Geology and Ore Deposits of the Darwin Quadrangle Inyo County, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 368

Prepared in cooperation with the State of California, Department of Natural Resources, Division of Mines

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By WAYNE E. HALL *and* E. M. MACKEVETT, JR.

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

By Wayne E. Hall and E. M. MacKevett, Jr.

ABSTRACT

The Darwin 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 and Argus Ranges, and Darwin Hills.

Paleozoic rocks range in age from Ordovician to Permian in a conformable sequence more than 13,000 feet thick. They are predominantly carbonate rocks 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 chiefly limestone.

Silurian and Ordovician rocks are restricted to the Talc City Hills. Ordovician strata are about 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 of Silurian and Devonian age. Devonian and Mississippian strata are best exposed in the Santa Rosa Hills and include 1,700 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 and Pennsylvanian(?) age. Part of the Lee Flat limestone is a time-stratigraphic equivalent of the Rest Spring shale, which occurs only within or adjacent to major fault zones in the northwestern part of the quadrangle. Pennsylvanian and Permian strata are more than 6,000 feet thick and are the most widespread Paleozoic rocks. They are divided into the Keeler Canyon formation of Pennsylvania and Permian age and the Owens Valley formation of Permian age; both consist predominantly of thinly bedded calcilutite and calcarenite. The Paleozoic rocks are intruded by several plutons of quartz monzonite of Mesozoic age. Limestones are commonly altered to calc-hornfels, calc-silicate rock, and tactite near intrusive contacts.

Cenozoic rocks include sedimentary and volcanic rocks of Pliocene(?) and younger age. The sedimentary rocks are divided into the Coso formation, fanglomerate from the Inyo Mountains, fanglomerate marginal to Darwin Wash, lake beds in Darwin Wash, and Recent alluvium. Volcanic rocks include a basaltic pyroclastic section as much as 920 feet thick that locally contains andesite interbedded near the top of the unit and younger olivine basalt flows that cover most of the northern half of the quadrangle. As the different lithologic units occur in separate areas with little interfingering or interlayering between the units, their relative ages are not definitely known.

The Paleozoic rocks are deformed into broad open folds except near plutonic bodies where the structure is complex owing to forcible intrusion. The Paleozoic strata about the northeast margin of the biotite-hornblende-quartz monzonite in the Coso Range are tightly folded and are disrupted by many faults. Left-lateral strike-slip faults and thrust faults are both structurally important. The extensive volcanic cover in the northern part of the quadrangle prevents a study of the deformation around the quartz monzonite in the northeastern part of the quadrangle.

Formation of the basin-range topography began before late Pliocene as shown by the fanglomerates of that age marginal to the Inyo Mountains and Coso Range. The Inyo Mountains, the Argus Range, and possible the Coso Range are east-tilted fault blocks. Extensive basalt covers on the east flanks of both the Inyo Mountains and Argus Range dip 5° to 15° E. 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 was $37½ million. The Darwin lead-silver-zinc district produced $29 million and the talc deposits about $5 million. Tungsten mines and small lead-silver-zinc mines produced $3½ million.

Nearly all of the lead-silver-zinc deposits occur in limestone or altered limestone. The most productive deposits surround quartz monzonite in the Darwin Hills in thinly bedded Pennsylvanian and Permian strata that are largely altered to calc-hornfels and tactite. Individual ore bodies occur as bedded replacements, vein deposits, and as steep pipe-shaped ore bodies in or near feeder fissures that strike N. 50° to 70° E. The hypogene ore consists of galena, sphalerite, pyrite, pyrrhotite, chalcopyrite, tetrahedrite, scheelite, andorite, matildite, and clausthalite. Near the surface 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 a lesser extent in quartzite peripheral to leucocratic quartz monzonite in the Talc City Hills. Shear zones in dolomite or contacts between quartzite and dolomite may localize talc.

Tungsten ore has been mined in the eastern part of the Darwin Hills and from the Thompson workings of the Darwin mine. The deposits are in calc-hornfels, tactite, and marble of Penn-

sylvanian and Permian age close to the contact of the biotite-hornblende-quartz monzonite in the Darwin Hills. Scheelite replaces pure limestone or 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. The area is between long 117°30′ and 117°45′ W. and lat 36°15′ and 36°30′ N. (fig. 1). Darwin, a small mining town in the southern part of the quadrangle, has a population of several hundred. A large modern mining camp is maintained by The Anaconda Co. 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 from Mojave to Owenyo. 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. An improved dirt road leads from State Highway 190 through the northern part of the quadrangle to Saline Valley. Many secondary roads lead to mines and prospects from these main roads.

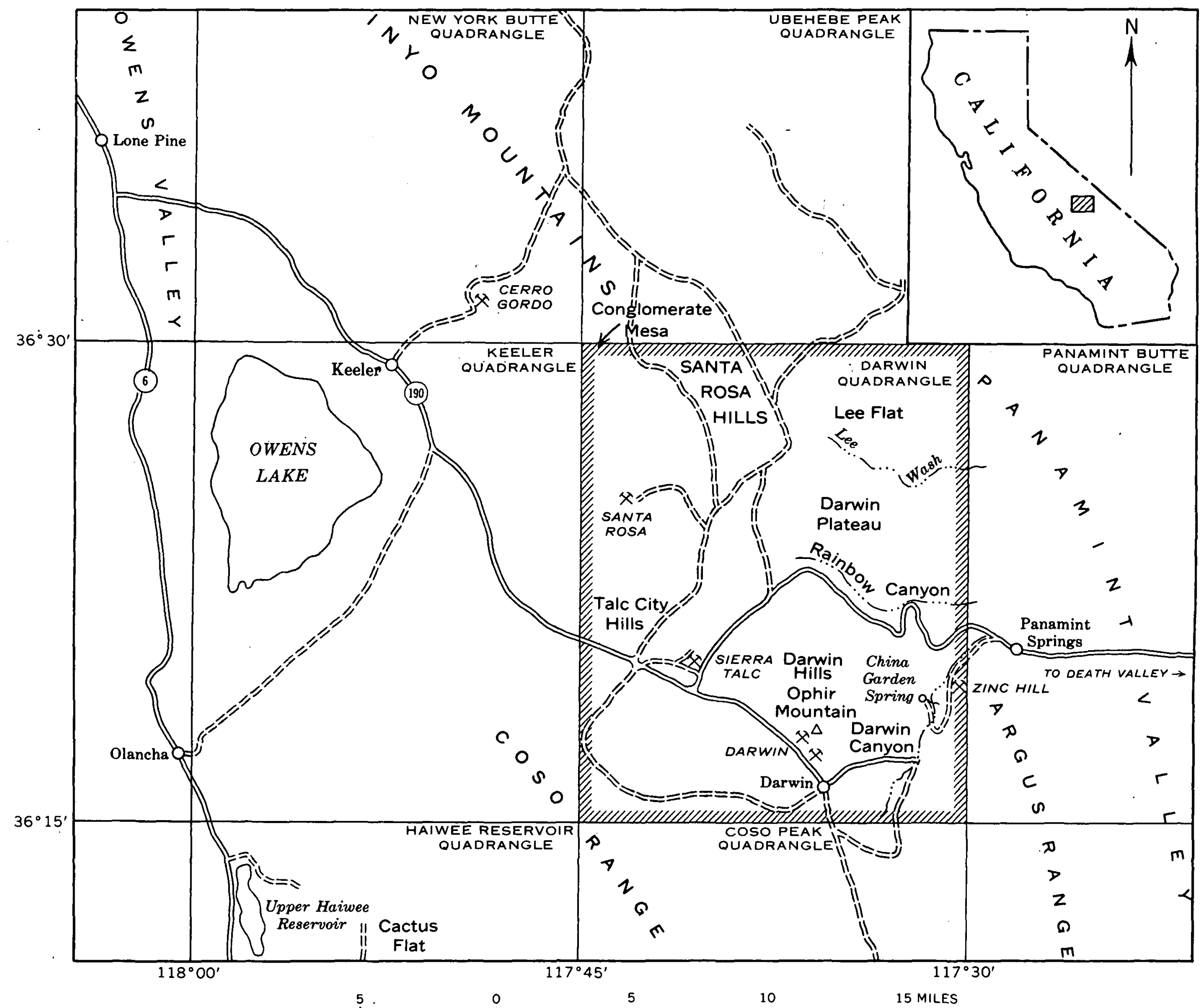

FIGURE 1.—Index map showing location of the Darwin quadrangle.

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 Division of Mines to study the Inyo County lead-silver-zinc deposits that occur between the Cerro Gordo district in the Inyo Mountains on the northwest and the Resting Springs district on the southeast (fig. 2). As part of this program the Ubehebe Peak quadrangle was mapped by McAllister (1952, 1955), the New York Butte quadrangle is being mapped by C. W. Merriam and W. C. Smith, and the Darwin quadrangle has been mapped by the writers (fig. 1).

The Darwin investigation is published in two reports. Detailed descriptions of the mineral deposits and large-scale maps of most of the principal mines were published in an earlier report (Hall and MacKevett, 1958). In the present report, emphasis is given to a description of the general geology of the Darwin quadrangle and to scientific aspects of the mineral deposits.

CLIMATE AND VEGETATION

The climate in the Darwin quadrangle is typically desert, and is characterized by scant rainfall, frequent strong winds, and a wide range in temperature. The climate of the closest weather station, at an altitude of 3,830 feet at Haiwee Reservoir 14 miles southwest of the Darwin quadrangle, is probably representative of most of the quadrangle except for the lower altitudes in Panamint Valley where the temperature is uncomfortably hot in the summer. The U.S. Weather Bureau's publication "Climatological Data" (Anon., 1948, p. 350–362) lists the following data for the Haiwee Reservoir station:

Annual rainfall.................inches..	6.06
Average January temperature..(degrees Fahrenheit)..	40.4
Average July temperature.................do....	81.7
Maximum recorded temperature in 1948..........do....	102.0
Minimum recorded temperature in 1948..........do....	14.0

Vegetation is mostly sparse. Sagebrush, Mormon tea (*Ephedra*), creosote brush (*Larrea*), Joshua (*Yucca*

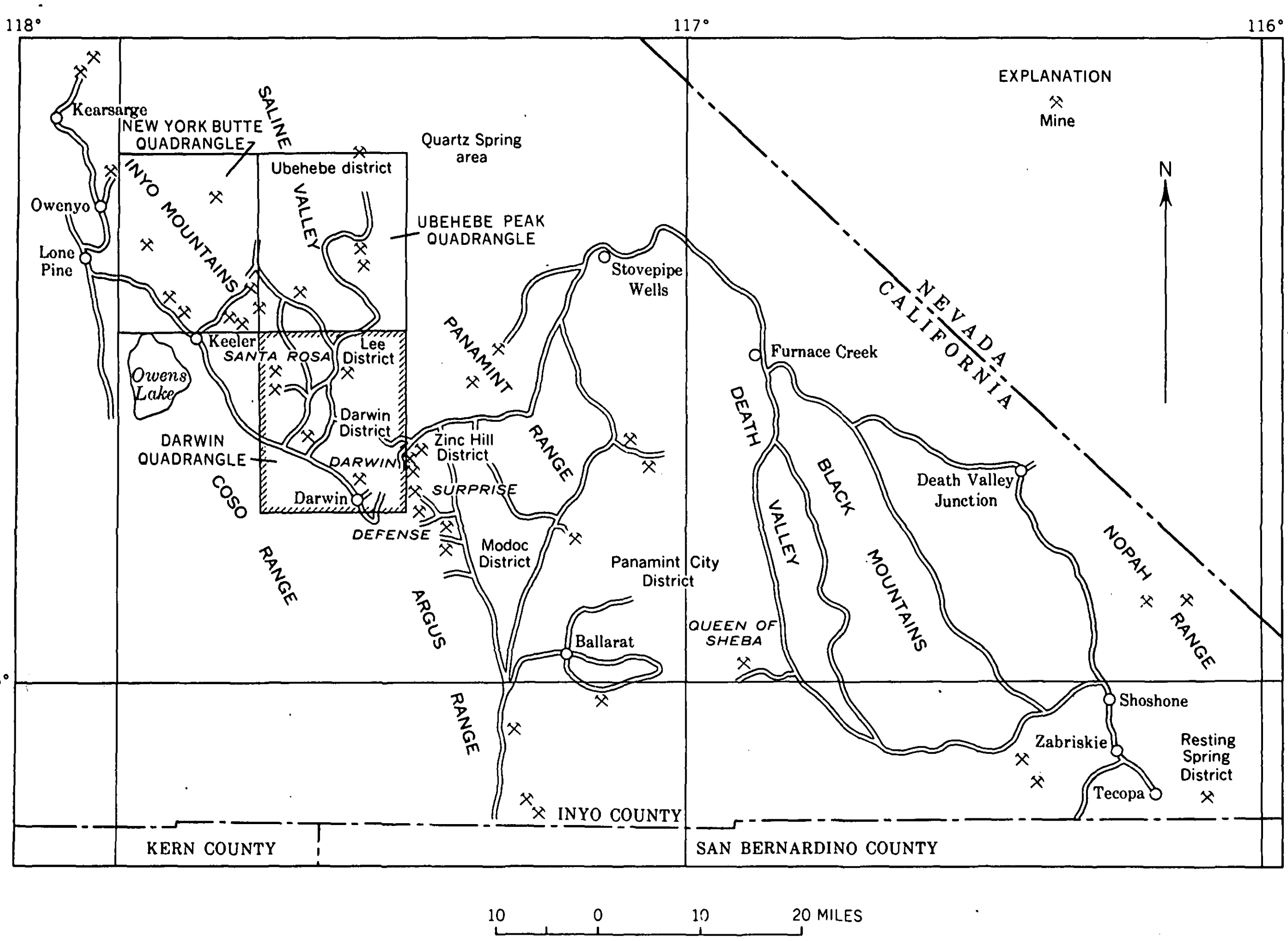

FIGURE 2.—Index map showing the location of Inyo County lead-silver-zinc deposits.

brevifolia), and cacti cover all except the northwestern part of the quadrangle near Conglomerate Mesa and the higher altitudes in the Coso Range, where piñon pines and junipers are prevalent. Joshua trees grow abundantly on Lee Flat.

TOPOGRAPHY

The Darwin quadrangle is in the western part of the Basin and Range physiographic 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, which drains into Panamint Valley (fig. 1). The south 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 and the northwest end of the Argus Range extends into the southeastern 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 more than 1,000 feet high.

The principal drainage is into Panamint Valley. Darwin Canyon drains the southeastern part of the quadrangle, including 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 Rainbow Canyon, and Lee Flat and the east slope of the Santa Rosa Hills are drained by Lee Wash. Drainage of the southwestern part of the quadrangle is to the west into Owens Valley.

WATER SUPPLY

Darwin Canyon provides the principal water supply. Small quantities of water have also been obtained from Black Spring in the Coso Range and from Mill Canyon in the northeastern part of the quadrangle. Shallow wells or springs in Darwin Canyon provide the water supply for the Darwin mine, a small tungsten mill in Darwin Canyon, a small mill and residence at China Garden Spring, and the motel at Panamint Springs. The Darwin mill and mining camp are supplied by 3 wells less than 60 feet deep in Darwin Canyon from which about 180 gpm (gallons per minute) of water 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 is funneled into the narrow mouth of Darwin Canyon. Water for the town of Darwin is piped 8 miles from springs in the Coso Range and must be trucked from Lone Pine, Keeler, 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 California 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 discussions of 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 reconnaissance study of the Inyo Mountains, and in a separate report he discusses the geology and ore deposits of the Darwin Hills. The first comprehensive study of the Darwin district was made by Kelley (1937; 1938) during the summers of 1935–36. 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 some late Pliocene or early Pleistocene vertebrate fauna from the Coso Range, but most of his work was west of the quadrangle. Hopper (1947) mapped about 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. T. E. Gay, Jr. and L. A. Wright (1954) mapped the Talc City district. Several mine geologists have published reports on the Darwin district. L. K. Wilson, (1943), former resident geologist for the Pacific Tungsten Co., discussed the geology and tungsten deposits on the east side of the Darwin Hills. D. L. Davis (Davis and Peterson, 1948), former resident geologist of the Anaconda Co., described the geology and ore deposits of the Darwin mine. 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 College.

The writers especially wish to express their thanks for the wholehearted cooperation of the mining people in the area. Dudley L. Davis and Malcolm B. Kildale of the Anaconda Co. particularly facilitated the work in the Darwin district, and the writers greatly benefited from many discussions of the geology with them. Special thanks are also due to John Eastlick, Reginald Skiles, Joel Teel, and Fred Tong of the Anaconda Co.;

E. H. Snyder of Combined Metals Reduction Co.; Alfred Glenn, lessee of the Lee mine; and Mrs. Agnes Reid of Panamint Springs.

FIELDWORK

The fieldwork began in April 1951 when E. M. MacKevett, Jr., and L. A. Brubaker mapped the Santa Rosa mine and several smaller mines in the quadrangle and wrote preliminary reports on their work (MacKevett, 1953). W. E. Hall and E. M. MacKevett, Jr., mapped the quadrangle on a topographic base at a scale of 1:40,000 from January to October 1952 and from May to October 1953 and the mines between May and September 1954 and in March 1955. The writers were ably assisted for short periods by Santi das Gupta, José Hernández, Víctor Mejía, E. H. Pampeyan, Dallas Peck, H. G. Stephens, and D. H. Thamer.

PALEOZOIC ROCKS

GENERAL FEATURES

The Paleozoic section in the Darwin quadrangle consists predominantly of carbonate rocks similar to formations in the eastern part of the Great Basin. Pre-Devonian rocks are mainly dolomite and quartzite, Devonian rocks are dolomite, limestone, quartzite, and shale, and Mississippian and younger Paleozoic rocks are mainly limestone (pl. 1). No volcanic or phosphatic material, and only minor carbonaceous material was recognized in the Paleozoic rocks. Most formations are well exposed and some units form bold, clifflike outcrops.

The Paleozoic rocks have an aggregate thickness greater than 13,000 feet. Poor exposures in parts of the section preclude 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), Bateman and Merriam (1954, map 11), and Merriam and Hall (1957) from the southern Inyo Mountains.

Outcrops of Paleozoic rocks are confined largely to five areas within the quadrangle. These areas, which are separated by alluviated or volcanic terrane, are: the Conglomerate Mesa area, the Santa Rosa Hills, the Talc City Hills, the Darwin Hills, and the Argus Range–Zinc Hill area (fig. 1). Pre-Devonian rocks are confined to the Talc City Hills. Devonian and Mississippian rocks crop out in the Santa Rosa Hills, the Talc City Hills, and locally in the northwestern part of the Darwin Hills. Pennsylvanian and Permian rocks, which constitute the thickest and most widespread sequence, occur in each of the five areas.

Formation names used by McAllister (1952, 1955) for the Ubehebe Peak quadrangle and Quartz Spring area are generally applicable and have been utilized (table 1). Thick continuous stratigraphic sections are lacking because of volcanic or alluvial cover or complex structure. Unconformities are apparently limited to Pennsylvanian and Permian parts of the section and probably represent short-time intervals. Lee Flat

TABLE 1.—*Sequence of rocks exposed in the Darwin quadrangle*

Age	Name	Character	Thickness (feet)
Recent	Alluvium	Unconsolidated alluvium, playa deposits, fanglomerate, landslide debris.	
Pleistocene	Lakebeds	White to light-gray fine-grained pumiceous ash, silt, clay, and diatomaceous earth.	58+
	Fanglomerate marginal to Darwin Wash	Gravels composed mainly of subrounded fragments of Pennsylvanian and Permian limestone, quartz monzonite, and basalt in a sandy matrix.	25+
	Olivine basalt	Mainly flows 10–100 ft thick. 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 in. in diameter in a clay and silt matrix. Probably is contemporaneous with the Coso formation.	30+
—?—?—?	and Coso formation	Arkose and clay, poorly bedded, white to buff, fine- to medium-grained.	30+
Pliocene	Andesite	Forms broad dome in upper pyroclastic unit; contains phenocrysts and clusters of plagioclase and hornblende in an aphanitic groundmass.	0–1, 230
	and Pyroclastic rocks	Upper unit: poorly bedded, mainly tuff-breccia and agglomerate and cinders.	
		Lower unit: well-bedded lapilli-tuff, scoriaceous basalt, and tuff-breccia.	0–910+
Cretaceous (?)	Hypabyssal rocks	Andesite porphyry, diorite, alaskite porphyry, and altered quartz latite(?) dikes.	
	Aplite and leucogranite	Includes 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 unit: limestone conglomerate 60 ft thick overlain by siltstone, calcarenite, and orthoquartzite	180+
		Middle unit: brick-red and yellowish-brown shale, subordinate siltstone and limestone.	200
		Lower unit: mainly fine-grained calcarenite in beds 1 to 2 ft thick; some thick limestone lenses, shale and siltstone.	2, 800

TABLE 1.—*Sequence of rocks exposed in the Darwin quadrangle*—Continued

Age	Name		Character	Thickness (feet)
Permian and Pennsylvanian	Keeler Canyon formation		Upper unit: calcilutite and fine-grained calcarenite with lesser pink fissile shale and limestone pebble conglomerate.	1,700
			Lower unit: thin-bedded limestone with intercalated limestone pebble conglomerate.	2,300
Pennsylvanian(?)	Rest Spring shale 0–50+	Lee Flat limestone	Thin-bedded dark-medium-gray limestone that is equivalent to Rest Spring shale and upper part of the Perdido.	960+
Mississippian	Perdido formation		Limestone and bedded chert	330
	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 and limestone in lower part of formation; minor quartzite. Brown fissile shale locally in upper part.	1,770+
Devonian and Silurian	Hidden Valley dolomite		Light-gray massive dolomite	1,000±
Upper Ordovician	Ely Springs dolomite		Dark-gray dolomite with chert beds and lenses; lesser light-gray dolomite	920±
Middle Ordovician	Eureka quartzite		Light-gray to white vitreous orthoquartzite	440
Lower Middle(?) and Lower Ordovician	Pogonip group		Light- and medium-gray thick-bedded dolomite; lesser thin-bedded dolomite and limestone.	1,570+
Unknown	Gneiss			

limestone, a time-stratigraphic equivalent of part of McAllister's (1952, 1955) Perdido formation and his Rest Spring shale, was described as a new formation by Hall and MacKevett (1958). Part of the Lee Flat limestone correlates with the Chainman shale in the southern Inyo Mountains (Merriam and Hall, 1957, p. 4). Nomenclature used by Merriam and Hall (1957, p. 4) has been adopted for the Pennsylvanian and Permian formations.

Most of the formations are fossiliferous, but large barren stratigraphic thicknesses occur between many collections in pre-Carboniferous rocks. The paleontologic record is best documented by an abundant Pennsylvanian and Permian fusulinid fauna and by corals and brachiopods in the Tin Mountain limestone of Mississippian age.

Three sedimentary rock names used in this report follow the usage of Pettijohn (1949). These are:

Orthoquartzite (Pettijohn, 1949, p. 237)—a sedimentary quartzite.

Calcarenite (Pettijohn, 1949, p. 300)—"* * * detrital carbonate rocks of sand-grain size (1/16 to 2 mm in diameter) that are with or without calcite cement and are composed mainly (more than 50 percent) of carbonate detritus."

Calcilutite (Pettijohn, 1949, p. 307)—detrital carbonate rock of grain size less than sand-grain size.

ORDOVICIAN SYSTEM

POGONIP GROUP

NAME AND DISTRIBUTION

The name Pogonip limestone was originally applied by King (1878, p. 187–195) to all beds on Pogonip Ridge at White Pine (Hamilton), Nev., between Prospect Mountain quartzite (Lower Cambrian) and Eureka quartzite (Middle Ordovician). The name was subsequently revised and restricted by Hague (1883, p. 253–263) to include beds between the Dunderberg shale (Upper Cambrian) and the Eureka quartzite, but some Upper Cambrian beds were still included in the Pogonip. Walcott (1923, p. 466) proposed restricting the formation further, but his proposal was not generally accepted and the U.S. Geological Survey continued to use the name as defined by Hague (Wilmarth, 1938, p. 1689). Merriam and Anderson (1942, p. 1683) proposed that the Pogonip be elevated to a group status, with inclusion of both the Upper Cambrian and the Ordovician. Hintze (1951, p. 11) proposed that the Pogonip be elevated to a group status to include only Ordovician rocks. Nolan and others (1956, p. 24) in their Eureka section accepted this and subdivided the Pogonip group into three formations—the Goodwin limestone, the Ninemile formation, and the Antelope Valley limestone listed from oldest to youngest. The Pogonip group is undifferentiated in our mapping and follows the usage of McAllister (1952, p. 11) for the rocks above the Nopah formation (Upper Cambrian) and below the Eureka quartzite (Middle Ordovician).

The Pogonip has been described by McAllister (1952, p. 10–12) from the Quartz Spring area, and from the Ubehebe Peak quadrangle (McAllister, 1955, p. 10) and equivalent rocks were described in the Inyo Mountains by Kirk (*in* Knopf, 1918, p. 34), Phleger (1933, p. 1–21), Merriam (1954, p. 10) and Langenheim and others (1956). Pogonip group in the Darwin quadrangle occurs only in the Talc City Hills (pls. 1, 2). Most outcrops of the Pogonip are faulted and folded; the thickest and most continuous exposures are about a mile northeast of the Alliance talc mine (fig. 3). The thick-bedded strata are erosion resistant and form bold outcrops. The thin-bedded strata form smooth, rounded slopes and in places slight topographic depressions.

THICKNESS AND STRATIGRAPHIC RELATIONS

An almost complete section of Pogonip is probably present in the Darwin quadrangle, although the base

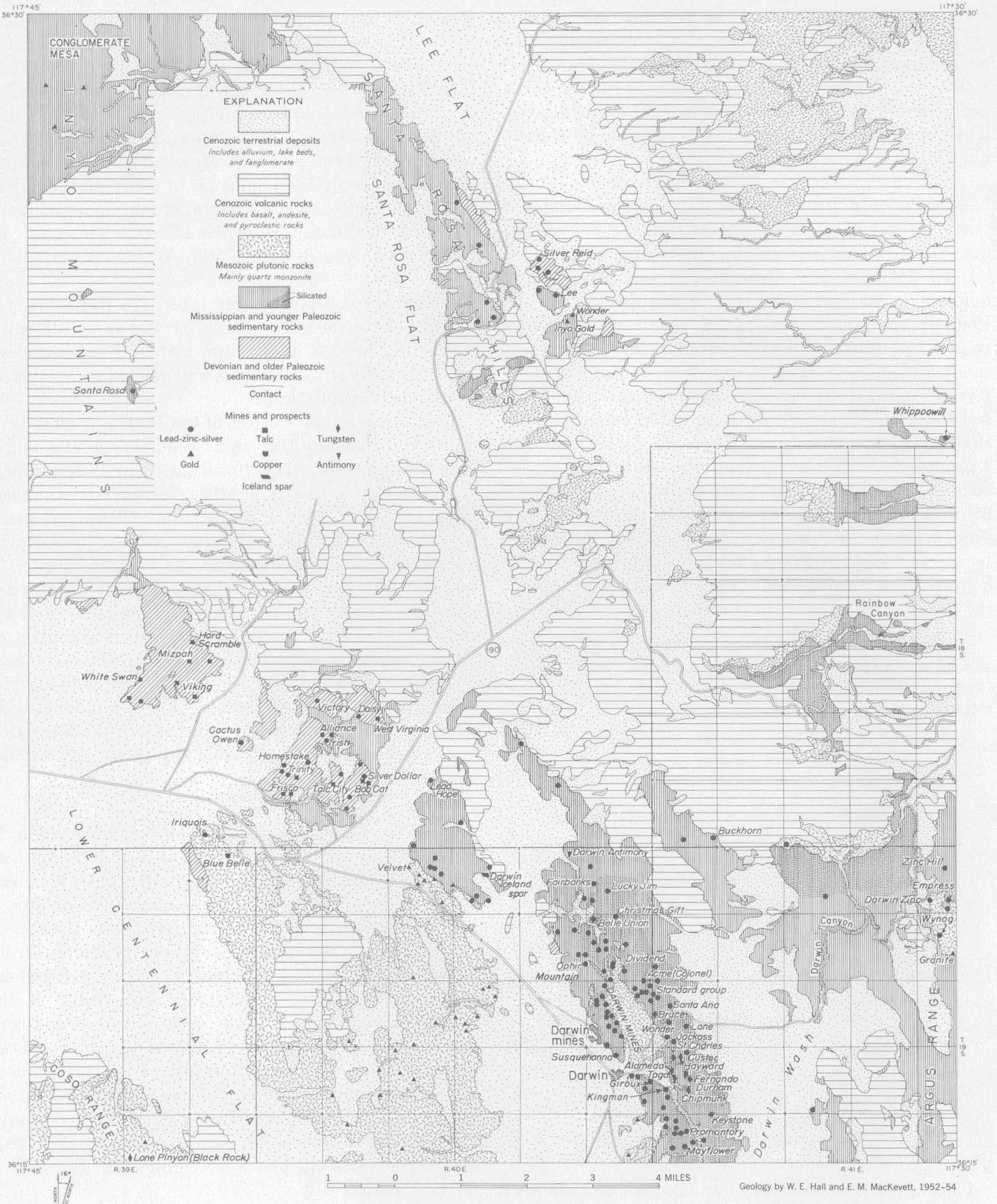

Figure 3.—Simplified geologic map of the Darwin quadrangle showing the geologic setting of the ore deposits.

of the formation is not exposed. The measured overturned section northeast of the Alliance talc mine is about 1,560 feet thick, but parts of this section lack good exposures and the base is faulted. McAllister (1952, p. 11) reports a thickness of 1,440 feet for a composite section of Pagonip in the Quartz Spring area. The Pogonip group is conformably overlain by Eureka quartzite.

LITHOLOGY

The Pogonip group in the Darwin quadrangle is characterized by a prevalence of light- and medium-gray thick-bedded dolomite and lesser amounts of thin-bedded dolomite and limestone. Crossbedded sandy dolomite is common at the top. The upper part of the Pogonip contains several conspicuous brown siliceous zones 8 to 178 feet thick that contain thinly interbedded sandy dolomite, limestone, and iron-stained chert referred to as having crepe structure by McAllister (1952, p. 10) because of their wavy nature. At some places in the measured section the crepe beds are folded and have a pronounced slip cleavage that produces marked crenulations. A zone of large gastropods is present 100 to 250 feet below the base of the Eureka quartzite nearly everywhere in the Pogonip. The crepe beds, the zone of large gastropods, and the conspicuous overlying Eureka quartzite distinguish the Pogonip from similar appearing younger dolomite in the section.

Section 5,000 feet N. 40° E. of the Alliance talc mine

Eureka quartzite.
Conformable contact.
Pogonip group:

		Feet
d	Dolomite, light- and medium-gray; and sandy dolomite, both thick bedded. Minor light-gray limestone. Contains two brown-weathering siliceous beds 10 and 25 ft thick. Crossbedding common near the top. *Palliseria robusta* Wilson is present 150 ft below top	540
c	Dolomite, brown-weathering silty and sandy, and limestone with abundant thin limonitic-stained chert interbeds. Crenulations abundant. Referred to as crepe beds	178
b	Dolomite, light- to dark-medium-gray, sandy in upper part. Locally contains lens-shaped brown-weathering chert nodules. Contains 4 beds 8 to 45 ft thick of gray thinly bedded limestone and dolomite with abundant thin siliceous, limonitic interbeds	393
a	Dolomite, medium-gray and light-gray, thick-bedded to massive. Contains minor sandy medium-gray dolomite	448
	Total	1,559

Base unexposed.

Unit a, the lowermost 448 feet exposed, consists predominantly of thick-bedded light-medium-gray and medium-gray dolomite interbedded with some thick-bedded sandy medium-gray and light-gray dolomite. Reuben J. Ross, Jr., suggests that this unit may belong to the Upper Cambrian Nopah formation (written communication, 1962), but faunal evidence is lacking. Unit b is 393 feet thick and consists mainly of light-medium-gray to dark-medium-gray dolomite. Sandy dolomite is abundant in the upper part. Lens-shaped medium-gray brown-weathering chert nodules as much as 6 inches long are abundant in some of the thick-bedded dolomite. Unit b contains four zones of crepe beds; the maximum thickness is 45 feet. This unit correlates roughly with units 4 and 5 of McAllister (1952, p. 11).

Unit c is a conspicuous crepe bed 178 feet thick. It consists of brown-weathering silty and sandy dolomite and thinly bedded highly iron stained irregular chert beds. Locally slip cleavage is well defined and produces conspicuous crenulations.

Unit d, the upper 540 feet of the Pogonip, consists of light- and medium-gray thick-bedded dolomite and a few beds of light-gray limestone 1 to 2 feet thick. Sandy dolomite that is locally crossbedded is increasingly abundant high in the section. Brown-weathering erosion-resistant zones of crepe beds are present; the highest of these forms conspicuous outcrops about 100 feet below the top of the Pogonip. Chert nodules are numerous locally, and remnants of large gastropods are abundant in a zone 150 to 260 feet below the contact of the Eureka quartzite. The genus *Girvanella* is common at the Viking mine (fig. 3). This unit includes McAllister's units 7 and 8 (1952, p. 11). Abundant sandy crossbedded dolomite in the upper part of the formation marks a transition between Pogonip group and Eureka quartzite.

AGE

The Pogonip group is Early and possibly very early Middle Ordovician in age. The only fossils found in the Darwin quadrangle in the Pogonip group are in unit d from a zone above the highest crepe beds of unit c, and stratigraphically 150 to 260 feet below the top of the formation; they are late Early or early Middle Ordovician age. Fossils were observed nearly everywhere this zone is exposed. Collections were made at the Viking talc mine and at the same stratigraphic zone 5,000 feet N. 40° E. of the Alliance talc mine. They were studied by Reuben J. Ross, Jr., of the U.S. Geological Survey, who reported as follows (written communication, 1954): "Pogonip limestone—high Lower or very low Middle Ordovician *Palliseria robusta* (Wilson). Unidentified cystoid plates belonging to *Paleocystites*, "*Receptaculites*"? sp."

Nolan and others (1956, p. 25) consider the fossils from the upper Pogonip group a Chazy fauna and Middle Ordovician in age. Helen Duncan (1956, p. 215), however, stated that G. A. Cooper and Edwin Kirk considered the fauna in the upper part of the Pogonip to be pre-Chazy and of Early Ordovician age. McAllister (1952, p. 11) reported fossils from his shaly unit 5, below the *Palliseria* zone, were identified by Josiah Bridge, in consultation with G. A. Cooper, who wrote:

"This fauna * * * is definitely of Lower Ordovician (Canadian) age." R. J. Ross, Jr. (*in* McAllister, 1956) studied a collection of McAllister's from another locality in the same shaly unit and reported the collection of fossils to be equivalent to the fauna of his *J* zone of the Garden City formation in northeastern Utah, and that the age is probably very late Early Ordovician.

EUREKA QUARTZITE

NAME AND DISTRIBUTION

Hague (1883, p. 253, 262) named the Eureka quartzite from exposures near Eureka, Nev. Lone Mountain was designated the type locality by Kirk (1933, p. 34), because the section is easily accessible and is the nearest satisfactory section to the town of Eureka. The formation crops out in the Talc City Hills mainly in faulted areas and as blocks and slivers in fault zones (pls. 1, 2). The most extensive exposures are at the north end of the Talc City Hills where the Eureka is exposed in a discontinuous band 3½ miles long along the flanks of a southward-plunging syncline. The most accessible complete section is north of the White Swan mine.

The Eureka quartzite is widely distributed throughout southeastern California and Nevada. It was described by McAllister (1952, p. 12, 13; 1955, p. 11; 1956) from the Quartz Spring area and the Ubehebe Peak quadrangle, by Merriam (1954, p. 10) from the Inyo-Death Valley region, and by Langenheim and others (1956, p. 2092) from the Inyo Mountains. Hopper (1947, p. 407) described the Eureka quartzite on the west side of Death Valley and Hazzard (1937, p. 324) described it at the north end of the Nopah Range. The formation is erosion resistant and commonly makes sharp and precipitous outcrops; where strongly jointed it weathers to large angular blocks.

THICKNESS AND STRATIGRAPHIC RELATIONS

A thickness of 440 feet of Eureka quartzite was measured in a northeastward-trending section from a point 1,200 feet N. 40° E. of the White Swan mine (pl. 2). This thickness is slightly greater than the 400 feet measured by McAllister (1952, p. 12–13) in the Ubehebe Peak quadrangle and Quartz Spring area and the 250 feet measured by Hopper (1947, p. 407) on the west side of Death Valley. Both upper and lower contacts of the Eureka quartzite are apparently conformable depositional contacts. The lower contact is marked by a change from light-gray sandy dolomite and limestone to very light gray vitreous orthoquartzite that weathers brown. Although the contact is well defined, the increase in arenaceous detritus near the top of the carbonate rocks of the Pogonip group indicates a transition prophetic of Eureka deposition. The upper contact is denoted by a sharp lithologic change from light-brown weathering vitreous orthoquartzite to dark-gray cherty Ely Springs dolomite.

LITHOLOGY

The Eureka quartzite, which is the best marker zone in the Paleozoic section, is a distinctive orthoquartzite characteristically light-gray to white and with a glistening vitreous luster. The orthoquartzite is well indurated and cemented by secondary silica. Despite thorough cementing and local minor metamorphic effects, individual quartz grains are megascopically discernible in some specimens. The distinctive lithology, luster, and light color, especially when contrasted with the overlying dark-gray Ely Springs dolomite, make it a reliable mappable unit (fig. 4).

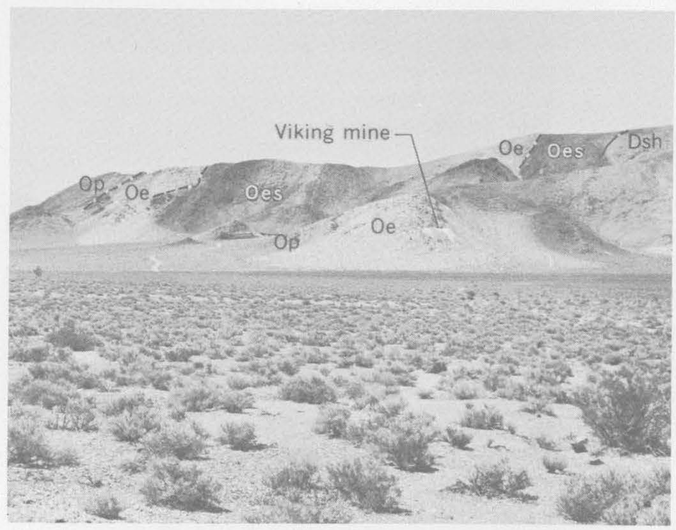

FIGURE 4.—Photograph of the Talc City Hills near the Viking mine showing the overturned Paleozoic of the Pogonip group (Op), Eureka quartzite (Oe), Ely Springs dolomite (Oes), and Hidden Valley dolomite (Dsh). The Eureka quartzite and the overlying dark-gray Ely Springs dolomite are the most conspicuous Paleozoic stratigraphic horizon markers. View looking northwest.

The lowermost 120 feet of the formation consists of yellowish-brown to dark-brown-weathering iron-stained orthoquartzite in beds 1 to 6 feet thick that range from white to light gray on fresh surfaces. Less abundant bluish-black stains are probably manganese oxide. Very thin crossbedding is conspicuous in this unit. Joints, spaced at about 5-foot intervals, intersect stratification at high angles locally in the basal unit. The uppermost 30 feet of the unit is marked by a zone of irregularly streaked and blotched bluish-gray, white, and brown orthoquartzite. The streaks, which are commonly less than an inch thick, are probably secondary features.

Thick-bedded white vitreous orthoquartzite and minor light-gray orthoquartzite in beds 1 to 2 feet thick constitute the middle 250 feet of the Eureka. This orthoquartzite weathers white and buff and to a lesser extent light brown and bluish gray. The uppermost 70 feet is locally thin-bedded light-gray vitreous orthoquartzite that weathers to sandy surfaces of variegated brown.

Section 1,200 feet N. 41° E. of the White Swan mine

Ely Springs dolomite.
Conformable contact.
Eureka quartzite:

		Feet
d	Orthoquartzite, light-gray, vitreous, thin-bedded. Brown with sandy appearance on weathered surface. The contact with the Ely Springs is sharp	70
c	Orthoquartzite, white and light-gray, vitreous, thick-bedded. Weathers white, light brown, or bluish gray	250
b	Orthoquartzite, irregularly streaked white, bluish-gray, and brown	30
a	Orthoquartzite, white to light-gray; weathers yellowish brown to dark brown. Beds 1 to 6 ft thick. Crossbedding is common	90
	Total	440

Conformable contact.
Pogonip group.

Thin-section study shows that the Eureka quartzite consists of well-rounded and sorted quartz grains that are tightly packed and cemented with silica. Individual quartz grains are fine- to medium-sand size and range mostly from 0.2 to 0.4 mm in diameter. Secondary overgrowths are indicated by thin peripheral rims of clear quartz grains in optical continuity with the original quartz grains. The quartz grains have strain shadows and are dotted with submicroscopic specks. Minor amounts of zircon and of late calcite and limonite are in most sections.

AGE

No fossils were found in the Eureka quartzite, but its age is fairly well substantiated by stratigraphic position. The upper part of the underlying Pogonip group is late Early or early Middle Ordovician in age; the overlying Ely Springs dolomite contains Richmond (Late Ordovician) fossils. It is reasonable to conclude that the Eureka quartzite is mainly if not entirely Middle Ordovician. The basal Eureka quartzite in the southern Inyo Mountains locally contains fossils of Black River or Trenton age (Merriam, 1954, p. 10). Langenheim and others (1956, p. 2092) correlate the Barrel Spring formation of Phleger (1933) in Mazourka Canyon in the Inyo Mountains with the lower part of the Eureka quartzite and consider it to be Mohawkian in age.

ELY SPRINGS DOLOMITE

NAME AND DISTRIBUTION

Ely Springs dolomite was named by Westgate and Knopf (1932, p. 15) from exposures in the Ely Springs Range about 12 miles west of Pioche, Nev. In the Darwin quadrangle the formation is mainly in the northwestern part of the Talc City Hills where it is one of the most widespread formations (pls. 1, 2). It crops out at the northernmost workings of the White Swan mine, and occurs in a continuous band 2 miles long on the flanks of the overturned syncline west of the Hard Scramble talc prospect (fig. 3). Most exposures of the Ely Springs are bounded by one or more faults, and the west flank of the Talc City Hills north of the White Swan mine is the only place where a complete section is present.

Ely Springs dolomite has been described in the Quartz Spring area and the Ubehebe Peak quadrangle (McAllister, 1952, p. 15), in the Inyo-Death Valley area by Merriam (1954, p. 10), and in Mazourka Canyon in the Inyo Mountains by Langenheim and others (1956, p. 2095). Hazzard (1937, p. 325) and Hopper (1947, p. 407) provisionally correlated dolomite overlying Eureka quartzite in the Nopah Range and on the west side of Death Valley with the Ely Springs (fig. 2). Like most dolomitic rocks of the area, the Ely Springs dolomite forms bold, rough outcrops. The dark-gray color of the cherty dolomite overlying white vitreous quartzite renders the lower part of the Ely Springs readily recognizable.

THICKNESS AND STRATIGRAPHIC RELATIONS

A measured section of Ely Springs dolomite 2,200 feet northeast of the White Swan mine is approximately 920 feet thick (pl. 2). The accuracy of this section is somewhat impaired by a minor fault and a small basalt plug. McAllister's (1952, p. 13) measured sections of Ely Springs dolomite in the Quartz Spring area are 940 and 740 feet thick.

The contact between Ely Springs dolomite and Eureka quartzite is conformable and is marked by a sharp change in lithology and color. The upper contact is conformable but transitional with the Hidden Valley dolomite. The Ely Springs-Hidden Valley contact is placed at the top of a dark-medium-gray dolomite band about 40 feet thick that overlies light-gray Ely Springs dolomite and is overlain by massive light-gray Hidden Valley dolomite.

LITHOLOGY

Ely Springs dolomite is largely dolomite and a lesser amount of chert. The lower unit of the Ely Springs, 320 feet thick in the measured section, consists mainly of dark-gray thick-bedded dolomite but includes abundant black chert. The chert in this distinctive unit occurs as conspicuous beds ½- to 2-inches thick separated by ½- to 2-foot thicknesses of dolomite and as thin lenses and irregularly shaped nodules. Brown-weathering sandy dolomite about 15 feet thick is in the lower part of this unit.

Light-gray dolomite and minor amounts of medium-gray dolomite constitute most of the massive-appearing upper unit, which is about 600 feet thick. A dark-medium-gray dolomite band about 40 feet thick is at the top of the formation. Chert is rare in the upper unit, but a few chert nodules are in the basal part. Locally the dolomite is mottled by different shades of gray, but most of the unit is uniformly light gray. Outcrops of the light-gray massive-appearing dolomite that lack stratigraphic continuity are difficult to distinguish from similar dolomite in the Pogonip group and Hidden Valley dolomite.

AGE

The lower unit of the Ely Springs is Late Ordovician in age; paleontologic evidence is lacking in the upper unit. The best preserved and most diversified fossil assemblage consists of silicified specimens in the dark-gray dolomite that forms the prominent hill half a mile N. 30° E. of the Viking talc mine. C. W. Merriam (oral communication) collected and provisionally identified the following fauna from this site.

Brachiopods:
- *Heterorthis* sp.
- *Glyptorthis* cf. *insculpta*
- *Thaerodonta* sp.
- *Lepidocyclus* n. sp. (probably at least two species, one large)
- *Platystrophia* sp.
- *Onniella* cf. *quadrata* Wang
- *Zygospira* n. sp.
- *Strophomena* n. sp.
- ?*Opikina* n. sp.
- *Plaesiomys* sp.

Corals:
- *Halysites*, large form
- *Columnaria* cf. *alveolata* (Goldfuss)
- Several solitary streptelasmid types both large and small

Another collection of brachiopods made in cherty dark-gray dolomite about 15 feet stratigraphically above the base of the Ely Springs on a small exposure 6,300 feet N. 18° W. of the White Swan mine was studied by Reuben J. Ross, Jr. (written communication, 1954) of the U.S. Geological Survey who reported:

f130=D142

Resserella aff. *R. corpulenta*

This is the only species present but it is abundant and nicely silicified. The specimens at hand are not strictly *R. corpulenta* and bear some resemblance to *R. multisecta*. The former is a Maquoketa and the latter an Eden form. It therefore is clear that the collection comes from Upper Ordovician rocks but these may not be uppermost Ordovician.

Ross also studied a collection from the upper unit 3,000 feet N. 15° E. of the Viking mine. This collection was in light-gray massive dolomite of the upper unit of the Ely Springs. Ross reported (written communication, 1954):

f132=D143

Thaerondonta cf. *T. dignata* Wang

Onniella cf. *O. quadrata* Wang

Silica cast of a shell, possibly referable to *Parastrophinella*. Small silicified shell similar in shape to *Zygospira* but not referable to that genus. The same or a very nearly identical species is known but is as yet undescribed from the uppermost Bighorn formation near Buffalo, Wyoming.

Numerous tetracorals.

There is a strong suggestion that this collection is essentially correlative with the Late Ordovician Maquoketa beds of Iowa, with the Stony Mountain formation of Manitoba, and with the uppermost Bighorn beds on the east flank of the Bighorn Mountains.

SILURIAN AND DEVONIAN SYSTEMS

HIDDEN VALLEY DOLOMITE

NAME AND DISTRIBUTION

Hidden Valley dolomite was named by McAllister (1952, p. 15) for exposures on the east side of Hidden Valley in the Quartz Spring area. Outcrops of folded and faulted Hidden Valley dolomite are in the Talc City Hills, and the largest and most westerly exposures are the core of a syncline that forms the ridge southwest of the Hard Scramble mine (pl. 2). The formation is also exposed at the Victory prospect, and near the Alliance, Talc City, and Trinity talc mines (fig. 3). Regionally the formation is exposed in the Quartz Spring area (McAllister, 1952, p. 15), the Ubehebe Peak quadrangle (McAllister, 1955, p. 11), and in the Inyo Mountains (Merriam, 1954, p. 11).

THICKNESS AND STRATIGRAPHIC RELATIONS

Probably most of the Hidden Valley dolomite is represented within the quadrangle, but continuous outcrops are lacking because of faulting. Lack of distinctive lithologic units and the massive character of the rocks preclude an accurate measurement of the thickness. The formation is 1,365 feet thick at its type locality in the Ubehebe Peak quadrangle (McAllister, 1952, p. 16). No satisfactory section of the Hidden Valley was found for measurement, but it has a probable thickness of about 1,000 feet on the hill half a mile north of the Viking talc mine where the top of the formation is eroded.

Hidden Valley dolomite conformably overlies the dark-gray dolomite at the top of the Ely Springs. The only exposures of the upper contact are at the Talc City mine, where the contact is placed at the base of a bed of interbedded orthoquartzite and sandy limestone 65 feet thick. The contact also marks a change from light-gray massive Hidden Valley to the prevalent mottled dolomite and limestone characteristic of the lower part of the Lost Burro formation.

LITHOLOGY

Within the Darwin quadrangle the Hidden Valley is uniformly light-gray massive to very thick bedded dolomite with little diversification in lithology or color. Two sandy quartzite beds 5 and 20 feet thick are interbedded in the massive dolomite on the ridge west of the Hard Scramble mine. A few calcite aggregates 2 to 3 inches in diameter are widely scattered in parts of the formation. A representative thin section of Hidden Valley dolomite is made up of a granoblastic mosaic of dolomite crystals that average about 0.3 mm in diameter. Quartz occurs in small quantities as rounded sand grains and along grain boundaries of dolomite.

AGE

The only Hidden Valley fossils found are in massive light-gray dolomite a few hundred feet northwest of the Alliance talc mine. The fossils are poor in quantity and state of preservation, and consist of an ornamented solitary coral and a colonial coral, probably a favositid. McAllister (1952, p. 16) reported the lower fossiliferous part of the Hidden Valley dolomite in the Quartz Spring area is Silurian, probably equivalent in age to the top of the Clinton group in the Niagaran series. McAllister (1952, p. 17) also reported that fossils from the upper part of the Hidden Valley from a zone 50 feet thick lying 15 to 65 feet below the top of the formation in the Andy Hills were identified by G. Arthur Cooper and determined as Lower Devonian in age. The zone was correlated with the Oriskany part of the restricted Nevada limestone (Merriam, 1940, pp. 52–53).

DEVONIAN SYSTEM

LOST BURRO FORMATION

NAME AND DISTRIBUTION

The name Lost Burro formation was applied by McAllister (1952, p. 18) to exposures at Lost Burro Gap in the northeastern part of the Ubehebe Peak quadrangle. In the Darwin quadrangle the Lost Burro is present at the southeast end of the Santa Rosa Hills, at the Talc City mine in the Talc City Hills, and locally on the west side of the Darwin Hills (pl. 1). A belt of Lost Burro crops out as a discontinuous band of white marble on the east side of the Santa Rosa Hills for 2½ miles near the Lee mine. The Lost Burro formation forms a northwestward-trending band 1,000 feet wide and 2 miles long at the Talc City mine, and a small outcrop of marble of the Lost Burro is on the west side of the Darwin Hills 2.2 miles N. 24° W. of Darwin. Two small enclaves of marble about 3.7 miles S. 27° W. of the northeast corner of the quadrangle lithologically resemble the Lost Burro, and are assigned to it.

Outside of the Darwin quadrangle the formation is well exposed near the Cerro Gordo mine in the New York Butte quadrangle according to Merriam (oral communication, 1954); it is abundant in the Ubehebe Peak quadrangle and Quartz Spring area (McAllister, 1952, p. 18; 1955, p. 11) and Hall and Stephens (1962) have mapped the formation on the south side of Towne Pass in the Panamint Range and at the Modoc mine in the Argus Range. The Lost Burro formation generally is erosion resistant, and is well exposed.

THICKNESS AND STRATIGRAPHIC RELATIONS

A stratigraphic thickness of 1,773 feet was measured for an incomplete Lost Burro section that trends northeastward from a point 2,000 feet S. 14° W. of hill 5525 near the southeast end of the Santa Rosa Hills beginning at a conformable contact with the overlying Tin Mountain limestone. The lower part of the formation is not exposed. The accuracy of the measured thickness is impaired by apparently minor faults in the middle part of the section. The only exposure of the base of the formation in the quadrangle is in the Talc City Hills on the east side of the Talc City mine where the formation contact is placed at the base of a 65-foot-thick band of interbedded orthoquartzite and sandy limestone that conformably overlies massive light-gray Hidden Valley dolomite. The folded and faulted exposures in the Talc City Hills are not amenable to stratigraphic measurement.

McAllister's (1952, p. 18) section of Lost Burro at the type locality in the Ubehebe Peak quadrangle is

1,525 feet thick, but he also reported a section from the Quartz Spring area that is questionably 2,245 feet thick (McAllister, 1952, p. 19).

LITHOLOGY

The Lost Burro formation consists of white and light-gray medium- to coarse-grained marble, light- and dark-gray dolomite, shale, orthoquartzite, and silty limestone. The lower part of the formation is mainly dolomitic, and the upper part is mainly limestone. Almost all the formation is exposed in the Talc City Hills, although the upper contact is eroded. The basal part of the Lost Burro formation is exposed only on the east side of the Talc City mine where it conformably overlies light-gray massive dolomite in an overturned section. The lowermost 65 feet of the formation consists of thinly bedded silty gray limestone and light-gray vitreous orthoquartzite, both of which weather light brown. The lower 40 feet of this unit consists of quartzite beds 1 to 4 inches thick interbedded with gray sandy limestone that weathers brown. The upper 25 feet is vitreous light-gray quartzite that resembles the Eureka quartzite, and it is apparently repeated by faulting. This unit is correlated with the Lippincott member in the Ubehebe Peak quadrangle (McAllister, 1955, p. 12).

The Lippincott member is overlain by about 300 feet of light-gray massive- to thick-bedded dolomite and has a faint mottled appearance due to irregular relicts of dark-gray dolomite. Several discontinuous beds of dark-gray fine-grained limestone about 40 to 50 feet thick are interbedded in the dolomite. The beds are discontinuous because of local dolomitization, particularly at the crests of folds. The dark-gray fine-grained relicts of dolomite in the light-gray medium-grained dolomite are probably relicts of the original dolomite that was recrystallized during intrusion of leucocratic quartz monzonite. The mottled effect of the dolomite distinguishes it from the Hidden Valley dolomite.

The mottled dolomite unit is overlain by light-gray fine- to medium-grained limestone that has a strong, steep lineation. Locally the limestone has abundant fragmentary masses of stromatoporoids and cladoporoid corals. The limestone is estimated to be 450 to 500 feet thick. A brown-weathering fissile shale about 150 feet thick overlying the limestone is the uppermost unit exposed in the Talc City Hills.

The middle and upper parts of the Lost Burro formation are exposed in the Santa Rosa Hills near the Lee Mine in a section more than 1,700 feet thick; the base of the formation is not exposed. Dolomite is absent in the Lost Burro formation here in contradistinction to the predominantly dolomitic section at the type locality (McAllister, 1952, p. 18–19). The lower 300 feet of the exposed section in the Santa Rosa Hills consists predominantly of interbedded white marble and medium-gray limestone in beds about 1 foot thick that locally contain stromatoporoids and cladoporoid corals. The upper part of the Lost Burro consists almost entirely of white and light-gray banded and streaked marble, but contains a few thin quartzite beds. The top of the formation is a 2-foot-thick light-gray sandy quartzite bed that conformably underlies dark-gray Tin Mountain limestone. The limestone and marble beds of the formation are generally free of sand, silt, and clay.

Partial section of the Lost Burro formation measured northeastward from a point 1,280 feet N. 65° W. of the main shaft of the Lee mine

Tin Mountain limestone.
Conformable contact.
Lost Burro formation:

	Feet
Marble, white, streaked and locally banded, bedding generally poor	760
Marble, massive, mottled light- and medium-gray	140
Limestone, medium-gray, fine-grained. Streaked with thin calcite veinlets and tremolite rosettes	53
Marble, coarse-grained, white, in beds about 3 ft. thick; locally banded and streaked by gray marble	190
Limestone, medium-gray, fine-grained	12
Marble, white, coarse-grained; locally streaked with light-gray bands	48
Marble, mottled white and light-gray; calcite veinlets	72
Marble, white, coarse-grained, thick-bedded	89
Limestone, medium-gray	5
Marble, white, banded, coarse-grained	6
Limestone, medium-gray, fine-grained	2
Marble, white, coarse-grained	8
Limestone, medium-gray, fine-grained, a few chert nodules	2
Marble, white, coarse-grained, locally banded, beds 1 to 4 ft thick	69
Limestone, light-gray, poorly preserved corals and bryozoa	6
Orthoquartzite, light-gray, light-brown-weathering, subvitreous	1
Marble, banded white and medium-gray; cladoporoid-bearing beds 1 to 3 ft thick; a few stromatoporoids	69
Limestone biostrome, mottled medium- and light-gray; consists mainly of stromatoporoids and cladoporoid corals	12
Marble, white and medium-gray, interbedded coarse-grained	49
Limestone, medium-gray; contains calcareous nodules	6
Limestone, medium-gray, fine-grained; in beds about 1 ft thick. Poorly preserved gastropods(?) in lowermost exposure	174
Total	1,773

Base unexposed.

The shale unit is exposed near the top of the Lost Burro formation in a tight syncline in the Talc City Hills northwest of the Talc City mine. The unit is about 200 feet thick and consists of green and brown thinly bedded shale and small amounts of siltstone.

Examination of thin sections of the white marble shows that the rock consists almost entirely of an interlocking mosaic of calcite that ranges from 0.5 to 3.0 mm in maximum dimension. Subordinate constituents that generally constitute less than 1 percent of the sections are an opaque mineral, probably graphite, and in one section highly calcic scapolite (meionite), and wollastonite.

AGE

Stromatoporoid and cladoporoid corals, the most abundant Lost Burro fauna in the Darwin quadrangle, help to establish the Devonian age of the formation, but are inadequate for precise dating within the system. Most specimens of these genera, particularly those from the Talc City and Darwin Hills, are stretched and poorly preserved. McAllister (1952, p. 19) believes that the Lost Burro formation in the Quartz Spring area and Ubehebe Peak quadrangle is Upper Devonian and in part questionable Middle Devonian. Stromatoporoids and cladoporoid corals are associated with *Stringocephalus* in the lower part of the Lost Burro formation in the New York Butte quadrangle according to C. W. Merriam (oral communication, 1954) and are upper Middle Devonian. It is likely that the Lost Burro formation is, by lithologic correlation with dated units in adjacent areas, both Middle and Late Devonian in age.

MISSISSIPPIAN SYSTEM

TIN MOUNTAIN LIMESTONE

NAME AND DISTRIBUTION

Tin Mountain limestone was named by McAllister (1952, p. 20) from exposures at the northernmost peak in the Panamint Range, but as this site is somewhat inaccessible, he designated the type locality on the southern slope of the hills about 2½ miles southeast of Quartz Spring.

The formation crops out in the Darwin quadrangle in two bands along the crest and east flank of the Santa Rosa Hills, near the Lee mine, and locally in the northwestern part of the Darwin Hills (pl. 1). It is also part of a thrust plate in the eastern Talc City Hills about three-quarters of a mile north of the Silver Dollar mine (pl. 2). Tin Mountain limestone was described by McAllister (1952, p. 20–22; 1955, p. 12) from the Quartz Spring area and the Ubehebe Peak quadrangle and by Merriam (1954, p. 11) in the Inyo Mountains. It has been mapped by Hall and Stephens (in press) in the Argus Range at the Surprise mine (fig. 2). The cliff-forming propensity of the lower part of the formation is well displayed on the eastern face of the Santa Rosa Hills. Except for a few beds, the remainder of the formation is moderately erosion resistant and is well exposed.

THICKNESS AND STRATIGRAPHIC RELATIONS

A stratigraphic thickness of 435 feet of Tin Mountain limestone was measured in the southern part of the Santa Rosa Hills from a section trending S. 16° W. from a point 1.5 miles N. 51° W. of the main shaft at the Lee mine. The abnormal apparent thickness of more than 500 feet at the Lee mine is due to repetition of part of the section by faulting. The Tin Mountain limestone is 475 feet thick at its type locality in the Quartz Spring area and 425 feet thick where measured in the Ubehebe Peak quadrangle (McAllister, 1952, p. 21).

Contacts with the underlying Lost Burro formation and overlying Perdido formation are conformable. The Lost Burro-Tin Mountain contact is distinct and marked by lithologic and color changes, whereas the Tin Mountain-Perdido contact is gradational and represented by the inception of bedded chert in the lowermost part of the Perdido formation in contrast to lenticular and nodular chert in the Tin Mountain limestone.

LITHOLOGY

Tin Mountain limestone consists predominantly of pure fine-grained, medium- to dark-gray limestone. Most of it is calcarenite and calcilutite. Some limestone beds consist almost entirely of crinoid fragments—encrinite of Pettijohn (1949, p. 301); they are abundant in the upper part of the formation. Chert lenses and nodules are common throughout most of the Tin Mountain limestone, but bedded chert is absent; these features distinguish the Tin Mountain from the overlying Perdido formation. Veinlets of white calcite are locally abundant. Tremolite and actinolite as individual crystals and aggregates are commonly formed in the limestone as a result of low-grade metamorphism. Near fault zones the limestone is commonly bleached and recrystallized and resembles the Lost Burro formation, but it generally lacks the banding characteristic of the Lost Burro.

The formation is divisible into two major units. The lower unit, 130 feet thick, is mainly dark-medium-gray limestone in beds 6 inches to 2 feet thick intercalated with iron-stained shaly partings ½ to 1 inch thick. A few scattered chert nodules are in this unit.

The upper unit is 305 feet thick and consists mainly of light- to dark-medium-gray limestone in beds ranging from 6 inches to 12 feet in thickness. Chert lenses as much as 4 feet long and 6 inches thick are present, and crinoid-rich beds are abundant.

The band of dark-gray fine-grained limestone at the Lee mine and on the east flank of the Santa Rosa Hills 6,500 feet N. 54° W. of the Lee mine can definitely be assigned to the Tin Mountain limestone on the basis of lithology and stratigraphic succession. The limestone 1 mile S. 80° W. of the Lee mine and in the band at the north end of the Santa Rosa Hills 3.2 miles N. 45° W. of the Lee mine is less certainly assigned to the Tin Mountain. Lithologically the limestone is similar to Tin Mountain. It is mainly a fine- to medium-grained medium-gray limestone that locally contains chert lenses and nodules. Individual beds are a few inches to several feet thick. Crinoid stems, solitary corals, and syringoporoid corals are abundant in the limestone. However, the beds are isoclinally folded and are cut by many faults so that no continuous stratigraphic succession is present and the correlations are mainly lithologic. The faunal evidence is inconclusive.

Section trending S. 16° W. from a point 1.5 miles N. 51° W. of the main shaft of the Lee mine

Perdido formation.
Conformable contact.
Tin Mountain limestone:

	Feet
Limestone, light-gray crinoid-rich, with thin iron-stained partings; chert in lenses attaining a maximum length of 4 ft and thickness of 4 in increasingly abundant near top of section	19
Limestone, medium-gray, in beds about 6 in thick; some iron-stained partings and chert lenses	20
Limestone, light-gray, crinoid-rich, in beds 1½ to 2 ft thick; small amounts of chert in lenses as much as 4 ft long and 6 in thick	31
Limestone, dark-medium-gray; in beds about 1 ft thick; abundant medium-gray, dark-brown weathering chert lenses as much as 4 ft long and 4 in thick	41
Limestone, light-gray; a few interspersed crinoidal remnants	12
Limestone, medium-gray; abundant chert lenses 3 to 4 ft long and 2 to 4 in thick; moderately abundant crinoids, solitary corals, and brachiopods	14
Limestone, light-gray, crinoidal; moderately abundant brown-weathering chert lenses	43
Marble, white, medium-grained; chert lenses altered white	63
Limestone, light-medium-gray, crinoid-rich; contains dark-gray, dark-brown weathering chert lenses and nodules; maximum dimensions of lenses 18 in long and 2 in thick	62
Limestone, dark-medium-gray; in beds ½ to 2 ft thick; iron-stained reddish-brown shaly partings ½ to 1 in thick; widely scattered chert nodules; some syringoporoid corals, solitary corals, and brachiopods	130
Total	435

Conformable contact.
Lost Burro formation.

Microscopic examination of thin sections shows that the rock is partly recrystallized fine-grained calcarenite. Calcite, which constitutes between 95 and 99 percent of the rock, occurs as subrounded grains of fine-sand size, as subangular recrystallized crystals as large as 0.5 mm in maximum dimension, and as cementing material. Some opaque minerals are generally present. Quartz occurs in very small amounts as cementing material. Randomly oriented tremolite laths that attain maximum dimensions of 5.0 mm in length and 0.2 mm in width are abundant in the bleached white limestone.

AGE AND CORRELATION

Tin Mountain limestone is Mississippian and probably at least in part equivalent to the Madison group. Numerous corals and brachiopods are in the formation, but the internal structures of most specimens have been obliterated by silicification and recrystallization. McAllister (1952, p. 21), on the basis of paleontologic evidence cited in his Quartz Spring area report, proposes that the Tin Mountain limestone is equivalent to the lower part of the Madison group.

Several collections of Tin Mountain fossils from the Santa Rosa Hills were examined by Helen Duncan and Mackenzie Gordon, Jr., and their findings substantiate an Early Mississippian age for the formation. Collections USGS 17564 and 17567 are from the limestone band about 3,000 feet S. 25° E. of the Lee mine that can definitely be correlated with the upper unit of the Tin Mountain on the basis of stratigraphic succession. A report by Mackenzie Gordon, Jr. (written communication, May 26, 1953) on brachiopods in collection USGS 17564 is given below:

Two of the brachiopod species are represented by at least one well preserved specimen each. These may represent undescribed species or variants of known species and appear to have affinities with late Kinderhook or early Osage forms. No definite age determination can be made on these few brachiopods, but it can be said that they appear to be of Early Mississippian age. The containing rocks are probably referrable to the Tin Mountain limestone of the Quartz Spring area.

USGS 17564, Santa Hills, 3,100 feet S. 27° E. of the main shaft of the Lee mine at an altitude of 5,130 feet.

Rhipidomella aff. *R. dalyana* (Miller)
Schizophoria sp.
Cleiothyridina cf. *C. hirsuta*
aff. *C. prouti* (Swallow)

The following are excerpts of a report by Helen Duncan (written communication, June 12, 1953):

The corals in USGS 17564 and USGS 17567 are comparable to genera and species that occur in the Tin Mountain limestone. * * *

The specimens in USGS 17564 are crudely silicified. The small horn coral cannot be identified because internal structures are destroyed. The corallites of the *Syringopora* have about the same size and spacing as those of *S. surcularia* Girty, a species that is widespread in Lower Mississippian rocks of the West.

USGS 17567. Santa Rosa Hills, 2,300 feet S. 25° E. of the Lee mine along the saddle in the ridge.

Syringopora cf. S. *aculeata* Girty
cf. *S. surcularia* Girty
Yavorskia? sp. indet.
Vesiculophyllum sp. indet.

* * * The Syringoporas are types common in the Lower Mississippian of the West. *Vesiculophyllum* seems to be diagnostic of the Lower Mississippian in the Great Basin and the Southwest. This coral assemblage is appropriate for the Tin Mountain.

Several collections of corals and brachiopods were made from the limestone beds about 1 mile S. 80° W. and 3.2 miles N. 45° W. of the Lee mine, which are assigned to the Tin Mountain on the basis of lithology. Several collections from the limestone in the area 1 mile S. 80° W. of the Lee mine were reported on by Mackenzie Gordon, Jr. (written communication, Feb. 25, 1953):

This report is based on 20 partly silicified and fragmentary fossil brachiopods from limestones collected at three localities in the southern part of the Santa Rosa Hills * * *. The corals and bryozoans were examined by Duncan. Taken as a whole, the fossils indicate an Early Mississippian age for the containing rocks.

USGS 144418. South end of Santa Rosa Hills 1 mile S. 80° W. of the Lee mine.
Horn corals, indet.
Brachiopod
Spirifer sp. A

USGS 14419. Santa Rosa Hills 6,100 feet S. 85° W. of the main shaft of the Lee mine.
Horn corals, indet.
Bryozoan
Eridopora? sp. indet.
Brachiopods
Rhipidomella? sp. indet.
Camarotoechia? sp.
Cyrtina n. sp.
Composita? sp. indet.

USGS 14421. Santa Rosa Hills, 1 mile S. 80° W. of the main shaft of the Lee mine at an altitude of 5,380 feet.
Horn corals
Brachiopods
Leptaena analoga (Phillips)
Productid, genus and species indet.
Rhipidomella cf. *R. oweni* (Hall)
Schizophoria sp. indet.
Tetracamera? sp.
Spirifer sp. A.

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 USGS 14418 and USGS 14421 along with poorly preserved horn corals that have a general Early 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 analoga* (Phillips) is typical of the rocks of Madison age but at one locality is known to range slightly 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, though 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.

Regarding the corals in USGS 14421, Helen Duncan (written communication, Feb. 25, 1953) reported:

This collection contains several specimens and fragments of horn corals. The smaller forms appear to be zaphrentoids. The two larger corals show indications of dissepiments and are probably either caninoids or clisiophyllids. Corals of this general type occur in the Tin Mountain limestone of the Panamint Range.

Three collections of corals were reported on from the band 3.2 miles N. 45° W. of the Lee mine. Fossils collected by J. F. McAllister from this band were examined by James Steele Williams and Helen Duncan. Williams (written communication, Jan. 18, 1949) reported:

USGS 17663. Four miles N. 39° W. of the Lee mine on the south side of the first gully south of the basalt capping.
Zaphrentoid horn corals, small, indet.
Lithostrotion sp. indet. (phaceloid type)
Crinoid columnals
Composita? sp. indet.

Of the corals, Miss Duncan says: "The small horn corals are fragmentary and silicified and indeterminate but they seem to be the zaphrentoid types that are common in Early Mississippian faunas. The presence of *Lithostrotion* in this collection is a strong support for a Mississippian age assignment. Although the specimen is recrystallized and not specifically identifiable, there can be little doubt that it is a simple lithostrotionoid type with a styliform columbella. Such corals first appear in the Lower Carboniferous. Phaceloid lithostrotionoids seem to have developed somewhat later than the massive forms, which occur sporadically in assemblages of late Kinderhook age."

Two other collections from the same band but probably higher in the formation were examined by Miss Duncan (written communication, June 12, 1953).

USGS 17566. 3.45 miles N. 46° W. of the main shaft of the Lee mine at an altitude of 6,080 feet.

This collection consists of several pieces of lithostrotionoid corals and a single fragment of a zaphrentoid. The material is so thoroughly recrystallized that sections are useless. The weathered surfaces indicate that one of the species is a phaceloid *Lithostrotion*. The other colonial coral is a massive form that belongs to either *Lithostrotion* or *Lithostrotionella*.

The presence of lithostrotionoid corals suggests that the rocks are probably Mississippian * * *

USGS 17565. 3.7 miles N. 44° W. of the main shaft of the Lee mine at an altitude of 6,080 feet.

This collection consists of a number of silicified and fragmentary corals and bryozoan. Silicification is so crude that structures needed to identify the corals are obliterated. In addition to the bryozoan *Cystodictya* sp. indet., this lot contains a small piece of a lithostrotionoid coral that is probably either *Lithostrotionella* or *Thysanophyllum* and at least three types of zaphrentoid corals.

USGS 17565 and 17566 appear to have come from beds of approximately the same age. The corals, however, are different from any that I have previously studied from this region. The fauna is apparently of Mississippian age, and might even be from the Tin Mountain, though it could be later.

Although this limestone at the north end of the Santa Rosa Hills lithologically resembles Tin Mountain limestone most closely, it can not be ruled out that it is not part of the Perdido formation or Lee Flat limestone. It does not resemble beds as young as the basal Keeler Canyon formation (Atoka).

PERDIDO FORMATION

NAME AND DISTRIBUTION

The Perdido formation was named by McAllister (1952, p. 22) from exposures in the Quartz Spring area. Rocks of the formation are best exposed in the Darwin quadrangle on the two prominent hills less than a mile south of the Lee mine. They are also in the northern part of the Santa Rosa Hills and in a narrow belt extending southeastward from the southern part of the Talc City Hills to the northwestern part of the Darwin Hills (fig. 2). McAllister (1952, p. 23-24; 1955, p. 12) described Perdido rocks from the Quartz Spring area and Ubehebe Peak quadrangle, and Merriam (1954, p. 11) described them in the Inyo Mountains. The Perdido formation crops out at the north end of the Argus Range in the Modoc district and on the west flank of the Panamint Range in the Panamint Butte quadrangle (Hall and Stephens, in press).

THICKNESS AND STRATIGRAPHIC RELATIONS

The Perdido formation ranges in thickness from 177 to more than 334 feet in the Darwin quadrangle. Most contacts of the Perdido are faulted, but the maximum thickness seems to be about 334 feet. A thickness of 610± feet was measured for the Perdido formation at its type locality in the Quartz Spring area by McAllister (1952, p. 24), who stated that the formation varies greatly in thickness.

The Perdido formation conformably overlies Tin Mountain limestone, and in the Darwin quadrangle is conformably overlain by Lee Flat limestone. The contact with the underlying Tin Mountain limestone is gradational and is placed at the first bedded chert in the section. The contact with the overlying Lee Flat limestone is sharp. The Rest Spring shale, which overlies the Perdido formation in the adjacent Ubehebe Peak quadrangle and Quartz Spring area (McAllister, 1952, p. 25; 1955, p. 13) is present only in fault zones in the Darwin quadrangle.

LITHOLOGY

The Perdido formation consists predominantly of gray medium-bedded limestone and interbedded chert. The lower part of the Perdido is predominantly limestone and thin beds of chert, whereas chert is prevalent at many places in the upper part. The limestone is mostly fine grained, although coarse clastic beds composed mainly of crinoid columnals are common. The color ranges from bluish-gray to dark-gray, and near intrusive rocks the limestone is bleached white. The lower part of the Perdido resembles the upper part of the Tin Mountain limestone. However, the Tin Mountain contains lenses and nodules of chert, and the Perdido contains thin chert beds. The chert is gray on fresh surfaces and weathers dark brown.

Chert is in beds generally less than 4 inches thick interbedded with limestone in the lower part of the Perdido. In the Santa Rosa Hills near the Lee mine,

A partial section of the Perdido 334 feet thick measured from a southward-trending traverse from a point 0.90 mile S. 39° E. of the main shaft at the Lee mine

Lee Flat limestone:
Conformable contact.
Perdido formation:

	Feet
Metamorphosed zone consisting of marble and white calcsilicate rock, some interbedded chert in beds 1 to 4 in thick, and 1-ft-thick beds of unsilicated medium-gray silty limestone	62
Siltstone, medium-brown, dark-brown weathering; in beds 1 to 2 in thick	9
Limestone, medium gray, in beds 1 to 4 in thick, and interbedded chert in beds that average about 1 ft in thickness; a few limestone lenses within the chert	21
Chert, white, in beds 1 to 2 ft thick	61
Limestone, medium-gray, in beds commonly 2 to 8 in thick with interbedded dark-gray, dark brown weathering chert 1 in to 1 ft thick; limestone in upper part of unit locally silty	117
Limestone, medium- and light-gray, bleached; in beds 2 to 4 in thick and containing interbedded chert 2-in-thick, chert is pinkish white and limestone partly silicated	64
Total	334

Fault contact with Tin Mountain limestone.

chert beds as much as 61 feet thick and some siltstone are more abundant than limestone in the upper part. However, most stratigraphic sections of Perdido lack thick beds of chert in the upper part, and the formation mostly has a uniform appearance of limestone and thin beds of chert.

The Perdido band that trends southeastward from the southern part of the Talc City Hills into the Darwin Hills consists of thinly bedded chert and limestone (pl. 1). The limestone and chert, which weather brown, are thinly bedded. No thick beds of chert are present.

The upper clastic siltstone, sandstone, shale, and limestone unit of the Perdido at the type locality (McAllister, 1952, p. 22) is not present in the Darwin quadrangle except for one fossiliferous locality in the eastern part of the Talc City Hills. The Darwin Perdido section correlates well lithologically and in thickness with the lower limy part of McAllister's type Perdido section.

Thin sections of limestone from the Perdido formation consist largely of irregular and rounded calcite crystals 0.02 to 0.03 mm in diameter that are in part recrystallized to coarser calcite rhombohedrons. Chert partly replaces calcite in all sections. Iron oxides, pyrite, and late calcite veinlets occur in small quantities. Tremolite in crystals as much as 3.0 mm long and 0.3 mm wide is interspersed throughout most sections.

AGE

The only Perdido fossils found in the Darwin quadrangle besides ubiquitous fragmentary crinoid columnals are in the eastern Talc City Hills in an area complicated by thrust faulting. The fossils are in a 2-foot-thick limestone bed within a predominantly siltstone unit, which includes large solitary corals, crinoid columnals, and brachiopod fragments. The fauna is too poorly preserved to provide diagnostic age information. McAllister (1952, p. 24, 25) presents evidence that the formation is Mississippian and includes rocks ranging in age possibly from Osage or late Kinderhook into Chester.

MISSISSIPPIAN AND PENNSYLVANIAN(?) SYSTEM

LEE FLAT LIMESTONE

NAME AND DISTRIBUTION

The Lee Flat limestone was named for exposures on the southwest side of Lee Flat (Hall and MacKevett, 1958, p. 8). The type locality of the formation trends southward from an altitude of 5,280 feet near the top of the prominent hill 0.9 miles S. 36° E. of the main shaft of the Lee mine to the contact with alluvium at the foot of the hill at an altitude of 5,000 feet. The most accessible good exposure of the formation is on the hill 3,000 feet south of the Lee mine where a section

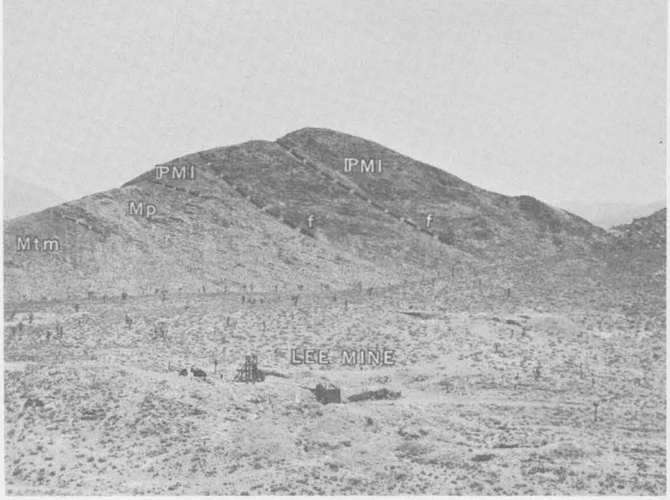

FIGURE 5.—Lee Flat limestone (PMl) viewed south from the Lee mine. The Lee Flat limestone conformably overlies the Perdido formation (Mp), which, in turn overlies the Tin Mountain limestone (Mtm). This is the most accessible section of Lee Flat limestone, but was not designated as the type locality because of the interruption of the section by steep faults (f).

from the Lost Burro formation to Lee Flat limestone is exposed. This exposure was not designated as the type locality as the section is faulted (fig. 5). The Lee Flat is also exposed in a strip 4½ miles long along the northeast slope of the Santa Rosa Hills, and in a band that extends from the northwestern part of the Darwin Hills into the southern part of the Talc City Hills, generally in fault-bounded outcrops (pl. 1). The formation is in a horst at the Zinc Hill and Empress mines in the Argus Range. Calc-hornfels exposed in Rainbow Canyon and adjacent canyons in the eastern part of the quadrangle is probably mainly metamorphosed Lee Flat limestone.

The formation commonly weathers to smooth surfaces that retain the dark-medium-gray of the unaltered rock. Locally, parts of the formation form craggy outcrops and minor cliffs.

THICKNESS AND STRATIGRAPHIC RELATIONS

Lee Flat limestone conformably overlies the Perdido formation, but its upper contact is not exposed in the Darwin quadrangle. The contact between the Lee Flat limestone and Perdido formation is marked by a change from interbedded limestone and chert near the top of the Perdido formation to thin-bedded Lee Flat limestone. The formation is at least 520 feet thick at its type locality—this thickness represents an incomplete section that was measured southwestward from the apparently conformable contact with the Perdido formation to a point where alluvium conceals the bedrock. The formation has an estimated maximum exposed thickness of 960 feet in the Santa Rosa Hills 4,700 feet N. 67° W. of the main shaft of the Lee mine, and the thickness is at least as great 3,000 feet south of the Lee mine on hill 5594. Owing to complex folding and faulting in both places, however, the section was not designated as a type locality.

LITHOLOGY

Lee Flat limestone consists mainly of thin-bedded fine-grained dark-medium-gray limestone admixed with small amounts of silt and clay. The formation is generally uniform in appearance and consists largely of calcilutite. Locally the limestone contains iron-stained partings or small lenses or thin beds of chert.

The formation is divisible into two units at the type locality. The lower unit, 136 feet thick, is predominantly thin-bedded, dark-medium-gray limestone but includes a few dark-gray, brown-weathering chert lenses and nodules and locally crinoid-rich beds. Iron-stained partings are moderately abundant near the top.

The upper unit, which is at least 384 feet thick, differs from the lower unit by its absence of chert and the moderate abundance of ½- to 3-inch thick iron-stained partings in parts of the section. The prevailing dark-medium-gray thin-bedded limestone of this unit is locally cut by narrow veinlets of white calcite.

Thin section study of the Lee Flat limestone shows that the rock is calcilutite and consists chiefly of small subrounded calcite grains that are less than 0.05 mm in average maximum diameter but that attain maximum diameters of 0.10 mm. Quartz, opaque minerals, and limonite make up about 1 to 2 percent of most sections. Elongate tremolite crystals as much as 4.0 mm long are abundant.

AGE, CORRELATION, AND ORIGIN

Crinoid fragments are the only fossils found in the Lee Flat limestone. The formation is probably a time-stratigraphic equivalent of the upper clastic part of the Perdido formation and the Rest Spring shale of the Ubehebe Peak quardrangle (McAllister, 1956) and is Mississippian and Pennsylvanian(?) in age (fig. 6). Time equivalence is indicated by Rest Spring shale conformably overlying the Perdido formation in the Quartz Spring and Ubehebe Peak areas (McAllister, 1952, p. 23; 1955, p. 13) and the Lee Flat limestone conformably overlying limestone and bedded chert that correlates with the lower unit of the Perdido formation at the type locality (McAllister 1952, p. 23). The Rest Spring shale in the Ubehebe Peak quadrangle is conformably overlain by thinly bedded limestone of Atoka or early Des Moines age (McAllister, 1956). The upper contact of the Lee Flat is not exposed in the Darwin quadrangle, but in the adjacent Panamint Butte quadrangle the writers have mapped Lee Flat limestone that is conformably overlain by thinly bedded limestone of Atoka or early Des Moines age. The lower rocks of the Perdido are Mississippian and probably are Osage or late Kinderhook (McAllister, 1952, p. 24). The Lee Flat limestone therefore is younger than late Kinderhook or Osage (early Mississippian) and older than Des Moines (Middle Pennsylvanian).

In a reconnaissance of parts of the Argus Range south and east of the Darwin quadrangle in the Modoc district the writers observed marble of the Lee Flat limestone. The marble underlies the Keeler Canyon formation and overlies limestone and bedded chert of the Perdido formation. No shale is present between the Perdido formation and the *Fusulinella* zone at the base of the Keeler Canyon formation. The lithology of the Lee Flat limestone is transitional between the clastic Upper Mississippian and Pennsylvanian(?) section in the Ubehebe Peak area and the massive, cliff-forming upper Monte Cristo limestone of the Nopah-Resting Springs area (Hazzard, 1954, p. 880). The cliff-forming Lee Flat limestone observed by the writers in the Argus Range lithologically resembles the Bullion limestone member of the Monte Cristo limestone described by Hazzard (1954, p. 881).

PENNSYLVANIAN(?) SYSTEM

REST SPRING SHALE

Rest Spring shale was named by McAllister (1952, p. 25) in the Quartz Spring area. Shale in the Darwin quadrangle that is mapped as Rest Spring on the basis of lithologic similarity is found only in several small outcrops in fault zones at the north end of the Santa Rosa Hills, at four places in the thrust fault in the Talc City Hills, and in a fault in the hills south of State Highway 190 about 2 miles N. 57° E. of the Silver Dollar mine (pl. 1). In the Talc City Hills 0.7 miles south of the Talc City mine both Rest Spring shale and Lee Flat limestone are present, but the exposures are poor; so the nature of the contacts is not known. It is likely that the association of Rest Spring shale with Lee Flat limestone indicates interfingering of the two formations.

The Rest Spring shale in the Darwin quadrangle is at least in part equivalent to the Chainman shale northwest of the Darwin quadrangle in the Inyo Mountains (Merriam and Hall, 1957, p. 4). The Chainman in the Inyo Mountains is the same unit as the black shale referred to the upper part of the White Pine shale of the Inyo Mountain (Kirk, in Knopf, 1918, p. 38; Merriam, 1954, p. 11).

In the Darwin quadrangle the Rest Spring shale consists predominantly of dark-brown fissile argillaceous shale and minor siltstone. Discoidal siliceous concretions that have a maximum dimension of about 6 inches are in the shale in the thrust fault at the Silver Dollar mine and at the northwest end of the Talc City

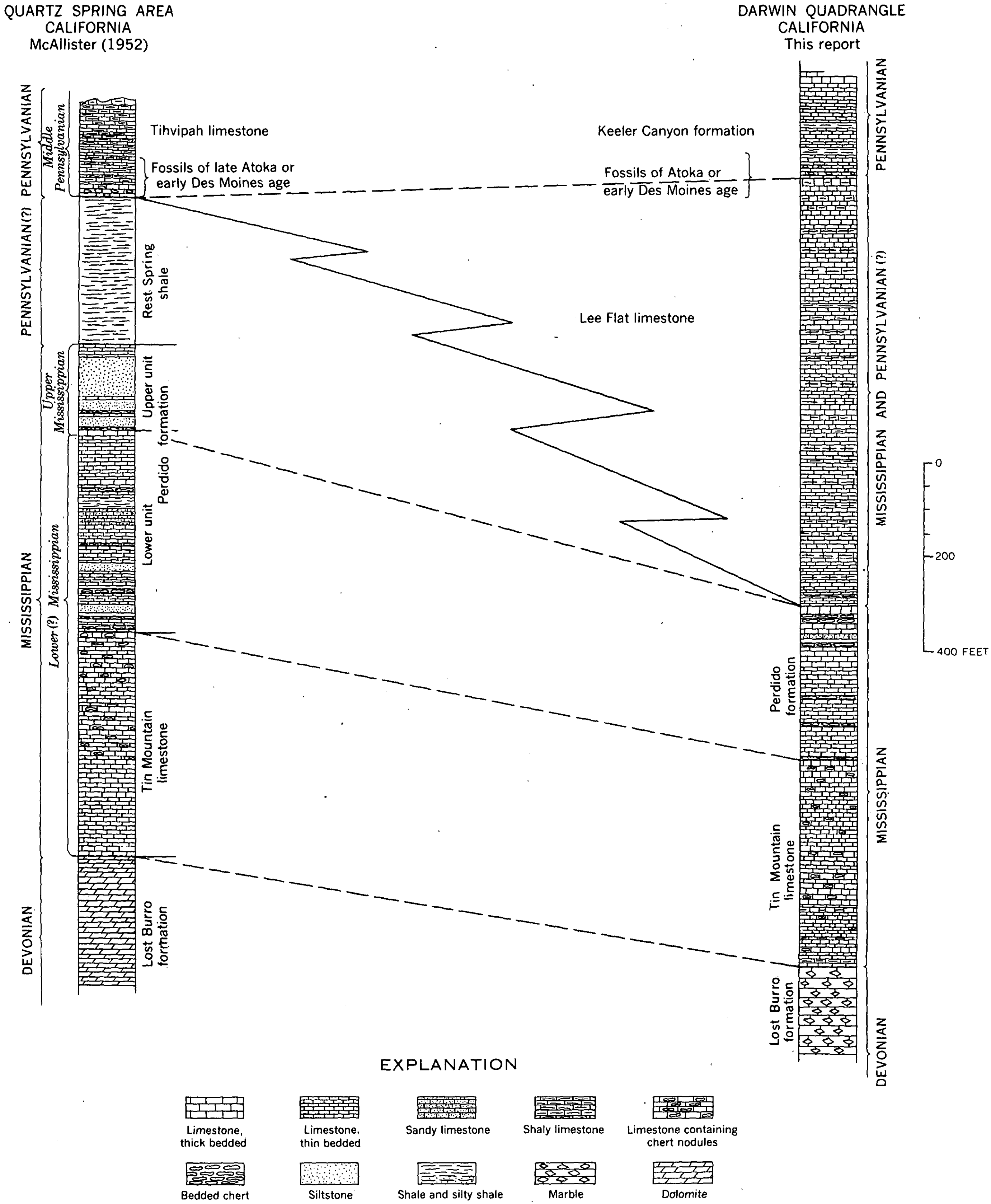

FIGURE 6.—Correlation of Carboniferous formations of the Quartz Spring area and Darwin quadrangle.

Hills 1.3 miles north of the northernmost workings of the White Swan mine (pl. 2).

The Rest Spring shale may be allochthonous in the Darwin quadrangle. Wherever Mississippian and Pennsylvanian rocks are exposed in normal stratigraphic sequence in the quadrangle, the Lee Flat limestone is below the *Fusulinella* zone of the Keeler Canyon and shale is absent. Several major faults trend N. 20° W. in the Santa Rosa Hills; they are probably left-lateral strike-slip faults. Except for a small outcrop at the north end of the Talc City Hills the Lee Flat limestone is either east of the westernmost strike-slip fault (the Santa Rosa Flat fault) in the Santa Rosa Hills or south of the Darwin tear fault, and the faulted exposures of Rest Spring shale are all west of the Santa Rosa Flat fault. Although the Rest Spring shale is found only in fault zones, so many faulted slivers of it are exposed in the Talc City Hills that it probably occurs in the northwestern part of the quadrangle under a deep cover of younger rocks. The shale and limestone facies may be contiguous in the Santa Rosa Hills because of left-lateral strike-slip faulting on the Santa Rosa Flat fault (pl. 1).

AGE AND CORRELATION

The Rest Spring shale is the time equivalent of part of the Lee Flat limestone of the Darwin quadrangle (fig. 6). The upper black shale of the Chainman in the Inyo Mountains is also correlative with the Rest Spring shale (McAllister, 1952, p. 26).

The age of the Rest Spring is equivocal. No fossils were found in it in the Darwin quadrangle. Kirk (*in* Knopf, 1918, p. 38), Merriam (1954, p. 11), and Merriam and Hall (1957, p. 5) considered the dark shale beds of the Chainman in the Inyo Mountains to be Late Mississippian. McAllister (1952, p. 26) considered the Rest Spring shale to be Pennsylvanian(?). In this report the Rest Spring in the Darwin quadrangle is considered Pennsylvanian(?).

PENNSYLVANIAN AND PERMIAN SYSTEMS

Pennsylvanian and Permian rocks predominate in the northwestern and southeastern parts of the quadrangle and constitute the most widespread and thickest Paleozoic sedimentary rocks; they have an aggregate thickness greater than 5,900 feet. These rocks are mainly silty limestone but include pure limestone, shale, siltstone, arenaceous limestone, and conglomerate. Well-defined lithologic changes that could be used as formational boundary markers are lacking. Pennsylvanian and Permian rocks are similar to those described by Merriam and Hall (1957) from the southern Inyo Mountains, and their names—Keeler Canyon and Owens Valley formations—are used in this report. Because of the gradational nature of the rock types, some contacts may not be precisely at the same stratigraphic position as at the type locality. Lateral variations in lithology in parts of the Pennsylvanian and Permian section are also a deterrent to precise stratigraphic correlation. McAllister (1955, p. 13) provisionally used the name Bird Spring(?) formation for similar Pennsylvanian and Permian rocks in the Ubehebe Peak quadrangle.

The Keeler Canyon and Owens Valley formations consist largely of clastic and limy deposits whose constituent particles range in size from silt to boulders. Characteristics indicative of shallow-water, nearshore deposition, such as crossbedded calcarenites and coarse conglomerate with subangular limestone fragments, are common. Disconformities in the Keeler Canyon and Owens Valley section are indicated by recurrence of fossiliferous pebble conglomerates that contain limestone pebbles of the Keeler Canyon in the lower part of the section and coarse conglomerate at Conglomerate Mesa. Local angualr unconformities are present but are not common.

Broad undulatory folds and moderate relief characterize most exposures of the Keeler Canyon and Owens Valley formations. Where the rocks are silicated, the relief is more rugged. The formations can commonly be recognized from a distance by the folded nature of the incompetent rocks in contrast to the throughgoing nature of the older strata (fig. 7).

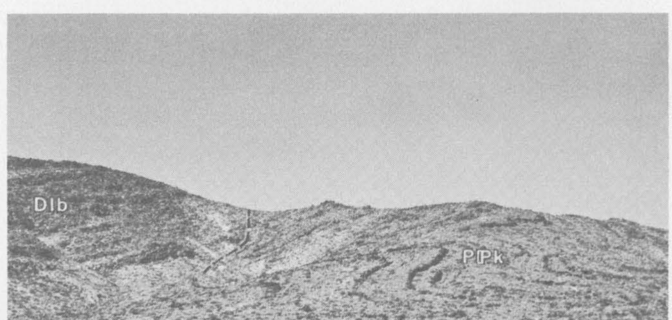

FIGURE 7.—Photograph showing the folded, incompetent nature of the Pennsylvania and Permian strata (PPK) in contrast to the throughgoing nature of the adjacent Lost Burro formation (Dlb) of Devonian age. The contact is a fault. View looking west at the east side of the Talc City Hills near the Silver Dollar mine.

KEELER CANYON FORMATION

NAME AND DISTRIBUTION

The name Keeler Canyon formation was proposed by Merriam and Hall (1957, p. 4) for the thick sequence of rocks east of the Estelle tunnel portal at the head of Keeler Canyon in the New York Butte quadrangle 2 miles southwest of Cerro Gordo Peak. Exposures of the formation in the Darwin quadrangle are on the west flank of the northern part of the Santa Rosa Hills, in the adjacent low hills to the northwest, and in the Talc City Hills and Darwin Hills (pl. 1). Conspicuously folded Keeler Canyon strata crop out in the eastern Talc City Hills and northwestern Darwin Hills and can be readily seen from State Highway 190. Generally the formation weathers to smooth slopes, but locally resistant beds form riblike outcrops and shaly parts form subdued topography.

THICKNESS AND STRATIGRAPHIC RELATIONS

There is no complete Keeler Canyon formation section suitable for stratigraphic measurement in the quadrangle. Partial sections were measured east of the Conglomerate Mesa road in the northwestern part of the quadrangle, in the Darwin Hills northeast and southwest of the Darwin Antimony mine, and on the west flank of the Santa Rosa Hills west of hill 6170 (pl. 1). These sections indicate a minimum thickness of 4,000 feet for the formation. The contacts with the underlying Lee Flat limestone or with the Rest Spring shale are faults. The conformable upper contact is gradational and difficult to define accurately. It is placed at the top of a predominantly pinkish shale unit stratigraphically below the inception of a chiefly silty and shaly limestone containing lenses of pure limestone or limestone conglomerate.

LITHOLOGY

The Keeler Canyon formation is divided into two units, a lower unit at least 2,300 feet thick consisting mainly of bluish-gray limestone and limestone pebble conglomerate, and a 1,770-foot-thick upper unit composed largely of pinkish shales and shaly limestone. Limestone pebble conglomerate, although not confined to Keeler Canyon rocks, is sufficiently abundant to be a characteristic of the formation.

LOWER UNIT

The 500 feet of the lower unit is best exposed in the northern part of the Santa Rosa Hills. Thinly bedded dark-gray limestone and intercalated 1- to 4-foot-thick gray limestone pebble conglomerate beds containing small fusulinids about 2 mm long and minor chert nodules constitute the lowermost 100 feet of the member. Spheroidal, black chert nodules about ½ to 2 inches in maximum diameter are conspicuous in the thicker limestone beds near the base. This zone is a reliable stratigraphic marker and is referred to as the "golfball" horizon. The superjacent 400 feet of section consists mainly of medium-gray shaly limestone intercalated with medium-gray limestone pebble conglomerate in beds 1 to 4 feet thick that contain fusulinids 3 to 5 mm long. Some of the pebbles are composed of subrounded chert. Minor iron-stained partings and scattered crinoid debris are in parts of the thinly bedded limestone.

West of the Darwin Antimony mine and southwest of the Darwin tear fault, strata of the lower member appear to be at least 2,300 feet thick, but the section is folded and faulted. It consists mainly of thin-bedded medium- and light-medium-gray limestone but includes local chert nodules, iron-stained partings, and crinoidal beds. Light-gray, brown-weathering silty limestone and calc-hornfels are abundant in the upper part of the member. The contact between the lower and upper units is gradational and is marked mainly by prevalent interbedded limestone and pink shale in the overlying unit. Pink shale is present but is not abundant in the lower unit.

Metamorphosed rocks in the central part of the Darwin Hills at the Darwin mine are correlated with the lower part of the Keeler Canyon formation on paleontologic and lithologic evidence. Thinly bedded bluish-gray limestone and calc-hornfels containing spheroidal chert nodules ½ to 1 inch in diameter are interbedded with calc-hornfels in the inverted syncline on the south slope of Ophir Mountain (pl. 3). Locally poorly preserved tiny fusulinids were observed in the limestone. This limestone and calc-hornfels zone, which is in fault contact with limestone lithologically identical to the Lee Flat limestone, is undoubtedly the golfball horizon at the base of the Keeler Canyon formation.

UPPER UNIT

The upper unit of the Keeler Canyon formation crops out in the Darwin Hills on hill 5979 east of the Darwin Antimony mine, in the low hills for 3 miles northwest of hill 5979, and in the northwestern part of the quadrangle 3 miles east of Conglomerate Mesa (pl. 1). It consists of thinly bedded bluish-gray calcilutite, fine-grained calcarenite, and pink shale and forms pinkish-gray slopes where unmetamorphosed in contrast to the grayish hue of slopes underlain by the lower member. This is particularly apparent in the low hills north of the Darwin Antimony mine. In the eastern part of the

Darwin Hills, the member is metamorphosed to calc-hornfels and hornfels that are dark-brown on weathered surfaces and gray on fresh surfaces. The dark-brown metamorphosed upper unit is in sharp contrast to the white and light-gray metamorphosed lower unit.

Lithologic details of the upper unit along a traverse that trends N. 70° E. from a point 140 feet east of the south shaft at the Darwin Antimony mine are summarized below. The section here is overturned; the beds strike north and dip steeply west, but their tops are to the east.

Section of upper unit 140 feet east of the south shaft at Darwin Antimony mine

Lower part of Owens Valley formation.
Conformable contact.

	Feet
Upper unit of the Keeler Canyon formation:	
Limy shale, pink and gray; shaly and silty limestone; and fusulinid-bearing limestone and pebble conglomerate. Shaly rocks constitute about 60 percent of section	410
Silty limestone, light-pinkish-gray, 2 to 10 ft thick inter-bedded with light-pinkish-gray, locally brown-weathering shale 10 to 20 ft thick. Crossbedding present locally in limestone	175
Limy shale, pinkish-gray	100
Limestone, massive, pinkish-gray, containing a 10-ft thick pink shale; section cut by minor faults	135
Limestone, light-pinkish-gray, massive; locally cut by calcite veinlets	200
Limestone light- and medium-gray, sandy and silty; in beds 1 to 2 ft thick; minor shaly partings	190
Limestone and fusulinid-bearing limestone pebble conglomerate containing a 15-ft thick pink limy shale	190
Limy shale, largely pink, and shaly limestone; brown and grayish-brown-weathering silty limestone and locally crossbedded fusulinid-bearing limestone pebble conglomerate are interbedded with pink shale in lower part of the section	300
Total	1,700

Gradational contact.
Lower unit of the Keeler Canyon formation:
The upper part consists mainly of light-medium-gray limestone with iron-stained partings and medium-gray fusulinid-bearing limestone pebble conglomerate in beds 1 to 2 ft thick. Shaly limestone is progressively more abundant near the upper contact.

The higher parts of the upper unit are well exposed 3 miles east of Conglomerate Mesa where pink shale and subordinate brownish-gray-weathering silty limestone of the upper unit of the Keeler Canyon formation grade into a conformable sequence of predominantly brown-weathering platy and silty limestone and subordinate shale of the lower part of the Owens Valley formation. Pink shale makes up about two-thirds of the upper 800 feet of the Keeler Canyon formation; the remainder is brown-weathering shale and silty limestone in beds 6 inches to 2 feet thick, and minor fusulinid-bearing limestone pebble conglomerates. The pink shale is underlain by 150-foot-thick light-gray to buff, tan-weathering siltstone. Below the siltstone the Keeler Canyon formation consists mainly of medium-gray and pinkish-gray, light-brown weathering thin-bedded silty limestone interbedded with lesser amounts of pink shale for an exposed thickness of 450 feet.

AGE AND CORRELATION

The Keeler Canyon formation ranges in age from probable Atoka or Des Moines (Middle Pennsylvanian) to Wolfcamp (early Permian). Fusulinids are the most abundant fossils, but in many places their structures are obscured by silicification and deformation. The lower unit of the Keeler Canyon formation contains fossils that range in age from probable late Atoka or early Des Moines to Wolfcamp. The lowermost approximate 200 feet of the formation is in part equivalent to McAllister's (1952, p. 26–27) Tihvipah limestone and paleontologically is characterized by small fusulinids of probable Atoka age.

The following is a summary of a report by Lloyd G. Henbest (written communication, 1953) on a collection made near the base of the Keeler Canyon formation in the Santa Rosa Hills.

f9591. Pennsylvanian, Atoka or Des Moines age. Locality 1.65 miles S. 79° W. of the Lee mine at an altitude of 5,270 feet.
Calcareous algae
Climacammina sp.
Endothyra sp.
Millerella? sp.
Fusulinella or *Wedekindellina* sp.
Fusulinella or possibly an early form of *Fusulina* sp.

The specimens are poorly preserved. The fusulinids are identified generically with only fair assurance and indicate Atoka or possibly very early Des Moines age. The other foraminifers listed give support but of very limited value to this age determination. The species of calcareous algae that seems to be represented here is a fossil of common occurrence in rocks of Atoka and Des Moines age. Though all of the species listed agree in indicating Atoka or possibly early Des Moines age, it is not certain that they are not of early Permian age.

A collection made about 400 feet stratigraphically above the base of the formation in the Santa Rosa Hills is considered to be probable late Wolfcamp in age by R. C. Douglass (written communication, 1953) in a summarized report as follows:

f9647. Permian. Locality in Santa Rosa Hills 3.60 miles N. 50° W. of the Lee mine at an altitude of 5,650 feet.
Climacammina sp.
Schubertella?
Staffella?sp.
Triticites?
Schwagerina spp. at least two forms

The material in this collection is poorly preserved. It is Permian, probably late Wolfcamp, in age.

The occurrence of Wolfcamp and probable Middle Pennsylvanian fossils within a stratigraphic interval of a few-hundred feet in the northwestern part of the quadrangle compared with a much thicker Pennsylvanian section elsewhere in the southern Inyo Mountains (Merriam and Hall, 1957, table 2) and Darwin quadrangle suggests a hiatus within the lower unit of the Keeler Canyon. The possibility of an unconformity cannot be ruled out, but the only physical evidence for it is the limestone pebble conglomerate beds that are concordant in the stratigraphic sequence and show no effects of erosion.

Two collections from near the upper contact of the Keeler Canyon formation were examined by R. C. Douglass (written communication, 1954). These collections, which are from the rolling hills northwest of the Santa Rosa Hills, contain *Climacammina* sp., *Schwagerina*, probably two or three fairly advanced species, and *Pseudoschwagerina* sp. Douglass believes this fauna is probably late Wolfcamp. Douglass (written communication, 1954) studied a collection from the northern Darwin Hills from the upper unit and provided the following faunal list and comment:

f9746. Locality in Darwin Hills 1.70 miles N. 48° W. of the Darwin Antimony mine at an altitude of 5,200 feet.
- Small indeterminate forams.
- *Climacammina* sp.
- *Tetrataxis* sp.
- *Schubertella?*
- *Schwagerina* spp. at least three species

This collection contains a fauna characteristic of the uppermost part of the type Wolfcamp, but it may be as young as early Leonard.

Two collections from the transitional zone between the Keeler Canyon and the lower part of the Owens Valley formation in the northern Darwin Hills were examined by Douglass (written communication, 1954):

F9748. Locality 0.93 miles N. 15° W. of the Darwin Antimony mine at an altitude of 5,290 ft and 1.20 miles N. 33° W. of VABM 5979.
- *Climacammina* sp.
- *Tetrataxis?*
- *Endothyra?*
- *Schwagerina* spp.
  - One aff. *S. compacta* (White)

Douglass believes this fauna probably represents Wolfcamp, possibly middle to late Wolfcamp.

F9749. Locality at north end of Darwin Hills at an altitude of 5,400 ft. Located 660 feet north of VABM 5979.
- Calcitornellids
- *Climacammina* sp.
- *Triticites* sp.
- *Schwagerina* spp. (possibly 3 species)
  - One aff. *S. diversiformis* Dunbar and Skinner
  - Another aff. *S. linearis* Dunbar and Skinner
- *Pseudoschwagerina* sp.
- *Parafusulina?*

Douglass states:

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

The Keeler Canyon formation in the Darwin Hills correlates reasonably well with that at the type section in the Inyo Mountains (Merriam and Hall, 1957, p. 4). However, because of lateral variations in the formation, the contact between the Keeler Canyon and Owens Valley formations cannot be placed at a precise stratigraphic horizon on the basis of lithology. The Keeler Canyon is partly equivalent to the Tihvipah limestone of the Quartz Spring area (McAllister, 1952, p. 26) and to part of the Bird Spring(?) formation in the Ubehebe Peak quadrangle (McAllister, 1955, p. 13). Pennsylvanian rocks that correlate with the Keeler Canyon formation were recognized in the Argus Range by Hopper (1947, p. 411).

OWENS VALLEY FORMATION

NAME AND DISTRIBUTION

The Owens Valley formation was named by Merriam and Hall (1957, p. 7) for strata of Permian age that are exposed in the foothills of the Inyo Mountains about 3 miles north of Owenyo (fig. 2). The Owens Valley formation near the type locality includes two formations previously described by Kirk (*in* Knopf, 1918, p. 42–43)—the Owenyo limestone and Reward conglomerate, now considered local members of the Owens Valley.

The formation is well exposed in the northwestern part of the Darwin quadrangle east and southeast of Conglomerate Mesa, in the southeastern part of the quadrangle in the Argus Range, and at the north end of Darwin Wash between the Argus Range and Darwin Hills (pl. 1).

The formation is subdivided informally into three units. The lowest unit is the thickest and is the most widely distributed. It is the only formation in the southeastern part of the quadrangle, and it underlies most of the low rolling hills east of Conglomerate Mesa. The middle unit occurs as a narrow band surrounding Conglomerate Mesa, while the upper unit forms the resistant capping and cliff exposures of Conglomerate Mesa (fig. 8).

LOWER UNIT

THICKNESS AND STRATIGRAPHIC RELATIONS

Where best exposed east of Conglomerate Mesa, the lower unit is about 2,800 feet thick. This thickness was computed from a measured stratigraphic section east of Conglomerate Mesa, but many minor folds and faults

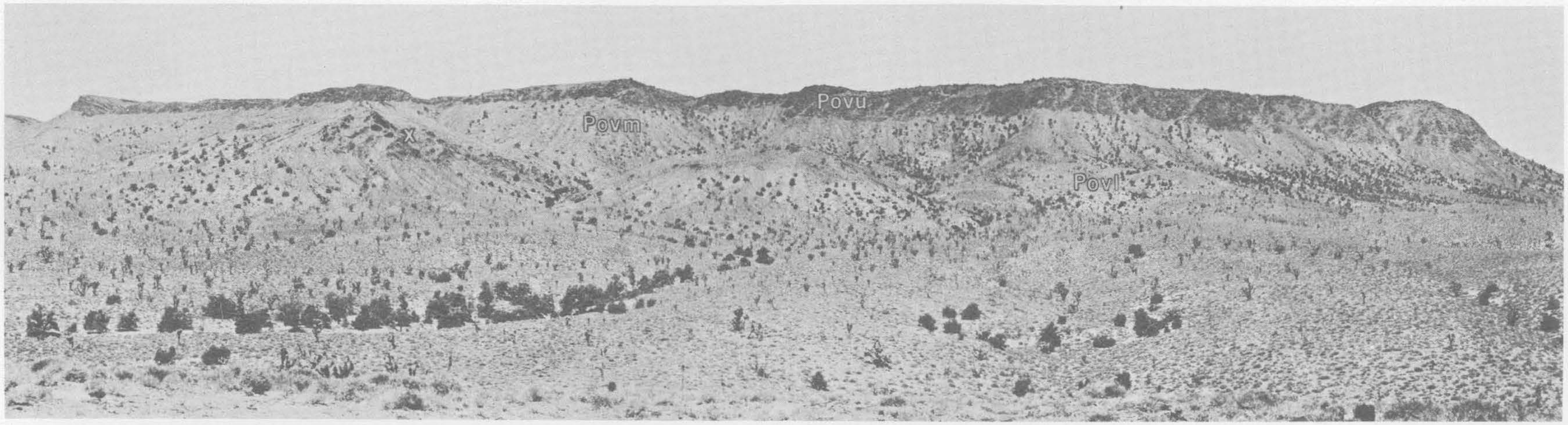

FIGURE 8.—Owens Valley formation at Conglomerate Mesa in the northwestern part of the quadrangle. The three units of the formation are exposed. The upper unit (Povu) is a resistant limestone conglomerate that forms a protective capping over the incompetent shaly middle unit (Povm). The lower unit (Povl) forms the rolling topography in the foreground. The prominent bioherm at (X) is fossil-bearing locality f119 from which the megafossils of the Owens Valley were collected.

in the section make this figure only an approximation. Lower strata of the Owens Valley in the southeastern part of the quadrangle are deformed into broad undulatory folds and are not amenable to stratigraphic measurements.

The upper and lower contacts of the lower unit are gradational. The contact with the Keeler Canyon formation is generally marked by the lithologic change from predominantly pink shale in the upper part of the Keeler Canyon to predominantly silty and sandy limestone with lenses of pure limestone and limestone breccia in the lower unit of the Owens Valley formation. In the Darwin Hills the contact of the base of the Owens Valley formation was placed at the base of a 450-foot-thick, brown-weathering siltstone 2,500 feet east of the Darwin Antimony mine. The contact of the lower and middle units of the Owens Valley formation is at the base of predominant fissile shale.

LITHOLOGY

The lower unit of the Owens Valley formation consists mainly of fine-grained calcarenite commonly in beds 1 to 2 feet thick. Shaly limestone, lenses of pure limestone and limestone breccia, shale, and siltstone are common. Lenses of massive bluish-gray limestone and limestone breccia as much as 40 feet thick are characteristic of the unit; these lenses are probably bioherms and are commonly highly fossiliferous. Limestone pebble conglomerates are not as abundant as in the Keeler Canyon formation. A poorly sorted limestone breccia along the Darwin Wash road 1¼ miles S. 33° E. of China Garden Spring is interpreted as formed by submarine slump. The limestone breccia contains rounded and subrounded fragments of dark-gray limestone in a light-brown sandy and silty limestone matrix. Fragments are mostly 1 to 3 inches in diameter, but some reach a maximum length of 2 feet. Fragments constitute about 20 percent of the rock.

The fine-grained calcarenite is commonly crossbedded. It is generally light or medium gray on fresh surfaces and weathers light brown. Associated thick, massive lens-shaped limestones are bluish gray on both fresh and weathered surfaces. Shale beds in the formation are variegated in pinks, grays, greens, and browns. The buff and brown siltstone weathers medium brown. Algal nodules 2 to 3 inches long are present in calcarenite in Darwin Canyon near Millers Spring, and metamorphosed ellipsoidal forms in calc-hornfels east of the Christmas Gift mine probably are metamorphosed algal nodules. The nodules contain abundant sponge spicules(?) and fusulinids, although the enclosing calcarenite is nearly devoid of fossils.

Summary of an eastward-trending stratigraphic section of the lower unit measured from the base of the middle unit of the Owens Valley formation east of Conglomerate Mesa about half a mile south of the quadrangle boundary

Owens Valley formation:
Middle unit.
Conformable contact.
Lower unit:

	Thickness[1] (feet)
Limestone and siltstone, largely yellowish gray, silty and sandy; massive bluish-gray limestone lenses in lower part of section as much as 40 ft thick; most thick limestone lenses are fusulinid bearing; some contain brachiopods, gastropods, and crinoidal debris; thin beds of greenish-brown shale and limestone pebble conglomerate high in section	265
Limestone, interbedded thin-bedded, gray, sandy and silty; and gray and yellowish-brown shale; minor pure gray limestone in beds 2 to 4 ft thick	822
Limestone, mainly brown-weathering, silty and platy; moderately abundant fusulinid-bearing medium-gray limestone beds and lenses 2 to 30 ft thick; some contain limestone fragments; minor amounts of pink and brown silty fissile shales with cleavage transecting bedding	300
Limestone, brown-weathering, platy and silty; and minor amounts of interbedded brown-weathering shale and fusulinid-bearing limestone pebble conglomerate	1,440
Total	2,827

Conformable contact.
Keeler Canyon formation.

[1] Approximate.

In the Darwin Hills a 450-foot-thick brown-weathering siltstone bed is at the base of the formation. This siltstone and its metamorphosed equivalent crop out abundantly on the eastern slopes of the Darwin Hills. Shaly and silty limestone containing lenses of massive bluish-gray limestone and limestone breccia overlies the siltstone.

AGE AND CORRELATION

Paleontologic evidence indicates that the lower unit ranges in age from late Wolfcamp into Leonard. The faunal assemblage consists largely of fusulinids, but includes large brachiopods, corals, ammonites, and gastropods. Most specimens are poorly preserved.

Five collections of fusulinids from the lower unit of the Owens Valley in the area east of Conglomerate Mesa were studied by R. C. Douglass. He reported a range in age from late Wolfcamp into Leonard. A collection from near the base of the Owens Valley was identified by Douglass (written communication, 1954) as follows:

f9645 Permian.

California, Inyo County, Darwin quadrangle. Locality 2.85 miles S. 86° E. of the NW. corner of the quadrangle.

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

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

Concerning a collection at the top of the lower unit of the Owens Valley, Douglass reports:

f9650 Permian.

California, Inyo County, Darwin quadrangle. Locality 1.20 miles S. 70° E. of the northwest corner of the 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.

The lower unit of the Owens Valley does not correlate precisely with the lower faunal zone of the Owens Valley given by Merriam and Hall (1957, p. 11). The lower unit in this report includes the thick sequence of silty limestone, sandy limestone, shale, and siltstone that underlies the predominantly shaly varicolored unit at the base of Conglomerate Mesa. *Parafusulina* sp., which is placed in the middle faunal zone of the Owens Valley formation, is in the upper part of the lower unit of the Owens Valley as mapped by the writers.

James Steele Williams summarized results of paleontologic studies of a megafossil assemblage collected about 200 feet stratigraphically below the top of the lower unit near Conglomerate Mesa. This collection was made from a thick, lenticular, craggy bioherm. Williams' summary follows:

USGS 17569 Darwin quadrangle, 1.32 miles S. 58° E. of the NW. corner of the quadrangle.

Byrozoa (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 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 costate and a deeper sulcus than are typical of that species. The *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 * * *.

Poorly preserved solitary corals, crinoid columnals, and fragments of brachipods are in several thicker limestone lenses near Conglomerate Mesa. One lithostrotionoid coral was collected near the top of the lower unit.

Twelve collections of fusulinids from the lower unit in the southeastern part of the quadrangle were examined by Douglass. *Pseudoschwagerina*, *Schwagerina*, or both, are present in all the collections. *Climacammina* is in eight. Other less widespread genera represented in the collections are *Schubertella*, *Paraschwagerina*, *Parafusulina*?, and *Pseudofusulina*?. *Triticites* sp. is present in only one collection from near the base of the formation.

Douglass believes that these collections indicate late Wolfcamp or early Leonard age. *Pseudoschwagerina* is the prevailing fusulinid in collections from the lower unit from the Talc City Hills and the extreme southern part of the Inyo Mountains.

Additional megafossils were found in the Owens Valley formation, but they were either badly preserved or were not diagnostic for age determination. Ammonites, which are too poorly preserved for generic determination, occur in sandstone on the east slope of the Darwin Hills. Bernard Kummell (written communication, 1954) reported they might be either Permian or Triassic. Solitary corals and crinoid columnals are abundant in fusulinid-bearing limestone in the Argus Range. Owing to the poor state of preservation, the corals were not studied.

MIDDLE UNIT

THICKNESS AND STRATIGRAPHIC RELATIONS

The middle unit is exposed only around the base of Conglomerate Mesa in the northwestern part of the quadrangle. Because of tight folds and poor outcrops resulting from the incompetence of this unit, a good section could not be measured. The mapped outcrop pattern indicates that the thickness is about 200 feet. The contact with the silty and sandy limestone of the lower member is gradational and conformable.

LITHOLOGY

The middle unit consists predominantly of shale but contains subordinate siltstone and limestone. Most of the shale is brick red or yellowish brown on fresh and weathered surfaces. Other shale beds are dark gray to nearly black, greenish gray, and light gray; these beds commonly weather to several shades of green and brown. The minor intercalated siltstone is yellowish gray on fresh surfaces and weathers yellowish brown. It is generally thinly bedded and contains abundant siliceous silt. Interbedded limestone layers are medium gray and weather brownish gray. They range from 1 to 4 feet in thickness and commonly contain abundant siliceous silt and sand. The cleavage of the fissile shales dips steeply westward across bedding. Quartz veins, which are less than 100 feet long, fill tension fractures in the shale.

UPPER UNIT

THICKNESS AND STRATIGRAPHIC RELATIONS

A minimum thickness of 180 feet of limestone conglomerate of the upper unit of the Owens Valley formation crops out at Conglomerate Mesa. The unit is restricted to this area in the Darwin quadrangle. Its present distribution is probably close to its original extent. The lower contact with the shale of the middle unit is sharp and disconformable. Local angular discordance along this contact mainly reflects minor slippage between the competent limestone conglomerate and incompetent shale, but at the south end of the mesa the discordance may be a local angular unconformity.

LITHOLOGY

The lower part of the upper unit consists of a 60-foot-thick limestone conglomerate that is overlain by a 30-foot-thick light-gray fine-grained orthoquartzite. The upper 90 feet of the unit is made up mainly of light-yellow and yellowish-brown-weathering siltstone and light-gray calcarenite with minor yellowish-weathering pebble conglomerate.

Clastic fragments greater than sand size generally constitute 40 to 60 percent of the yellowish-brown- and brown-weathering conglomerate—a unique rock in the Darwin quadrangle Paleozoic section. Coarse fragments that range in size from 1 to 4 inches in maximum diameter are most abundant but a few larger fragments are present. Gray silty limestone and, to a lesser extent, pink and light-gray chert form most of the rudaceous material. The limestone fragments commonly are subrounded to rounded and the chert fragments are subangular. The sand-size matrix constituents are mainly siliceous. In places the conglomerate has been largely replaced by chert.

Several small isolated outcrops of coarse-grained sandstone south of Conglomerate Mesa near the western boundary of the quadrangle are stratigraphic equivalents of the limestone conglomerate. The light-gray locally crossbedded sandstones are composed largely of subangular and subrounded siliceous and limy grains.

AGE AND CORRELATION

No fossils were found in the upper unit within the Darwin quadrangle. The upper unit of the Owens Valley at Conglomerate Mesa is correlated with the upper part of the Owens Valley at the type locality in the Inyo Range (Merriam and Hall, 1957, p. 11), where it contains *Neospirifer pseudocameratus* and *Punctospirifer pulcher* and is probably Word (middle Permian) or Guadalupe (late Permian) in age.

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 (pl. 1). 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 probably the Lost Burro formation to the north in an unnamed canyon 3.70 miles S. 63° W. of the northeast corner of the quadrangle and the lower unit of the Owens Valley formation to the south in the Argus Range (pl. 1). The calc-hornfels is probably both Carboniferous and Permian in age.

GNEISS

Gneiss crops out only in the southwestern part of the quadrangle as several small roof pendants or screens marginal to biotite-hornblende-quartz monzonite (pl. 1). 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 ROCKS

INTRUSIVE ROCKS

Plutonic rocks are exposed in about 10 percent of the quadrangle, and possibly an additional 10 percent of plutonic rocks underlie 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 common in small bodies at the border of bodies of quartz monzonite and as thin dikes intruding it. Quartz monzonite as used in this report is a granitoid rock that contains essential quartz, potassium-feldspar, and plagioclase; the ratio of potassium-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 and in the central Darwin Hills. Unaltered biotite-hornblende-quartz monzonite crops out in the northeastern part of the quadrangle in steep, eastward-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 is called the Hunter Mountain quartz monzonite by McAllister (1956). The name Hunter Mountain quartz monzonite may be extended to the biotite-hornblende-quartz monzonite in the northeast quarter of the quadrangle. The name has not been applied to the other bodies of biotite-hornblende-quartz monzonite because of the uncertainty of correlating widely separated intrusive bodies whose age cannot be closely dated, and because the intrusive bodies have a heterogeneous appearance owing to the assimilation of a large amount of silty limestone.

Biotite-hornblende-quartz monzonite is the most easily weathered rock in the Darwin Hills and Coso Range, where it forms gentle grus-covered slopes. The slopes are marked by outcrops of resistant leucogranite or aplite that does not reflect the composition of the grus-covered areas. Therefore few fresh quartz monzonite specimens were found for petrographic study.

PETROGRAPHY

The biotite-hornblende-quartz monzonite is a light-gray rock that has a specked appearance produced by scattered mafic minerals. The texture ranges from equigranular, with an average grain size of 2 to 3 mm, to porphyritic, where 10 to 20 percent phenocrysts of pink potassium feldspar as much as 1½ cm long occur in a finer grained light-gray equigranular groundmass. The uncontaminated rock is predominantly quartz monzonite, but it ranges in composition from granodiorite to quartz monzonite. Essential minerals are quartz, potassium feldspar, plagioclase, and more than 5 percent hornblende and biotite (fig. 9).

Feldspar makes up 62 to 76 percent of the rock with nearly equal amounts of plagioclase and potassium feldspar. Plagioclase ranges from calcic oligoclase (An_{28}) to andesine (An_{45}); it commonly shows normal zoning. The potassium feldspar is microperthitic, and some of it has microcline twinning, particularly the phenocrysts. The quartz content ranges from 5 to 30 percent. 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 northeastern part of the quadrangle, augite; they range from 8 to 30 percent by volume. Hornblende is predominant in the biotite-hornblende-quartz monzonite from the Coso Range and 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.

The stock in the Darwin Hills is a heterogeneous intrusive mass composed predominantly of biotite-hornblende-quartz monzonite and granodiorite, but the rocks are deeply weathered and few unaltered specimens were found for study. Near the Definance and Thompson workings of the Darwin mine the intrusive mass is hybrid 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 various bodies. The quartz monzonite in the Coso Range contains more quartz and less mafic minerals than the quartz monzonite from the northeastern part of the quadrangle. Augite is common in the quartz monzonite in the northeastern part of the quadrangle but was not observed in the quartz monzonite in the Coso Range. Hunter Mountain quartz monzonite in the Ubehebe Peak quadrangle (McAllister, 1956) is also 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 the Hunter Mountain quartz monzonite 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. The border facies rocks are not distinguished on our map (pl. 1). These quartz-poor rocks probably formed by assimilation of the silty limestone and dolomite country rock by the biotite-hornblende-quartz monzonite.

Except for the low quartz content, monzonite is similar to quartz monzonite in mineralogy and texture. Syenodiorite megascopically also is similar, except for containing more plagioclase than the monzonite. Locally syenodiorite also contains small amounts of tour-

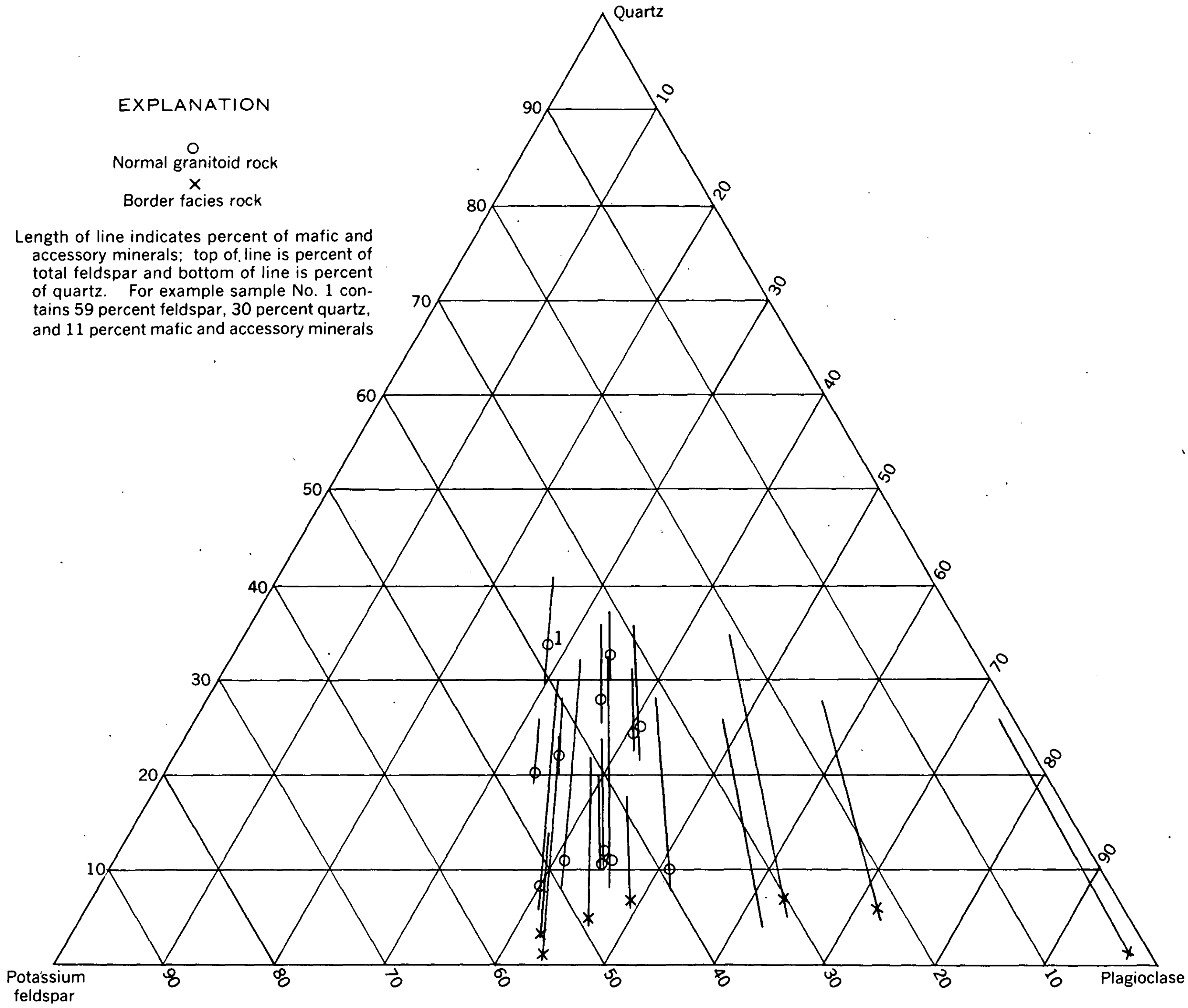

Figure 9.—Triangular diagram showing percentages of essential minerals in the biotite-hornblende-quartz monzonite (after Johannsen, 1939, v. 1, p. 152.)

maline and scapolite, variety dipyre, in veinlets transecting and replacing plagioclase.

AGE

The granitoid rocks in the Darwin quadrangle intrude Permian strata and are overlain by late Cenozoic rocks. In the Inyo Mountains they intrude shale and volcanic rocks of Late Triassic age (Knoff, 1918, p. 60). Two intrusions of biotite-hornblende-quartz monzonite in the Argus Range several miles east of the Darwin quadrangle were dated by the lead-alpha and potassium-argon methods as 180 million years (T. W. Stern and H. H. Thomas, written communication, 1961). Thus they are very Early Jurassic (Kulp, 1961).

These dated intrusions are correlated by the writers with the biotite-hornblende-quartz monzonite in the Darwin quadrangle. They are considerably older than the Sierra Nevada batholith with which they were previously provisionally correlated by Hall and MacKevett (1958). The geologic quadrangle map was compiled before these age determinations were made, and the biotite-hornblende-quartz monzonite is shown as Cretaceous(?) on the maps for this report.

The two dated samples of biotite-hornblende-quartz monzonite were collected from the east side of the Argus Range a few miles east of the Darwin quadrangle. Sample DW-1 was collected in Darwin Canyon 1 mile west of Panamint Springs at an altitude of 2,120 feet.

The locality is at the north end of the Argus Range in the Panamint Butte quadrangle. Sample TC–1 is from Thompson Canyon 1.4 miles S. 85° W. of the Modoc mine at an altitude of 3,910 feet on the east side of the Argus Range in the Maturango Peak quadrangle. It is from the north end of the large mass of quartz monzonite that underlies Maturango Peak.

Herman H. Thomas (written communication, 1961) dated sample DW–1 as 182 million years and sample TC–1 as 178 million years by potassium-argon. Data for the calculations are given below:

Sample No.	Ar^{40} *(ppm)*	K^{40} *(ppm)*	Ar^{40}/K^{40}	*Radiogenic argon* (percent)	*Age (million years)*
DW–1	0.0915	8.07	0.0113	94	182
TC–1	.0671	6.07	.0110	93	178

Potassium analysis is by C. O. Ingamells, Pennsylvania State University. Constants used:

$$\lambda\beta=4.76\times10^{-10}/\text{year}$$
$$\lambda\epsilon=0.589\times10^{-10}/\text{year}$$
$$K^{40}/K=0.000120\text{g./g.}$$

Possible error about 5 percent of determined value.

T. W. Stern (written communication, 1961) dated the zircon of the same samples by the lead-alpha method. Sample TC–1 was determined as 180±20 million years and sample DW–1 as 210±25 million years. Data for the samples are given below:

Sample No.	*α/mg per hr*	Pb (*ppm*)[1]	*Calculated age*[2] (*million years*)
DW–1	134	11.1	210±25
TC–1	188	13.7	180±20

[1] Analysts: Charles Annell and Harold Westley.

[2] The lead-alpha ages were calculated by T. W. Stern from the following equation:

$$T=C\ \text{Pb}/\alpha$$

where T is the calculated age in millions of years, C is a constant based upon the U/Th ratio, Pb is the lead content in parts per million, and α is the alpha counts per milligram per hour. The following constants were used:

Assumed U/Th ratio	*C*
1	2485

Age is rounded off to nearest 10 m.y. The error quoted is that due only to uncertainties in analytical techniques.

LEUCOCRATIC QUARTZ MONZONITE

DISTRIBUTION

Leucocratic quartz monzonite crops out in stocks in the Talc City Hills and at Zinc Hill in the Argus Range. Most slopes underlain by leucocratic quartz monzonite in 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 generally contains less than 5 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, sodic oligoclase, and orthoclase. Feldspars constitute 70 to 75 percent of the rock and occur in about equal quantities. Orthoclase is microperthitic and commonly forms phenocrysts that poikilitically enclose all other minerals. Biotite, the predominant mafic mineral, generally constitutes less than 5 percent of the rock, although as much as 7 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 uncertain, but the leucocratic quartz monzonite probably is the younger rock. They are in contact only in the low grus-covered hills west of Darwin where the rocks are poorly exposed. The shape of the southeast end of the stock in the Talc City Hills suggests a tongue of a younger leucocratic quartz monzonite intruding the biotite-hornblende-quartz monzonite. The more sodic composition of the plagioclase and the smaller mafic mineral content of the leucocratic quartz monzonite suggests from the Bowen reaction series that it is a later differentiate and hence the younger rock.

Lithologically the leucocratic quartz monzonite most closely resembles in texture and mineralogy the orthoclase-albite granite at Rawson Creek in the Sierra Nevada (Knopf, 1918, p. 68). According to P. C. Bateman (oral communication, 1957) this is a widespread rock type along the eastern front of the Sierra Nevada.

APLITE AND LEUCOGRANITE

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 (pl. 1). Leucogranite is most common in the northeastern 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 and 1 inch to 3 feet wide. 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 2,500 feet northeast of Darwin on the west side of the stock of biotite-hornblende-quartz monzonite in the Darwin Hills.

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 in the northeastern 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; some is replaced by albite.

The leucogranite and aplite in the Darwin Hills contain more plagioclase than most of the other bodies. Plagioclase and orthoclase are present in about equal quantities and make up about 70 percent of the rock. Plagioclase is albite (An_9); orthoclase is microperthitic. Hematite coats the feldspar and produces a light-pink or purplish color. The feldspar is in large part hydrothermally altered to sericite, and pyrite is sparsely disseminated through the rock. Within the weathered zone pyrite is altered to limonite.

DIKES

ALTERED ANDESITE PORPHYRY DIKES

Highly altered fine-grained, porphyritic greenish-gray dikes of andesitic composition crop out in the Santa Rosa mine area, the eastern part of the quadrangle south of Rainbow Canyon, and near Conglomerate Mesa (pl. 1). Similar dikes have been described from the Ubehebe Peak quadrangle as altered porphyritic dikes by McAllister (1956). The dikes are part of an extensive swarm that extends at least from the north end of the Argus Range in the Panamint Butte quadrangle northwestward across the Darwin Plateau and Inyo Mountains to the Sierra Nevada—a distance of more than 50 miles (fig. 1). This dike swarm was described recently by Moore and Hopson (1961).

The andesite porphyry dikes range from 2 to 6 feet in thickness. They strike predominantly between N. 70° W. and west, and dip about vertically. They are greenish gray on freshly broken surfaces and weather to several shades of brown. The dikes exposed at low altitudes develop dark-brown desert-varnished surfaces similar to that on basalt.

The andesite porphyry dikes consist mainly of saussuritized plagioclase phenocrysts in a fine-grained pilotaxitic groundmass composed largely of elongate saussuritized plagioclase. The plagioclase phenocrysts average about 1 by 2 mm, and the groundmass plagioclase is about 0.2 mm long and 0.03 mm wide. The rock is altered mainly to albite, epidote, calcite, and chlorite. Quartz, limonite, sericite, clay minerals, and stilbite are less common secondary minerals. The meager assemblage of primary minerals includes a few skeletal remnants of augite phenocrysts, and very small amounts of apatite, sphene, magnetite, and pyrite.

The dikes cut granitic rocks in the northeastern part of the quadrangle. Elsewhere they cut Paleozoic rocks. The dikes were emplaced after consolidation of the batholithic rocks and before late Tertiary volcanic activity, and they probably are Cretaceous or early Tertiary in age.

DIORITE

Dikes of several compositions crop out in the southern part of the quadrangle. These are mainly diorite but include altered quartz latite, syenite, and one alaskite porphyry. They are grouped with diorite dikes on the map. The most abundant are altered dark greenish-gray diorite dikes that cut biotite-hornblende-quartz monzonite in the low hills west of Darwin and Paloezoic rocks near Darwin Falls. The dikes are restricted to the margins of plutonic bodies or to contact metamorphosed zones about plutons. A porphyritic texture is common. The least altered are fine-grained, porphyritic dikes that consist mainly of hornblende, oligoclase, epidote, and magnetite. Most are completely altered to chlorite, albite, calcite, clinozoisite, and magnetite.

Felsic dikes are present both in the Darwin Hills and in the Talc City Hills. Dikes in the Darwin Hills include both alaskite porphyry and syenite. An alaskite porphyry dike 3 feet thick, which crops out half a mile east of Ophir Mountain, contains phenocrysts of quartz and albite about 2 mm long in a light-gray aphanitic groundmass composed mainly of albite and quartz and minor accessory magnetite, apatite, and sphene. Syenite is common in the Darwin mine area, and it is probably formed by feldspathization (pl. 3). It is described under rock alteration.

Felsic dikes are exposed in the pit at the Frisco talc mine and at the surface at the Talc City mine in the Talc City Hills. They are light-gray fine-grained dikes that are partly to wholly replaced by chlorite and minor talc. The dikes probably were quartz latite. They have a pilotaxitic texture and consist of quartz, orthoclase, and oligoclase. No primary mafic minerals remain. The feldspar is partly to completely replaced by chlorite. The alteration of these dikes is closely related to talc ore bodies.

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 pyroclastic rocks, and basalt flows and dikes. The probable correlation of the late Cenozoic rocks is given in table 2.

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: Olivine basaltic flows some tuff and small basalt intrusive rocks.	Lake deposits	Old fanglomerate marginal to Darwin Wash.
		Coso formation	Old fanglomerate from the Inyo Mountains.
Pliocene(?)	Upper pyroclastic unit and andesite: Basaltic 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

PLIOCENE(?)

PYROCLASTIC ROCKS

Pyroclastic rocks are distributed extensively throughout the northern half of the quadrangle. Particularly good sections of pyroclastic rocks are exposed in the Inyo Mountains west and north of the Santa Rosa mine and in the large canyon 1½ miles southwest of the Santa Rosa mine. They are exposed in many places on Lee Flat and in most of the deep canyons that drain eastward into Panamint Valley in the northeastern part of the quadrangle.

The pyroclastic rocks are readily eroded except locally near cinder cones, where they are very permeable and are resistant to erosion as they have little or no surface runoff. In places spires 3 to 4 feet high are formed that commonly are capped by bombs or fragments of basalt. Cavernous erosional features are locally formed in the agglomerate and tuff-breccia.

THICKNESS AND RELATION TO OTHER ROCKS

The thickness of the pyroclastic section ranges from 0 to more than 910 feet and is greatest at local vents; it thins quaquaversally from them. The maximum thickness of 910 feet was measured on the north side of the canyon 1½ miles southwest of the Santa Rosa mine. A partial section 730 feet thick was measured on the south side of the canyon. The bottom of the pyroclastic section is not exposed at either place.

The pyroclastic rocks rest nonconformably on silicated limestone of Paleozoic age and on granitic rocks in Rainbow Canyon in the eastern part of the quadrangle. The andesite south and southeast of the Santa Rosa mine is interbedded near the top of the pyroclastic section. The base of the andesite is conformable upon bedded pyroclastic rocks 2,200 feet S. 30° E. of the Santa Rosa mine and small concordant bodies of andesite are interbedded with pyroclastic rocks near the main body of andesite south of the Santa Rosa mine and on the east slope of hill 5572 in the central part of the quadrangle.

The pyroclastic rocks are overlain unconformably by olivine basalt and a few intercalated thin lapilli-tuff beds. Most of the rocks dip less than 25°, probably repsenting initial dips away from volcanic centers. However, in the basin 1½ miles southwest of the Santa Rosa mine dips up to 41° were measured in pyroclastic rocks underlying nearly horizontal basalt; these dips indicate a period of tilting between the deposition of the pyroclastic rocks and the extrusion of the basalt.

LITHOLOGY

The pyroclastic rocks include agglomerate, tuff-breccia, lapilli-tuff, scoria, and volcanic cinders—all of basaltic composition—and some intercalated olivine basalt flows, andesite, and pumice. The pyroclastic section is divided into two units. The lower unit is well-bedded tuff, lapilli-tuff, and tuff-breccia; the upper unit is poorly bedded basaltic agglomerate, cinders, and lapilli-tuff and varies greatly in thickness, ranging from 0 to more than 500 feet. It is localized near the volcanic vents, whereas the lower unit is more widespread. Two partial sections of pyroclastic rocks in a canyon 1½ miles southwest of the Santa Rosa mine are shown in figure 10; these sections are 720 and 910 feet thick. The base of the pyroclastic rocks is not exposed in either section.

LOWER PYROCLASTIC UNIT

Light-brown and yellowish-brown well-bedded tuff, lapilli-tuff, and tuff-breccia in beds mostly 2 to 5 feet thick make up most of the lower pyroclastic section (fig. 11). The tuff and lapilli-tuff are yellowish brown,

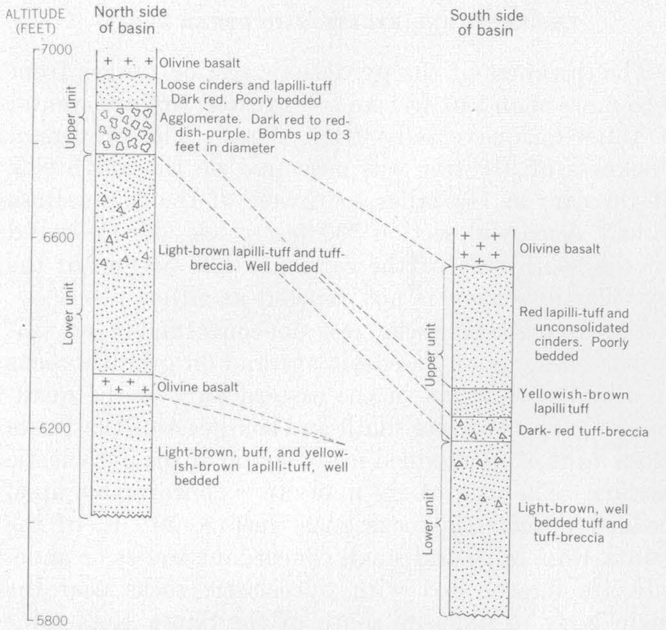

FIGURE 10.—Partial sections of Pliocene(?) pyroclastic basaltic rocks in the Inyo Mountains 1½ miles southwest of the Santa Rosa mine.

light brown, or grayish brown. The most abundant tuffaceous rock is lapilli-tuff with rounded fragments of scoria, red basalt, and cinders from ⅛ to 1 inch in diameter that is somewhat indurated though may be crumbled easily in the hand. Lapilli-tuff is interbedded with tuff-breccia that contains irregular to rounded fragments and bombs of olivine basalt and scoria in a tuff or lapilli-tuff matrix. The fine-grained interbedded tuffs are composed mainly of fragments of basalt and cinders, but also contain some fragments of quartz, augite and olivine crystals, and volcanic glass.

FIGURE 11.—Lower well-bedded unit of Pliocene(?) pyroclastic rocks in the southern Inyo Mountains. The pyroclastic rocks consist of tuff-breccia and lapilli-tuff of basaltic composition. View looking south from the basin 1½ miles southwest of the Santa Rosa mine.

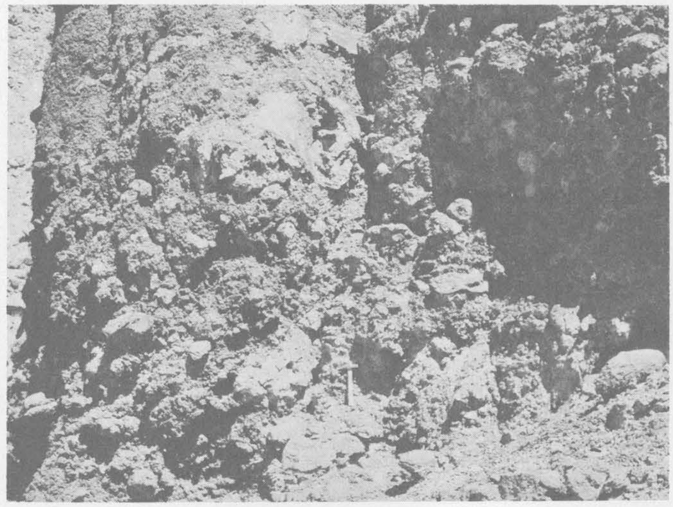

FIGURE 12.—Agglomerate in the poorly bedded upper unit of Pliocene(?) pyroclastic rocks in the southern Inyo Mountains. The agglomerate contains bombs and ropy and irregular fragments of basalt as much as 3 feet long in a lapilli-tuff matrix. View looking north in the basin 1½ miles S. 70° W. of the Santa Rosa mine.

They are more indurated than lapilli-tuff, and are cemented with calcite and chalcedony.

UPPER PYROCLASTIC UNIT

The upper proclastic unit is composed of agglomerate, cinders, volcanic breccia, tuff-breccia, and red scoriaceous basalt; the color is red, reddish brown, or a deep reddish purple. Bedding in this unit is mostly indistinct.

The agglomerate consists of volcanic bombs, loglike masses of ropy lava, and irregular fragments of basalt and scoria in a lapilli-tuff matrix (fig. 12). The agglomerate is poorly indurated and has poor to indistinct bedding; it occurs only near vents. Volcanic breccia and tuff-breccia are interbedded with the agglomerate. The tuff-breccia consists of 10 to 20 percent bombs and fragments of basalt in a lapilli-tuff matrix. It is generally moderately indurated and well bedded. Figure 13 is a photograph of a sawed volcanic bomb, which shows its internal structures. The bulk specific gravity of the bomb is 2.33 compared to 2.76 for the dense part of an olivine basalt flow in the same area. Very little of the bomb is scoriaceous. The center of the bomb is dense, and, in general, it becomes more vesicular outward. Nearly all the vesicles are less than 0.5 mm in diameter. The vesicular parts form discontinuous concentric bands. Volcanic breccia contains fragments of scoria and basalt mostly ranging from 1 to 6 inches in diameter with little or no matrix material. The fragments are mainly subrounded. Small cinder cones are present locally on top of the pyroclastic section. The cinders are mostly bright red, but some are gray to reddish gray. They are uncemented and show no bedding.

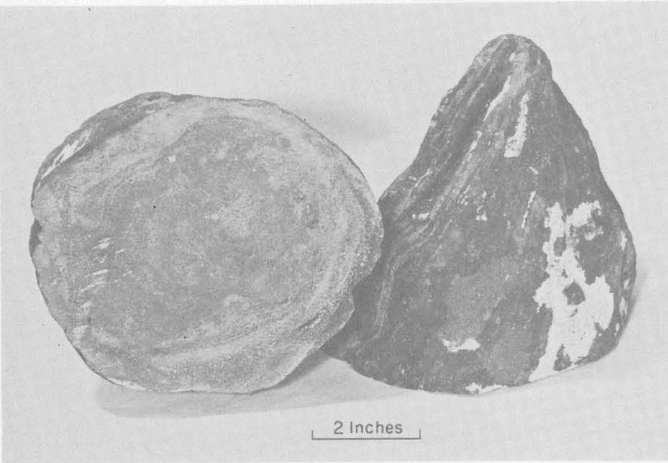

FIGURE 13.—Photograph of a sawed volcanic bomb of olivine basalt showing its internal structure. The center of the bomb is dense and the border is more vesicular. The vesicles are mostly less than 0.5 mm in diameter and form discontinuous concentric bands. Specific gravity of the bomb is 2.33.

A few thin lenticular pumice beds are near the top of the pyroclastic section. They range from 3 to 8 feet in thickness and can be traced only a few hundred feet. The pumice is impure and contains as much as 20 percent rounded grains of quartz and fragments of basalt.

ANDESITE

Andesite is exposed south and southeast of the Santa Rosa mine over an area of 3 square miles; several smaller bodies are in the central part of the quadrangle on hill 5572. Andesite is resistant to weathering and commonly forms bold reddish-colored cliffs. Joints are sharply defined, and in areas of moderate relief bouldery outcrops are formed. Cavernous weathering occurs in places on north slopes.

Andesite south of the Santa Rosa mine forms a broad dome interbedded in the upper pyroclastic unit. The base of the dome is exposed resting concordantly on tuff-breccia 2,200 feet S. 65° E. of the Santa Rosa mine. Elsewhere the base of the dome is not exposed as the flanks are covered by basalt or alluvium or, in places, the contacts are faults. Flow structures are well defined in places and suggest the presence of a dome-shaped mass. The maximum exposed thickness of andesite is 1,230 feet on hill 6950, 1½ miles southeast of the Santa Rosa mine, but the base is not exposed there.

The andesite is a porphyritic rock that contains phenocrysts and clusters as much as 10 mm long of plagioclase laths and euhedral phenocrysts of hornblende up to 4 mm long in an aphanitic groundmass. There are two color varieties of the rock. 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 two color varieties occur throughout the dome and have no recognized stratigraphic significance within the dome.

PETROGRAPHY

The gray porphyritic andesite contains phenocrysts of plagioclase, hornblende, and minor biotite, augite, and quartz in a fine-grained and in part glassy groundmass. Plagioclase constitutes 60 to 65 percent of the rock as subhedral phenocrysts of andesine that are normally zoned from An_{46} to An_{34} and as microlites of composition An_{38} to An_{40}. Carlsbad twinning is predominant, although some phenocrysts have broad albite twinning. Hornblende, the main mafic mineral, forms as much as 30 percent of the rock and occurs as euhedral lath-shaped phenocrysts that are strongly pleochroic with X=yellowish green, Y=brownish green, and Z=dark olive green. Biotite phenocrysts up to 1 mm long constitute as much as 7 percent of the rock; they are extremely pleochroic from light brown or greenish brown to very dark brown. Augite, quartz, and orthoclase may be present in small quantities as phenocrysts. The groundmass consists predominantly of plagioclase, hornblende, and volcanic glass and contains minor quartz, orthoclase, biotite, augite, apatite, and zircon. The groundmass has a trachytic texture. The andesite has a few small vesicles that are in part filled with calcite and chabazite.

Texturally and mineralogically the reddish andesite resembles the gray andesite except that oxyhornblende and hematite occur in the reddish andesite instead of common green hornblende. The oxyhornblende occurs as euhedral lath-shaped phenocrysts similar in size and shape to the hornblende in the gray andesite. The oxyhornblende is extremely pleochroic from light brown to very dark reddish brown and has thin opaque borders of hematite. Hematite occurs as euhedral thin plates and as tiny disseminated specks through the groundmass, giving the rock its reddish color.

AGE

The andesite is probably late Pliocene in age. It is interbedded in the upper unit of pyroclastic rocks, is overlain by flows of olivine basalt, and is cut by basin-range faults in the Darwin quadrangle. In the Haiwee Reservoir quadrangle, southwest of the Darwin quadrangle, the andesite appears to be identical with the porphyritic andesite in the Darwin quadrangle. Hopper (1947, p. 414) states that the andesite in the Haiwee Reservoir quadrangle unconformably underlies the tuffs and lakebeds of the Coso formation of late Pliocene or early Pleistocene age, and he suggests that the andesite may correlate with the andesite of late Miocene age described by Hulin (1934, p. 420) in the

Searles Basin quadrangle. The writers made a reconnaissance traverse over the andesite in the Coso Range between Cactus Flat and Haiwee Reservoir (fig. 1), and they believe that the andesite is interbedded in the Coso formation. The Coso formation west of the andesite body contains andesite fragments, but at Cactus Flat beds identical with and contiguous with beds known to be part of the Coso underlie the andesite. Therefore the andesite at Cactus Flat is contemporaneous with beds low in the Coso formation and is probably of late Pliocene age.

OLD FANGLOMERATE FROM THE INYO MOUNTAINS

Erosional remnants of fans marginal to the Inyo Mountains occur southwest of the Talc City Hills near State Highway 190 (pl. 1). They form small hills that rise 15 to 30 feet above the surrounding Recent alluvium. The fans are composed of angular to subrounded fragments as much as 18 inches in diameter of sedimentary rocks of Silurian and Ordovician age in a clay and silt matrix. The fragments are limestone, buff to dark-gray dolomite, and quartzite from the Pogonip group and the 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 probably formed in a small pond on the alluvial plain. South of State Highway 190 the fanglomerate is overlain by 5 to 20 feet of basaltic tuff, minor pumice, and olivine basalt flows.

The source of the fanglomerate must have been the Inyo Mountains and Talc City Hills to the north and northwest. No other remnants of fanglomerate remain in that direction, but this is the only direction for a local source of Silurian and Ordovician rocks. In addition south of State Highway 190 fragments in the fanglomerate are smaller and more rounded than those in remnants north of the road, closer to the Talc City Hills.

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

COSO FORMATION

The Coso formation so designated by Shultz (1937) is exposed locally in the west-central and southwestern parts of the quadrangle northeast and east of the Coso Range, where it is part of extensive fans west of the quadrangle marginal to the Coso Range. Early writers described these deposits as lake-beds (Fairbanks, 1896, p. 69; Campbell, 1902, p. 20; Trowbridge, 1911, p. 726), but later writers 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 fine- to medium-grained arkosic sand and clay in indistinct beds 1 to 2 inches thick. These materials were derived nearly entirely from disintegration of granitic rocks of the Coso Range. At the north end of the Coso Range in the Darwin quadrangle the Coso 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 formation 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 Quaternary olivine basalt and associated thin tuff beds.

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

PLEISTOCENE

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 that cut all the older rocks; it occurs 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 pyroclastic rocks, 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 cover a much larger area than at present.

The flows range from 10 to about 100 feet in thickness, and the aggregate of flows totals a maximum thickness of about 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 unconformably overlie a thick sequence of pyroclastic rocks, or where the pyroclastic rocks are missing, basalt nonconformably overlies granitic rocks or Paleozoic sedimentary rocks. Individual basalt flows commonly have a systematic internal structure. A rubble zone at the base is 6 inches to 2 feet thick. Above the basal rubble zone the basalt flows have 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 massive basalt ranges from a few feet to 50 feet in thickness; locally it 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 containing phenocrysts of olivine, plagioclase and augite in an aphanitic groundmass. It is dark gray on fresh surfaces and weathers to dark yellowish brown; in many places it is blackened by desert varnish. Vesicles are common near the top and bottom of flows; those near the bottom are elongated parallel to the direction of flow.

Thin sections show that the phenocrysts are predominantly olivine, but include small amounts of plagioclase and augite in a groundmass of plagioclase, olivine, augite, biotite, and glass. The olivine phenocrysts are euhedral to subhedral crystals 1 to 2 mm in diameter and are partly altered to iddingsite, antigorite, or goethite. Near the Santa Rosa mine the basalt contains fragments of quartz surrounded by thin reaction rims 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}. Tiny subhedral olivine grains and glass each constitute about 20 percent of the groundmass and are interstitial to plagioclase. Augite is the predominant pyroxene mineral, although pigeonite was observed in some thin sections.

AGE

The extensive cap 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 in the Coso Range. Kelley (1938, p. 513) and Hopper (1947, p. 417) consider that the olivine basalt is older than the lakebeds of middle or late Pleistocene age in Darwin Wash. The writers agree although the evidence is not conclusive. The contact between basalt and lakebeds is masked by talus, and lakebeds east of the road in Darwin Wash contain no basalt fragments although they are only 200 feet from basalt and lie 60 feet lower in elevation.

Some olivine basalt definitely is older than the lakebeds because older fanglomerate marginal to Darwin Wash contains fragments of olivine basalt. The fanglomerate is the same age or slightly older than the lakebeds. In Darwin Canyon a flow of olivine basalt also overlies older fanglomerate and is probably younger than the lakebeds.

OLD FANGLOMERATE MARGINAL TO DARWIN WASH

Remnants of large 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 cut the fan east of Darwin Wash on the west flank of the Argus Range and expose as much as 25 feet of fanglomerate, but the base is not exposed. The fanglomerate is overlain by a few feet of lakebeds in secs. 16 and 21, T. 19 S., R. 41 E. Fanglomerate may in part interfinger with the lakebeds but the gullies are not deep enough to show whether it does.

The fanglomerate is composed mainly of subrounded fragments of limestone of Pennsylvanian and Permian age, quartz monzonite, red basaltic agglomerate, and a little olivine basalt in a pebbly sand matrix. The fragments are mostly 1 to 4 inches in diameter, although a few fragments reach a maximum length of 2 feet.

The fanglomerate marginal to Darwin Wash 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 lakebeds 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 flows of olivine basalt.

LAKEBEDS

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

The lakebeds consist of a mixture of white to light-gray fine-grained pumiceous ash, silt, clay, and diatomaceous earth in beds 6 inches to 4 feet thick. The grains range from 0.05 to 0.1 mm in diameter. One bed 18 inches thick and 5 feet below the top of the exposure of lakebeds in the SE¼ sec. 20, T. 19 S., R. 41 E. on the east side of the main gully in Darwin Wash resembles tufa but is a bentonitic clay that shrank and cracked in drying. At the surface the bed has a porous, cellular texture, but on freshly broken surfaces the cells are seen to be filled with clay balls. The cells are 1 mm to 1½ cm in diameter. Cross sections of the cells are mostly rectangular with rounded corners, but some are irregular. The cell partitions are fine-grained calcium carbonate. The clay balls are friable and easily eroded away, leaving a cellular texture at the surface.

Kenneth E. Lohman of the U.S. Geological Survey made 11 collections of diatoms from the lakebeds in Darwin Wash and concluded that the beds were middle to late Pleistocene in age. His report of June 15, 1954, is given below:

Diatoms from lakebeds in Darwin Wash

[Relative abundance is indicated by A, abundant; C, common; F, frequent; and R, rare. Asterisk (*) indicates Darwin species that also occur in the Utah formations]

USGS diatom locality	4225	4224	4226	4227	4228	4229	4233
Stratigraphic interval in feet below loc. 4225	0	7	9	14	19	25	58
Amphora ovalis Kützing*							C
Anomoeoneis polygramma (Ehrenberg) Pfitzer*							A
sculpta Ehrenberg							C
sphaeropora (Ehrenberg) Pfitzer							F
sp			R			R	
Caloneis bacillum (Grunow) Mereschkowsky*				F	R		
schumaniana (Grunow) Cleve*					R		
silicula var. *truncatula* Grunow							F
Campylodiscus clypeus Ehrenberg							F
cf. *C. clypeus* Ehrenberg							F
Cocconeis placentula Ehrenberg*					R		
Cymatopleura solea (Brebisson) Wm. Smith*							F
Cymbella mexicana (Ehrenberg) Schmidt*							R
parva (Wm. Smith) Cleve*							F
n. sp. A*							F
turgida Gregory*							F
sp				R			F
Denticula cf. *D. tenuis* var. *mesolepta* Grunow	F						
thermalis Kützing	A	F	C	F	A	F	C
Diploneis ovalis (Hilse) Cleve*	R	R		R			
Epithemia argus (Ehrenberg) Kützing*	C	F	F	F	F		F
zebra var. *saxonica* Kützing*	R		R	R	F		
Fragilaria brevistriata Grunow*		R	R				R
Gomphonema angustatum (Kützing) Rabenhorst	R				R		
bohemicum Reichelt and Fricke	R						
lanceolatum Ehrenberg*				R	F		
lanceolatum var. *insignis* (Grunow)					R		
Hantzschia amphioxys Grunow*	F			F	F	R	F
Mastogloia elliptica (Agardh) Cleve*	F						
Navicula cf. *N. amphibola* Cleve					R		
cari Ehrenberg	R						
cf. *N. euspidata* var. *ambigua* (Ehrenberg) Cleve							R
guatamalensis Cleve and Grunow							C
oblonga Kützing*							A
peregrina (Ehrenberg) Kützing							R
cf. *N. radiosa* Kützing*							F
cf. *N. simplex* Krasske	R						
spp	R			R	R		F
Neidium iridis (Ehrenberg) Cleve							R
Nitzschia amphibia Grunow	R						
angustata (Wm. Smith) Grunow							R
tryblionella Hamtzsch*							R
Pinnularia microstauron (Ehrenberg) Cleve*	R		F		F		R
microstauron var. *brebissonii* (Kützing) Hustedt	R				F		F
viridis (Nitzsch) Ehrenberg*	R			R	F		C
Rhopalodia gibba (Ehrenberg) Muller*				R	F		C
gibberula (Ehrenberg) Muller*	F	F	F		C	R	
gibberula var. *succincta* (Brebisson) Fricke	F						
gibberula var. *margaritifera* Rabenhorst	R						
Scoliopleura peisonis Grunow*				R			C
Stauroneis cf. *S. phoenicenteron* Ehrenberg				R			
Stephanodiscus astraea (Ehrenberg) Grunow							F
astraea var. *intermedia* Fricke							R
carconensis var. *pusilla* Grunow							R
Surirella spp							C

Lohman reported,

This assemblage of nonmarine diatoms is indicative of a lake basin in which the earliest beds (loc. 4233) were deposited in water having a fairly high salinity, possibly as high as 1,000–2,000 parts per million of NaCl, culminating in much fresher water at the top of the section, representing the last recorded level of the lake at this locality. The relatively high frequency of several species characteristic of hot springs, such as *Denticula thermalis*, throughout the section strongly suggests that hot springs were active in the vicinity during the time represented by the 58 feet of sediment studied. It is entirely possible that the hot-spring activity was localized near the site of the collections, but as all the collections came from an area not exceeding a few acres, nothing regarding the areal extent of such activity is indicated. The lake as a whole was certainly not a hot-spring basin, as many diatoms not characteristic of hot springs are also present. The hot-spring assemblage was merely contributed to a normal lake of moderate temperature and may have come from hot springs feeding a small stream which emptied into the lake basin not too far from the site of the collections. A considerable quantity of calcium carbonate (another common byproduct of some hot springs) is present in all the collections (they all effervesced with hydrochloric acid) and this also may have been contributed by hot springs, but, of course, not necessarily so.

The best age assignment that can be made for this assemblage is middle to late Pleistocene, based in part upon the high percentage of species still represented in living assemblages and in part upon a comparison with very similar assemblages from the Provo and Bonneville formations in Utah. The Darwin species that also occur in the Utah formations are indicated in the list of species by an asterisk (*). *Cymbella* n. sp. A. has been described from the Provo formation in a manuscript I now have in preparation. The Provo and Bonneville formations are considered to be late Pleistocene in age by Charles Hunt and others who have worked in that area. It should be mentioned that one diatom hitherto known only from late Pliocene rocks, *Stephanodiscus carconensis* var. *pusilla*, was found in the lowest diatomaceous bed in the Darwin Wash section, but only one individual was found, and its battered condition suggests that it was reworked from older beds.

A small area of dissected lakebeds is exposed on the Darwin Plateau in secs. 1 and 12 (projected), T. 18 S., R. 40 E. 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 mostly of alluvial fan material, but include slope wash and stream gravels. The largest areas of alluvium are Lower Centennial Flat, Santa Rosa Flat, Lee Flat, and Darwin Wash (pl. 1). Recent alluvium includes some older alluvial fan material on Lee Flat that has been uplifted and is currently being dissected.

STRUCTURE

Structurally the Darwin quadrangle consists of folded Paleozoic rocks that are intruded by several plutons and interrupted by many faults (pl. 1). 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 bedding trends N. 60° to 85° W. and has been tightly folded. 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 tilting the beds and forming the present 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 contracts was difficult to evaluate. Bedding was conformable wherever unfaulted contacts were observed. The only recognized major unconformity in the area truncates Paleozoic rocks and intrusive rocks of late Mesozoic age.

Local unconformities and disconformities occur within the Pennsylvanian and Permian strata (fig. 14). A local unconformity in crossbedded calcarenite in the lower unit of the Owens Valley formation can be seen from the road 3,000 feet north of Millers Spring. This unconformity can be traced only several hundred feet

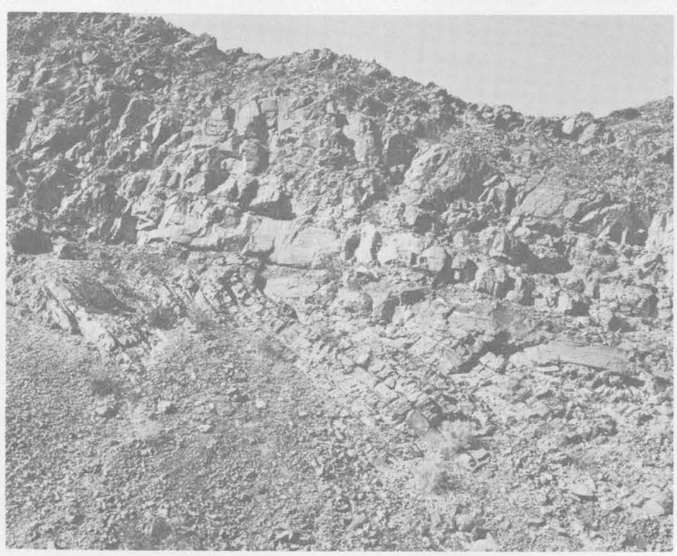

FIGURE 14.—Local angular unconformity in the lower unit of the Owens Valley formation in Darwin Canyon. View looking north from the road 3,000 feet north of Millers Spring. The unconformity is within a block between two branches of the Darwin tear fault.

as it is within a block between two strands of the Darwin tear fault (pl. 1).

The contact between the middle and upper units of the Owens Valley formation is disconformable. The limestone conglomerate of the upper unit at 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.

Minor hiatuses may be represented by pronounced changes in lithology, particularly in the change from massive dolomite and limestone to pure quartzite, as between the Pogonip group and the overlying Eureka quartzite. The stratigraphic sequence from Lower Ordovician to Permian is virtually complete, however, judging from the incomplete fossil record, but a hiatus may exist between the Pennsylvanian and Permian. The faunal zones in the Pennsylvanian strata have a wide range in thickness. This may be due both to cutting out of part of the section by faults and to original variations in thickness. For example, the *Triticites* zone (Upper Pennsylvanian) in the Keeler Canyon formation at the type locality in the New York Butte quadrangle is about 2,000 feet thick (Merriam and Hall, 1957, p. 6–7), but on the west flank of the Santa Rosa Hills in the Darwin quadrangle the *Triticites* zone is only several hundred feet thick. The *Triticites* zone in the Darwin Hill is possibly as much as 4,000 feet thick, but this figure is uncertain as the fossils are not abundant, and the structure is complex. The writers believe that this variation in thickness of Upper Pennsylvanian strata is due to local nondeposition in a nearshore environment as no evidence of erosion at the top of the *Triticites* zone was found in the Darwin quadrangle.

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 northwestern part of the quadrangle, in the Santa Rosa Hills, and in the southeastern part of the quadrangle in Darwin Wash and the Argus Range (pl. 1). The Pennsylvanian and Permian rocks are thinly bedded incompetent strata that formed many small drag folds superposed on the limbs of the major folds (fig. 7), but the drag folds are not reflected in the underlying strata. 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 northward in Darwin Wash (pl. 1, section *C-C′*). The east limb of the syncline is approximately a dipslope on the west slope of the Argus Range except for several minor folds. The west limb is largely covered by alluvium in Darwin Wash, but it is exposed in the low hills at the north end of Darwin Wash. The west limb is tightly crumpled adjacent to the biotite-hornblende-quartz monzonite in the Darwin Hills, and most of the beds are 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 northward (pl. 1). North of Darwin Falls the syncline loses its identity, and the rocks probably become progressively older northward, although silication of the limestone makes correlation uncertain (pl. 1).

DARWIN HILLS OVERTURNED SYNCLINE

The major structural feature in the Darwin Hills is an overturned syncline that was intruded near its axis by a stock and is cut by many faults (pl. 1, section C–C¹). This fold is a complex crumple on the west limb of the Darwin Wash syncline, and is caused by forceful intrusion of the batholith of the Coso Range. West of the stock the dips are generally homoclinal to the west, but the beds are overturned. North of the Darwin tear fault on the north side of hill VABM 5979 abundant crossbedding in thin-bedded limestone in the upper part of the lower unit and the upper unit of the Keeler Canyon formation show that the westward-dipping beds are overturned.

South of the tear fault the Keeler Canyon formation is mostly altered to calc-hornfels, and all internal structures have been destroyed. However, the strata can be shown to be progressively younger toward the east (pl. 1). White marble on the hill 4,000 feet N. 45° W. of Ophir Mountain is identical with marble of the Lost Burro formation and contains fragmentary remains that resemble cladoporoid corals. 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 are compatible with correlation to the Tin Mountain. The next limestone band to the east on hill 5654 is a medium-gray limestone that includes abundant bedded chert and is mapped as the Perdido formation. This is followed to the east in strata on Ophir Mountain by limestone similar to the Lee Flat limestone and then by the golf-ball horizon that contains sparse tiny fusulinids at the

FIGURE 15.—View looking south 1,800 feet southeast of the Christmas Gift mine showing the tight folds in the calc-hornfels of the lower unit of the Owens Valley formation on the east side of the Darwin stock. A belt about 800 feet wide of tight folds can be traced the length of the Darwin Hills. The belt is transitional between gently folded strata to the east and overturned strata to the west.

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 unit of the 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).

FIGURE 16.—Photograph of an 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.

The axis of the overturned syncline in the Darwin Hills is in a belt of tight folds on the east side of the Darwin stock (pl. 1, section C–C′; fig. 15). At some places the most westerly fold in the belt is readily recognizable as an overturned syncline, but in other places 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 16 is given mainly to show a locality where overturning 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 sharply defined where the beds are right side up and is an aid in determining the structure. Where bedding is overturned the cleavage is much more poorly defined and tends to parallel bedding.

A similar overturned syncline is well exposed in the Fernando mine area 250 feet southeast of the easternmost workings (fig. 3). This is the westernmost fold recognized in the belt of isoclinal folds, and all the strata west of this fold are considered overturned.

Several small open folds are superposed on the overturned limb of the syncline, for example, the open anticlinal folds in the Defiance mine area and on the southwest flank of Ophir Mountain (pl. 3). Both folds have younger beds in the center and older beds on the flanks and are actually inverted synclines on the basis of relative ages of the rocks as described, for example, by White and Jahns (1950, p. 196).

TALC CITY HILLS SYNCLINE

Ordovician and Silurian rocks at the north end of the Talc City Hills form an overturned syncline plunging southeastward that is broken by many faults (pl. 2). Hidden Valley dolomite is in the core of the syncline and Ely Springs dolomite, Eureka quartzite, and Pogonip group are in successive bands on the flanks. The syncline loses its identity in many fault blocks and tight folds at the southeast end of the Talc City Hills between the Homestake mine and the Alliance talc mine (fig. 3; pl. 2). The axis of a second faulted syncline 1,800 feet south of the Alliance talc mine passes through the Talc City mine. Devonian limestone and shale are in the core of the syncline, and Ordovician quartzite and dolomite and Silurian dolomite are on the flanks. South of the Silver Dollar mine the overturned syncline bends toward the south and is warped into several steeply plunging folds. The folds are shown on plate 2 by the trace of the contact of limestone and dolomite in the Lost Burro formation. As the main syncline is overturned, folds superposed on the overturned limb have overturned bedding. Thus anticlinal folds superposed on the overturned limb of the syncline have younger beds in the core and are inverted synclines.

SANTA ROSA HILLS WARP

The Paleozoic rocks in the Santa Rosa Hills and in the low rolling hills east of Conglomerate Mesa dip mainly west or southwest except for small open folds in the area east of Conglomerate Mesa (figs. 2, 16A). Devonian and Mississippian rocks in the Santa Rosa Hills strike about N. 30° W. and dip to the southwest. Southeast of the Lee mine the strike changes from N. 30° W. counterclockwise to about N. 80° W., 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, which probably is a continuation under the volcanic cover of the band of Lost Burro marble in the Santa Rosa Hills, shows a swing or warp in the prevolcanic structure. This swing in structure is interpreted as warping of beds concordantly around the south end of the pluton of Hunter Mountain quartz monzonite by forcible intrusion.

FAULTS

Faults are largely responsible for breaking up of the Paleozoic strata into many isolated blocks that are separated by alluvium or volcanic cover. The faults can be divided into four groups as follows: thrust, strike-slip, mineralized strike, and basin-range faults. The last group is late Cenozoic in age while the others are of late Mesozoic age.

THRUST FAULTS

Thrust faults are localized along the margin of the biotite-hornblende-quarte monzonite in the Coso Range. Two thrust faults have been mapped—the Talc City thrust in the Talc City Hills (pl. 2) and the Davis thrust in the Darwin Hills (pl. 3). The thrusting along both faults was toward the east or northeast away from the intrusive mass.

TALC CITY THRUST

In the Talc City Hills 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 many steep faults trending N. 70° to 80° W., and it has been in part removed by erosion (fig. 4). 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 (pl. 2). At the Alliance talc mine Eureka quartzite and Ely Springs dolomite are thrust over folded thinly bedded limestone of the Keeler Canyon formation (fig. 17). 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. The thrust is also exposed at the Irish lease

FIGURE 17.—Talc City thrust at the Alliance talc mine. Two klippen of Ely Springs dolomite (Oes) and Eureka quartzite (Oe) over Pennsylvanian and Permian Keeler Canyon formation (PPk) 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.

in the southeast part of the Alliance mine where shale lithologically similar to Rest Spring shale is present in the fault zone. A steep fault has displaced the thrust fault in the workings of the Irish lease but the trace of the fault is flat-lying to the east of the mine.

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. Rest Spring shale is also present here 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. 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, Lee Flat(?) limestone, and the lower unit of the Owens Valley formation of Permian age.

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 Pogonip is thrust over the Keeler Canyon formation. The net slip is probably about 3 miles, but this is not much more than a guess based on projecting the geology from the southern Inyo Mountains (Bateman and Merriam, 1954, map 11).

DAVIS THRUST

A thrust fault that strikes northerly and dips 23° to 60° W. crops out in the Darwin mine area (pl. 3). Where exposed it involves only strata of the lower part of the 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. 3). Many drag folds are localized in thinly bedded limestone in the hanging wall of the thrust. The largest and more conspicuous is the open anticlinal shaped fold in the southwest side of Ophir Mountain (pl. 3). The drag folds have a dextral pattern and most plunge gently to the north. They 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 above the Davis thrust (pl. 1). 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 like those near the Davis thrust. Most of the drag folds plunge gently to the north. A strong lineation that plunges steeply down dip in the *a* direction is developed in some of the drag folds (pl. 3). The lineation is shown by stretching of rounded chert nodules in the golfball horizon and by the disruption of sandy limonitic beds ¼ to ½ inch thick into pencillike units 6 to 8 inches long. Drag folds bordering the faults overlying the Davis thrust indicate that they are normal faults. The Davis thrust was caused by forceful intrusion of the batholith of the Coso Range, which overturned the Keeler Canyon and thrust it up and toward the northeast. The overlying normal faults probably indicate minor readjustments upon relaxation of the push from the intrusion, but they could be formed if each footwall block was 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 (pl. 1).

The two major faults in the Santa Rosa Hills are the Lee and the Santa Rosa Flat faults (pl. 1). 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 westward. 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 a left-lateral strike-slip displacement with the east block moving N. 30° W. is postulated. The faults must have a reverse component also as older beds are brought up to the west. The strike-slip movement is postulated on the basis of near juxtaposition of the Lee Flat limestone and Rest Spring shale on opposite sides of the faults. Part of the Lee Flat limestone in the Darwin quadrangle is a time-stratigraphic equivalent of the Rest Spring shale. It occurs only on the east side of the Lee fault in the Santa Rosa Hills, whereas Rest Spring shale occurs locally in the Santa Rosa Flat fault zone and to the southwest in fault zones in the Talc City Hills. Reconnaissance work has shown that Lee Flat limestone is present and shale is absent in the Argus Range to the southeast. The facies change from Rest Spring shale to Lee Flat limestone on opposite

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sides of the faults in the Santa Rosa Hills is abrupt, and the Lee Flat limestone probably was faulted from the southeast to near juxtaposition with the Rest Spring shale. The gash veins along the Santa Rosa Flat and Lee faults also indicate a left-lateral displacement for these faults. The Tin Mountain limestone between the two faults was tightly drag folded. The limestone, which probably was under shallow cover at the time of faulting, shattered like a brittle rock at the crest of folds instead of flowing plastically.

Two systems of transverse strike-slip faults occur in the Darwin Hills. The major set strikes N. 60° to 80° W.; the minor set strikes 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 of leucocratic quartz monzonite at Zinc Hill to the Talc City Hills, where it merges with the local N. 60° to 80° W. structural trend in the talc district (pl. 1). The displacement of the Darwin tear fault is 2,200 feet, with the north block moving westward relative to the south block. The direction of movement is shown by drag, nearly horizontal slickensides, and mullion structures. The displacement is shown by 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 that contains 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 between the Darwin tear fault and the Independence workings of the Darwin mines (pl. 1). The Standard fault is a mineralized fault zone as much as 50 feet thick that cuts biotite-hornblende-quartz monzonite in the Darwin Hills; the fault passes through the Standard group of claims in sec. 18, T. 19 S., R. 41 E. The long adit on the Standard claim is along this fault (fig. 3). The displacement on the fault apparently is several hundred feet, north side west.

The second set strikes N. 60° to 80° E. These faults are abundant at all the principal lead-silver-zinc and tungsten mines in the Darwin Hills south of the Darwin tear fault. They are mineralized faults that cut biotite-hornblende-quartz monzonite, and they are one of the important ore controls for both tungsten and lead-silver-zinc ore bodies. Displacement is small on these left-lateral faults. The north block has moved west less than 200 feet relative to the south block on all of them. Faults in this set include the Copper, Water tank, Lane, Bernon, 434, and Defiance faults (pl. 3) and northeastward-striking faults near the Fernando and St. Charles mines (fig. 3). The direction of movement is shown by offset of biotite-hornblende-quartz monzonite and by abundant nearly horizontal slickensides. Most of the faults that strike N. 60° to 80° E. are cut off by the Davis thrust, but some faults displace the thrust (pl. 3). 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 would have right-lateral displacement if they were complementary. Nor does it appear likely that the faults that strike N. 60° to 80° E. are 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 report on shears of the second order used the Darwin faults as one of his examples, and he called the faults that strike N. 60° to 80° E. shears of the second order. He defined 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

$$\left(45^\circ - \frac{\phi}{2}\right)$$

where ϕ is the angle of kinetic friction. A shear of the second order seems a reasonable explanation for these faults.

MINERALIZED STEEP STRIKE FAULTS

Steep mineralized strike faults are in both the Darwin Hills and the Talc City Hills. In the Darwin mine, ore is localized in steep north-striking faults. The faults are concentrated near the faults that strike N. 60° to 80° E. and die out away from these transverse faults. Displacement on the northward-striking faults is negligible. They are probably tension fractures formed at about the same time as the transverse N. 60° to 80° E. faults.

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. These faults are mineralized and commonly localize talc ore bodies. The Talc City thrust is displaced vertically by the faults, but the north side may have been either raised or lowered (pl. 1, section *B–B′*). The vertical displacement of the thrust could be caused by strike-slip movement, vertical movement, or by a combination of both.

FOLIATION

Foliation is poorly defined in the Paleozoic rocks in the Darwin quadrangle. Locally the Keeler Canyon and Owens Valley formations have a fracture cleavage. It is well-defined in the middle unit of fissile shale in the Owens Valley formation on the east side of Conglomerate Mesa (pl. 1). The fracture cleavage is as much as 90° to bedding, and the shale must be examined closely for bedding. Fracture cleavage is also locally developed in the belt of tightly folded rocks on the east side of the Darwin stock. At the Lucky Jim mine the fracture cleavage is an aid in working out the structure.

SUMMARY

The probable sequence of events during the late Mesozoic orogeny is summarized below. The Paleozoic strata were first deformed into a series of broad open folds that formed the Darwin Wash syncline and tilted the Paleozoic rocks in the Santa Rosa Hills homoclinally westward. These folds have flat-lying axes that trend northward. The gently folded Paleozoic strata were then forcefully intruded by biotite-hornblende-quartz monzonite in the Coso Range and in the northeastern part of the quadrangle during the Jurassic period. In the Darwin Hills older strata brought up by the intrusion in the Coso Range 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 and formed normal bedding plane faults (pl. 1, section C–C^1). The Paleozoic rocks were folded and faulted before silication of the limestone around the intrusive body. 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 late compression. The tightly folded structures in calc-hornfels reflect plastic deformation of incompetent beds and indicate that the folding preceded silication of the limestone.

The Paleozoic strata in the Talc City Hills and southern Santa Rosa Hills were squeezed between the two major intrusive masses (pl. 1). The beds were rotated from a northerly to a N. 60° to 80° W. strike. Deformation caused rupture along the Darwin tear fault and Standard fault. The Darwin tear fault must have moved both before and after silication. 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, and the thrust sheet was broken by steep strike faults.

CENOZOIC STRUCTURES

The Darwin quadrangle is on the east flank of a broad regional warp of probably late Pliocene age that had an axis along the east side of Owens Valley. All the mountain ranges and basins in both the Darwin quadrangle and adjacent Panamint Butte quadrangle on the east are east-tilted fault blocks. This includes the southern Inyo Mountains, Coso Range, Darwin Hills, Argus Range, and Panamint Range. The Sierra Nevada is the west side of the warp. Although the broad warp is the principal Cenozoic structural feature, it is only evident where late Cenozoic basaltic flows form extensive dipslopes. Examples of basaltic dipslopes are in the southern Inyo Mountains northwest of the talc mines and on Darwin Plateau, which slopes toward Panamint Valley.

The warp has been broken by north-trending faults into a series of east-tilted blocks that form basins and ranges. The faults may have either normal or reverse movement, although in the area as a whole normal faults are more abundant. The observed displacement on most faults is only a few tens of feet, although a few have displacements of hundreds of feet.

Northward-striking late Cenozoic faults form conspicuous topographic features in the eastern part of the quadrangle. A swarm of steep faults, most of which are downthrown on the east, displace the extensive basaltic capping in the northeastern part of the quadrangle and in part caused the depression of Panamint Valley. 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 on the east. Another swarm of steep faults south of these faults is on the west flank of the Argus Range, but this swarm has the opposite displacement with the east side up. Blocks between these faults, though, are tilted toward the east. 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 northeastern part of the quadrangle.

The Argus Range is an east-tilted fault block. Olivine basalt on the west flank of the Argus Range has been displaced about 1,600 feet in a series of step faults (fig. 18). The basalt on the east flank dips mostly 10° to 15° E. and basin-range faults are much less common. Most of the faults on the tilted east side are normal faults that are downthrown on the mountain side.

The south end of the Inyo Mountains is also an east-tilted fault block. Knopf (1918, p. 88) described the step faults on the west flank of the range. The total displacement of the step faults on the west flank of the

FIGURE 18.—View of the west flank of the Argus Range from Darwin Wash showing a step-faulted basaltic flow. The range is an east-tilted fault block.

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° E. and are broken by a few basin-range faults (pl. 1). The most conspicuous fault on the east flank, the Santa Rosa fault, drops the east side about 400 feet. Other faults on the east flank show only small displacement of the basaltic 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 on both the east and the west sides 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 Coso Range extends only slightly into the Darwin quadrangle, and owing to the lack of an extensive basalt cover the structure is not definitely known. The most conspicuous fault is a fault downthrown on the west along the northeast front of the range. Such faults are common at the foot of east-tilted fault blocks.

METAMORPHISM

Most of the Paleozoic sedimentary rocks and a few of the Mesozoic intrusive rocks are somewhat altered. The alteration has been caused mainly by igneous metamorphism and to a lesser extent by regional metamorphism. The recrystallization of the Hidden Valley dolomite and the limestone of the Lost Burro formation may have been done by regional metamorphism, but both formations in the quadrangle are located near borders of areas affected by igneous metamorphism. Only igneous metamorphism is described.

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, induced within the intrusion, or exomorphic, induced within the invaded rock. Alteration of the igneous rocks has been on a small scale, but changes in limestone near intrusive bodies are widespread. The most important exomorphic change is the contact metamorphism and contact metasomatism of limestone—the formation of calc-hornfels and tactite.

METAMORPHISM WITHIN THE IGNEOUS ROCKS

The major intrusive bodies in the Darwin quadrangle are not altered. The northern part of the biotite-hornblende-quartz monzonite in the Darwin Hills, however, probably was intensely altered at or slightly after the time of emplacement. Quartz monzonite at the surface near the Thompson workings of the Darwin mine is a highly iron-stained, deeply weathered rock, whereas at the south end of the stock the quartz monzonite is unaltered (pl. 3). Because of the deep weathering, it was impossible to find fresh specimens to study. It is probable that the weathering was due to previous argillic alteration of the quartz monzonite.

METAMORPHISM OF LIMESTONE

The various limestones of post-Silurian age have reacted differently to metamorphism. The Lost Burro formation of Devonian age was bleached and nearly completely recrystallized to marble, but 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 near intrusive bodies. The original composition of the limestone is chiefly responsible for the type of alteration. Limestone in the Lost Burro formation is clean and recrystallized to marble, whereas the limestone beds of the Lee Flat, Keeler Canyon, and Owens Valley formations are mostly silty, sandy, or argillaceous and formed silicated limestones.

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 the Lee Flat limestone north and south of the stock of leucocratic quartz monzonite at Zinc Hill is bleached and recrystallized to white marble for 500 to 900 feet. Locally, 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.

DOLOMITIZATION

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. Regional mapping by the U.S. Geological Survey in adjacent areas (McAllister, 1952, 1955; Merriam, 1954) has shown that these strata are sedimentary dolomite. However, the dolomite over much of the Talc City Hills is recrystallized and does not resemble its counterpart in less altered areas. The Silurian and Devonian dolomite 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 but included thin beds of medium-gray limestone in the Devonian. The dolomite was recrystallized near the stock of leucocratic quartz monzonite to buff massive dolomite, and the thin limestone beds 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 about 150 feet (pl. 3). At the Zinc Hill mine Mississippian limestone is also altered to dolomite along or near faults.

All the dolomite in the Talc City Hills was considered by Page (1951, p. 8) to have formed by hydrothermal alteration of limestone. Quadrangle mapping by McAllister (1955), C. W. Merriam and W. C. Smith (Bateman and Merriam, 1954, map 11) in the New York Butte quadrangle, and by the writers, however, has shown that most of the dolomite in the Ordovician, Silurian, and lower part of the Devonian has a regional distribution. Peripheral to the stock of leucocratic quartz monzonite in the Talc City Hills much of the stratified dolomite is recrystallized to a massive, buff dolomite that does not resemble dolomite in equivalent stratigraphic positions in unaltered sections. Relicts of the unaltered dolomite in the massive buff-colored dolomite commonly give it a mottled appearance. The limestone-dolomite contact in the Lost Burro formation is well exposed 2,500 feet east of the Talc City mine; it is virtually conformable but is locally irregular owing to the dolomitization at the crests of folds (pl. 2). Several limestone beds less than 50 feet thick that are interbedded with the dolomite are in part dolomitized and have a discontinuous outcrop pattern.

ALTERATION TO CALC-HORNFELS, CALC-SILICATE ROCK, AND TACTITE

Alteration of limestone and impure limestone to calc-hornfels, calc-silicate rock, and tactite has been widespread about the major intrusive bodies. The alteration is shown by an overlay pattern on the regional map (pl. 1). Calc-hornfels is a dense aphanitic light-colored rock generally considered to form by the virtually isochemical recrystallization of impure limestone. The mineralogy of calc-hornfels varies, but it contains some or all of the following minerals: diopside, wollastonite, idocrase, garnet, relict calcite, plagioclase, orthoclase, quartz, tremolite, and epidote. Tactite (Hess, 1918, p. 378) is a rock formed by contact metamorphism of limestone or dolomite into which foreign matter has been introduced by hot solutions or gases from the intruding magma. In the Darwin Hills light-colored tactite, composed predominantly of wollastonite, idocrase, and garnet, and calc-hornfels have gradational contacts, and they are not everywhere distinguished on the mine maps. Light-colored tactite is shown as medium-grained calc-silicate rock on the Darwin mine map (pl. 3); however, a dark-colored tactite composed of epidote, idocrase, or andradite that is localized at intrusive contacts or along faults, especially at intersections with pure limestone beds within several hundred feet of an intrusive contact, may readily be distinguished (pl. 3).

The Lee Flat limestone and Keeler Canyon and Owens Valley formations were particularly susceptible to alteration to calc-hornfels and tactite minerals. The largest area of calc-hornfels is in the Darwin Hills as a contact metamorphic alteration around biotite-hornblende-quartz monzonite. Impure limestone beds of Pennsylvanian and Permian age are altered to calc-hornfels and locally to tactite in an area 4½ miles long and 1 mile wide (pl. 1). The Darwin tear fault is the approximate northern limit of the alteration. Parts of a large area of calc-hornfels are 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. Calc-hornfels also crops out around the intrusive body at the south end of the Santa Rosa Hills and in the southern Inyo Mountains at the Santa Rosa mine (pl. 1).

In the Darwin Hills the altered rock ranges in general from medium-grained light-colored calc-silicate rock and minor dark tactite close to the contact of biotite-hornblende-quartz monzonite through dense white, light-gray, brown or greenish-gray calc-hornfels to partly silicated limestone at the outer margins of the altered zone (pl. 3). Although the alteration generally is more intense and the altered rock is coarser grained near the intrusive body, many exceptions occur because of differences in composition of the original beds and because of more intense alteration close to ore bodies and faults. For example, at the Defiance workings of the Darwin mine (pl. 3) dense white calc-hornfels is in a band 50 to 100 feet wide adjacent to the biotite-hornblende-quartz monzonite, 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.

Samples of silicated limestone were taken at 25-foot intervals away from the Defiance ore body on the 570, 700, and 800 levels and at irregular intervals over the surface for a study of the alteration (pl. 3). At the outer margin of the altered zone silication is selective; impure limestone beds are partly or completely altered to calc-hornfels but purer limestone beds are unchanged. Differences in color, grain size, and mineralogy occur between adjacent thin calc-hornfels beds. The silty limestone beds are readily converted to calc-hornfels. The grain size is commonly 0.02 to 0.05 mm. Tremolite, orthoclase, scapolite, clinozoisite, and sphene may be present.

In the Defiance area east of the Davis thrust, the alteration is more intense (pl. 3). The calc-hornfels and calc-silicate rock here typically is a white to light greenish gray rock that consists predominantly of wol-

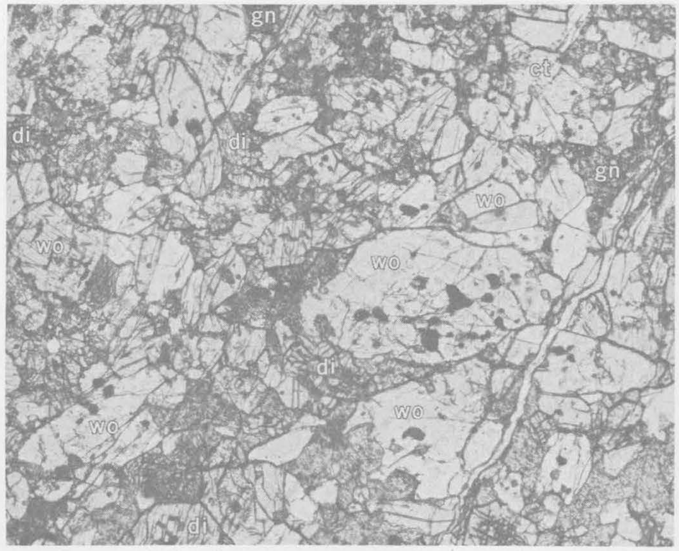


FIGURE 19.—Photomicrograph of medium-grained light-gray calc-silicate rock from the inner zone of contact-metamorphosed limestone from the Defiance area. The rock consists almost entirely of wollastonite (wo) and diopside (di). A veinlet of calcite (ct) cuts the rock. The initial stage of replacement of diopside and wollastonite by garnet (gn) is shown. Plane polarized light, 40 ×.

lastonite and diopside (fig. 19). Garnet idocrase, orthoclase, clinozoisite, oligoclase, forsterite, tremolite, sillimanite, sphene, and apatite may be present. Grain size is mostly 0.5 to 2 mm, but locally it is coarser. Garnet and idocrase replace diopside and wollastonite (fig. 20) as the grade of metamorphism increases. The dense white calc-hornfels in the inner zone of contact metamorphosed limestone at the Defiance workings (pl. 3) is composed nearly entirely of wollastonite (fig. 21). It forms felted masses of laths less than 0.1 mm long with diopside in dense calc-hornfels. Near intrusions wollastonite forms megacrystalline radial masses and a few large crystals as much as 6 inches long that are replaced by garnet and idocrase (fig. 22). As the amount of garnet and idocrase increase, the rock becomes greenish gray to light green. Garnet and idocrase, the principal late minerals formed during the period of silication, are common gangue minerals in the replacement ore bodies (fig. 23). The garnet is light-green andradite. It is slightly birefringent and very commonly it 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-silicate rock and tactite, but it increases in grain size and abundance near ore bodies and intrusive contacts. Locally tactite composed entirely of garnet is found along intrusive contacts or in faults near them. Idocrase is generally associated with garnet but is much less abundant. It occurs as euhedral to subhedral prisms in the medium-grained calc-silicate rock (pl. 3).

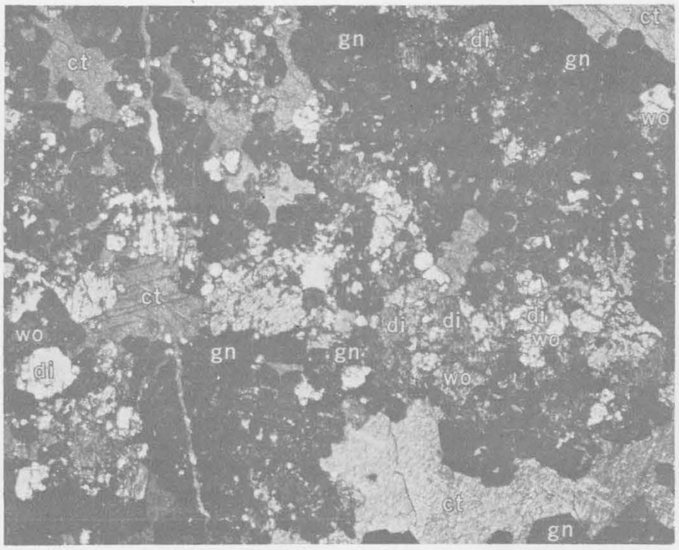


FIGURE 20.—Photomicrograph of light-green tactite composed predominantly of garnet (gn). Corroded relicts of diopside (di), wollastonite (wo) and calcite (ct) are in the garnet. Specimen from the 800 level of the Defiance workings. Crossed nicols, 44 ×.

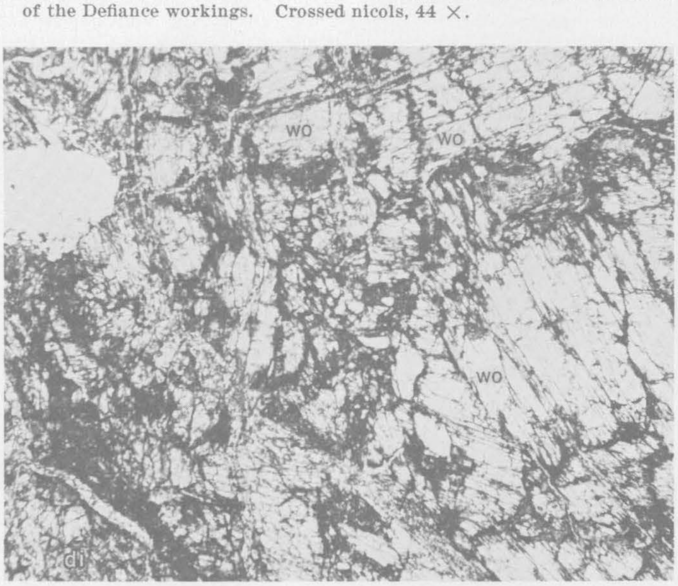


FIGURE 21.—White fine-grained calc-hornfels. The rock is composed of tabular and radial crystals of wollastonite (wo) with interstitial calcite (dark). Only one diopside (di) crystal is present in the photomicrograph, but the mineral is disseminated in small amounts throughout the rock. Plane polarized light, 22 ×.

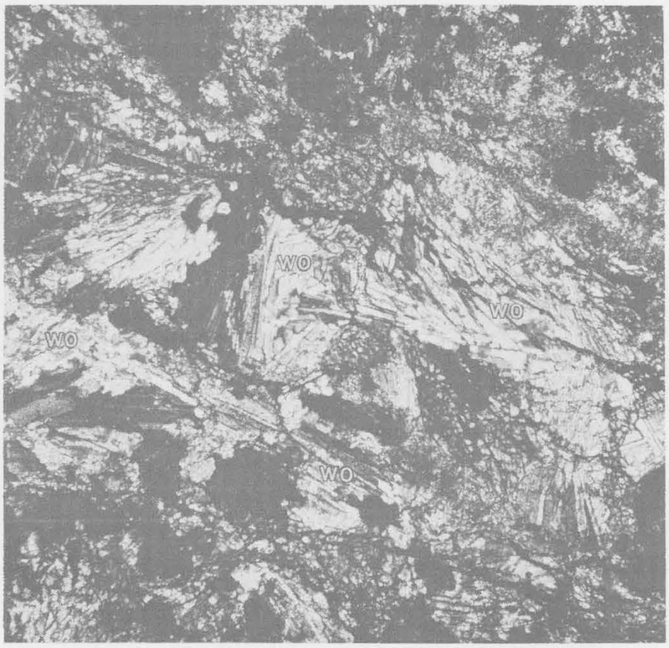


FIGURE 22.—Photomicrograph of light-greenish-gray tactite composed of coarse-grained wollastonite (wo) that is partly replaced by andradite garnet (dark mineral). Specimen from the inner zone of metamorphosed limestone in the Defiance workings of the Darwin mine. Crossed nicols, 22 ×.

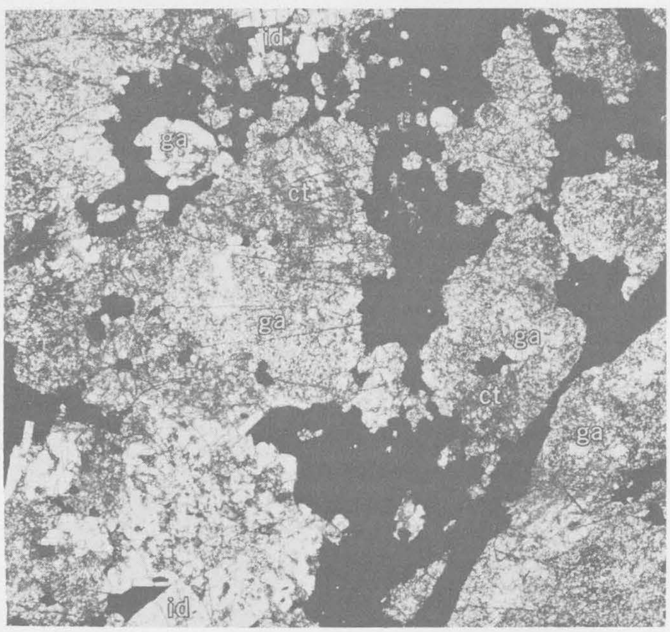


FIGURE 23.—Photomicrograph of specimen of low-grade ore showing replacement of garnet (ga) and idocrase (id) tactite by sulfide minerals (dark). Some relict calcite (ct) is present in the garnet. Specimen from the 800 level of the Defiance workings. Plane polarized light, 30 ×.

Some material was added to the medium-grained calc-silicate rock that is so widespread in the Darwin mine area. Two analyses of unaltered limestone from the Fairbanks mine and from an area near the Lead Hope mine (fig. 3) were compared with one analysis of calc-silicate rock from the surface between the Bernon and Defiance workings of the Darwin mine (pl. 3). These samples were taken from strata believed to be the approximate unaltered equivalent of the medium-grained calc-silicate rock in the Defiance area of the Darwin mine. The calc-silicate rock consists predominantly of wollastonite but contains some garnet, idocrase, and diopside. The results of the analyses are given in table 3. The most pronounced chemical changes during silication 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 virtually unchanged.

TABLE 3.—*Analyses of limestone and calc-hornfels from the Darwin Hills*

[Rapid analyses by P. L. D. Elmore, K. E. White, and P. W. Scott, U.S. Geological Survey 1954–55]

	A	B	C
SiO_2	26.6	13.1	42.1
Al_2O_3	2.6	1.6	5.3
Total Fe as FeO	.94	.57	2.1
MgO	2.2	1.6	2.9
CaO	36.5	47.5	37.1
Na_2O	.44	.16	.22
K_2O	.56	.40	.38
TiO_2	.20	.10	.29
P_2O_5	.11	.10	.18
CO_2	28.6	34.8	6.9
H_2O	---------	.40	1.4
Total	99	100	99

A. Limestone of the Keeler Canyon formation from the Lead Hope mine.
B. Limestone of the Keeler Canyon formation from the Fairbanks mine.
C. Medium-grained calc-silicate rock from the surface between the Bernon and Defiance workings of the Darwin mine.

Dark-green tactite locally replaces calc-hornfels and medium-grained calc-silicate rock along faults near intrusive contacts. Garnet generally is the predominant mineral and may be the only mineral present, forming the rock garnetite. Tremolite, garnet, 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 generally less than 50 feet long.

ALTERATION TO FELDSPATHIC ROCK

Locally calc-hornfels is altered to a feldspathic rock at the margins of the stock of biotite-hornblende-quartz monzonite in the Darwin Hills and around some of the small satellitic bodies. The most conspicuous feldspathic rock is in the Defiance workings of the Darwin mine and along the crest of the ridge 600 feet southwest of the Defiance inclined shaft (pl. 3). It is exposed on the 800 level of the Defiance workings 185 feet N. 15° E. of the main shaft in a dike. It probably formed by replacement and contains perthitic orthoclase, pyrite, fluorite, and sphalerite.

The feldspathic rock ranges from a porphyroblastic rock that contains euhedral porphyroblasts of perthitic orthoclase as much as half an inch square in a groundmass of orthoclase ½ to 1 mm in diameter, to calc-hornfels containing diopside, garnet, and calcite or wollastonite, diopside, and calcite that is partly replaced by feldspar (fig. 24). Where the replacement is complete, orthoclase makes up nearly 100 percent of the rock, and the rock is a kalisyenite. Kalisyenite occurs as thin dikes of probable replacement origin that cut calc-hornfels and as irregular zones within masses of partly feldspathized calc-hornfels. Sulfide minerals

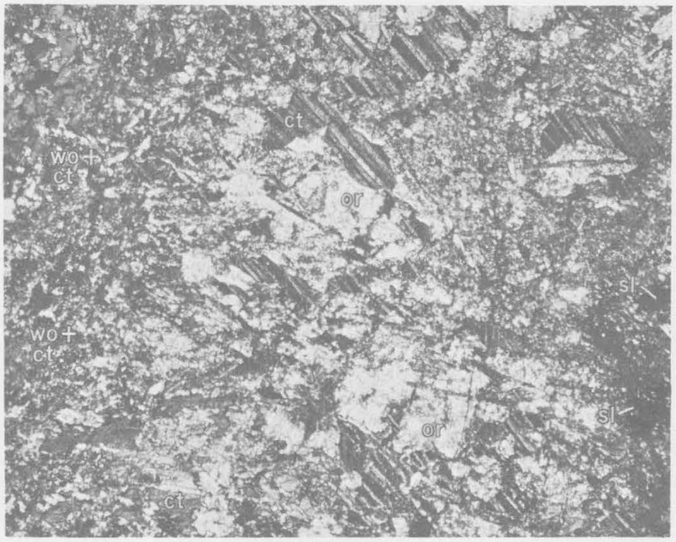


FIGURE 24.—Photomicrograph of partly feldspathized calc-hornfels. On the left side of the photomicrograph is a fine-grained mixture of wollastonite (wo) and calcite (ct). Perthitic orthoclase (or) corrodes and replaces the fine-grained calcite and wollastonite and coarsely crystalline calcite. A veinlet of sphalerite (sl) (dark mineral on the lower right) cuts the rock and is the youngest mineral. Crossed nicols, 30 ×.

and fluorite are abundant (fig. 25). Pyrite and sphalerite are the most abundant sulfide minerals and commonly constitute more than 10 percent of the rock. Galena may be present. Fluorite is a deep purple variety and may constitute several percent of the rock.

ALTERATION TO AMPHIBOLITE

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

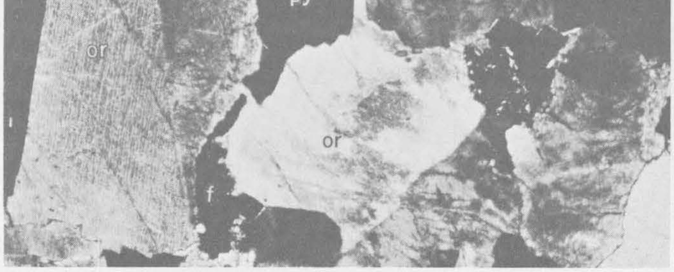


FIGURE 25.—Photomicrograph of kalisyenite dike from the Defiance working of the Darwin mine. The dike consists of coarse-grained orthoclase (or) that is partly replaced by purple fluorite (f), pyrite (py), and sphalerite (sl). Minor calcite (ct) is a relict mineral between grains of orthoclase. Crossed nicols, 30 ×.

fourths of a mile north of Darwin Canyon, and for 1 mile in the canyon 1½ miles north of Darwin Falls (pl. 1). 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 but includes 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 transition zone 10 to 20 feet wide 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 small amounts of 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 finely disseminated through the groundmass and also 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 the silty limestones are recognizable. 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 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.

GEOLOGIC HISTORY

The Paleozoic era was marked by nearly continuous deposition of marine sediments from the Early Ordovician to well within the Permian; no major unconformities or hiatuses were recognized. Lithology and fossils of the Lower Ordovician Pogonip group, the oldest rocks in the quadrangle, indicate that the predominantly carbonate rocks were formed in a deepwater marine environment. Local admixing of sand grains and crossbedding near the top of the formation manifest a transition from deepwater deposition for the older dolomites and limestones to shallow-water conditions during the Middle Ordovician. Littoral subzone or beach conditions probably prevailed during Middle Ordovician time and resulted in the deposition of well-sorted quartz sand of the Eureka quartzite, probably a second cycle orthoquartzite. Ely Springs dolomite and Hidden Valley dolomite were formed in seas that covered the area during Late Ordovician time and during the Silurian and Devonian. Marine deposition continued through the Devonian, mainly forming limestone in contrast to the preponderance of dolomite in pre-Devonian seas.

Marine sedimentation continued throughout the Mississippian. The limestone units of the Tin Mountain limestone and Perdido formation were largely formed in placid seas devoid of foreign detritus. Calcilutite of the Lee Flat limestone records marine deposition that was likely derived from a low-relief landmass.

Continued marine deposition in a nearshore environment formed the calcarenite and calcilutite characteristic of the Pennsylvanian and Permian. Recurrent emergences are indicated by intercalated limestone conglomerate and minor unconformities, and widespread crossbedding indicates a nearshore environment. Most of the emergences probably were short lived and of limited extent, but locally folding was concomitant with uplift. The coarse limestone conglomerate of the upper part of the 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 before the advent of the Mesozoic intrusions. The Paleozoic rocks were then regionally warped in response to the forceful intrusion of the Hunter Mountain batholith and the Coso batholith. 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. Subareal erosion probably was active throughout most of the era.

There is a gap in the geologic record between the Mesozoic intrusions and ore deposits and the advent of volcanism during the late Pliocene. This gap probably represents a period mainly of erosion. By late Pliocene time the land surface 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 of 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 Range and the Inyo Mountains contains part of this mature surface.

The present basins and ranges had their inception at least as far back as late Pliocene time when uplift of the Coso Range and Inyo Mountains caused the formation of extensive piedmont fans that interfinger with lacustrine deposits in Owens Valley. Volcanic activity was common during the Pliocene, and it continued intermittently into the Quaternary. Pyroclastic rocks of basaltic composition are abundant 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 pyroclastic rocks in the Inyo Mountains near the Santa Rosa mine, was extruded as domes during the late Pliocene or early Pleistocene. The pyroclastic rocks were tilted locally before the outflow of the extensive olivine basalt flows that cap most of the northern part of the Darwin quadrangle.

Uplift of the Argus and Coso Ranges, and the Inyo Mountains continued through the Pleistocene and Recent. 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 and in this way lowered the base level of erosion to Panamint Valley and caused dissection of the lakebeds. Erosion and intermittent uplift have continued in the Recent.

ORE DEPOSITS

The Darwin quadrangle contains commercially important deposits of lead-silver-zinc and steatite-grade talc, and some tungsten, copper, gold, and antimony (fig. 3). Large deposits of limestone, dolomite, and quartzite are known, but they have not been exploited owing to remoteness from market and railroad transportation. The total value of mineral production to 1952 is about $37½ million. The Darwin lead-silver-zinc district has accounted for $29 million and the talc deposits for about $5 million. 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 northeastern part of the quadrangle, and the Santa Rosa 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.

HISTORY AND PRODUCTION

The following history of mining before 1945 was compiled entirely from the literature. The following references supplied most of the information: Burchard (1884), Chalfant (1933), Kelley (1938), Norman and Stewart (1951), and Robinson (1877). Statements of history prior to 1945 not otherwise credited originally came from one of these articles. Mining in the Darwin quadrangle dates back to November 1874 when rich silver ore was discovered in the Darwin Hills by a Mexican reportedly searching for a lost pack mule (Chalfant, 1933, p. 274). During the ensuing decade the rich silver ores were extensively exploited, and by 1883 more than $2 million in bullion had been recovered. During this time Darwin is reported to have had a population of 5,000. The Christmas Gift, Lucky Jim, Defiance, and Independence mines produced most of the ore the first few years. The New Coso Mining Co. obtained the Lucky Jim and Christmas Gift mines in May 1875, and they developed both properties rapidly during the following few years. A report to the stockholders, dated April 1, 1877, gives the production from the two properties as 226,672 ounces of silver and 1,920,261 pounds of lead worth $410,350. The Defiance and Independence mines were in production by 1875 as reported in the Coso Mining News of December 24, 1875, and by 1883 they produced $1,280,000 of bullion (Burchard, 1884, p. 164). The ores in the district were treated at Darwin in three smelters—the capacity of the Cuervo was 20 tons per day, the Defiance 60 tons, and the New Coso 100 tons (Goodyear, 1888, p. 226). Bullion was hauled by teams of horses to Los Angeles. At the time of Goodyear's visit in 1888, the district was nearly dormant, and the smelters were permanently closed owing to exhaustion of the easily mined, high-grade near-surface ores (Goodyear, 1888, p. 226).

From 1888 until World War I the Darwin mines were operated intermittently on a small scale by the New Coso Mining Co., Inyo County Mining and Development Co., Independence Mining Co., and others. From 1915 until 1928, when the price of lead and zinc was too low to be mined profitably, the district was fairly active. In 1915 the Darwin Development Co., later called the Darwin Lead and Silver Mining and Development Co., and finally the Darwin Silver Co., consolidated the Lucky Jim, Promontory, Lane, and Columbia mines and about 1918 obtained control of the Defiance and Independence mines. In 1925, C. H. Lord leased the properties and operated them from 1925 to 1927 as the American Metals, Inc. In 1928 the Lucky Jim mine was gutted by a fire and rendered inaccessible. The district was idle from 1928 until 1936. From 1937 until August 1, 1945, the properties were controlled by the Darwin Lead Co., the Imperial Smelting and Refining Co., Imperial Metals, Inc., and Darwin Mines.

On August 1, 1945, The Anaconda Co. purchased the Bernon, Defiance, Driver, Essex, Independence, Lane, Lucky Jim, Promontory, Rip Van Winkle, and Thompson mines, and other small properties in the Darwin quadrangle and the Columbia mine at the south end of the Darwin Hills in the Coso Peak quadrangle, and they have operated some of them continuously since 1945 except for brief shutdowns in 1948 and from March 1954 to January 1955. The Defiance, Essex, Independence, and Thompson mines produced most of the ore. The Lucky Jim mine was rehabilitated in 1948 but did not produce any ore.

Talc was probably first mined in the Talc City Hills in 1915. Waring and Huguenin (1919, p. 126) described operations at the Talc City mine under the name Simonds talc mine in their biennial report for 1915–16. In 1918 the Simonds talc mine was purchased by the Inyo Talc Co., which later was renamed the Sierra Talc and Clay Co. They have operated the Talc City mine and several smaller deposits continuously since then.

Scheelite was first described in the Darwin Hills by Hess and Larsen (1922, p. 268); Kelley (1938, p. 543) mentioned scheelite at the Bruce mine in the Darwin Hills, but the tungsten deposits remained undeveloped until 1940 when Frank Watkins, C. W. Fletcher, and others organized the Darwin Consolidated Tungsten Co. to develop them. The Pacific Tungsten Co. leased the claims in 1941, and the following year they produced 30,940 tons of ore that averaged about 1 percent WO_3 (Wilson, 1943, p. 544). The ore was treated at a mill near Keeler owned by the West Coast Tungsten Corp. Howard Miller and Louis Warnken operated the Durham-Fernando, Hayward, and St. Charles mines from 1951 to 1953 and the Hayward and St. Charles mines during 1954–55. Location of mines are shown in figure 3. The ore was treated in a mill in Darwin Wash. The Ajax Tungsten Corp. obtained a lease on the Durham-Fernando property in 1954, and they shipped their ore to Bishop for treatment. The lead-silver ore at the Thompson mine of the Darwin group contains some scheelite. At present it is not recovered, except for local high-grade concentrations that are stockpiled.

The total metal production from the Darwin quadrangle through 1951 was 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 short ton units of WO_3. Norman and Stewart (1951, p. 29) gave the production of antimony from the Darwin Antimony mine as "50 to 100 tons of ore assaying more than 30 percent antimony." The annual production from 1875 to 1951 excluding tungsten and antimony is given in table 4.

Talc is the only nonmetallic commodity produced in the area. No record was found of the total production from the Talc City Hills. The production from the Talc City mine, which has produced most of the talc in the district, is given in table 5. The total production of the Talc City mine from 1915 through 1947 is 218,485 tons.

TABLE 4.—*Gold, silver, copper, lead, and zinc produced from the Darwin quadrangle* [1]

Year	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Operators
1875–83		1,571,000 (estimated)				Defiance, Independence, New Coso Mining Co.
1888–92	23.51					Phoenix.
1893	7.26	26,759				Custer mine, J. A. McKenzie, H. Mettler, Phoenix.
1894		70,095				Christmas Gift mine, Henry Mettler.
1895		19,362				Custer mine, J. A. McKenzie, Henry Mettler.
1897		5,517				J. A. McKenzie and W. W. Boswell.
1898	64	54,800				R. C. Troeger.
1899		37,349				Custer, Last Chance Mining Co., J. A. McKenzie, Phoenix.
1900	741	13,178				W. W. Boswell, J. A. McKenzie, Phoenix
1901	591	14,333				Do.
1902		4,360				J. A. McKenzie, Phoenix mine.
1903	39	14,814		11,905		J. A. McKenzie.
1904	25	12,276		3,200		Inyo County Mining & Development Co., J. A. McKenzie.
1905	24.19	5,036	2,600	2,042		Christmas Gift mine, Inyo County Mining & Development Co.
1906		3,970		36,842		C. R. Bradford, Inyo County Mining & Development Co., New Coso Mining Co.
1907		12,600		100,000		New Coso Mining Co.
1908	4	17,785		182,405		Do.
1909	23.87	3,271	462	75,235		Christmas Gift mine, New Coso Mining Co., S. H. Reynolds.
1910	75	16,718	904	277,609		New Coso Mining Co., S. H. Reynolds, Silver Dollar mine.
1911	9.80	24,494	4,760	427,467		C. A. Bradford, Custer mine, New Coso Mining Co., S. H. Reynolds, Santa Rosa mine, Silver Dollar mine.
1912	38.32	11,210	13,210	215,710		Christmas Gift mine, Independence Mining Co., New Coso Mining Co.
1913	64.44	29,291	6,097	475,998		Christmas Gift mine, Custer mine, New Coso Mining Co., J. C. Roeper, M. J. Summers.
1914	6.02	13,043	1,256	195,667		Christmas Gift mine, New Coso Mining Co.
1915	3	10,998	543	122,713		Christmas Gift mine, Darwin Development Corp., Theo Peterson.
1916	38	132,836	38,658	2,046,618		Christmas Gift mine, Darwin Mines Corp., Santa Rosa mine.
1917	339	221,634	374,222	4,063,758	78,586	Christmas Gift mine, Custer mine, Darwin Mines Corp., Theo Peterson, Santa Rosa mine, M. J. Summers, Zinc Hill mine.
1918	202.61	145,381	76,741	3,614,161	1,040,000	A. A. Belin, Custer mine, Darwin Silver Co., Rooney and Bradford, Santa Rosa mine, Zinc Hill mine.
1919	40.97	46,082	39,926	980,945	291,540	Custer mine, Darwin Silver Co., Theo Peterson, Santa Rosa mine, M. J. Summers, Zinc Hill mine.
1920	19.66	31,773	23,313	683,436	669,140	Buckhorn, Custer mine, Darwin Silver Co., Jackass, Lee, Theo Peterson, Santa Rosa mine, M. J. Summers, Zinc Hill mine.
1921	2.15	3,886	2,791	109,613		Darwin Silver Co., A. G. Kirby, Santa Rosa mine.
1922	61.6	89,736	8,097	957,815	83,540	A. G. Kirby, Santa Rosa mine, Zinc Hill mine.
1923	154.8	127,716	19,088	2,087,763		Christmas Gift mine, A. G. Kirby, Santa Rosa mine.
1924	69.68	49,102	17,617	1,048,588	76,947	A. G. Kirby, Santa Rosa mine.
1925	3	23,723	18,218	573,648	150,430	A. A. Belin, L. D. Foreman & Co., Santa Rosa mine, Zinc Hill mine.
1926	44.25	39,745	10,803	1,202,855	86,060	American Metals, Inc., Christmas Gift mine, Santa Rosa mine, Zinc Hill mine.
1927	53.44	41,004	10,156	1,301,323		American Metals, Inc., Christmas Gift mine, L. D. Foreman & Co., Santa Rosa mine.
1928	13.11	7,209	13,050	202,459		American Metals, Inc.
1929	4.01	3,568	4,509	117,228		Santa Rosa mine.
1930	7.65	904	1,631	25,285		Do.
1931	0.45	1,349	270	31,650		Do.
1932	9.35	22,515	6,835	572,164		Do.

See footnote at end of table.

TABLE 4.—*Gold, silver, copper, lead, and zinc produced from the Darwin quadrangle* [1]—Continued

Year	Gold (ounces)	Silver (ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Operators
1933	4.20	2,609	1,325	104,112	----------	Do.
1934	6.39	7,777	8,364	242,415	----------	Do.
1935	95.14	5,575	10,290	155,457	----------	Custer mine, Santa Rosa mine.
1936	14.25	9,755	16,563	269,850	----------	Santa Rosa mine.
1937	174	70,526	14,417	1,240,741	----------	Custer mine, Darwin Keystone Ltd., Darwin Lead Co., L. D. Foreman & Co., Santa Rosa mine, Louis Warnken, Jr.
1938	26	7,860	2,846	143,756	----------	Darwin Keystone Ltd., Darwin Lead Co., Santa Rosa mine, Louis Warnken, Jr.
1939	5	146	----------	----------	----------	J. B. Anthony.
1940	7	748	170	32,712	----------	Custer mine, Keystone mine, Theo Peterson.
1941	81	32,915	16,501	1,434,884	383,720	Imperial Metals, Inc., Keystone mine, Zinc Hill mine.
1942	185	54,935	4,422	1,543,824	650,400	Imperial Metals, Inc., L. D. Foreman & Co., Zinc Hill mine.
1943	0.31	138,880	----------	4,901,412	38,760	Darwin Mines, Zinc Hill mine.
1944	4.00	252,900	10,327	5,218,000	1,110,000	Darwin Mines, L. D. Foreman & Co., Wonder mine.
1945	377	575,069	130,931	10,428,000	1,992,000	The Anaconda Co., L. D. Foreman & Co.
1946	443	871,621	200,340	15,450,891	1,720,539	The Anaconda Co., Empress mine, L. D. Foreman & Co.
1947	557	1,126,906	148,949	14,055,988	1,231,641	The Anaconda Co., Custer mine, Empress mine, L. D. Foreman & Co., Santa Rosa mine, Wonder mine, Zinc Hill mine.
1948	495	418,263	165,708	12,773,984	9,016,300	The Anaconda Co., Custer mine, Empress mine, L. D. Foreman & Co., Santa Rosa mine, St. Charles mine.
1949	232	354,861	131,583	9,994,337	8,148,444	The Anaconda Co., Custer mine, Empress mine, Santa Rosa mine, Zinc Hill mine.
1950	365	602,263	208,118	16,991,027	10,474,000	The Anaconda Co., Santa Rosa mine.
1951	422	574,765	223,091	14,395,209	9,441,670	The Anaconda Co., Empress mine, Lee mine.
	6,296.43	8,089,256	1,989,702 994.9 (tons)	131,122,098 65,561	46,683,717 23,341.9	

[1] Compiled from records of the U.S. Bureau of Mines and from Minerals Yearbook. The data for the Darwin district from 1888 to 1942 was compiled by Charles W. Merrill of the U.S. Bureau of Mines (from Hall and MacKevett, 1958).

TABLE 5.—*Talc produced from the Talc City mine* [1]

Year	Tons	Year	Tons
1915	300	1932	[2] 4,398
1916	428	1933	3,402
1917	620	1934	3,640
1918	2,000	1935	3,766
1919	3,398	1936	6,667
1920	7,087	1937	9,829
1921	4,300	1938	8,800
1922	5,325	1939	7,640
1923	5,685	1940	9,691
1924	5,202	1941	5,890
1925	4,517	1942	12,600
1926	5,462	1943	15,526
1927	5,273	1944	13,325
1928	6,195	1945	14,908
1929	6,370	1946	11,113
1930	5,561	1947	15,169
1931	4,398		
		Total	218,485

[1] Published with the permission of the Sierra Talc and Clay Co. Compiled by L. A. Wright of the California State Division of Mines (from Hall and MacKevett, 1958, p. 71).
[2] Estimate.

LEAD-SILVER-ZINC DEPOSITS

DISTRIBUTION

The lead-silver-zinc deposits are concentrated in Paleozoic limestone close to intrusive contacts. The largest deposits are adjacent to the stock in the Darwin Hills in the southern part of the quadrangle. The principal mines are the Darwin, Lucky Jim, Christmas Gift, Lane, Custer, and Promontory. Other ore deposits are near the stock at Zinc Hill 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 a few small deposits in the Talc City Hills (fig. 3). The name "Darwin mine" is used in this report to include all the properties through which the Radiore tunnel passes (pl. 3). 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 the relict host-rock minerals garnet, idocrase, diopside, wollastonite, quartz, and feldspar. Jasper and calcite are the abundant gangue minerals in most of the fissure deposits and relict host-rock minerals in the replacement ore bodies.

The texture of the primary ore ranges from very 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, occurs in some of the mines where pyrrhotite is abundant.

The oxidized lead-silver ore in the Darwin district, 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 a little galena occurs near the margins of some of the lead-silver-zinc ore bodies in the Darwin mine. The silver ore contains andorite, clausthalite, galena, matildite, and pyrite in a gangue of calcite and relict host rock. Matildite and clausthalite are in exsolved laths in galena. 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 hard light- to dark-gray porous mass composed mainly of hemimorphite, and includes thin coatings and crystals of cerargyrite. Some relict primary ore is present that consists of coarse galena and small amounts of 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

Bedded deposits economically 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. 3); the 430 stope ore body; the Blue and Red veins in the Defiance workings; and the ore bodies at the Custer, Jackass, and Promontory mines. Small bedded ore bodies are also at the Empress and Zinc Hill mines in the Zinc Hill district. The ore bodies contain from a few tens to more than half a million tons of ore. The contacts between the bedded deposits and barren or slightly pyritized wallrock are sharp. However the grade within the ore body is not uniform along strike, and some lower grade parts have been left behind as pillars.

IRREGULAR REPLACEMENT ORE BODIES

The only important irregular replacement ore body is in the Defiance workings of the Darwin mine (pl. 3). It is a vertical pipe-shaped zone about 250 by 350 feet in horizontal section and contains many isolated ore bodies. It has been mined vertically for about 550 feet. The downward extent has not been determined. Ore bodies within the zone 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 in thickness and are as much as 35 feet thick. The Essex vein has been mined for 800 feet downdip (pl. 3); the Lucky Jim vein for 920 feet. All the other veins apparently have a lesser length downdip. Contacts of the veins with barren country rock are sharp. Minable high-grade ore is commonly localized in ore 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. These ore shoots plunge toward the west.

ORE BODIES IN FLAT-LYING FRACTURES

Small silver-rich ore bodies are localized is flat-lying fractures in the Lee district at the Lee mine and Silver Reid prospect (pl. 9). The flat-lying fractures are in part parallel to bedding and in part transect bedding; they are localized between steep faults. The largest known ore body was about 40 feet long, 35 feet wide, and averaged about 6 feet in thickness. Most of the ore bodies mined in the past 20 years were 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-hornfels close to intrusive contacts with quartz monzonite. A few smaller deposits are in limestone or marble. Anticlinal 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

Deposits in the Darwin and Zinc Hill districts are generally 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 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 mass 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 (fig. 3). Two exceptions, the Custer and Fernando mines, are within 100 feet of quartz monzonite offshoots of the stock (fig. 3). The deposits in the Zinc Hill district are clustered about the stock of leucocratic quartz monzonite at Zinc Hill (fig. 3). The Empress mine is on the contact of the stock, and the Zinc Hill mine is 2,300 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 original limestone is metamorphosed to calc-hornfels, and an inclusion of quartz monzonite is in an andesite porphyry dike; both the calc-hornfels and the inclusion indicate proximity to a plutonic mass. The deposits in the Lee district are the farthest from a known intrusion. 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 seems to be especially 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 (pl. 1; 3). 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 formation; 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 and Permian age. The deposits in the Darwin district are in calc-hornfels of the lower unit of the Keeler Canyon formation. The Santa Rosa mine is in calc-hornfels of the lower unit of the Owens Valley formation of Permian age.

Dolomite seems 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 9 and 17 miles north of the Darwin quadrangle in the Ubehebe district (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 in age and no one formation is particularly favorable, within mineralized areas certain beds are favorable. Generally 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 the stock of biotite-hornblende-quartz monzonite (pl. 3). The ore is in a medium-grained, light-colored idocrase-garnet-wollastonite rock formed by contact metamorphism of a fairly pure limestone bed, 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 (inverted synclines in part) are important in localizing some bedded ore bodies. An inverted synclinal axis that plunges gently northwestward extends from the main opencut near the Defiance shaft N. 30° W. to the Bernon mine (pl. 3). 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. 3). Steep north-striking faults localize ore along the crest of the fold. Anticlinal structures are evident at the Custer mine and the Wonder mine on the east side of the stock of biotite-hornblende-quartz monzonite in the Darwin Hills (fig. 3).

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: (a) steep N. 70° E. faults; (b) steep N. 70° W. faults; (c) the Davis thrust, which strikes north and dips west; and (d) steep north-striking faults that have little displacement. Steep N. 70° E. 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 Bernon, 434, and Water tank faults (pl. 3) is localized in these faults. The bedded ore bodies and the irregular replacement ore body in the Defiance workings are localized close to the N. 70° E. Defiance fault (pl. 3).

The Essex is the only ore body localized in a N. 70° W. fault (pl. 3). The other two major N. 70° W. faults—the Darwin tear fault and the Standard fault—are mineralized but contain very little ore.

The Davis thrust fault is a premineralization fault that apparently confined the ore solutions between it and biotite-hornblende-quartz monzonite. All the known ore bodies in the district lie below the thrust, and premineralization faults above the thrust are only slightly mineralized.

Steep north-striking faults are an important ore control in the Thompson and Independence workings in the Darwin mine. The northward-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. 3).

At the Zinc Hill mine ore replaces a favorable bed near a series of steep north- to northeastward-striking premineralization faults that probably were instrumental in localizing ore (pl. 8).

Flat-lying fractures localize ore between major steep faults 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 northward-striking faults that dip mostly 30° to 65° W., although a few 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 (a) Ore and sulfide minerals and (b) Gangue minerals. The supergene minerals are subdivided into minerals in the sulfide zone and those in the oxide 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 writers are listed and credit or reference for the identification is given 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	$CuFeS_2$
Clausthalite	$PbSe$
Enargite(?)	Cu_3AsS_4
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	$(Cu,Fe)_{12}Sb_4S_{13}$-$(Cu,Fe)_{12}As_4S_{13}$
Gangue minerals:	
Barite	$BaSO_4$
Calcite	$CaCO_3$
Chalcedony	SiO_2
Deweylite	$Mg_4Si_3O_{10}\cdot 6H_2O$
Diopside	$CaMgSi_2O_6$
Fluorite	CaF_2
Garnet sp (andradite)	$Ca_3(Al,Fe)_2Si_3O_{12}$
Idocrase	$Ca_{10}(Mg,Fe)_2(OH)_2Al_4Si_9O_{34}(OH)_2$
Jasper	SiO_2
Montmorillonite	$(Al,Mg)_8(Si_4O_{10})_3\cdot(OH)_{10}\cdot 12H_2O$
Orthoclase	$KAlSi_3O_8$
Quartz	SiO_2
Sericite	$(H,K)AlSiO_4$
Wollastonite	$CaSiO_3$

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	$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$
Azurite	$Cu_3(OH)_2(CO_3)_2$
Bindheimite	$Pb_2Sb_2O_6(O,OH)$
Bismutite	$(BiO)_2(CO_3)$
Brochantite	$Cu_4(SO_4)(OH)_6$
Caledonite	$Cu_2Pb_5(SO_4)_3(CO_3)(OH)_6$
Cerargyrite	AgCl
Cerussite	$PbCO_3$
Chalcanthite	$CuSO_4 \cdot 5H_2O$
Chrysocolla	$CuSiO_3 \cdot 2H_2O$
Creedite	$Ca_3Al_2F_4(OH,F)_6(SO_4) \cdot 2H_2O$
Crocoite	$PbCrO_4$
Cuprite	Cu_2O
Goslarite	$ZnSO_4 \cdot 7H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$
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	$FeSO_4 \cdot 7H_2O$
Mimetite	$(PbCl)Pb_4(AsO_4)_3$
Plumbojarosite	$PbFe_6(SO_4)_4(OH)_{12}$
Pseudomalachite	$Cu_{10}(PO_4)_4(OH)_8 \cdot 2H_2O$
Pyrolusite	MnO_2
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	$Fe_3P_2O_8 \cdot 8H_2O$
Wulfenite	$PbMO_4$

HYPOGENE MINERALS

ORE AND SULFIDE MINERALS

Andorite ($PbAgSb_3S_6$).—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 generally less than 2 mm long that are conspicuously striated. In polished section the color of the andorite 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. 26). Andorite(?) has been provisionally identified by Milton (written communication, 1954) from the Round Valley mine in the Bishop district, Inyo County.

Arsenopyrite (FeAsS).—Small amounts of arsenopyrite occur in the ore at the Darwin and Santa Rosa mines. 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(?) (Bi).—Assays and spectrographic analysis show bismuth minerals to be present in the Darwin ores, but the mineralogy is not well known. Steel galena from the Essex workings gives distinct bismuth peaks on the X-ray spectrometer. Minute white, strongly anisotropic inclusions in the galena and in andorite may be native bismuth.

Bismuthinite (Bi_2S_3).—Bismuthinite associated with scheelite was identified at the north end of the Durham ore body near the Fernando fault (fig. 2, 2A). The mineral is mostly altered to bismutite. The bismuthinite is in bladed masses as much as 1 inch long that are coated with powdery green bismutite.

Bornite (Cu_5FeS_4).—Small amounts of bornite are 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 (fig. 27).

Chalcopyrite ($CuFeS_2$).—Most lead-silver-zinc deposits contain small amounts of chalcopyrite; it is the principal mineral in copper prospects on the east side of the Darwin Hills. Chalcopyrite occurs as minute blebs in sphalerite that undoubtedly formed by exsolution, and commonly occurs with pyrite and pyrrhotite in the Darwin mine (fig. 28).

Clausthalite (PbSe).—Clausthalite was identified by x-ray diffraction pattern in a "galena" from the Darwin mine that contained 7.8 percent selenium, 6.13 percent silver, 20.67 percent bismuth, and 2.4 percent tellurium. Clausthalite and matildite had exsolved from the "galena", but a homogeneous galena solid solution was formed by heating at 500°C for 5 hours.

Enargite(?).—(Cu_3AsS_4)—Enargite(?) was identified by Charles Milton (written communication, 1954) from specimens of silver-rich ore from the 534 stope of the Thompson workings of the Darwin mine.

Galena (PbS).—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-grained galena in the Defiance workings of the Darwin mine has warped cleav-

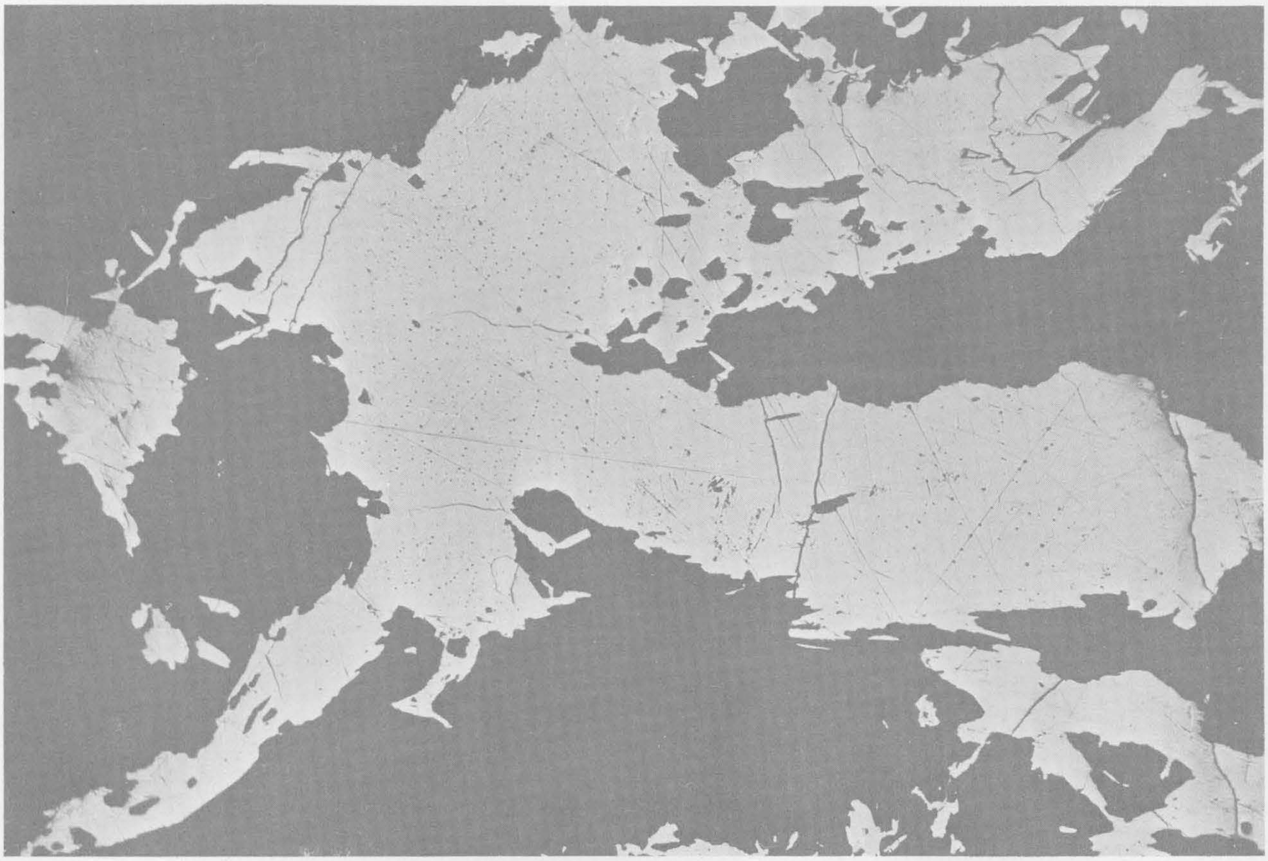
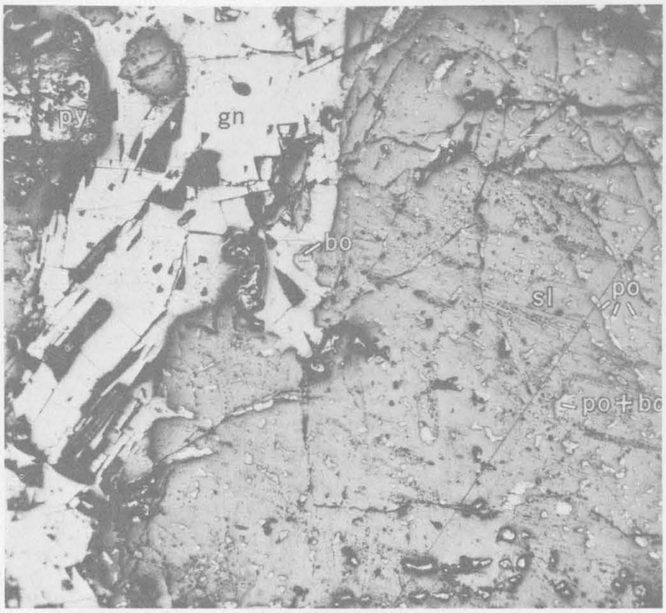


FIGURE 26.—Photomicrograph of andorite that contains inclusions of bismuth (?). Specimen from the 437 stope of the Thompson workings, of the Darwin mine. Plane polarized light, 60 ×.



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 polarized light, 40 ×.

B. Some of the pyrrhotite inclusions have rims of bornite (bo). Plane polarized light, 250 ×.

FIGURE 27.—PHOTOMICROGRAPHS OF SPHALERITE (SL) FROM THE THOMPSON WORKINGS OF THE DARWIN MINE.

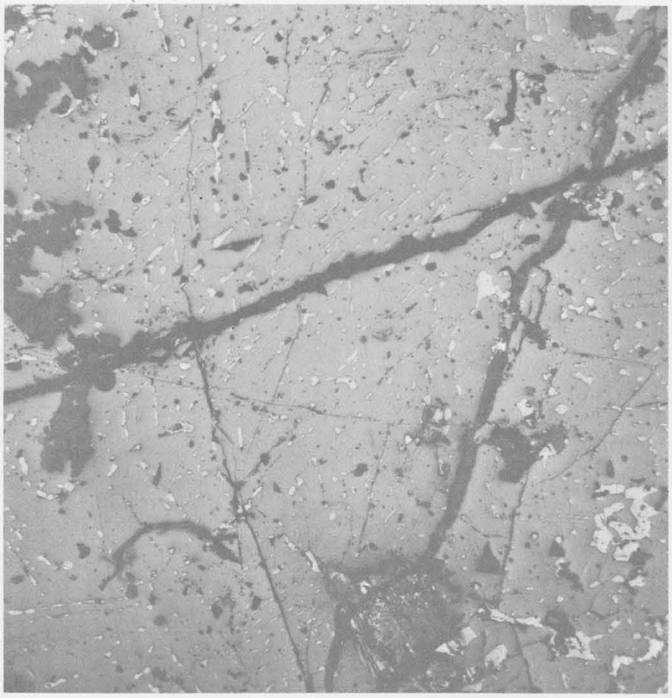


FIGURE 28.—Exsolution pattern of chalcopyrite (light) in sphalerite (medium gray) from the Darwin mine. Chalcopyrite occurs as oriented segregation veinlets and blebs in the sphalerite. Plane polarized light, 40 ×.

age 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.

The galena is all argentiferous, and chemical analyses show that some of it contains appreciable amounts of bismuth, selenium, and tellurium (Hall, 1959, p. 940). Analyses of 12 galena samples from the Darwin mine are given in table 6.

In general, selenium, silver, and bismuth are most abundant in galena from ore bodies in the northern part of the Darwin mine area in the Essex and Thompson workings (pl. 3). Minute inclusions of matildite ($AgBiS_2$) were identified by X-ray diffraction pattern in the last three galena samples listed in table 6. A mineral count was made of matildite in the galena containing 2.11 percent selenium, 3.79 percent silver, and 7.86 percent bismuth. This galena contains 1.8 percent microscopic inclusions of matildite, which account only for about 20 percent of the silver and bismuth. The rest of the silver and bismuth is either in solid solution in the galena or is in inclusions too small to be seen under the microscope. The "galena" containing 7.8 percent selenium, 6.13 percent silver, 20.67 percent bismuth, and 2.4 percent tellurium is a mixture of 3 phases—galena, clausthalite (PbSe), and matildite. The identification is based on X-ray-defraction pattern, polished-section study, and on chemical analysis. Megascopically this "galena" looks like a sulfosalt and is the mineral listed by Hall and MacKevett (1958, p. 16) as an unknown lead-bismuth-selenium sulfosalt. It forms thin tabular crystals as much as 1 centimeter long that are commonly warped and are conspicuously striated parallel to its long dimension. By heating the "galena" with 3 phases for 5 hours at 500°C and quenching in water, a homogeneous galena was obtained. It is evident that the three phases—galena, matildite, and clausthalite in what megascopically looks like one mineral—originally crystallized at a high temperature as a homogeneous galena but included abundant bismuth, selenium, tellurium, and silver in solid solution and exsolved into three phases on cooling.

TABLE 6.—*Analyses of bismuth, selenium, and silver in galena from the Darwin mine*[1]

Name of workings	Location of sample (level)	Selenium (percent)	Silver (percent)	Bismuth (percent)	Unit cell (pure galena= 5.936A)
Defiance	1200	0.018	0.14	0.48	5.9313±.001
Do	570	.025	.12	.080	5.9307
Do	400	.030	.12	.06	5.9298
Thompson	700	.0088	.26	<.004	5.9387
Do	700	.39	.76	.26	------
Do	700	1.16	.018	.018	5.9452
Do	500	.011	.046	.035	5.9422
Do	500	.74	.058	<.004	5.9440
Do	3A	.39	.11	.16	5.9350
Essex	200	1.24	2.47	4.65	5.9146
Do	200	2.11	3.79	7.86	5.923
Thompson	400	[2] 7.8	6.13	20.67	5.88

[1] Analyst, S. M. Berthold, Joseph Budinsky, Esma Campbell, M. K. Carron, and Janet D. Fletcher.
[2] In addition there is 2.4 percent tellurium in this galena.

Guanajuatite (?) (Bi_2Se_3).—Spectrographic and chemical analyses show that both bismuth and selenium are present in andorite and in some of the galena from the Thompson and Essex workings of the Darwin mine. Both minerals contain minute blebs that are white in polished section and have strong anisotropism and may be guanajuatite.

Matildite ($AgBiS_2$).—Tiny oriented lamellar inclusions of matildite are intergrown with galena in ore from the Essex vein of the Darwin mine. The lamellae are gelena white in polished section and are moderately anisotropic. They are not visible in plane polarized light, but are readily seen under crossed nicols or when the section is etched with nitric acid (fig. 29). The identification is based on similarity to matildite described by Palache, Berman, Frondel (1944, p. 429) and by Edwards (1954, p. 111), on X-ray-defraction pattern, and on chemical analyses of galena showing the presence of silver and bismuth. The lamellae probably formed by exsolution from a bismuthian and argentian galena stable at high temperature, as the matildite readily goes into solid solution in the galena when heated at 500°C.

FIGURE 29.—Galena (gn) and its alteration product cerussite (ce) with elongate inclusions of matildite ($AgBiS_2$) (ma). The polished section is etched with nitric acid to show the matildite, as the inclusions are not visible in plane polarized light in unetched specimens. Specimen from the Essex workings of the Darwin mine. Crossed nicols, 50 ×.

Pyrite (FeS_2).—Pyrite is abundant in all the lead-zinc deposits in the Darwin district and at the Santa Rosa mine, but it is a 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 the calc-hornfels near the Darwin mine. It occurs both as cubes and pyritohedrons as much as 1 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.

Pyrrhotite ($Fe_{1-x}S$).—Pyrrhotite is common in the primary ore in the Darwin mine; it commonly forms a banded ore. It replaces pyrite but is replaced by sphalerite, galena, and chalcopyrite. It also forms irregular blebs oriented along cleavage in sphalerite and probably formed by exsolution (fig. 27).

Scheelite ($CaWO_3$).—Scheelite is common in the lead-silver-zinc ore bodies in the Darwin district and as discrete tungsten ore bodies that contain 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 3/8 to 1/2 inch in diameter are embedded in fine-grained galena. In the oxided zone the scheelite is loosely embedded in a crumbly mass of cerussite, limonite, and jarosite.

Sphalerite (ZnS).—Sphalerite is present in about equal quantities as galena in most of the primary ore in the deeper ore bodies being mined at the Darwin mine in 1956, 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-hornfels and tactite 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 as the FeS content increases. The dark iron-rich sphalerites formed at a higher temperature than the light-colored sphalerite. Iron analyses of 20 sphalerites and their significance are given on page 69.

Stannite (Cu_2FeSnS_4).—Stannite was identified by Charles Milton (written communication, 1954) from silver-rich ore containing matildite and galena from the Thompson workings of the Darwin mine.

Tetrahedrite-tennantite ($(Cu,Fe)_{12}Sb_4S_{13}$–$(Cu,Fe)_{12}As_4S_{13}$).—Small amounts of tetrahedrite or tennantite are in galena in the Darwin mine. The mineral is most commonly near the border of galena in grains too small to determine whether arsenic or antimony is predominant (fig. 31). Kelley (1938, p. 544) reports tennantite in the ore, and Carlisle and others (1954, p. 46) report tetrahedrite.

GANGUE MINERALS

Barite ($BaSO_4$).—Barite is one of the predominant gangue minerals at the Lee mine and the Silver Reid prospect. It was not identified in ore from the Darwin or Zinc Hill districts.

Calcite ($CaCO_3$).—Calcite is one of the predominant gangue minerals in most of the lead-silver-zinc deposits in the Darwin district. It is abundant at the Custer mine, the Defiance workings of the Darwin mine, and at the Darwin Iceland Spar prospect. It ranges in color from milky white to brownish gray, and rhombohedrons as much as 18 inches on a side are common. Calcite also occurs as an interstitial mineral in the calc-hornfels and as late veinlets that cut the ore.

Chalcedony (SiO_2).—Chalcedony is a common gangue mineral at the Santa Rosa mine. It forms light-tan to light-gray cryptocrystalline masses in the veins associated with ore minerals.

Deweylite ($Mg_4Si_3O_{10} \cdot 6H_2O$).—Deweylite was identified from the 570 level of the Defiance workings. The identification was based on an X-ray study 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.

Diopside ($CaMgSi_2O_6$).—Diopside is a common gangue mineral in the replacement lead-silver-zinc ore bodies in the Darwin mine and it is a major constituent of the calc-silicate country rock.

Fluorite (CaF_2).—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. *andradite* ($Ca_3(Al,Fe)_2Si_3O_{12}$).—Garnet is a characteristic gangue mineral in the lead-silver 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 near the andradite end of the grossularite-andradite series.

Idocrase ($Ca_{10}(Mg,Fe)_2(OH)_2Al_4Si_9O_{34}(OH)_2$).—Fine- to medium-grained idocrase is common in the lead-silver-zinc deposits in the Darwin district, and it is abundant in calc-silicate rock. It occurs 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 (SiO_2).—Jasper is a common gangue mineral in the veins at the Santa Rosa mine and in the veins that trend N. 70° E. in the Darwin district.

Montmorillonite ($(Al,Mg)_8(Si_4O_{10})_3 \cdot (OH)_{10} \cdot 12H_2O$).—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.

Orthoclase ($KAlSi_3O_8$).—Orthoclase is abundant locally in the replacement ore in the Darwin mine, and it is present in coarse-grained masses near intrusive contacts southwest of the Defiance workings.

Quartz (SiO_2).—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 ($(H,K)AlSiO_4$).—Sericite is a common alteration product along fault zones in the Darwin mine. Plumbojarosite is commonly associated with it.

Wollastonite ($CaSiO_3$).—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. The minerals were identified in specimens kindly given to the writers by The Anaconda Co. or in specimens collected from dumps. Specimens of low-grade oxidized ore were collected in the Darwin and Santa Rosa mines. The occurrences of the supergene minerals are not well known and, therefore, the writers have not described each mineral separately as they have with the primary minerals.

SULFIDE ZONE

Very little supergene enriched ore remains in the ore deposits 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 of the minerals replace the primary ore minerals. Some of the high-grade oxidized silver ore contains sooty argentite. 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 working on the 920 level. At the Darwin mine the ore is largely oxidized to the 400 level, and both primary and secondary minerals are present to the deepest level (in 1955)—the 1100 level of the Defiance workings.

Cerussite, the principal secondary lead mineral, forms radial aggregates of euhedral crystals as much as 1-inch long that rest upon porous finer grained masses of limonite, cerussite and other oxidized lead minerals. The larger crystals are white and have a vitreous luster; the smaller crystals are yellowish or brownish owing to surface coatings of iron oxides. Anglesite, crocoite, mimetite, plumbojarosite, pyromorphite, 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 writers. Leadhillite was questionably 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 Darwin mines, and Santa

Rosa, and formerly both linarite and caledonite were common ore minerals from Darwin. Antlerite, aurichalcite, azurite, brochantite, chalcanthite, chrysocolla, cuprite, malachite, and tenorite were also identified. Pseudomalachite has been reported by Woodhouse (*in* Murdoch and Webb, 1956, p. 260).

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, cerargryite, 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 (*in* Murdoch and Webb, 1956, p. 343). Goslarite and melanterite are in some of the workings in the Darwin mine. Bismutite was observed in the Fernando mine as coatings on bismuthinite crystals, but it may have been in the oxidized ore from the Essex vein of the Darwin mine as this vein contained a large amount of bismuth.

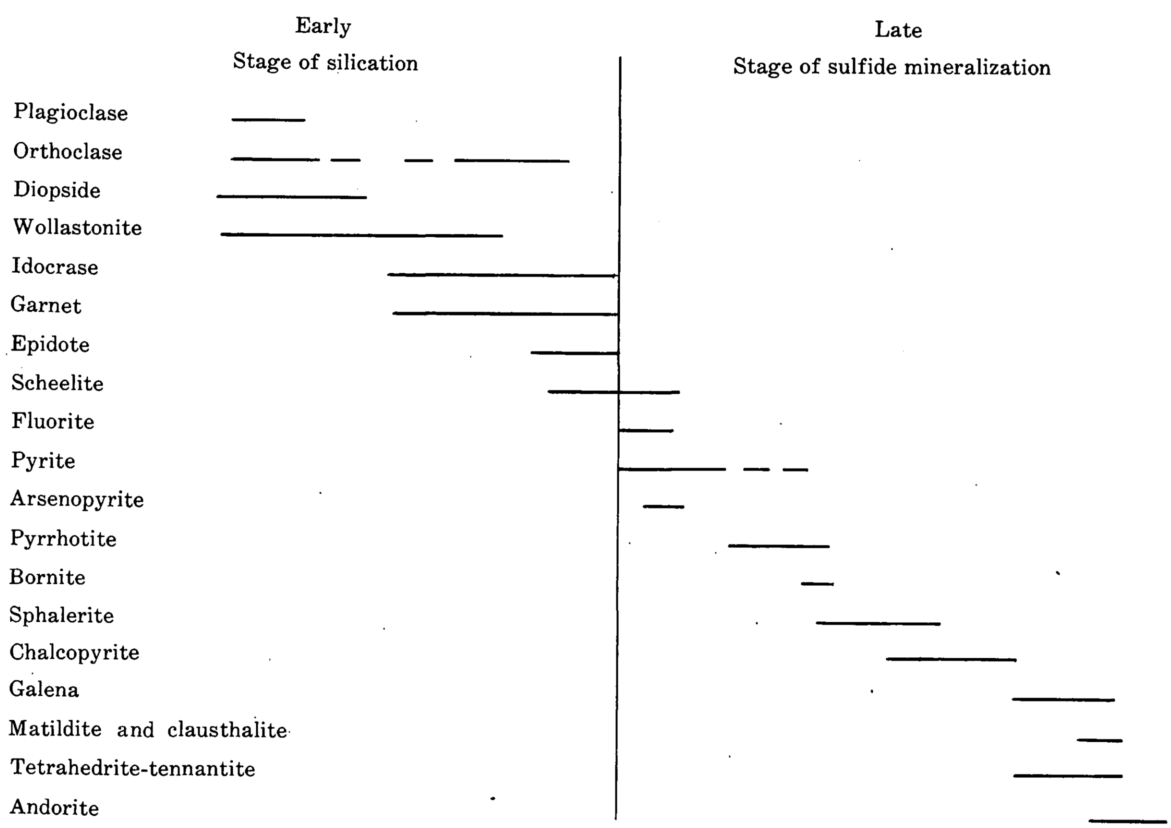
Hemimorphite is the predominant secondary mineral in the oxidized zinc ore at the Zinc Hill and Lee mines. It has a mammillary habit, and the color ranges from colorless to white, pink, green, gray, or brown. The local pink color at the Zinc Hill mine is due to a thin coating of hematite. Hydrozincite 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 occurs in small pockets in oxidized ore in the Zinc Hill district, but none was found in the Darwin district.

PARAGENESIS

The paragenesis of the principal ore and gangue minerals is shown diagramatically in table 7. 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 first altered to dense, aphanitic calc-hornfels. The composition of the calc-hornfels de-

TABLE 7.—*Paragenesis of principal primary ore and gangue minerals*



pended upon the purity of the original limestone. Impure limestones recrystallized to a very fine grained rock containing orthoclase, oligoclase, diopside, and quartz. Purer limestones were altered to fine-grained wollastonite-diopside calc-hornfels (fig. 19). Silica was added and carbon dioxide lost by this alteration. As the intensity of alteration increased, 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. 22). Locally orthoclase replaces calc-silicate rock (figs. 24, 25).

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 and idocrase (fig. 23) and is later than scheelite as shown by its veining of filling between euhedral scheelite crystals in scheelite ore from the Thompson workings. Pyrite occurs as corroded relicts or is veined by all the other sulfide minerals. It is corroded by pyrrhotite (fig. 30) but apparently is contemporaneous with rare arsenopyrite. Sphalerite, chalcopyrite, and galena contain corroded relicts of pyrite (fig. 31). Pyrrhotite contains corroded relicts of pyrite (fig. 30), and occurs as oriented blebs in sphalerite (fig. 27*A*). Bornite forms thin borders on some pyrrhotite blebs (fig. 27*B*). Chalcopyrite occurs mainly as oriented inclusions in sphalerite. Sphalerite and chalcopyrite are replaced by galena (figs. 31, 32), but galena and tetrahedrite-tennantite show mutual boundaries and are contemporaneous. Matildite occurs only as oriented laths within galena, possibly exsolved from it (fig. 29). Clausthalite also exsolved from galena.

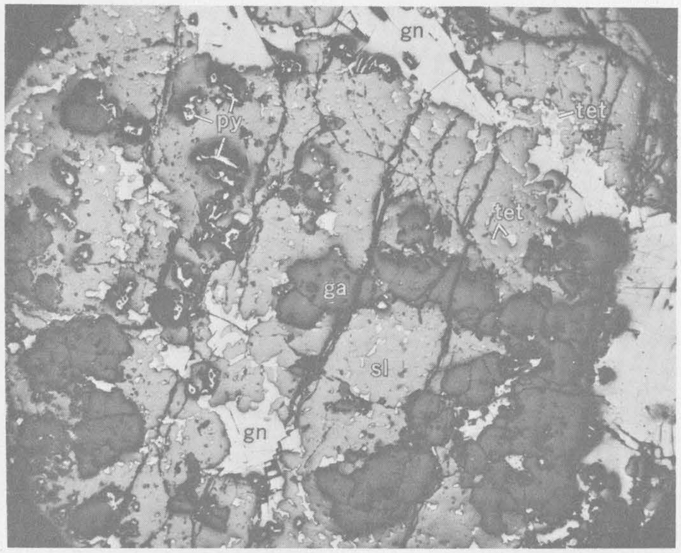


FIGURE 31.—Photomicrograph of zinc-rich ore from the Darwin mine showing replacement of garnet (ga) by sulfide ore. Partly corroded garnet occurs as relicts in a groundmass of galena (gn), sphalerite (sl) pyrite (py), and minor tetrahedrite (tet). Pyrite is the earliest sulfide mineral as it is in corroded relicts in sphalerite and galena. Sphalerite is veined and corroded by galena. Galena and tetrahedrite have a mutual pattern and are contemporaneous. Plane polarized light, 40 ×.

The relative ages of andorite and galena are not known definitely but andorite is probably younger. Small galena ore bodies show a primary zoning with galena and sphalerite in the center and andorite and galena with abundant bismuth, selenium, and silver on

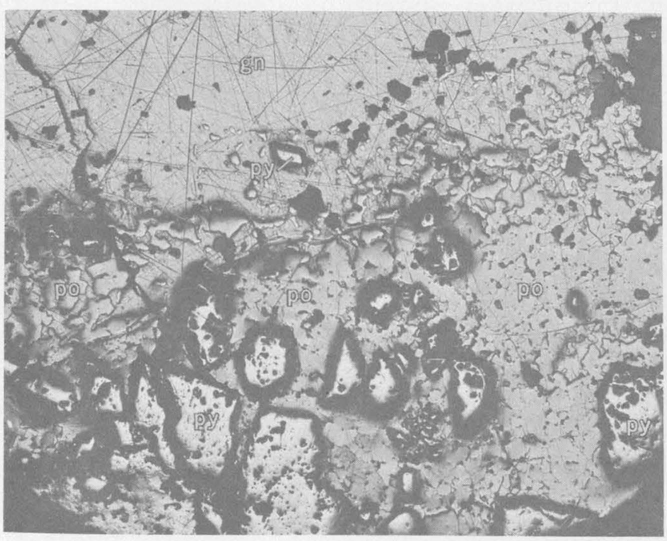


FIGURE 30.—Photomicrograph of ore from the Darwin mine. Pyrite (py) occurs as corroded relicts in pyrrhotite (po) and galena (gn). Pyrrhotite is corroded by and occurs as relicts in galena. Plane polarized light, 44 ×.

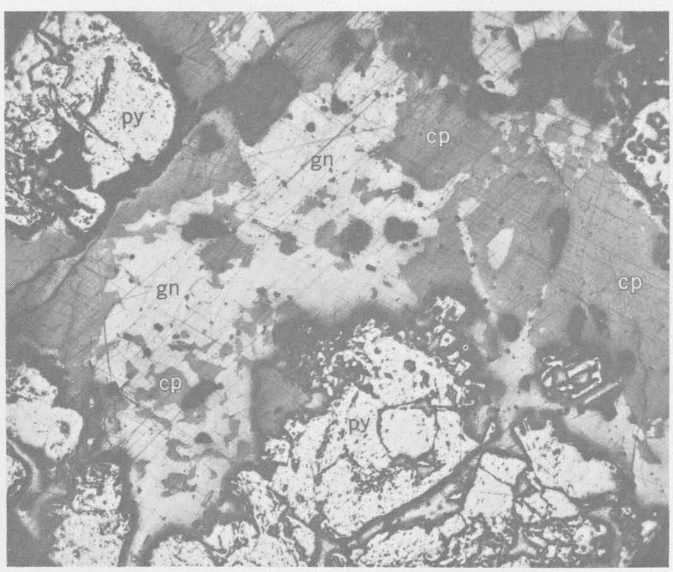


FIGURE 32.—Photomicrograph of ore from the Darwin mine. The paragenesis is pyrite (py), chalcopyrite (cp), and galena (gn). Pyrite is corroded by and occurs as relicts in chalcopyrite and galena and the chalcopyrite in turn occurs as irregular relicts in galena. Plane polarized light, 40 ×.

the borders. On the nebulous basis of this zoning andorite is considered the younger.

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 (pl. 3). The near-surface primary ore in the bedded deposits 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 steep pipelike Defiance ore body in the vicinity of the 400 level consisted predominantly of galena that contained less silver than the bedded deposits. Some sphalerite is present in this ore. With increasing depth in the pipelike ore body the ratio of zinc to lead increases and the silver content decreases slightly. Pyrite markedly increases in the deeper levels of the mine, and chalcopyrite locally is abundant. The gangue minerals are predominantly garnet, wollastonite, and calcite. It must be emphasized, however, that many local variations occur 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.

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 the stock of biotite-hornblende-quartz monzonite (pl. 1; fig. 3). Lead-silver ore is found along the same fault 450 feet farther from the stock than scheelite, although it is close to a small satellitic intrusion. Similarly the scheelite ore at the St. Charles No. 3 workings is close to the biotite-hornblende-quartz monzonite and the lead-silver ore on one of the same fractures at the Custer mine is farther from the intrusive contact. In Lane Canyon, scheelite in calc-silicate rock along the crest of an anticline is 450 feet from the intrusive contact but silver-lead ore at the Lane and Santa Ana mines to the east is even farther from the intrusion.

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, whereas the lead-silver ore with no scheelite is in a bedding plane fault at the footwall contact of the 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 deep except where local conditions restrict the circulation of groundwater, and oxidized ore is known to a depth of more than 1,000 feet. All 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 deepest level on the 920 level. In the Darwin mine most ore below the 570 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 (the 1,100 level in 1955). On the other hand, sills have restricted the circulation of groundwater in the Darwin mine, 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 in the Zinc Hill district. 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 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 area 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 much richer in lead and silver. Complete smelter returns of the New Coso Mining Co. 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 by the writers consist predominantly of cerussite, relict galena, and small amounts of 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 when oxidized, 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 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 virtually in place. Sphalerite was attacked by the ground water, 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 is in limestone and contains little pyrite, apparently was done by ground water that contained no free acid, and the stability relationships of the supergene minerals are different from those prevailing at Darwin where oxidation was done by acid ground water. The stable zinc mineral, hemimorphite, forms high-grade zinc-rich ore bodies virtually in place. The silver mineral is 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.

The oxidized ore at the Lee mine consists mainly of hemimorphite, chalcedony, bindheimite, cerargyrite, and relict galena. Cerussite and anglesite are in thin bands surrounding relict galena, and very little is present in the cellular oxide ore admixed with hemimorphite (fig. 33). Evidence indicates that under the environment prevailing at the Lee mine that hemimorphite and cerargyrite are stable minerals and formed virtually in place. Very little sphalerite is found in the ore as it is unstable and readily alters to hemimorphite whereas galena is less readily altered and remains as corroded relicts.

Similarly at the Zinc Hill mine the supergene ore consists predominantly of hemimorphite. The Zinc

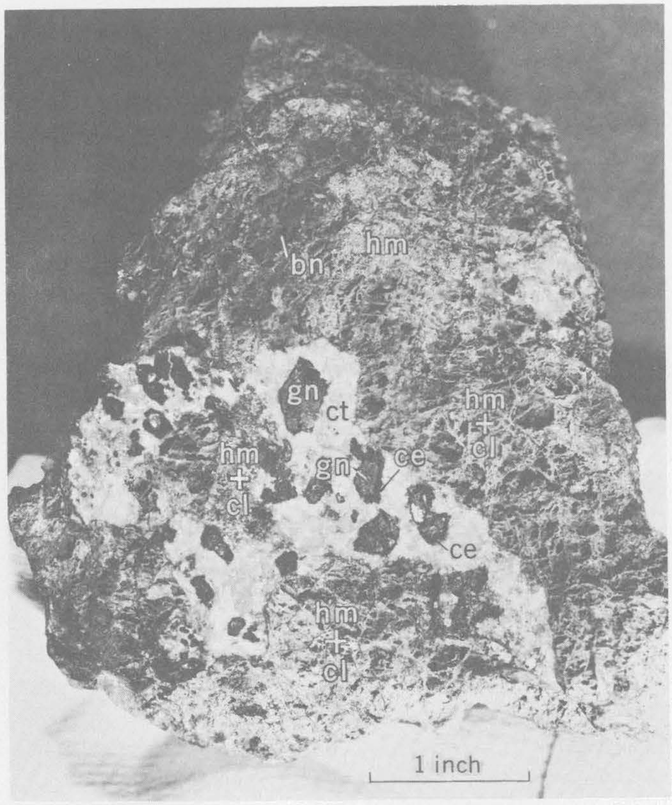


FIGURE 33.—Photograph of partly oxidized ore from the Lee mine. Galena (gn) and calcite (ct) occur as relicts in a cellular mass of hemimorphite (hm), chalcedony (cl), bindheimite (bn) $[Pb_2Sb_2O_6(O,OH)]$, and cerargyrite listed in order of decreasing abundance. Cerargyrite is present locally in vugs in hemimorphite but cannot be distinguished in the photograph. Cerussite (ce) and anglesite are limited to a thin rim about galena.

Hill ore differs from that at the Lee mine; it has a low content of silver. The primary ore from the upper ore body at Zinc Hill averaged 22.28 percent zinc, 1.33 percent lead, and 1.43 ounces of silver per ton (Hall and MacKevett, 1958). Oxide ore from the same ore body averaged 36.9 percent zinc, but the lead and silver content of the ore is not known. Oxide ore that was mined from 1917 to 1920 averaged approximately 45 percent zinc, 1 percent lead, 3 ounces of silver per ton, and 1½ percent iron, but this ore came from different ore bodies and no primary ore remains. Hemimorphite is the principal supergene mineral in all the oxidized ore bodies. It formed virtually in place as the oxide ore has the same structural control as the primary ore and relict galena remains in most places. Hydrozincite and smithsonite are also present. Hydrozincite is mainly concentrated near the borders and the bottom of the flat-lying ore bodies. Smithsonite is rare, but is found in thin veinlets beneath the ore bodies and was transported farther than the other supergene zinc minerals. Cerussite and anglesite occur only in small quantities.

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 Darwin district lead-silver-zinc deposits were considered by Knopf (1914, p. 7) to range from contact metamorphic deposits 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 writers, however, agree with Knopf that the deposits were deposited throughout 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 writers believe 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 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 minerals. The early formed lead-zinc ore bodies are replacement ore bodies that have mainly a silicate gangue, as the pipelike vertical replacement ore body in the Defiance workings (pl. 3). With falling temperature the hydrothermal solutions apparently became less reactive, and the resultant mesothermal deposits filled fissures. 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 (pl. 3; fig. 3).

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 a little 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 or not 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, 20 samples of sphalerite were analyzed for the iron sulfide content, which might be used as a temperature indicator as shown by Kullerud (1953) and as applied by Fryklund and Fletcher (1956) to sphalerite from the Star mine in the Coeur d'Alene district. Kullerud (1953) has shown that under equilibrium conditions with pyrrhotite the amount of iron sulfide in sphalerite is a function of temperature, and can be used as a geologic thermometer. Sphalerite deposited in equilibrium only with pyrite is not a useful geologic thermometer as shown by Barton and Kullerud (1958, p. 228), because sphalerite with a definite percentage of iron sulfide formed in equilibrium with pyrite can be deposited under a large range in temperature. Much of the sphalerite in the Darwin quadrangle is deposited in equilibrium only with pyrite.

Sphalerite deposited in equilibrium with pyrite in the Darwin quadrangle has an iron sulfide content of 0.24 to 6.98 molecular percent (table 8). This sphalerite may be deposited from less than 200°C to about 600°C (Barton and Kullerud, 1958, p. 228). The lowest iron sulfide content of sphalerite is 0.24 molecular percent from colorless sphalerite from the Lee Mine. The lead-silver-zinc ore is in unaltered fine-grained limestone, and the temperature of deposition was probably less than 125°C.

TABLE 8.—ZnS-FeS *content of sphalerites from the Darwin quadrangle*

Sample No.	Mine	Level	Mole percent [1] FeS	Mineral association	Indicated temperature of deposition
Dsl-1	Lee		0.24	Calcite, barite, galena.	Not determinate.
Dsl-2	Zinc Hill		.74	Calcite	Do.
Dsl-3	Santa Rosa		6.46	Pyrite, galena, jasper.	Do.
2	Defiance workings, Darwin mine.	1,100	[3] 6.4	Pyrite, galena, diopside.	Do.
4	do	1,100	6.98	Pyrite, garnet, diopside.	Do.
5	Defiance workings.	1,000	[3] 3.4	Pyrite, galena, calcite.	Do.
6	do	1,000	3.92	Pyrite, diopside, garnet.	Do.
7	do	1,000	4.83	Pyrite, galena	Do.
10	do	900	6.25	Pyrite, diopside, garnet.	Do.
14	do	800	5.09	do	Do.
15	do	700	[3] 4.6	Pyrite, galena	Do.
23	do	250	5.44	Pyrite, diopside, garnet.	Do.
3479	Thompson workings, Darwin mine.	200	7.88	Pyrrhotite, pyrite, galena.	285°C.
3481	do	100	3.90	Pyrite, calcite, diopside.	Not determinate.
3482	do	3A	[3] 8.7	Pyrrhotite, galena	320°C.
3483	do	3A	2.45	Pyrite, calcite, diopside.	Not determinate.
3489	do	700	[2,3] 20.	Magnetite, pyrrhotite, galena, pyrite.	560°C.
3491	do	600	[2] 14.2	Pyrrhotite, pyrite, galena.	480°C.
3505	do	700	[2,3] 19.6	Pyrrhotite, pyrite, galena, magnetite.	560°C.
3508	do	600	[2] 17.5	Pyrrhotite, magnetite, pyrite, galena, garnet, tetrahedrite.	520°C.

[1] Analyst: L. E. Reichen.
[2] Contains exsolution blebs of pyrrhotite.
[3] Analyzed by H. G. Stephens and W. E. Hall by fluorescent X-ray spectrographic analysis.

Six samples of sphalerite from the Defiance workings of the Darwin mine contained 3.92 to 6.98 molecular percent iron sulfide. The sphalerite in the Defiance replacement ore body was deposited in equilibrium with pyrite, and no pyrrhotite is present. This sphalerite could be deposited at a temperature between approximately 500° and 650°C (Barton and Kullerud, 1958, p. 228).

Much of the sphalerite in the Thompson and Essex workings of the Darwin mine was deposited in equilibrium with pyrrhotite and can be used as a geologic thermometer. Some of the sphalerite has oriented pyrrhotite blebs as shown in figure 27, and this is interpreted as an exsolution texture. Two samples of sphalerite from the 700 level of the Essex and Thompson workings contained 19.6 and 20 molecular percent iron sulfide. Two samples 100 feet higher on the 600 level contained 14.2 and 17.5 molecular percent iron sulfide. A sample 447 feet higher in the Thompson workings contained 7.88 molecular percent iron sulfide.

The range in temperature indicated by the range from 7.88 to 20 molecular percent iron sulfide is about 300°C in the upper part of the Thompson mine to 550°C on the 700 level. The iron sulfide content of the sphalerite in the Thompson and Essex workings indicates that the ore in the Darwin mine was deposited under a considerable range in temperature. However most of the sphalerite in the mine is deposited in equilibrium with pyrite, and not enough is deposited in equilibrium with pyrrhotite to get a good idea of the range in temperature for the whole mine. The temperatures indicated by the sphalerite confirm Knoff's (1914) early statements that the Darwin ores were deposited under a considerable range in temperature, and the deposits should be classified as contact metasomatic ranging to mesothermal.

Description of pyrometasomatic lead-silver-zinc deposits are not abundant 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, N. Mex., the Sirena mine near Zimapán, Mexico, and the Darwin district. More recently Simons and Mapes (1956) have described the deposits of the Zimapán district which, like the Darwin deposits, grade from pyrometasomatic replacement deposits in a silicate gangue to mesothermal deposits in a carbonate gangue. Jasper 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 Zimapán 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 Zimapán, 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 organized New Coso mining district. The district has produced an estimated $29 million in lead, silver, zinc, and minor copper. Most of the ore came from the Darwin mine, which consists of consolidation 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 siltstone that ranges in age from Devonian on the west side of the Darwin Hills to Permian on the east (pls. 1, 3). 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 a stock of biotite-hornblende-quartz monzonite in the central part of the district and in the Coso Range. The Paleozoic rocks dip predominantly to the west except for local folds. Within 4,000 feet of the stock of the Darwin Hills the sedimentary rocks are mostly metamorphosed to calc-hornfels. A description of the unaltered rocks is given under "Paleozoic rocks," and the alteration is described under "Metamorphism."

STRUCTURE

Structurally the Darwin Hills are an overturned syncline with an axial plane that dips about 50° W. A stock of biotite-hornblende-quartz monzonite intruded Paleozoic rocks near the axis of the syncline. The Paleozoic rocks west of the stock strike northward and dip mainly 30° to 70° W. in an overturned section on the west limb of the major syncline.

Small open folds are superposed on the overturned limb of the syncline, and these folds localize some of the principal ore bodies in the Darwin mine. The folds are all inverted structures. One is on the west flank of Ophir Mountain and can readily be seen from the Darwin mining camp. Similar inverted folds are between the Defiance and Bernon workings, in the Independence workings, and on the west side of the Darwin Hills adjacent to the Darwin mining camp.

The Paleozoic rocks in the Darwin district are broken by four sets of faults. The strongest set is left-lateral strike-slip faults that strike N. 70° W. and dip steeply (pls. 1, 3). Examples are the Darwin tear fault and the Standard fault. Another set of left-lateral strike-slip faults strikes N. 70° E. and dips steeply. These faults are the feeder fissures for the lead-silver-zinc and for the tungsten deposits of the Darwin district. The horizontal displacement is shown by offset of beds, axial planes of folds, and by abundant nearly horizontal slickensides and mullion structures.

The other two sets of faults strike north. One set dips steeply and the other dips 30° to 55° W. The steep faults have little displacement but are important in localizing ore in some of the mines. The west-dipping faults include both thrust faults and normal faults. The most important is the Davis thrust, which is exposed along the side of the hill above the Independence, Essex, and Bernon workings and at the water tanks near the Water tank fault (pl. 3). The net slip is not known. The Ophir fault is parallel to, but west of, the Davis thrust. It is a bedding-plane fault that probably has little displacement.

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, the 430 stope ore body and Blue and Red veins in the Defiance workings, 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 levels along the crest of an anticlinal-shaped fold between two quartz monzonite sills, and directly below the Davis thrust (pl. 3). This ore zone is 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 this zone is not all ore. Individual stopes within the zone have maximum dimensions of about 140 feet in length, 60 feet in width, and 40 feet in height. The contacts of individual ore bodies in this ore zone are mostly sharp, and only barren calc-hornfels or highly pyritized calc-hornfels 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. 3). The bedded veins are along the crest and west limb of an anticlinal-shaped (inverted syncline) fold between two sills of quartz diorite (pl. 3). 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 downdip. 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 downdip. The contacts of the veins and pyritized calc-hornfels country rock are sharp. The grade of ore within the veins, however, is erratic.

The ore body mined from the 430 and 520–12 stopes is another important bedded deposit in the Defiance mine (pl. 4). The ore body was about 150 feet long, 40 feet thick, and extended about 360 feet downdip. The shape, nature of the ore, and method of mining of this ore body is described in detail by Davis and Peterson (1948, p. 3–6). It extended from the 110 to the 520 level. Below the 520 level the ore occurs as a steep irregular replacement of calc-silicate rock.

The only important irregular replacement ore zone in the Darwin district is in the Defiance workings adjacent to the Defiance fault (pl. 3). It is a vertical mineralized zone that has been developed from the bottom of the bedded ore bodies at the 520 level to the 1000 level. The average cross sectional area of the mineralized zone is about 350 feet long and 200 feet wide. On the 700 level 12 percent of an area 400 feet long and 130 feet wide is ore, and on the 800 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 premineralized Defiance fault, which strikes northeast and dips steeply to the northwest, cuts diagonally through the mineralized area, and many 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. faults, steep N. 70° W. faults, and steep north-striking faults. The most notable N. 70° E. 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 (pl. 5). The ore shoot has a strike length of 160 feet and an average thickness of 3 feet; it plunges steeply southwestward. 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 (pl. 5). Other smaller northeastward-striking veins are the 229 and 235 ore bodies in the Thompson workings, ore bodies along the Mickey Summers and Water tank faults (pl. 3) and the Lane vein in the Lane mine (fig. 3).

The only economically important steep northwest-striking vein is the Essex vein in the Darwin mine (pl. 3). This high-grade vein 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 northwestward-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-hornfels 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 in August 1954. About 400 residual soil samples were collected on a grid at 50-foot intervals by James Prentice, of the U.S. Geological Survey, in the Bernon and Defiance area, and about 100 chip samples were collected on the Defiance tunnel level and the 570, 700, and 800 levels of the Defiance workings by the authors. 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 U.S. Geological Survey.

The area around two veins that crop out in the open-cuts in the Defiance workings along the crest of an open inverted syncline near the Defiance fault was sampled as a known control area (pl. 6). The fold is continuous between the Defiance and Bernon workings, but little ore is known in this geologically favorable area, and 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.

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 2 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 was collected for each rock sample.

Distribution of lead-zinc-copper.—The distribution of total lead-zinc-copper in residual soil is shown in plate 6. The distribution of the plutonic rocks and the location of the principal faults are also given. The strongest anomaly of total lead-zinc-copper, expressed in parts per million (ppm), is over the Defiance workings. This anomaly is probably much greater than 7,000 ppm, but the maximum quantities determined in the 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 more than the maximum. The copper assays were mostly less than 200 ppm.

Near the Defiance workings 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 decreases 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 low in total lead-zinc-copper. A small high anomaly is near the west 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, which extends farther south than known ore. Two geochemical anomalies between the Bernon and Copper faults have not been explored. One anomaly is 300 feet N. 5° W. of the Bernon shaft in an area that has a large quantity of disseminated limonite at the surface. The other anomaly is at the contact of biotite-hornblende-quartz monzonite 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 (pl. 7). The bismuth content of the residual soil ranges from less than 10 to 250 ppm. The bismuth anomalies agree in general with the anomalies shown by total lead-copper-zinc. Adjacent to the Defiance ore bodies, bismuth ranges from 100 to 250 ppm, and it drops off to 10 to 15 ppm beyond 80 feet from ore. Another bismuth high, 260 feet S. 80° W. of the Defiance shaft, 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 of samples from the northeastern part of the area tested suggest that the bismuth is greater than above background, but the data are sparse. The total lead-zinc-copper anomaly 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 increases 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. Throughout 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. Two anomalies were also found in unexplored areas. Antimony seems less promising than bismuth in reflecting ore. The antimony content decreased rapidly away from the Defiance ore body, so it provided very little larger target than that of the ore body itself. The antimony was more satisfactory in reflecting the Bernon ore body. Silver gave unfavorable 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 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 proved highly successful, but during the past few years most of the major ore bodies have bottomed. 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 for 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 body 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 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 on the west or hanging-wall side of it. The ore above the thrust shown on plate 3 is projected and actually is on the footwall of the thrust. To the south in the Defiance workings the contact of the Darwin stock and the Davis thrust diverge, and the fault seems to be less important in localizing ore except near the satellitic body of quartz monzonite southwest of the Defiance workings. At present the shape of the Darwin stock is not known, and the writers only use the term "stock" because it has been used extensively. However, the west side of the intrusive body ends in a series of sills that bottom in the Defiance workings (pl. 3), and a diamond-drill hole extending 700 feet east from the 800 level did not cut granitic rock. The writers feel that the intrusive mass may have a floor and be a laccolith. If so, a large area under the outcrop of the intrusive mass may contain undiscovered ore bodies.

Little exploration has been done southeast of the Defiance mine along the Water tank and Mickey Summers faults near the intrusive mass (pl. 3) where the alteration is similar to that in the Defiance area, and much of the outcrop is iron stained. A few prospect pits have been dug, but no exploration has been done at 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 westward-dipping fault that passes through the Belle Union mine and the west side of the Lucky Jim mine (pl. 1; fig. 3). This fault is similar to the Davis thrust in that it localized intense silication of limestone below it. A geochemical prospecting program similar to the one described in this report for the Defiance area might help pinpoint areas favorable for further prospecting.

ZINC HILL DISTRICT

The Zinc Hill district is 3½ 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 in the district is about 30°. Individual properties are described in a previous report by the writers (Hall and MacKevett, 1958), and only a generalized description of the district 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 record of production was found for it. The recorded production for the district from 1917 to 1951 is about 3,560,000 pounds of zinc, 285,000 pounds of lead, 8,500 ounces of silver, and 14,000 pounds of copper.[1]

[1] Compiled from Hall and MacKevett (1958, p. 41–45).

GEOLOGY

The Zinc Hill district is underlain by limestone and marble of Mississippian and Permian age that is intruded by leucocratic quartz monzonite and by dikes and small irregular plugs of diorite (pl. 1). The stratigraphy of the area is given in table 9. Both the Empress and the Zinc Hill mines are underlain by marble and limestone of Mississippian age in a northward-trending horst about 1,000 feet wide that can be traced from the Darwin tear fault north for 2 miles (pl. 1). 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, the Perdido formation, and the Lee Flat limestone are probably represented within the horst, but it is all mapped as Lee Flat as most of the marble within the horst resembles it.

TABLE 9.—*Geologic column of the Zinc Hill district*

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

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 shale.

The Zinc Hill stock, a small intrusive mass 5,000 feet long and 2,000 feet wide, crops out between the Empress mine and the Darwin tear fault (pl. 1). It is 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 intrusive masses are too small to show on the quadrangle map (pl. 1).

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 more than 2,700 feet. Within the horst the limestone and marble are cut by many steep faults that trend N. 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 northwestward-trending faults is very young. These faults displace the Zinc Hill fault (Hall and MacKevett, 1958) 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 where they cut a favorable limestone or marble bed. Both primary and oxidized zinc ore is present. The primary ore from the Zinc Hill mine is predominantly sphalerite but includes small amounts of galena, pyrite, and chalcopyrite in a predominantly calcite gangue containing 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 a few. Ore at the Empress mine consists mainly of galena, but contains 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 cut off on 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 8. It is a bedded replacement of the favorable marble bed, called the Colorado bed by the owners. The lower stope in the upper workings is about 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, disk-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 northwestward-trending faults (Hall and MacKevett, 1958, p. 49). 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 downdip for a thickness of 3 to 12 feet.

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

Locally the ore in the Empress and Zinc Hill mines is slightly radioactive. At the Empress mine local radioactivity ranged from 0.04 to 0.15 mr per hr compared to a background of 0.02 mr per hr. At the Zinc Hill mine 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 part of the Lee district in the Darwin quadrangle comprises a small area in the southern part of the Santa Rosa Hills (fig. 2). The Lee mine (formerly known as the Emigrant mine) and the Silver Reid prospect are the only properties that have been developed. Production, which is recorded only from the Lee mine, was mainly during the 1870's and early 1880's. De Groot (1890, p. 213) mentioned that activity in the 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) reported 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.[2] The production since 1951 was furnished by the mine owners and is given in table 10.

[2] Published with permission of the mine owners.

TABLE 10.—*Assay data of ore shipped from the Lee mine, 1951 to 1955* [1]

Year	Tons	Copper (percent)	Lead (percent)	Zinc (percent)	Silver (ounces per ton)	Gold (ounces per ton)
1951	41	0.45	2.4	16.3	61.3	0.025
1951	35	.25	1.5	17.6	48.0	.025
1952	44	.45	1.5	22.75	89.76	.035
1953	35	.425	9.85	21.05	93.95	.037
1953	42	.24	7.9	17.75	59.6	.025
1954	49	.2	4.5	24.0	53.9	------

[1] Published with permission of the mine owners.

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. 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 formation consists of 1,770 feet of white and light-gray medium- to coarse-grained marble. The Lost Burro is conformably overlain by the Tin Mountain limestone, which underlies most of the Lee mine area. The formation is about 400 feet thick and consists of medium-gray cherty limestone in beds ½ to 2 feet thick.

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 along the flat-lying faults that are in part controlled by bedding. Most of the steep faults are only slightly mineralized except at the intersection with the mineralized flat-lying faults. Locally the 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 in thickness. Most of the ore bodies mined during the past few years are much smaller and have produced less than 100 tons of ore.

At the Silver Reid prospect the largest known ore body in 40 feet long, and 20 feet wide, and averages 2 feet in thickness (pl. 9). 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. Angelsite, 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 occur mainly as thin rims a few millimeters thick between the galena and cellular oxide ore. Small amounts of sphalerite, pyrite, and tetrahedrite remain. Sphalerite probably was originally an abundant ore mineral, but it is more readily attacked by ground water than galena, and little of it remains.

DEPOSITS IN THE INYO MOUNTAINS AND TALC CITY HILLS

The only lead-silver-zinc deposits in the Inyo Mountains and Talc City Hills are the Santa Rosa mine and several small deposits in the Talc City Hills, including the Cactus Owen, Homestake, and Silver Dollar mines (fig. 3). The Santa Rosa mine was described by MacKevett (1953, 9 p.), and the other deposits are described by Hall and MacKevett (1958).

The Santa Rosa mine is an isolated lead-zinc deposit in the Inyo Mountains (fig. 3). It is in an inlier of calc-hornfels of Permian age in an area almost completely covered by andesite and basaltic flows and pyroclastic rocks of Cenozoic age. The mine was discovered in 1910, and was operated continuously until 1938, except during 1912–15. It has been operated only intermittently since 1938. Total production is 36,854 tons of ore from which 11,990,792 pounds of lead, 487,347 pounds of copper, 4,105 pounds of zinc, 426,543 ounces of silver, and 479 ounces of gold were recovered (MacKevett, 1953, p. 4). The Silver Dollar mine is the only lead-silver-zinc deposit in the Talc City Hills that has a recorded production. It produced 469,782 pounds of lead and 19,694 ounces of silver during 1910–15 (Hall and MacKevett, 1958, p. 57).

SANTA ROSA MINE

The Santa Rosa mine is a vein deposit in an inlier of the lower unit of the Owens Valley formation that is metamorphosed to calc-hornfels. The inlier is about 2,000 feet long and 600 feet wide and is encompassed by Cenozoic volcanic rocks of andesitic and basaltic composition. The calc-hornfels is intruded by steep andesitic porphyry dikes that are 2 to 6 feet thick and strike about N. 70° W. The calc-hornfels and the surrounding pyroclastic rocks are cut by basalt dikes.

Structurally the Santa Rosa mine is in a horst that is bounded by steep north-trending faults. The calc-hornfels within the horst strikes northward and dips 30° to 70° E. It is cut by three sets of mineralized faults (MacKevett, 1953, p. 1), two of which strike north. Most of these dip 30° to 60° W., but a few dip 55° to 80° east. The third set strikes east and dips about vertically.

Ore occurs in veins in the three sets of faults within the horst. The veins are 100 to 700 feet long and average 3 to 4 feet thick. Those that dip west are the most important economically. The ore is mostly oxidized and consists mainly of cerussite and hemimorphite in a gangue of limonite, jasper, and calcite. Some primary ore is in the lower crosscut, and locally relict primary minerals are in oxide ore. The primary ore contains galena, sphalerite, pyrite, chalcopyrite, and arsenopyrite listed in order of decreasing abundance.

DEPOSITS IN THE TALC CITY HILLS

The lead-silver-zinc deposits in the Talc City Hills are small (fig. 3). They are all in limestone, and dolomite and quartzite are unfavorable host rock. The deposits are in steeply dipping faults that strike N. 40° to 75° W. At the Silver Dollar mine, the only mine with a recorded production, the Lost Burro formation of Devonian age is thrust over the Keeler Canyon formation of Pennsylvanian and Permian age (Hall and MacKevett, 1958 pl. 2). The thrust fault is exposed 300 feet north of the main pit where a sliver of Rest Spring shale has been dragged along the fault. The ore is in the Keeler Canyon formation in a shear zone that strikes N. 50° W. and dips steeply northeast. The size of the ore body, estimated from the size of the main pit, was about 35 feet long, 30 feet thick, and was mined 90 feet down dip. The nature of the ore is not known as little remains in the workings.

The Cactus Owen and Homestake prospects are in thin-bedded bluish-gray limestone of the Lost Burro formation that is in part bleached and recrystallized to marble. Steep strike faults are abundant in the limestone. The faults are iron stained and locally contain pockets of cerussite, hemimorphite, and oxidized copper minerals in a gangue of quartz and calcite.

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. 3). The deposits are all 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 Dudley L. Davis (oral communication, 1955). A small amount of scheelite has also 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 (1958, see section on tungsten deposits by Hall, MacKevett, and Lemmon). L. K. Wilson (1943, p. 543–560), geologist for the Pacific Tungsten Co., described the tungsten deposits and the operations of the Pacific Tungsten Co. 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 described 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 unit of the Keeler Canyon formation of Pennsylvanian and 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 intrusion. The tactite consists mainly of garnet (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 premineralization left-lateral strike-slip faults that strike N. 70° E.

ORE BODIES

Scheelite locally replaces pure limestone and tactite beds close to and within faults that strike N. 70° E. (pl. 10). Most of the ore is found within three limestone beds known as the Durham, Frisco, and Alameda beds. Only the Durham ore body extends more than 60 feet vertically (fig. 34). 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 near the contact with the underlying 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 (pl. 10). Its thickness ranges from 2½ to 35 feet.

Three replacement ore bodies have been mined from the Alameda beds near N. 70° E. faults (pl. 10). Two are at the intersection of the Alameda beds with the Fernando shear zone; the third is 1,000 feet northwest of the Fernando shear at the Alameda shaft (pl. 10). The largest of these ore bodies is at the intersection of the Alameda beds with the Fernando shear 950 feet S. 80° W. of the Fernando adit. It has been developed by an opencut 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 remained at the bottom.

The ore in the St. Charles-Hayward area is in N. 70° E. faults that dip steeply to the northwest (pl. 10). The largest ore body is developed by the St. Charles No. 1 workings. The ore shoot was 140 feet long, 2 to 10 feet thick, and 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 No. 3 workings is in thin veins or streaks along N. 70° E. faults, and no scheelite is disseminated in the wallrock between faults. The streaks range from a fraction of an inch to 6 inches in thickness and can be mined only by highly selective methods or where fractures are sufficiently close that several can be mined together. Some 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 about 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 for an average width of 15 feet on the 200 and 300 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 to 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 fault (pl. 10). Scheelite is localized along fractures for 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 faults that strike N. 70° E.; scheelite may be present whether the wallrock 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 wallrock is calc-hornfels. The ore body rakes to the west parallel with bedding.

Granitic rocks must be nearby to form 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 commonly localized by faults.

MINERALOGY

The primary tungsten ore contains scheelite in a gangue of marble or calc-silicate rock containing grossularite-andradite, calcite, fluorite, idocrase, wollastonite, diopside and pyrite. Bismuthinite is present at the Fernando mine. At the Thompson workings of the Darwin 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.

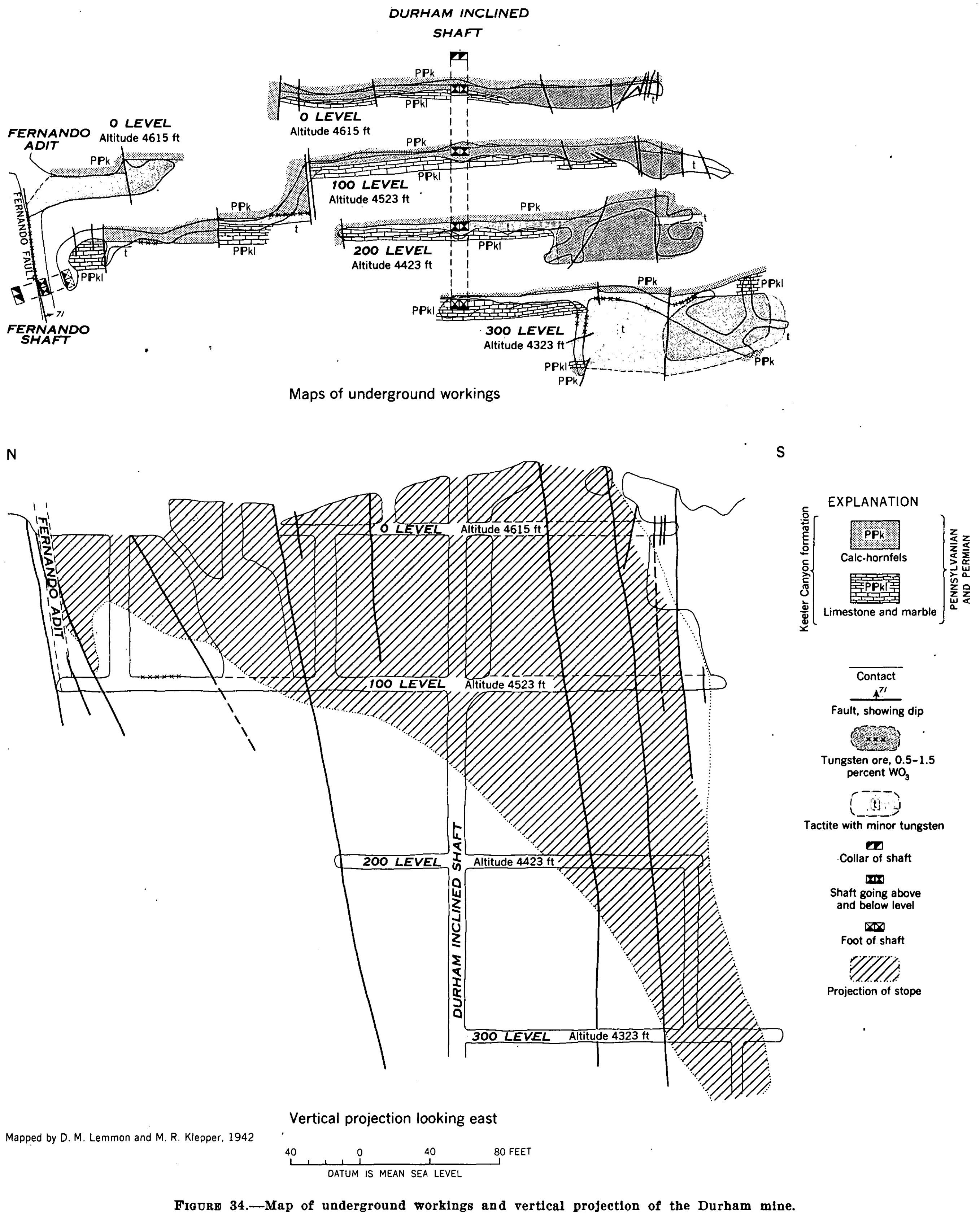


Figure 34.—Map of underground workings and vertical projection of the Durham mine.

The scheelite is commonly in euhedral crystals as much as 2 inches in diameter. At the Darwin mine euhedral to subhedral crystals of scheelite predominately 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 they occur elsewhere along the same ore controlling structures farther from the Darwin stock.

The Durham ore body contains bismuthinite and pyrite near the intersection of the Durham bed with the Fernando fault (pl. 10). The bismuthinite is in tabular crystals as much as 2 inches long in calcite veinlets that cut the 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 partly 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 virtually unaltered, but all the other minerals were oxidized or partly leached; thus, the ore has undergone residual enrichment of tungsten.

DEPOSITS IN THE COSO RANGE

A few small tungsten deposits are on the northeast slope of the Coso Range 8 to 10 miles southwest of Darwin, but only the Lone Pinyon prospect near Black Springs lies within the quadrangle (fig. 3). The deposits are within roof pendants or screens of metasedimentary rocks in quartz monzonite of the Coso batholith. None are extensive.

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 about 3½ miles north of Darwin (fig. 3). The production 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 and 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 containing minor secondary antimony minerals in sheared limestone and ranges from a few inches to 3 feet in thickness. 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 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 levels north of the main shaft.

Copper minerals are associated with nearly all the lead-silver-zinc deposits and 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. 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 virtually pure, massive, compact talc containing less than 1.5 percent CaO, 1.5 percent combined FeO and Fe_2O_3, and 4 percent Al_2O_3 and that is suitable for the manufacture of certain ceramics. Massive chlorite, associated with some of the talc deposits, is used in cordierite ceramics and 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 could be used for super refractory silica brick. Limestone is prevalent in the Santa Rosa and Darwin Hills. The Lee Flat limestone and limestone of the Keeler Canyon and Owens Valley formations are predominantly silty. Two analyses of limestone in the Darwin Hills are given in table 3. The Tin Mountain limestone and upper part of the Lost Burro formation are purer limestones, but no analyses are available. Massive dolomite in the Devonian and older formations is abundant in the Talc City Hills, but no analyses of it are available.

STEATITE-GRADE TALC

Steatite-talc deposits are restricted to an area of about 6 square miles in the Talc City Hills about 6 miles northwest of Darwin (pl. 2). 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 (table 5). 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 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 rocks 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 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 seems to be about 75 feet thick and is repeated by faulting. This member is shown as stratified dolomite and limestone and as silica rock 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 about 300 feet of light-gray to buff massive dolomite. A few beds of limestone are 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 by a stock of leucocratic quartz monzonite at the south end of the Talc City Hills. 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; they originally probably were quartz latite. Fine-grained highly altered dark-green dikes 2 to 6 inches thick also intrude Devonian rocks at the Talc City mine.

TALC ORE BODIES

The talc deposits are only briefly described here, as excellent descriptions and maps of individual properties are given by Page (1951) from whom much of the following description is taken. The writers mapped the surface geology of the Talc City Hills on a scale of 1:40,000, but did not map the talc deposits.

The talc deposits are localized mainly in shear zones in massive buff dolomite and to a lesser extent in quartzite and along contacts between dolomite and quartzite or dolomite and dolomitic limestone near leucocratic quartz monzonite. Dolomite of the Lost Burro formation is the principal host rock, although some deposits are in dolomite of the Pogonip group, the Ely Springs, and the Hidden Valley. Both the Eureka quartzite and the quartzite in the Lost Burro 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 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 stock of leucocratic quartz monzonite. Talc in the Alliance mine (pl. 2) 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 irregular, and horses of unreplaced country rock are common in some of the talc bodies. Page (1951, p. 13, 16) reported 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 Klinefelter, Speil, and Gottlieb (*in* Page, 1951, p. 12).

Sample	1A	1B	1E	Theoretical
SiO_2	62.30	58.06	60.05	63.50
Al_2O_3	1.98	.85	.45	
TiO_2	.04			
Fe_2O_3	1.30	1.21	1.36	
CaO	.64	.43	.09	
MgO	28.26	31.85	32.10	31.7
KNaO	.47	1.14	.13	
Ignition 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 replace dolomite and quartzite and were formed by thermal waters traveling along shears and contacts. Spatially the deposits are peripheral to the stock of leucocratic quartz monzonite, and the size of the deposits is approximately proportional to nearness to the intrusive contact. Both suggest that the thermal waters were given off by the intrusive body during a late stage of crystallization and 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 mass was the source of heat and the alteration was caused by recirculation of heated ground water. It is not necessary to postulate a large-scale introduction of magnesia or silica. Most of the deposits and, without exception, all 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.

Chemical analysis of the chlorite

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

	Percent		Percent
SiO_2	29.0	K_2O	.02
Al_2O_3	25.0	TiO_2	.40
Fe_2O_3	.7	P_2O_5	.22
FeO	.82	MnO	.01
MgO	30.6	H_2O	12.6
CaO	.36	CO_2	<.05
Na_2O	0.04		

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 +, 2*V* small, $n_\alpha = 1.573 \pm 0.003$; $n_\beta = 1.574 \pm 0.003$; $n_\alpha = 1.583 \pm 0.003$. This closely fits the optical properties of amesite given by Winchell (1936, p. 643).

X-ray diffraction pattern

dA	Intensity	dA	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 14A 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. 1458) have shown the existence of both types of amesite—the 7A kaolin type and the 14A chlorite type. The differential thermal analysis curve also fits a 14A chlorite.

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