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STRUCTURE AND ORE DEPOSITS OF THE DARWIN QUADRANGLE, INYO COUNTY, CALIFORNIA

by

Wayne Everett Hall, 1920-

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SUMMARY

This report presents a description of the regional geology and mineral deposits of the Darwin quadrangle as part of a long-range program by the U. S. Geological Survey in cooperation with the California Division of Mines to study the Inyo County lead-silver-zinc deposits. The quadrangle encompasses 240 square miles in the west-central part of Inyo County between long. 117°30' W. and 117°45' W. and between lat. 36°15' N. and 36°30' N. It includes parts of the Inyo Mountains, Coso Range, Argus Range, and Darwin Hills.

The Paleozoic rocks range in age from Ordovician to Permian in a conformable sequence more than 13,000 feet thick. They are predominantly carbonates that in large part correlate with widespread formations in the eastern part of the Great Basin. Pre-Devonian rocks are predominantly dolomite and quartzite; Devonian rocks are limestone, dolomite, quartzite, and shale; and Mississippian and younger Paleozoic rocks are predominantly limestone.

Silurian and Ordovician rocks are restricted to the Talc City Hills. Ordovician strata are approximately 3,000 feet thick and include the Pogonip group, Eureka quartzite, and Ely Springs dolomite. The Ely Springs is overlain by about 1,000 feet of massive light-gray Hidden Valley dolomite. Devonian and Mississippian strata are best exposed in the Santa Rosa Hills and include 1,770 feet of Lost Burro formation of Devonian age, 435 feet of Tin Mountain limestone and 330 feet of Perdido formation of Mississippian age, and more than 960 feet of Lee Flat limestone of Mississippian-Pennsylvanian(?) age. Pennsylvanian

and Permian strata are more than 6,000 feet thick and are the most widespread Paleozoic rocks. They are mainly thinly bedded calcarenite and calcilutite.

The Paleozoic rocks are intruded by quartz monzonite of Cretaceous age. Limestones are commonly altered to calc-hornfels and tactite near intrusive contacts. Most of the northern half of the quadrangle is covered by olivine basalt and andesite of late Cenozoic age.

The Paleozoic rocks are deformed into broad open folds except near plutonic bodies. About the margin of the biotite-hornblende-quartz monzonite in the Coso Range the Paleozoic strata are tightly folded and are disrupted by many faults. Left-lateral strike-slip faults and thrust faults are both important.

The Basin-Ranges had their inception prior to the late Pliocene. Both the Inyo Mountains and the Argus Range are east-tilted fault blocks. Step faults are conspicuous features on the west flank of both ranges.

The quadrangle contains important deposits of lead-silver-zinc and steatite-grade talc, and some tungsten, copper, gold, and antimony. The total value of the mineral production up to 1952 is $37,500,000. The Darwin lead-silver-zinc district has a total production of $29,000,000 and the talc deposits about $5,000,000.

Lead-silver-zinc deposits are restricted to limy parts of the section. By far the most productive deposits are in the Darwin Hills in thinly bedded Pennsylvanian-Permian strata that are in large part altered to calc-silicate rock. The ore bodies are in or near feeder fissures that strike N. 50° to 70° E. Individual ore bodies occur as bedded replacements, vein deposits, and as steep pipe-shaped ore bodies. The hypogene ore consists of galena, sphalerite, pyrite, pyrrhotite, chalcopyrite, tetrahedrite, scheelite, andorite, and franckeite. Except in the deeper levels of the Darwin mine the ore is in large part oxidized to a crumbly mass of limonite, jarosite, cerussite, and hemimorphite.

The talc deposits occur as elongate pods or lenses in massive dolomite and to lesser extent in quartzite peripheral to the Talc City stock. Shear zones in dolomite or contacts between quartzite and dolomite may localize talc.

Tungsten has been recovered in the Darwin district from mines in the eastern part of the Darwin Hills. Scheelite is the principal tungsten mineral. The deposits are in calc-hornfels, tactite, and marble of Permian age close to the eastern contact of biotite-hornblende-quartz monzonite. Scheelite ore bodies are found as replacements of pure limestone or in tactite close to intersections with mineralized faults that strike N. 70° E. Most of the ore is within three limestone beds locally known as the Durham, Frisco, and Alameda beds. The ore bodies are mostly small.

INTRODUCTION

Location

The Darwin quadrangle is in eastern California in the central part of Inyo County. It includes the area between meridians 117°30' and 117°45' W. and between parallels of latitude 36°15' and 36°30' N. (fig. 1). The principal settlement is Darwin, a small mining town of several hundred people located in the southern part of the quadrangle. A large modern mining camp is maintained by The Anaconda Company at the Darwin mine 1 mile north of Darwin, and residences are maintained at some of the smaller mines and at the principal water supplies in Darwin Wash and at China Garden Spring.

Lone Pine, 27 miles northwest of the quadrangle, is the principal marketing center for the area. It is on a branch line of the Southern Pacific Railroad. Paved State Highway 190, extending from Lone Pine to Death Valley, passes through the center of the quadrangle. A paved road extends from State Highway 190 to Darwin and to the Darwin mining camp, and an improved dirt road leads from State Highway 190 through the northern part of the quadrangle to Saline Valley. Many roads of varying conditions lead to mines and prospects from these main roads.

Purpose and scope

The investigation of the Darwin quadrangle is part of a long range program by the U. S. Geological Survey in cooperation with the California State Division of Mines to study the Inyo County lead-silver-zinc deposits that occur between the Cerro Gordo district in

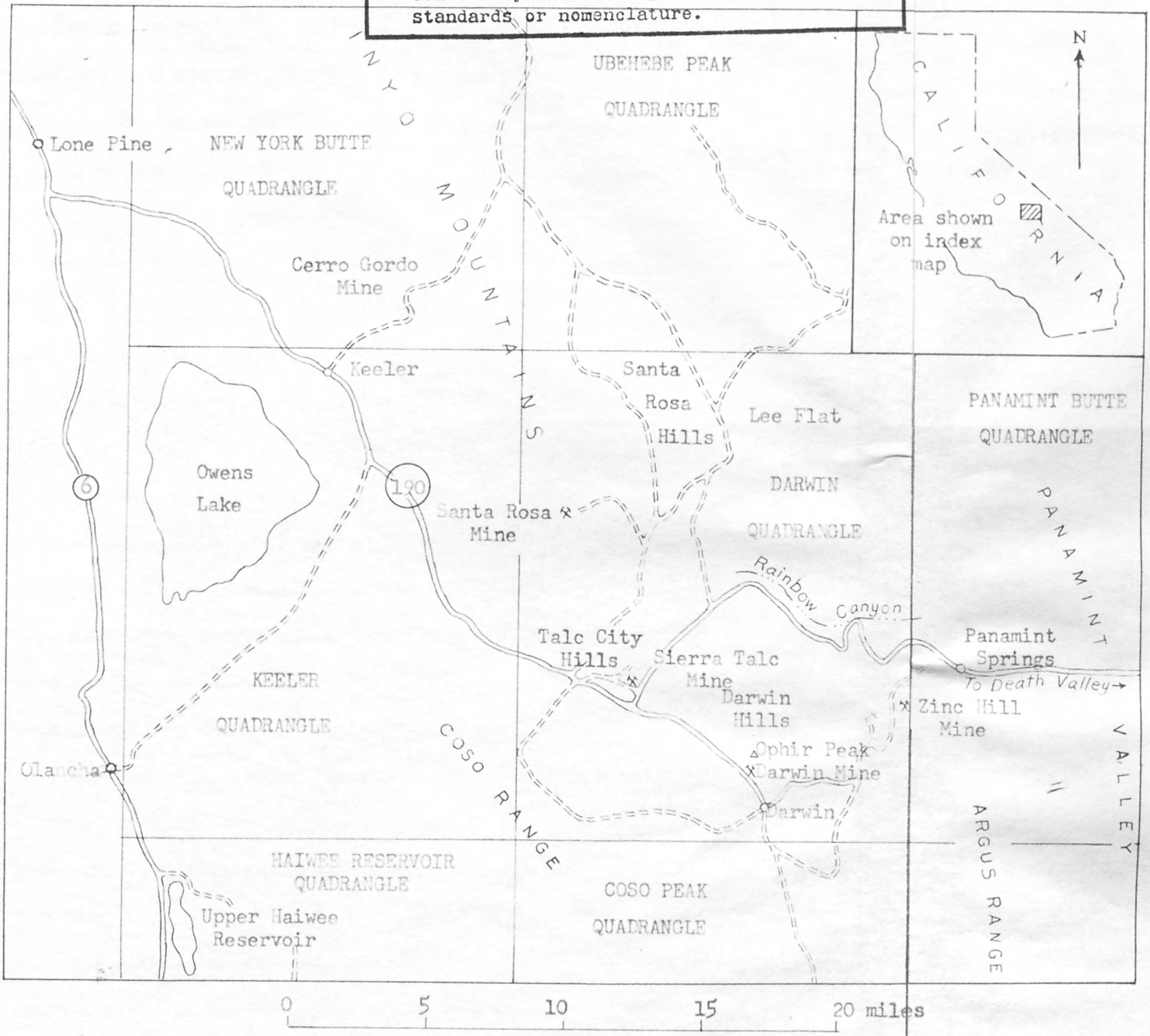

Figure 1.--Index map showing location of the Darwin quadrangle.

the Inyo Mountains on the northwest and the Resting Springs district on the southeast. As part of this program, McAllister (1952, 1955) mapped the Ubehebe Peak quadrangle, Hall and MacKevett the Darwin quadrangle (in press), and W. C. Smith and C. W. Merriam are mapping the New York Butte quadrangle.

The Darwin investigation was divided into 2 parts. The first was a study of the general geology of the quadrangle in order to understand the regional setting of the mineral deposits. The quadrangle was mapped with the assistance of E. M. MacKevett, Jr. during the periods January through October 1952 and May through October 1953. Mapping was done on a topographic base, Darwin quadrangle edition of 1951, on a scale of 1:40,000.

The second part of the investigation was a detailed study of the mineral deposits by Hall and MacKevett during 1954. Emphasis was given to a study of the lead-silver-zinc deposits, and detailed maps were made of 13 of the mines. Individual talc and tungsten deposits were not mapped except for minor new workings, as they had previously been studied by the U. S. Geological Survey (see Hall and MacKevett, in press and Page, 1951). However the geologic setting of these mineral deposits--the stratigraphy and structure--was not understood previously and this was one of the major problems.

Climate and vegetation

The climate in the Darwin quadrangle is typically desert, and is characterized by scant rainfall, frequent strong winds, and a considerable range in temperature. The closest weather station is at

Haiwee Reservoir, 14 miles southwest of the Darwin quadrangle at an altitude of 3,830 feet, but the data there are probably representative of most of the quadrangle except for the lower altitudes in Panamint Valley where the temperature is unconfortably hot in the summer. The U. S. Weather Bureau's publication Climatological Data (1948) lists the following data for the Haiwee Reservoir station:

Annual rainfall	6.06 inches
Average January temperature	40.4° F
Average July temperature	81.7° F
Maximum recorded temperature in 1948	102° F
Minimum recorded temperature in 1948	14.0° F

Vegetation is mostly sparse. Sagebrush, Mormon tea (Ephedra), creosote brush (Larrea), Joshua (Yucca brevifolia), and some cacti form a light vegetative cover over all except the northwestern part of the quadrangle near Conglomerate Mesa and in the higher altitudes in the Coso Range, where pinon pines and junipers are prevalent. A thick stand of Joshua trees is present on Lee Flat.

Topography

Physiographically the Darwin quadrangle is in the western part of the Basin and Range province. Altitudes range from a maximum of 7,731 feet in the Inyo Mountains to a minimum of 1,960 feet in the canyon 2 miles north of Rainbow Canyon on the west side of Panamint Valley (see pl. 1 for locality names). The southern end of the Inyo Mountains occupies most of the northwestern quarter of the quadrangle. The north end of the Coso Range extends into the southwestern part of the quadrangle. The rest of the area is mainly an alluvial and lava-capped plateau with altitudes of 4,500 to 5,500 feet. The most rugged topography is in the eastern part of the quadrangle where narrow, deeply incised canyons draining into Panamint Valley are cut into the lava-capped Darwin Plateau. Rainbow Canyon has steep walls that are in places over 1,000 feet high.

The principal drainage is eastward into Panamint Valley. Darwin Canyon drains the southeastern part of the quadrangle between the Argus Range, the Darwin Hills, and the alluviated area west of Darwin. The east slope of the Inyo Mountains and the west slope of the Santa Rosa Hills are drained by Santa Rosa Wash and Rainbow Canyon, while Lee Flat and the east slope of the Santa Rosa Hills are drained by Lee Wash. Drainage of the southwest part of the quadrangle is to the west through Centennial Flat into Owens Valley.

Water supply

Shallow wells in Darwin Canyon provide the principal water supply for the mining industry. In addition small quantities of water have been obtained from Black Springs in the Coso Range and from Mill Canyon in the northeast part of the quadrangle. The Darwin mill and mining camp are supplied by 3 wells less than 60 feet deep in Darwin Canyon from which approximately 180 gallons of water per minute are pumped, with a lift of about 1,840 feet. The water is supplied from a drainage basin of 165 square miles on the west flank of the Argus Range and the northeast flank of the Coso Range, and this water is funneled into Darwin Canyon. Water for the town of Darwin is piped 8 miles from Centennial Spring in the Coso Range. Water must be trucked from Lone Pine or Darwin to the Santa Rosa mine, the Talc City district, and the Lee district.

Previous work and acknowledgments

The earliest discussions of the geology of the Darwin area are in reports of the State Mineralogist (Crawford, 1894 and 1896; De Groot, 1890, p. 209-218; and Goodyear, 1888, p. 224-309) and by Burchard (1884) and Raymond (1877, p. 25-30). These reports deal primarily with mining activity, but they also have notes on the geology of local mine areas. Knopf (1914) visited the Darwin area in May 1913 during his study of the Inyo Mountains, and in his report he discusses the geology and ore deposits of the Darwin Hills. The first comprehensive study of the Darwin district was made by Kelley (1938) during the summers of 1935 and 1936. He made a geologic map of the Darwin Hills on a scale of 1,000 feet to the inch and mapped a few of the mines on a larger scale. In 1937 Schultz described a late Pliocene or early Pleistocene vertebrate fauna from the Coso Range, but most of his work was west of the quadrangle. Hopper (1947) mapped approximately 90 square miles across the southern part of the quadrangle in his study of a strip 6 miles wide from the Sierra Nevada to Death Valley.

The U. S. Geological Survey had geologists working in the Darwin quadrangle during World War II in its commodity study program. C. W. Merriam and L. C. Craig studied the lead-zinc deposits; D. M. Lemmon and others studied the tungsten deposits of the Darwin Hills; and

B. M. Page (1951) and L. A. Wright studied the talc deposits of the Talc City Hills. Several mine geologists have published papers on the Darwin district. L. K. Wilson (1943), resident geologist for the Pacific Tungsten Company, discussed the geology and tungsten deposits on the east side of the Darwin Hills. D. L. Davis (Davis and Peterson, 1948), resident geologist of The Anaconda Company, described the geology and ore deposits of the Darwin Mines.

The writer was ably assisted from January 1952 to June 1955 by E. M. MacKevett, Jr. of the U. S. Geological Survey. MacKevett assisted during the course of all the field mapping, in the preparation of a report on the mines for the California Division of Mines (Hall and MacKevett, in press), and in the early stages of the preparation of the section on stratigraphy for a final report prepared for the U. S. Geological Survey. Victor Mejia, E. H. Pampeyan, Dallas Peck, and D. H. Thamer gave able assistance in the field during short periods of assignment to the project.

Work in the field was greatly benefited by discussions with J. F. McAllister and C. W. Merriam of the U. S. Geological Survey, M. P. Billings of Harvard University, and C. E. Stearns of Tufts University. The writer especially wishes to express his thanks for the wholehearted cooperation of the mining people in the area. Dudley L. Davis and Malcolm B. Kildale of The Anaconda Company particularly facilitated the work in the Darwin district, and the writer greatly benefited from many discussions of the geology with them.

PALEOZOIC ROCKS

General statement

The Paleozoic section in the Darwin quadrangle consists predominantly of carbonate rocks similar to the eastern facies of Paleozoic rocks in the Great Basin. Pre-Devonian rocks are mainly dolomite; Devonian rocks are dolomite, limestone, and quartzite; and Mississippian and younger Paleozoic rocks are mainly limestone (pl. 2). Chief exceptions are the Eureka quartzite of Ordovician age and some shale and siltstone in Carboniferous and Permian rocks. No volcanic or phosphatic, and only minor carbonaceous material was recognized in the Paleozoic rocks. Most formations are well exposed and some units form bold, cliff outcrops.

The Paleozoic rocks have an aggregate thickness greater than 13,000 feet. Lack of exposure in parts of the section precludes a more accurate appraisal of the total thickness. The Paleozoic rocks are similar to those described by McAllister (1952, 1955) from the adjacent Ubehebe Peak quadrangle and Quartz Spring area, and Merriam (1954) and Merriam and Hall (1957) from the southern Inyo Mountains.

Formation names used by McAllister (1952, 1955) in most instances have been utilized (table 1). Thick continuous stratigraphic sections are lacking because of volcanic or alluvial cover or structural complications. Unconformities are apparently limited to Pennsylvanian and Permian parts of the section and probably represent small time intervals. Lee Flat limestone, a time-stratigraphic equivalent of part of McAllister's (1952, 1955) Perdido formation and his Rest Spring shale, is described as a new formation. The Lee Flat limestone correlates

Table 1.--Geologic column for Darwin quadrangle.

Age	Name	Character	Thickness (feet)
Recent	Alluvium	Unconsolidated alluvium, playa deposits, lake beds, fanglomerate, and landslide deposits.	
Pleistocene	Lake deposits	White to light-gray, very fine-grained pumiceous ash, silt, clay, and diatomaceous earth.	58+
	Fanglomerate marginal to Darwin Wash	Fanglomerate composed mainly of subrounded fragments of Pennsylvanian-Permian limestone quartz monzonite, and basalt in a sandy matrix.	25+
	Olivine basalt	Mainly flows 10-100 feet thick; minor intrusives. A few undifferentiated flows in Darwin Canyon are younger than fanglomerate marginal to Darwin Wash.	0-600
	Fanglomerate from Inyo Mountains	Gravel. Angular to subrounded fragments of Ordovician and Silurian rocks up to 18 inches in diameter in a clay and silt matrix.	30+
	and		
	Coso formation	Arkose and clay, poorly bedded, white to buff, fine- to medium-grained.	30+
	Pyroclastic rocks and andesite	Upper unit: Well-bedded tuff-breccia, lapilli-tuff, scoriaceous basalt, and basalt cinders. Andesite forms broad dome in upper pyroclastic unit: contains phenocrysts and clusters of plagioclase and hornblende in an aphanitic groundmass.	0-310+
		Lower unit: poorly bedded agglomerate and tuff-breccia.	0-750

Cretaceous(?)	Hypabyssal rocks	Andesite porphyry, diorite and alaskite porphyry dikes.	
		Aplite, pegmatite, and leucogranite.	
	Amphibolite	Includes amphibolite, epidote amphibolite, hornblende gabbro, and diorite.	
Cretaceous	Biotite-hornblende-quartz monzonite and leucocratic quartz monzonite	Mainly quartz monzonite with other granitic rock types.	
Permian	Owens Valley formation	Upper: Limestone conglomerate, siltstone, calcarenite, and orthoquartzite	180+
		Middle: Brick-red and yellowish-brown shale; subordinate siltstone and limestone.	200
		Lower: Mainly fine-grained calcarenite in beds 1 to 2 feet thick; some thick limestone lenses, shale and siltstone.	2,800
Pennsylvanian and Permian	Keeler Canyon formation	Upper: Calcilutite and fine-grained calcarenite and lesser pink shale, siltstone and limestone pebble conglomerate.	1,700
		Lower: Thin-bedded calcarenite and intercalated limestone pebble conglomerate.	2,300

Pennsylvanian (?)	Rest Spring shale		Rest Spring shale: dark brown and greenish-gray fissile shale, minor siltstone.	0-50+
Pennsylvanian (?) and Mississippian		Lee Flat limestone	Thin-bedded, dark-medium-gray limestone.	960+
Mississippian	Perdido formation		Limestone and bedded chert.	330
Mississippian	Tin Mountain limestone		Fossiliferous thin- to thick-bedded limestone with chert lenses and nodules	435
Devonian	Lost Burro formation		Coarse-grained white and light-gray marble; dolomite, quartzite, and limestone in lower part of formation; shale locally in upper part.	1,770+
Silurian and Devonian(?)	Hidden Valley dolomite		Light-gray, massive dolomite.	1,000±
Upper Ordovician	Ely Springs dolomite		Dark-gray dolomite with chert beds and lenses; some light-gray dolomite.	920±
Middle Ordovician	Eureka quartzite		Light-gray to white vitreous quartzite.	440
Lower Ordovician	Pogonip group		Light- and medium-gray thick bedded dolomite; some thin-bedded dolomite and limestone.	1,570±

with part of the Chainman shale in the southern Inyo Mountains (Merriam and Hall, 1957, p. 4). Nomenclature used by Merriam and Hall (1957) has been adopted for the Pennsylvanian and Permian formations.

Pogonip group

The Pogonip group of Early and Middle Ordovician age is the oldest formation exposed in the quadrangle (pls. 2 and 3). It crops out in isolated or fault-bounded bodies along the southwest side of the Talc City Hills and at the east end of the hills west of the West Virginia claim (fig. 2). The exposed section west of the West Virginia claim is 1,570 feet thick, which represents most of the Pogonip group, although the base of the sequence is unexposed.

The group consists predominantly of light-gray, medium- to thick-bedded dolomite, but includes limestone, shaly limestone, and siliceous limestone in the middle and upper parts. The siliceous limestone beds weather dark brown and form a distinctive horizon marker. Cross-bedding is common near the top of the Pogonip.

A widespread fossiliferous bed is present in the Pogonip about 250 feet below the contact with the Eureka quartzite. The fossils, which include *Receptaculites*, abundant large gastropods *Palliseria longwelli* and *Maclurites* sp.?, and probable algal remains, are indicative of Chazy age (Middle Ordovician). Elsewhere the lower part of the Pogonip has been dated as Early Ordovician (McAllister, 1952, p. 11; Nolan and others, 1956, p. 25).

Eureka quartzite

Eureka quartzite is abundantly exposed in the Talc City Hills,

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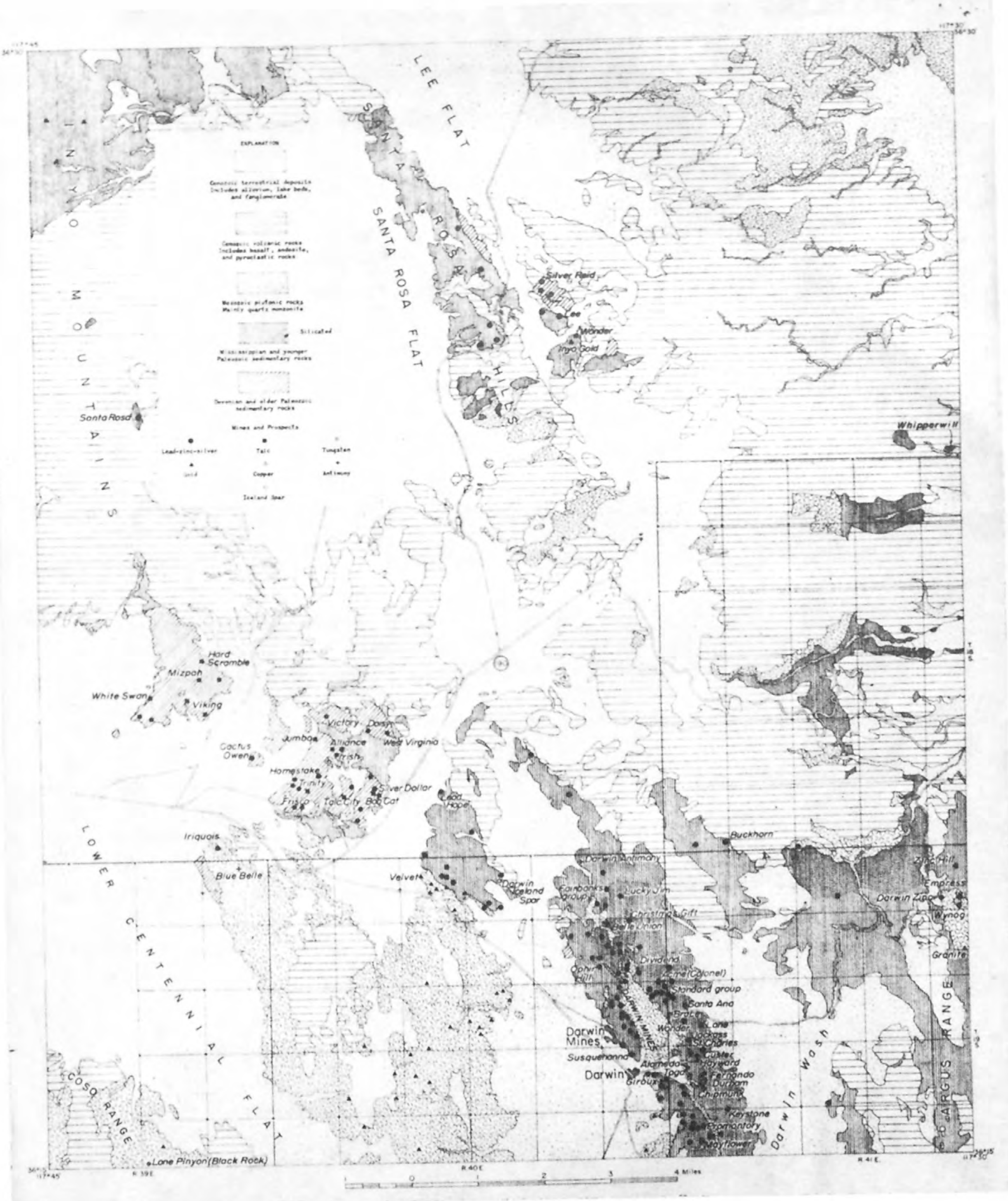

Figure 2.--Simplified geologic map of the Darwin quadrangle showing location of mines and prospects.

where it forms distinctive white, glistening outcrops. It is on both flanks of the overturned syncline at the northwest end of the Talc City Hills 1,600 feet northeast of the White Swan mine and at the Hard Scramble talc prospect (fig. 2; pl. 3). Isolated patches of Eureka crop out between the Alliance talc mine and the Cactus Owen prospect. Most contacts of the Eureka are faults, and isolated blocks of Eureka quartzite as much as several hundred feet long are common in fault zones in the Pogonip group and Ely Springs dolomite. The Eureka is the most distinctive horizon marker in the Paleozoic section (fig. 3).

The formation is 440 feet thick in an unfaulted section on the ridge 2,000 feet N. 30° E. of the White Swan talc mine. The formation consists almost entirely of white vitreous quartzite, but brown-weathering, in part platy quartzite crops out locally above the basal contact. Individual quartz grains are mostly of coarse silt size. Cross-bedding is common in the basal part of the formation.

The age of the Eureka is Middle Ordovician and possibly in part Late Ordovician in age. It lies above Middle Ordovician fossils near the top of the Pogonip and below the fossiliferous Ely Springs dolomite of Late Ordovician age.

Ely Springs dolomite

Exposures of Ely Springs dolomite are confined to the Talc City Hills. The formation crops out mainly in the northwestern part of the hills on both flanks of an overturned syncline (pl. 3). Other exposures are at the Trinity talc mine, in two bands extending west from the Alliance talc mine, and on the hill 1 mile east of the Viking talc

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Figure 3.--Photograph of the Talc City Hills near the Viking mine showing the overturned Paleozoic section of Pogonip group (a), Eureka quartzite (b), Ely Springs dolomite (c), and Hidden Valley dolomite (d). The Eureka quartzite and the overlying dark-gray Ely Springs dolomite are the most conspicuous Paleozoic stratigraphic horizon markers.

mine (fig. 2). A complete section of Ely Springs dolomite on the ridge 3,500 feet N. 6° E. of the White Swan mine is 920 feet thick. The lower part of the formation consists of dark-gray, thick-bedded dolomite with irregular lenses and nodules of chert. It grades upward through medium-gray to massive, light-gray dolomite. A 50-foot thick bed of dark-gray dolomite is present at most places at the top of the formation.

The contact of the Ely Springs dolomite with the underlying Eureka quartzite, marked by abrupt lithologic and color changes, forms the most conspicuous formational boundary in the Paleozoic section. The formation has been dated as Late Ordovician by C. W. Merriam of the U. S. Geological Survey based on fossils collected from the lower part of the Ely Springs on the ridge south of the Hard Scramble prospect (pl. 3).

Hidden Valley dolomite

Hidden Valley dolomite crops out for 1¼ miles along the crest of the ridge in the core of the syncline 1,400 feet west of the Hard Scramble prospect, and other smaller outcrops are present north of the Alliance talc mine, 700 feet south of the Talc City mine, and 300 feet north of the Trinity talc mine (pl. 3). The formation consists entirely of massive, buff to light-gray dolomite. The dolomite is recrystallized, and very little bedding is evident. The entire Hidden Valley section is not present at any one locality within the quadrangle. Approximately 1,000 feet of Hidden Valley dolomite is exposed along the ridge between the White Swan talc mine and the Hard Scramble prospect, although the upper part of the formation is eroded.

Only meager indeterminate fossil remains were found in the Hidden Valley dolomite in the Talc City Hills. In the Quartz Spring area McAllister (1952, p. 16) dated the Hidden Valley dolomite as Silurian and Early Devonian.

Lost Burro formation

The Lost Burro formation crops out in the Santa Rosa Hills at the Silver Reid prospect, in the Talc City Hills at the Cactus Owen, Homestake, and Talc City mines, and on the west flank of the Darwin Hills (pl. 2). No complete section of the Lost Burro is exposed in the quadrangle, but the thickness is probably greater than 1,700 feet and a composite section may be as much as 2,400 feet. The accuracy of this estimate is impaired by minor faulting and folding. The formation consists of light-gray dolomite, quartzite, sandy limestone, and chert in the lower part and white to light-gray marble with local thin quartzite beds and locally shale in the upper part. The lower part of the formation is exposed at the Talc City mine. It consists of 65 feet of interbedded brown-weathering quartzite, sandy limestone, and chert and is correlated with the Lippincott member (McAllister, 1955, p. 12). This lower part is overlain by about 600 feet of light-gray mottled dolomite that, in turn, is overlain by light-gray limestone and shale. The upper part of the formation is exposed in the Santa Rosa Hills at the Silver Reid prospect, and it consists of white to light-gray marble with minor thin quartzite beds. The marble is finely banded with alternating white and medium-gray layers. Some medium-gray limestone beds within the white marble contain abundant cladoporoids and stromatoporoids.

Correlation of this part of the stratigraphic section with the type Lost Burro formation in the Quartz Spring area in the northern Panamint Range (McAllister, 1952, p. 19) was made both on lithologic similarity and equivalent stratigraphic position under abundantly fossiliferous lower Mississippian beds. In the Darwin quadrangle the Lost Burro contains only a meager fossil record, but in the Quartz Spring area it is dated as Upper and probably in part Middle Devonian on the basis of well-preserved brachiopods (McAllister, 1952, p. 19).

Tin Mountain limestone

Tin Mountain limestone crops out for 4 miles along the crest of the Santa Rosa Hills, and smaller exposures are at the Lee mine and locally along the west flank of the Darwin Hills (pl. 2). The formation is 435 feet thick at the south end of the Santa Rosa Hills. The dominant rock type is medium- to dark-gray, fine-grained limestone in beds 1/2 foot to 12 feet thick. Chert lenses and nodules and crinoidal debris are common throughout the Tin Mountain limestone. At the south end of the Santa Rosa Hills the Tin Mountain limestone is bleached and in part recrystallized to marble, so that it resembles marble of the Lost Burro formation. Elsewhere a sharp color contrast distinguishes the dark limestone of the Tin Mountain from the underlying coarse-grained white marble of the Lost Burro formation.

The Tin Mountain limestone is the most fossiliferous formation in the quadrangle and contains numerous corals, brachiopods, bryozoans, and crinoidal stems. Several collections of fossils from the Tin Mountain limestone from the Santa Rosa Hills were examined by Helen Duncan and Mackenzie Gordon, Jr., of the U. S. Geological Survey, and the latter summarized his findings of the brachiopods as follows:

> "The three collections appear to represent approximately the same faunal assemblage. The small narrow Spirifer sp. A, with rather long dental plates and about 5 ribs on each side of a narrow sinus in the pedicle valve, occurs both in collection F-1 and F-7 along with poorly preserved horn corals that have a general lower Mississippian aspect, according to Miss Duncan.
>
> Cyrtina and Leptaena are genera that range through Silurian and Devonian rocks and into the lower Mississippian. In the western United States Leptaena analaga (Phillips) is typical of the rocks of Madison age and is not definitely known to range higher. In the mid-continent this species and several cyrtinas are known in rocks of Kinderhook and Osage age and are not known to range as high as uppermost Osage. Rhipidomella oweni (Hall) with which several partly crushed silicified specimens are here compared is a widespread lower Osage form. The presence of the large productid, through too poorly preserved to identify even as to genus, precludes a Devonian age for the assemblage. The rest of the specimens are not well preserved or entire enough to add any evidence to that discussed above.
>
> In summary, the fossils can be said to represent an early Mississippian (Madison) fauna. In terms of mid-continent stratigraphy they are believed to be not younger than Osage in age and may be Kinderhook in age."

Perdido formation

The Perdido formation is present mainly in the Santa Rosa Hills conformably overlying Tin Mountain limestone and is present locally at the south end of the Talc City Hills and on the western flank of the Darwin Hills (pl. 2). The formation is approximately 325 feet thick in the Santa Rosa Hills. It consists predominantly of limestone, silty limestone, and chert. Thin-bedded, medium-gray limestone with thin layers of bedded chert are characteristic of the lower part of the formation. Chert is much more abundant in the upper part of the formation where it is present in beds as much as 60 feet thick at the south end of the Santa Rosa Hills. The lithology of the lower part of the Perdido formation and the upper part of the Tin Mountain limestone is similar and the contact between the two is placed at the base of the lowermost bedded chert in the Perdido formation.

The Perdido formation is much thinner in the Darwin quadrangle than in the Quartz Spring area where McAllister (1952, p. 23) measured a section about 610 feet thick. The Perdido formation in the Darwin quadrangle is similar in lithology to the lower part of the Perdido formation in the Quartz Spring area, and the upper clastic part of the Perdido is missing. The age of the formation, according to McAllister (1952, p. 24), is Mississippian based on fossils in the Ubehebe Peak quadrangle and the Quartz Spring area.

Lee Flat limestone

The Lee Flat limestone is named for exposures near Lee Flat, a Joshua tree-studded, alluviated area east of the Santa Rosa Hills. The type section trends south from near the top of the prominent hill 4,800 feet S. 36° E. of the main shaft of the Lee mine. The formation is exposed for 4½ miles along the northeast side of the Santa Rosa Hills, and it forms the prominent hill 3,000 feet south of the Lee mine (fig. 4). Smaller outcrops of Lee Flat limestone are in the southern part of the Talc City Hills and along the west flank of the Darwin Hills.

The predominant rock is thin-bedded, medium- to dark-gray limestone. Locally the generally uniform appearance of the limestone

Figure 4.--Lee Flat limestone (Mlf) viewed south from the Lee mine. The Lee Flat limestone conformably overlies the Perdido formation (Mp). This is the most accessible section of Lee Flat limestone, but was not designated as the type locality because of the interruption of the section by steep faults (f).

is broken by thin, sandy iron-stained partings or by thin beds and lenses of chert. The Lee Flat limestone is at least 520 feet thick at the type locality where it conformably overlies the Perdido formation. The upper part of the limestone is covered by alluvium. The formation is estimated to be more than 960 feet thick on the hill 3,000 feet south of the Lee mine, but the top of the formation is covered by basalt and alluvium, and faulting in the exposed section vitiates the estimate (fig. 4).

The only fossils found in the Lee Flat limestone are crinoid fragments; consequently the age of the formation is derived from its stratigraphic position. The formation lies conformably on limestone and chert that are correlated with the lower part of the Perdido formation in the Ubehebe Peak quadrangle, where the lowest beds are probably early Mississippian (see Helen Duncan in McAllister, 1952, p. 24). The top beds of the Perdido formation in the Quartz Spring area are of Chester age (late Mississippian) (McAllister, 1952, p. 24). The Lee Flat limestone occupies the same stratigraphic position that the upper part of the Perdido formation and all the Rest Spring shale occupy in the Ubehebe Peak quadrangle (fig. 5), (McAllister, 1955). It represents a facies change from a clastic section of siltstone, shale, and minor limestone in the Ubehebe Peak quadrangle and Quartz Spring area to fine-grained limestone in the Darwin quadrangle. In the Darwin Hills the Lee Flat limestone is overlain by the Keeler Canyon formation, which ranges in age from probable Atoka or Des Moines (Pennsylvanian) to upper Wolfcamp (Permian). Therefore the Lee Flat limestone is

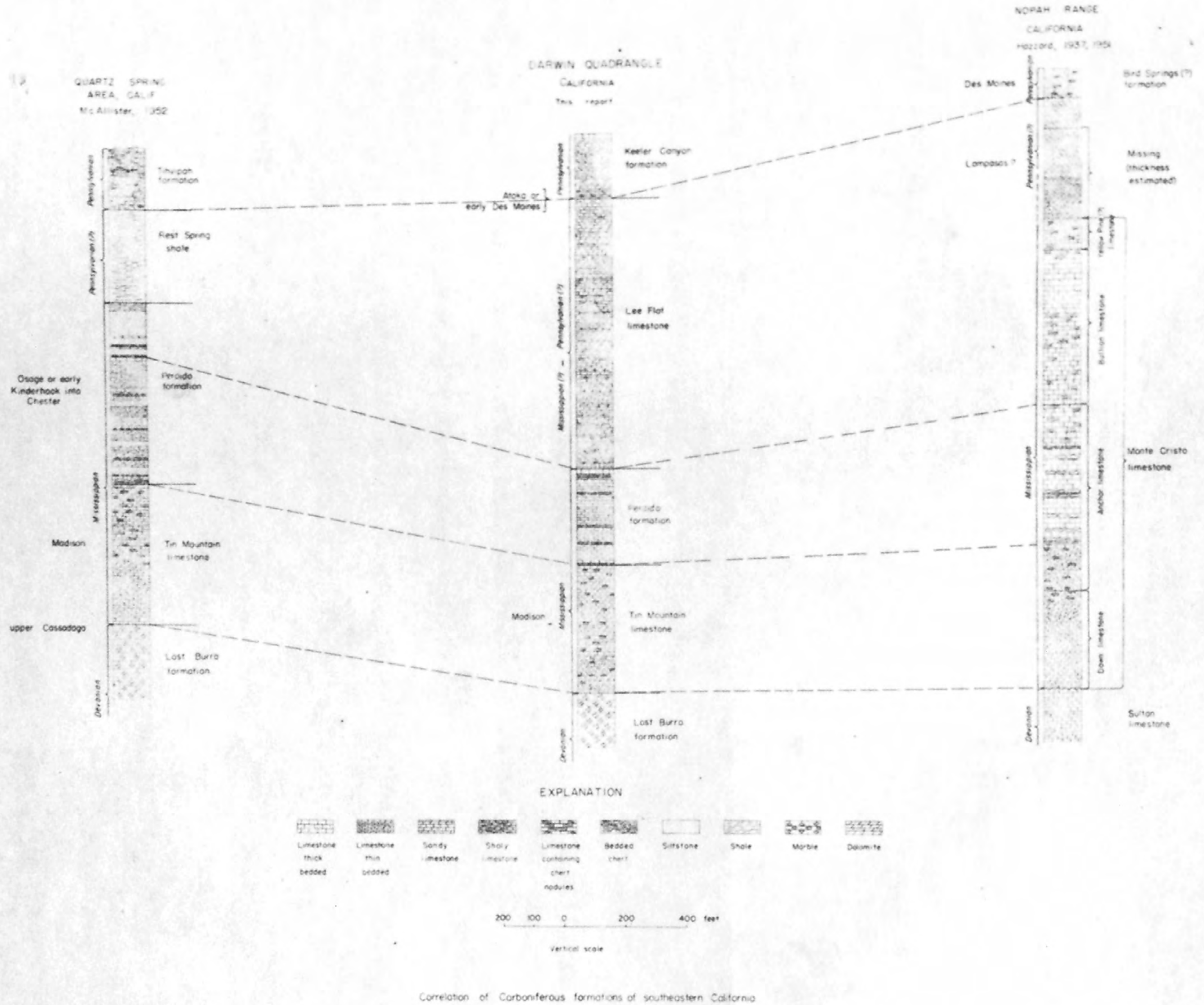


Figure 5.--Correlation of Carboniferous formations of California.

younger than middle Mississippian and older than middle Pennsylvanian. It is probably a time-stratigraphic equivalent of the Chainman shale, which is late Mississippian in age (Nolan and others, 1956, p. 59).

Rest Spring shale

The Rest Spring shale is present as slivers in major fault zones in the Darwin quadrangle in the northern part of the Darwin Hills, in the Santa Rosa Hills, and in the Talc City Hills. The formation consists of dark-brown, fissile shale. The Lee Flat limestone conformably overlies the lower part of the Perdido formation in the Darwin quadrangle, and the upper part of the Perdido formation and the Rest Spring shale are absent except in fault zones. The Rest Spring shale is probably a stratigraphic equivalent of the upper part of the Lee Flat limestone as discussed previously. No fossils were found in the Rest Spring shale, but it is considered Pennsylvanian(?) by McAllister (1952, p. 26) in the Quartz Spring area where it conformably underlies thinly bedded limestone containing fusulinids of middle Pennsylvanian age. The Chainman shale, a stratigraphic equivalent in the southern Inyo Mountains, is considered late Mississippian by Merriam and Hall (1957, p. 5).

Keeler Canyon formation

The Keeler Canyon formation is named for a thick sequence of limestone exposed in Keeler Canyon in the New York Butte quadrangle and east of the portal of the Estelle tunnel 2 miles southwest of Cerro Gordo Peak in the southern part of the Inyo Mountains (Merriam and Hall, 1957, p. 4). The formation crops out in the Darwin quadrangle in the northern part of the Santa Rosa Hills, the eastern part of the Talc City Hills, and in the western part of the Darwin Hills (pl. 2). No complete uninterrupted section is present in the quadrangle, but a composite of measured partial sections in the western part of the Santa Rosa Hills indicates an approximate thickness of 4,000 feet.

The Keeler Canyon formation is divided informally into two members in the Darwin quadrangle. The lower member, which is estimated to be about 2,300 feet thick, consists of thin- to medium-bedded, bluish-gray limestone with minor limestone pebble conglomerate. It underlies the hill west of the Darwin Antimony mine in sec. 2, T. 19 S., R. 40 E. at the north end of the Darwin Hills, and the calc-hornfels that underlies Ophir Mountain and all of the Darwin mine area is a metamorphosed part of the lower member (pls. 1 and 2).

The upper member consists of pink shale, bluish-gray silty limestone, and limy siltstone. Cross-bedding is common near the top of the upper member, but it was not observed in the lower member. A measured section along the ridge trending east from the Darwin Antimony mine is 1,700 feet thick. The contact between the lower and upper members is gradational, and it is arbitrarily placed below the abundant pink shale and pink silty limestone. Slopes underlain by the upper member have a pinkish hue in contrast to a grayish hue of slopes underlain by the lower member.

The Keeler Canyon formation ranges in age from probable Atoka or Des Moines (Pennsylvanian) to probable late Wolfcamp (Permian) according to L. G. Henbest and R. C. Douglass of the U. S. Geological Survey. Fusulinids are the most abundant fossils, but in many the internal structures are impaired by silicification to such an extent that assured identifications are unobtainable.

A report by Lloyd G. Henbest of the U. S. Geological Survey concerning a collection of fusulinids from near the base of the Keeler Canyon formation in the Santa Rosa Hills 1.58 miles S. 77° W. of the Lee mine is given below.

F-9591--Pennsylvanian, Atoka or Des Moines age.

Solenoporoid Algae
Climacammina sp.
Endothyra sp.
Millerella? sp.
Fusulinella sp. or *Wedekindellina* sp.
Fusulinella sp. or an early form of *Fusulina*

> "Most of the specimens show massive deformation and poor preservation. The fusulinids are identified generically with fair assurance. The age indicated is Atoka or very early Des Moines. The foraminiferal association gives support of very limited value to this age determination. The species of solenoporoid Algae is a fossil of common occurrence in the Rocky Mountain region. In my experience, it is limited to rocks of Atoka and of approximately the first half of Des Moines age. By the fusulinids alone, in this state of preservation, I could not definitely prove that they are not of early Permian age. The assemblage and especially the peculiar solenoporoid all agree in indicating Atoka or early Des Moines age."

The collections of fusulinids were made at the top of the upper member of the Keeler Canyon formation at the north end of the Darwin Hills northeast of the Darwin Antimony mine. These collections were examined by R. C. Douglass of the U. S. Geological Survey and his reports are given below.

F-9748 "At north end of Darwin Hills in sec. 35 (projected), T. 18 S., R. 40 E. at elevation 5,290 feet. Located 3.92 miles N. 73° E. from road junction of state highway 190 and Darwin turn off and 1.20 miles N. 33° W. of VABM 5979. In thinly bedded blue-gray, fine grained limestone.

Climacammina sp.
Tetrataxis?
Endothyra?
Schwagerina spp.
One aff. *S. compacta* (White)

Evidence on the age of this sample is inconclusive. The sample is probably of Wolfcamp age, possibly middle to late Wolfcamp.

F-9749 At north end of Darwin Hills at elevation 5,400 feet. Located in gully 660 feet north of VABM 5979 and 4.39 miles N. 86½° E. of junction of state highway 190 and Darwin turn off. In 3-foot thick limestone bed interbedded in pink fissile shale.

Calcitornellids
Climacammina sp.
Triticites sp.
Schwagerina spp. (possibly 3 species)
One aff. *S. diversiformis* Dunbar & Skinner
Another aff. *S. linearis* Dunbar & Skinner
Pseudoschwagerina sp.
Parafusulina?

This assemblage contains elements common to the uppermost Wolfcamp and lower Leonard formations. It can probably be correlated with this boundary zone with fair certainty."

Owens Valley formation

The name Owens Valley formation is applied by Merriam and Hall (1957, p. 7) to a sequence of limestones and shales exposed in the Inyo Mountains. The formation is abundantly exposed in the Darwin quadrangle. It underlies Conglomerate Mesa and the group of low hills at the head of Santa Rosa Flat in the northwestern part of the quadrangle, and it is present in the southeastern part of the quadrangle on the east side of the Darwin Hills, in Darwin Canyon, and on the west flank of the Argus Range (pls. 1 and 2).

The Owens Valley formation, which is more than 3,200 feet thick, consists of interbedded calcarenite, silty limestone, pure limestone, siltstone, and shale. It is divided informally into 3 members, all of which are present on the east side of Conglomerate Mesa (fig. 6). The lower member is about 2,800 feet thick and consists of calcarenite, shaly limestone, lenses of pure limestone, shale, and siltstone. Lenses of bluish-gray, pure limestone as much as 40 feet thick and several thousand feet long are characteristic of the lower member, and cross-bedded calcarenite is abundant. Algal nodules containing abundant sponge spicules, fusulinids, and algae are present in shaly limestone in Darwin Canyon. A 450-foot thick, brown-weathering siltstone is at the base of the formation at most places in the Darwin Hills.

The middle shale member of the Owens Valley formation is exposed only in the northwestern part of the quadrangle along the foot of Conglomerate Mesa (fig. 6). It is approximately 200 feet thick, but the incompetence of the beds and poor outcrop preclude an accurate measurement of thickness. The middle member consists preponderantly of shale but includes subordinate siltstone and limestone. Most of the shale is brick red or yellowish-brown on both fresh and weathered surfaces, but some is dark gray or greenish-gray.

The upper limestone conglomerate member forms the resistant capping and cliff exposures of Conglomerate Mesa (fig. 6, pl. 2). It

Figure 6.--Owens Valley formation at Conglomerate Mesa in the northwest part of the quadrangle. The three members of the formation are exposed. The upper member (a) is a resistant limestone conglomerate that forms a protective capping over the incompetent shaly middle member (b). The lower member (c) forms the rolling topography in the foreground. The prominent bioherm at (d) is fossil locality F-119 from which the megafossils of the Owens Valley were collected.

has a minimum thickness of 180 feet in the Darwin quadrangle, and consists of limestone conglomerate, siltstone, and sandstone. The contact with the underlying middle shale member is disconformable. In the adjacent Ubehebe Peak quadrangle the limestone conglomerate in the stratigraphic equivalent upper part of the Bird Spring(?) formation has a maximum thickness of 600 feet (McAllister, 1955, p. 14). The conglomerate contains fragments of gray limestone and silty limestone mostly 1 inch to 4 inches in diameter in a sand-sized matrix of limestone and chert. In places the conglomerate has been nearly completely silicified.

The age of the Owens Valley formation ranges from late Wolfcamp (lower Permian) to probably Word or Guadalupe (Permian). The lower limestone member ranges in age from late Wolfcamp into Leonard. The faunal assemblage includes fusulinids, corals, brachiopods, ammonites, and gastropods.

Two collections from near the base of the Owens Valley formation in the northwestern part of the quadrangle were studied by R. C. Douglass of the U. S. Geological Survey and were determined as probably late Wolfcamp in age. Collection F-9645 is 2.85 miles S. 86½° E. of the northwest corner of the quadrangle; collection F-9648 is 2.20 miles S. 80° E. of the northwest corner. The descriptions by Douglass are given below.

F-9645 Permian
California, Inyo County, Darwin quadrangle

Schubertella sp.
Triticites? sp.
Schwagerina spp.
Pseudoschwagerina? sp.

"The material in this collection is fractured and silicified. It is of Permian age, probably upper Wolfcamp."

F-9648 Permian
California, Inyo County, Darwin quadrangle

Schwagerina spp. advanced forms
Pseudoschwagerina sp.

"This sample is of Permian age, probably upper Wolfcamp."

Two collections were made at the top of the lower member of the Owens Valley formation. Collection F-9650 of fusulinids was from a limestone lens 40 feet thick in silty limestone 1.20 miles S. 71° E. of the northwest corner of the quadrangle. Collection F-119 is 1.30 miles S. 58° E. of the northwest corner (point d in fig. 6). It is a collection of gastropods, corals, brachiopods, and bryozoa from a craggy limestone lens 84 feet thick that is stratigraphically a few feet below collection F-9650.

R. C. Douglass studied collection F-9650 and reports:

F-9650 Permian
California, Inyo County, Darwin quadrangle

"There are many small forms in this collection most of which seem to be immature individuals of the following genera, but some of which may be Endothyra and Schubertella.

Schwagerina spp. advanced forms related to S. guembeli Dunbar and Skinner

Parafusulina sp.

This sample is the youngest of the lot studied for this report. It is Permian in age and is probably equivalent to the Leonard."

James Steele Williams of the U. S. Geological Survey in 1953 summarized results of paleontological studies of a megafossil assemblage collected from locality F-119 near the top of the lower limestone member as follows:

"Bryozoa (identified by Helen Duncan)
Stenodiscus? sp. indet. (no close age significance)

Brachiopoda
Meekella sp. indet. large form
Dictyoclostus sp. indet., related to D. ivesi bassi McKee
Dictyoclostus? sp. indet., possibly related to D. ivesi (Newberry)
Enteletes? sp. indet.

Gastropods
Three specimens of gastropods were reported on separately by Ellis Yochelson.

Two are indeterminate and one represents an undetermined species of the genus Peruvispira which was described from beds said to be Lower Permian age in Peru but has been found in beds in the U. S. that range from Wolfcamp to Word in age."

"The large Dictyoclostus in the above list is crushed and incomplete but as nearly as one can tell it is probably a D. ivesi variety bassi McKee. The smaller one is related to D. ivesi (Newberry) as restricted by McKee but it appears to have coarser costae and a deeper sulcus than are typical of that species. The species of Meekella in mature individuals is larger than most Pennsylvanian species. On these rather slender grounds I believe that the collection is probably of Leonard or younger Permian age. It is not the typical Owenyo fauna but appears to me to be older than that fauna. I do not believe it is as old as typical McCloud. It may however be an unusual facies of one of these faunas."

No fossils were found in the middle shale member or the upper limestone conglomerate member of the Owens Valley formation. The middle shale member is probably Leonard or younger Permian age as it conformably overlies the lower member, the upper part of which contains fossils that are considered by James Steele Williams to be Leonard or younger Permian age as cited above. The Reward conglomerate and fossiliferous Owenyo limestone (Knopf, 1918, p. 42-45) in the Inyo Range are included in the upper part of the Owens Valley formation by Merriam and Hall (1957, p. 2). On the basis of the Owenyo fauna and fossils from time equivalent rocks in the New York Butte quadrangle, Merriam believes the limestone conglomerate member is Permian, probably Guadalupe.

Undifferentiated Paleozoic silicated limestone

Calc-hornfels that cannot be correlated definitely in the stratigraphic column occurs near the eastern border of the quadrangle in Rainbow and nearby canyons and as inliers surrounded by basalt. The calc-hornfels is mainly a white to light-gray, dense diopside-rich rock, but locally some relict bluish-gray limestone with tremolite needles remains. It occurs between a small inlier of probable Lost Burro formation to the north in an unnamed canyon 3.70 miles S. 63° W. of the northeast corner of the quadrangle and lower Owens Valley formation to the south in the Argus Range. The calc-hornfels is probably both Carboniferous and Permian in age.

Gneiss

Gneiss crops out only in the southwest part of the quadrangle as several small roof pendants or screens marginal to biotite-hornblende-quartz monzonite. The rock is a fine- to medium-grained gneiss consisting mainly of biotite, quartz, and feldspar. Foliation strikes north to northwest and dips steeply. The gneiss is cut by some sills of biotite-hornblende-quartz monzonite. Its age is not known.

MESOZOIC PLUTONIC ROCKS

Plutonic rocks are exposed at the surface over approximately 10 percent of the quadrangle, and possibly an additional 10 percent has a basement complex of plutonic rocks under a cover of basalt or alluvium. The plutonic rocks are divided into two lithologic types--biotite-hornblende-quartz monzonite and leucocratic quartz monzonite. Minor leucogranite, aplite, and pegmatite are commonly present in small bodies at the border of bodies of quartz monzonite and as thin dikes intruding it. The term quartz monzonite as used in this paper is a granitoid rock that contains essential quartz, K-feldspar, and plagioclase; the ratio of K-feldspar to plagioclase is between 1 to 2 and 2 to 1. Otherwise names of plutonic rocks in this report follow the definitions of Johannsen (1939, p. 141-161).

Biotite-hornblende-quartz monzonite

Biotite-hornblende-quartz monzonite is the predominant plutonic rock type in the northeastern part of the quadrangle, in the Coso Range in the southwestern part, and in the central part of the Darwin Hills. Unaltered biotite-hornblende-quartz monzonite crops out in the northeastern part of the quadrangle in steep, east-trending canyons where the rock has been exposed by faulting or by erosion of the overlying basalt. The quartz monzonite extends northward into the Ubehebe Peak quadrangle where it has been described as the Hunter Mountain quartz monzonite by McAllister (1956). In the Darwin Hills and Coso Range, biotite-hornblende-quartz monzonite is the most easily weathered rock, and it forms gentle slopes that tend to be grus covered or marked by areas of resistant rock of leucocratic granite or aplite that does not reflect the composition of the grus-covered areas. Therefore few fresh specimens were found for a petrographic study of these bodies.

The stock of the Darwin Hills is a heterogeneous intrusive composed predominantly of biotite-hornblende-quartz monzonite and granodiorite similar to that in the Coso Range, but the rocks are deeply weathered and few unaltered specimens were found for study. Near the Defiance and Thompson workings of the Darwin mine the intrusive is heterogeneous and consists largely of granodiorite, quartz diorite, and diorite.

Megascopically the biotite-hornblende-quartz monzonite from the northeastern part of the quadrangle, Coso Range, and the least contaminated parts of the stock in the Darwin Hills are similar in color and texture. However there are some overall differences between quartz monzonite from the different bodies. The biotite-hornblende-quartz monzonite in the Coso Range contains more quartz and less mafic minerals than that from the northeastern part of the quadrangle. Augite is a common mafic mineral in the quartz monzonite in the northeastern part of the quadrangle but was not observed in the quartz monzonite in the Coso Range. These differences are believed to be due mainly to assimilation of limestone by the biotite-hornblende-quartz monzonite magma in the northeastern part of the quadrangle rather than due to an intrinsic difference in the parent magmas. Quartz monzonite of the Hunter Mountain batholith in the Ubehebe Peak quadrangle (McAllister, 1956) is also relatively low in quartz, and it is probable that the exposures of the batholith are closer to the former roof than the exposures of biotite-hornblende-quartz monzonite in the Coso Range. The border facies of biotite-hornblende-quartz monzonite in the Hunter Mountain batholith are quartz-poor rocks that include monzonite, syenodiorite, and gabbro. Generally the border facies rocks are slightly coarser grained and are darker than the typical biotite-hornblende-quartz monzonite, but in some exposures the two are indistinguishable. They are mapped as the same rock because they are part of the same body, but the border facies rocks are more calcic owing to assimilation of limestone country rock.

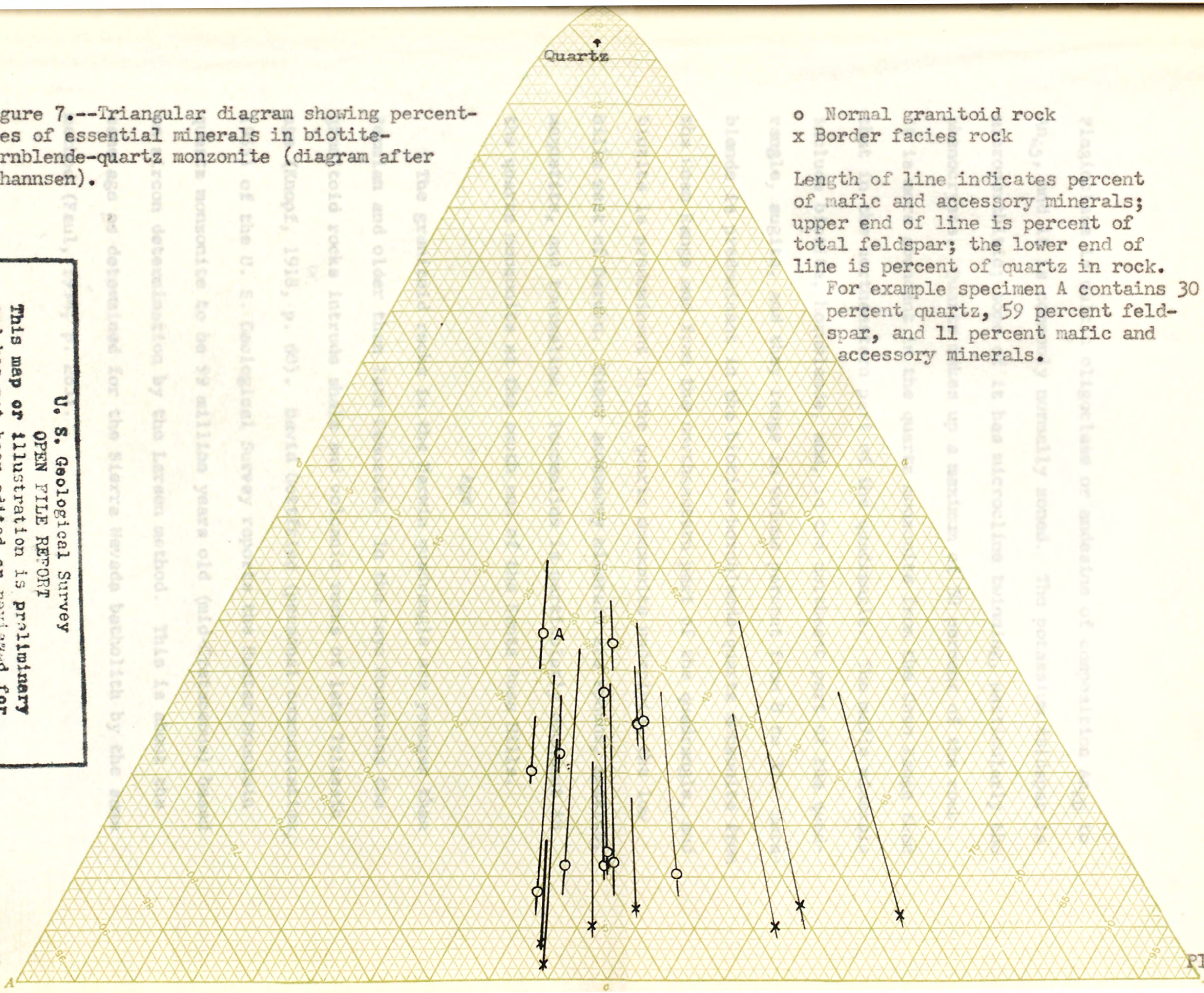
Petrography

The biotite-hornblende-quartz monzonite is a light-gray rock that has a speckled appearance produced by a scattering of dark ferramagnesian minerals. The texture ranges from equigranular, with an average grain size of 2 to 3 mm, to porphyritic, with 10 to 20 percent phenocrysts of pink potassium feldspar as much as 1½ cm long in a finer grained light-gray equigranular groundmass. The uncontaminated rock is predominantly quartz monzonite but ranges in composition from granodiorite to quartz monzonite. Essential minerals are quartz, potassium feldspar, plagioclase, and over five percent hornblende and biotite (fig. 7). Feldspar makes up 62 to 76 percent of the rock; plagioclase and potassium feldspar are in about equal quantities.

Figure 7.--Triangular diagram showing percentages of essential minerals in biotite-hornblende-quartz monzonite (diagram after Johannsen).

o Normal granitoid rock
x Border facies rock

Length of line indicates percent of mafic and accessory minerals; upper end of line is percent of total feldspar; the lower end of line is percent of quartz in rock.
For example specimen A contains 30 percent quartz, 59 percent feldspar, and 11 percent mafic and accessory minerals.



Plagioclase is calcic oligoclase or andesine of composition An_{28} to An_{45}, and it is commonly normally zoned. The potassium feldspar is microperthitic; some of it has microcline twinning, particularly the phenocrysts. Quartz makes up a maximum of 30 percent of the rock. It is more abundant in the quartz monzonite from the Coso Range than that in the northeastern part of the quadrangle. The mafic minerals include biotite, hornblende, and, in the northeast part of the quadrangle, augite, and they range in volume percent from 8 to 30. Hornblende is predominant in the biotite-hornblende-quartz monzonite from the Coso Range and from the northeastern part of the quadrangle, and biotite is predominant in the quartz monzonite underlying the low hills west of Darwin. Minor accessory minerals are sphene, apatite, magnetite, and tourmaline. Tourmaline is particularly abundant in the quartz monzonite at the south end of the Santa Rosa Hills.

Age

The granitoid rocks in the Darwin quadrangle are younger than Permian and older than late Cenozoic. In the Inyo Mountains the granitoid rocks intrude shale and volcanic rocks of late Triassic age (Knopf, 1918, p. 60). David Gottfried (personal communication, 1955) of the U. S. Geological Survey reports the Hunter Mountain quartz monzonite to be 99 million years old (mid-Cretaceous) based on zircon determination by the Larsen method. This is about the same age as determined for the Sierra Nevada batholith by the same method (Faul, 1954, p. 265).

Leucocratic quartz monzonite

Distribution

Leucocratic quartz monzonite is present in stocks in the Talc City Hills and at Zinc Hill in the Argus Range. Most slopes underlain by leucocratic quartz monzonite on the Talc City Hills are grus covered, and only a few shallow gullies expose relatively unweathered rock. Leucocratic quartz monzonite at Zinc Hill is in an area of rugged relief, and is well exposed.

Petrography

Leucocratic quartz monzonite is a medium- to coarse-grained, light-grayish-pink rock that contains mostly less than five percent mafic minerals. The texture ranges from equigranular to porphyritic; locally the rock contains pink feldspar crystals as much as 1½ cm long in a medium-grained equigranular groundmass. Dark fine-grained inclusions less than 1½ inches long are disseminated sparsely through the quartz monzonite. The leucocratic quartz monzonite is lighter colored and coarser grained than the more widespread biotite-hornblende-quartz monzonite.

Essential minerals in the rock are quartz, plagioclase, and orthoclase. Feldspars constitute 70 to 75 percent of the rock and are present in about equal quantities. Orthoclase is microperthite and commonly forms phenocrysts that poikilitically enclose all the other minerals. Plagioclase is sodic oligoclase. Biotite is the predominant mafic mineral and generally constitutes less than five percent of the rock, although as much as seven percent has been observed; it is in part altered to chlorite. Hornblende may be present in small quantities. Minor accessory minerals are allanite, apatite, magnetite, pyrite, sphene, and tourmaline.

Age

The relative age of the biotite-hornblende-quartz monzonite and the leucocratic quartz-monzonite is not definitely known, although it is probable that the leucocratic quartz monzonite is the younger rock. They are in contact only in the low hills west of Darwin where the rocks are deeply weathered and are poorly exposed. The shape of the stock at the southeast end of the Talc City Hills suggests that it is a tongue of a younger rock intruding the biotite-hornblende-quartz monzonite. The composition of the leucocratic quartz monzonite in containing a more sodic plagioclase and less mafic minerals than the biotite-hornblende-quartz monzonite suggests that it is the younger differentiate.

Lithologically the leucocratic quartz monzonite most closely resembles in texture and mineralogy the orthoclase-albite granite at Rawson Creek in the Sierra Nevada, which is described by Knopf (1918, p. 68) although correlation without substantiation by some age data would be hazardous. According to P. C. Bateman (oral communication, 1957) this is a widespread rock type along the eastern front of the Sierra Nevada.

Amphibolite

Amphibolite crops out for 2 miles in Darwin Canyon near Darwin Falls, for 0.2 miles in the canyon three-fourths mile north of Darwin

Canyon, and for 1 mile in the canyon 1½ miles north of Darwin Falls (fig. 2). It nonconformably underlies olivine basalt in the canyons, and it probably underlies basalt in most of the area between the canyons. A few small areas of amphibolite are present around the Christmas Gift and Darwin mines.

Amphibolite is characterized by its nonhomogeneity. Most of it is a fine-grained, greenish-gray rock that is cut by stringers and lenses of epidote. It grades locally into a porphyritic rock with porphyroblasts of hornblende in a fine-grained groundmass. The weathered surface is dark green to dark brown. Small pegmatitic lenses of hornblende and plagioclase are irregularly distributed through the diorite; the contacts of the pegmatite lenses are gradational. Bedding, which is readily recognized in the adjacent calc-hornfels, locally can be recognized in the amphibolite.

Amphibolite grades outward in a distance of 10 to 20 feet into calc-hornfels in Darwin Canyon below Darwin Falls. Near the contact of amphibolite the calc-hornfels contains small irregular masses of epidote and thin veinlets of amphibolite that are mostly parallel to bedding. Abundant dikes and small plugs of amphibolite cut calc-hornfels and limestone close to the main body of amphibolite at Darwin Falls.

The amphibolite map unit is composed principally of amphibolite, epidote amphibolite, hornblende diorite, and hornblende gabbro. They are fine-grained rocks composed of hornblende, plagioclase, and clinozoisite and minor quartz, calcite, scapolite, apatite, and magnetite.

The amount of plagioclase ranges from zero in some of the amphibolites to a maximum of about 50 percent in diorite and gabbro, and it ranges in composition from albite to labradorite. The calcic plagioclase forms euhedral crystals with prominent albite twinning; the sodic plagioclase is anhedral and lacks twinning. Hornblende forms porphyroblasts commonly 6 to 8 mm long that poikilitically enclose all other minerals. Clinozoisite is both finely disseminated through the groundmass and forms large porphyroblasts. Hornblende is the predominant mafic mineral in the rocks with calcic plagioclase; clinozoisite is more abundant where the plagioclase is albite. Highly calcic scapolite is common in epidote amphibolite, but is much less abundant in the diorite and gabbro. Epidote amphibolite contains hornblende, clinozoisite, zoisite, and scapolite, and it differs from the diorite mainly in the lack of plagioclase.

Some relict textures and structures of silty limestones are recognizable in the amphibolite. Locally relict bedding structures can be recognized in the amphibolite near the contact with calc-hornfels. Corroded calcite grains disseminated through the groundmass of the epidote amphibolite and some of the diorite are interpreted as relicts. The paragenesis is interpreted as follows:

1. Intrusion of quartz monzonite into silty limestone.

2. The impure limestone is altered to epidote amphibolite with the formation of clinozoisite, albite, scapolite, and minor hornblende and chlorite. Some relict calcite is present.

3. Epidote amphibolite is further altered to amphibolite and

diorite. Clinozoisite is converted to hornblende; plagioclase becomes more calcic. The grain size is increased and locally becomes pegmatitic.

Epidote amphibolite is believed to be the first step in the alteration of calc-hornfels to amphibolite. The epidote amphibolite is finer grained and more heterogeneous than amphibolite and diorite. It contains abundant corroded relicts of calcite disseminated through the groundmass. Clinozoisite locally has a network of amphibole through it, which is interpreted as replacement of clinozoisite by amphibole. The groundmass of the epidote- and clinozoisite-bearing rocks is much finer grained than the diorite. If the epidote and clinozoisite were formed by saussuritic alteration of a diorite, the granularity of the original rock should have been somewhat preserved.

Aplite and leucocratic granite

The youngest batholithic rocks are leucogranite, aplite, and minor pegmatite. They are concentrated in small bodies near the borders of quartz monzonite intrusions and in thin dikes cutting quartz monzonite. Leucogranite is most common in the northeast part of the quadrangle where the largest body is 4,200 feet long and 900 feet wide. Aplite and pegmatite are in dikes mostly less than 100 feet long that are 1 inch to 3 feet long. Aplite and leucogranite are common in dikes and small irregular bodies in the Coso Range and Talc City Hills, and a body of leucogranite is on the west side of the stock in the Darwin Hills 2,500 feet northeast of Darwin.

The leucogranite is a pinkish-white, fine-grained rock that consists predominantly of feldspar and quartz. Minor accessory minerals are apatite, biotite, hornblende, magnetite, and sphene. Tourmaline is locally abundant in the bodies marginal to the biotite-hornblende-quartz monzonite in the northeast part of the quadrangle. The rock contains 50 to 58 percent orthoclase, 30 to 33 percent quartz, 9 to 15 percent plagioclase of composition An_8 to An_{15}, 1 to 2 percent biotite, and less than 1 percent each of the other accessory minerals. Biotite is in large part altered to chlorite. Orthoclase is microperthitic. Locally it is in part replaced by albite.

Hypabyssal rocks

Hypabyssal rocks include dikes of andesite porphyry, diorite, and alaskite. Andesite porphyry dikes are widely distributed in the Paleozoic rocks and are unconformably overlain by volcanic rocks of late Cenozoic age. They are particularly abundant in a dike swarm at the north end of the Argus Range. The dikes are 2 to 6 feet thick and strike mostly about N. 70° W. and dip approximately vertically. They are greenish-gray on fresh surfaces and weather to shades of brown. The andesite porphyry dikes are highly altered and consist of plagioclase phenocrysts with saussuritic alteration in a fine-grained pilotaxitic groundmass composed mainly of albite, epidote, chlorite, calcite, and stilbite. An alaskite porphyry dike crops out half a mile east of Ophir Mountain. The dike contains phenocrysts of albite and quartz 2 to 4 mm long in a cryptocrystalline groundmass composed of albite, quartz, and minor epidote and chlorite. Diorite dikes and irregular bodies at Darwin Falls in calc-hornfels are similar to the larger amphibolite and diorite body at Darwin Falls described previously.

CENOZOIC ROCKS

Late Cenozoic deposits include both sedimentary and volcanic rocks. Sedimentary deposits are mainly fanglomerates, but also include lacustrine deposits in Darwin Wash and on Darwin Plateau. Volcanic rocks include andesite, minor pumice, basaltic pyroclastics, and basalt flows and dikes. The probable correlation of the late Cenozoic rocks is given in table 2.

Pliocene rocks

Agglomerate and lapilli-tuff

Pyroclastic rocks are widely distributed throughout the northern half of the quadrangle and are best exposed in the Inyo Mountains at the Santa Rosa mine and in the basin 1½ miles to the southwest. The pyroclastic section ranges from 0 to greater than 910 feet thick. The maximum thickness is near local vents. Pyroclastic rocks rest nonconformably on a mature surface cut on Paleozoic sedimentary rocks and Mesozoic granitic rocks. Andesite is interbedded with the pyroclastics south and southeast of the Santa Rosa mine. The pyroclastics are unconformably overlain by olivine basalt flows. Most of the pyroclastics dip less than 25°, but dips up to 41° were measured in pyroclastics underlying nearly horizontal basalt and indicate a period of tilting prior to the extrusion of the basalt.

The pyroclastic rocks consist of agglomerate, tuff-breccia, lapilli-tuff, scoria, and volcanic cinders, all of basaltic composition. Locally thin layers of pumice are present. The lower part of the pyroclastic section consists of well-bedded light-brown and yellowish-brown

Table 2.--Correlation of late Cenozoic volcanic and sedimentary rocks.

Age	Volcanic rocks	Sedimentary deposits
Recent		Alluvium including fanglomerate, playa deposits, landslide deposits, and slope wash.
Pleistocene	Olivine basalt	Lake deposits dated by Lohman on the basis of diatoms as middle to late Pleistocene in Darwin Wash and;
		Old fanglomerate marginal to Darwin Wash.
	Olivine basalt flows, some tuff and small basalt intrusives	Old fanglomerate from the Inyo Mountains and,
		Coso formation: Arkose and clay Dated on the basis of a vertebrate fauna as late Pliocene or early Pleistocene by Schultz. Andesite is interbedded in the Coso formation in the Haiwee Reservoir quadrangle.
Pliocene	Upper pyroclastic unit and andesite: Basalt agglomerate and tuff-breccia; minor pumice; andesite is interbedded in this unit.	
	Lower pyroclastic unit: Well-bedded basaltic tuff, lapilli-tuff, and tuff-breccia, mainly yellow and yellowish-brown	
Unconformity		

lapilli-tuff and tuff-breccia (fig. 8). The upper part is poorly bedded and consists mainly of red or reddish-brown agglomerate, cinders, volcanic breccia, tuff-breccia, and scoriaceous basalt (fig. 9).

Andesite

Andesite is exposed south and southeast of the Santa Rosa mine over an area of about 3 square miles. The andesite, which crops out in bold reddish cliffs, forms a broad dome interbedded in the upper part of the pyroclastics. It is a porphyritic rock containing phenocrysts and clusters of plagioclase up to 10 mm long and euhedral phenocrysts of hornblende up to 4 mm long in an aphanitic groundmass. Two color varieties are present. One is light gray on fresh surfaces and weathers dark gray; the other is reddish to reddish-gray on fresh surfaces and weathers reddish brown. The reddish andesite owes its color to the presence of oxyhornblende and hematite.

Petrographically the andesite consists of plagioclase of composition An_{46} to An_{34}, hornblende or oxyhornblende, biotite, volcanic glass, and minor amounts of cristobalite, quartz, orthoclase, augite, apatite, and zircon.

Coso formation

The Coso formation is exposed locally in the west-central and southwest parts of the quadrangle northeast and east of the Coso Range, where it is part of extensive fans marginal to the Coso Range west of the quadrangle. Early writers described these deposits as lake beds (Fairbanks, 1896, p. 69; Campbell, 1902, p. 20; Trowbridge,

Figure 8.--Lower well-bedded pyroclastic unit in the southern Inyo Mountains. The pyroclastics consist of tuff-breccia and lapilli-tuff of basaltic composition. View looking south from the basin 2 miles southwest of the Santa Rosa mine.

Figure 9.--Agglomerate in the upper pyroclastic unit in the southern Inyo Mountains. The agglomerate contains bombs and ropy and irregular fragments of basalt as much as 3 feet long in a lapilli-tuff matrix. View looking north in the basin 1½ miles S. 70° W. of the Santa Rosa mine.

1911, p. 726), but later writers have demonstrated that the beds are in large part alluvial fans, the lower reaches of which interfinger with or are overlain by lacustrine deposits (Schultz, 1937, p. 78; Hopper, 1947, p. 415).

In the mapped area the Coso formation forms low, white hills that rise 5 to 30 feet above the Recent alluvium. The beds are predominantly white- to buff-colored, fine- to medium-grained arkosic sand and clay that are poorly bedded and indurated in beds one to two inches thick. These materials were derived from disintegration of granitic rocks of the Coso Range. At the north end of the Coso Range the formation is overlain by a 5- to 15-foot thick bed of fine-grained, light-brown basaltic tuff, which, in turn, is overlain by olivine basalt. Elsewhere in the quadrangle the formation is dissected and in part covered by Recent alluvium.

The Coso formation dips 1° to 8° NE away from the Coso Range. No volcanic material was seen in the arkosic beds within the mapped area, but fragments of agglomerate are present in the Coso beds on the west side of the Coso Range between Cactus Flat and Haiwee Reservoir. Therefore the Coso formation is younger than at least some of the pyroclastic rocks, but is older than the olivine basalt and associated thin lapilli-tuff beds.

Schultz (1937, p. 98) found vertebrate fossils in coarse arkosic Coso beds west of the Darwin quadrangle that are late Pliocene or early Pleistocene in age.

Old fanglomerate from the Inyo Mountains

Erosional remnants of fans marginal to the Inyo Mountains are present southwest of the Talc City Hills near State Highway 190. They form small hills that rise 15 to 30 feet above the surrounding Recent alluvium. The fans are composed of angular to subrounded fragments up to 18 inches in diameter of sedimentary and metamorphic rocks of Silurian and Ordovician age in a clay and silt matrix. The fragments are limestone, buff to dark-gray dolomite, and quartzite of the Pogonip, Eureka, Ely Springs, and Hidden Valley formations. A quarry at the Frisco talc mine in the Talc City Hills exposes similar older fan material containing an indurated lens of well-bedded, clastic limy shale and siltstone faulted against Hidden Valley dolomite. The limy shale formed in a small pond on the alluvial plain. South of Highway 190 the fanglomerate is overlain by 5 to 20 feet of basaltic tuff, minor pumice, and by olivine basalt flows.

The fanglomerate underlies olivine basalt and is probably the same age as the nearby Coso formation.

Pleistocene rocks

Olivine basalt

Basalt covers a large part of the surface of the northern two-thirds of the quadrangle as thin flows on a mature erosion surface and as dikes cutting all the older rocks, and it is present in several isolated patches in the southern third of the quadrangle. Thin dikes, which are in part feeders for the basalt flows and are in part contemporaneous with the underlying pyroclastics, cut all the older rocks but are especially abundant around vents. Basalt probably at one time covered all the northern part of the quadrangle, but in the southern part it is localized around vents and probably originally did not have a much greater extent than at present.

Individual flows range from 10 feet to about 100 feet thick, and the aggregate of flows totals a maximum thickness of approximately 600 feet in the east-central part of the quadrangle. Some lapilli-tuff beds 5 to 10 feet thick are interbedded with the basalt. Basalt flows in part unconformably overlie a thick sequence of pyroclastics, or, where the pyroclastics are missing, basalt nonconformably overlies granitic rocks or Paleozoic sedimentary rocks. Individual basalt flows commonly have a systematic internal structure. At the base is a 6-inch to 2-foot rubble zone. Above the rubble zone the basalt has a platy structure over a thickness of 2 to 4 feet, and this grades upward into massive basalt that contains a few stretched vesicles. The thickness of the massive basalt ranges from a few feet to 50 feet; locally the massive basalt has columnar jointing. Massive basalt grades upward into scoriaceous basalt and scoria at the top of a flow. Overlying flows repeat the sequence.

Petrography

The basalt is a finely porphyritic rock with 1 to 2 mm phenocrysts of olivine and a few smaller phenocrysts of plagioclase and augite in an aphanitic groundmass. It is dark gray on fresh surfaces and weathers to dark yellowish brown that in many places is blackened by desert varnish. Vesicles are common near the tops and bottoms of flows; those near the bottom are elongate parallel to flow contacts.

Thin section study shows that the rock is an olivine basalt with a porphyritic texture. Phenocrysts are predominantly olivine, but include minor plagioclase and augite, in a groundmass of plagioclase, olivine, augite, biotite, and glass. The olivine phenocrysts are euhedral to subhedral crystals a maximum of 2 mm long that are partly altered to iddingsite, antigorite, or goethite. Near the Santa Rosa mine the basalt contains embayed fragments of quartz surrounded by a thin reaction rim of sphene. The quartz fragments are probably xenocrysts.

The groundmass mainly has a trachytic texture, but, where much glass is present, it has an intersertal texture. Plagioclase constitutes at least 60 percent of the groundmass. It is in elongate laths 0.1 to 0.3 mm long of labradorite of composition An_{57} to An_{60}. Olivine constitutes about 20 percent of the groundmass as tiny subhedral grains that are interstitial to plagioclase. Augite is the predominant pyroxene mineral, although pigeonite was observed in some thin sections. As much as 20 percent of the groundmass is made up of volcanic glass that is interstitial to the plagioclase laths.

Vesicular structures are common at the tops and bottoms of flows. Locally the vesicles are filled with quartz, thomsonite, or cristobalite. Some of the vesicles have an outer rim of thomsonite and the center is filled with calcite. Cristobalite is present in some vesicles as tiny spheres about 0.3 mm in diameter; others are coated with small euhedral quartz crystals.

Age

The extensive capping of olivine basalt flows is early Pleistocene or younger in age. The basalt sheets may be of several ages. Olivine basalt overlies the Coso formation of late Pliocene or early Pleistocene age in the Coso Range. Kelley (1938, p. 513) and Hopper (1947, p. 417) consider that the olivine basalt flows are older than the lake beds in Darwin Wash. This is probably correct, although it is not conclusive as the contact between basalt and lake beds is masked by talus and lake beds east of the road in Darwin Wash that are only 200 feet from basalt and lie 60 feet lower in elevation contain no basalt fragments.

Older fanglomerate marginal to Darwin Wash contains fragments of olivine basalt. The fanglomerate is the same age as the lake beds, so some olivine basalt definitely is older than the lake beds. In Darwin Canyon a flow of olivine basalt also overlies older fanglomerate and is probably younger than the lake beds.

Old fanglomerate marginal to Darwin Wash

Remnants of large older fans are widespread marginal to Darwin Wash. The fans have been broken into isolated patches by uplift along basin-range faults and erosion from the rejuvenated streams. Gullies cutting the fan east of Darwin Wash on the west flank of the Argus Range expose a maximum thickness of 25 feet of fanglomerate, but the base is not exposed. The fanglomerate is overlain by a few feet of Darwin Wash lake beds in secs. 16 and 21, T. 19 S., R. 41 E. but may in part interfinger with the lake beds. However, the gullies do not cut deeply enough to show if the interfingering exists.

The older fanglomerate is composed mainly of subrounded fragments of limestone of Pennsylvanian-Permian age, quartz monzonite, and agglomerate, and minor olivine basalt in a pebbly sand matrix. The fragments are mostly 1 to 4 inches in diameter, with occasional fragments a maximum of 2 feet long.

The older fanglomerate is probably middle Pleistocene in age. Locally it is tilted eastward by basin-range faults. It is older or possibly in part contemporaneous with the Darwin Wash lake beds of middle to late Pleistocene age, but is younger than the basaltic pyroclastic rocks of probable late Pliocene age and younger than at least some of the olivine basalt flows.

Lake deposits

Conspicuous white, medium-bedded lake beds crop out in Darwin Wash 1½ miles east and southeast of Lane mill. A thickness of 58 feet of nearly horizontal lake beds is exposed in gullies, but the base is not exposed. The lake beds interfinger to the south with older fanglomerate from the Coso Range, and they mainly underlie but also interfinger near the top with older fanglomerate from the Darwin Hills. On the east 25 feet of lake beds overlie the fanglomerate from the Argus Range, but gullies do not cut deep enough into the fanglomerate to determine if the lake beds also interfinger in part with the fanglomerate. Recent fans from the Darwin Hills cover the lake beds on the west side of Darwin Wash, and on the east side of the Wash the lake beds have been uplifted and tilted by basin-range faults.

The lake beds consist of a mixture of white to light-gray fine-grained pumiceous ash, silt, clay, and diatomaceous earth in beds half a foot to 4 feet thick. Grain size is 0.05 to 0.1 mm.

Kenneth E. Lohman (written communication, 1954) of the U. S. Geological Survey made 11 collections of diatoms from the Darwin Wash lake beds and concluded that they were middle to late Pleistocene in age.

A small area of dissected lake beds is exposed on the Darwin Plateau in secs. 1 and 12 (projected), T. 18 S., R. 40 E. (pl. 1). The beds are composed of fine-grained, light-gray silt and clay and have a minimum thickness of 15 feet. The beds grade westward into fanglomerate toward a group of low hills of quartz monzonite. The sediments were deposited in a basin behind a flow of olivine basalt.

Recent unconsolidated gravels and alluvium

Recent deposits consist for the greatest part of alluvial fan material, but includes slopewash and stream gravels. The largest areas of alluvium are Lower Centennial Flat, Santa Rosa Flat, Lee Flat, and Darwin Wash. Some older alluvial fan material on Lee Flat that has been uplifted and is currently being dissected is included in the Recent alluvium.

STRUCTURE

Structurally the Darwin quadrangle is located on the west limb of a major anticlinorium, the axis of which trends N. 15° W. and is located near the crest of the Panamint Range 15 miles east of the quadrangle. Paleozoic rocks have been folded into a series of open folds on the west limb of the anticlinorium and have been broken by numerous faults (pl. 4). Bedding strikes north to N. 30° W. except in the central part of the quadrangle from the Talc City Hills eastward to Panamint Valley where it trends N. 60° to 85° W. Faults have broken the Paleozoic rocks into several structural units. Thrust faults and steep faults, some with possible large strike-slip movement, were formed during the late Mesozoic orogeny. Normal faults of late Cenozoic age were important in forming the basin and range topography.

Structure of the pre-Tertiary rocks

Unconformities

No major unconformities were recognized within the Paleozoic section, although owing to the discontinuous outcrop pattern due to faulting and erosion the nature of some of the contacts was difficult to evaluate. Bedding was conformable though wherever unfaulted contacts were observed. The only recognized major unconformity in the area truncates Paleozoic sedimentary rocks and intrusive rocks of late Mesozoic age.

Local unconformities and disconformities are present within the Pennsylvanian and Permian strata (fig. 10). A local unconformity in cross-bedded calcarenite in the lower Owens Valley formation can be seen from the road 3,000 feet north of Millers Spring. This unconformity can be traced only a few hundred feet, as it is in a block between two strands of the Darwin tear fault.

Figure 10.--Local angular unconformity in the lower member of the Owens Valley formation in Darwin Canyon. View looking north from the road 3,000 feet north of Millers Spring. The unconformity is within a block between two branches of the Darwin tear fault.

The contact between the middle and upper Owens Valley formation is disconformable. The upper Owens Valley limestone conglomerate of Conglomerate Mesa contains limestone pebbles and boulders as much as 8 inches in diameter that have been eroded from the underlying Permian rocks. Locally at the south end of Conglomerate Mesa near the western border of the quadrangle the contact is probably an angular unconformity, although the contact is poorly exposed.

No major hiatuses were recognized in the Paleozoic section, but minor ones may be represented by pronounced changes in lithology, particularly in the change from massive dolomite and limestone to pure quartzite, as between the upper Pogonip group and the overlying Eureka quartzite. The stratigraphic sequence from Lower Ordovician to Permian is essentially complete, however, as far as is known from the rather poorly preserved and incomplete fossil record.

Folds

Paleozoic strata were deformed into a series of broad open folds with axes trending north to N. 20° W. during the early stages of the late Mesozoic orogeny. This folding is reflected in the Paleozoic rocks east of Conglomerate Mesa in the northwest part of the quadrangle, in the Santa Rosa Hills, and in the southeast part of the quadrangle in Darwin Wash and the Argus Range. The Pennsylvanian-Permian rocks, which consist of thinly bedded strata, acted as an incompetent member during folding and formed many small drag folds superposed on the limbs of the broader folds, but the drag folds are not reflected in the strata underlying the Keeler Canyon formation.

The axial planes of the drag folds in general parallel those of the major folds.

Darwin Wash syncline

The major fold in the southeastern part of the quadrangle is a broad open syncline with an axis trending north in Darwin Wash (pl. 4C). The east limb of the syncline is approximately a dip slope on the west slope of the Argus Range but contains several minor folds. The west limb is largely covered by alluvium in Darwin Wash, but it is exposed in a group of low hills at the north end of Darwin Wash. The west limb of the syncline is tightly crumpled adjacent to the biotite-hornblende-quartz monzonite in the Darwin Hills and the beds are mainly overturned. The axis of the syncline is horizontal south of the Darwin tear fault, and north of the fault to Darwin Falls the syncline plunges to the north. North of Darwin Falls the syncline loses its identity in highly metamorphosed rocks (pl. 2).

Darwin Hills overturned syncline

The major structure in the Darwin Hills is an overturned syncline that was intruded near its axis by a stock and is cut by many faults (pl. 4C). This fold is a complex crumple on the west limb of the Darwin Wash syncline and is believed due to forcible intrusion of the Coso batholith. On the west side of the stock in the Darwin Hills dips are generally homoclinal to the west, but bedding is overturned. North of the Darwin tear fault on the north side of hill VABM 5979 thinly bedded limestone of the upper Keeler Canyon formation has abundant cross-bedding that shows tops to the east, although bedding dips west. South of the tear fault the limestone is mostly altered to calc-hornfels, and all internal structures have been destroyed. However, by correlation with stratigraphy north of the tear fault, the strata can be shown to get progressively younger toward the east. White marble on the hill 4,000 feet N. 45° W. of Ophir Peak is identical to marble of the Lost Burro formation and contains fragmentary remains suggestive of cladoporoid. The gray, medium to thickly bedded limestone band adjacent on the east is lithologically similar to the lower Mississippian Tin Mountain limestone. It contains poorly preserved syringoporoid and solitary corals, which is compatible with correlation to the Tin Mountain. The next limestone band to the east on hill 5654 is a medium-gray limestone with abundant bedded chert that is correlated with the Perdido formation. This is followed to the east in strata on Ophir Peak by limestone similar to the Lee Flat limestone and then by the "golfball" horizon with sparse tiny fusulinids at the base of the Keeler Canyon formation. Strata on the east side of the Darwin Hills at the Lane mine are calc-hornfels of the lower Owens Valley formation. Fusulinid collections from near the Lane mine and south of the Keystone mine are considered by R. C. Douglass (written communication, 1954) to be characteristic of the latest Wolfcamp (Permian).

The axis of the overturned syncline in the Darwin Hills is approximately along the east contact of the Darwin stock in a belt of tightly folded Paleozoic rocks (pls. 2 and 4C). At some places in this belt the most westerly fold is readily recognizable as an overturned syncline, but in others the folds are not well exposed and it is difficult to demonstrate convincingly that the strata on the west limb are overturned. The folds are difficult to photograph and figure 11 is reproduced mainly to show a locality where overturning of the strata can be demonstrated. It shows an overturned syncline in the Lucky Jim mine area involving partly silicated thinly bedded limestone of the Keeler Canyon formation. Fracture cleavage that dips steeper than bedding is well developed where the beds are right-side-up and is an aid in determining the structure. Where bedding is overturned the cleavage is much poorer and tends to parallel bedding. To the northwest the structure is complicated by several additional small folds that are interpreted as minor folds on the overturned limb of the syncline.

All the mines in the Darwin group are in the overturned west limb of the syncline (pl. 5). Several minor open folds are superposed on this limb, e. g. the open anticlinal-shaped folds in the Defiance mine area and on the southwest flank of Ophir Mountain (pl. 5). Both folds have younger beds in the center and older beds on the flanks so are actually inverted synclines on the basis of relative ages of the rocks as used, for example, by White and Jahns (1950, p. 196).

Talc City Hills syncline

The north end of the Talc City Hills is a syncline plunging southeast that is broken by many faults (pls. 3 and 4B). Hidden Valley dolomite is in the core of the syncline and Ely Springs dolomite, Eureka quartzite, and Pogonip limestone are in successive

Figure 11.--Photograph of overturned isoclinal syncline in the Lucky Jim mine area. Strata in the lower left (a) are right-side-up; bedding is nearly horizontal at b; strata overturn at c and are overturned in the upper right (d). View looking south in Lucky Jim Canyon 550 feet N. 57° E. of the Lucky Jim main shaft.

bands on the flanks. The syncline loses its identity in a number of fault blocks and tight folds at the southeast end of the Talc City Hills between the Homestake mine and the Alliance talc mine (pl. 3). The axis of a second faulted syncline is 1,800 feet south of the Alliance talc mine (pl. 3). Devonian limestone and shale are in the core of the syncline and quartzite and dolomite of Ordovician and Silurian age are on the flanks. South of the Silver Dollar mine overturned strata bend toward the south and are warped into several steeply plunging folds. The folds are shown on plate 3 by the trace of the contact of limestone and dolomite in the Lost Burro formation. As the beds are overturned, anticlinal-shaped folds superposed on the overturned strata have younger beds in the core and are inverted synclines. The folding of the overturned strata is a result of drag by the Talc City thrust.

Santa Rosa Hills warp

The Paleozoic rocks in the Santa Rosa Hills and in the low rolling hills east of Conglomerate Mesa dip mainly to the west or southwest except for minor open folds in the area east of Conglomerate Mesa. Devonian and Mississippian rocks in the Santa Rosa Hills strike approximately N. 30° W. and dip to the southwest. Southeast of the Lee mine the strike changes from N. 30° W. counterclockwise to N. 70° E. and the strata dip southerly. Marble of the Lost Burro formation crops out in a canyon 3.7 miles S. 27° W. of the northeast corner of the quadrangle under a basalt cover. This marble is a continuation under the volcanic cover of the band of Lost Burro marble in the

Santa Rosa Hills and evinces a swing or warp in structure under the volcanic cover. This swing in structure at the south end of the Santa Rosa Hills is interpreted as warping of the beds concordantly around the south end of the Hunter Mountain batholith by forcible intrusion.

Faults

Faults break up the Paleozoic stratigraphy into many isolated blocks that are separated by alluvium or volcanic cover. The faults are divided into four groups: thrust faults, strike-slip faults, mineralized strike faults, and basin-range faults. The last group is late Cenozoic whereas the others are late Mesozoic.

Thrust faults

Thrust faults are localized along the margin of the Coso batholith in the southwest part of the quadrangle. Two thrust faults have been mapped--the Talc City thrust in the Talc City Hills and the Davis thrust in the Darwin Hills. In both the thrusting is toward the east or northeast away from the intrusive.

Talc City thrust.--In the Talc City Hills Paleozoic rocks of Mississippian to Ordovician age have been thrust principally over folded Pennsylvanian and Permian strata. The thrust sheet originally was at least 5 miles long in a northwesterly direction and 2 miles wide, but it subsequently was broken by later steep faults trending N. 70° to 80° W., and it has been in part removed by erosion (pls. 3, 4B). The thrust is exposed at only a few localities. The most accessible exposures are at the Alliance talc mine and at the Silver

Dollar mine. At the Alliance talc mine Eureka quartzite and Ely Springs dolomite are thrust over folded thinly bedded limestone of the Keeler Canyon formation (fig. 12). Two klippen of Eureka quartzite and Ely Springs dolomite thrust over Pennsylvanian limestone of the Keeler Canyon formation are exposed a few hundred feet south of the Alliance talc mine. At the Irish lease of the Alliance mine Eureka quartzite and Ely Springs dolomite are thrust over Keeler Canyon limestone. Shale lithologically similar to Rest Spring shale is present in the fault zone. Locally a steep fault has displaced the thrust fault in the workings of the Irish lease. However the trace of the Ely Springs-Keeler Canyon fault contact to the east contours the topography and is a flat-lying thrust.

At the Silver Dollar mine massive buff dolomite of the Devonian Lost Burro formation is thrust over the Keeler Canyon formation. The thrust is exposed 300 feet north of the main pit of the lead-silver workings where Rest Spring shale is present in the fault zone. About 3,000 feet north of the Silver Dollar mine an imbricate structure is exposed. Medium-bedded gray Tin Mountain limestone is thrust over the Perdido formation, which, in turn, is thrust over Rest Spring shale and the Keeler Canyon formation (pl. 3). At the north end of the Talc City Hills 1.3 miles north of the northernmost workings of the White Swan mine the Pogonip group and Eureka quartzite are thrust over Rest Spring shale and the lower Owens Valley formation of Permian age.

Figure 12.--Talc City thrust at the Alliance talc mine. Two klippen of Ely Springs dolomite (Oes) and Eureka quartzite (Oe) over Pennsylvanian Keeler Canyon formation (kc) are exposed near the center of the picture several hundred feet south of the Alliance talc mine. At the Irish lease the thrust fault is displaced locally by a steep fault, so the contact in the workings is steep, but it continues as a flat-lying thrust contact east of the workings as shown by its sinuous trace. View looking north at the Alliance talc mine.

The thrust sheet moved toward the northeast, but as the area southwest of the Talc City Hills is covered by alluvium, the net slip cannot be measured. The stratigraphic throw of the fault is locally as much as 5,900 feet where the Eureka is thrust over the Keeler Canyon formation.

Davis thrust.--A thrust fault that strikes northerly and dips 23° to 60° W. crops out in the Darwin mine area. The thrust where exposed involves only strata of the lower Keeler Canyon formation. The fault is exposed at the surface at the Essex and Independence workings of the Darwin mine, 500 feet west of the portal of the Thompson adit, and 600 feet west of the portal of the Defiance adit (pl. 5). Many drag folds are localized in thinly bedded limestone in the hanging wall of the thrust. The largest and most prominent is the open "anticlinal-shaped" fold in the south side of Ophir Peak (pl. 5). The drag folds have a dextral pattern and plunge mostly gently to the north. The drag folds indicate a thrust movement toward the northeast, but the net slip is not known.

All the contacts between formations on the west side of the Darwin Hills are faults that are parallel to but overlie the Davis thrust. The limestone and marble within a few feet of the faults are intensely drag folded, but the drag folds have a sinistral pattern instead of a dextral pattern as those localized near the Davis thrust. Most of the drag folds plunge gently to the north. A strong lineation that plunges steeply down the dip in the "a" direction is developed in some of the drag folds. The lineation is shown by stretching of rounded chert nodules in the "golfball" horizon and by the disrupture of sandy limonitic beds ¼ to ½ inch thick into pencils 6 to 8 inches long. Drag folds on the faults overlying the Davis thrust indicate that they are normal faults. The Davis thrust was caused by forcible intrusion of the Coso batholith, which overturned the Keeler Canyon strata and thrust it up and toward the northeast. The overlying faults probably indicate minor readjustments upon relaxation of the push from the intrusion, but they could be formed by each footwall block being thrust up farther than the corresponding hanging-wall block.

Strike-slip faults

Strike-slip faults are present both in the Santa Rosa Hills and in the Darwin Hills. The faults characteristically have a left-lateral displacement. Those in the Santa Rosa Hills trend about N. 30° W. parallel to the strike of bedding and dip 55° to 60° SW., whereas those in the Darwin Hills are steeply dipping transverse faults.

Two major faults in the Santa Rosa Hills are the Lee fault and the Santa Rosa Flat fault (pls. 2 and 4A). Both trend about N. 30° W. parallel to the strike of bedding and dip about 60° SW. Small calcite-filled gash fractures that strike about N. 80° W. and dip steeply north are localized near the faults. The block of Mississippian Tin Mountain limestone between the two faults is tightly folded and has axial planes that dip steeply west (pl. 4A). The folds are poorly exposed except in a few gullies as the limestone in the crests of the folds is shattered. The plunge of the folds could not be determined.

The amount and direction of displacement on the Santa Rosa Flat and Lee faults are not known, but the faults must have a reverse component as older beds are brought up to the west. They are postulated to have a left-lateral strike-slip displacement also with the east block moving N. 30° W. The strike-slip displacement is postulated on the basis of orientation of the gash veins, which are steep calcite-filled tension fractures that strike about N. 80° E. The gash veins suggest counterclockwise displacement on the faults.

The Tin Mountain limestone between the Lee and Santa Rosa Flat faults was tightly drag folded (pl. 4C). The limestone probably was under shallow cover at the time of faulting so that it acted like a brittle rock and shattered at the crest of folds instead of flowing plastically.

Two systems of transverse strike-slip faults are present in the Darwin Hills. One set strikes N. 60° to 80° W.; the other set N. 60° to 80° E. Faults of both systems have left-lateral displacement. The major fault is the Darwin tear fault, which was described previously by Kelley (1938, p. 518) and Hopper (1947, p. 420). It trends N. 70° to 80° W. from the Argus Range at the south end of the stock at Zinc Hill to the Talc City Hills, where it is lost in the local N. 60° to 80° W. trend in the talc district. The displacement of the Darwin tear fault is 2,200 feet, the north block moving west relative to the south block. The direction of movement is shown by drag and by nearly horizontal slickensides and mullion structures. The sense of displacement is shown by the offset of the following displaced units; the contact between the Keeler Canyon and Owens Valley formations, the axis of the syncline in Darwin Wash, and a conspicuous limestone bed 10 feet thick with abundant solitary corals and crinoidal debris that crops out 2,200 feet N. 28° W. of Millers Spring. The vertical displacement is negligible as both steeply dipping and horizontal beds in flat topography have the same offset.

Another left-lateral transverse strike-slip fault--the Standard fault--is located between the Darwin tear fault and the Independence workings of the Darwin mine (pl. 2). It is a mineralized fault zone as much as 50 feet thick that cuts the stock of the Darwin Hills; the fault passes through the Standard group of claims in sec. 18, T. 19 S., R. 41 E. and the long adit on the Standard claim is along this fault. The displacement on the fault apparently is several hundred feet, north side west.

The second set of transverse strike-slip faults, which strike N. 60° to 80° E., are present in the Darwin Hills south of the Darwin tear fault. These faults are very abundant at all the principal lead-silver-zinc and tungsten mines in the district. They are mineralized faults that cut biotite-hornblende-quartz monzonite in the Darwin Hills, and they are one of the important ore controls for both tungsten and lead-silver-zinc ore bodies. Displacement on the faults is small. They are left-lateral faults, and the north block has moved west less than 200 feet relative to the south block in all the faults. Faults in this set include the Copper, Water tank, Lane, St. Charles, and Fernando faults in the Darwin and the Fernando-St. Charles mine areas.

The direction of movement is shown by offset of the stock of the Darwin Hills and by abundant nearly horizontal slickensides. Most of the N. 60° to 80° E. faults are cut off by the Davis thrust; some also displace the thrust (pl. 5). The Copper fault displaces the Davis thrust 90 feet, north side west.

The two sets of transverse strike-slip faults cannot be complementary shears as both are left-lateral faults; one set should have right-lateral displacement if the faults were complementary. Nor does it appear likely that the N. 60° to 80° E. faults can be tension fractures, as the displacement is mainly strike-slip and the fault zones are too sheared to be formed under tension. McKinstry (1953, p. 404) in his paper on shears of the second order used Darwin as one of his examples, and he called the faults that strike N. 60° to 80° E. shears of the second order. He defines a shear of the second order as one caused by change in orientation of the planes of maximum shearing stress due to friction during movement along a shear plane. The maximum shearing stress changes from 45° before movement to an approximate angle given by the formula $45° - \frac{\phi}{2}$ where ϕ is the angle of kinetic friction. A shear of the second order seems a reasonable explanation for this set of shear planes, which has only a small difference in strike and has the same sense of displacement as the major N. 70° W. strike-slip faults.

Mineralized steep strike faults

Steep mineralized strike faults are present both in the Darwin Hills and the Talc City Hills. In the Darwin Hills steep north-striking faults commonly localize ore in the Darwin mine. The faults are concentrated near the N. 60° to 80° E. faults and die out away from them. Displacement on the north-striking faults is negligible.

In the Talc City Hills the overthrust sheet is displaced by several N. 60° to 80° W. faults that are parallel to the strike of the beds in the thrust sheet (pl. 3). These faults are mineralized and commonly localize talc ore bodies. The direction of net slip is not known as no marker beds are offset. The Talc City thrust is displaced vertically by the faults, but there is no pattern as to whether the north side is raised or lowered (pl. 4B). The vertical displacement of the thrust could be done by either strike-slip or dip-slip movement.

Foliation

Foliation in general is poorly developed in the Paleozoic rocks. Locally the Keeler Canyon and Owens Valley formations have a fracture cleavage. It is best developed in the middle shale member of the Owens Valley formation on the east side of Conglomerate Mesa, where the shale locally is fissile. The fissility is as much as 90° to bedding, but the shale must be examined closely for bedding. Fracture cleavage is also developed locally in the belt of tightly folded rocks on the east side of the Darwin stock. At the Lucky Jim mine fracture cleavage is an aid in working out structure.

Summary

The probable sequence during the late Mesozoic orogeny is summarized below. The Paleozoic strata were first deformed into a series of broad open folds, forming the Darwin Wash syncline and tilting the

Paleozoic rocks in the Santa Rosa Hills to homoclinal west dips. These folds have flat-lying axes that trend northerly. After the period of gentle folding the Paleozoic strata were forcibly intruded by the batholith of the Coso Range in the southwestern part of the quadrangle and by the batholith of Hunter Mountain in the northeastern part during middle Cretaceous time. In the Darwin Hills older strata were brought up by the intrusion of the batholith of the Coso Range and were overturned, tightly folded, and faulted. With release of pressure by cooling and crystallization of the batholith, minor adjustments took place on the west limb of the Darwin syncline forming the normal bedding plane faults. The Paleozoic rocks were folded and faulted prior to the period of silication of the limestone around the intrusive. The tight folds spatially are directly related to the periphery of the batholith, but the folding cannot be due to a buttressing effect of a large intrusive body during post-batholithic compression. The tightly folded structures in calc-hornfels reflects plastic deformation of incompetent beds and necessitates that the folding was done prior to silication of the limestone.

The Paleozoic strata in the Talc City Hills and southern Santa Rosa Hills were squeezed between the Coso and Hunter Mountain batholiths. The beds were rotated from a northerly strike to a N. 60° to 80° W. strike. Deformation of the structure caused rupture along the Darwin tear fault and Standard fault. The Darwin tear fault must have had both pre- and post-silication movement. It controlled in part the silication of the limestone in the Darwin Hills, but the silicated limestone has also been sheared. After rotation of the beds older Paleozoic rocks were thrust northeast over Carboniferous and Permian beds in the Talc City Hills, probably contemporaneous with movement on the Davis thrust in the Darwin Hills. The Talc City thrust sheet was broken by steep strike faults.

Cenozoic structures

North-striking late Cenozoic faults are responsible for the present basin-range topography. Basin-range faults are most conspicuous in the eastern part of the quadrangle. A swarm of steep faults, most of which are downthrown to the east, is present in the northeast part of the quadrangle and is in part responsible for the depression of Panamint Valley to the east of the Darwin quadrangle. The displacement of basalt on most of the faults is less than 50 feet, but the basin-range fault that passes through Darwin Falls is downthrown more than 400 feet to the east. Another swarm of steep faults on direct strike south of these faults is present on the west flank of the Argus Range, but this swarm has the opposite displacement with the east side up. The faults in the Argus Range cannot be traced north of the lower reaches of Darwin Wash, and they probably are not continuations of the faults in the northeast part of the quadrangle.

The structure of the Argus Range is an east tilted fault block. A flow of olivine basalt on the west flank of the Argus Range has been displaced approximately 1,600 feet in a series of step faults (fig. 13). East of the Darwin quadrangle the basalt on the east flank dips mostly 10 to 15 degrees east, and basin-range faults are much less common. Most of the faults on the tilted east side are mountain-down faults.

Figure 13.--View of the west flank of the Argus Range from Darwin Wash showing a step-faulted basalt flow.

The southern end of the Inyo Mountains is also an east tilted fault block. Knopf (1918, p. 88) has described the step faulting on the west flank of the range. Displacement along the step faults on the west flank of the Inyo Mountains in the Keeler quadrangle is about 2,000 feet. Basalt flows on the east flank of the southern Inyo Mountains are tilted to an average dip of about 10 degrees east and are broken by a few basin-range faults. The most prominent fault on the east flank is the Santa Rosa fault, which is downthrown on the east side about 400 feet (pl. 2). Other faults on the east flank show only minor displacement of the basalt flows, but most of them are downthrown on the mountain side. North of the Keeler and Darwin quadrangles, late Tertiary and Quaternary uplift of the Inyo Mountains must be much greater, but basalt is absent so no readily recognizable displaced marker bed is present.

Some of the strike faults in the Santa Rosa Hills have had renewed movement of late Tertiary or Quaternary age. The fault zones are jumbled masses of breccia and gouge in contrast to the healed fault zones of the older faults, and they have excellent topographic expression. Remnants of basalt flows in the Santa Rosa Hills have been uplifted about 500 feet relative to the flows on Lee Flat by late Cenozoic movement.

The small part of the Coso Range that extends into the Darwin quadrangle lacks an extensive basalt cover, so the structure is not known. The most conspicuous fault is a mountain-down fault along the northeast front of the range (pl. 2). Such faults are very common at the foot of east tilted fault blocks. The basalt that is present dips gently to the northeast.

METAMORPHISM

Most of the Paleozoic sedimentary rocks and some of the late Mesozoic intrusive rocks are altered to some extent. The alteration has been caused mainly by igneous metamorphism and possibly some by dynamic metamorphism. Some of the recrystallization of the Hidden Valley dolomite and the limestone of the Lost Burro formation may be related to orogenic stresses, but both formations in the quadrangle are located near borders of areas affected by igneous metamorphism and this, coupled with the discontinuous nature of the outcrop, makes it difficult to differentiate between changes related to crustal movements and those related to intrusive bodies.

Igneous metamorphism

Igneous metamorphism includes all the physical, mineralogical, and chemical changes induced in a rock by intrusion of a plutonic body. The changes are either endomorphic, changes induced within the intrusive, or exomorphic, changes induced within the invaded rock.

Metamorphism within the igneous rocks

Endomorphic changes of the igneous rocks within the Darwin quadrangle have been on a small scale. The major intrusive bodies--the batholith of the Coso Range, the batholith of Hunter Mountain, and the stock of the Talc City Hills--were not altered during the period of emplacement. The stock of the Darwin Hills, however, probably was intensely altered at the time of emplacement near the Thompson workings of the Darwin mine. Quartz monzonite at the surface near the Thompson workings is a highly iron-stained, deeply weathered rock, while at the south end of the stock the quartz monzonite is unaltered or only slightly weathered. Because of the deep weathering at the north end, it was impossible to find fresh specimens to study. It is probable that the deep weathering was due to previous hydrothermal alteration of the quartz monzonite, which made the rock more amenable to weathering.

Metamorphism of limestone

The limestones of the various formations of post-Silurian age have reacted in different manners to metamorphism. The Lost Burro formation of Devonian age was bleached and nearly completely recrystallized to marble, while the Tin Mountain limestone and the Perdido formation were only slightly affected by metamorphism. The Lee Flat limestone, Keeler Canyon formation, and the Owens Valley formation were extensively altered to calc-hornfels and tactite.

Recrystallization to marble

The Lost Burro formation of Devonian age was the most susceptible limestone for recrystallization to marble. The upper 1,100 feet of the Lost Burro formation in the Darwin quadrangle is entirely recrystallized to white or light-gray marble. About half of the lower 650 feet of the exposed section of the Lost Burro formation northeast of the Lee mine is bleached and recrystallized.

The Tin Mountain limestone is bleached and recrystallized to marble in a band about 1,000 feet wide on the west side of the Lee Flat fault 5,000 feet S. 70° W. of the Lee mine. The Lee Flat limestone is also bleached and recrystallized to marble in a band 500 to 600 feet wide north of the Darwin mining camp along the west side of the Darwin Hills. In the Argus Range both to the north and south of the stock at Zinc Hill the Lee Flat limestone has been faulted up in contact with the Owens Valley formation. The limestone south of the stock for a distance of 900 feet to the Darwin tear fault is bleached and recrystallized to white marble, and north of the stock it is bleached and recrystallized for a distance of about 500 feet. Locally some pure limestone lenses in the Owens Valley formation are recrystallized to marble. On the whole recrystallization to marble in the Mississippian and younger limestones is on a small scale and is limited to strong fault zones and close to contacts with igneous bodies.

Alteration to dolomite

Dolomitization is not widespread in Paleozoic rocks in the Darwin quadrangle. Most of the dolomite in the quadrangle is in Devonian, Silurian, and Ordovician strata in the Talc City Hills. All of the dolomite was considered by Page (1951, p. 8) to have formed by hydrothermal alteration of limestone. Regional mapping by the U. S. Geological Survey in adjacent areas (McAllister, 1952, 1955; Merriam, 1954) has shown that dolomite is indigeneous to this part of the section. However, the dolomite over much of the section in the Talc City Hills does not resemble its counterpart in less altered areas. This is especially true of the Silurian and Devonian dolomite, which is massive and buff-colored in the Talc City Hills but is more commonly medium-bedded light- to medium-gray dolomite where unaltered. At some places in the Talc City mine area relicts of light- to medium-gray dolomite remain in the massive buff dolomite and several beds of limestone can be traced discontinuously in the dolomite. The original lower Devonian and Silurian strata were light-gray medium-bedded dolomite with some thin beds of medium-gray limestone in the Devonian. The dolomite was recrystallized near the stock of the Talc City Hills to buff, massive dolomite, and the thin limestone interbeds were in part dolomitized, particularly at the crests of folds.

In the Darwin mine area and at the Zinc Hill mine limestone locally has been dolomitized along faults. At the Darwin mine 2,500 feet south of Ophir Mountain the Lee Flat limestone is altered to massive buff dolomite along a bedding plane fault for a distance of about 150 feet (pl. 4). At the Zinc Hill mine Mississippian limestone is also altered to dolomite along or near faults. The dolomitization is part of the late Mesozoic period of mineralization.

Silication of limestone

Alteration of limestone and impure limestone to calc-hornfels and medium-grained calc-silicate rock has been widespread about the Coso batholith and Hunter Mountain batholith; the alteration is shown by an overlay pattern on the regional map (pl. 2). Calc-hornfels is a dense, aphanitic, light-colored rock formed by the silication of impure limestone. The mineralogy may be quite diverse but includes part (some) or all of the following minerals: diopside, wollastonite, idocrase, garnet, relict calcite, plagioclase, orthoclase, quartz, tremolite, and epidote. Compositional layers parallel to bedding are common. Calc-hornfels grades into medium-grained calc-silicate rock composed predominantly of wollastonite, idocrase, and garnet adjacent to intrusions. Minor dark-colored tactite composed of epidote, idocrase, or andradite is localized at intrusive contacts or along faults, especially at intersections with pure limestone beds, within several hundred feet of an intrusive contact.

The Lee Flat limestone, Keeler Canyon formation, and Owens Valley formation were particularly susceptible to alteration to calc-silicate minerals, but the Tin Mountain limestone and marble of the Lost Burro formation were similarly altered over small areas. The largest area of calc-hornfels is in the Darwin Hills as a metamorphic halo around the Darwin stock and Coso batholith. Impure limestones of Pennsylvanian and Permian age are altered to calc-hornfels, medium-grained calc-silicate rock, and locally to tactite over an area 4½ miles long and 1 mile wide (pl. 2). The Darwin tear fault is the approximate northern limit of the alteration. Calc-hornfels is exposed under basalt in the eastern part of the quadrangle near Darwin Falls and in all the canyons draining into Panamint Valley from Darwin Canyon to the canyon 2 miles north of Rainbow Canyon. Calc-hornfels must underlie much of the extensive basalt cover in this area. Other areas of calc-hornfels are around the intrusive at the south end of the Santa Rosa Hills and in the southern Inyo Mountains at the Santa Rosa mine.

In the Darwin Hills the altered limestone ranges in general from medium-grained light-colored calc-silicate rock and minor dark tactite close to the contact of the Darwin stock through dense white, light-gray, or greenish-gray calc-hornfels to partly silicated limestone at the outer margins of the altered zone. Although in general the alteration is more intense and the altered rock is coarser grained near the margins of the Darwin stock, many exceptions occur because of differerences in composition of the original bed, because of more intense alteration close to ore bodies, and because of the influence of faults as carriers of water and heat. For example, at the Defiance workings of the Darwin mine dense white calc-hornfels is present in a band 50 to 100 feet wide adjacent to the stock, and medium-grained calc-silicate rock occurs westward for the next 500 feet to the Davis thrust. West of the Davis thrust the calc-hornfels is dense and grades into partly silicated limestone interbedded with unaltered limestone. The calc-silicate rock in general is coarser grained near the pipe-shaped replacement ore body in the Defiance mine and is finer away from ore.

A study of the alteration was made of the Defiance area in the Darwin mine, and samples were taken at 25-foot intervals away from the Defiance ore body on the 570-, 700-, and 800-foot levels and at irregular intervals over the surface. At the outer margin of the silicated zone alteration is selective and impure limestone beds are partly or even completely altered to calc-hornfels while purer limestone beds are unaltered. The alteration is selective and differences in color, grain size, and mineralogy occur between adjacent thin beds. The silty limestone beds are readily altered to calc-hornfels. The grain size is commonly 0.02 to 0.05 mm. Tremolite, orthoclase, scapolite, clinozoisite, and sphene may be present. The pure limestone beds are unaltered or are recrystallized to marble.

East of the Davis thrust in the inner zone of contact metamorphism the alteration is more intense. The silicated limestone here typically is a white to light-greenish-gray rock that consists predominantly of wollastonite and diopside (fig. 14). Oligoclase, sphene, forsterite, orthoclase, garnet, idocrase, sillimanite, and apatite may be present. Grain size is mostly 0.5 to 2 mm, but locally is coarser grained. With increasing grade of metamorphism garnet and idocrase replace diopside and wollastonite (fig. 15). The dense white calc-hornfels in the inner zone of contact metamorphosed limestone at the Defiance workings is composed nearly entirely of wollastonite. It forms felted masses of laths less than 0.1 mm long with diopside. Near intrusions wollastonite forms megacrystalline radial masses and occasional large prisms as much as 6 inches long that are partly replaced by garnet and idocrase. With increasing amounts of garnet and idocrase the rock becomes greenish-gray to light-green. Garnet and idocrase are the principal late minerals formed during the period of silication, and they are common gangue minerals in the replacement ore bodies (fig. 16). The garnet is light-green grossularite-andradite. It is slightly birefrigent and very commonly is zoned. The specific gravity ranges from 3.627 to 3.872 and the index of refraction is 1.826 to 1.885. Garnet is widespread through the calc-hornfels and calc-silicate rock; it is more abundant and is coarser grained near ore

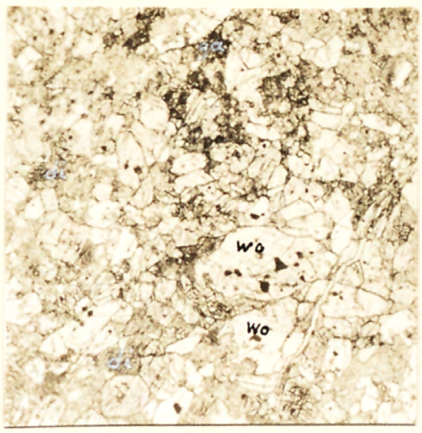


Figure 14.--Photomicrograph of medium-grained light-gray calc-silicate rock from the inner zone of contact metamorphosed limestone from the Defiance area. The rock consists almost entirely of wollastonite (wo) and diopside (di). A veinlet of calcite (ct) cuts the rock. The initial stage of replacement of wollastonite and diopside by garnet (gn) is shown. Plane light, 40x.

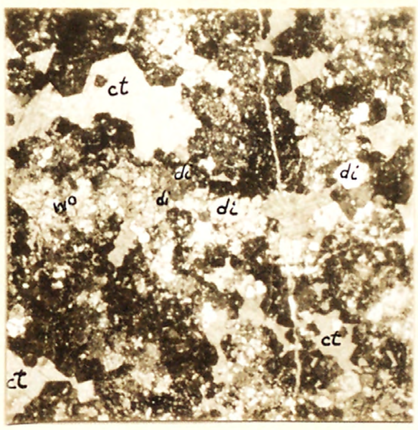


Figure 15.--Photomicrograph of light-green calc-silicate rock composed predominantly of garnet (gn). Corroded relicts of diopside (di), wollastonite (wo), and calcite (ct) are in the garnet. Specimen from the 800-foot level of the Defiance workings. Crossed nicols, 44x.

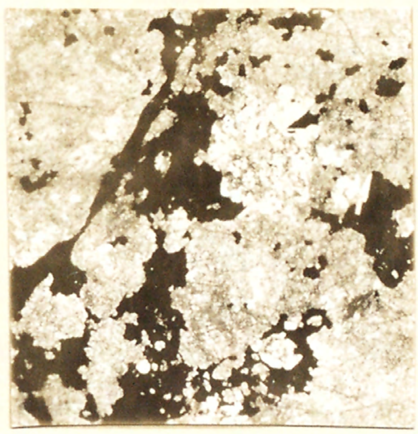


Figure 16.--Photomicrograph of low-grade ore showing replacement of garnet (gn) and idocrase (id) tactite by sulfide minerals (dark). Some relict calcite (ct) is present in the garnet. Specimen from the 800-foot level of the Defiance workings. Plane light, 30x.

bodies and intrusive contacts. Locally tactite composed entirely of garnet is found along intrusive contacts or in faults near intrusive contacts. Idocrase is generally associated with garnet, but is much less abundant. It occurs as euhedral to subhedral crystals in the medium-grained calc-silicate rock. Idocrase is very conspicuous on weathered surfaces of calc-silicate rock in the Darwin mine area.

Some material was added to the calc-silicate rock, which is so widespread in the Darwin mine area (pl. 5). A sample was analyzed of unaltered limestone from the Fairbanks mine from strata believed to be the approximate unaltered equivalent of the medium-grained calc-silicate rock in the Defiance area of the Darwin mine. A sample of calc-hornfels from the surface between the Bernon and Defiance workings of the Darwin mine was also analyzed. The calc-silicate rock consists predominantly of wollastonite but contains some garnet, idocrase, diopside, and relict calcite. The results are given in table 3. The most pronounced chemical changes in alteration are an increase in silica and decrease in carbon dioxide. It is probable also that some alumina was added. Iron, magnesia, lime, and alkalies remained essentially unchanged.

Dark-green tactite locally replaces calc-hornfels and light-colored calc-silicate rock along faults and intrusive contacts. Garnet generally is the predominant mineral and may be the only mineral present. Tremolite, epidote, zoisite, and coarse-grained calcite are commonly present. The dark tactite forms mainly as a replacement of pure limestone and marble. It is in small bodies a few inches to several feet wide and mostly less than 50 feet long.

Table 3.--Analyses of limestone and calc-silicate rock from the Darwin Hills.*

	A	B
SiO_2	13.1	42.1
Al_2O_3	1.6	5.3
Total Fe as FeO	0.57	2.1
MgO	1.6	2.9
CaO	47.5	37.1
Na_2O	0.16	0.22
K_2O	0.40	0.38
TiO_2	.10	0.29
P_2O_5	.10	0.18
CO_2	34.8	6.9
H_2O	0.40	1.4
Sum	100	99

A. Limestone of the Keeler Canyon formation from the Fairbanks mine.

B. Medium-grained calc-silicate rock from between the Bernon-Defiance workings of the Darwin mine.

* Analyses by P. L. D. Elmore, K. E. White, and P. W. Scott of the U. S. Geological Survey, 1954 and 1955.

Alteration to feldspathic rock

Locally calc-silicate rock is altered to a feldspathic rock at the margins of the Darwin stock and around some of the small satellitic bodies. The most conspicuous alteration is in the Defiance workings of the Darwin mine and along the crest of the ridge 600 feet southwest of the Defiance inclined shaft. Feldspathic rock is exposed on the 800-foot level of the Defiance workings 185 feet N. 15° E. of the main shaft in a dike containing perthitic orthoclase, pyrite, fluorite, and sphalerite. Southwest of the Defiance workings feldspar replaces calc-silicate rock around a small plug of quartz monzonite (fig. 17, pl. 5).

GEOLOGIC HISTORY

The Paleozoic Era was marked by nearly continuous deposition of marine sediments from the Lower Ordovician to within the Permian; no major unconformities or hiatuses were recognized. During the Early and Middle Ordovician the Pogonip group was deposited in probable deep marine water. Local admixing of sand grains and the presence of cross-bedding near the top of the formation manifest a transition from deep-water deposition for the older dolomites and limestones to shallow water conditions near the end of Chazy time. Littoral sub-zone or beach conditions probably prevailed during Middle Ordovician time and resulted in the deposition of well-sorted quartz sand of the Eureka quartzite. Ely Springs dolomite and Hidden Valley dolomite were formed in seas that covered the area during Late Ordovician time and during the Silurian. Marine deposition continued through the Devonian, mainly forming limestone in contrast to the preponderence of dolomite in pre-Devonian seas.

Figure 17.--Photomicrograph of partly feldspathized calc-silicate rock. On the left side of the photograph is a fine-grained mixture of wollastonite (wo) and calcite (ct). Perthitic orthoclase (or) corrodes and replaces the fine calcite and wollastonite and coarsely crystalline calcite. A veinlet of sphalerite (dark mineral on the lower right) cuts the rock and is the youngest mineral. Crossed nicols, 30x.

Marine sedimentation continued throughout the Mississippian. The bio-limestones of the Tin Mountain limestone and Perdido formation were largely formed in placid seas devoid of foreign detritus. Calcarenites of the Lee Flat limestone were likely derived from erosion of a low-relief landmass. Continued marine deposition in a near-shore environment formed the calcarenites characteristic of the Pennsylvanian and Permian. Recurrent emergences are indicated by intercalated limestone conglomerate and minor unconformities, and widespread cross-bedding chronicles a near-shore environment. Most of the emergences are believed to have been short-lived and of limited extent, but locally folding was concomitant with uplift. The coarse limestone conglomerate of the upper Owens Valley formation probably accumulated in a local basin as a result of rapid local differential uplift.

Orogeny was the dominant feature of the Mesozoic Era, although the exact age of the diastrophism is not well documented. The Paleozoic rocks were uplifted and folded prior to the intrusions of the late Mesozoic granitic rocks. They were then regionally warped and thrust faulted in response to the forcible intrusion of the late Mesozoic plutons. Faulting and fracturing, some subsequent to the partial solidification of the granitic rocks, preceded the deposition of ore and gangue minerals during the late stages of orogeny.

There is a gap in the geologic record between the late Mesozoic orogeny and mineralization, and the advent of volcanism during the late Pliocene. This probably represents a period mainly of erosion. By late Pliocene time the land had been eroded to a mature surface of low relief. This surface has been correlated by Hopper (1947, p. 400) with the late Pliocene Ricardo erosion surface (Baker, 1912, p. 138; Merriam, 1919, p. 529) cut across tilted lower Pliocene beds in the El Paso Range about 75 miles to the south. The Darwin senesland of Maxson (1950, p. 101) between the Argus and Inyo Mountains contains part of this mature surface.

The basin-ranges had their inception at least as far back as late Pliocene when uplift of the Coso Range and Inyo Mountains caused the formation of extensive piedmont fans that interfinger with lacustrine deposits in Owens Valley. There was considerable volcanic activity during the Pliocene, and it continued intermittently into the Quaternary. Pyroclastic fragments of basaltic composition are common in the lowermost beds of the late Pliocene or early Pleistocene Coso formation at Cactus Flat on the west flank of the Coso Range in the Haiwee Reservoir quadrangle. Andesite, which locally is interbedded in the Coso formation at Cactus Flat and is interbedded in basaltic pyroclastics in the Inyo Mountains near the Santa Rosa mine, was extruded as domes during the late Pliocene or early Pleistocene. The pyroclastics were tilted locally prior to the outflow of the extensive olivine basalt flows that cap most of the northern part of the Darwin quadrangle.

Uplift of the Argus Range, Coso Range, and Inyo Mountains continued through the Pleistocene. The olivine basalt flows of Pleistocene age have been tilted and step faulted. A lake was formed in Darwin Wash during middle or late Pleistocene. Headward erosion of Darwin

Canyon subsequently captured the drainage of Darwin Wash, thus lowering base level of erosion to Panamint Valley and causing dissection of the lake beds. Erosion has continued through the Recent.

ORE DEPOSITS

Introduction

The Darwin quadrangle contains important deposits of lead-silver-zinc and steatite-grade talc, and some tungsten, copper, gold, and antimony (fig. 2). Large deposits of limestone, dolomite, and quartzite are known, but they have not been exploited owing to remoteness from market and rail transportation. The total value of mineral production up to 1952 is approximately $37,500,000. The Darwin lead-silver district has accounted for $29,000,000 and the talc deposits for about $5,000,000. The remainder of the production has come from other lead-silver-zinc deposits scattered throughout the quadrangle and from the tungsten deposits in the Darwin Hills. The major lead-silver-zinc deposits are in the Darwin Hills, but smaller deposits have been developed at Zinc Hill in the Argus Range, the Lee district in the north-central part of the quadrangle, and the Santa Rose mine in the Inyo Mountains. Steatite-grade talc has been mined continuously since 1917 from the Talc City Hills, principally from the Talc City mine. Scheelite was first mined in 1940 from deposits about 1 mile east of Darwin, and production has been intermittent since then. Small amounts of copper, gold, and antimony have been recovered from deposits in the Darwin Hills.

The production of metallic ores from the Darwin quadrangle through 1951 totals approximately 6,300 ounces of gold, 8 million ounces of silver, 1,000 tons of copper, 65,000 tons of lead, 23,000 tons of zinc, and 35,000 units of WO_3 (compiled from Hall and MacKevett, in press). Norman and Stewart (1951, p. 29) give the production of antimony from the Darwin Antimony mine as "50 to 100 tons of ore assaying more than 30 percent antimony."

Talc and chlorite are the only nonmetallic commodities produced in the quadrangle. No record was found of the total production of these commodities from the Talc City district. The production from the Talc City mine, which has produced most of the talc in the district, is 218,485 tons_/.

_/ Published with the permission of the Sierra Talc and Clay Company. Production compiled by L. A. Wright of the California State Division of Mines.

Lead-silver-zinc deposits

Distribution

The lead-silver-zinc deposits are concentrated in Paleozoic limestone close to intrusive contacts (fig. 2). The largest deposits are adjacent to the Darwin stock in the southern part of the quadrangle. The principal mines are the Darwin, Lucky Jim, Christmas Gift, Lane, Custer, and Promontory. Other deposits are near the Zinc Hill stock at the north end of the Argus Range, the Santa Rosa mine in the Inyo Mountains, the Lee mine on the east side of the Santa Rosa Hills, and some small deposits in the Talc City Hills (fig. 2). The name Darwin mine is used in this report to include all the properties through which the Radiore tunnel passes (pl. 5). This includes the former Bernon, Defiance, Essex, Independence, Rip Van Winkle, and Thompson mines, and each of these properties will be referred to as workings of the Darwin mine.

Character of ore

Both primary and secondary lead-silver-zinc ore is mined in the Darwin quadrangle. Prior to 1945 mainly oxidized lead-silver ore was mined, but since then more primary than oxide ore has been produced. In the Darwin district sulfide minerals generally constitute more than 75 percent of the primary ore. The ore consists principally of galena and sphalerite and lesser amounts of pyrite, chalcopyrite, and pyrrhotite. The average grade of ore is about 6 percent lead, 6 percent zinc, 6 ounces of silver per ton, and a small amount of copper. Gangue minerals are calcite, fluorite, jasper, and such relict host rock minerals as garnet, idocrase, diopside, wollastonite, quartz, and feldspar. Jasper and calcite are the abundant gangue minerals in most of the fissure deposits and calc-silicate minerals in the replacement ore bodies.

The texture of the ore ranges from extremely fine-grained steel galena to coarsely crystalline ore containing galena and sphalerite crystals ½ to 1 inch in diameter. Steel galena is particularly abundant in the Essex vein. Banded ore, although not characteristic of the Darwin district, is present in some of the mines, particularly where pyrrhotite is abundant.

The oxidized ore, except where jasper is the principal gangue mineral, is a soft friable mass consisting principally of cerussite and limonite, and most of it can be disintegrated easily by hand.

Silver ore containing little galena is present near the margins of some of the lead-silver-zinc ore bodies in the Darwin mine. The silver ore contains franckeite, andorite, pyrite, and an unidentified, probably new, lead-bismuth-selenium sulfosalt in a gangue of calcite and relict host rock. Whereas sulfide minerals are predominant in the lead-silver-zinc ore, the silver ore commonly contains only several percent of metallic minerals.

The ore in the Zinc Hill district contains more zinc than that at Darwin. Primary ore from the Zinc Hill mine averages 22 percent zinc and 1.3 percent lead. The ore consists of medium- to coarse-grained sphalerite, galena, and minor pyrite in a calcite gangue.

Most of the ore mined from the Santa Rosa and Lee mines was oxidized. Oxidized ore at the Lee mine is much harder than that from Darwin and consists of a light- to dark-gray porous mass of hemimorphite with minor coatings and crystals of cerargyrite. Some relict primary ore is present that contains coarse galena and minor sphalerite in a gangue of calcite and barite.

Forms of ore bodies

The ore bodies occur as bedded deposits, irregular replacement bodies close to major faults, fissure or vein deposits, and small ore bodies in flat-lying fractures.

Bedded deposits

Economically the bedded deposits are the most important. They are common in the Darwin and Zinc Hill districts. Notable examples in the Darwin district are the bedded ore bodies in the Independence workings (pl. 6); the 430 stope ore body, the Blue and Red veins in the Defiance workings (pl. 6); and the ore bodies at the Custer, Jackass, and Promontory mines. Small bedded ore bodies are also present at the Empress and Zinc Hill mines in the Zinc Hill district. The ore bodies range in size from a few tens of tons to over half a million tons. The contacts between the bedded deposits and barren or slightly pyritized wall rock are sharp. However, the grade within an ore body is not uniform along strike and some lower grade parts have been left behind as pillars in mining.

Irregular replacement ore bodies

The only important irregular replacement ore body is in the Defiance workings below the bedded ore bodies (pl. 6). It is a vertical ore body that is discontinuously mineralized over a cross sectional area approximately 250 feet by 350 feet, and has been mined a vertical distance of about 550 feet. The downward extent has not been determined. Many individual ore bodies are within this ore zone and only the mined ore bodies are shown in plate 6. Individual ore bodies have gradational contacts with barren or pyritized calc-silicate rock.

Vein deposits

Fissure or vein deposits are present in the Darwin district, at the Santa Rosa mine in the Inyo Mountains, and at a few small deposits in the Talc City Hills. In the Darwin district the veins are as much as 460 feet long; they average 2 to 8 feet thick and are as much as 35 feet thick. The Essex vein has been mined for 800 feet down the dip; the Lucky Jim vein for 920 feet. All the other veins have a lesser known length down the dip. Contacts of the veins with barren country rock are sharp. Minable high-grade ore is commonly localized in shoots within the veins. At the Christmas Gift and Lucky Jim mines the ore is localized in the parts of the veins that have approximately a northeast strike and the parts that have a more easterly strike are nearly barren. The ore shoots plunge toward the west.

Ore bodies in flat-lying fractures

Small, silver-rich ore bodies are localized in flat-lying fractures in the Lee district at the Lee mine and Silver Reid prospect. The flat-lying fractures are in part parallel to bedding and in part transect bedding; they are localized between steep strike-slip faults. The largest known ore body was about 40 feet long, 35 feet wide, and averaged about 6 feet thick. Most of the ore bodies mined in the past 20 years are smaller and yielded 50 to 100 tons of ore each.

Ore controls

Most of the lead-silver-zinc ore bodies in the Darwin quadrangle are in calc-silicate rock close to intrusive contacts with quartz monzonite. A few smaller deposits are in limestone or marble. Anticlinal-shaped structures are important in localizing some ore bodies in the Darwin mine. A fault control is evident for nearly all the deposits. Thrust faults, steep strike-slip faults, and high-angle normal faults have each played a part in localizing certain ore bodies.

Nearness to intrusive contacts

The deposits in the Darwin and Zinc Hill districts are all within a few hundred feet of an intrusive contact. In the Defiance and Independence workings of the Darwin mine much of the ore is adjacent to the stock of biotite-hornblende-quartz monzonite, and all the ore is close to quartz monzonite inasmuch as the workings cut many small satellitic offshoots of the stock. The mines on the east side of the stock in general are farther from the intrusive than those on the west side. The Lane mine is 2,500 feet from the stock, the Keystone 1,000 feet, the Wonder 600 feet. Two exceptions, the Custer and Fernando mines, are within 100 feet of quartz monzonite. The deposits in the Zinc Hill district are clustered about the stock of leucocratic quartz monzonite. The Empress mine is on the contact of quartz monzonite, and the Zinc Hill mine is 2,300 feet north of it.

At the Santa Rosa mine quartz monzonite does not crop out, but a plutonic mass probably lies a short distance below the surface. The limestone is metamorphosed to calc-hornfels, and an inclusion of quartz monzonite is present in an andesite porphyry dike; both indicate proximity to a plutonic mass. The deposits in the Lee district are the farthest from a known intrusion in the Darwin quadrangle. The Lee mine is in unaltered limestone 6,500 feet northeast of the closest exposure of quartz monzonite, and the Silver Reid prospect is 7,600 feet distant.

Relationship of ore deposits to stratigraphy

No one formation in the Darwin quadrangle appears to be unusually favorable for lead-silver-zinc deposits. In general, limestone is favorable and dolomite, quartzite, and shale are unfavorable. No lead-silver-zinc deposits in the quadrangle are in beds older than Devonian. As shown chronologically below, all systems from Devonian through Permian contain lead-silver-zinc ore deposits. The Silver Reid prospect in the Lee district and the Cactus Owen and Homestake prospects in the Talc City Hills are in the Lost Burro formation of Devonian age, as is the Cerro Gordo mine in the New York Butte quadrangle 3½ miles northwest of the Darwin quadrangle. In the Talc City Hills small lead-silver-zinc deposits are in limy parts of the Lost Burro; the more extensive dolomite contains only talc deposits. The Lee, Zinc Hill, and Empress mines are in Mississippian limestone. The Silver Dollar mine in the Talc City Hills is in the Keeler Canyon formation of Pennsylvanian-Permian age. The deposits in the Darwin district are in calc-silicate rock of the lower unit of the Keeler Canyon formation. The Santa Rosa mine is in calc-hornfels of the lower member of the Owens Valley formation of Permian age.

Dolomite appears to be unfavorable for lead-silver-zinc deposits in the Darwin quadrangle, but it is the host rock for at least two lead-silver-zinc deposits in the Ubehebe district 9 and 17 miles north of the Darwin quadrangle (McAllister, 1955, p. 23, 32). Ore at the Ubehebe mine is in Ely Springs dolomite and that at the Lippincott mine is in dolomite of the Lost Burro formation.

Although lead-silver-zinc deposits occur in all formations from Devonian to Permian and no one formation is particularly favorable, within mineralized areas certain beds are favorable. Usually one or more other favorable ore controls are instrumental in localizing ore within a favorable bed. At the Zinc Hill mine all the known ore is in a favorable marble bed 200 feet thick and the overlying and underlying limestone is only slightly mineralized. The favorable marble bed is replaced by ore close to steep faults, and these faults are only slightly mineralized where they cut the overlying and underlying limestone beds. At the Darwin mine the ore deposits are restricted to a favorable stratigraphic zone between the Davis thrust and biotite-hornblende-quartz monzonite. The ore is in a medium-grained, light-colored idocrase-garnet-wollastonite rock, whereas the dense gray and white calc-hornfels west of the Davis thrust is unfavorable for ore. Folds and faults play an important role in localizing ore within this favorable zone.

Relationship of ore to folds

In the Darwin district anticlinal-shaped folds are important in localizing some bedded ore bodies. An inverted synclinal axis that plunges gently northwest extends from the main open cut at the portal of the Defiance shaft N. 30° W. to the Bernon mine (pl. 5). The Blue and Red veins are along the crest and west flank of the fold. An inverted syncline localizes the large bedded ore body in the Independence mine between the 200 and 3A levels (pl. 6). Steep north-striking faults localize ore along the crest of the fold. Anticlinal-shaped structures are also evident at the Custer mine and the Wonder mine on the east side of the biotite-hornblende-quartz monzonite in the Darwin Hills.

Relationship of ore to faults

A fault control is evident for all the ore bodies in the Darwin quadrangle. In the Darwin district four groups of faults have been instrumental in localizing ore. They are: (1) steep N. 70° E.-striking faults; (2) steep N. 70° W.-striking faults; (3) the Davis thrust, which strikes north and dips west; and (4) steep north-striking faults that have little displacement (pl. 5). Steep N. 70° E.-striking faults apparently served as feeder channels for the ore solutions, and all ore bodies in the Darwin district are localized along them or close to them by other favorable controls. Ore at the Lucky Jim and Christmas Gift mines and in the Darwin mine in the 229, 234, Bernon, 434, and Water tank faults is localized in these faults (see for example pl. 5). The bedded ore bodies and the irregular replacement ore body in the Defiance workings are localized close to the N. 70° E. fault (pl. 7).

The Essex is the only ore body localized in a N. 70° W. fault (pls. 5 and 8). The other two major N. 70° W. faults--the Darwin tear fault and the Standard fault--are mineralized but contain very little ore (pl. 2).

The Davis thrust fault is a pre-mineral fault that apparently confined the ore solutions between it and the underlying biotite-hornblende-quartz monzonite (see pls. 5, 6, 7, and 8). All the known ore bodies in the district lie below the thrust, and pre-mineral faults above the thrust are only slightly mineralized.

Steep north-striking faults are an important ore control in the Thompson and Independence mines. The north-striking faults are most intensely mineralized close to a major N. 70° E. fault. Commonly the ore replaced a favorable bed that is transected by a steep north-striking fault, as in the Independence ore body (pl. 6).

At the Zinc Hill mine ore replaces a favorable bed near a series of steep north- to northeast-striking pre-mineral faults that probably were instrumental in localizing ore (pl. 9).

Flat-lying fractures between major steep faults localize ore in the Lee district. The flat-lying fractures are tension fractures that have had little or no displacement and were probably formed by differential displacement on the major steep faults.

At the Santa Rosa mine in the Inyo Mountains ore is in north-striking faults that dip mostly 30° to 65° W., although some dip to the east. Pinching and swelling of the faults localizes some of the ore shoots.

Mineralogy

A list of the minerals identified or reported in the lead-silver-zinc deposits of the Darwin quadrangle is given below. The list is divided into two major groups--hypogene minerals and supergene minerals. The hypogene minerals are subdivided into Ore and sulfide minerals and Gangue minerals. The supergene minerals are subdivided into minerals in the sulfide zone and those in the oxidized zone. The minerals are listed alphabetically under each heading. The identification of the more uncommon minerals was verified by an X-ray diffraction pattern if the mineral was sufficiently abundant and could be separated. The X-ray spectrograph was utilized to determine qualitative compositions of some minerals and of minute inclusions that are common in the steel galena and in some of the sulfosalts. Minerals identified by previous workers but not verified by the writer is listed with credit or reference for the identification under description of the mineral.

Hypogene minerals

Ore and sulfide minerals

Andorite	$PbAgSb_3S_6$
Arsenopyrite	FeAsS
Bismuth(?)	Bi
Bismuthinite	Bi_2S_3
Bornite	Cu_5FeS_4
Chalcopyrite	$CuFeS_2$
Franckeite	$Pb_5Sn_3Sb_2S_{14}$
Galena	PbS
Guanajuatite(?)	Bi_2Se_3
Matildite	$AgBiS_2$
Pyrite	FeS_2
Pyrrhotite	$Fe_{1-x}S$
Scheelite	$CaWO_4$
Sphalerite	ZnS
Stannite	Cu_2FeSnS_4
Tetrahedrite - Tennanite	$(Cu,Fe)_{12}Sb_4S_{13}$-$(Cu,Fe)_{12}As_4S_{13}$
Unknown lead-bismuth-selenium sulfosalt	

Gangue minerals

Barite	$BaSO_4$
Calcite	$CaCO_3$
Chalcedony	SiO_2
Deweylite	$Mg_4Si_3O_{10}\cdot 6H_2O$
Diopside	$CaMgSi_2O_6$

Hypogene minerals (continued)

Gangue minerals (continued)

Fluorite	CaF_2
Garnet sp andradite	$(Ca)_3(Al,Fe)_2Si_3O_{12}$
Idocrase	$Ca_6Al(OH,F)\ Al_2(SiO_4)_5$
Jasper	SiO_2
Montmorillonite	$(Al,Mg)_8(Si_4O_{10})_3.(OH)_{10}.12H_2O$
Orthoclase	$KAlSi_3O_8$
Quartz	SiO_2
Sericite	$(H,K)AlSiO_4$
Wollastonite	$(Ca,Fe,Mn)SiO_3$

Supergene minerals

Sulfide zone

Argentite	Ag_2S
Chalcocite	Cu_2S
Covellite	CuS

Oxide zone

Anglesite	$PbSO_4$
Antlerite	$Cu_3(OH)_4SO_4$
Aurichalcite	$(Zn,Cu)_5(OH)_6(CO_3)_2$
Autunite	$Ca(UO_2)_2(PO_4)_2.10\text{-}12H_2O$
Azurite	$Cu_3(OH)_2(CO_3)_2$
Bindheimite	$Pb_2Sb_2O_6(O,OH)$
Bismutite	$(BiO)_2(CO_3)$
Brochantite	$Cu_4(SO_4)(OH)_6$

Supergene minerals (continued)

Oxide zone (continued)

Caledonite	$Cu_2Pb_5(SO_4)_3(CO_3)(OH)_6$
Cerargyrite	$AgCl$
Cerussite	$PbCO_3$
Chalcanthite	$CuSO_4.5H_2O$
Chrysocolla	$CuSiO_3.2H_2O$
Creedite	$Ca_3Al_2F_4(OH,F)_6(SO_4).2H_2O$
Crocoite	$PbCrO_4$
Cuprite	Cu_2O
Goslarite	$ZnSO_4.7H_2O$
Gypsum	$CaSO_4.2H_2O$
Hematite	Fe_2O_3
Hemimorphite	$H_2Zn_2SiO_5$
Hydrozincite	$Zn_5(OH)_6(CO_3)_2$
Jarosite	$KFe_3(SO_4)_2(OH)_6$
Leadhillite	$Pb_4(SO_4)(CO_3)_2(OH)_2$
Limonite	Hydrous iron oxide
Linarite	$PbCu(SO_4)(OH)_2$
Malachite	$Cu_2(OH)_2(CO_3)$
Melanterite	$FeSO_4.7H_2O$
Mimetite	$(PbCl)Pb_4(AsO_4)_3$
Plumbojarosite	$PbFe_6(SO_4)_4(OH)_{12}$
Pseudomalachite	$Cu_{10}(PO_4)_4(OH)_8.2H_2O$
Pyrolusite	MnO_2

Supergene minerals (continued)

Oxide zone (continued)

Pyromorphite	$Pb_5(PO_4,AsO_4)_3Cl$
Silver (native)	Ag
Smithsonite	$ZnCO_3$
Stolzite	$PbWO_3$
Sulfur	S
Tenorite	CuO
Vanadinite	$Pb_5(VO_4)_3Cl$
Vivianite	$Fe_3P_2O_8.8H_2O$
Wulfenite	$PbMO_4$

Hypogene ore and sulfide minerals

Andorite.--Andorite was identified by Charles Milton (written communication, 1954) of the U. S. Geological Survey from specimens from the A437 stope above the 400 level of the Thompson workings of the Darwin mine (X-ray film 6794). It forms a silver-rich ore with pyrite and minor chalcopyrite and sphalerite at the margin of a galena-rich ore body. The andorite occurs in thin tabular crystals mostly less than 2 mm long that are prominently striated. In polished section the color is galena white, and it is moderately anisotropic in shades of gray. The andorite is in a gangue of coarsely crystalline calcite and less abundant garnet and idocrase. Minute irregular, white, strongly anisotropic inclusions of native bismuth(?) are disseminated through the andorite (fig. 18). Andorite(?) has been provisionally identified from Inyo County by Milton from the Round Valley mine in the Bishop district.

Figure 18.--Photomicrograph of andorite that contains inclusions of bismuth(?). Specimen from the Thompson 437 stope of the Darwin mine. Plane light, 60x.

Arsenopyrite.--Minor amounts of arsenopyrite are present in the Darwin mine and at the Santa Rosa mine. It is associated with pyrite and pyrrhotite and was one of the first sulfide minerals deposited. It is in diamond-shaped grains that are less than 0.5 mm long.

Bismuth(?).--Bismuth minerals are known from assays and spectrographic analysis to be present in the Darwin ores, but the mineralogy is not well known. Steel galena from the Essex mine gives distinct bismuth peaks on the X-ray spectrometer. Minute light-colored strongly anisotropic inclusions in the galena and in andorite may be native bismuth (fig. 18).

Bismuthinite.--Bismuthinite associated with scheelite was identified at the north end of the Durham ore body near the Fernando fault. The mineral is mostly altered to bismutite. The bismuthinite is in bladed masses as much as one inch long that are coated with powdery green bismutite.

Bornite.--Small amounts of bornite are present in the Darwin and Santa Rosa mines. At the Darwin mine bornite occurs as a rim about some pyrrhotite inclusions in sphalerite and as inclusions in galena (see fig. 21).

Chalcopyrite.--Small amounts of chalcopyrite are present in most of the lead-silver-zinc deposits, and it is a predominant mineral in some copper prospects on the east side of the Darwin Hills. Chalcopyrite occurs as minute inclusions in sphalerite that undoubtedly formed by exsolution, and it is commonly present with pyrite and pyrrhotite in the Darwin mine.

Franckeite.--Franckeite was identified by Charles Milton and J. M. Axelrod of the U. S. Geological Survey from specimens of silver-rich ore from the 534 stope in the Thompson workings of the Darwin mine. It forms thin, tabular elongate crystals as much as 1 cm long that are commonly warped and are prominently striated parallel to their long direction. In polished section the franckeite looks like two minerals, one with a smooth surface and one with a rough surface (fig. 19), but X-ray patterns of both are similar to patterns of franckeite (USNM 95417) from the Porvenir mine, Bolivia. Franckeite occurs with andorite on the margins of galena-rich ore bodies and is associated with pyrite and minor stannite, sphalerite, and chalcopyrite in a gangue of coarse white calcite, garnet, and idocrase.

Galena.--Galena is the predominant sulfide mineral in the Darwin district and at the Santa Rosa mine. It ranges in texture from steel galena to coarsely crystalline masses that average as much as half an inch in diameter. Some coarse galena in the Defiance workings of the Darwin mine has warped cleavage faces. The warping is apparently due to translation gliding. The d-values and relative intensity of the lines in the X-ray diffraction pattern of the warped crystal agree precisely with those given in the ASTM Diffraction Data Cards for galena. All the galena is argentiferous, and spectrographic analysis shows that some of it contains appreciable bismuth and selenium. Galena from the Essex vein analyzed by Emma Campbell of the U. S. Geological Survey contained 2.11 percent selenium.

Figure 19.--Photomicrograph of franckeite from the Thompson 534 stope of the Darwin mine. This appears to be two minerals, smooth and rough respectively, but the X-ray patters of the two are similar according to J. M. Axelrod of the U. S. Geological Survey. Plane light, 60x.

Guanajuatite(?).--Both bismuth and selenium are shown by spectrographic analyses to be present in andorite and galena from the Thompson and Essex workings of the Darwin mine. Both minerals contain minute inclusions that are white in polished section and have strong anisotropism and may be guanajuatite.

Matildite.--Tiny oriented lamellar inclusions of matildite are intergrown with galena in ore from the Essex vein of the Darwin mine. The lamellae are galena white in polished section and are moderately anisotropic. They are not visible in plane light, but are readily seen under crossed nicols or when the section is etched with nitric acid (fig. 20). The identification is based on similarity to matildite described by Palache, Berman, Frondel (1944, p. 429) and by Edwards (1954, p. 111) and on X-ray spectrometer analysis of galena showing the presence of silver and bismuth. The inclusions are believed to have formed by exsolution from a bismuthian and argentian galena stable only at high temperature.

Pyrite.--Pyrite is abundant in all the lead-zinc deposits in the Darwin district and at the Santa Rosa mine, but it is a very minor constituent of the ores at the Lee and Zinc Hill mines. Pyrite is also widely disseminated in the biotite-hornblende-quartz monzonite and in calc-silicate rock near the Darwin mine. It is present both as cubes and pyritohedrons as much as one inch in diameter, and is the earliest sulfide mineral deposited. Some pyrite has an exploded bomb texture, and the fractures are filled with later sulfide minerals.

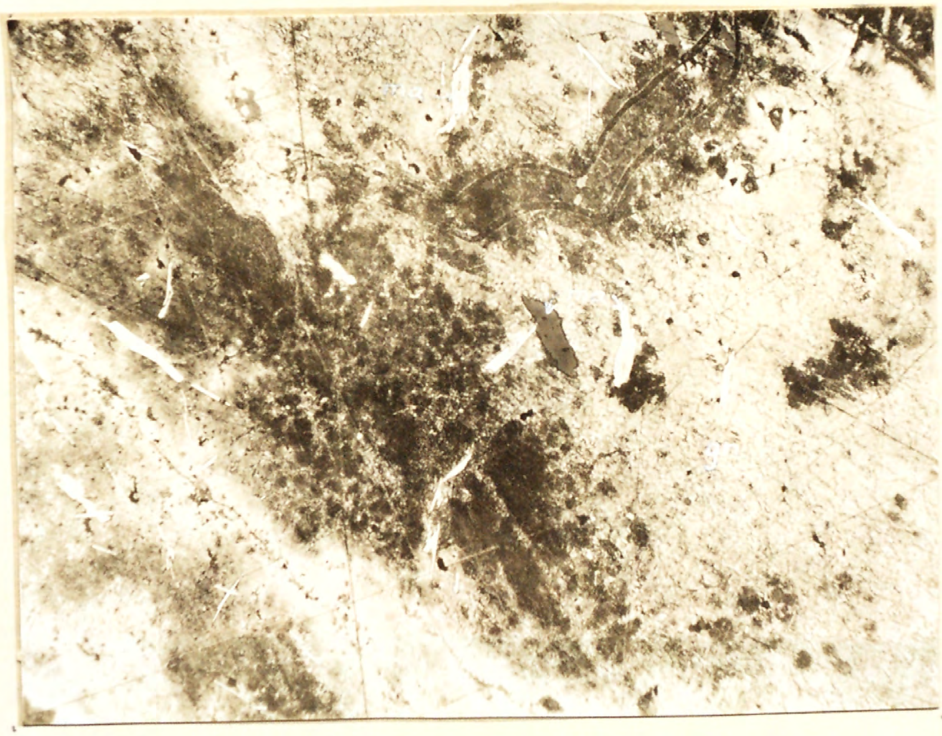
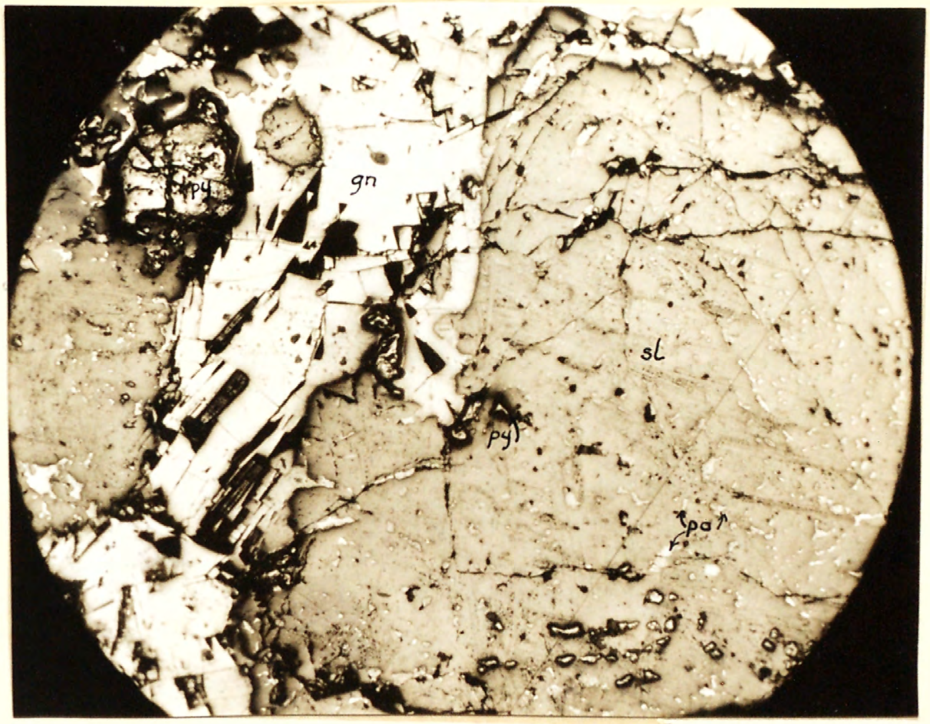


Figure 20.--Galena (gn) and its alternation product cerussite (ce) with elongate inclusions of matildite (elongate white and medium gray inclusions) that has exsolved from bismuthian and argentian galena. The inclusions are not visible in plane light in unetched specimens. The polished section is etched with nitric acid to show the matildite. Specimen from the Essex workings of the Darwin mine. Crossed nicols, 50x.

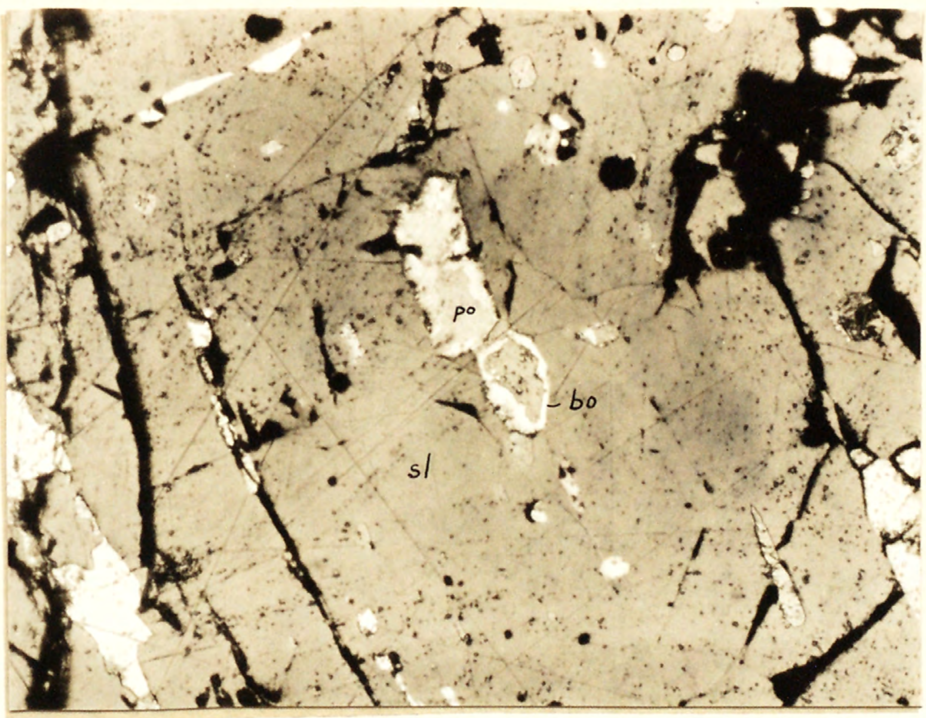
Pyrrhotite.--Pyrrhotite is common in the primary ore in the Darwin mine, where it commonly forms a banded ore. It replaces pyrite but is replaced by sphalerite, galena, and chalcopyrite. It also occurs as irregular blebs oriented along cleavage in sphalerite and probably formed by exsolution (fig. 21).

Scheelite.--Scheelite is common in the lead-silver-zinc ore bodies in the Darwin district and as discrete tungsten ore bodies with little or no sulfide minerals. It is associated with galena in the Thompson workings of the Darwin mine and at the Jackass mine. In the Thompson workings subhedral to euhedral scheelite crystals commonly three-eighths to one-half inch in diameter are embedded in fine-grained galena. In the oxidized zone the scheelite is loosely embedded in a crumbly mass of cerussite, limonite, and jarosite.

Sphalerite.--Sphalerite is present in about the same quantities as galena in most of the primary ore in the deeper ore bodies currently being mined at the Darwin mine, and it is the predominant mineral in the primary ore at the Zinc Hill mine. The sphalerite is generally coarser grained than galena and is commonly in crystals as much as 1½ inches in diameter. The color of the sphalerite in calc-silicate rock is dark grayish-brown at the Santa Rosa mine and in the Darwin district. At the Zinc Hill mine, where the ore is in marble, the sphalerite is a much lighter color--being pale brown. It is lightest in color at the Lee mine--a light grayish yellow--where it is in unaltered limestone. The color of sphalerite darkens with increasing FeS content. Generally dark iron-rich sphalerites formed at a higher temperature than light-colored sphalerite (see table 5).



A



B

Figure 21.--Photomicrographs of sphalerite (sl) from the Thompson workings of the Darwin mine. A. The sphalerite contains corroded relicts of pyrite (py) and is, in turn, veined by galena (gn). Pyrrhotite (po) inclusions form a triangular pattern in the sphalerite. This is interpreted as an exsolution pattern. Plane light, 40x. B. Some of the pyrrhotite inclusions have rims of bornite (bo). Plane light, 250x.

Stannite.--Stannite was identified by Charles Milton (written communication, 1954) from silver-rich ore from the Thompson workings of the Darwin mine. The stannite is associated with franckeite at the margin of galena ore bodies.

Tetrahedrite-tennantite.--Small amounts of tetrahedrite or tennantite are present in galena in the Darwin mine (fig. 21). The mineral is most commonly near the border of galena in grains too small to determine whether arsenic or antimony is predominant. Kelley (1938, p. 544) reports tennantite in the ore, and Carlisle and others (1954, p. 46) report tetrahedrite.

Unidentified lead-bismuth-selenium sulfosalt.--An unidentified lead-bismuth-selenium sulfosalt that probably is a new mineral is present in the 534 stope of the Thompson workings of the Darwin mine associated with andorite and franckeite. The sulfosalt is a silver-white tabular mineral that is prominently striated parallel to its long direction. It has a specific gravity of 6.64. Microchemical tests and X-ray spectrometer patterns show it to contain lead, bismuth, and selenium. The X-ray diffraction pattern is as follows:

dA	relative intensity	dA	relative intensity
3.67		2.03	
3.51		1.91	
3.43		1.87	
3.33		1.80	
3.02	1	1.76	
2.98	2	1.72	
2.85		1.69	
2.48		1.66	
2.27		1.47	
2.15		1.34	
2.09	3	1.20	

The powder diffraction pattern does not agree closely with any mineral listed in the ASTM file or with any sulfide mineral listed by Harcourt (1942). This mineral was referred to the U. S. Geological Survey Geochemistry and Petrology laboratory where it is currently being studied. Charles Milton (written communication, 1956) reports, "Joe Axelrod's (diffraction patterns) IWX 725, April 18, 1956 and IWX 740, June 29, 1956, indicate an unknown sulfo-salt, or possibly such with mixture of galena, a cubic mineral isostructural with galena, and franckeite. Your finding selenium and bismuth, etc. is confirmed by X-ray fluorescence analysis. There are a number of ill-defined lead-bismuth-selenium sulfo-salts which will have to be studied in reference to your material."

Hypogene gangue minerals

Barite.--Barite is one of the predominant gangue minerals at the Lee mine and the Silver Reid prospect. It was not identified from ore from the Darwin or Zinc Hill districts.

Calcite.--Calcite is one of the predominant gangue minerals in most of the lead-silver-zinc deposits in the Darwin district. It is particularly abundant at the Custer mine and the Defiance workings of the Darwin mine. It ranges in color from milky white to brownish-gray, and rhombohedrons as much as 18 inches on a side are common. Calcite is also present as an interstitial mineral in the calc-hornfels and as late veinlets that cut the ore.

Chalcedony.--Chalcedony is a common gangue mineral at the Santa Rosa mine. It forms light-tan to light-gray cryptocrystalline masses associated with ore minerals.

Deweylite.--Deweylite was identified from the 570 level of the Defiance workings by Fred A. Hildebrand (written communication, 1953). It forms pale greenish-yellow amorphous masses that are intergrown with montmorillonite. Pyrite in the form of pyritohedrons as much as 1½ inches long that have thin black coatings of chalcocite is disseminated through the deweylite.

Fluorite.--Fluorite is associated with galena in many deposits in the Darwin district. It is in anhedral to subhedral grains mostly a few millimeters in diameter that range in color from white to shades of blue, green, and rose. The mineral is most abundant in ore bodies close to igneous contacts.

Garnet sp grossularite-andradite.--Garnet is a characteristic gangue mineral in the lead-silver-zinc deposits in the Darwin Hills. It is a pale green variety that occurs in dodecahedrons a few millimeters in diameter. The garnet is slightly birefrigent, and it has an index of refraction of 1.848 to 1.850. The specific gravity averages about 3.75, and ranges from 3.583 to 3.885 as determined on a Berman balance. The garnet is nearer the andradite end of the grossularite-andradite series.

Idocrase.--Fine- to medium-grained idocrase is common in the lead-silver-zinc deposits in the Darwin district, and it is abundant in the surrounding calc-silicate rock. It is present in subhedral to euhedral prismatic grains mostly 2 to 4 mm long that are light olive in color. The idocrase is coarser grained and more abundant near intrusive contacts.

Jasper.--Jasper is a common gangue mineral in the veins at the Santa Rosa mine and in the N. 70° E. veins in the Darwin district. It is cryptocrystalline silica that is colored dark red to dark reddish-brown by iron oxides.

Montmorillonite.--Montmorillonite, intergrown with deweylite in a fault zone in the irregular replacement ore body in the Defiance workings of the Darwin mine, was identified by Fred A. Hildebrand (written communication, 1953). It forms amorphous pale greenish-yellow masses.

Quartz.--Quartz is not abundant in most of the lead-silver-zinc deposits, but some is present with calcite and garnet in the ore at Darwin.

Sericite.--Sericite is a common alteration product along some of the fault zones in the Darwin mine.

Wollastonite.--Wollastonite is one of the most abundant minerals in the calc-silicate rock close to intrusive contacts, and locally coarsely crystalline aggregates consist of prismatic crystals as much as 6 inches long. The grain size decreases rapidly away from intrusive contacts.

Supergene minerals

Most of the near-surface, high-grade supergene ore was mined out in the 1870's so little of this ore was seen in place. Most minerals were identified from specimens kindly donated by The Anaconda Company or from specimens collected from dumps. Some specimens of low-grade oxidized ore were collected in the Darwin mine and Santa Rosa mine. The occurrences of the supergene minerals are not well known and, therefore, they are not described separately.

Sulfide zone.--Very little supergene enriched ore remains in the Darwin quadrangle, but small amounts of chalcocite, covellite, and sooty argentite are present locally. Chalcocite and covellite form black coatings on pyrite, and thin veinlets replace the primary ore minerals. Sooty argentite is present in some of the high-grade oxidized silver ore. It undoubtedly was abundant in the rich oxidized ore mined in the 1870's.

Oxide zone.--The zone of oxidation is deep at most places in the Darwin quadrangle, and the ore is largely oxidized to a crumbly mass composed mainly of cerussite, limonite, and hemimorphite, except where protected by an impermeable zone or in the deep levels of a few mines. At the Lucky Jim mine the ore is oxidized and only a few relicts of galena remain in the deepest workings on the 920-foot level. At the Darwin mine the ore is largely oxidized to the 400-foot level, and both primary and secondary minerals are present to the deepest level--the 1100-foot level of the Defiance workings.

Cerussite, the principal secondary lead mineral, forms radial aggregates of euhedral crystals as much as one inch long that rest upon porous finer grained masses of limonite, cerussite, and other oxidized lead minerals. The larger crystals are white with a vitreous luster; the smaller crystals are yellowish or brownish owing to surface coatings of iron oxides. Anglesite, crocoite, mimetite, plumbojarosite, pyromorphite, stolzite, vanadinite, and wulfenite are less abundant secondary lead minerals in the Darwin mine. Anglesite commonly forms a thin dense zone between relict galena and cerussite. Clusters of stolzite in oxidized lead ore at the Thompson mine are reported by Tucker and Sampson (1941, p. 567) and by Dudley L. Davis (oral communication, 1955). The occurrence was not verified by the writer. Leadhillite was identified from the Santa Rosa mine, but was not observed in the Darwin district.

Secondary copper minerals are common in the oxidized lead-silver ore at the Santa Rosa mine and in the Darwin mine, and formerly both linarite and caledonite were common ore minerals from Darwin. In addition, antlerite, aurichalcite, azurite, brochantite, chalcanthite, chrysocolla, cuprite, malachite, and tenorite were identified. Pseudomalachite has been reported by Woodhouse (<u>in</u> Murdoch and Webb, 1956, p. 260).

Some of the oxidized near-surface ore mined during the early history of the Darwin district is reported to have contained as much as 950 ounces per ton in silver (Raymond, 1877, p. 30). Native silver, cerargyrite, and sooty argentite are reported in the oxidized ore at Darwin (Kelley, 1938, p. 546; Davis and Peterson, 1948, p. 2; Carlisle and others, 1954, p. 46).

Gypsum, hematite, jarosite, and limonite are common gangue minerals in the oxidized lead-silver ore, and bismutite, creedite, goslarite, melanterite, pyrolusite, and sulfur are less abundant minerals. Vitreous white prismatic crystals of creedite line cavities in partly oxidized lead ore containing galena and fluorite. Vivianite crystals on quartz have been reported by Woodhouse (<u>in</u> Murdoch and Webb, 1956, p. 343). Goslarite and melanterite are present in some of the workings in the Darwin mine. Bismutite was observed only in the Fernando mine as coatings on bismuthinite crystals, but it may have been present in the oxidized ore from the Essex vein of the Darwin mine as this vein contained considerable bismuth.

Hemimorphite is the predominant secondary mineral in the oxidized zinc ore at the Zinc Hill and Lee mines. It has a mammillary habit, and the color ranges from colorless to white, pink, green, gray, or brown. The local pink color at the Zinc Hill mine is due to a thin coating of hematite. Hydrozincite and smithsonite are near the borders of the secondary zinc ore bodies and in fractures below them.

Cerargyrite and bindheimite are associated with hemimorphite at the Lee mine. Euhedral crystals of cerargyrite 1 to 2 mm in diameter in the form of cubes commonly modified by octahedral faces locally are abundant in cavities in the hemimorphite. Autunite is present in small pockets in oxidized ore in the Zinc Hill district--none was found in the Darwin district.

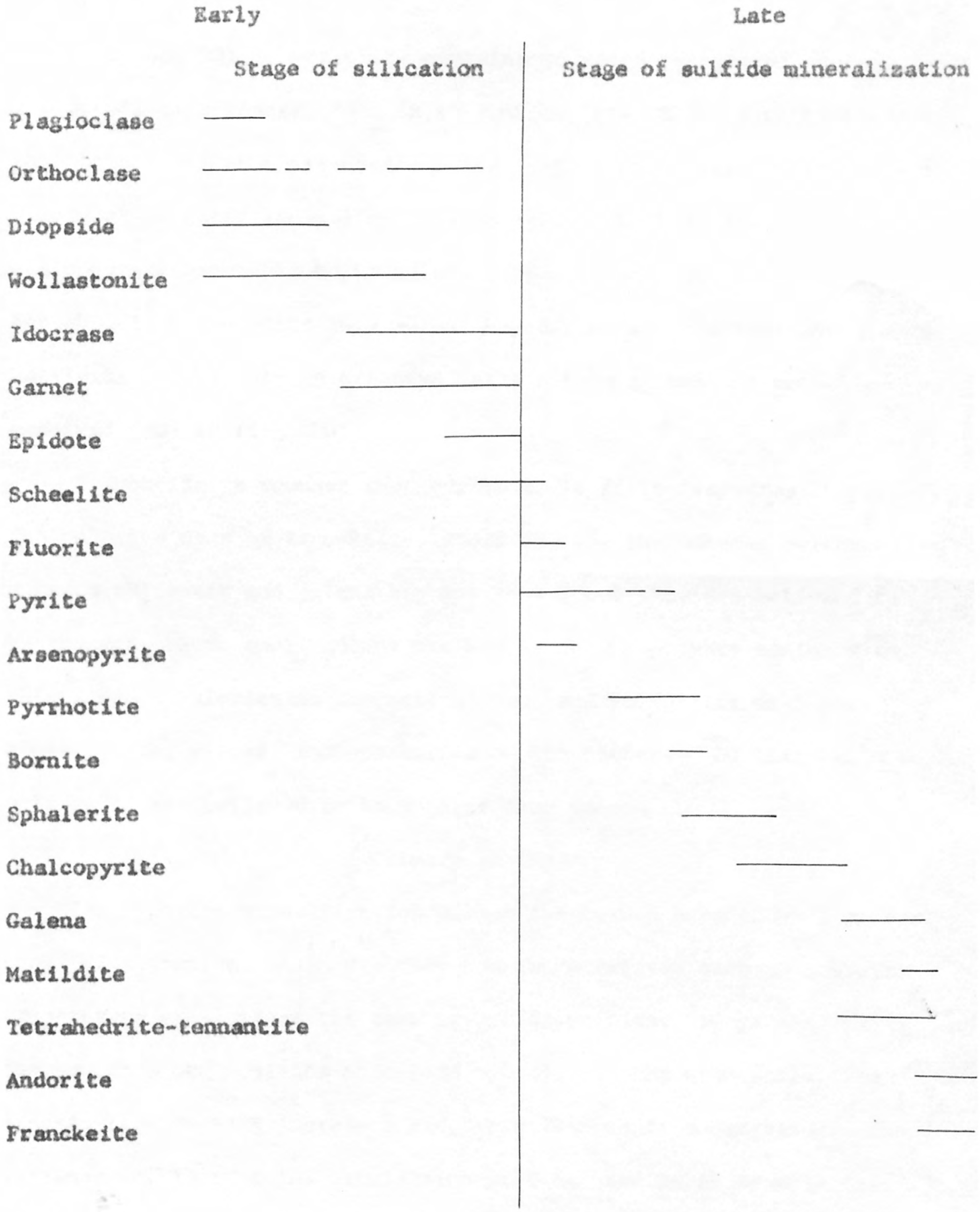
Paragenesis

The paragenesis of the principal ore and gangue minerals is shown diagramatically in table 4. The mineralization is divided into an early stage of silication of limestone and a later stage of sulfide mineralization. A period of fracturing separates the two stages.

Limestone was altered first to dense, aphanitic calc-hornfels. With increasing intensity of alteration, wollastonite increased in grain size and was replaced by andradite garnet and by idocrase, forming a coarse-grained idocrase-garnet-wollastonite calc-silicate rock (fig. 14). Locally orthoclase replaces the calc-silicate rock (fig. 17).

Scheelite, the earliest ore mineral, is in part later than the period of silication as shown by its common occurrence along fractures, but at the Jackass mine scheelite, disseminated in calc-silicate rock, formed during the last stage of silication. Pyrite is the earliest sulfide mineral. It replaces garnet (fig. 22) and idocrase and is later than scheelite as shown by its filling between euhedral scheelite crystals in ore from the Thompson workings. Pyrite occurs as corroded relicts or is veined by all the other sulfide minerals. It is corroded

Table 4.--Paragenesis of principal primary ore and gangue minerals.



by pyrrhotite but apparently is contemporaneous with rare arsenopyrite. Sphalerite, chalcopyrite, and galena contain corroded relicts of pyrite (figs. 22 and 23). Pyrrhotite contains corroded relicts of pyrite, and occurs as oriented blebs in sphalerite (fig. 21). Bornite forms thin borders on some pyrrhotite blebs (fig. 21B). Chalcopyrite occurs mainly as oriented inclusions in sphalerite. Both sphalerite and chalcopyrite are replaced by galena (figs. 21 and 23). Galena and tetrahedrite-tennantite show mutual boundaries and are contemporaneous. Matildite occurs only as oriented laths within galena and probably exsolved from it (fig. 20).

Franckeite is younger than pyrite as it fills fractures in pyrite. The relative ages of franckeite, andorite, and the unknown selenium-bismuth sulfosalt and galena are not known, but they are believed to be younger. Some small galena ore bodies show a primary zoning with galena and sphalerite in the central part and sulfosalts with only minor pyrite, galena, and sphalerite on the borders. On this basis the sulfosalts are believed to be younger than galena.

Primary zoning

The hypogene mineralization within the Darwin area shows a general zonal distribution, which probably can be correlated with an overall temperature gradient at the time of ore deposition. In general the near-surface ore contains more lead and silver, but with depth, the zinc-to-lead content increases and the silver content decreases. The Defiance workings of the Darwin mine will be used as an example (see pl. 7). The near-surface primary ore above the 400-foot level in the

bedded deposits, such as the Red and Blue veins, consisted mainly of galena with an above-average content of silver. The gangue minerals are largely calcite, fluorite, and jasper. The upper part of the vertical replacement ore body below the bedded deposits consisted predominantly of galena that contained less silver than the bedded deposits. Some sphalerite is present in this ore. With increasing depth in the vertical replacement ore body the ratio of zinc to lead increases and the silver content decreases slightly. Pyrite markedly increases below the 1000-foot level, and chalcopyrite locally is abundant. The gangue minerals are predominantly garnet, wollastonite, and calcite. It must be emphasized, however, that there are many local variations within this general zonal distribution.

The relative position of the lead-silver and tungsten ore bodies on the east side of the Darwin stock also suggests zoning. The lead-silver ore bodies are farther out along the same faults that control tungsten ore bodies (fig. 2).

Scheelite with little or no associated galena is found along the Fernando fault in calc-silicate rock and calc-hornfels in the Fernando adit as far as 660 feet from the contact of biotite-hornblende-quartz monzonite (pl. 2). Lead-silver ore is found along the same fault 450 feet farther from the igneous contact than scheelite at the old Fernando workings. Similarly the scheelite ore at the St. Charles No. 3 workings is close to the stock, and the lead-silver ore on one of the same fractures at the Custer mine is farther from the intrusive. Scheelite in Lane Canyon is found in calc-silicate rock along the crest of an anticline 450 feet from the contact of the intrusive but lead-silver ore at the Lane and Santa Ana mines to the east is farther from the intrusive.

The Jackass mine, where both scheelite and lead-silver ore are found within a few feet of each other, is an exception to the spatial zoning on the east side of the stock. Scheelite is disseminated in calc-silicate rock while the lead-silver ore with no scheelite is in a bedding plane fault at the footwall contact of tactite with calc-hornfels and is undoubtedly later.

Oxidation and enrichment

Prior to 1942 mainly oxidized lead-silver ore had been produced from the mines in the Darwin quadrangle. At most places the zone of oxidation is rather deep except where local conditions restrict the circulation of groundwater, and oxidized ore is known to a depth of over 1,000 feet. All the northeast-striking faults have permitted deep circulation of groundwater, and the ore in or near them is mostly oxidized. In the Darwin district some oxidized ore is present on the deepest levels of all the mines. At the Lucky Jim mine nearly all the ore is oxidized to the 920-foot level. In the Darwin mine most ore below the 570-foot level in the irregular replacement ore body in the Defiance workings is hypogene, but along or near the Defiance fault the ore is partly oxidized to the bottom workings on the 1100-foot level. On the other hand, sills have restricted the circulation of groundwater, and the ore under them is mainly primary.

Most of the ore at both the Santa Rosa and Lee mines in the northern part of the quadrangle is oxidized. At the Santa Rosa mine the ore is oxidized at the bottom of the Hesson workings 350 feet below the surface. Oxidation is shallow in the Zinc Hill district. The upper ore body at the Zinc Hill mine was oxidized for 20 to 40 feet below the surface, and at the Empress mine primary ore extends to the surface. Two factors are responsible for the shallow depth of oxidation at Zinc Hill. First, the topography is rugged and rapid erosion prevents deep weathering. Second, strong basin-range fault zones uphill from both the Empress ore body and the upper ore body at the Zinc Hill mine drain off a large part of the descending surface and groundwater before it reaches the ore zone and thereby inhibits oxidation of the ore.

Residual enrichment by leaching of calcium, iron, sulfur, zinc, and probably silica has been important in the Darwin district and at the Santa Rosa mine. The oxidized ore consistently averages less zinc and more lead and silver than the primary ore. At the Darwin mine the primary ore during the period 1950 to 1954 averaged about 6 ounces of silver per ton, 6 to 6½ percent lead, and 6½ to 7 percent zinc. The oxidized ore mined from the same general areas during the same period averaged about 7 ounces of silver per ton, 7½ percent lead, and 4½ to 5 percent zinc. Old records and the early literature both indicate that the near-surface oxide ore was considerably richer in lead and silver. Complete smelter returns of the New Coso Mining Company from 1875 to 1877 show that they recovered 20.5 percent lead and 47 ounces of silver per ton of ore from the Christmas Gift and Lucky Jim mines (Robinson, 1877, p. 38). Burchard (1884, p. 164) states that the Defiance and Independence ore averaged 30 percent lead and $40 (31 ounces) of silver per ton. The zinc content of this high-grade oxide ore was low. Small pods of high-grade ore observed in the Darwin mine consist predominantly of cerussite, relict galena, and minor gangue. The grade is erratic, but typically the ore assays 12 to 25 ounces of silver per ton, 20 to 25 percent lead, and 3 to 4 percent zinc.

The mineralogy of the oxide ore depends upon the nature of the primary ore. The lead-silver-zinc deposits with abundant pyrite, which liberates sulfuric acid in weathering, are enriched in lead and silver and lose zinc in weathering. Examples are the deposits in the Darwin district and the Santa Rosa mine. There is little transportation of lead, and the oxide ore, commonly with relict galena scattered through it, has the same structural control as the primary ore. Galena altered first to anglesite and then to cerussite, which is insoluble and formed essentially in place. Sphalerite was attacked by the groundwater, and much of the zinc was removed in solution, although some was precipitated as hemimorphite and hydrozincite.

The oxidation of the ore at the Zinc Hill and Lee mines where the ore contains little pyrite apparently was done by groundwater that contained no free acid, and the stability relationships of the supergene minerals are different from that prevailing at Darwin where oxidation was done by acid groundwater. Zinc in the form of hemimorphite is a stable mineral and forms high-grade zinc-rich ore bodies essentially in situ. Silver is present in cerargyrite. Very little lead--mostly as relict galena--is present in the ore. This is in marked contrast to Darwin where zinc is leached, and the oxidized ore is rich in lead and silver and is low in zinc. At both the Lee and Zinc Hills mines, the primary ore consists mainly of sphalerite and galena, and little pyrite or chalcopyrite is present. At the Lee mine the primary ore consists mainly of coarsely crystalline galena and nearly colorless sphalerite in a gangue of barite, calcite, chalcedony, and quartz. As the accessible workings extend less than 75 feet below the surface, all the observed ore is in part oxidized and it was not possible to determine the ratio of sphalerite to galena in the primary ore. Relict galena is common in the oxidized ore, but only small amounts of nearly colorless sphalerite were found. It seems likely that the ratio of sphalerite to galena in the primary ore was much higher than the ratio that is present now in the partly oxidized ore and that the sphalerite was readily altered to hemimorphite.

Classification and origin

The ore deposits in the Darwin district occur in light-colored calc-silicate rock, and calc-hornfels as irregular replacement ore bodies, bedded replacement ore bodies, and as fissure fillings. Other lead-silver-zinc deposits in the quadrangle are in veins or bedded deposits in calc-hornfels, marble, and limestone. The deposits in the Darwin district were considered by Knopf (1914, p. 7) to range from contact metamorphic to fissure fillings of hydrothermal origin at moderate temperature, and by Kelley (1937, p. 1007; 1938, p. 550) to be mesothermal deposits.

The distribution of deposits shows a close spatial control between ore deposits and intrusive bodies. However, the ore deposits are younger than both the intrusive rock and the surrounding contact metamorphic aureole, as shown in the Darwin district where ore is localized in fractures that cut both the Darwin stock and calc-hornfels. Because the sulfide mineralization is younger than the silication in the contact aureole and because some of the deposits are fissure fillings that have a regularity in strike and dip, Kelley (1937, p. 1007) considered all the deposits to be mesothermal and to be genetically identical.

The writer, however, agrees with Knopf that the deposits were deposited over a range in temperature. In places a mineral zoning can be demonstrated, as on the east side of the Darwin stock where chalcopyrite and scheelite bodies are nearly adjacent to the stock and lead-silver ore bodies are more distant. Ore in the Defiance workings shows a vertical zoning. The near-surface ore is in bedded deposits that contain coarsely crystalline calcite, jasper, and fluorite as common gangue minerals. On the deeper levels the ore is in an irregular replacement ore body that has andradite, wollastonite, idocrase, orthoclase, and calcite as common gangue minerals. In the replacement ore body the ratio of zinc to lead, the chalcopyrite content, and the pyrite content increase with depth.

The writer believes the irregular replacement ore body in the Defiance workings should be classified as a pyrometasomatic deposit on the basis of mineral association. Andradite and idocrase are the principal gangue minerals. Pyrite is widely disseminated through the calc-silicate rock, but the other sulfide minerals are late in the sequence and are controlled in general by brecciated zones in the silicated limestone. There appears to have been a nearly continuous sequence of mineralization. The limestone was first altered to calc-hornfels and light-colored calc-silicate rock, and this resulted mainly in an increase in silica and decrease in carbon dioxide. Scheelite was deposited during the last phase of the silication. A period of fracturing separated the silication of the limestone from the introduction of sulfide and ore minerals. The early formed lead-zinc ore bodies are replacement ore bodies that have mainly a silicate gangue, as the vertical replacement ore body in the Defiance workings. Scheelite is a common mineral in the replacement ore. With falling temperature the hydrothermal solutions apparently became less reactive, and the resultant mesothermal deposits filled fissures or made bedded deposits. Calcite and jasper are the main gangue minerals in these mesothermal deposits. Examples are the Blue and Red veins exposed at the surface of the Defiance workings, the Essex vein, and ore at the Lucky Jim, Christmas Gift, and Santa Rosa mines.

Ore at the Zinc Hill and Lee mines was deposited under even less intense pressure-temperature conditions, and they might be considered leptothermal deposits. Ore at the Lee mine is in faults in unaltered limestone. Calcite and barite are the main gangue minerals. Galena, light-colored sphalerite, and minor tetrahedrite are the principal ore minerals. Pyrite is rare. Possibly the antimony deposit in unaltered limestone at the north end of the Darwin Hills is a still weaker phase of the sequence of late Mesozoic mineralization. However, this is an isolated deposit, and it is not known whether it belongs in the mineralization sequence related to the Darwin stock.

In order to get further data on the temperature of deposition of the lead-silver-zinc ores in the Darwin quadrangle, 4 samples of sphalerite were analyzed for FeS content, which might be used as a temperature scale as shown by Kullerud (1953) and as applied by Fryklund and Fletcher (1956) to ore in the Star mine in the Coeur d'Alene district. Copper was also determined so that a correction could be made for iron in chalcopyrite blebs in sphalerite. The analyses in table 5 show that the FeS content ranged from 0.24 molecular percent in colorless sphalerite from the Lee mine to 14.40 percent for sphalerite from replacement ore in the Defiance workings of the Darwin mine. This indicates a probable range of temperature of from less than 138° C. for the ore in the Lee mine to 430° C. for ore in the Darwin mine if the ore was deposited at atmospheric pressure. The correction for total pressure would increase these figures approximately 25° C. for each 1,000 atmospheres total pressure.

Sphalerite from the Defiance workings locally contains exsolved pyrrhotite blebs oriented within the crystal, and it is probable that equilibrium was obtained in the (Fe,Zn)S crystal. The 14.40 molecular

Table 5.--ZnS-FeS content of sphalerites from the Darwin quadrangle.

	Dsl 1	Dsl 2	Dsl 3	Dsl 4
Zn	65.83%	65.09%	61.40%	55.53%
Fe	0.13	0.39	3.38	7.49
Cu	.0	0.0	0.0	0.13
Weight percent				
ZnS	99.80	99.37	94.50	87.75
FeS	0.20	0.63	5.50	12.25
Molecular percent				
ZnS	99.76	99.26	93.54	85.60
FeS	0.24	0.74	6.46	14.40
Color of sphalerite	Colorless	Light ruby	Resin	Dark resin
Mineral association	Calcite, barite	Calcite	Jasper, pyrite	Andradite, idocrase, pyrite, pyrrhotite
Temperature of deposition (from Kullerud)	138° C.	138° C.	180° C.	430° C.

Dsl 1 Sphalerite from the Lee mine.

Dsl 2 Sphalerite from the Zinc Hill mine.

Dsl 3 Sphalerite from the Santa Rosa mine.

Dsl 4 Sphalerite from the replacement ore body in the Defiance workings of the Darwin mine.

percent FeS in the β(Fe,Zn)S crystal indicates a temperature of 455° C., assuming deposition at 1,000 atmospheres total pressure.

The β(Fe,Zn)S crystal from the Santa Rosa mine may not be in equilibrium as no pyrrhotite is known in the deposit, and the indicated temperature of 180° C. (uncorrected for pressure) must be considered a minimum temperature. Pyrite and chalcopyrite are associated with the sphalerite. Kullerud's (1953) temperature curves are for the system FeS-ZnS and to use the same curves for the assemblage pyrite-sphalerite must be done with reservations. Kullerud (1953, p. 107) published data obtained by T. Rosenqvist on the FeS activity of iron sulfides of composition ranging from FeS to FeS_2. Rosenqvist's studies show that the FeS activity of FeS_2 is less than 5 percent smaller than that of stoichiometric FeS, but that when sulfur is added in excess of that indicated by the FeS_2 formula, a sharp drop occurs in the FeS activity.

It is probable that the β(Fe,Zn)S crystals from the Zinc Hill and Lee mines are not in equilibrium as both deposits contain very little pyrite and no pyrrhotite. The indicated temperatures of both deposits must be considered minimum temperatures.

Descriptions of pyrometasomatic lead-silver-zinc deposits are not numerous in the literature. Knopf (1933, p. 552) lists only the Darwin district as an example of a lead-silver-zinc pyrometasomatic deposit. Lindgren (1933, p. 724-725) includes the Magdalena mine in New Mexico, zinc deposits at Hanover, New Mexico, the Sirena mine near Zimapan, Mexico, and the Darwin district. More recently Simons and Mapes (1956) have described the deposits of the Zimapan district, which, like the

Darwin deposits, grade from pyrometasomatic replacement deposits in a silicate gangue to mesothermal deposits in a carbonate gangue. Jasper though is not as common as it is in the mesothermal deposits at Darwin. In addition to a change of gangue minerals, the mesothermal deposits at Zimapan contain less arsenopyrite, chalcopyrite, and pyrrhotite and the sulfide minerals are coarser grained than the pyrometasomatic deposits. The lower temperature deposits in the Darwin quadrangle, like those at Zimapan, are coarser grained and show an approximate similar zonation of ore and sulfide minerals.

Darwin lead-silver-zinc district

The Darwin lead-silver-zinc district comprises the area of the Darwin Hills in the south-central part of the Darwin quadrangle. It lies within the legally constituted New Coso mining district. The district has yielded an estimated production of 29 million dollars in lead, silver, zinc, and minor copper. Most of the production came from the Darwin mine, which consists of a consilidation of the former Bernon, Defiance, Essex, Independence, Intermediate, Rip Van Winkle, and Thompson mines.

Geology

The Darwin Hills are underlain by a thick sequence of limestone, silty and sandy limestone, shale, and minor siltstone that ranges in age from Devonian on the west side of the Darwin Hills to Permian on the east (pls. 2 and 5). The formations represented are Lost Burro formation, Tin Mountain limestone, Perdido formation, Lee Flat limestone, Keeler Canyon formation, and Owens Valley formation. The

Paleozoic rocks are intruded by biotite-hornblende-quartz monzonite in the central part of the district and in the Coso Range west of the Darwin Hills. The Paleozoic rocks dip predominantly to the west except for minor local folds. Within 4,000 feet of the biotite-hornblende-quartz monzonite in the Darwin Hills the sedimentary rocks are mostly metamorphosed to calc-hornfels. A description of the unaltered rocks is given under "Stratigraphy", and the alteration is described under "Rock alteration".

Ore deposits

Three of the four structural types of lead-silver-zinc ore bodies in the Darwin quadrangle are in the Darwin district. They are bedded deposits, irregular replacement ore bodies, and vein deposits in fissures. Bedded deposits are the most common. Notable examples are the bedded ore bodies in the Independence workings (pl. 6), the 430 stope ore body and Blue, Red, and Green veins in the Defiance workings (pl. 7), and the ore bodies at the Custer, Jackass, and Promontory mines.

The largest bedded ore body is in the Independence workings between the 200- and 400-foot levels along the crest of an anticlinal-shaped fold between two quartz monzonite sills, and directly below the Davis thrust (pl. 6). The ore zone extends 400 feet along strike, a maximum of 160 feet thick, and 700 feet across the crest and down the west limb of the fold. It must be emphasized that not all this is ore. Individual stopes within this ore zone have maximum dimensions of about 140 feet long, 60 feet wide, and 40 feet high. The contacts of individual ore bodies in this ore zone are mostly sharp, and only barren calc-silicate rock or highly pyritized calc-silicate rock lies between individual ore bodies.

Two readily accessible bedded ore bodies--the Blue and Red veins--are well exposed at the surface of the Defiance workings of the Darwin mine. The shapes of the ore bodies may be inferred from the surface stopes, which have remained open since the ore was mined in the 1870's (pl. 7). The bedded veins are along the crest and west limb of an anticlinal-shaped fold between two sills of quartz diorite (pl. 5 and pl. 7). On the Defiance tunnel level the Blue vein is about 300 feet long, 2 to 8 feet thick, and has been mined discontinuously for 400 feet down the dip. The Red vein is exposed intermittently by stopes for a strike length of 400 feet. It is 2 to 6 feet thick and has been mined 500 feet down the dip. The contacts of the veins and pyritized calc-silicate country rock are sharp. The grade of ore within the veins, however, is erratic, and considerable low-grade ore was left behind in mining.

The ore body mined from the 430 and 520-12 stopes is another important bedded deposit in the Defiance mine. The ore body was about 150 feet long, 40 feet thick, and extended about 360 feet down the dip. The shape, nature of the ore, and method of mining of this ore body are described in detail by Davis and Peterson (1948, p. 3-6). It extended from the 110- to the 520-foot level. Below the 520-foot level the ore occurs as a steep irregular replacement of calc-silicate rock.

The only important irregular replacement ore zone is in the Defiance workings adjacent to the Defiance fault (pl. 7). It is a vertical mineralized zone that has been developed from the bottom of the bedded ore bodies at the 520-foot level to the 1000-foot level. The average cross sectional area of the mineralized zone is about 350 feet long and 200 feet wide. On the 700-foot level 12 percent of an area 400 feet long and 130 feet wide is ore, and on the 800-foot level 15 percent of an area about 320 feet long and 220 feet wide is ore. Contacts of individual ore pods within this zone are gradational. The pre-mineral Defiance fault, which strikes northeast and dips steeply to the northwest, cuts diagonally through the mineralized area. Numerous small faults are localized close to this fault and formed a strongly brecciated zone that served to localize later ore solutions.

Vein deposits are in persistent faults in many mines in the district. Three sets of faults have localized ore--they are steep N. 70° E.-striking faults, steep N. 70° W.-striking faults, and steep north-striking faults. The most notable N. 70° E.-striking veins are at the Christmas Gift, Darwin, Lane, and Lucky Jim mines. At the Christmas Gift mine an ore shoot has been mined from the Christmas Gift vein between the surface and the No. 6 level, a vertical distance of 146 feet. The ore shoot has a strike length of 160 feet and an average thickness of 3 feet; it plunges steeply southwest. The ore shoot at the Lucky Jim mine has a maximum strike length of 460 feet on the 200 level, and it plunges steeply to the southwest. The ore shoots at both mines are localized in parts of the faults that strike nearly northeast, and the parts of the faults with more easterly strike are mostly barren. Other smaller northeast-striking veins are the 229 and 235 ore bodies in the Thompson workings, ore bodies along the Mickey Summer and Water tank faults in the Rip Van Winkle mine, and the Lane vein in the Lane mine (see Hall and MacKevett, in press).

The only economically important steep northwest-striking vein is the Essex vein in the Darwin mine (pl. 8). It is a high-grade vein that has a maximum length of about 500 feet, an average thickness of 8 feet, and has been mined 650 feet vertically. The other two major northwest-striking faults--the Darwin tear fault and the Standard fault--contain very little ore.

Steep north-striking faults have had some effect in localizing ore. The bedded ore bodies commonly make out along bedding from an intersection of a steep fault.

Geochemical prospecting

The distribution in residual soil over calc-silicate rock of lead, zinc, copper, silver, antimony, and bismuth in relation to lead-silver-zinc ore bodies in the Defiance-Bernon area of the Darwin mine was investigated during August 1954 (pl. 10). Approximately 400 residual soil samples were collected on a grid at 50-foot intervals by James Prentice, Sampler for the Geochemical Exploration Section of the U. S. Geological Survey, in the Bernon and Defiance areas, and about 100 chip samples were collected on the Defiance tunnel level and the 570-, 700-, and 800-foot levels of the Defiance workings by E. M. MacKevett, Jr. and the writer. Each sample was analyzed for lead, zinc, and copper and about a third were analyzed for antimony, bismuth, and silver; these trace analyses were made by H. E. Crowe of the Geochemical Exploration Section.

The area around two veins that crop out in the open cuts in the Defiance workings along the crest of an open anticlinal-shaped fold near the Defiance fault was sampled as a known area (pl. 10). The fold is continuous between the Defiance and Bernon workings, but as little ore is known in this geologically favorable area, it was sampled as an area favorable for undiscovered hidden ore. It is cut by two N. 70° E. faults--the 434 and Bernon. Some ore was mined from the Bernon workings, but it does not crop out at the surface. Very little ore is known along the 434 fault.

Sampling procedure.--Soil samples were taken on a 50-foot grid system over the Bernon and Defiance area. The samples were taken at a depth of about 4 inches. Each sample was screened through an 80-mesh screen and the coarse material was rejected. Each sample weighed about two pounds. Chip samples were taken at 25-foot intervals in the underground workings of the Defiance ore body. Small chips were collected from the back if possible or from the wall over a radius of 3 feet. About 15 grams were collected for each rock sample.

Distribution of lead-zinc-copper.--The distribution of total lead-zinc-copper in residual soil is shown in plate 10. The distribution of the plutonic rocks and the location of the principal faults is also given. The strongest anomaly of total lead-zinc-copper expressed in parts per million (ppm) is over the Defiance workings. The anomaly over the Defiance workings is probably much greater than 7,000 ppm, but the maximum quantities determined in the Geochemical Prospecting analytical laboratory at the time of the exploration was 4,000 ppm for lead and 3,000 ppm for zinc and all the samples within the 7,000 contour were over the maximum. In subsequent work the maxima were increased to 5,000 ppm for both lead and zinc. The copper assays were mostly less than 200 ppm.

In the Defiance area the 7,000 ppm contour outlines the area over the known ore bodies, and the anomaly is elongated along the Defiance fault, which probably is the feeder channel. The anomaly drops off in about 300 feet to a background in the mine area of 1,000 to 2,000 ppm. The background of soil over unaltered limestone several miles from the mine area is only 120 ppm of total heavy metals.

Most of the area near the 434 fault is a geochemical low in total lead-zinc-copper. A small high is present near the western end of the fault near the intersection with the Davis thrust, but no ore is known in this area. As a whole the 434 fault has much less lead-zinc-copper than the other N. 70° E. faults that were sampled.

The hidden Bernon ore body 70 feet below the collar of the Bernon shaft is reflected by a geochemical high. The high extends farther south than known ore. Two geochemical anomalies between the Bernon and Copper faults have not been explored. One is 300 feet N. 5° W. of the Bernon shaft in an area that has considerable disseminated limonite at the surface. The other anomaly is at the contact of the Darwin stock midway between the Bernon and Copper faults. The whole Copper fault is another geochemical high, similar to the Defiance fault, but only a small amount of exploration work has been done along it.

Antimony, bismuth, and silver were determined on about a third of the samples. Only the bismuth values are contoured on the anomaly map (pl. 10). The bismuth content of the residual soil ranges from less than 10 to 350 ppm. The bismuth anomalies agree in general with the anomalies shown by total lead-copper-zinc. Adjacent to the Defiance ore bodies the bismuth content ranges from 100 to 350 ppm, and it drops off to 10 to 15 ppm beyond 80 feet from ore. Another bismuth high is 260 feet S. 80° W. of the Defiance shaft. This is about 300 feet above the 430 and 520-12 stope ore body in the Defiance workings and may be an anomaly reflecting it.

Most of the area between the Defiance and Bernon workings contains less than 10 ppm of bismuth. The bismuth increases to 70 to 90 ppm over the Bernon ore body. Several analyses in the northeastern part of the area tested suggest that the bismuth is considerably above background. The total lead-zinc-copper is high in this area also, but no ore is known.

Antimony and silver seem to be unsatisfactory in reflecting ore. The content of antimony and silver in the ore is high, but the content of each in residual soil falls off to background values generally within a few feet of ore. The antimony content of the Defiance ore is 45 to 100 ppm. Twenty-feet from ore in residual soil the antimony content falls off to less than 15 ppm. Most of the soil between the Bernon and Defiance workings contains less than 4 ppm of antimony. Over the Bernon ore body the antimony content increased to 15 to 40 ppm. The ore in the Defiance pit assayed from 4 to 9 ounces of silver (140 to

315 ppm), but the silver content dropped to less than 3 ppm in soil a few feet from ore. No anomaly in silver was apparent over the Bernon ore body. Over most of the tested area the silver content was less than 2 ppm.

In conclusion, geochemical prospecting of soil could be a useful tool in the Darwin district. Heavy metals (total lead-zinc-copper) and bismuth tests both gave promising results in the Defiance-Bernon area. The two known ore bodies in the tested area were reflected by pronounced anomalies. In addition, two anomalies were found in unexplored areas. Antimony seems less promising than bismuth in reflecting ore. The antimony content dropped off rapidly around the Defiance ore body, so it provided very little larger target than that of the ore body itself. The antimony was a little better in reflecting the Bernon ore body. Silver gave discouraging results. Nearly all the residual soil has less than 2 ppm of silver, and only the ore itself has a high silver content.

Rock chip samples were not as satisfactory in reflecting ore as the soil samples. Some rock chip samples taken as a comparison with residual soil samples in general contained less total heavy metals, and gave more erratic results. The underground rock chip samples, in general, increased in total heavy metal content toward ore bodies, but the analyses were quite erratic and many samples gave anomalous results.

Future of the district

New ore in the Darwin district has been found in the past mainly by following downward ore bodies exposed at the surface or in the upper workings of the mine. This procedure has proven highly successful, but during the past few years most of the major ore bodies apparently are bottoming in low-grade pyritic ore. The future of the district lies in finding new major ore bodies rather than extensions of old ones.

The possibilities for finding new ore bodies have not been exhausted. A mastery of the stratigraphy, structure, and rock alteration and their relationship to ore is essential to a successful program. Many areas remain to be explored from the present workings of the Darwin mine, but enough drilling has been done to make chances of discovery of another large ore body like the Defiance seem dim. Ore in the Darwin mine is in a medium-grained idocrase-garnet-wollastonite rock; dense, dark calc-hornfels like that west of the Davis thrust and unaltered limestone are unfavorable. Nearness to an intrusive is important, and the largest ore bodies are within a few hundred feet of granitic rock. Faults play a part in localizing all the known ore--even the bedded deposits are localized close to N. 70° E. faults, which appear to be feeder faults. Anticlinal-shaped structures are particularly favorable, although ore is not restricted to them. Recognition and intelligent use of these ore controls will undoubtedly result in the discovery of new, probably small, ore bodies near the present workings in the Darwin mine. In the Thompson-Essex-Independence workings the Davis thrust is an important ore control, and little or no ore has been found to the west or hanging-wall side of it. To the south in the Defiance workings where the contact of the Darwin stock and the

Davis thrust diverge, the fault seems to be less important in localizing ore except near the satellitic body of quartz monzonite southwest of the Defiance workings. As yet the shape of the Darwin stock is not known, and the term stock is used only because it was used in the past. However, on the west the intrusive ends in a series of sills that bottom in the Defiance workings (pl. 7), and a diamond-drill hole extending 700 feet east from the 800 level did not cut granitic rock. It is possible that the intrusive may have a floor and be a laccolith. If so, a large area under the outcrop of the intrusive may contain undiscovered ore bodies.

Very little work has been done southeast of the Defiance mine along the Water tank and Mickey Summers faults near the intrusive (pl. 5). The alteration is similar to that in the Defiance area, and much of the outcrop is ironstained. A few prospect pits have been dug in this area, but no exploration has been done in depth.

Another area of extensive garnet-idocrase-wollastonite rock that may be favorable for ore is north of the Standard fault on the footwall side of the west-dipping fault that passes through the Belle Union mine and the west side of the Lucky Jim mine area (fig. 2 and pl. 2). This fault is similar in all respects to the Davis thrust, and served to localize intense alteration of limestone below it. A geochemical prospecting program in this area similar to the one in the Defiance area might help pinpoint areas favorable for further prospecting.

Zinc Hill district

The Zinc Hill district is 6½ miles N. 65° E. of Darwin on the west slope of the Argus Range. Relief in the area is rugged, and access to some places is difficult. The average slope is about 30°. Individual properties are described in a previous report (Hall and MacKevett, in press) and only a generalized description is given here. The Zinc Hill and Empress mines are the only properties with a recorded production up to 1952. The Darwin Zinc mine has several hundred feet of workings, but no production record was found for it. The recorded production for the district from 1917 to 1951 is approximately 3,560,000 pounds of zinc, 285,000 pounds of lead, 8,500 ounces of silver, and 14,000 pounds of copper (compiled from Hall and MacKevett, in press).

Geology

The Zinc Hill district is underlain by limestone and marble of Mississippian and Permian age that are intruded by leucocratic quartz monzonite and by dikes and small irregular plugs of diorite. The stratigraphy of the area is given in table 6. Both the Empress and Zinc Hill mines are in marble and limestone of Mississippian age in a north-trending horst approximately 1,000 feet wide that can be traced from the Darwin tear fault north for 2 miles (pl. 2). A minimum thickness of 580 feet of unfossiliferous marble and limestone crops out in the horst. The section is correlated with the Mississippian on the basis of lithologic similarity to Mississippian formations found elsewhere in the quadrangle. The upper part of the Tin Mountain limestone,

Table 6.--Geologic column of the Zinc Hill district.

Age	Name	Lithology	Thickness (feet)
Cretaceous?	Diorite dikes and plugs		
Cretaceous	Leucocratic quartz monzonite		
Permian	Owens Valley formation	Limestone, thinly bedded, silty	
Fault contact			
Pennsylvanian(?) Mississippian	Lee Flat limestone(?)	Marble, white	130+
		Limestone, blue-gray, thinly bedded. Contains interbedded chert.	130
		Marble (ore horizon at Zinc Hill mine)	180
Mississippian	Perdido formation(?)	Marble with 2 to 4 inch chert beds	20
		Limestone, blue-gray, with bedded chert	100
	Tin Mountain limestone(?)	Limestone, blue-gray and marble	20+

the Perdido formation, and the Lee Flat limestone are probably represented within the horst, but it is all mapped as Lee Flat limestone as most of the marble within the horst resembles it.

The Owens Valley formation of Permian age crops out on the east and west sides of the horst. It consists of thinly bedded, silty bluish-gray limestone and minor shale.

The Zinc Hill stock, a small intrusive 5,000 feet long and 2,000 feet wide, crops out between the Empress mine and the Darwin tear fault. It is composed of medium-grained leucocratic quartz monzonite. Locally close to the stock the Mississippian limestone is altered to calc-hornfels and dark-brown tactite. Dikes and irregular plugs of fine-grained greenish-gray diorite and quartz diorite intrude the Mississippian marble and limestone in many places between the Empress and Zinc Hill mines, but most of these intrusives are too small to show on the quadrangle map (pl. 2).

Structure

The horst containing the productive mines is bounded by steep north-trending faults. Bedding within the horst strikes predominantly northwest to west and dips 10° to 40° N. and that in the Permian limestone on either side strikes mainly N. 45° to 75° E. and dips 17° to 63° NW. The Zinc Hill fault, which bounds the horst on the west and the major fault that bounds the horst on the east each have a stratigraphic displacement of over 2,700 feet. Within the horst the limestone and marble are cut by many steep faults that trend north to N. 45° E. and N. 45° to 70° W. These faults have had several periods of movement and many of them are mineralized or dolomitized. The latest movement on the northwest-trending faults is young because they displace the Zinc Hill fault, which has late Tertiary or Quaternary displacement.

The leucocratic quartz monzonite is within the horst, and is cut off on the west by the Zinc Hill fault. The Empress mine is in a roof pendant of Mississippian limestone.

Ore deposits

Ore occurs as small replacement bodies parallel to bedding and to a lesser extent along faults that cut a favorable limestone or marble bed (pl. 9). Both primary and oxidized zinc ore is present. The primary ore from the Zinc Hill mine is predominantly sphalerite with small amounts of galena, pyrite, and chalcopyrite in a calcite gangue that contains some quartz, jasper, and gypsum. The oxidized ore consists mainly of hemimorphite, but hydrozincite is abundant locally near the margins of some ore bodies, and smithsonite is rare in veinlets below ore bodies. At the Empress mine galena is predominant, with lesser amounts of sphalerite, chalcopyrite, and pyrite in a quartz-rich gangue. Secondary ore minerals are anglesite, azurite, cerussite, chrysocolla, malachite, and wulfenite.

At the Zinc Hill mine a favorable marble bed 180 feet thick crops out for 1,500 feet in a northwesterly direction. It is faulted off on both the east and west by the faults bounding the horst. Minable ore bodies are in four localized areas within the favorable bed. Intersections of north to N. 45° E. faults with the favorable bed are apparent ore controls.

The largest ore body is shown in plate 9. It is a bedded replacement of a marble bed, the Colorado bed of the owners. The lower stope in the upper workings is approximately 80 feet long, 60 feet wide, and 10 to 16 feet high. The outline of the stope reflects approximately the shape of the flat-lying, disc-shaped ore body. Approximately a third of the ore removed from this stope was primary and the rest was oxidized zinc ore. Primary ore extends to within 40 feet of the surface. Several smaller bedded deposits were mined from the lower, westernmost workings on the property.

Small oxidized zinc ore bodies in the lower workings of the Zinc Hill mine are localized along northwest-trending faults (Hall and MacKevett, in press). The most strongly mineralized fault, which strikes N. 60° W. and dips 30° to 50° NE., is stoped discontinuously for 200 feet along strike and 50 feet down the dip over a thickness of 3 to 12 feet.

At the Empress mine the ore body is a bedded replacement of limestone near the contact with leucocratic quartz monzonite, and the deposit extends as a quartz vein in the intrusive. Ore can be traced on the surface approximately 400 feet, where it ranges in thickness from a few inches to 6 feet. The ore body is thicker and higher grade at the north end within quartz monzonite and thinner and more discontinuous to the south in limestone.

Locally the ore at both the Empress and Zinc Hill mines is slightly radioactive. At the Empress mine local radioactivity ranged from 0.04 to 0.15 MR/hr against a background of 0.02 MR/hr. At the

Zinc Hill mine some ore containing hydrozincite in the lower workings had a local radioactivity of 4 to 10 times background. The source of the radioactivity was not definitely determined, although one specimen contained a small amount of a micaceous orange mineral, probably autunite.

Lee district

The Lee district comprises a small area in the southern part of the Santa Rosa Hills. The Lee mine (formerly known as the Emigrant mine) and the Silver Reid prospect are the only properties that have been developed (fig. 2). Production, which is recorded only from the Lee mine, was chiefly during the 1870's and early 1880's. De Groot (1890, p. 213) mentions that activity in the Lee district was waning by 1888. Since then the Lee mine has been operated only intermittently on a small scale by lessees.

The total production of the district is not known. Tucker and Sampson (1938, p. 443) report that 250 tons of ore shipped during 1927 averaged $49 (64 ounces) per ton in silver. L. D. Warnken shipped 226 tons of dump material in 1938 that contained 750 ounces of silver. The average grade of 246 tons of ore mined since 1951 is 4.53 percent lead, 20.1 percent zinc, and 67.4 ounces of silver per ton (Hall and MacKevett, in press).

Geology

The south end of the Santa Rosa Hills in the Lee district is underlain by a conformable sequence of limestone and marble of Devonian and Mississippian age (pl. 2). The Silver Reid prospect is in the Lost

Burro formation, which crops out in a narrow band along the east flank of the Santa Rosa Hills. The Lost Burro is conformably overlain by the Tin Mountain limestone, which underlies most of the Lee mine area.

Structure

The Paleozoic rocks strike N. 45° W. to west and dip mainly southwest in a concordant sequence. They are cut by two sets of faults. One set strikes N. 70° W. approximately parallel to the strike of bedding and dips steeply. The other set strikes N. 20° to 70° W. and dips gently southwest. The low-angle faults have no appreciable displacement and occur between the major steep faults. In the Lee mine the beds dip gently and the flat-lying faults are approximately parallel to bedding. At the Silver Reid prospect they transect the steeply dipping bedding.

Ore deposits

Small, discontinuous ore bodies are localized in flat-lying faults, and major steep faults are only slightly mineralized except at the intersection with the mineralized flat-lying faults. Locally ore bodies steepen adjacent to the major steep faults. At the Lee mine the largest ore body was about 40 feet long, 35 feet wide, and averaged 6 feet thick. Most of the ore bodies mined during the past few years are much smaller and have yielded less than 100 tons of ore each.

At the Silver Reid prospect the largest known ore body is 40 feet long, 20 feet wide, and averages 2 feet thick. The ore body is localized in a nearly horizontal fault between two steep N. 70° W. faults that are 22 feet apart. At least five other flat veins are exposed on the property, but they are not extensively developed.

The workings at both the Lee mine and the Silver Reid prospect are shallow. Most of the ore is oxidized and only relicts of the primary minerals remain. The ore at the Lee mine consists mainly of hemimorphite and cerargyrite. Anglesite, aurichalcite, azurite, bindheimite, native copper, cerussite, and chrysocolla have also been identified. Gangue minerals are principally barite, calcite, chalcedony, and quartz. Cerargyrite occurs as euhedral cubes less than 1 mm on a side modified by octahedral faces. Galena is the most abundant remaining primary mineral. It occurs as coarsely crystalline relicts in masses of hemimorphite. Cerussite and anglesite are present mainly as thin rims a few millimeters thick between the galena and cellular oxide ore. Minor amounts of sphalerite, pyrite, and tetrahedrite remain. Sphalerite probably was originally an abundant ore mineral, but as it is more readily attacked by groundwater than galena, little of it remains.

Tungsten deposits

Distribution

Tungsten has been recovered from the Darwin quadrangle principally from mines in the eastern part of the Darwin Hills 1 to 1½ miles east and northeast of Darwin (fig. 2). All of the deposits are contact metamorphic. Scheelite is the principal tungsten mineral. It has also been recovered from the Darwin mine from small high-grade concentrations in lead-silver-zinc deposits, and stolzite has been reported in the oxidized ore by Tucker and Sampson (1941, p. 567) and by Davis (Dudley L. Davis, oral communication, 1955). A small amount of scheelite has been mined from small deposits on the northeast slope of the Coso Range about 8 miles west and southwest of Darwin, mainly just south of the Darwin quadrangle. One deposit--the Lone Pinyon--lies within the quadrangle in sec. 26, T. 19 S., R. 39 E.

Previous work and acknowledgments

Hess and Larsen (1922, p. 268) first mentioned the occurrence of scheelite in the Darwin district. The tungsten deposits were mapped by a U. S. Geological Survey party under D. M. Lemmon from November 3, 1941 to March 4, 1942. Their maps are published in the report on the ore deposits of the Darwin quadrangle by Hall and MacKevett (see section on tungsten deposits by Hall, MacKevett, and Lemmon, in press). L. K. Wilson (1943, p. 543-560), geologist for the Pacific Tungsten Company, described the tungsten deposits and the operations of the Pacific Tungsten Company from 1941 to 1943. The U. S. Bureau of Mines trenched and sampled nine properties in the Darwin district from November 1941 to January 1942 and published assay maps of their results (Butner, 1949). Bateman and Irwin (1954, p. 34) briefly describe the deposits.

Deposits in the Darwin district

Geology

Contact metamorphic tungsten deposits in the Darwin district are peripheral to the Darwin stock of biotite-hornblende-quartz monzonite. Most of the deposits are in the eastern part of the Darwin Hills in the lower member of the Keeler Canyon formation of Pennsylvanian-Permian age. The tungsten deposits are localized mainly in the pure limestone beds interbedded with silty and sandy limestone that is metamorphosed to calc-hornfels.

The relatively pure limestone beds are in part unmetamorphosed and in part recrystallized to marble. Locally the marble and limestone are altered to tactite within a few hundred feet of the intrusive. The tactite consists mainly of grossularite-andradite and idocrase, but some contains epidote, orthoclase, diopside, wollastonite, and calcite.

The Paleozoic rocks are tilted into an overturned section that strikes north and dips 30° to 78° W. The Paleozoic and plutonic rocks are broken by several pre-mineral N. 70° E.-striking left-lateral strike-slip faults.

Ore bodies

Scheelite locally replaces pure limestone and tactite close to N. 70° E.-striking faults and within the N. 70° E. faults (see Hall and MacKevett, in press). Most of the ore is found within three limestone beds known as the Durham, Frisco, and Alameda beds. Only the Durham ore body is known to extend more than 60 feet vertically. The Durham and Alameda ore bodies replace pure limestone and tactite near the Fernando shear zone. The Durham ore body is a replacement of the Durham limestone bed where it is in contact with calc-hornfels. The ore body is 350 feet long at the surface and has been mined to a depth of 350 feet where the ore body is only 30 feet long. Its thickness ranges from 2½ to 35 feet.

Three replacement ore bodies were mined from the Alameda bed near N. 70° E. faults. Two are at the intersection of the Alameda bed with the Fernando shear zone; the third is 1,000 feet northwest of the

Fernando shear at the Alameda shaft. The largest of these ore bodies is at the intersection of the Alameda bed with the Fernando shear 950 feet S. 80° W. of the Fernando adit. It has been developed by an open cut 50 feet long parallel to the strike of the enclosing limestone, 60 feet wide, and about 20 feet deep. A drift was being driven in 1955 under the pit to develop ore that remain at the bottom.

The ore in the St. Charles-Hayward area is in N. 70° E. faults that dip steeply to the northwest. The ore shoot, 140 feet long and 2 to 10 feet thick, was mined from the surface to an average depth of about 45 feet. Most of the scheelite exposed in the St. Charles No. 2 and St. Charles No. 3 workings is in thin veins or streaks along N. 70° E. faults, and no scheelite is disseminated in the wall rock between faults. The streaks range from a fraction of an inch to 6 inches thick and can be mined only by highly selective methods or where fractures are sufficiently close that several can be mined together. Some of the streaks contain 10 to 30 percent WO_3, but the grade of ore over a mining width would probably average only about 0.2 to 0.3 percent WO_3.

Grade

The grade of ore mined from the district has averaged about 0.75 percent WO_3. Wilson (1943, p. 558) reports that from 1941 to 1942 approximately 32,000 tons of ore averaging more than 1 percent WO_3 was mined from the Darwin Hills. The ore at the Durham mine averaged 1 percent WO_3 over an average width of 15 feet on the 200-foot and 300-foot levels (Wilson, 1943, p. 558). The grade of ore at the St. Charles No. 1 mine was high and ranged from 2 to 10 percent WO_3. Ore in the district mined from 1951-1955 averaged about 0.5 percent WO_3.

Submarginal ore is present at the Fernando mine and to a lesser extent at the St. Charles No. 3 mine. The submarginal ore at the Fernando mine is exposed in the main Fernando adit along the Fernando shear zone. Scheelite is localized along fractures over a length of 610 feet and a width up to 50 feet; some parts of this area are estimated to contain 0.2 to 0.5 percent WO_3.

Ore controls

The ore controls for scheelite are both stratigraphic and structural. Pure limestone, and tactite formed as an alteration of it, are more favorable for ore than dense calc-hornfels. However, the dense calc-hornfels cannot be eliminated as a possible host rock as some ore has been mined from it. The bedded replacement body at the Durham mine selectively replaced tactite and pure limestone. Most other occurrences of scheelite in the district are along N. 70° E.-striking faults, and scheelite may be present whether the wall rock is tactite, limestone, or calc-hornfels. Commonly the scheelite zone is widest where a fault cuts tactite and thins to a narrow stringer where the fault cuts calc-hornfels. In the St. Charles No. 1 workings and in the Hayward mine, ore has been mined from veins in calc-hornfels. At the Hayward mine the ore is widest in tactite, and the vein thins to a stringer to the east where the wall rock is calc-hornfels. The ore body rakes to the west parallel with bedding.

Granitic rocks must be nearby for either tactite or scheelite. The most favorable places for ore are where small satellitic intrusive bodies crosscut structure. The tactite and scheelite do not necessarily form on the intrusive contact, but are within a few hundred feet of intrusive rocks. The deposits are localized by faults.

Mineralogy

The primary tungsten ore contains scheelite in a gangue of predominantly grossularite-andradite, calcite, fluorite, idocrase, wollastonite, diopside, and pyrite. Bismuthinite is present at the Fernando mine. At the Thompson mine scheelite is associated with galena, sphalerite, pyrite, chalcopyrite, fluorite, and calcite in light-colored calc-silicate rock composed of idocrase, garnet, wollastonite, diopside, and epidote.

The scheelite is commonly in euhedral crystals as much as 2 inches in diameter. At the Thompson mine euhedral to subhedral crystals of scheelite predominantly 3/8 to 3/4 inch in diameter are surrounded and in places veined and slightly corroded by sulfide minerals. Davis and Peterson (1948, p. 2) described euhedral scheelite crystals in a powdery matrix of limonite, jarosite, and clay minerals from the oxidized ore in the Thompson mine. At the Durham, Fernando, and St. Charles mines tungsten ore bodies contain only small amounts of galena and sphalerite but these minerals occur elsewhere along the same ore controlling structures farther from the Darwin stock.

The Durham ore body of the Fernando mine contains bismuthinite and pyrite near the intersection of the Durham bed with the Fernando shear zone. The bismuthinite is in tabular crystals as much as 2 inches long in calcite veinlets that cut tactite. It is mostly pseudomorphously replaced by light-green powdery bismutite. The tungsten ore mined from the Durham ore body had an average bismuth metal content of approximately 0.05 percent, but none was recovered.

Most of the ore is oxidized and consists of euhedral to subhedral crystals and grains of scheelite in a crumbly matrix of limonite, calcite, and partially decomposed calc-silicate minerals. Chrysocolla, azurite, malachite, and gypsum coat some of the fractures. The scheelite in the upper stopes of the Thompson workings of the Darwin mine is embedded in a crumbly matrix of limonite, jarosite, cerussite, and clay minerals. The scheelite remained essentially unaltered but all the other minerals were oxidized or partly leached; thus, the ore has undergone some residual enrichment of tungsten.

Other deposits

A small amount of antimony and copper have been mined from the Darwin district. The only antimony produced is from the Darwin Antimony mine, which is 2 miles north of Darwin (fig. 2). The production of antimony from the mine is reported by Norman and Stewart (1951, p. 29) as "50 to 100 tons of ore assaying more than 30 percent antimony". Ore is localized along a bedding plane fault in thinly bedded limestone of the Keeler Canyon formation of Pennsylvanian-Permian age. Stibnite is exposed intermittently at the surface and in the underground workings over a strike length of 120 feet. Ore consists of stibnite with minor secondary antimony minerals in sheared limestone and ranges from a few inches to 3 feet thick. Calcite and limonite are the main gangue minerals. All the ore was mined from a small stope in the footwall between the 100 and 150-foot levels about 40 feet south of the main shaft. Small discontinuous seams and pods of stibnite less than 1 inch thick are exposed on the 100 and 150-foot levels north of the main shaft.

Copper minerals are associated with nearly all the lead-silver-zinc deposits and with some of the tungsten deposits. In a few deposits in limestone, copper minerals are the principal ore minerals. The copper prospects are in the vicinity of the Giroux mine about half a mile east of Darwin (fig. 2). Mining activity was mostly during the late 1890's and the first few years of this century. A blast furnace was built at the Lane mine in 1898, and a small amount of copper matte was recovered (Waring and Huguenin, 1919, p. 99). Chalcopyrite is the primary ore mineral, but it is mostly oxidized to azurite, chrysocolla, and malachite. All the prospects are small and have not been worked for many years.

Nonmetallic commodities

Nonmetallic commodities in the Darwin quadrangle include steatite-grade talc, massive chlorite (which locally is called "pyrophyllite"), limestone, dolomite, and quartzite. Only steatite-talc and chlorite are important commercially at present. The term steatite is used herein in the restricted sense of Engel (1949, p. 1018) for essentially pure, massive, compact talc containing less than 1.5 percent CaO, less than 1.5 percent combined FeO and Fe_2O_3, and less than 4 percent Al_2O_3. Massive chlorite, associated with some of the talc deposits, is used in certain cordierite ceramics and as a filter in insecticides.

The deposits of limestone, dolomite, and quartzite have not been exploited owing to remoteness to rail transportation and market, and because similar materials are more readily available on the east side of Owens Valley adjacent to a branch line of the Southern Pacific Railroad. The upper part of the Eureka quartzite is very pure and is satisfactory for super refractory silica brick.

Steatite

Steatite-talc deposits are restricted to an area of about six square miles in the Talc City Hills about six miles northwest of Darwin (pl. 3). One of the deposits--the Talc City mine--has been one of the principal domestic sources of steatite-talc since 1915. From 1915 to 1948 the Talc City mine produced 218,485 tons of ore.[1]

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[1] Production data compiled by L. A. Wright of the California Division of Mines, and data published with the permission of the mine owners.

The production of the other deposits is not known, but is much smaller than that of the Talc City mine.

The talc deposits were studied by B. M. Page and L. A. Wright for the U. S. Geological Survey in 1942, and Page (1951) subsequently published a comprehensive report describing steatite-talc deposits in Inyo County. T. E. Gay, Jr. and L. A. Wright (1954, Map sheet no. 12) mapped the geology of the Talc City Hills, and briefly described the stratigraphy and structure.

Geology

The Talc City Hills are underlain by sedimentary rocks of Early Ordovician to Permian age that are intruded by leucocratic quartz monzonite of Cretaceous age and by felsic dikes. Silurian and Ordovician rocks are mainly dolomite and quartzite; Mississippian and younger Paleozoic rocks are predominantly limestone. The lower part of the Devonian consists of dolomite, limestone, and quartzite; the upper part is limestone and shale. The Devonian and older rocks are thrust over younger Paleozoic rocks.

The most important deposit--the Talc City--is in the Lost Burro formation of Devonian age. It is in the basal siliceous and limy Lippincott member, which is named and described from the type locality in the Ubehebe Peak quadrangle by McAllister (1955, p. 12). At the Talc City mine the Lippincott member is highly faulted so the thickness is not known, but it appears to be about 75 feet thick and is repeated by faulting. This member is shown as stratified dolomite and limestone (sdl) and as silica rock (si) on the large-scale surface map of Page (1951, pl. 1). The talc is localized in the massive dolomite close to quartzite of the Lippincott member. The Lippincott member is overlain by approximately 300 feet of light-gray- to buff, massive dolomite. Some beds of limestone are present within the dolomite, and these beds are in part dolomitized, particularly at the crests of tight folds. The dolomite is overlain by light-gray, fine- to medium-grained limestone, which is exposed at the north and east sides of the hill containing the Talc City mine.

The Paleozoic rocks are intruded at the south end of the Talc City Hills by a stock of leucocratic quartz monzonite. At the Frisco mine thin highly altered light-colored dikes are exposed in the main chlorite pit. The dikes are completely altered to clay minerals, chlorite, and sericite, so their original composition is not known, but they originally probably were quartz latite. Fine-grained, highly altered dark-green dikes 2 to 6 inches thick intrude Devonian rocks at the Talc City mine.

Talc ore bodies

The talc deposits are only briefly described here, as descriptions and maps of individual properties are given by Page (1951) from whom much of the following description is taken. MacKevett and the writer mapped the surface geology (pl. 3) but did not map any of the talc deposits.

The talc deposits are localized mainly in shear zones in massive buff dolomite, to a lesser extent in quartzite, and along contacts between dolomite and quartzite near leucocratic quartz monzonite. Dolomite of the Lost Burro formation is the principal host rock, although some deposits are in Pogonip, Ely Springs, and Hidden Valley dolomite. Both the Eureka quartzite and quartzite in the Lost Burro formation are replaced by talc at some places.

The steatite-talc bodies are irregular elongate lenses and pods that dip steeply. The largest ore bodies are at the Talc City mine where two ore bodies are exposed for a length of about 500 feet and have a maximum width of 50 feet. One extends about 400 feet below the surface and the other about 100 feet. The other talc deposits are much smaller and most of them have yielded only a few thousand tons each. In general, the size of the ore bodies diminishes with increasing distance from the Talc City stock of leucocratic quartz monzonite. Talc in the Alliance mine is in a sheared zone about 200 feet long and a maximum of 30 feet thick; at the Trinity mine the glory hole, which probably represents the approximate size of the ore body, is about 150 feet long, 50 feet wide, and 50 feet deep. The walls of most of the ore bodies are very irregular, and horses of unreplaced country rock are common in some of the talc bodies. Page (1951, p. 13, 16) reports that gradational contacts and false walls are common, and that large offshoots containing hundreds of tons of ore extend from the main talc masses following joints and shears.

The steatite-talc is grayish-green, pale green, gray, or dull white. Some is massive, but much of it is highly sheared. Fractures commonly are lightly limonite-stained or contain small dendrites of manganese oxides. The run-of-mine ore is exceptionally pure. The following analyses are from Page (1951, p. 12).

Sample	1A	1B	1E	Theoretical
SiO_2	62.30	58.06	60.05	63.50
Al_2O_3	1.98	0.85	0.45	-
TiO_2	0.04	-	-	-
Fe_2O_3	1.30	1.21	1.36	-
CaO	0.64	0.43	0.09	-
MgO	28.26	31.85	32.10	31.7
KNaO	0.47	1.14	0.13	-
Ig. Loss	5.25	5.68	5.41	4.8
Total	100.24	99.22	99.59	100.0

1A. Probably from Talc City mine.

1B. From Talc City mine.

1E. From Talc City mine.

Origin

The talc deposits were formed by replacement of dolomite and quartzite by thermal waters traveling along shears and contacts. Spatially the deposits are peripheral to leucocratic quartz monzonite, and the size of the deposits is approximately proportional to nearness to the intrusive contact. Possibly the thermal waters were given off by the intrusive during a late stage of crystallization. This would explain the distribution of deposits around the stock and the diminishing size of deposits with increasing distance from the pluton. It is also possible, however, that the intrusive was the source of heat and the alteration was caused by circulation of heated groundwater. It is not necessary to postulate a large-scale introduction of magnesia or silica. Nearly all of the deposits, and without exception, all of the large talc bodies, have both dolomite and quartzite in close proximity, so that a local source of magnesia and silica is at hand. No talc alteration was observed in limestone or shale, and only small pods of talc were found in massive dolomite that has no local source of silica. On the negative side, the quartzite does not show evidence of large-scale corrosion or replacement. At most places the quartzite is massive and only slightly replaced, and talc is restricted to places where it is fractured.

Chlorite deposits

A large part of the production of the Frisco mine is massive green chlorite that locally is called "pyrophyllite". The chlorite occurs in shear zones 2 to 15 feet thick in dolomite and in felsic dikes that are altered to chlorite, sericite, and clay minerals. A chemical analysis[1] of the chlorite is given below:

	Percent		Percent
SiO_2	29.0	Na_2O	0.04
Al_2O_3	25.0	K_2O	0.02
Fe_2O_3	0.7	TiO_2	0.40
FeO	0.82	P_2O_5	0.22
MgO	30.6	MnO	0.01
CaO	0.36	H_2O	12.6
		CO_2	0.05
			100.

_/ Analyzed by P. L. D. Elmore and K. E. White of the U. S. Geological Survey.

The chemical analysis suggests that the chloritic rock is a mixture of approximately 87 percent amesite and 13 percent talc.

Optical, x-ray, and differential thermal analysis data show that the chlorite is amesite with a chlorite structure. The chlorite has the following optical properties: optic sign +, 2V small, = 1.573 ± 0.003; = 1.574 ± 0.003; = 1.583 ± 0.003. This closely fits the optical properties of amesite given by Winchell (1936, p. 643). The x-ray diffraction pattern is given below:

dA_o	Intensity	dA_o	Intensity
1.397	10	2.44	16
1.537	12	2.54	20
1.57	10	2.85	20
1.82	5	3.56	83
1.88	8	4.745	83
2.00	16	7.14	100
2.26	8	14.255	45
2.38	8		

The x-ray data confirm that the mineral has a chlorite-type structure. It has a strong 14Å series of basal reflections and is not similar to amesite from the type locality, which has a kaolin-type structure (Gruner, 1944, p. 422). Nelson and Roy (1953, p. 344) have shown the existence of both types of amesite--the 7Å kaolin type and the 14Å chlorite type. The differential thermal analysis curve also fits a 14Å chlorite.

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