. The black chert contains foraminifers and forms thin lenses to about 6 inches thick. Limestone conglomerate lenses are present and contain subangular to subrounded pebbles 10 to 25 mm in diameter of dark-gray limestone cemented by gray limestone. The conglomerate weathers to a medium gray. The "striped beds" are a widespread feature of the Oswaldo Formation in the Santa Rita quadrangle but were recognized with certainty in only one place in the thesis area. These beds consist of 30 to 50 feet of alternating 1- to 3-inch-thick limestone and

Figure 11. Limestone Beds of the Oswaldo Formation

Figure 12. Argillaceous Limestone Beds of the Syrena Formation

and silty limestone beds. The limestone weathers gray, and the silty limestone weathers tan , giving the beds a striped appearance (Jones et al., 1967). These beds occur below the uppermost 2- to 6-foot thick limestone bed in the Oswaldo Formation (Jones et al., 1967). Brachiopods, crinoid stems, corals, and fusulinids were noted in the formation.

In the Santa Rita quadrangle, the Oswaldo Formation varies in thickness from 330 to 420 feet (Jones et al., 1967). As the base of the Oswaldo is not present in the area mapped, the thickness of the formation could not be determined directly. Using Figure 2 (in pocket), the geologic map of the Santa Rita quadrangle by Jones et al. (1967), and supplementary cross sections, it appears that the Oswaldo Formation is about 400 feet thick in the area mapped.

The Oswaldo Formation is intruded by a sill of hornblende quartz diorite (Fig. 2, in pocket). In the study area, the lower contact is approximately 100 to 175 feet below the top of the Oswaldo. Pre-sill faulting may account for this difference.

Alteration noted in the Oswaldo Formation consists of fracture fillings of secondary calcite and iron oxide stain along fractures. Along the west contact with the hornblende quartz diorite sill, the limestone is bleached and recrystallized about 50 to 100 feet horizontally away from the contact. This represents a distance of 10 to 15 feet into the limestone perpendicular to the contact.

The Syrena Formation consists primarily of argillaceous limestones in the area mapped (Figure 2). The contact with the Oswaldo Formation is placed at the first thick series of argillaceous limestone beds above the typical light-gray, relatively pure limestone beds of the

Oswaldo Formation. In places, lenses of limestone conglomerate may be present at the contact. Where the lenses are present, they are placed in the Syrena Formation. This arbitrary contact is based on the best criteria available and holds throughout the area mapped (Fig. 2, in pocket).

The argillaceous limestone beds (Fig. 12) are light brown and noncalcareous on weathered surfaces and black and moderately calcareous on fresh surfaces. The limestone is moderately fissile. In the argillaceous limestone beds, especially near the base of the formation, thin lenses of relatively pure, light-gray limestone may occur. These lenses are on the order of 50 feet in length.

Immediately below the contact with the Abo Formation, the Syrena is, in places, composed of nodular limestone beds containing nodules of gray limestone cemented by gray limestone. The nodular appearance is best noted on weathered surfaces. In other places, these upper beds consist of alternating thin limestone and calcareous shale beds. The limestone is medium gray, and the shale is green brown. The contact is placed at the top of the uppermost gray limestone or nodular limestone bed below the red beds of the Abo Formation (Fig. 2).

Within the Syrena Formation, the "eye beds" are a typical feature of the Syrena and are a common occurrence in the area mapped. These beds consist of nodules of medium-gray limestone surrounded by a thick coating of light-brown argillaceous limestone. On weathering, the relatively pure limestone nodules become recessed in the more resistant argillaceous material. The amount of argillaceous limestone surrounding the nodules is much thicker than that of a similar feature in the Oswaldo Formation. The Syrena also contains lenses of limestone pebble

conglomerate and limestone and chert-pebble conglomerate. In general, the conglomerates consist of angular to rounded granules, pebbles, and sand-size particles 0.5 to 35 mm in diameter of limestone or limestone and chert cemented by limestone and argillaceous limestone. The conglomerates are medium to dark gray on fresh surfaces and weather light brown and light to dark gray. Some conglomerates are composed of clots of dark-gray limestone to 50 mm in diameter in red calcareous cement. The lenses are usually less than 2 feet thick and are usually not over 100 feet long.

Thin light-gray limestone beds and lenses are present in the formation. However, limestone where present in the Syrena Formation is usually dark gray.

Calcareous shale beds are common in the formation, but they are usually not well exposed. The calcareous shales vary from pale orange red to green gray or brown to olive green. Iron oxide banding may be present. Where alternating sequences of limestones and calcareous shales or argillaceous limestones are present, the limestone beds form benches and the other material usually forms the tops of the benches and is covered.

Fossils are abundant in this formation and include brachiopods, crinoid stems, bryozoa, fusulinids, and corals. Thin beds composed entirely of fossils cemented by argillaceous limestone are common. According to Jones et al. (1967), the fossil evidence indicates that the Syrena is probably Late Pennsylvanian in age.

The thickness of the Syrena Formation varies in the Santa Rita quadrangle from 170 to 390 feet (Jones et al., 1967). In the thesis area,

this formation is approximately 320 feet thick (Fig. 13, section I-I', in pocket).

Alteration and mineralization in the Syrena Formation consist of fracture fillings of secondary calcite, iron oxide stains along fractures, and jasperoid replacements and fracture fillings. The jasperoid forms extensive bodies along faults in the Syrena and along fault contacts between the Syrena and Oswaldo Formations (Figs. 2 and 14, in pocket). The jasperoid has also replaced portions of selected beds adjacent to faults in the Syrena.

Abo Formation. The Lower Permian Abo Formation rarely crops out in the area studied, tending instead to form a red soil unit containing considerable float from the overlying Beartooth Quartzite (Fig. 5). Parts of the formation do crop out in stream beds and in a very few exposures on steep hillsides where erosion has been rapid (Fig. 2, in pocket), but nowhere in the area is a full section of the Abo exposed.

The Abo cropping out in the thesis area is a dark-reddish brown and yellow-brown calcareous mudstone. Some exposures consist of red-brown calcareous mudstone granules set in a yellow-brown calcareous mudstone matrix, while others contain yellow-brown granules of calcareous mudstone set in a red-brown calcareous mudstone matrix. In places, the mudstone becomes somewhat fissile and can be termed a calcareous shale. The calcareous mudstone beds often contain nodules of light-gray limestone set in the calcareous mudstone matrix. These nodules range from a few millimeters to over 6 cm in diameter and are composed of 2 to 5 mm subrounded limestone nodules cemented by limestone.

Limestone conglomerate lenses occur within the calcareous mudstones and shales of the Abo Formation. The conglomerates are dark reddish brown and gray and consist of subrounded granules of limestone of the same colors and a few granules of dark-gray chert in a very fine grained matrix of yellow, red, and white subrounded limestone grains cemented by limestone. The lenses are up to 2 feet thick and of undetermined length.

Some very impure limestone present in the Abo resembles the calcareous mudstone in color and appearance. With the increase in calcium carbonate, the texture becomes that of an aphanitic limestone.

As no good exposures of the Abo exist in the area mapped and all areas of colluvial Abo have faults trending into them from the surrounding Beartooth and Syrena Formations (Fig. 2, in pocket) no exact thickness of Abo Formation can be determined. In the Santa Rita quadrangle, the thickness of the Abo varies from 0 to 265 feet (Jones et al., 1967). In the area covered by this report, the Abo apparently is about 145 feet thick.

The lower contact with the Syrena Formation is disconformable (Jones et al., 1967) and is readily but only approximately located by the appearance of the light-gray to tan argillaceous limestones or gray nodular limestones of the Syrena Formation and, where present, by the basal limestone conglomerate lenses of the Abo Formation. The upper contact with the Beartooth Quartzite is unconformable and is denoted in the field by the tendency of the Abo to stain the Beartooth float red in areas where the cover is not thick and, in one area, by the presence of limestone conglomerate lenses at the top of the Abo Formation.

The age of the Abo Formation is based on its stratigraphic position and on its disconformable relationship to the Upper Pennsylvanian beds of the underlying Magdalena Group (Jones et al., 1967). No fossils were found in the Abo in this area and Jones et al. (1967) state that the only fossils in the Abo Formation in the Santa Rita quadrangle are derived from older formations. The Abo may be correlative with the Colina Limestone and Epitaph Dolomite formations of the Naco Group to the west in Arizona and interfingers with the Hueco Limestone to the east (Jones et al., 1967). Faunas in the Hueco establish its age, and that of the Abo, as late Wolfcamp and early Leonard (Jones et al., 1967).

Mesozoic Rocks

Beartooth Quartzite. The Late(?) Cretaceous Beartooth Quartzite covers more surface area in the region examined than any other rock type. This formation crops out in fault blocks along the south side of the Nancy fault and in a broad belt aligned roughly north-south down the center of the study area south of the Nancy fault (Fig. 2, in pocket). The Beartooth Quartzite lies unconformably on the red beds of the Abo Formation and is conformably overlain by the shale member of the Colorado Formation (Jones et al., 1967).

The Beartooth consists predominantly of a fine-grained to very fine grained, light-gray to light-brown vitreous orthoquartzite which contains some intergranular clay material and varying amounts of iron oxide staining (Fig. 15). The quartzite weathers to a light red brown or light gray. Paige (1916) states that the quartzite is a sandstone which nearly everywhere has been changed to quartzite by secondary silicification. In thin section, the quartzite was seen to consist of

Figure 15. Beartooth Quartzite

Figure 16. Quartz and Chert-pebble Conglomerate in the Beartooth Quartzite

interlocking subangular grains of quartz with about 5 percent secondary iron oxide distributed along grain boundaries.

Weathered surfaces of some quartzite beds show irregular worm-like markings and many beds are solution pitted from the weathering processes. A few very fine grained light-gray to black and green-brown sandy shale and shale beds occur within the formation. The green-brown sandy shale beds contain abundant chlorite and secondary iron oxides.

Long, thin lenses of quartz and chert-pebble conglomerate occur in the quartzite beds and consist of subrounded light-gray to black, white and red quartz and chert pebbles and fine-grained to very fine grained light-gray to white subrounded quartz grains cemented by silica (Fig. 16). These lenses are about 20 feet or more thick and as much as 1,400 feet or more long. Jones et al. (1967) note that these lenses are conspicuous features near the base and top of the formation.

Bedding in the Beartooth Quartzite is generally thick and very irregular in nature, containing many warps and rolls. Cross-bedding is common. For these reasons, attitudes are taken with difficulty and uncertainty in most places. The Beartooth is quite resistant to erosion, forming ledges, cliffs, and dip slopes. The talus from erosion of the Beartooth tends partially to obscure outcrops. For this reason, areas containing many small Beartooth outcrops were shown as single outcrops to facilitate mapping (Fig. 2, in pocket). Furthermore, the talus obscures structures to the extent that they cannot be traced for any distance through the Beartooth. The talus also makes the locating of contacts difficult unless the formations are in outcrop contact, because Beartooth talus tends to obscure talus from other formations. The lower

contact with the Abo Formation is approximated (Fig. 2) both for this reason and because of the lack of outcrops of Abo Formation due to its susceptibility to erosion. The upper contact of the Beartooth with the shale member of the Colorado Formation is readily distinguished where the two are in outcrop contact (Fig. 2). The contact becomes more difficult to locate where neither of the formations crops out near the contact and increasingly more difficult to locate where Beartooth float partially obscures Colorado float.

While no accurate measurement of the thickness of Beartooth Quartzite could be obtained, the formation in the study area is about 130 feet thick. In the Santa Rita quadrangle, the Beartooth varies in thickness from 50 to 140 feet (Jones et al., 1967). No fossils were found in this formation.

The lithologic features of the Beartooth Quartzite are typical of sediments deposited by a transgressive sea on an area of low relief (Hewitt, 1959). The Beartooth Quartzite has been correlated by Darton (1928), Cobban and Reeside (1952), and Pike (1947) with the Sarten Sandstone in the Cooks Range north of Deming, New Mexico, on the basis of similar lithology and stratigraphic position. Fossils in limy beds in the middle of the Sarten have been identified as Early Cretaceous (Jones et al., 1967). These workers believe that the Beartooth represents the initial stage of the cyle of sedimentation that produced the beds of the Colorado Formation, whose age is firmly established as Late Cretaceous. Either the deposition of the Beartooth and Colorado sediments began in Early Cretaceous time and continued without interruption into Late Cretaceous time or the Beartooth is correlative with

only the upper part of the Sarten (Jones et al., 1967). An increase in sand content in the shale member of the Colorado Formation was noted as the contact with the Beartooth is approached. This increase in sand content seems to indicate continuous or nearly continuous deposition between the Beartooth and the Colorado Formations. The presence of a high amount of limonite in the sandy shale units of the shale member of the Colorado Formation indicates a shallow environment of deposition with short periods of emergence for the basal Colorado Formation. It would seem likely that nearly continuous deposition between the Beartooth and Colorado Formations took place and that the Beartooth is, therefore, correlative with only the upper part of the Sarten Sandstone.

Colorado Formation. In most of the Santa Rita quadrangle, the Colorado Formation consists of two mappable units, a basal shale member and an upper sandstone member (Jones et al., 1967). In the area covered by this report, the formation is readily divisible into the two members (Fig. 2, in pocket).

The shale member is composed of yellow-brown, gray, and black sandy shale units generally in the lower part of the member, and black, fissile shale generally in the upper part. The sandy shale contains a few 0.5 mm subrounded, clear to gray quartz grains in a very fine grained quartz and clay matrix which is usually calcareous. The sandy shale often contains up to 35 percent limonite which produces a light-yellow-brown color on weathered rock surfaces. The sandy shale unit in contact with the Beartooth Quartzite is more sandy than the shale above it, is yellow brown, quite high in limonite content, and contains very fine grains of white to light-gray quartz in a clay matrix. The matrix

is not calcareous. The sandy shale has a coarsely fissile bedding pattern and produces a blocky fracture pattern across the bedding. One lens of dark-gray limestone approximately 25 feet long and 1 foot thick was found in the sandy shale. Where the sandy shale has been cut by the eastern basalt dike (Fig. 2, in pocket), the shale has been bleached and silicified and secondary calcite has been formed.

The black shale units are very thinly bedded with laminae 0.25 to 3.0 mm thick (most are less than 2.0 mm thick), contain some brown laminae, and are quite fissile (Fig. 17). All samples tested were calcareous. The shale has a blocky fracture across the laminae, and thin calcite coatings are common on fractures. A few large, to 1 foot in diameter, nodules of black, impure limestone were found in the black shale. X-ray analyses (Jones et al., 1967) indicate that the shale consists of about 40 percent quartz, 40 percent clay, 10 percent calcite, 5 percent dolomite, and 5 percent organic material. A calcareous layer contains about 60 percent calcite, 15 percent quartz, and 25 percent clay and organic matter.

Attitudes are quite readily and accurately taken on the shale beds. A reliable thickness of 192 feet for the shale member in this portion of the Lampbright West area was obtained from cross sections (Fig. 13, section F-F', in pocket).

The sandstone member of the Colorado Formation in this area is a light to medium gray-brown and light-gray sandstone. It is composed of 0.1 to 0.2 mm subangular to subrounded quartz grains and lesser amounts of black rock fragments which are moderately well cemented by quartz and clay. The rock is well bedded with laminations of

Figure 17. Shale of the Colorado Formation

0.2 to 17 mm thick, most laminations are less than 1 mm thick. The rock contains small to moderate amounts of limonite which is concentrated in some laminae and depleted in other laminae. This feature gives the rock a banded appearance. Cross-bedding is common. The rock tends to weather to rounded surfaces and is a lighter shade of the same color found on fresh surfaces. Sandstone concretions are not uncommon in this member and vary in size from about 1 inch to more than 1 foot in diameter. Near the east-central edge of the area (Fig. 2, in pocket), the sandstone is calcareous adjacent to a fault zone which is part of the Nancy fault system. In this area, red-brown, ringlike banding also occurs in the sandstone.

The sandstone member has been intruded by a sill of quartz diorite porphyry in this area (Fig. 2). Where the sandstone and the sill are in contact, chlorite is present for a vertical distance of 50 feet or more into the sandstone below the sill. In thin section, the chlorite was identified as ripidolite. The ripidolite occurs as very finely divided aggregates accompanied by secondary iron oxides and surrounds subrounded to angular grains of quartz and orthoclase. This alteration was noted in the sandstone for a horizontal distance from the present contact of 300 feet in one area and up to 100 feet in another.

The sill and the sandstone beneath the sill form part of the present erosion surface. No sandstone is present above the sill in the area mapped nor in adjacent sections. From cross sections of the area (Fig. 13, sections G-G' and H-H', in pocket), there are at least 110 feet of the sandstone member present below the sill. As Jones et al. (1967) point out, the upper limit of the Colorado Formation is an erosional

surface. It is the present erosion surface in some places and an older surface in others. Because of this erosional surface, the original thickness of the Colorado Formation is nowhere preserved. Total preserved thicknesses of the Colorado Formation vary from 675 to 920 feet in the region, of which approximately the lower 200 feet are the shale member (Jones et al., 1967). Paige (1916) has estimated an original thickness of not less than 2,000 feet for the Colorado Formation in the Silver City region. In the area included in this study (Fig. 2, in pocket), there is a total preserved thickness of at least 302 feet of Colorado Formation including 192 feet of the lower shale member and at least 110 feet of the upper sandstone member.

The age of the Colorado Formation is firmly established as Late Cretaceous by fossil evidence (Jones et al., 1967). Fossils are scarce in the Colorado Formation; one brachiopod, a gryphaea horizon, and one gastropod were noted in the sandy shale units. No fossils were found in the sandstone member.

The Colorado Formation was originally widespread in south-central New Mexico, but much of it was eroded in Late Cretaceous time, prior to deposition of volcanic rocks in Late Cretaceous or early Tertiary time. The Colorado Formation is the equivalent of the Colorado Group which is the established name for beds representing the lower half of Late Cretaceous time in many areas in the Rocky Mountains. The sandstone member of the Colorado Formation is equivalen in age to the Greenhorn Limestone in Colorado, Wyoming, and eastern parts of northern New Mexico. The shale meber is equivalent to the Graneros Shale which underlies the Greenhorn Limestone and which is the base of the Colorado Group in northern New Mexico (Jones et al., 1967).

Cenozoic Rocks

Quaternary Alluvium. Alluvium was mapped where it appeared to be more than 4 feet thick over a significant surface area and where significant geological relationships were obscured (Fig. 2, in pocket). The alluvium is composed of soil, sand, gravel, and boulders derived from all the rock types in the area. No volcanic rocks or other rock types from outside the area and no rocks containing ore minerals were found in the alluvium. Transport distance to the site of deposition is minimal.

In the area studied, this unit corresponds to the "younger alluvium" of Jones et al. (1967) and is of Holocene age. The thickest deposit of alluvium in this area is on the order of 15 feet thick.

Quaternary Colluvium. Colluvium of Holocene age includes slope soil and talus derived mainly from the underlying formation and was mapped as the formation it covers. Colluvium is noted on the geologic map (Fig. 2, in pocket) by a lighter shade of the formation color between outcrops.

Igneous Rocks

Mesozoic(?) Rocks

Late Cretaceous(?) igneous rocks include two types of quartz diorite sills which were the first rocks intruded into the sediments of the thesis area and the Santa Rita quadrangle. The quartz diorite porphyry sill ("earlier quartz diorite" of Lasky, 1936) is a medium-grained porphyritic rock characterized by large, corroded, and often doubly terminated quartz crystals and by large euhedral books of altered biotite. The

other type of sill is composed of hornblende quartz diorite ("later quartz diorite" of Lasky, 1936) which appears almost equigranular and is distinguished by abundant altered hornblende laths and by the general absence of quartz and biotite phenocrysts. The rocks are sill-like but broadly discordant (Lasky, 1936), becoming laccolithic in places (Jones et al., 1967). The hornblende quartz diorite also forms thin dikes in several areas of the Santa Rita quadrangle (Jones et al., 1967). Lasky (1936) describes an area northeast of the Kneeling Nun, a prominent topographic feature east of the Chino mine (Fig. 5), where two of these dikes cut a quartz diorite porphyry sill. This relationship is the basis of the assignment of relative ages to the two rock types which Lasky describes as so nearly identical in mineral and chemical composition that they may be considered as having been injected by closely spaced pulses of the same magmatic differentiate. The similarities of and differences in the two rock types are shown by modal analyses in Tables 1 and 2 and by total spectrographic analyses in Table 3. Lasky believed that the earlier injection took place during resorption of the quartz crystals in the magma and that the later injection occurred when resorption was nearly completed.

The quartz diorite injections took place after deposition of the Colorado Formation and before emplacement of the andesite breccia in the North Star Basin area and in the area west of the Santa Rita quadrangle (Jones et al., 1967).

Quartz Diorite Porphyry. A sill of quartz diorite porphyry (the "upper sill" composed of "earlier quartz diorite" of Lasky, 1936) intrudes the sandstone member of the Colorado Formation approximately 302 feet

TABLE 1.--Modes of Quartz Diorite Porphyry

na, not applicable; ---, absent; Tr., trace; C, common. Reported as volume percent.

	10	Avg. 10-15	Kep-2
Matrix (quartz and feldspar	61	61	
(quartz and plagioclase			40
Major phenocrysts:			
Quartz	5	3	10
Plagioclase		26	
Plagioclase (An_{5-36})	26		
Plagioclase (An_{34})			30
Hornblende	na	na	na
Biotite	na	na	na
Accessory minerals:			
Magnetite	1	Tr.	2
Sphene	---	Tr.	---
Apatite	Tr.	Tr.	Tr.
Allanite	Tr.	Tr.	---
Zircon	---	Tr.	---
Alteration minerals:			
Epidote	Tr.	3	3
Calcite	2	C	---
Sericite	C	C	C
Illite	Tr.	Tr.	---
Montmorillonite	Tr.	Tr.	C
Zoisite	---	Tr.	Tr.
Albite	---	Tr.	---
Chlorite	C	C	
Biotite	---	Tr.	
Chlorite and Biotite			12
Iron oxides, secondary	---		C
Magnetite	---	Tr.	---
Quartz	---	Tr.	---
Pyrite	---	Tr.	---

10. Field No. JC-23-52. Sill 5,200 feet N. 48° E. of Kneeling Nun (Jones et al., 1967).

Avg. 10-15. Averages of six thin sections of quartz diorite porphyry (Jones et al., 1967).

Kep-2. Sill 8,900 feet N. 55° E. of Kneeling Nun (this study).

TABLE 2.--Modes of Hornblende Quartz Diorite

na, not applicable; ---, not present; Tr., trace; C, common; A, abundant. Reported as volume percent.

	5	7	Klp-2
Matrix	48	70	45
Quartz	21	na	20
Orthoclase	27	na	25
Major phenocrysts:			
Plagioclase (maximum An_{45})	28		
Plagioclase (maximum An_{52})		25	
Plagioclase (maximum An_{65})			30
Hornblende	na	5	na
Accessory minerals:			
Quartz	Tr.	Tr.	C
Biotite	Tr	---	---
Ilmenite-magnetite	1	Tr.	1
Apatite	Tr.	Tr.	Tr.
Zircon	Tr.	Tr.	C
Alteration minerals:			
Epidote	10	C	1
Calcite	---	C	---
Sericite	Tr.	C	Tr.
Kaolinite-montmorillonite(?)	---	---	C
Zoisite	---	---	C
Albite	Tr.	C	---
Chlorite	2	C	
Biotite	10	---	
Chlorite and biotite			20
Iron oxides, secondary	C	---	A
Quartz	Tr.	---	---
Pyrite	1	---	---

5. Field No. JC-7-56. Altered; near powerline in south center sec. 19, T. 17 S., R. 11 W. (Jones et al., 1967).

7. Estimated average mode of 27 thin sections (Jones et al., 1967).

Klp-2. Sill 200 feet south of boundary line between secs. 19 and 30, T. 17 S., R. 11 W., and 200 feet east of Delk Ranch road (Fig. 2, in pocket).

TABLE 3.--Results of Total Spectrographic Analyses of 12 Samples of Quartz Diorite Porphyry and 12 Samples of Hornblende Quartz Diorite*

	Kep			Klp		
Element	High	Low	Average	High	Low	Average
Al	8.0	4.1	6.17	8.0	6.0	7.0
Ba	0.2	0.06	0.12	0.15	0.04	0.14
Be	.0003		.00018	.0004		.00023
Ca	5.0		1.5	5.0	.1	2.0
Cr	.002	.0015	.0018	.004	.002	.0024
Co	.003		.00057	.003		.00047
Cu	.2	.0006	.029	.1	.0006	.026
Ga	.001	.0006	.00089	.0015	.0008	.00087
Ge	.00003	.00001	.00001	.0004		.000009
Fe	4.0	.9	2.96	4.0	1.5	3.71
La	.008	.003	.0056	.007	.004	.0055
Pb	.015	.00015	.0034	.02	.00015	.0030
Mg	1.0	.15	.55	1.5	.2	.72
Mn	.3		.067	.2	.0015	.053
Mo	.006		Tr	.006		Tr
Ni	.0004		Tr	.001		.0004
P	.07		.043	.15	.03	.067
K	3.0	.06	1.83	4.0	.03	2.20
Sc	.001	.0005	.0007	.0015	.0007	.0009
Si	10		10	10		10
Ag	.00002		Tr	.0001		.000015
Na	2.0	.02	.041	3.0		.094
Sr	.1		.036	.15		.058
Tl	.0002		.00011	.0002		.00013
Sn	.0015	.00006	.00055	.0015	.00008	.00043
Ti	.4	.3	.32	.5	.3	.40
W	.0002		Tr	.0002		Tr
V	.007	.004	.005	.008	.005	.007
Y	.005		.004	.006	.002	.004
Zn	.04		.0013	.02		.0010
Zr	.03	.015	.022	.03	.015	.026

* From McKelvey (1969). Analyses are reported in percent and have an accuracy of ± 30 percent.

above the base of the formation in sec. 31, T. 17 S., R. 11 W. (Fig. 2, in pocket; and Fig. 13, sections F-F' and G-G', in pocket). This sill extends in continuous outcrop from 0.5 mile east of the Chino mine through sec. 36 and the S1/2 sec. 25, T. 17 S., R. 12 W. into the southwestern edge of the thesis area.

Megascopically, the rock is a medium-grained porphyry composed of white, somewhat altered 2 by 3 mm feldspar phenocrysts, vitreous quartz crystals 1 to 2 mm in diameter, which are rounded in cross section and sometimes doubly terminated, euhedral altered biotite books to 4 mm in diameter, and a few altered hornblende laths to 1 mm in length in a medium-brown aphanitic groundmass. The feldspars and matrix are everywhere somewhat altered. On fresh surfaces, the rock is light gray-brown and weathers to medium brown. The sill in the area mapped is quite weathered; in some localities outside the thesis area, silicification has rendered it more resistant.

In thin section (Fig. 18), the quartz diorite porphyry is found to be a weakly to moderately altered porphyritic rock consisting of approximately 60 percent phenocrysts in a very fine grained groundmass. The phenocrysts are plagioclase, quartz, and hornblende. The plagioclase is weakly altered to epidote, montmorillonite, minor amounts of sericite, and trace amounts of zoisite, is somewhat corroded, and exhibits carlsbad, pericline, and carlsbad-albite twinning. Measurement of extinction angles on the carlsbad-albite twins yielded a plagioclase composition of andesine of An_{34}. The quartz phenocrysts are rounded and deeply embayed. They exist as single crystals and as clusters of crystals, all of which show evidence of partial resorption. Relict hornblende phenocrysts

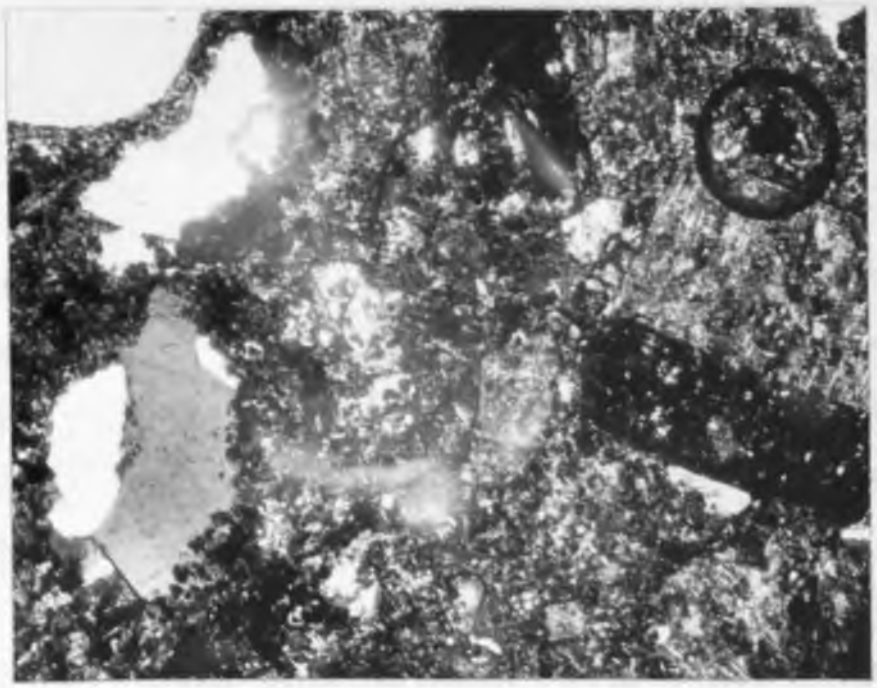


Figure 18. Photomicrograph of Thin Section of Quartz Diorite Porphyry

The surface is composed of phenocrysts of plagioclase, corroded and embayed quartz, and totally altered hornblende in a groundmass of quartz and plagioclase. Subordinate amounts of magnetite, apatite, epidote, sericite, montmorillonite, zoisite, chlorite, biotite, and secondary iron oxides are present. Crossed nicols, X31.

were identified. Altered books of biotite, which can be readily identified in hand specimen, were not seen in the thin section examined. The hornblende, and presumably the biotite, are completely altered to epidote, chlorite, biotite, and iron oxides. Because of the high degree of alteration of these minerals, no attempt was made to estimate the percentages of original biotite and hornblende in the rock. Opaque minerals are secondary iron oxides and magnetite. Trace amounts of orthoclase and apatite were noted. The groundmass consists mainly of very fine grained anhedral quartz and laths of feldspar which appear to be plagioclase, with subordinate amounts of epidote, chlorite, secondary iron oxides, and magnetite. The plagioclase exhibits carlsbad and possibly carlsbad-albite twinning. A modal analysis was determined for this rock (Table 1) with an analysis by Jones et al. (1967) for a sample taken from the same sill at a nearby location and an average analysis computed by Jones et al. (1967) from six thin sections.

The quartz diorite porphyry in secs. 25 and 36, T. 17 S., R. 12 W. has a chilled border in places that is not readily distinguished in hand specimen from the hornblende quartz diorite. This chilled border was not found in the area mapped.

The original thickness of this sill is not determinable as it forms part of the present erosion surface. The preserved thickness in the thesis area is at least 190 feet (Fig. 13, section G-G', in pocket). Adjacent to the thesis area, in sec. 36, T. 17 S., R. 12 W., the preserved thickness is at least 250 feet with a probable thickness of 440 feet. Lasky (1936) has stated that in the Bayard area this sill has a minimum possible thickness of 450 feet. Jones et al. (1967) suggest that the original

thickness of the upper sill was probably more than 500 feet and may have been more than 1,000 feet. Two recent diamond drill holes south of the Chino mine have penetrated 894 feet and 901 feet of quartz diorite porphyry before entering the Colorado Formation, and one drill hole in sec. 36, T. 17 S., R. 12 W. passed through 820 feet of this sill before entering the Colorado Formation (Baltosser, personal communication, 1970). The estimate given by Jones et al. (1967) of more than 1,000 feet for the original thickness of this sill is quite reasonable.

Hornblende Quartz Diorite. Hornblende quartz diorite forms a sill which crops out mainly in sec. 19, T. 17 S., R. 11 W. and extends southward into the northeast corner of sec. 30 where it is offset by the Nancy fault (Fig. 2, in pocket). The sill intrudes the Oswaldo Formation approximately 105 to 175 feet below the top of the formation. Both the upper and lower contacts of the sill and the Oswaldo Formation are present in the area included in this study (Fig. 2, in pocket; and Fig. 13, section A-A', in pocket). Jones et al. (1967) state that this sill intrudes the Oswaldo Formation at various levels in the eastern part of the Santa Rita quadrangle from 60 to 200 feet above the base. A similar sill in the Central mining district is known as the Marker or Hanover sill and occurs at levels varying from 35 to 110 feet above the base of the Oswaldo Formation (Jones et al., 1967). As the base of the Oswaldo Formation is not present in the area mapped, the geologic map prepared by Jones et al. (1967) was used to project a level for the base of the sill in the area mapped. This level is about 285 feet above the base of the Oswaldo Formation. The sill forms a prominent hill to the north of the boundary between secs. 19 and 30, T. 17 S., R. 11 W. This hill extends into sec.

30. The thickness of the sill in the area of this hill is considerably more than that further to the north as shown on the Geologic Map of the Santa Rita Quadrangle, Grant County, New Mexico (Jones et al., 1967), and the sill is apparently laccolithic in the area of this hill. The sill is faulted and, as most faults are impossible to trace for any distance through the sill, no thickness for the sill could be determined in the area mapped. It is estimated that the sill is at least 200 feet thick in this area.

In hand specimen, the hornblende quartz diorite is a medium-brown, fine-grained rock which weathers to a darker shade of brown. In some places, the rock is clearly porphyritic, in others the rock is nearly equigranular. The clay-altered groundmass is aphanitic and contains weakly to moderately altered, 0.5 by 1 mm to 2 by 3 mm plagioclase phenocrysts, 0.5 by 1 mm to 0.5 by 5 mm laths of altered hornblende, a few altered books of biotite 0.5 mm in diameter, and a trace of apatite which is less than 0.5 mm in length. Alignment of hornblende laths occurs in places.

In thin section (Fig. 19), the porphyritic nature of the hornblende quartz diorite is clearly observed. The rock consists of phenocrysts of plagioclase, hornblende, and quartz in a very fine grained groundmass of anhedral quartz and orthoclase. The plagioclase exhibits albite, carlsbad, pericline, and carlsbad-albite twinning. Measurement of extinction angles indicates a plagioclase composition of labradorite at An_{58-65}. The plagioclase phenocrysts are weakly to moderately altered to sericite, zoisite, and clay minerals, which are too fine grained for positive identification but are probably in the kaolinite or montmorillonite families.

Figure 19. Photomicrograph of Thin Section of Hornblende Quartz Diorite

The surface is composed of phenocrysts of plagioclase and hornblende which is almost totally altered to chlorite, biotite, and epidote, in a groundmass of quartz and orthoclase. Subordinate amounts of quartz, magnetite, apatite, zircon, sericite, zoisite, kaolinite-montmorillonite(?), and secondary iron oxides are present. Crossed nicols, X75.

The hornblende is almost completely replaced by chlorite, biotite, and epidote. Relict hornblende crystal structure is well preserved in this rock. Minor amounts of magnetite, secondary iron oxides, zircon, and traces of apatite occur in the rock. Some quartz occurs as phenocrysts in the groundmass. The quartz phenocrysts are smaller than the plagioclase phenocrysts and are much smaller than the quartz phenocrysts in the quartz diorite porphyry. A modal analysis of hornblende quartz diorite is given in Table 2 with an analysis by Jones et al. (1967) for a sample taken nearby and an average modal analysis derived by Jones et al (1967) from the results of 27 thin sections examined by Lasky (1936).

Pronounced bleaching of the hornblende quartz diorite was noted near some major faults. Epidote coating fractures near fault zones was observed in a few places. A 6-inch vein of hematite was found in a fault zone in the sill which is exposed in a roadcut near the western contact with the Oswaldo Formation.

Cenozoic Rocks

Trachyte. A small plug of trachyte (Fig. 4) with associated dikes is exposed in the south-central portion of the area mapped (Fig. 2, in pocket). The plug and dikes are in contact with the Beartooth Quartzite at the present surface elevations. The plug is roughly oval in plan and measures about 470 feet by 650 feet in surface dimensions. The dikes vary from 10 to 80 feet wide and are exposed for a maximum distance of 570 feet from the plug.

Megascopically, the trachyte contains a few scattered quartz phenocrysts 1 mm in cross section and 1.5 mm in long section and a few light-gray 1.5 by 1 mm euhedral feldspar phenocrysts which are clay

altered. The phenocrysts are set in a ligh-gray aphanitic groundmass. The trachyte is light gray on fresh surfaces and weathers light to medium brown. Very thin coatings of secondary manganese oxide and secondary iron oxides coat fractures in the trachyte.

In thin section (Fig. 20) the rock contains a few phenocrysts consisting of slightly rounded quartz and plagioclase which is almost totally altered to sericite. The phenocrysts are in a very fine grained groundmass of anhedral orthoclase which is weakly to moderately altered to very fine grained kaolinite and minor amounts of anhedral quartz (Table 4). Trace amounts of chlorite and pyrite are present. The groundmass also contains very fine grained, nearly opaque material which is irresolvable under the microscope. One veinlet of secondary orthoclase was noted. The veinlet cuts all other minerals (Fig. 20).

The plug and dikes have been called "felsitic rhyolite" by Jones et al. (1967). As the quartz content is less than 10 percent in the thin sections examined, a better name for the rock, at least in the thesis area, is trachyte.

Flow banding and foliation are pronounced in the trachyte, but no strong trends are apparent. Some overturning of these features occurs.

Megascopically, the contacts of the trachyte and the Beartooth Quartzite are silicified and show a tendency for the trachyte to assimilate some of the quartzite. In thin section (Fig. 21) the trachyte is finer grained at the contact, indicating chilling. The trachyte is flow banded parallel to the contact. Fragments of the quartzite have been engulfed by the trachyte, and the trachyte has intruded into the quartzite along grain boundaries. The engulfed quartzite is embayed and corroded more than

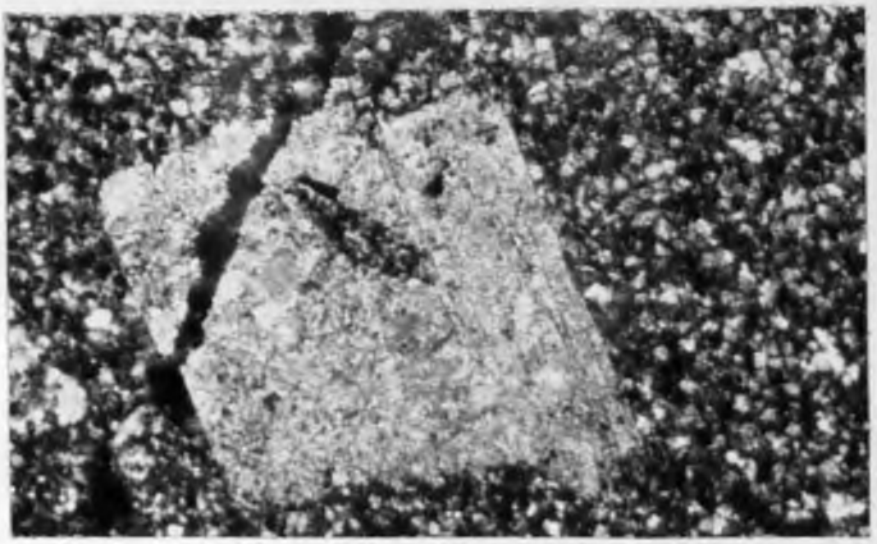


Figure 20. Photomicrograph of Thin Section of Trachyte

The surface is composed of a few scattered phenocrysts of quartz and plagioclase which is almost totally altered to sericite in a groundmass of orthoclase and minor amounts of quartz. Kaolinite is common but not abundant, and traces of chlorite, pyrite, and secondary iron oxides are present. A veinlet of orthoclase cuts the other minerals. Crossed nicols, X31.

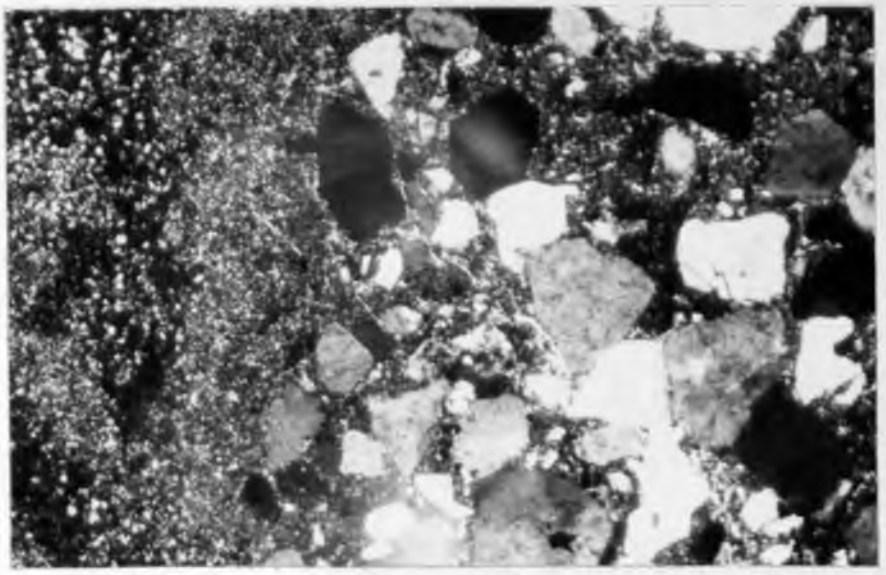


Figure 21. Photomicrograph of Thin Section of Contact Between Trachyte and Beartooth Quartzite

Trachyte has invaded and partially assimilated Beartooth Quartzite. Crossed nicols, X31.

TABLE 4.--Mode of Trachyte

Na, not applicable; Tr., trace; C, common. Reported in volume percent.

	Tri-1
Matrix	97
Orthoclase	90
Quartz	7
Major phenocrysts:	
Quartz	Tr.
Plagioclase	na
Alteration minerals:	
Orthoclase	Tr.
Kaolinite	C
Sericite, after plagioclase	Tr.
Chlorite	Tr.
Iron oxides, secondary	Tr.
Pyrite	Tr.

Tri-1. Trachyte plug sample 200 feet N. 80° W. of K.C.C. marker 68R-6319 (Fig. 2, in pocket).

the quartzite at the contact. Secondary iron oxides occur around quartz grains on the Beartooth side of the contact, but not in the engulfed quartzite fragments. No other mineralization, other than a trace of pyrite disseminated in the plug rock, is evident in the plug, the dikes, along the contacts, or in the wall rocks.

Several small dikes of trachyte less than 6 inches wide cut the trachyte plug and are evidence of multiple intrusion. Very little brecciation and no extensive fracturing exist along the contacts, and it is presumed that the intrusive pulses were closely spaced in time. In thin section, the dike material is nearly identical in mineralogy to that of the plug. Many patches of clay exist in the dike rock and appear to be superimposed on the groundmass. Much of the clay appears to be amorphous to very weakly birefringent and is optically most consistent with kaolinite. The thin section was thick and difficult to work with. The texture of the dike rock is finer grained than that of the plug rock.

One small pebble dike consisting of subrounded pebbles of trachyte, and possibly pebbles of sediments, in a matrix of trachyte and comminuted rock is exposed in the canyon west of the plug (Fig. 2, in pocket). The exposure is small and could not be traced away from the canyon walls. The pebble dike is in sharp contact with Beartooth Quartzite on the northwest and is covered by alluvium on all other sides. Microscopically, the rock contains traces of plagioclase phenocrysts which are completely altered to sericite, anhedral grains of quartz (5 percent), anhedral grains of orthoclase (50 percent) which are moderately altered to very fine grained clay minerals which may be kaolinite and sericite, and very fine grained material mixed with secondary iron oxides which

may be comminuted rock (45 percent). The texture is fine grained but not as fine grained as that of the plug rock.

The relative age of the trachyte plug and dikes is known only as post-Cretaceous. The plug and dikes are assumed to be related to the extrusion of the rhyolite tuffs of Miocene(?) age (Jones et al., 1967).

Basalt. Two basalt dikes crop out south of the Nancy fault near the center of the section line between secs. 30 and 31, T. 17 S., R. 11 W. (Fig. 2, in pocket). The western dike trends N. 68° E. and dips about 80°S. The dike is 15 feet wide and is exposed for 35 feet along the trend. The eastern dike varies from 20 to 130 feet in width and averages about 90 feet in width. This dike, where exposed, trends N. 4° E. for 210 feet, then N. 55° W. for 180 feet, and is nearly vertical.

Megascopically, the rock is black on fresh surfaces and contains red-brown altered hornblende phenocrysts in an aphanitic groundmass. On weathered surfaces, the rock is a medium red brown and medium gray and contains conspicuous holes left by the weathering away of the altered hornblende phenocrysts. In places, the basalt breaks into thin, nearly horizontal slabs. The western dike is exposed in a stream bed. The rock is medium gray, highly altered, possibly by supergene processes, and contains moderate amounts of secondary iron oxides. The rock in this exposure is very incompetent as indicated by its tendency to crumble where broken.

A thin section of a sample of the eastern basalt dike (Fig. 22) contains about 5 percent hornblende which has been pseudomorphically replaced by biotite. The phenocrysts are corroded, but enough of the

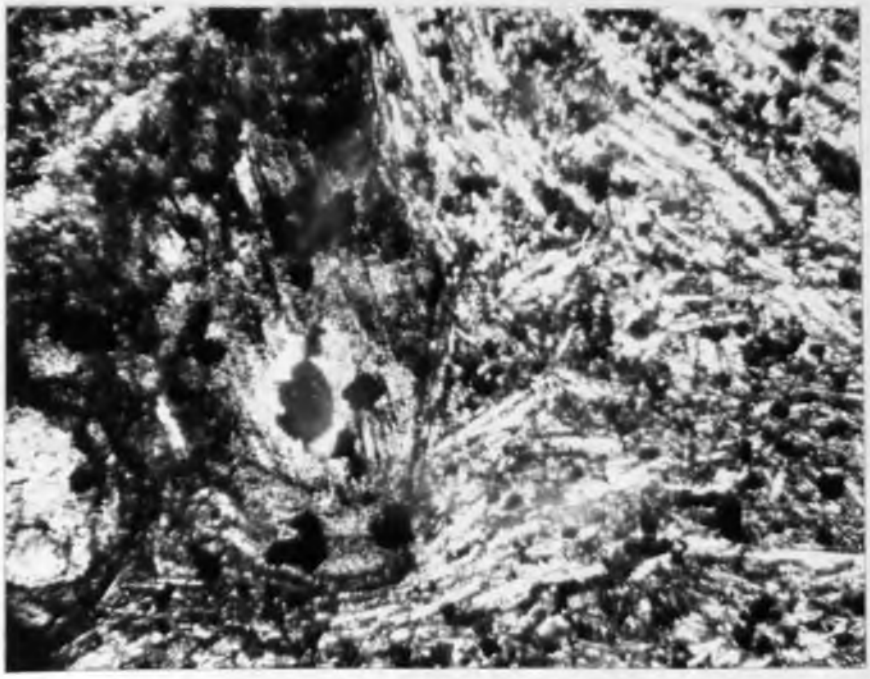


Figure 22. Photomicrograph of Thin Section of Basalt Dike Showing Flow Orientation of Plagioclase Laths.

The surface is composed of relict hornblende phenocrysts which are altered to biotite in a groundmass of plagioclase and magnetite. Minor amounts of quartz, apatite, and clinopyroxene are present. Crossed nicols, X75.

original structure remains to tell that most, and probably all, of the phenocrysts were originally hornblende. The phenocrysts are in a very fine grained matrix composed primarily of plagioclase laths and magnetite grains, with subordinate quartz, biotite, apatite, clinopyroxene which is probably augite or pigeonite, and trace amounts of chlorite (Table 5). The plagioclase laths exhibit some carlsbad twinning and possibly some albite twinning whose determination revealed a composition of labradorite at An_{52}. The plagioclase is unaltered, and the laths exhibit flow orientation.

The basalt dikes were probably feeders for the basaltic andesite flows which may have once covered the area. Remnants of these flows exist southwest of the area mapped on Nun Ridge (Fig. 5). The basalt dikes may be equivalent to the basaltic andesite of Jones et al. (1967) of Miocene(?) age.

Structure

Folds

The thesis area is situated on the northeast flank of a northwest-trending regional syncline. The regional strike of the sedimentary beds in the area is about N. 30° W. with a dip of about 15° SW. Folding superimposed on this regional feature consists of local warps related to faulting and igneous intrusions.

The hornblende quartz diorite sill in sec. 30, T. 17 S., R. 11 W. has intruded the limestone beds of the Oswaldo Formation (Fig. 2, in pocket). Dips on the sedimentary beds decrease to the southwest away from the exposed western contact. This feature is interpreted as

TABLE 5.--Mode of Basalt

na, not applicable; Tr., trace; C, common. Reported in volume percent.

	1
Matrix	95
Plagioclase (An_{52})	70
Major phenocrysts:	
Hornblende	na
Accessory minerals:	
Quartz	Tr.
Biotite	C
Apatite	2
Clinopyroxene	5
Magnetite	15
Alteration minerals:	
Biotite, pseudomorphs after hornblende	5
Chlorite	Tr.

1. Dike 850 feet S. 30° W. of K.C.C. survey marker 68N-6564 (Fig. 2, in pocket).

evidence of decreasing thickness of the sill from northeast to southwest and is also interpreted as evidence of increasing expansion of the sedimentary section from southwest to northeast. It is concluded that the sedimentary section was arched over a portion of the sill which is laccolithic in this area.

Strikes and dips of the sedimentary horizons southeast of the 1/4 cor. sec. 25, T. 17 S., R. 12 W. and sec. 30, T. 17 S., R. 11 W. (Fig. 2) denote the presence of a syncline in this area. The syncline has a northeast axial trend which plunges to the southwest. The quartz diorite porphyry sill is present to the southwest along the axial trend of the syncline. The sediments exposed around the edge of the sill have attitudes which apparently conform to an extension of the syncline into the sedimentary rocks below the sill. It is possible that this downwarp was formed by the intrusion of the quartz diorite porphyry sill into the sandstone member of the Colorado Formation in this area.

A small plunging anticline is present in a stream bed in the south-central portion of the area mapped (Fig. 2). The axis trends northeast and plunges southwest.

Nearly vertical contacts between the trachyte plug with its associated dikes and the sedimentary wall rocks show that the plug is a piercement intrusion (Fig. 2, in pocket; and Fig. 13, sections G-G' and I-I', in pocket). Attitudes of the sedimentary rocks near the plug and dikes are in general agreement with attitudes of the sedimentary rocks away from the plug and dikes. No extreme warping of beds and no thrust faulting have occurred near the plug and dikes. Where the trachyte and Beartooth Quartzite are in outcrop contact, both megascopic and

microscopic examination of the contact rocks revealed pieces of Beartooth Quartzite that were surrounded and partially assimilated by the trachyte. This evidence leads to the conclusion that the trachyte plug with its associated dikes was a passive intrusive complex, tending to stope its way upward by assimilating the country rock it passed through rather than being forcibly injected into and through the overlying sediments.

In the thesis area, minor drag folding is commonly present adjacent to faults with moderate to large displacements. Block-fault tilting of beds is common throughout the study area (Figs. 2 and 13, in pocket).

Faults

Faulting in the thesis area is of the high-angle normal displacement type, with some faults possessing a strike-slip component. No reverse or thrust faulting is known to have occurred in the area. No evidence of Holocene faulting was noted.

As can be seen on the geologic map (Fig. 2), much of the major faulting of the area can be related to the Nancy fault which trends about N. 80° E. and which is the most prominent fault in the thesis area. Structural adjustments along the Nancy fault are in the form of block faulting (Fig. 2, in pocket; and Figure 13, sections B-B', C-C', H-H', I-I', and J-J', in pocket). The displaced blocks are bounded by faults which trend into the Nancy fault and which, with the Nancy fault, comprise the Nancy fault system. In one part of the study area, Beartooth Quartzite has been displaced downward on the south side of the Nancy fault against the Syrena Formation on the north side (Fig. 2). Faulting has removed the

Abo Formation from this area; therefore, it is evident that the maximum vertical offset along the Nancy fault is at least 145 feet. Vertical displacements on other faults in the study area vary from inches to almost 100 feet.

A rose diagram of the faults mapped in the area is shown on Figure 23. A strong fault trend of N. 10° E. to N. 50° E. is evident. Rose diagrams were plotted for faults occurring north of the Nancy fault (Fig. 24) and for faults occurring south of the Nancy fault (Fig. 25). Faults north of the Nancy fault display a dominant trend of N. 40°-80° E., while faults south of the Nancy fault possess a strong trend of N. 10°-40° E. In all of the diagrams, faulting of northwest trend is clearly subordinate. The differences in fault trends north and south of the Nancy fault and the relative high amount of displacement on the Nancy fault indicate that the Nancy fault is a major structure. Faults on the north side of the Nancy fault may belong to one structural subprovince while those on the south side of the Nancy fault may belong to a different subprovince.

The hornblende quartz diorite sill lies north of the Nancy fault and has intruded the Oswaldo Formation at various levels (Fig. 2, in pocket). This is interpreted as pre-sill movement on faults belonging to the Nancy fault system. Some faults belonging to the Nancy fault system and the Nancy fault itself cut both the sedimentary beds and the sill. The Nancy fault has displaced the limestone beds of the Oswaldo Formation downward on the south side of the fault against hornblende quartz diorite sill on the north side of the fault. This period of movement on the Nancy fault system occurred after the sill was in place. It would appear

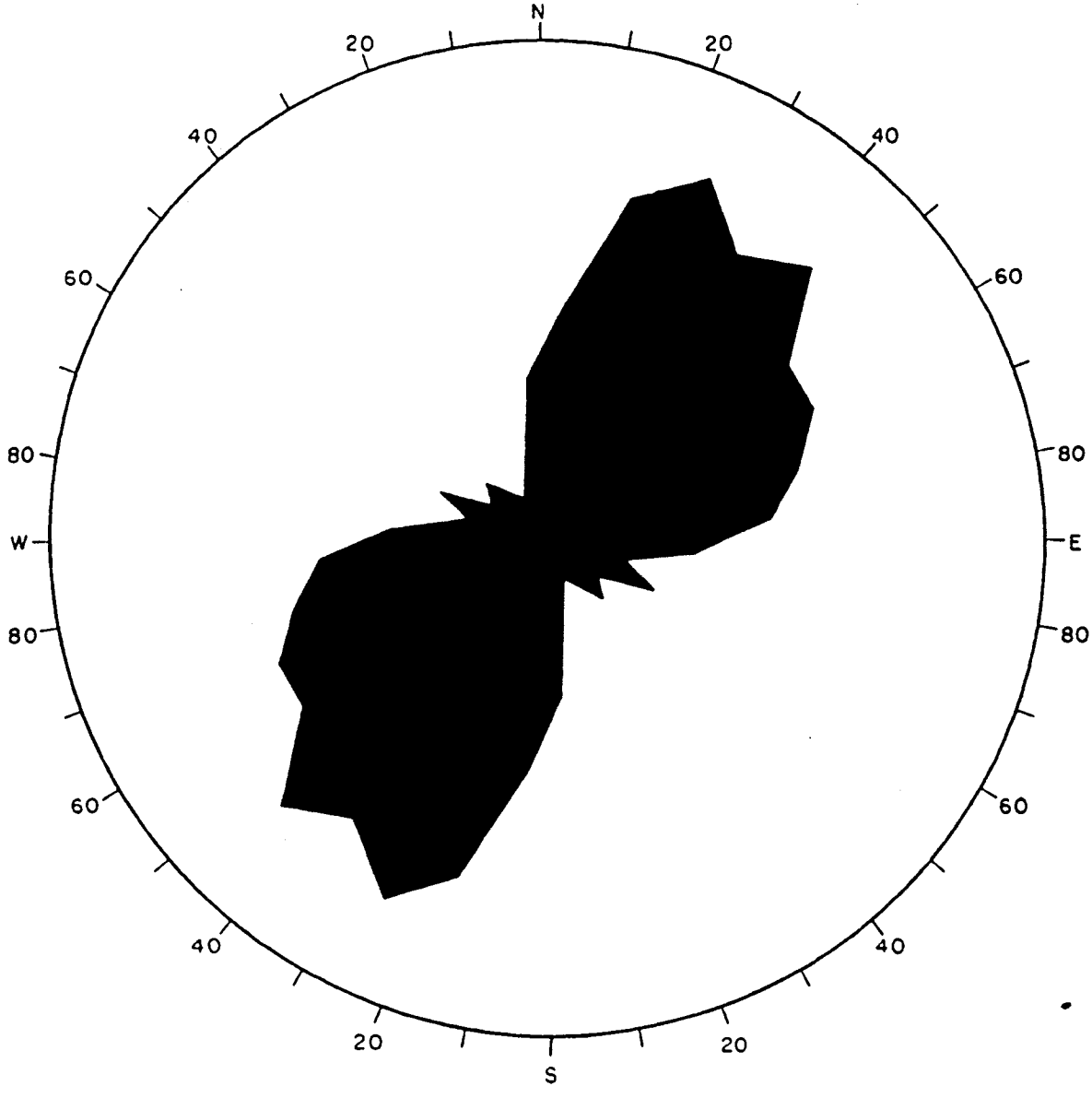


Figure 23. Rose Diagram of Faults in the Study Area

Faults were classed into 10° groups by strike beginning with 0°-10° and plotted at the median for the group beginning with 5°.

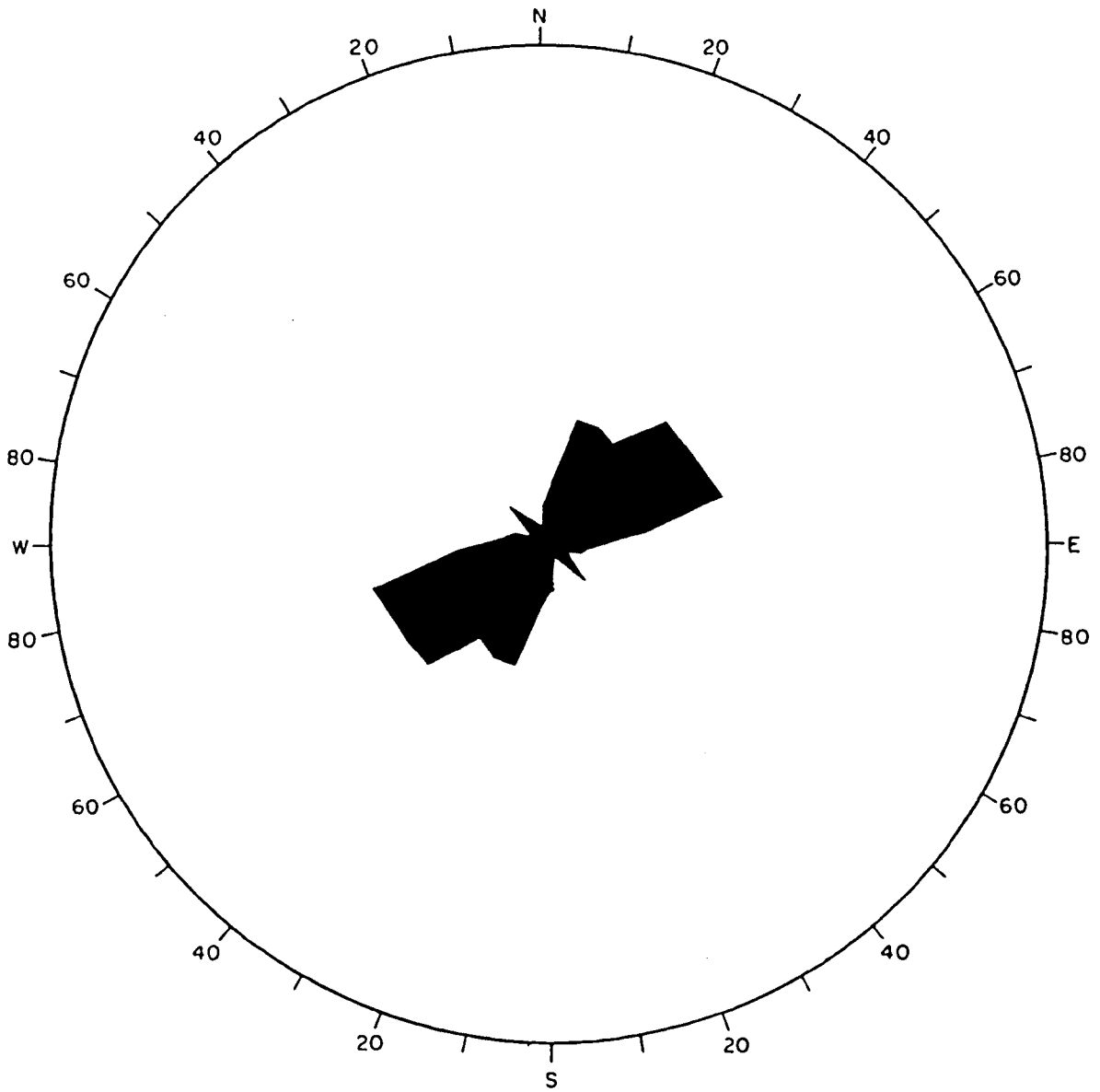


Figure 24. Rose Diagram of Faults North of the Nancy Fault

Faults were classed into 10^{o} groups by strike beginning with 0^{o}-10^{o} and plotted at the median for the group beginning with 5^{o}.

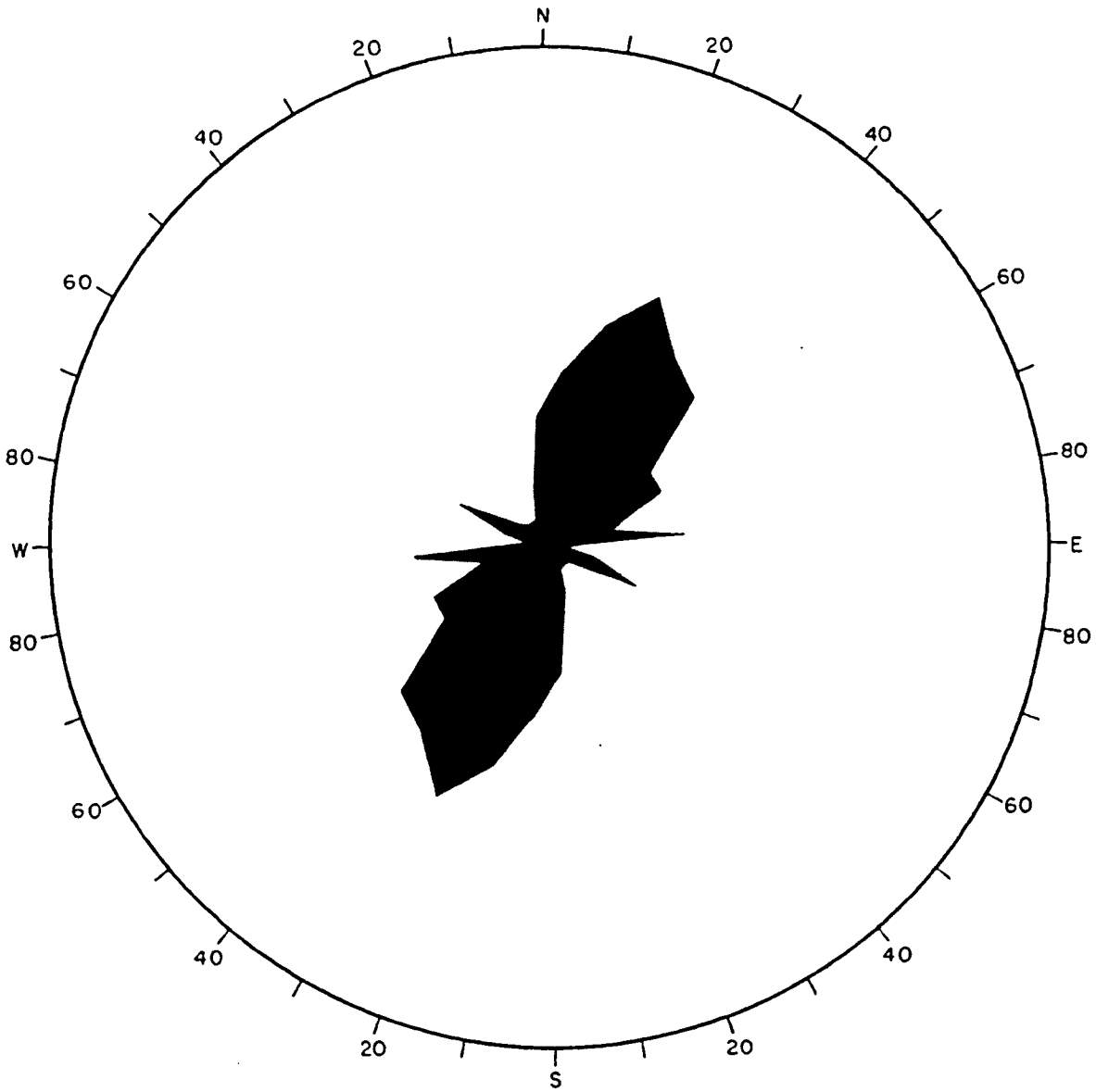


Figure 25. Rose Diagram of Faults South of the Nancy Fault

Faults were classed into 10^{o} groups by strike beginning with 0^{o}-10^{o} and plotted at the median for the group beginning with 5^{o}.

that the Nancy fault system formed sometime after deposition of the Colorado Formation and before intrusion of the hornblende quartz diorite sill and that a later, and apparently the main, period of movement occurred sometime after the sill was emplaced.

North of the Nancy fault, the Hornet fault is queried on the geologic map (Fig. 2, in pocket) as the extension of the fault into the thesis area is uncertain. Displacement on the Hornet fault could not be determined, but it appears to be much less in the thesis area than the displacement on the Nancy fault.

South of the Nancy fault, an unnamed major fault in the southern part of the area mapped (Fig. 2) trends about N. 85° W. and has displaced a quartz diorite porphyry sill on the south side of the fault down against the sandstone member of the Colorado Formation on the north side of the fault and the shale member of the Colorado Formation on the south side of the fault down against Beartooth Quartzite on the north side of the fault. This fault is offset in the western part of the thesis area by faults of a younger set. West of the thesis area, the fault trends toward the southwest extension of the Nancy fault and the Chino mine area (Fig. 8). Jones et al. (1967) extend this fault to the east where it is cut off by or merges with a northeast-trending fault (Fig. 8). Detailed field work has shown this situation to be somewhat different than reported by Jones et al. (1967). Figure 2 (in pocket) shows a fault pair in this area which trends about N. 80° W. and bounds a large block of Beartooth Quartzite which is in fault contact with the Abo Formation on the north and on the south. Evidence of faulting includes outcrops of conglomerate of the Abo Formation near outcrops of Beartooth Quartzite and

colluvial contacts between the Abo Formation and Beartooth Quartzite, all of whichare topographically lower than the normal contacts to the north and south. Blocks of Beartooth Quartzite in this zone are rotated from the normal attitudes of the sedimentary beds in the surrounding areas (Fig. 2, in pocket). The blocks and outcrops in the zone are quite large and appear to be in place and not transported by gravity. Pieces of quartz diorite porphyry occur as float within this zone but are not found on the hill slopes north or south of the zone. It is believed that the float could have been derived from blocks of a sill of quartz diorite porphyry which may have existed in the sandstone member of the Colorado Formation which once overlay this area and were dragged into place along the faults. Displacement on the western part of the fault pair is not determined but is very likely quite small as the faults appear to die out in this area. At the east edge of the thesis area (Fig. 2), the fault-bounded block of Beartooth Quartzite has been displaced downward some 80 feet (Fig. 13, section J-J', in pocket). The Beartooth Quartzite fault block thus may be a hinged block with the hinge line buried under colluvium to the west of the traceable extent of the fault pair.

Alteration

In the following discussion, alteration related to deuteric, hydrothermal, and supergene processes will be discussed. Deuteric processes are taken to mean those autometamorphic alteration processes which occur during the emplacement and crystallization of an igneous mass and are processes which involve the activities of heat and chemically active fluids within the igneous body. Processes which occur after the deuteric alteration and those which impose alteration other than

purely thermal metamorphism on the host rocks of the intrusive mass are considered to be hydrothermal processes. It is recognized that deuteric and hydrothermal processes can be a continuum within an intrusive igneous body and that while deuteric processes may be taking place in a partially crystallized portion of the mass, hydrothermal processes may be occurring in a crystallized portion of the body. Thus, for example, while the deep central portion of a plug is crystallizing and deuteric processes are altering the early formed minerals, hydrothermal fluids derived from the central portion of the intrusive body may be altering the crystallized rock near the edges of the body and altering or introducing minerals into the host rocks. It is further recognized that as the igneous body is being emplaced, heat and chemically active fluids derived from the body probably emanate outward from the igneous mass to mix with meteoric waters and react with the country rocks. These changes are also classed as hydrothermal. Supergene processes are those processes related to erosion and weathering which alter and remove rock constituents.

All of the igneous rocks in the area show some form of alteration. Quartz phenocrysts are strongly corroded and embayed in the quartz diorite porphyry and weakly corroded in the trachyte. Plagioclase phenocrysts in the trachyte are highly altered to sericite, while orthoclase in the groundmass is only weakly to moderately altered to kaolinite. Plagioclase in the quartz diorite porphyry is somewhat corroded and is weakly altered to montmorillonite, sericite, and epidote. In the hornblende quartz diorite, the plagioclase is weakly to moderately altered to kaolinite-montmorillonite(?), sericite, and zoisite. Biotite and hornblende in the quartz diorite porphyry are completely altered to chlorite, epidote,

and secondary iron oxides. Hornblende in the hornblende quartz diorite is totally altered to chlorite, biotite, and epidote. Hornblende in the basalt is completely altered to biotite. These forms of alteration appear to have occurred during crystallization of the igneous body in which they occur and may have been formed by deuteric alteration processes.

It was pointed out that deuteric and hydrothermal processes can be a continuum and recognition of the division of the two may be difficult to impossible in some cases. The development of chlorite and epidote in the quartz diorite sills might reflect weak propylitic alteration by a distant hydrothermal source or may be due to deuteric alteration processes which occurred within the sills during the period of crystallization. Epidote does occur along a few fractures near faults and along some faults in the sills. This epidote may have had a hydrothermal origin. Whether the alteration formed from hydrothermal solutions evolved from the later crystallizing rocks in the source chambers of the sills or from external igneous sources not directly related to the formation of the sills is a question which has not been resolved. The number of occurrences of epidote related to fractures and faults is small.

Orthoclase veinlets in the trachyte cut all other minerals in the rocks (Fig. 20). This orthoclase is obviously a late feature and may represent a stage of hydrothermal alteration which is related to the intrusion of the trachyte. The Beartooth Quartzite in contact with the trachyte is silicified and contains minor amounts of secondary iron oxides at the contact. The silicification and the introduction of the primary iron minerals represent hydrothermal alteration related to the intrusion of the trachyte. Supergene processes converted the primary iron minerals, possibly

pyrite, to secondary iron oxides. Hydrothermal solutions released from the quartz diorite porphyry sill probably introduced the chlorite and primary iron minerals into the underlying sandstone member of the Colorado Formation. The primary iron minerals which may have been magnetite were later oxidized by supergene processes to secondary iron oxides. The shale member of the Colorado Formation has been bleached and silicified by the eastern basalt dike. A high amount of calcite is present in the shale at the contact and part of the calcite is in the form of rosettes. The bleaching, silicification, and calcite are possibly the result of hydrothermal processes related to the intrusion of the basalt. Too much calcite is present to attribute its origin to concentration of the calcite present in the shale. However, the calcite may have been derived from calcareous sediments transected by the dike and redeposited in the shale. Bleaching and recrystallization of the limestone beds of the Oswaldo Formation above the hornblende quartz diorite sill may be the result of hydothermal activity related to the intrusion of the sill.

The groundmass of the western basalt dike is highly altered, while that of the eastern basalt dike is quite fresh. As the western basalt dike crops out in a stream bed, it is possible that supergene processes may be responsible for the destruction of the groundmass of this dike. Limonite, hematite, and manganese oxide coatings on fractures and faults are present in the quartz diorite porphyry, the hornblende quartz diorite, the trachyte, and the Beartooth Quartzite, and hematite and limonite coatings occur on fractures and faults in the other rocks of the thesis area. The coatings are very thin. Iridescent limonite has formed, in places, along fractures in the Beartooth Quartzite. These

secondary iron oxides, except for the ones in the scattered gossans, vein fillings, and in the jasperoid deposits, may be derived from the supergene alteration of iron-bearing minerals in the overlying or surrounding rocks and can be classed as downward or laterally transported. The secondary iron oxides which are present in the gossans, vein fillings, and jasperoid deposits are probably the result of supergene oxidation of pyrite and possibly other primary iron-bearing minerals which once existed in these features. The Oswaldo, Syrena, and the Abo Formations, and the shale member of the Colorado Formation contain some secondary calcite as fracture fillings. These veinlets approach 4 inches in width in the limestones and are less than 1 inch wide in the shale member of the Colorado Formation. As no calcite veinlets occur in the noncalcareous rocks in the thesis area, it would seem that this calcite probably has not been hydrothermally introduced into the fractures. Excluding the calcite in the shale member of the Colorado Formation at the contact with the basalt dike, it appears that the calcite fracture fillings in the calcareous rocks of the thesis area were probably formed by supergene weathering processes which dissolved the calcite from the calcareous beds and redeposited it in the fractures.

The sandy shale units of the Colorado Formation often contain much limonite which is along bedding planes and disseminated in the matrix. The Beartooth Quartzite contains intergranular hematite in most places. The secondary iron oxides are pervasive and rather uniformly distributed throughout the beds in which they occur. No fracture control of this mineralization was observed. Other sedimentary rock exposures away from the highly mineralized areas of the Santa Rita quadrangle

contain pyrite which is evidently an original depositional feature of the sedimentary unit (Baltosser, personal commun., 1970). This secondary iron oxide is thought to be derived by supergene oxidation processes from primary iron-bearing particulates that were deposited by sedimentary processes in sediments in intermittently submerged shallow sea environments.

Research by Nielsen (1970) has shown that on the east side of the Santa Rita stock, tactite or bleached marble alteration in the limestone beds of the Oswaldo and Syrena Formations is visible to about 3,000 feet from the stock margin. Primary copper and magnetite mineralization is present in these beds to about 2,000 feet from the stock margin. Recognizable minerals in the visible alteration halo outside the ore zone are comprised of an inner suite of andradite, epidote, and diopside with lesser amounts of quartz, magnetite, actinolite, and pyrite, and an outer suite of calcite, quartz, and tremolite with lesser amounts of kaolinite, diopside, andradite, epidote, pyrite, and sphalerite. The visible alteration halo extends almost twice as far in the calcareous shales of the Syrena Formation as in the limestone beds and has been detected up to about 5,000 feet from the east margin of the Santa Rita stock. Chalcopyrite is generally present in a disseminated copper tactite zone to about 2,000 feet from the stock contact, but ore grade is attained only locally and the highest grade is along the stock contact. Two mineral suites comprise the alteration halo beyond the disseminated copper tactite zone and these consist of an inner suite of epidote, quartz, andradite, diopside, pyrite, magnetite, and chlorite with lesser amounts of plagioclase, and an outer greenish-gray, flinty hornfels suite composed of calcite, quartz, plagioclase, and actinolite with lesser amounts

of epidote, garnet, chlorite, and pyrite. X-ray diffraction analyses have detected microscopic alteration effects in the calcareous shales to a distance of 8,000 feet from the stock contact (Nielsen, 1970).

The western edge of the thesis area is about 10,000 feet from the stock-sediment contact on the east side of the Chino mine. Nielsen's work indicates that no alteration effects related to the Santa Rita stock should be visible in the Syrena and Oswaldo Formations in the thesis area. Detailed mapping of the area bears this out. However, no work of this nature has been performed in the quartz diorite porphyry sill which extends from near the east edge of the Chino mine into the thesis area. For this reason, it is difficult to say conclusively whether the alteration in the sill is deuteric alone or is combined with hydrothermal alteration related to the Santa Rita stock or to another igneous source, perhaps the deeper roots of the sill itself. No apparent increasing or decreasing alteration trends in the direction of Santa Rita, or for that matter, in any direction, were noted in the portions of the sills in the thesis area. From this observation and the results of Nielsen's (1970) work, it would appear that the thesis area is outside the zone of visible hydrothermal alteration effects of the Santa Rita stock. It also seems probable that the alteration within the sills is deuteric while the epidote alteration along fractures and faults in the sills is of hydrothermal origin and from an unknown source.

In conclusion, alteration in the thesis area is, for the most part, directly relatable to exposed sources or to surface processes which are occurring at the present time. No alteration pattern indicative of a hidden ore body or buried intrusive stock was observed. No apparent

alteration effects of the Santa Rita stock on the rocks of the thesis area were observed.

Mineralization

Evidence of mineralization in the study area is sparse. Pyrite was found in two places in a bed of dark-gray shaly quartzite in the Beartooth Quartzite. This pyrite is cubic in habit and disseminated in the rock. Occurrences of pyrite, such as this, are not uncommon in the Santa Rita region, and pyrite is found disseminated in other sediments away from the highly mineralized areas of the region (Baltosser, personal communication, 1970). A few pieces of Beartooth Quartzite float containing limonite boxworks after pyrite were found. There was never enough of this material present to trace it to its place of origin. Limonite boxworks after pyrite were encountered in a few fault zones in the Beartooth Quartzite and the shale member of the Colorado Formation. This limonite is present in fault systems that appear to be major zones of weakness which trend toward the Chino area. The origin of this pyrite may have been through lateral migration of solutions from the Santa Rita stock system along the major fault systems or through hydrothermal activity accompanying other igneous intrusions in or near the study area. The faults containing the limonite are thought to have formed following the intrusions of the quartz diorite sills and possibly prior to the intrusion of the Santa Rita stock. Limonite boxworks after pyrite were also found in a very few places in the quartzite of the Beartooth Quartzite and more commonly in a few conglomerate beds in the Beartooth. The boxworks are confined to individual beds and do not appear to be related to

fractures or faults. The pyrite may have been a clastic constituent during sedimentary deposition.

Other mineralization in the thesis area includes a 1-foot-wide vein of hollandite and manganite filling a fault in Beartooth Quartzite in the Nancy fault system. The minerals were identified by X-ray analyses on material taken from a polished slab of the vein material. This vein is exposed for 20 feet along the fault trend. Lateral migration of mineralizing solutions from the Santa Rita stock along the Nancy fault could have produced this mineralization. It will be recalled, however, that recent work by Nielsen (1970) has indicated that the thesis area is probably beyond the eastern extent of visible alteration and mineralization effects produced by the Santa Rita stock system. Mineralization of this type was not observed anywhere else in the thesis area. It is possible that the origin of this vein filling is related to migration of hydrothermal solutions into this part of the Nancy fault system from other centers of igneous activity in or near the thesis area. A 6-inch-wide vein of hematite occurs in a fault zone in the hornblende quartz diorite sill near the western contact with the Oswaldo Formation. This vein filling of hematite probably consisted originally of primary iron minerals, such as magnetite or specular hematite, which have since been oxidized to the hematite. The primary minerals may have been deposited from hydrothermal solutions tapped from the nearly consolidated sill by the fault.

Jasperoid Deposits

Extensive jasperoid deposits occur in the N1/2 sec. 30, T. 17 S., R. 11 W. (Fig. 14, in pocket). These bodies (Fig. 26) are composed primarily of cryptocrystalline silica with lesser amounts of secondary iron oxide minerals and material which under the microscope

A

B

Figure 26. Jasperoid Deposits

A. Jasperoid replacing beds of argillaceous limestone of the Syrena Formation. Attitude of jasperoid in foreground conforms to attitude of underlying and adjacent argillaceous limestone beds.

B. Jasperoid replacing argillaceous limestone of the Syrena Formation. Note sharp contact of jasperoid and argillaceous limestone.

appears to be a mixture of secondary iron oxides and an amorphous to very nearly amorphous material. The jasperoid has replaced limestone and argillaceous limestone of the Syrena and Oswaldo Formations. Location of these deposits is controlled in part by faults which belong to the Nancy fault system. Replacement of a bed or beds adjacent to a fault has occurred in continuous bands along the faults and in elongate bodies apparently randomly spaced along the faults and which are separated by unaltered limestone or argillaceous limestone (Fig. 14, in pocket).

In places, jasperoid also replaces the limestone and argillaceous limestone in individual beds adjacent to the fault zones (Fig. 26). These deposits are not confined to any one bed or sequence of beds, but they appear to be restricted to the limestone and argillaceous limestone beds in the thesis area. Fresh limestone or argillaceous limestone can occur next to, below, and apparently above the portion of the bed that was replaced by jasperoid material.

Blocks of limestone or argillaceous limestone are surrounded by jasperoid in places. Knife-edge contacts exist between the jasperoid material and the surrounded calcareous blocks, and the blocks have not been visibly altered (Fig. 26). Fossil molds and fossils which have been replaced by jasperoid are common in places.

In hand specimen, the jasperoid may be white, light to medium gray, yellow brown, or various shades of red, brown, and red brown. More commonly, the rock is composed of more than one of these hues. The jasperoid is seen in this section to consist of fine-grained to very fine grained, angular to subrounded quartz grains with varying amounts

of secondary iron oxides and material composed of secondary iron oxides and an amorphous or very nearly amorphous substance. Clusters of medium-grained quartz crystals occur in the finer grained material. The clusters are subrounded and are embayed by the finer grained jasperoid (Fig. 27). Veinlets of medium-grained angular quartz crystals cut the other jasperoid material, and a vug lined with medium-grained quartz crystals was noted in the finer grained jasperoid.

Opaline quartz has been found in a few jasperoid exposures. Vugs lined with small quartz crystals are a common occurrence, as are cavities after pyrite. The jasperoid is often highly fractured, and brecciated jasperoid cemented by more jasperoid occurs in places.

Total spectrographic analyses were run on 10 representative jasperoid samples (Fig. 14, in pocket) under the direction of D. Norton, Geochemical Research and Laboratory Division, Kennecott Exploration, Inc. Accuracy of the total spectrographic method is about $\pm$ 30 percent. The classification of Young and Lovering (1966) was selected for evaluation of the results which are presented in Table 6. The results of the evaluation show that three samples fall in the "unfavorable" class, six samples are in the "probably unfavorable" class, and one sample is in the "possibly favorable" class. None of the microscopic work usually employed in this classification was performed. If this work were carried out and all the favorable factors were present in the samples evaluated, the best possible results would be five "possibly favorable" samples and five "probably favorable" samples. Two thin sections of samples not analyzed were examined, and none of the favorable microscopic

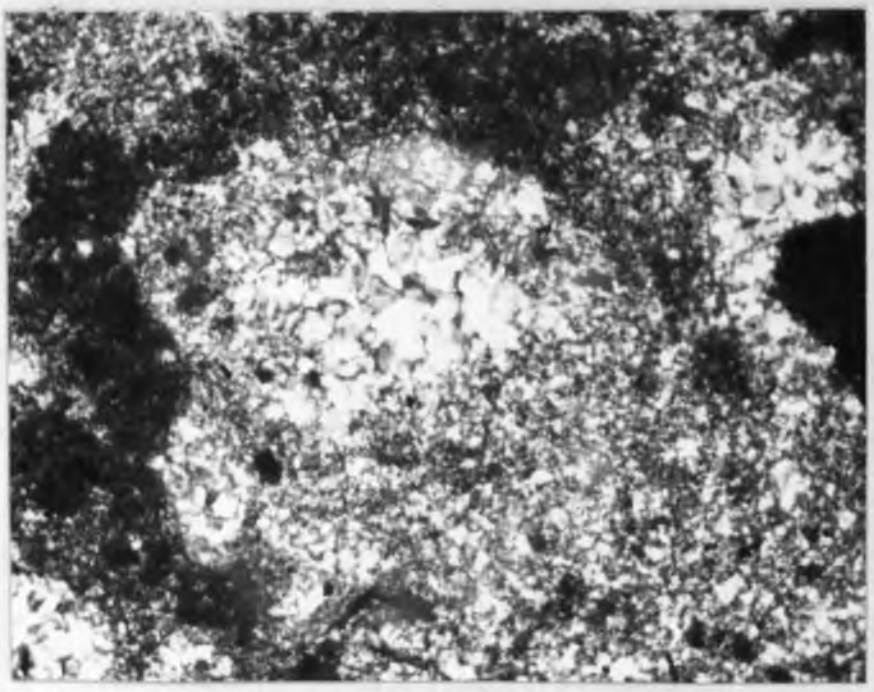


Figure 27. Photomicrograph of Thin Section of Jasperoid Rock

The surface is composed of clusters of medium-grained quartz crystals which are corroded by the finer grained jasperoid material composed of quartz, secondary iron oxides, and a mixture of secondary iron oxides and amorphous or nearly amorphous material. Crossed nicols, X75.

TABLE 6.--Classification of Jasperoid Samples by Young and Lovering (1966) System

Assigned favorability values follow criteria.

Sample No.	LB-6		LB-8		LB-13		LB-18	
Color*	B,D	-1	D	-2	E,F	-1	H	0
Texture**	NB	+2	R,BX	+2	NB	+2	NB	+2
Supergene Minerals					jarosite(?)	+2		
Fe (%)	0.10	0	0.15	0	0.20	0	0.10	0
Mg (%)	0.02	-1	0.015	-1	0.08	-1	0.055	-1
Cu (%)	0.0007	0	0.003	+3	nil	0	nil	0
Pb (%)	0.0003	0	0.0004	0	0.0004	0	0.00025	0
Ag (%)	0.00015	+3	0.0001	0	0.00003	0	0.00006	0
Mo (%)	nil	0	nil	0	nil	0	nil	0
Zn (%)	nil	0	nil	0	nil	0	nil	0
Total		+3		+2		+2		+1
Class	probably unfavorable		probably unfavorable		probably unfavorable		probably unfavorable	

*Colors based on Rock-Color Chart (Goddard, Chm., 1951):
A - pale yellowish orange (10 YR 8/6)
B - grayish orange pink (5 YR 7/2)
C - pale red (5 R 6/2)
D - moderate red (5 R 5/4)
E - dusky red (5 R 3/4)
F - pale brown (5 YR 5/2)
G - moderate reddish brown (10 R 4/6)
H - white (N 9), grays (N 6-N 8)

**Textures: NB, not broken; B, broken; HB, highly broken; R, reticulated; J, jigsaw pattern; BX, brecciated.

TABLE 6.--Classification of Jasperoid Samples by Young and Lovering (1966) System--Continued

Assigned favorability values follow criteria.

Sample No.	LB-24		LB-27		LB-32		LB-37	
Color*	B,H	+1	E,H	-2	A,H	+1	B,C	-1
Texture**	NB,HB	+2	NB,HB	+2	NB,HB	+2	NB,HB	+2
Supergene Minerals	jarosite(?)	+2			jarosite	+2		
Fe (%)	0.10	0	0.10	0	0.40	0	0.10	0
Mg (%)	0.03	-1	0.02	-1	0.04	-1	0.015	-1
Cu (%)	nil	0	0.0007	0	nil	0	0.0007	0
Pb (%)	0.0002	0	0.0004	0	0.0004	0	0.0002	0
Ag (%)	0.00007	0	0.0001	0	0.00008	0	0.00006	0
Mo (%)	nil	0	nil	0	nil	0	nil	0
Zn (%)	nil	0	nil	0	0.001	0	nil	0
Total		+4		-1		+4		0
Class	probably unfavorable		unfavorable		probably unfavorable		unfavorable	

*Colors based on Rock-Color Chart (Goddard, Chm., 1951):
A - pale yellowish orange (10 YR 8/6)
B - grayish orange pink (5 YR 7/2)
C - pale red (5 R 6/2)
D - moderate red (5 R 5/4)
E - dusky red (5 R 3/4)
F - pale brown (5 YR 5/2)
G - moderate reddish brown (10 R 4/6)
H - white (N 9), grays (N 6—N 8)

**Textures: NB, not broken; B, broken; HB, highly broken; R, reticulated; J, jigsaw pattern; BX, brecciated.

TABLE 6.--Classification of Jasperoid Samples by Young and Lovering (1966) System--Continued

Assigned favorability values follow criteria.

Sample No.	LB-39		LB-42		
Color*	B,H	+1	G,H	-2	
Texture**	NB,J	+2	NB,B	+2	
Supergene Minerals	jarosite(?)	+2			
Fe (%)	0.10	0	0.10	0	
Mg (%)	0.02	-1	0.02	-1	
Cu (%)	nil	0	nil	0	
Pb (%)	0.0003	0	0.0002	0	
Ag (%)	0.00027	+3	0.00006	0	
Mo (%)	nil	0	nil	0	
Zn (%)	nil	0	nil	0	
Total		+7		-1	
Class	possibly favorable		unfavorable		

*Colors based on Rock-Color Chart (Goddard, Chm., 1951):
A - pale yellowish orange (10 YR 8/6)
B - grayish orange pink (5 YR 7/2)
C - pale red (5 R 6/2)
D - moderate red (5 R 5/4)
E - dusky red (5 R 3/4)
F - pale brown (5 YR 5/2)
G - moderate reddish brown (10 R 4/6)
H - white (N 9), grays (N 6-N 8)

Textures: NB, not broken; B, broken; HB, highly broken; R, reticulated; J, jigsaw pattern; BX, brecciated.

attributes were observed to occur in the samples examined. Based on these results and the results of the trace element analyses which fall in the lower range of the favorability scale, it would seem likely that few of the favorable microscopic factors are present in the Lampbright West jasperoids.

One day was spent examining some of the favorable and unfavorable jasperoid deposits at Lake Valley, New Mexico. The favorable jasperoids from the mine areas have a different appearance than those in the Lampbright West area. The favorable Lake Valley jasperoids in the mine areas are commonly green, white, yellow brown, and red and generally have a pearly luster. These favorable jasperoids contain large amounts of manganese oxide minerals, hematite, and many vugs lined with small-size to medium-size quartz crystals. The unfavorable jasperoids are gray, white, and shades of red, often resemble a metaquartzite, and are similar in appearance to the Lampbright West jasperoids.

The results of the evaluation of the Lampbright West jasperoids show that under the Young and Lovering (1966) classification, the jasperoid deposits may be classified as essentially "unfavorable." The results may be considered as an indication that ore mineralization probably does not exist within the framework of the hydrothermal system which has produced the jasperoid deposits.

Origin of the jasperoid deposits is not certain. The jasperoid probably was produced by a hydrothermal system related to some of the igneous activity in the area. Some of the other jasperoid deposits which occur in the district are in calcareous host rocks which are apparently underlain by quartz diorite sills. Jasperoid is known to occur in the sills

themselves in places, although not in the thesis area. The results of the mapping show that the deposits in the thesis area are related to faults belonging to the Nancy fault system which cut the hornblende quartz diorite sill. Evidently the jasperoid was deposited at some time after the hornblende quartz diorite sill was emplaced. These features limit the likely sources of the jasperoid to the Santa Rita stock system, the hornblende quartz diorite sill, and an unknown source. Solutions containing silica, iron, and sulfur could have migrated into the thesis area as part of the hydrothermal system related to the Santa Rita stock along the Nancy fault system until favorable conditions were met and the jasperoid deposited. The Santa Rita stock system was indeed a source of the elements necessary for the formation of jasperoid as proved by the existence of tactite alteration and mineralization at Chino which was derived from solutions related to the Santa Rita stock system. However, no jasperoid deposits are known to occur in the sedimentary rock units along the Nancy fault system west of sec. 30, T. 17 S., R. 11 W. Jasperoid is found in only one place in the Nancy fault itself, and that occurrence is in the fault contact between the Oswaldo Formation and the Hornblende quartz diorite sill, and no jasperoid crops out in the thesis area south of the Nancy fault. It might be argued that the north side of the Nancy fault is the hanging-wall side and was more favorable to mineralizing solutions than the south side. From all indications, the Nancy fault is very nearly vertical, and the hanging-wall side should not have exerted much more influence on mineralizing solutions than the footwall side.

The hornblende quartz diorite sill is offset by faults belonging to the Nancy fault system and by the Nancy fault itself. Hydrothermal

solutions could have been concentrated in the sill during the late stages of cooling and crystallization of the sill at which time the sill might have been tapped by faults during the main stage of faulting on the Nancy fault system. The solutions might have then migrated into the host rocks of the sill along the faults until proper conditions for jasperoid deposition were reached. A water well drilled north of the Nancy fault and west of sec. 30, T. 17 S., R. 11 W has intersected hornblende quartz diorite sill. From this it is reasonable to assume that the sill extends across the northern part of the thesis area and is present in the sedimentary rocks beneath the jasperoid deposits.

The third possibility is that a hydrothermal system related to an unknown igneous body, presumably located beneath the jasperoid deposits, could have produced the jasperoid deposits. The results of the aeromagnetic survey and the vertical ground magnetic survey presented in the next section show that if such an igneous body is present and is above the Precambrian basement, it has no appreciable amount of magnetite associated with it.

It is easy to call upon a hidden source of hydrothermal activity and to relate mineralization and alteration features to this source. This hypothesis is one which in many instances is both difficult to prove and to refute. But when other possible sources of hydrothermal activity are present in an area, it seems wiser to consider the unknown source explanation as an alternative solution to be utilized only if all other possible explanations can be discounted. For the Lampbright West jasperoid deposits, the evidence available at this time indicates that the most

likely source of the jasperoid was a hydrothermal system related to the hornblende quartz diorite sill.

Regardless of the source of the jasperoid material, petrographic examinations of this material indicates that there may have been at least three or four stages of silica deposition in the jasperoid deposits. The first stage is probably that of formation of the cluster of medium-grained quartz crystals which are embayed by finer grained jasperoid material and possibly the jasperoid breccia fragments which are cemented by more jasperoid. A thin section of the breccia fragments would disclose whether or not the breccia fragments contain the embayed clusters of quartz crystals. If the breccia fragments contain the embayed clusters, then the embayed clusters represent the first stage of silica deposition and the breccia fragments represent the second stage. If no clusters of quartz crystals are present then the stage relations between the embayed clusters and the breccia fragments are obscure and one or two stages of silica deposition could be represented. The finer grained material which embays the clusters of quartz crystals and which surrounds the breccia fragments represents the next stage of silica deposition. This stage is followed by a stage of silica deposition represented by veinlets of medium-grained quartz crystals which cut the finer grained jasperoid material. The jasperoid may have been deposited in successive stages separated by periods of nondeposition during which time tectonic adjustments fractured and brecciated the jasperoid. It is also possible that the jasperoid could have been deposited by a continuous process with brecciation of the earlier crystallized jasperoid produced by solution brecciation, by tectonic adjustments of the area, or by a combination of

these processes. There is no indication that displacement occurred along the faults during or following jasperoid deposition, nor are the calcareous host rocks brecciated or highly fractured. The possibility of tectonic adjustments producing the brecciation cannot be ruled out on this basis; however, as jasperoid is quite brittle, it is probable that much less stress is necessary to fracture and brecciate the jasperoid than to fracture and brecciate the less brittle calcareous host rocks.

The proper conditions for deposition of the jasperoid might have been the sudden cooling of the solutions, possibly by mixing with meteoric water, the encountering of favorable beds by the solutions at which time the jasperoid replaced the host rock, or combinations of both conditions. As the silica was being deposited, iron and sulfur formed pyrite within the silica from which some, and possibly all, of the secondary iron oxides were derived. It will be recalled that the jasperoid fills faults and replaces the wall rocks along the faults, extending out into the host rock by replacing individual beds in some places. It appears, then, that both processes were in effect. As the faults along which the jasperoid bodies are located are barren of jasperoid in places and as apparently no single type of limestone or argillaceous limestone bed was favored for replacement, it appears that the physical conditions for jasperoid deposition in the thesis area were the dominant factors in determining the location of jasperoid deposits along the faults.

A hypothetical model of the events and processes culminating in deposition of the jasperoid deposits in the study area would begin with the initial stage of faulting on the Nancy fault system. The hornblende quartz diorite sill was then intruded at different levels in the

Oswaldo Formation and crystallization of the rock led to the formation of hydrothermal solutions rich in silica, iron, and sulfur. Since not all faults which cut the sill contain jasperoid, it would appear that the hydrothermal fluids were concentrated in certain areas of the sill. The main stage of faulting on this part of the Nancy fault system then occurred and some of the faults which cut the hornblende quartz diorite sill tapped zones in the sill in which the hydrothermal fluids were concentrated. The hydrothermal solutions ascended into the sedimentary beds along the faults until proper conditions for deposition of the jasperoid were reached. At this time, the jasperoid precipitated in the fault and replaced the country rock adjacent to the fault to form a body of jasperoid. The deposition process occurred in stages, either separated by intervals of nondeposition or as a continuous process, marked by brecciation of the early crystallized jasperoid material and by cementing of these breccias by more jasperoid. After deposition of the jasperoid was completed, final stresses fractured the jasperoid.

If this model is valid, jasperoid deposits could exist beneath the layered rocks south of the Nancy fault and beneath those west and north of the jasperoid deposits exposed in the thesis area. Factors determining the existence of jasperoid deposits would be the presence or absence of the hornblende quartz diorite sill, zones of concentration of a silica-rich hydrothermal solution in the sill, and faults which tapped these zones and served as channelways into the overlying rocks.

VERTICAL MAGNETICS

A vertical ground magnetic survey was conducted in the area of interest in hopes of establishing the existence or absence of tactite replacement bodies containing magnetite at depth in the favorable sedimentary horizons and their associated intrusive bodies. It was also the purpose of this survey to establish the correlation between the results of vertical ground magnetic surveys and total field aeromagnetic surveys in this region. The results of the ground magnetic survey are shown on Figure 28 (in pocket). Figure 29 shows the results of part of an aeromagnetic survey of the Santa Rita quadrangle by Jones et al. (1964) and is presented here for comparison.

The study area lies on the southwest flank and inferred crest of a large-size aeromagnetic high (Fig. 29). This aeromagnetic anomaly forms the regional magnetic gradient of the ground magnetic survey. The results of the ground magnetic survey (Fig. 28) show that this regional gradient ranges from about 270 gammas above the datum plane in the southwest corner of the area to about 580 gammas above the datum plane in the northeast corner of the area. This gradient conforms quite well to the outline and inferred gradient of the aeromagnetic anomaly. The aeromagnetic high has been interpreted by P. M. Wright, Kennecott Exploration, Inc. (personal communication, 1970) to be a basement or near-basement anomaly. He concludes from susceptibility calculations that the susceptibility of this anomaly is lower than that usually measured in tactite mineralization containing magnetite. It is, of course, possible

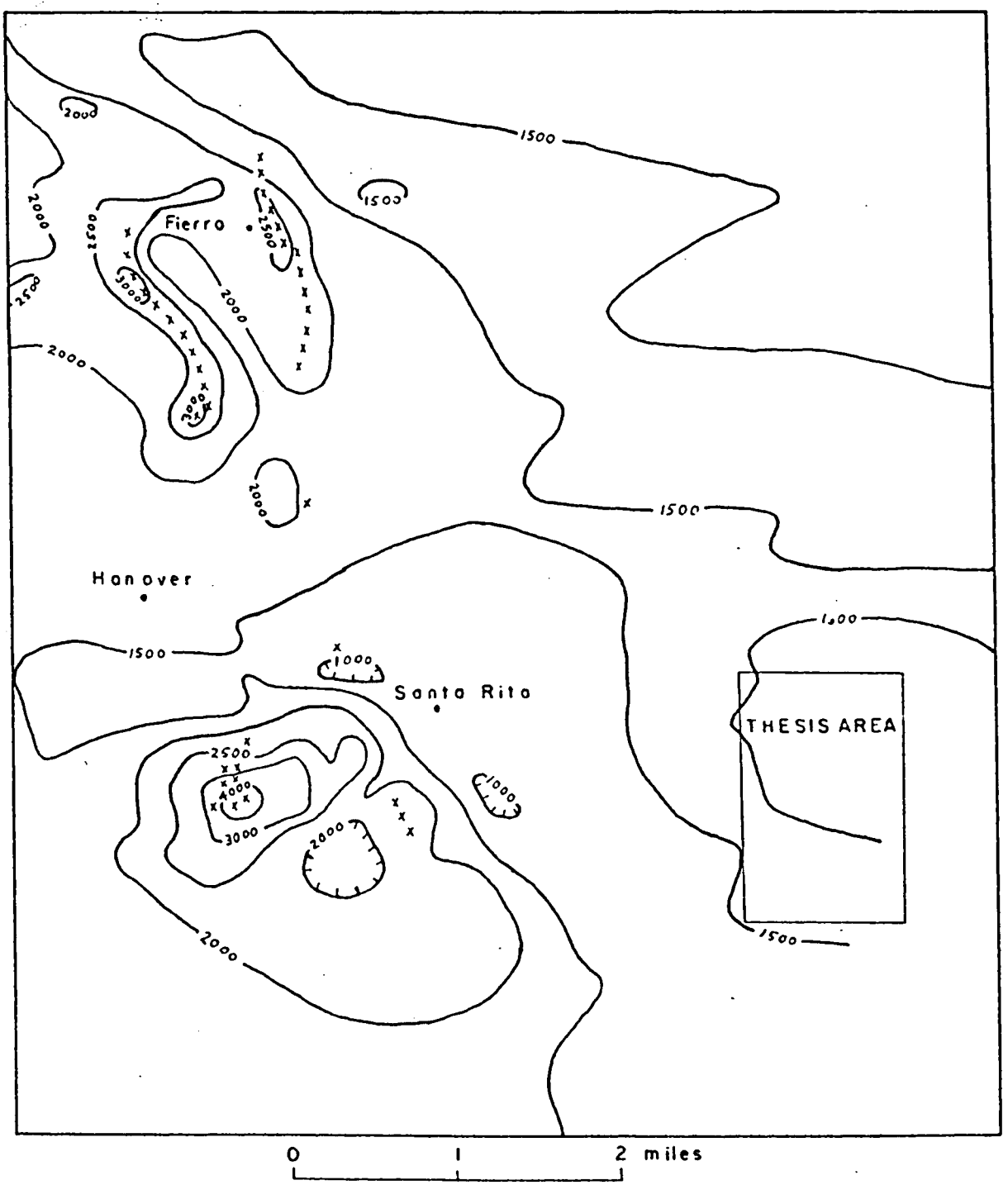


Figure 29. Aeromagnetic Intensity Map of a Portion of the Santa Rita Quadrangle.--Modified from Jones et al., 1964, map GP-424

Magnetic contours are relative to arbitrary datum. "X" denotes large shallow magnetite deposits.

that magnetite-deficient tactite mineralization is present in the lower portions of the Paleozoic section and is the cause of the anomaly. The depth to the basement in this area is calculated to be about 2,000 feet. It is also possible that the anomaly might be the result of an intrusion in the basement rocks which has a higher susceptibility than that of the surrounding rocks. Another explanation is provided by the variable nature of the basement complex. The basement rocks exposed along the Mimbres fault to the east of the thesis area are Precambrian greenstone. At Chino and in the Hanover-Fierro area, the Precambrian basement is composed of granite and granite gneiss. Although susceptibilities have not been measured or calculated for the greenstone and the granitic rocks, it is reasonable to assume that they are dissimilar and that the susceptibilities for the granite and granite gneiss are probably higher than that of the greenstone. It is possible that the aeromagnetic high could reflect an area of the basement complex which contains granitic rocks and which is surrounded by greenstone.

Several magnetically anomalous areas are superimposed on the ground magnetic survey regional gradient. These anomalies are referred to in this section by the reference point (RP) numbers shown on Figure 28 (in pocket). Anomaly RP-1 is a 30-gamma magnetic high with a corresponding magnetic low, designated RP-2, which is located north of the high and has a magnitude of 55 gammas below the regional gradient for this area. These anomalies are attributed to the quartz diorite porphyry sill which crops out in this area and which contains about 2 volume percent magnetite. Instrument readings in this area were erratic and may indicate a nonuniform distribution of magnetite in the sill.

The regional magnetic high for the study area, designated RP-3, is located in the northeast corner of the thesis area and reflects the crest of the large aeromagnetic high. This anomaly registers 580 gammas above the datum plane. The slight steepening of the gradient in this area may be accounted for by the hornblende quartz diorite sill which crops out in the area. This sill contains about 1 volume percent magnetite.

Two prominent magnetic anomalies occur east of the 1/4 corner of sec. 25, T. 17 S., R. 11 W. and sec. 30, T. 17 S, R. 11 W. and are designated RP-4 and RP-5. Anomaly RP-4 is a magnetic high of 110 gammas. Readings of more than 1100 gammas above the regional value in this area were obtained in the center of this anomaly but were highly erratic. This area contains a basalt dike which is in outcrop contact with shale of the Colorado Formation. The dike rock contains up to 15 volume percent magnetite. The erratic nature of the readings in this area was attributed to the possible presence of variable quantities of magnetite in the basalt and the short distances between the magnetometer and these variable amounts of magnetite. Simple statistical treatment of the data yielded the figure of 110 gammas above the regional value for this area.

Anomaly RP-5 is a magnetic high of 100 gammas and is in an area in which outcrops of sandstone of the Colorado Formation are surrounded by alluvium. The depth to the top of the body causing this anomaly was calculated by the Peters Rule (Riddell, 1966) to be about 27 feet below the surface. This figure may be erroneous due to the nonsymmetrical outline of the anomaly. However, the steep gradients associated with this anomaly indicate that the source is not deep.

The resemblance between the RP-5 and RP-4 anomalies is evident. The geologic map (Fig. 2, in pocket) indicates that the western basalt dike trends toward the RP-5 anomaly. The source of this anomaly is interpreted to be a basalt dike which may be an extension of the same dike which produced the RP-4 anomaly. The area between the RP-4 and RP-5 anomalies is an area of lower magnetic intensity than either of these anomalies yet is still a high compared to the regional value for this area. This feature is interpreted as an indication of the thinning of the dike in this area. The geologic map (Fig. 2) shows that the western outcrop of the basalt dike is thin in this area compared to the eastern outcrop and that the magnetic interpretation is probably correct.

The magnetic nature of the trachyte plug and dikes is of significance, in a negative way, to this study. No magnetic anomalies exist over or near these rocks. No magnetic minerals were observed in the trachyte or in the wall rocks at the surface. From the magnetic survey data, it is interpreted that no mineralization containing magnetic minerals is present at depth in or adjacent to these intrusive bodies. It appears that the susceptibility of the trachyte is the same as that of the sedimentary rocks in the area.

Irregularities are present in the contour lines of the ground magnetic map (Fig. 28, in pocket) which do not outline a well-defined anomaly and are usually on the order of 30 gammas or less. These irregularities are attributed to superficial variations due to possible irregularities in the magnetic nature of the surface and near-surface rocks which is reflected in the choice of survey stations and to the effects of temperature and diurnal variations. Although the Askania magnetometer has a

precision of 1 to 3 gammas, it was noticed in some areas other than those already noted as erratic that check readings taken a few feet away from the initial survey station produced a slight variance in readings. While the Askania magnetometer is insulated to prevent the necessity of employing temperature variation corrections in the reduction of the data, slight variances in the readings due to temperature variations could occur. Diurnal variations of 2 to 51 gammas were recorded with most variations being on the order of 17 gammas. The readings recorded on a traverse were corrected for these diurnal variations on the basis that the variations approximate a regular rate of change (Wright, personal communication, 1969). As this is only an approximation, slight errors persist in the corrected data.

The formula $\Delta V = 8/3\pi R^3 I/Z^3$ (Wright, personal communication, 1970) was used to define the limits of detection of the vertical ground magnetic survey, where ΔV is the vertical field magnetic anomaly of a sphere, R is the radius of the sphere, Z is the depth to the center of the sphere, and I is the magnetization which is the product of the susceptibility K and the vertical field strength of the earth V which is 50,000 gammas. As it is possible to use an unlimited number of combinations of factors in this formula, certain assumptions based on the advice of Wright (personal communication, 1970) were made to arrive at a meaningful conclusion. A ΔV of 50 gammas was considered as the smallest anomaly of interest, a K value of $50,000 \times 10^{-6}$ cgs units was assumed for tactite containing magnetite similar to that present in ore bodies in the Central mining district. The formula was thus reduced to $R = Z/7$ which contains the variables of prime interest to the survey, depth and

size. Assuming a tonnage factor of 7 cubic feet per ton, the smallest magnetite-tactite body detectable at depths of up to 500 feet below the surface would be on the order of 200,000 tons. At 1,000 feet below the surface, the minimum tonnage detectable increases to about 2 million tons, and at 2,000 feet below the surface, the minimum tonnage detectable is about 17 million tons. For a spherical body containing 1 percent magnetite, k is $3,000 \times 10^{-6}$ cgs units (Wright, personal communication, 1970), and the tonnage factor is estimated at about 10 cubic feet of rock per ton. With these parameters, it was calculated that bodies larger than 2 million tons can be detected at a depth of up to 500 feet, bodies over 15 million tons at depths of up to 1,000 feet, and bodies of more than 124 million tons at depths of up to 2,000 feet. These figures are approximations, but they provide some indication of the limits of detection of the vertical ground magnetic survey.

Brant (1966) has reported that the Arizona Laramide intrusions are only weakly magnetic with susceptibilities of 500×10^{-6} cgs units or less and are frequently in a background of more magnetic basement rocks. These intrusions are often reflected by magnetic lows. In the Central mining district, Laramide intrusions have average susceptibilities of 1,000 to $6,000 \times 10^{-6}$ cgs units and have intruded sediments which have no measurable susceptibilities (Wright, personal communication, 1970). The trachyte in sec. 31, T. 17 S., R. 11 W. is unusual in that it apparently has no measurable susceptibility. It is possible that any of the other Laramide intrusions which have intruded the sedimentary section in the thesis area would probably be detected as magnetic

highs if the size, depth, and magnetite content are within the limits of detection.

It is concluded that magnetite-bearing tactite mineralization and Laramide intrusive stocks containing magnetite are not present at depth in the thesis area or, if present, they are not within the depth, size, and magnetite content parameters calculated as guidelines for the limits of detection in the vertical ground magnetic survey. It is further concluded that there is a close correlation on a broad scale between the results of vertical ground magnetic surveys and total field aeromagnetic surveys in this area. As aeromagnetic surveys do not delineate the large-scale magnetic features of an area, it is conceivable that a small-size to medium-size ore body containing magnetite could be overlooked. Therefore, vertical ground magnetic surveys can and should be utilized as follow-up surveys to total field aeromagnetic prospecting in areas of interest in this region.

INTERPRETATION OF GEOLOGIC EVENTS

During Paleozoic time, the Santa Rita area lay near the northeast margin of the east-trending Sonoran geosyncline and received about 3,150 feet of sediments (Rose and Baltosser, 1966; Jones et al., 1967). All periods are represented, but disconformities are present between most of the formations (Rose and Baltosser, 1966). Erosion or nondeposition has resulted in the absence of Lower and Middle Cambrian, Upper Silurian, Lower and Middle Devonian, Upper Mississippian, Lower Pennsylvanian, and Upper Permian rocks. The Lower Permian Abo Formation is not present west of the Chino mine (Rose and Baltosser, 1966) but forms a section to 265 feet thick east of the mine.

The area was a highland from at least Late Pennsylvanian or Early Permian through Early Cretaceous time (Kottlowski, 1963). During Late Triassic time, extensive uplift occurred in southern Arizona and southwestern New Mexico (Anderson, 1966). Triassic and Jurassic rocks are not present in the region.

A deep basin of sedimentation was present in southern Arizona and southwestern New Mexico in Early Cretaceous time, and about 16,500 feet of sediments (Zeller, 1970) were deposited in the Little Hatchet Mountains in southwestern New Mexico, but no Early Cretaceous sedimentary rocks are found in the Santa Rita area (Rose and Baltosser, 1966). In Late Cretaceous time, more than 1,150 feet of sediments were deposited in the Santa Rita region. A period of considerable erosion followed deposition of the Colorado Formation (Rose and Baltosser, 1966).

In Late Cretaceous or possibly early Tertiary time, the quartz diorite porphyry sills were intruded into the sediments of the area, followed closely in time by the hornblende quartz diorite sills and dikes. Tectonic adjustments, in the form of gentle warping of beds and some faulting preceded and accompanied intrusion of the sills. The strata were warped downward beneath the quartz diorite porphyry sill southeast of the 1/4 corner of sec. 25, T. 17 S., R. 12 W. and sec. 30, T. 17 S., R. 11 W. and were flexed upward above the hornblende quartz diorite sill in sec. 30, T. 17 S., R. 11 W. The stratagraphic level at which the hornblende quartz diorite sill was intruded into the sedimentary rocks is not constant and may reflect pre-sill faulting in this area. Post-sill movement then occurred along the faults which formed prior to the intrusion of the sill. The jasperoid deposits, if indeed they are genetically related to the quartz diorite sills, formed at this time from solutions which originated in the sills and followed fault channels to the places of deposition of silica and pyrite from the solutions. Brecciated jasperoid rock cemented by silica which is fractured indicates that some movement may have occurred during and after emplacement of the jasperoid material. There is no evidence of displacement along the faults during this period. Following intrusion of the sills, the strata were flexed into the broad, shallow, northwest-trending syncline. This flexing may well have caused the final shattering of the jasperoid rock.

The major fault and fracture pattern in the Santa Rita quadrangle formed following the formation of the regional syncline. The Santa Rita horst formed at this time when the Mimbres, Barringer, and the group of east-northeast-trending normal faults were formed (Jones et al., 1967).

The major faulting in the thesis area probably occurred in this period and included the main period of movement on the Nancy fault system and the unnamed major fault in the N1/2 sec. 31, T. 17 S., R. 11 W. In the Nancy fault system, all faults on the south side of the Nancy fault probably formed at this time and most, if not all, of the faults on the north side of the Nancy fault that do not contain jasperoid material were probably formed at this time.

The Santa Rita, Hanover-Fierro, and Copper Flat stocks were intruded in early Tertiary time. The Santa Rita stock has been dated at 63 m.y. by the K-Ar method (Schwartz, 1959). The intrusion of the stocks was accompanied by the main period of mineralization that occurred in the district. Probably at this time a very minor amount of pyrite was deposited in a few faults in the thesis area. It is possible that the vein of hollandite and manganite was deposited in a fault belonging to the Nancy fault system at this time. This mineralization may have been transported laterally into the area from the Santa Rita stock system along fault channels or may have been genetically related to other igneous activity in or near the thesis area.

A considerable period of erosion preceded the Tertiary volcanic epoch and produced much of the secondary enrichment at the Chino mine (Rose and Baltosser, 1966). During this time and in the final period of erosion which has lasted to the present, the pyrite veins and the pyrite in the jasperoid deposits in the thesis area were oxidized by weathering processes to secondary iron oxide minerals. In Miocene(?) time, the trachyte and felsitic rhyolite plugs and dikes intruded the layered rocks of the region and produced the rhyolite tuffs (Jones et al., 1967) which

may have once covered the thesis area. This period was followed by intrusion of the basalt dikes which were probably feeders for the basaltic andesite flows (Jones et al., 1967). These flows may have also covered the thesis area at one time.

A period of erosion followed the volcanic epoch and has lasted to the present time. This period of erosion has produced the Quaternary alluvium and colluvium. Basin and Range faulting occurred following the volcanic epoch and affected the Miocene(?), Pliocene, and Pleistocene(?) valley fill in the Mimbres River basin and produced the regional horst blocks (Jones et al., 1967).

ECONOMIC CONSIDERATIONS

The results of the mapping, the ground magnetic and aeromagnetic surveys, and the jasperoid evaluation indicate, within the limitations of these tools, that the probability for the existence of a major undiscovered ore body in the thesis area is minimal. However, it is realized that magnetite-barren copper, lead, zinc, and silver replacement bodies could exist at depth in the favorable horizons and have not been detected by the magnetic surveys. It is also true that deposits containing magnetite which are smaller than the detectable limits of the magnetic methods employed could exist at depth and not be discovered, but these deposits would possibly be too small or too deep to be extracted economically with present mining techniques. No large magnetite-barren stock system would be expected to exist in the thesis area in conjunction with any of these hypothetical deposits because the structural geology of the area indicates no doming or extensive fracturing over such a hypothetical stock.

The jasperoid evaluation system, while considered to be the best system available at this time, has not been extensively tested and much work is needed to evaluate and possibly refine this technique. Ore mineralization could possibly exist in this hydrothermal system and not be detected by the present evaluation system.

That the large-size magnetic anomaly which exists partly in the thesis area could reflect magnetite-associated mineralization in the Precambrian basement complex is a possibility which cannot be ruled out

completely at this time. The depths to the center of this anomaly and the lack of a shallower anomaly which might indicate ore replacement bodies in the favorable hosts above the basement complex lessen the chances of this being a magnetite-bearing ore horizon. As the major ore deposits in the district are associated with magnetite mineralization, the possibility of the basement anomaly being reflective of a set of conditions in which magnetite mineralization and ore mineralization remained in the basement rocks rather than forming tactite mineralization in the overlying favorable host rocks or that magnetite stayed in the basement rocks while magnetite-barren ore deposits formed in the overlying sediments appears unlikely.

It cannot be known beyond doubt whether or not ore mineralization is present or how much ore mineralization exists at depth in the study area unless the area is drilled out on closely spaced centers. The data presented here indicate that the chances of ore mineralization which is economically feasible to mine are not very good. It is concluded that time and money invested in further exploration for undiscovered ore bodies might have a better chance of a return on investment in more favorable areas. With this in mind, the feasibility of utilizing the land as possible future leach dump sites for the solution mining of copper-bearing waste rock from the Chino mine should be determined.

The possible leach dump sites can be limited first on the basis of rock reactivity. Reactive rocks in the study area include those of the Oswaldo, Syrena, and Abo Formations and, to a much lesser extent, the shale member of the Colorado Formation. Samples of shale from the Colorado Formation and limestone from the Syrena Formation were placed

in a pond containing circulating solutions from a present leach dump for a period of 3 months. At the end of this time, the shale remained essentially unaffected by the leach solutions, while the limestone underwent continuous dissolution with no evidence of cessation at the end of the 3-month period. It is concluded that any leaching of mine waste rock over limestone will result in dissolution of the limestone with an accompanying high loss of acid, an increase in solution pH, and a resultant loss of copper in solution. The effect of the calcareous mudstones of the Abo Formation on leach solutions should be much the same as that of the limestones. The areas underlain by Oswaldo, Syrena, and Abo Formations should be disqualified, at least until an effective and economic means of sealing the surface can be devised. On this basis, the areas north of the Nancy fault (Fig. 2, in pocket), including the area of the hornblende quartz diorite sill which drains onto limestone, and those areas which drain to the east into the creek which parallels the Delk Ranch road are disqualified. The remainder of the thesis area (Fig. 2) extending from the Nancy fault to the southern boundary and from the western boundary to the north-trending ridge line traversing the eastern portion of the thesis area south of the Nancy fault can be considered. Surface drainage in this area is from west to east and from east to west from the ridge lines into two major streams in the central and southwest portions of the area (Fig. 2). Their confluence is at the extreme south-central portion of the area mapped. These streams drain southeastward, and leach solutions will drain into these streams and flow southward to a catch pond presumably located south of the area mapped.

Subsurface drainage in this area is to the southwest along bedding planes in the sediments and along the contact between the quartz diorite porphyry sill and the sandstone member of the Colorado Formation. Not including the area underlain by the Abo Formation, the area east of the central stream bed (Fig. 2, in pocket) is nearly a dip slope which is underlain by Beartooth Quartzite. This area is highly impermeable, and water has been noted to seep out of the colluvial cover for several days following a heavy rain. However, the area underlain by Abo Formation should be sealed with a layer of impermeable material prior to constructing the leach dumps. West of the central stream bed, the area is no longer a dip slope and more bedding plane surfaces are exposed. Although it is believed that leakage of leach solutions into the ground-water system along these bedding planes would be slight, added insurance against leakage could be provided by covering this area with a layer of waste rock containing a high amount of clay minerals from the Chino mine before constructing the leach dumps.

Faults and fractures in the area under consideration are tight, and very little permeable gouge is present in the faults. These structures can be considered as nearly impervious to leach solutions.

Prior to construction of the leach dumps, areas of dense vegetation growth should be cleared to prevent absorption of copper-bearing solutions by the organic materials. The two stock tanks in this area should be breached to prevent entrapment of leach solutions.

CONCLUSIONS AND RECOMMENDATIONS

The results of work performed in sec. 30 and N1/2 sec. 31, T. 17 S., R. 11 W. have shown that the ore potential for this area is not very good. The area should be designated as nonmineral land and utilized for purposes other than mining. A large portion of this area could be used for the leaching of copper-bearing waste rock from the Chino mine.

The examination of alteration and mineralization in the thesis area confirms the results of work by Nielsen (1970) in showing that the study area is probably beyond the fringes of the alteration and mineralization patterns associated with the Santa Rita stock system. The possible exceptions to this statement include the jasperoid deposits, the vein of hollandite and manganite, and the veins of secondary iron oxides after pyrite gossans. These features all occur along fault systems which can be traced into or trend toward the Chino mine area and which may have served as conduits for mineralizing solutions originating in the Santa Rita stock system.

Evaluation of capping has shown that much of the iron staining in the area may have been derived from the iron minerals which were original constituents in some of the rock units in the area. Iron staining along fractures may have been derived in this manner or in some places may be related to migration of mineralizing solutions along fractures from igneous intrusions in or near the study area.

This study has demonstrated the close correlation between the results of aeromagnetic, vertical ground magnetic, and geologic mapping surveys in the region. It is recommended that the three tools be used in conjunction in future exploration projects in the Central mining district.

It is also recommended that research pertaining to the nature and origin of jasperoids be continued. Additional field work and laboratory research on jasperoids in the Central mining district should help to clarify the origin of the jasperoid deposits in sec. 30, T. 17 S., R. 11 W. The classification scheme devised by Young and Lovering (1966) should be evaluated in other districts, both in areas of known ore mineralization and in areas of known absence of ore mineralization. If necessary, their system should be revised. It is hoped that jasperoid evaluation can eventually be perfected and become a more useful exploration tool. At that time, the jasperoid deposits in the thesis area should be reevaluated.

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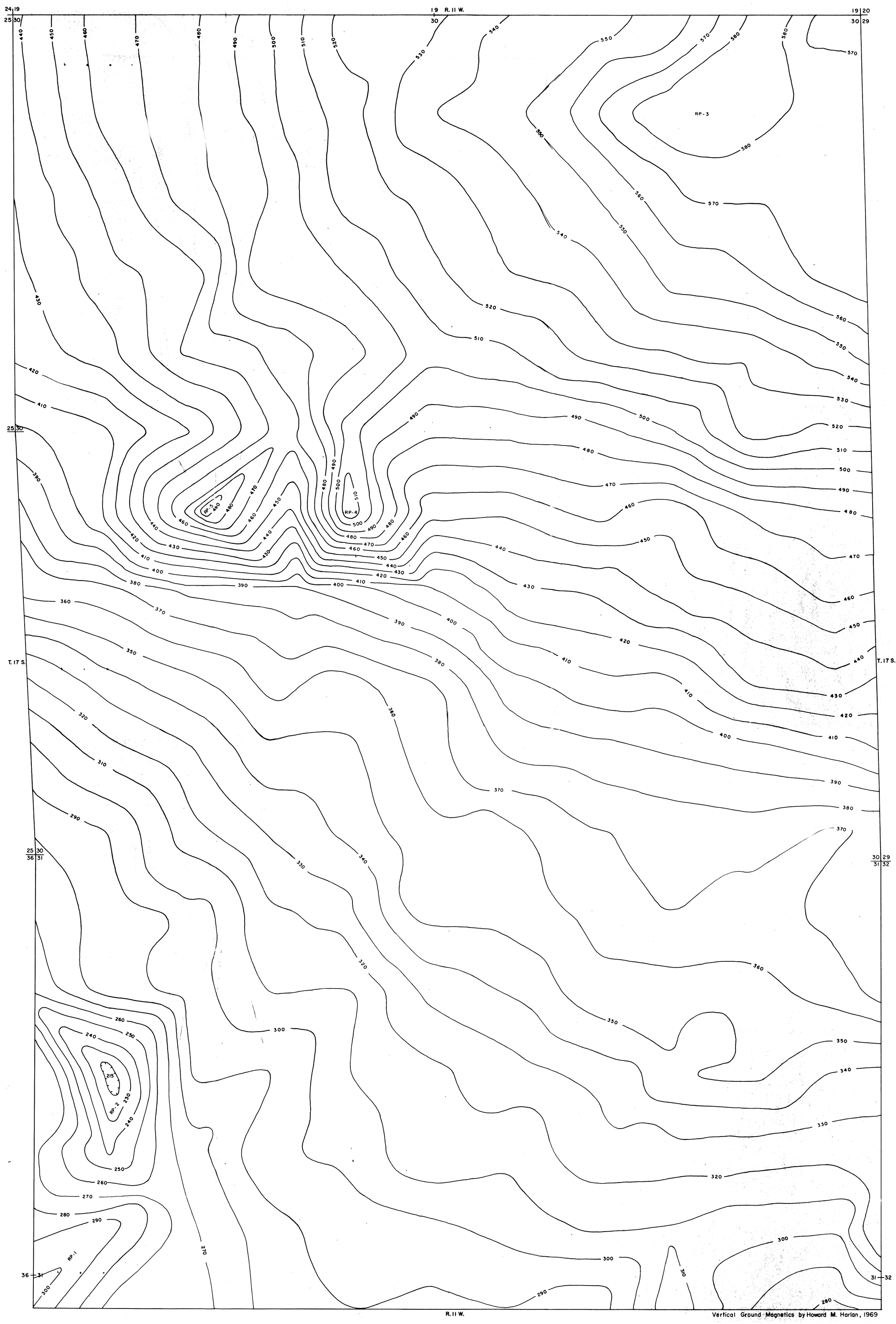


FIGURE 28

VERTICAL GROUND MAGNETIC INTENSITY MAP OF A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO

APPROXIMATE MEAN
DECLINATION, 1966

SCALE : 1 = 2400

500 0 FEET 500 1000

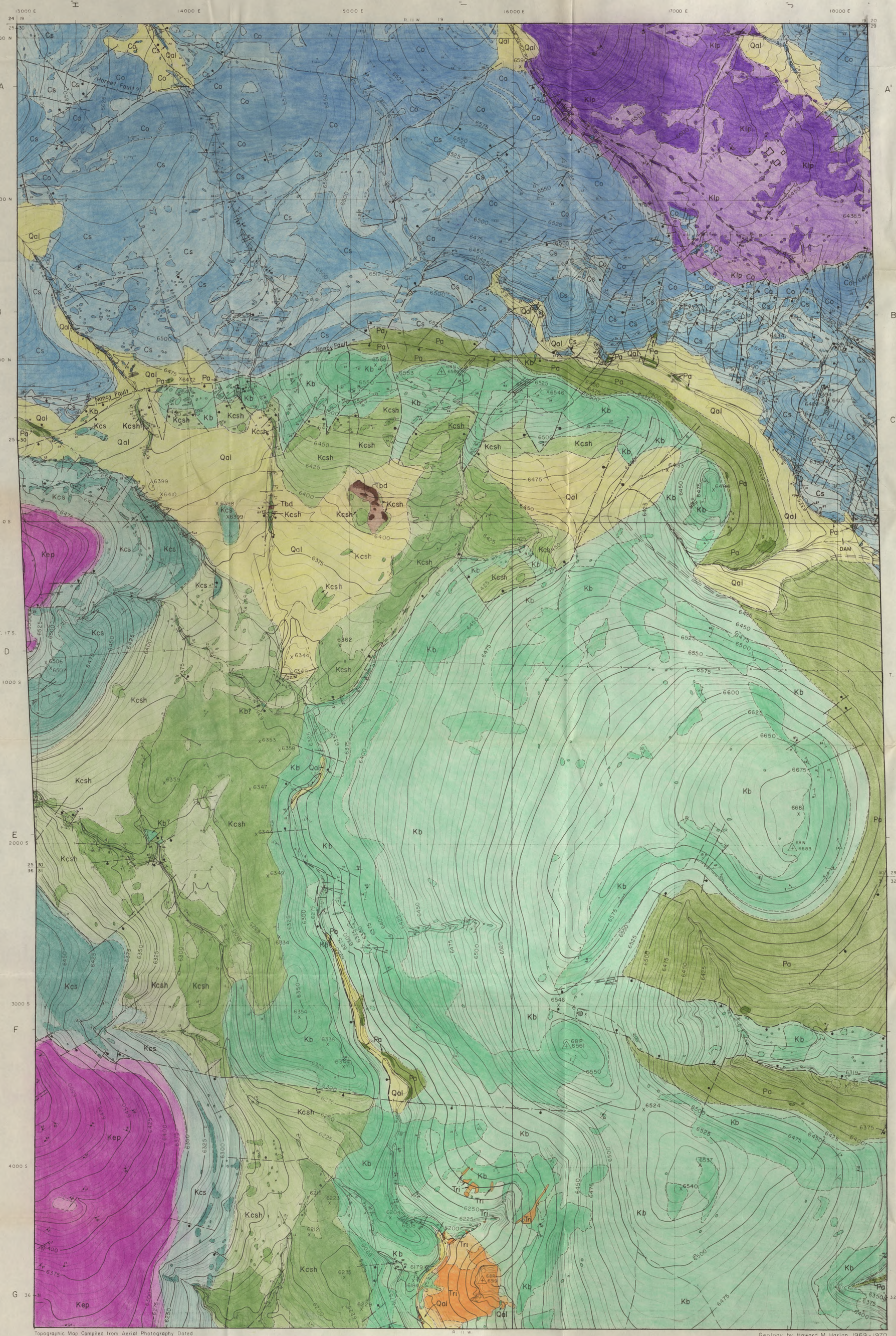
CONTOUR INTERVAL = 10 GAMMAS

DATUM PLANE = 21,000 GAMMAS

EXPLANATION

RP-4

REFERENCE POINTS



EXPLANATION

RECENT

Qal

ALLUVIUM
Sand, gravel, and, soil. Mapped where over 4 feet thick and where significant geologic relations are hidden

UNCONFORMITY

MIOCENE (?)

Tbd

BASALT
Dikes of basalt. Relative age unknown, assumed to be feeders of Miocene (?) basaltic andesite flows

DISCONFORMITY

Tri

TRACHYTE
Dikes and plugs. Relative age unknown, assumed to be related to Miocene (?) extrusive rhyolite tuffs

UNCONFORMITY

UPPER CRETACEOUS (?)

Klp

HORNBLENDE QUARTZ DIORITE
Sills and laccoliths of fine grained quartz diorite

Kep

QUARTZ DIORITE PORPHYRY
Sills of medium-grained quartz diorite porphyry

UPPER CRETACEOUS

Kcs
Kcsh

COLORADO FORMATION
Kcs, sandstone member; fine-grained quartz sandstone. Original thickness not known, at least 110 feet preserved in area
Kcsh, shale member; black shale and brown sandy shale. 192 feet thick

Kb

BEARTOOTH QUARTZITE
Fine-grained orthoquartzite, some shale beds and lenses of chert and quartz pebble conglomerate. 130 feet thick

UNCONFORMITY

LOWER PERMIAN

Pa

ABO FORMATION
Red and yellow calcareous mudstone, shale, and impure limestone. Some limestone conglomerate lenses. 145 feet thick

PENNSYLVANIAN — MAGDALENA GROUP

Cs

SYRENA FORMATION
Argillaceous limestone and calcareous shale, some shale and dark gray limestone. 318 feet thick

Co

OSWALDO FORMATION
Light gray limestone, some shale and argillaceous limestone. 388 feet thick

OUTCROP OUTLINE
Dashed where approximate. Lightly colored areas between outcrops indicate colluvium composed of soil and talus derived mainly from the underlying formation

CONTACT
Dip shown by arrow. Dashed where approximate, queried where inferred

ANGLE NORMAL FAULT
Bar and ball on downthrown side; dip shown by arrow; vertical fault indicated by cross bar. Dashed where approximate, queried where inferred

STRIKE AND DIP OF BEDS
Queried where approximate

STRIKE AND DIP OF JOINTS

ANTICLINE
Showing trace of axial plane and bearing and direction of plunge of axis. Dashed where approximate

PROSPECT PIT

ROAD

FENCE

BUILDINGS

WINDMILL

CATTLE TANK

DAM

68 P
6561
K.C.C. SURVEY MARKER

GRID
Grid is part of Chino Mines co-ordinate system. NOS-EOW is in Chino Pit

Topographic Map Compiled from Aerial Photography Dated December, 1968 by Stitzer, Pafford & Associates - Tucson

Geology by Howard M. Harlan, 1969 - 1970

FIGURE 2

GEOLOGIC MAP OF A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1966

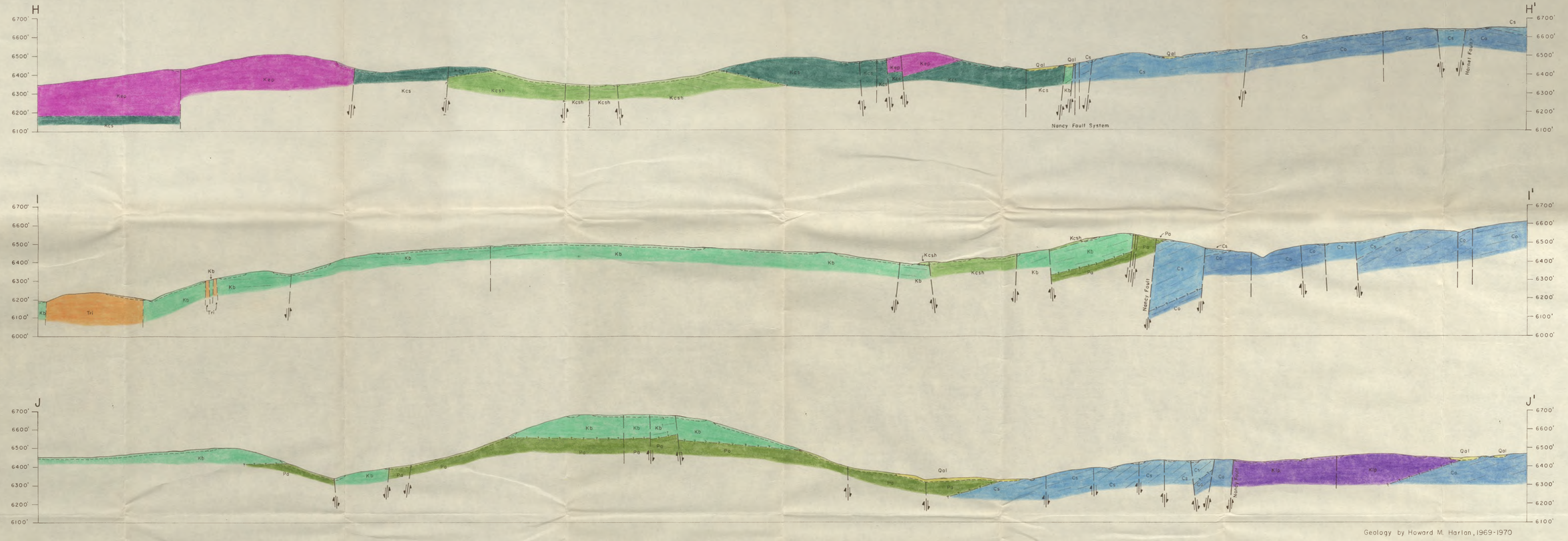
SCALE = 1:2400
500 0 FEET 500 1000
CONTOUR INTERVAL = 5 FEET

Geology by Howard M. Harlan, 1969-1970

FIGURE 13

GEOLOGIC SECTIONS OF A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO

Part 1 of 2



Geology by Howard M. Harlan, 1969-1970

FIGURE 13 -- Continued

GEOLOGIC SECTIONS OF A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO

Part 2 of 2

SCALE: 1 = 2400

500 0 FEET 500 1000

LOOKING WEST
NO VERTICAL EXAGGERATION

EXPLANATION

High Angle Normal Fault, Showing Direction of Relative Movement

Attitude of Bedding

SEE FIGURE 2 FOR LOCATIONS AND OTHER EXPLANATION

24 | 19
25 | 30

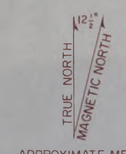
19
30

19 | 20
30 | 29

25 - 30

Geology By Howard M. Harlan, 1969-1970

FIGURE 14
JASPEROID DEPOSITS IN A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO



APPROXIMATE MEAN
DECLINATION, 1966

SCALE : 1 = 2400

500 0 FEET 500 1000

EXPLANATION

Jasperoid Outcrop

Colluvial Jasperoid
Subsurface Inferred to be Jasperoid

LB - 36
Sample Location

145

6253

GEOLOGY AND GROUND MAGNETIC SURVEY OF A PORTION OF THE LAMPBRIGHT WEST AREA, GRANT COUNTY, NEW MEXICO

by

Howard Marshall Harlan II

WRAP AROUND