Geology of the Panamint Butte Quadrangle, Inyo County, California

By WAYNE E. HALL

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GEOLOGY OF THE PANAMINT BUTTE QUADRANGLE, INYO COUNTY, CALIFORNIA

By WAYNE E. HALL

ABSTRACT

The Panamint Butte quadrangle is in central Inyo County, Calif., on the west side of Death Valley. It encompasses the northern parts of the Argus Range, Panamint Valley, and the Panamint Range.

The quadrangle is underlain by a sequence, more than 15,000 feet thick, of metamorphic and sedimentary rocks of Precambrian(?) and Paleozoic age which is intruded by Mesozoic plutonic rocks and andesite porphyry dikes. The section is unconformably overlain by Cenozoic volcanic rocks and sedimentary deposits.

Precambrian(?) metamorphic rocks are exposed in two small windows below thrust faults in the Panamint Range. Precambrian(?) rocks include micaceous and limy quartzite, mica schist, hornblende-biotite gneiss, and dolomite.

Paleozoic rocks range in age from Early Cambrian to Permian and form a conformable sequence approximately 15,000 feet thick. Pre-Devonian rocks crop out only in the Panamint Range. They are predominantly dolomite, but include limestone, quartzite, and shale. Devonian and younger Paleozoic rocks crop out in both the Argus and Panamint Ranges. They are predominantly limestones and silty and shaly limestones.

Plutons of biotite-hornblende-quartz monzonite and leucocratic quartz monzonite intrude the Paleozoic rocks in both the Argus and Panamint Ranges. The age of the intrusive rocks is approximately 180 million years (Early Jurassic). A swarm of altered andesite porphyry dikes striking N. 70° W. intrude the Paleozoic rocks and quartz monzonite at the north end of the Argus Range. This swarm of dikes has been traced for 85 miles to the northwest.

Cenozoic deposits cover Panamint Valley and much of the Panamint Range in the vicinity of Towne Pass. They include Pliocene and younger sedimentary and volcanic rocks. Approximately 10,000 feet of fanglomerates of three ages, each separated by angular unconformities, are present near Towne Pass. The maximum fill in the northern Panamint basin is 500 feet.

The Paleozoic rocks were deformed into broad open folds prior to the intrusion of the quartz monzonite plutons. The Paleozoic rocks were thrust and again folded by Mesozoic intrusion of the Hunter Mountain Quartz Monzonite batholith in the Panamint Range and the plutons of quartz monzonite in the northern Argus Range.

During the Cenozoic, thrust faulting under shallow cover caused extensive shattering of the Paleozoic strata. The rocks were disrupted by steep faults to form the present basin and range topography. Additional movement occurred as landslides during the late Cenozoic. In the Towne Pass area the extensive shattering caused by Tertiary thrusting formed chaos-type structures, which are part of a belt of similar structures extending southeast through the Death Valley area. The chaos formed by gravity sliding off domal structures during the middle(?) Cenozoic.

INTRODUCTION

The Panamint Butte 15-minute quadrangle is in Inyo County, Calif., on the west side of Death Valley (fig. 1). The quadrangle includes parts of the Panamint Range on the east, Panamint Valley in the central part of the quadrangle, and the Argus Range in the southwestern part. Access to the quadrangle is provided by State Highway 190, which extends from Olancha to Death Valley crossing

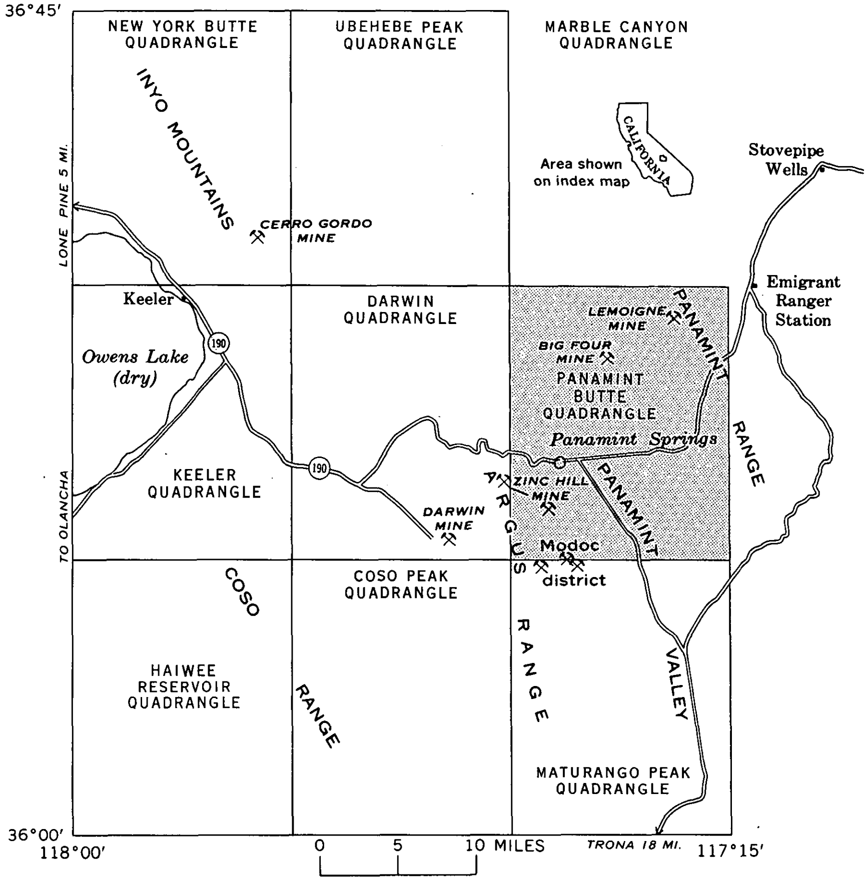

FIGURE 1.—Index map showing the location of the Panamint Butte quadrangle.

the quadrangle in an east-west direction. An improved county road passes through Panamint Valley from Trona (fig. 1). Gravel roads, frequently washed out during summer storms, lead from the major roads to the producing mines. When the road to the Lemoigne mine is washed out, the high parts of the Panamint Range are difficult to reach. A four-wheel drive vehicle provides access to some areas from Panamint Valley. It is possible to drive to Mill Canyon in the northwestern part of the quadrangle and skirt the sand dunes on the east to reach the head of Panamint Valley in the north-central part of the quadrangle. Dolomite Canyon at an altitude of 3,800 feet and Lemoigne Canyon at an altitude of 4,200 feet can be reached, with difficulty, by jeep.

The only public accommodations in the quadrangle are a resort motel, restaurant, and gas station at Panamint Springs. Lone Pine, 46 miles west of the quadrangle, and Trona, 38 miles to the south, are the principal supply centers.

CLIMATE AND VEGETATION

The Panamint Butte region has a desert climate typified by slight rainfall, wide temperature range, and frequent strong winds. The temperatures in Panamint Valley are oppressively hot in summer, but are pleasant during the remainder of the year. The winters are mild; snow falls occasionally above 5,000 feet. The following data are for Trona (U.S. Weather Bureau, 1958):

Highest temperature	114°F.
Lowest temperature	23°F.
Annual mean temperature	67°F.
Annual rainfall	6.0 inches.

Vegetation is sparse. Valley floors, gullies, and moderate slopes have scattered sagebrush and creosote bush. Steep slopes are nearly bare. A few pinyon pine and desert juniper grow above 5,000 feet, and Joshua trees are found along the crest of the Panamint Range at 5,000–6,000 feet.

WATER SUPPLY

The water supply is very limited. The only spring within the quadrangle is one near Panamint Springs, which supplies the California Highway Department substation. Several reliable springs are a short distance outside the quadrangle. The largest is at Darwin Falls and supplies water to the Panamint Springs Resort, 3 miles to the east. The mines in the Modoc district obtain water from the Jack Gunn, French Madam, and Thompson Springs, which are 1–2 miles to the southwest in the Argus Range (Maturango Peak quadrangle). In the Panamint Range near the quadrangle, the only

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reliable spring that is not polluted by the wild burros is Cottonwood Spring, 1 mile north of the quadrangle in the Marble Canyon quadrangle.

PREVIOUS WORK

Little information has been available on the geology of the Panamint Butte quadrangle. The earliest geologic map that includes the area is a reconnaissance map of southern Nevada and southeastern California by Spurr (1903, pl. 1), who made a threefold division of the rocks into fine- and coarse-grained igneous rocks and Cambrian rocks. Hopper (1947, pl. 1) made the first major contribution with his strip map from the Sierra Nevada to Death Valley, which covers the south end of the quadrangle.

Other geologists who worked in nearby areas include Gale (1914), who studied Panamint basin; Murphy (1930, 1932), who mapped the area around Panamint City; Maxson (1950), who made a physiographic study of the Panamint Range; Sears (1955), who mapped in the vicinity of Tucki Mountain in the Panamint Range; Johnson (1957), who mapped part of the Manly Peak quadrangle; and Lanphere (1962), who studied the geology of the Wildrose area. McAllister (1952, 1955, 1956) mapped the Ubehebe Peak quadrangle and adjacent Quartz Spring area, Merriam (1963) mapped the Cerro Gordo District, and MacKevett (1953) described the Santa Rosa mine in the Inyo Mountains. Hall and MacKevett (1958, 1962) mapped the Darwin quadrangle, and Hall and Stephens (1963) described the mines in the Panamint Butte quadrangle and Modoc district.

ACKNOWLEDGMENTS

This paper is a product of a cooperative program of the U.S. Geological Survey and the California Division of Mines and Geology to study the Inyo County lead-silver-zinc deposits.

The writer wishes to express his appreciation to the mine owners and operators for their cooperation in this study. Matt Ryan, of the National Park Service at Emigrant Station in Death Valley, and Mrs. Ryan extended many courtesies. J. F. McAllister of the U.S. Geological Survey spent 4 days in the field with the writer and was of great assistance with stratigraphic and structural problems. Fossils were identified by the following paleontologists of the U.S. Geological Survey: Jean M. Berdan, R. C. Douglass, Helen Duncan, J. Thomas Dutro, Mackenzie Gordon, Jr., W. H. Hass, Kenneth E. Lohman, W. A. Oliver, Jr., A. R. Palmer, R. J. Ross, Jr., W. J. Sando, and Ellis Yochelson; fossils were also identified by Richard S. Boardman of the U.S. National Museum.

Hal G. Stephens was my colleague on the project from 1956 to 1959. He participated equally with me in the preparation of the geologic map (Hall and Stephens, 1962) and in the preparation of the economic report (Hall and Stephens, 1963). I am grateful to F. J. Kleinhampl and D. C. Ross for their critical reviews of the manuscript.

GENERAL GEOLOGY

The Panamint Butte quadrangle is underlain by a sequence of sedimentary and metamorphic rocks of Precambrian(?) to Permian age that is intruded by quartz monzonite plutons of Early Jurassic age and by altered andesite porphyry dikes of Cretaceous(?) age (table 1). Late Cenozoic volcanic rocks and sedimentary deposits unconformably overlie the older rocks.

TABLE 1.—*Stratigraphic sequence in the Panamint Butte quadrangle*

Era	Period	Epoch	Name	Lithology	Thickness (ft.)
Cenozoic	Quaternary	Holocene	Alluvium	Unconsolidated alluvium, playa deposits, fanglomerate, dune sand, talus deposits	0–500
				Unconformity	
		Pleistocene	Fan No. 1	Unconsolidated fanglomerate, elevated, dissected, and slightly tilted	0–100
				Unconformity	
			Lacustrine deposits	White to light-gray fine-grained pumiceous ash, silt, clay, diatomaceous earth, fresh-water limestone, and tufa	0–200
	Quaternary or Tertiary	Pleistocene or Pliocene	Fanglomerate No. 2	Moderately consolidated, elevated, dissected, and tilted fanglomerate. Includes some lacustrine deposits. Included in Nova Formation by Hopper (1947)	2,600
	Tertiary	Pliocene	Olivine basalt	Extensive flows that form ridge cappings and dip slopes	0–560
				Angular unconformity	
			Quartz-olivine basalt	Quartz-olivine basalt flows and pyroclastic rocks; intercalated in top of fanglomerate No. 3. Commonly altered to greenish or purplish color	430
			Fanglomerate No. 3	Red consolidated conglomerate and monolithologic breccia. Included in part in Nova Formation by Hopper (1947)	7,800+
			Rhyolite tuff	Rhyolite tuff; in part welded	0–150
Mesozoic	Cretaceous (?)		Andesite porphyry dikes	Andesite porphyry, altered	
	Jurassic		Leucocratic quartz monzonite		
			Biotite-hornblende-quartz monzonite		

TABLE 1.—*Stratigraphic sequence in the Panamint Butte quadrangle*—Continued

Era	Period	Epoch	Name	Lithology	Thickness (ft.)
				Unconformity	
Paleozoic	Permian		Owens Valley Formation	Thin- to medium-bedded gray and blue silty limestone and calcarenite. Some siltstone, shale, and lenses of limestone and limestone breccia	2,400
	Pennsylvanian		Keeler Canyon Formation	Thin-bedded silty and sandy limestone, clean limestone, limestone breccia, shale, and siltstone	2,685
	Pennsylvanian ? Mississippian		Lee Flat Limestone	Medium- to thick-bedded white marble. Locally dolomitic	650
	Mississippian		Perdido Formation	Thin-bedded bluish-gray limestone with abundant thin beds and veinlets of brown-weathering chert	360
	Mississippian		Tin Mountain limestone,	Thin- to thick-bedded limestone with minor chert. Locally recrystallized to marble. Highly fossiliferous	450
	Devonian		Lost Burro Formation	White and light-gray medium-bedded marble, gray limestone, and dolomite, and minor brown quartzite at base	1,500
	Silurian		Hidden Valley Dolomite	Light-gray medium- bedded dolomite. Chert and thin quartzite beds in lower part	400
	Ordovician		Ely Springs Dolomite	Light-gray dolomite in upper part; dark-gray cherty dolomite in lower part	670
			Eureka Quartzite	White, gray, and red vitreous quartzite and some tan and gray dolomite in middle and lower part	285
			Pogonip Group	Gray and brownish-gray medium- to thick-bedded dolomite	1,400
	Cambrian		Nopah Formation	Light- and dark-gray dolomite. Thin-bedded shale and silty limestone in basal unit	1,500
			Bonanza King Formation	Thin- to thick-bedded gray limestone, dolomite, and minor shale	1,600
			Carrara Formation	Thin-bedded limy shale, siltstone, and limestone with abundant silty lenses. Altered to quartz-mica schist, garnet gneiss, quartzite, and dolomitic marble near the Hunter Mountain batholith	700+
	Precambrian(?)			Quartz-mica schist, micaceous quartzite, and dolomite	700+

Precambrian(?) metamorphic rocks crop out in two small exposures, and their thickness is not known. Quartzite, gneiss, and schist are the predominant rock types. They are overlain with structural discontinuity by an apparently conformable sequence of Paleozoic rocks, approximately 15,000 feet thick, ranging in age from Middle Cambrian to Permian. Dolomite and quartzite predominate in the pre-Devonian Paleozoic rocks, whereas limestone and marble make up most of the Devonian and younger Paleozoic rocks.

The area is complex structurally. The rocks are displaced by numerous faults and gravity slides. Much of the Paleozoic rock on the west face of the Pamamint Range is shattered, and in this area it is not uncommon for parts of the stratigraphic section to be sliced out because of structural deformation or to be out of place because of gravity sliding. It was not possible to show the extent of shattering of the rocks, the thinning of stratigraphic units, or the amount of gravity sliding at the scale of the geologic map.

PRECAMBRIAN(?) ROCKS

Schist, gneiss, and quartzite of probable late Precambrian age are exposed beneath thrust faults in two small windows along the crest of the Panamint Range. The rocks of probable Precambrian age consist dominantly of quartz-mica schist, micaceous quartzite, and biotite-hornblende gneiss. In the canyon 2 miles south of Nova Canyon in the Panamint Range, a 700-foot-thick section of quartzite and some dolomite is provisionally assigned to the Precambrian(?) (pl. 1). The upper 50 feet is white vitreous quartzite, and the lower part of the section is interbedded reddish or reddish-brown micaceous and limy quartzites and sandy dolomite. The quartzites generally contain rounded silt- to sand-size quartz grains, abundant sericite, and several percent of unaltered plagioclase and microcline. This quartzitic and dolomitic unit is similar to the Surprise Formation of Murphy (1930), although the small isolated exposure precludes making even a tentative correlation.

A small area of quartz-mica schist is exposed in the canyon 3 miles N. 57° W. of the Lemoigne mine below a thrust fault contact with Cambrian rocks. The unit is predominantly coarse-grained reddish-brown quartz-muscovite-biotite schist, interbedded with reddish quartzite. It is provisionally assigned to the Precambrian(?) on the basis of lithology and grade of metamorphism, but the unit could be a contact metamorphosed clastic section of Cambrian rocks.

PALEOZOIC ROCKS

CAMBRIAN SYSTEM

Few Cambrian fossils have been found in the 10 square miles of predominantly carbonate rocks assigned to the Cambrian in the Panamint Butte quadrangle. The assignment to the Cambrian System is based on lithologic similarity to Cambrian rocks described from nearby areas by McAllister (1952, p. 8–9; 1955, p. 10; 1956), Hazzard (1937, p. 299–322), R. J. Ross, Jr. (1964), D. C. Ross (1965), and Cornwall and Kleinhampl (1961) and on stratigraphic position below fossiliferous Lower Ordovician rocks of the Pogonip Group on the north side of Dolomite Canyon, 2 miles north of State Highway 190 in the Panamint Range. In the northeastern part of the quadrangle, the Cambrian is divided into the Carrara Formation of Early and Middle Cambrian age and the Bonanza King Formation of Middle and Late Cambrian age. The Cambrian strata in Dolomite Canyon have been divided into two formations—the Bonanza King Formation overlain conformably by the Nopah Formation (pl. 1; fig. 2).

CARRARA FORMATION

The Carrara Formation, of Early and Middle Cambrian age, was named by Cornwall and Kleinhampl (1961) for a sequence of interstratified shale and limestone in Carrara Canyon in the Bare Mountain quadrangle, Nevada. The formation is exposed in the Panamint Butte quadrangle beneath a thrust fault in the Lemoigne mine area (pl. 1). A gneissic band 2 miles long, 1.25 miles west of the Lemoigne mine, is probably contact metamorphosed strata of the Carrara.

Several hundred feet of reddish-brown thinly bedded limy shale, limy siltstone, and bluish limestone with abundant yellow, brown, and reddish irregular silty lenses is exposed beneath a thrust fault (pl. 1) in the canyon in the Lemoigne mine area. This unit lithologically resembles the top of the Carrara Formation described by Cornwall and Kleinhampl (1961). Two collections of fossils from this section were examined by A. R. Palmer (written commun., 1964), who reported that

> One collection (P–599) contains no apparent fossils. Collection P–502 contained one piece of a fragmentary trilobite that represents the genus *Glossopleura.* This is a characteristic fossil of the thin-bedded limestones that form the upper 200 feet of the Carrara Formation in the Death Valley region.

Glossopleura is not restricted to the Carrara Formation, for it has been found in the Papoose Lake Member of the Bonanza King Formation (A. R. Palmer, written commun., 1965); however, the

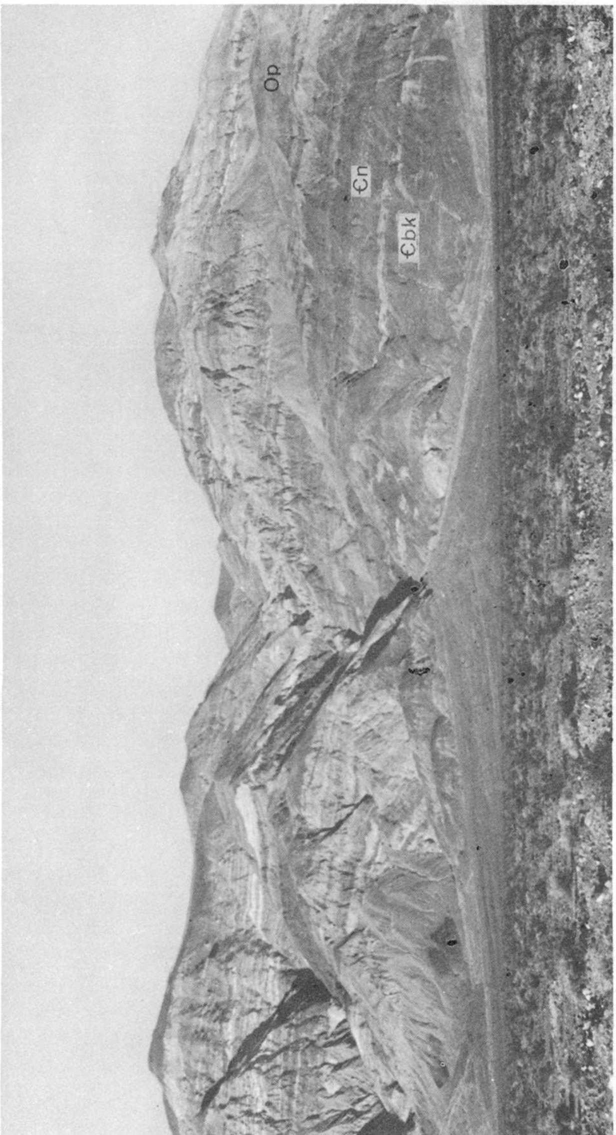

FIGURE 2.—West face of the Panamint Range north of Dolomite Canyon. The Bonanza King Formation (€bk), Nopah Formation (€n), and Pogonip Group (Op) underlie the hill in the foreground. The base of the Nopah Formation is the prominent light-colored band near the base of the hill. This band is lithologically equivalent to the Dunderberg Shale. Photograph by H. G. Stephens.

lithology in conjunction with the fossil is characteristic of the Carrara.

The gneissic band of contact metamorphosed Carrara Formation is approximately 700 feet thick, but the base is not exposed. This unit consists of quartz-mica schist, siltstone, coarse-grained garnet gneiss, quartzite, and gray dolomite, in beds ½–3 feet thick. The color of the rocks is brown and greenish brown. Foliation is parallel to bedding. The gneiss and schist contain dark-red and reddish-brown garnets as much as a quarter of an inch in diameter in a fine-grained groundmass of biotite, hornblende, muscovite, plagioclase, quartz, and calcite. The gneiss is conformably overlain by dolomitic marble of the Bonanza King Formation that grades to the east into unmetamorphosed dolomite of the Bonanza King Formation. All the gneiss lies within a zone of contact metamorphism near the Hunter Mountain batholith.

BONANZA KING FORMATION

Name and Distribution

The Bonanza King Formation was named by Hazzard and Mason (1936, p. 234) for a sequence of dark- and light-gray dolomite of Middle and Late Cambrian age in the Providence Mountains, Calif. The formation crops out on the north side of Dolomite Canyon and in a thrust sheet in the vicinity of the Lemoigne mine (pl. 1). The formation has been described in the northern Panamint Range in the Quartz Spring area and in the Ubehebe Peak quadrangle by McAllister (1952, p. 8; 1955, p. 10; 1956). Sears (1955, p. 140) described the Bonanza King Formation from the central Panamint Range in the area between Tucki Mountain and Wildrose Canyon, and D. C. Ross (1965, p. 17) described it in the Inyo Mountains.

Thickness and Stratigraphic Relations

An incomplete section, 1,600 feet thick, of the Bonanza King Formation is at the foot of the Panamint Range 1.7 miles north of Dolomite Canyon, but the base of the formation is not exposed (pl. 1). An incomplete section estimated to be 2,000 feet crops out in the vicinity of the Lemoigne mine. This section is in an overthrust sheet, and the estimate of thickness may be considerably in error owing to structural complexities.

The upper contact of the Bonanza King Formation is sharp and conformable with the overlying Nopah Formation. It is marked by a change in lithology from thin- to medium-bedded gray limestone and dolomite to brown-stained thinly bedded shale and limestone. The lower contact is exposed only in the metamorphosed section 1.25 miles west of the Lemoigne mine, near the contact with the Hunter

Mountain batholith. Here the base of the formation is a white and light-gray dolomitic marble unit that conformably overlies a gneissic unit of metamorphosed Carrara Formation.

Lithology

The Bonanza King Formation north of Dolomite Canyon consists predominantly of thin- to thick-bedded dark-gray limestone with some thin buff-colored beds of dolomite. The dark-gray limestone locally is mottled by buff-colored dolomitized parts that in places amount to 40 percent of the rock. When viewed from a distance, the limestone appears thickly bedded because of widely spaced partings, but weathered surfaces commonly show thin bedding.

The Bonanza King Formation at the Lemoigne mine consists of thin- and medium-bedded gray limestone, dolomite, and some shale. The lower part is predominantly white and light-gray marble, dolomitic marble, and thinly bedded dark-gray limestone. The upper part is predominantly thin- to medium-bedded dark-gray dolomite, but includes some shale beds, most of which are less than 25 feet thick, and some light-gray beds of dolomite. Thin limestone beds are intercalated in the shale units. Half a mile east of the Lemoigne mine in the upper part of the Bonanza King Formation, there is a gradational west-to-east change from thin- to medium-bedded dark-gray dolomite to a medium- to thick-bedded gray, light-gray, and brownish-gray dolomite, which is similar to the Nopah Formation in the exposures near Dolomite Canyon. The basal brown shale unit of the Nopah Formation, however, is not present, and all the dolomite here is considered to be Bonanza King. On the ridge 1 mile southwest of the Lemoigne mine, white marble and dolomitic marble in the thrust sheet contain very poorly preserved fossils that resemble some in the Silurian and Lower Devonian Hidden Valley Dolomite. Hence, it is possible some shattered Silurian and Devonian strata, in a structurally complex zone, are also included as Bonanza King.

Age

No fossils were found in the Bonanza King. The formation is considered to be Middle and Late Cambrian in age; a Late Cambrian fauna is found in rocks overlying the formation north of Dolomite Canyon.

NOPAH FORMATION

Hazzard (1937, p. 320) gave the name Nopah Formation to a sequence of Upper Cambrian rocks in the northern part of the Nopah Range. Rocks assigned to the Nopah Formation in the Panamint Butte quadrangle crop out in the Panamint Range in a band 2.5 miles long on the north side of Dolomite Canyon. Dolomite, lime-

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stone, and marble in the vicinity of the Big Four mine are provisionally assigned to the Nopah Formation (pl. 1). The carbonate rocks near the Big Four mine are recrystallized in the contact aureole of the Hunter Mountain batholith; so the original character of the carbonates and fossils were destroyed.

The Nopah Formation has a thickness of 1,500 feet on the ridge 1.6 miles north of the mouth of Dolomite Canyon (pl. 1). This compares well with a thickness of 1,600 feet in the Quartz Spring area (McAllister, 1952, p. 9) and 1,740 feet in the Nopah Range (Hazzard, 1937, p. 321). The lower contact is marked by a sharp change in color and lithology between the brown-weathering thinly bedded limestone, shale, and siltstone basal member and the dark-gray limestone and dolomite of the Bonanza King Formation. The upper contact with the Pogonip Group is much less clearly defined, but is characterized by a change from a thickly bedded conspicuously banded dark-gray and buff-colored dolomite in the Nopah Formation to a thin- and medium-bedded dolomite and limestone that weathers brownish gray in the Pogonip Group.

Lithology

The Nopah Formation consists almost entirely of dolomite except for a basal shale and limestone unit 225 feet thick. The basal unit consists of thinly interstratified gray and brownish-gray limestone, olive-green shale, and brown-weathering siltstone and cherty limestone. The whole unit makes a conspicuous marker bed because of its dark-brown color on weathered surfaces (fig. 2), and it correlates at least in part with the Dunderberg Shale in the Atomic Energy Commission Nevada proving grounds (Johnson and Hibbard, 1957). Above the basal limestone unit is a succession of gray and buff dolomite layers 20 feet to several hundred feet thick that give a striped appearance to the formation. Dark-gray dolomite is most abundant in the lower part of the formation, whereas buff-colored dolomite dominates the upper part.

Age

Fragmentary fossils that confirm a Late Cambrian age were found in a single sample collected from the brown shaly limestone unit at the base of the Nopah. A. R. Palmer (written commun., 1962) reported that

> The rock is a somewhat recrystallized echinodermal hash in which trilobite material, if there was any, is now destroyed. The insoluble residue, however, yielded acrotretid brachiopods of the genus *Linnarssonella* and a couple of Cambrian conodonts. These confirm the field identification of Dunderberg (= lower Nopah) for the sample. Conodonts have not been found yet below

the Upper Cambrian, and *Linnarssonella* is a distinctive short-ranging genus found only in the upper beds of the Dunderberg or basal beds of the Nopah and equivalents over all the Great Basin.

ORDOVICIAN SYSTEM

POGONIP GROUP

The name Pogonip Group is used here in the restricted sense of Hintze (1951, p. 11) and Nolan, Merriam, and Williams (1956, p. 24), as a group including rocks of Ordovician age below the Eureka Quartzite. As originally defined by King (1878, p. 187–195), the Pogonip Limestone included all rocks between the Prospect Mountain Quartzite (Early Cambrian) and Eureka Quartzite (Middle Ordovician); the name was revised by Hague (1883, p. 253–263) to include beds between the Dunderberg Shale (Upper Cambrian) and Eureka Quartzite. Later Hintze (1951, p. 11) redefined the Pogonip as a group and further restricted it to include only rocks of Ordovician age. Nolan, Merriam, and Williams (1956) divided the Pogonip Group into the Goodwin, Ninemile, and Antelope Valley Formations in the Eureka district. Because of alteration of the section, the author did not try to subdivide the group. R. J. Ross, Jr. (1964, p. 41), however, measured a section of Pogonip in the Panamint Butte quadrangle 2.25 miles south-southeast of Panamint Butte and provisionally identified these formations, although he queried some of his correlations because of the degree of dolomitization.

The Pogonip Group crops out in the Panamint Butte quadrangle for approximately 2.5 miles in and north of Dolomite Canyon. Complete sections of the Pogonip Group are present along the ridge 1.5 miles north of the mouth of Dolomite Canyon and on the steep slope 2.25 miles north of the mouth of the canyon. The Pogonip Group also crops out in the vicinity of the Big Four mine and at the south end of Lake Hill (pl. 1).

Thickness and Stratigraphic Relations

A complete section of the Pogonip Group 1,260 feet thick was measured in the Panamint Range 4.1 miles N. 70° E. of BM 2081 on State Highway 190 (pl. 1). It is estimated to be 1,400 feet thick along the ridge 1.5 miles north of the mouth of Dolomite Canyon. The Pogonip is 1,440 feet thick in the Quartz Spring area in the northern Panamint Range (McAllister, 1952, p. 11) and more than 1,570 feet thick in the Darwin quadrangle (Hall and MacKevett, 1958, p. 7). It is overlain apparently conformably by the Eureka Quartzite. R. J. Ross, Jr. (1964, p. 42) measured a section of Pogonip 1,278 feet thick in the Panamint Butte quadrangle 3.75 miles east-northeast of Lake Hill. He included 130 feet of interbedded quartzose rocks and dolomite between definite Eureka Quartzite and definite Pogonip Group as part of the Pogonip. These highly clastic beds are arbitrarily included in the Eureka Quartzite because lithologically they more closely resemble these overlying rocks and form a mappable unit with them, although they are transitional between the two formations.

Lithology

The Pogonip Group consists predominantly of light- and medium-gray fine-grained dolomite in beds 1–10 feet thick. The dolomite weathers light brownish gray. The upper part of the group is sandy and silty and grades into the overlying Eureka Quartzite. Several brown and reddish-brown cherty units as much as 135 feet thick, containing features referred to by McAllister (1952, p. 10) as "crepe structures," are prominent marker beds in the upper part of the Pogonip. The crepe structure consists of thinly bedded gray and brownish-gray limestone and dolomite interbedded with thin brown irregular chert beds. A zone of large gastropods is almost invariably present in the upper part of the Pogonip above the crepe beds and is so characteristic of the upper Pogonip that it can be considered a distinctive lithologic unit (fig. 3).

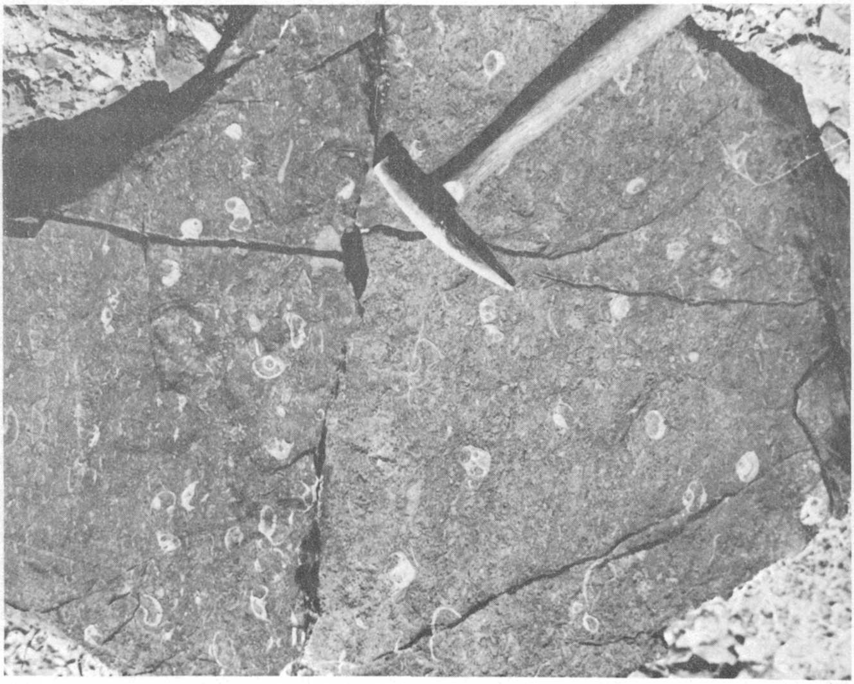

FIGURE 3.—*Palliseria robusta* (Wilson) zone of the upper part of the Pogonip Group in the measured section on the south side of Dolomite Canyon.

The following section was measured along the steep exposure on the north side of an extensive talus slope 4.15 miles N. 7° E. of BM 2081 on State Highway 190:

Eureka Quartzite.
(Conformable contact.)
Pogonip Group:

	Thickness (ft)
Dolomite, light-gray; weathers light brownish gray; contains scattered chert nodules; beds 2–10 in. thick; bottom 10 ft contains *Palliseria robusta* (Wilson)	100
Dolomite, medium-gray, and reddish-brown chert; beds 0.25–1 in. thick (crepe bed No. 3)	18
Dolomite, light-gray and brownish-gray, fine-grained; in beds 1–3 ft thick; contains *Girvanella* near top of unit	275
Dolomite, light-brown, thinly bedded; abundant dark-brown chert beds 0.12–0.25 in. thick (crepe bed No. 2)	36
Dolomite, light-gray and medium-gray; weathers light brownish gray; fine grained; beds 1–24 in. thick; some lenses and thin beds of light-gray and brown chert	63
Sandy dolomite, brownish-gray, brown, white, thinly bedded; interbedded with gray chert beds 1–8 in. thick (crepe bed No. 1)	43
Dolomite, light-gray and light-brownish-gray, fine-grained; beds 1–4 ft thick; locally scattered chert spicules; some thin chert beds near the bottom	335
Dolomite, light-gray and light-brownish-gray, fine-grained, medium- to thick-bedded; shattered and appears more massive than overlying strata	390
	1,260

(Conformable contract.)
Nopah Formation.

Age

The Pogonip Group is generally considered to be of Early and Middle Ordovician age. The only fossils found are in the upper part of the formation. Large gastropods lie within 150 feet of the top of the Pogonip nearly everywhere that this part of the section crops out (fig. 3). They were identified as *Palliseria robusta* (Wilson) by Reuben J. Ross, Jr., of the U.S. Geological Survey, from collections of similar gastropods in the adjacent Darwin quadrangle (Ross in Hall and MacKevett, 1962), and he reported they are high Lower or very low Middle Ordovician. *Receptaculites* sp. cf. *R. elongatus* Walcott was identified by Jean M. Berdan (written commun., 1957), and *Anomalorthis* sp., unidentified cystid plates, and probable *Girvanella* were identified by Reuben J. Ross, Jr., from the zone of *Palliseria* on the south side of Dolomite Canyon. Ross (1965, p. 44) later made a collection of silicified fossils from a dolomitic limestone about 30 feet above the *Palliseria* zone in the Panamint Butte quadrangle. He identified the silicified bryozoans as species found in the fauna from the *Anomalorthis* zone of the Antelope Valley Limestone of the Pogonip Group, as defined by Nolan, Merriam, and Williams (1956, p. 28–29); they considered the fossils from the upper Pogonip Group to be a Chazy fauna and to be Middle Ordovician in age.

EUREKA QUARTZITE

The Eureka Quartzite was named by Hague (1883, p. 262) from exposures near Eureka, Nev. The formation crops out on the west flank of the Panamint Range in the vicinity of Dolomite Canyon on the steep slope 4.5 miles N. 8° E. of BM 2081 on Highway 190 and in the basin 1 mile N. 22° E. of the Big Four mine. It is also exposed discontinuously in a jumbled section 1.25 miles S. 26° E. of Towne Pass. The most easily accessible complete section is on the south side of Dolomite Canyon 2.75 miles N. 31° E. of BM 2081. Another complete section is 3.25 miles north of Dolomite Canyon.

The Eureka Quartzite and the dark-gray Ely Springs Dolomite form one of the most distinctive units in the Paleozoic section, and they have been recognized over a wide area in southeastern California and Nevada.

Thickness and Stratigraphic Relations

Two stratigraphic sections of the Eureka Quartzite were measured. One, on the south side of Dolomite Canyon 2.75 miles N. 31° E. of BM 2081, is 285 feet thick; the other, 2.25 miles north of Dolomite Canyon at an altitude of 5,200 feet, is 250 feet thick. The Eureka is 440 feet thick to the west in the Darwin quadrangle (Hall and MacKevett, 1962) and 400 feet thick to the northwest in the Quartz Spring area (McAllister, 1952, p. 12). The upper contact with the overlying Ely Springs Dolomite is sharp and conformable. It is marked by a change from white vitreous quartzite to dark-gray cherty dolomite. The lower contact in the Panamint Butte quadrangle is gradational and not well defined. The contact was placed at a color change from brownish-gray slightly sandy dolomite in the Pogonip to pinkish or reddish sandy dolomite with some thin quartzite beds in the basal Eureka. This contact may not correlate with that in adjacent areas because the basal Eureka here is in large part dolomitic, unlike the typically vitreous quartzite in nearby areas in the Darwin quadrangle and elsewhere in the Panamint Range (Hunt and Mabey, 1966, p. 36). The name Eureka is retained here even though the section resembles the Mazourka Canyon section in the Inyo Mountains, where equivalent beds are called the Barrel Spring and Johnson Spring Formations by D. C. Ross (1966, p. 25).

Lithology

The Eureka Quartzite is much more dolomitic and shaly here than in sections described in adjacent areas by McAllister (1952, p. 12; 1956) or by Hall and MacKevett (1962). The Eureka consists of two units—a lower thinly bedded dolomitic unit and an upper quartzitic unit. The lower unit consists of interbedded light-brown, pink, and reddish-gray silty and sandy dolomite, sandy limestone, shale, and argillaceous quartzite. Lavender shale beds about a quarter of an inch thick are interbedded with some of the silty dolomite. The upper unit consists almost entirely of vitreous quartzite and is about 125 feet thick. The quartzite is white or light gray at the base and top of the upper unit and dark red or reddish gray in the middle of the unit.

The following section was measured in a small tributary canyon on the south side of Dolomite Canyon, 2.75 miles N. 31° E. of BM 2081 (pl. 1):

Ely Springs Dolomite.
(Sharp conformable contact.)

Eureka Quartzite:	*Thickness (ft)*
Quartzite, white, vitreous	35
Quartzite, greenish-gray and dark-reddish-gray	36
Quartzite, white and light-pink, vitreous	11
Quartzite, light-pink, reddish-gray, and dark-red; beds ¼–24 in. thick	11
Quartzite, white and light-gray, vitreous	23
Shale, black, siliceous; interbedded with light-gray shaly dolomite and minor quartzite; beds 1–24 in. thick	82
Dolomite, medium-gray; mottled appearance on weathered surface; beds 2–6 in. thick; some lavender shale beds ¼ in. thick	35
Quartzite, fine-grained, silty. Sandy dolomite and sandy limestone; light pink or light brown on fresh surfaces; weathers light brown	50
Quartzite, light-brown, argillaceous	2
(Transitional contact.)	285

Pogonip Group.

Another section was measured 4.2 miles N. 12° E. of BM 2081, starting at an altitude of 5,200 feet.

Ely Springs Dolomite.
(Sharp conformable contact.)

Eureka Quartzite:	*Thickness (ft)*
Quartzite, white and light-gray, vitreous; some gray shaly dolomite beds 1–2 in. thick	82
Quartzite, dark-gray; beds 6–12 in. thick	18
Quartzite, dark-red, vitreous	9
Quartzite, white and light-gray, vitreous; part is stained light red	36
Dolomite, reddish, reddish-gray, and brown, silty; beds 1–6 ft thick	105
	250

Pogonip Group.

Age

No fossils were found in the Eureka Quartzite, but on the basis of stratigraphic position, it is Middle Ordovician in age. The upper part of the Pogonip is abundantly fossiliferous, with a Chazy (early Middle Ordovician) fauna. The basal part of the overlying Ely Springs Dolomite contains fossils of Late Ordovician age.

ELY SPRINGS DOLOMITE

The Ely Springs Dolomite was named by Westgate and Knopf (1932, p. 15) for exposures of dolomite overlying the Eureka Quartzite in the Ely Springs Range west of Pioche, Nev. In the Panamint Butte quadrangle, it crops out in the vicinity of Dolomite Canyon and on Lake Hill in Panamint Valley (pl. 1). A complete section is exposed on the steep slope 4.5 miles N. 10° E. of BM 2081 on State Highway 190. The Ely Springs Dolomite forms a conspicuous dark band above the white Eureka Quartzite—a combination that makes a distinctive marker horizon in southeastern California (fig. 4).

Thickness and Stratigraphic Relations

The Ely Springs Dolomite is 670 feet thick in a measured section on the south side of Dolomite Canyon, 2.55 miles N. 31° E. of BM 2081. This compares with an approximate 920-foot thickness in the Darwin quadrangle (Hall and MacKevett, 1962), 940- and 740-foot thicknesses in two measured sections in the Quartz Spring area (McAllister, 1952, p. 13), and 270-foot thickness in the Inyo Mountains (Merriam, 1963, p. 10).

The Ely Springs Dolomite is overlain apparently conformably by the Hidden Valley Dolomite of Silurian and Early Devonian age. The contact between the two is gradational, and in places the two formations cannot be differentiated.

Lithology

The Ely Springs Dolomite consists of a lower unit of dark-gray cherty dolomite and an upper unit of light-gray dolomite. The lower unit forms a distinctive dark-gray band above the white Eureka Quartzite. The lower unit, which is 395 feet thick in the measured section 2.55 miles N. 31° E. of BM 2081, consists of medium-bedded dark-gray dolomite with abundant dark-gray chert lenses and nodules. The dolomite becomes progressively lighter in color upward in the section. The upper unit consists of light- and medium-gray thickly bedded dolomite. Chert is almost completely lacking. The upper unit grades into uniform light-gray medium- to thick-bedded

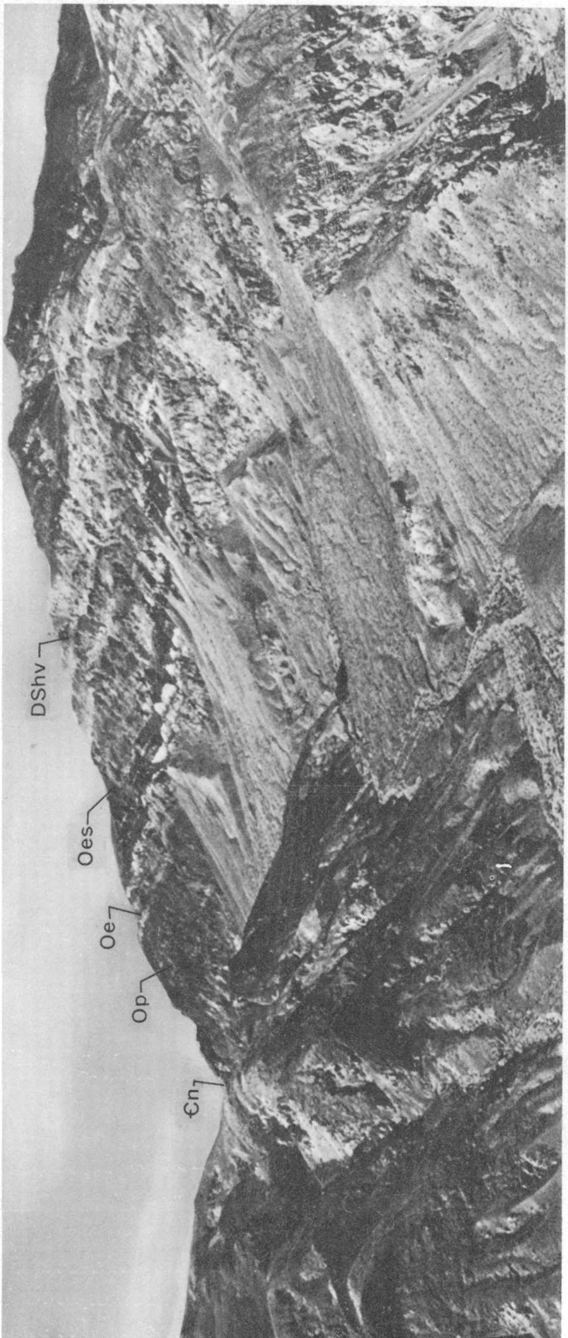

FIGURE 4.—Cambrian, Ordovician, and Silurian formations exposed on west face of Panamint Range on north side of Dolomite Canyon. Єn, Nopah Formation; Op, Pogonip Group; Oe, Eureka Quartzite; Oes, Ely Springs Dolomite; DShv, Hidden Valley Dolomite. Photograph by H. G. Stephens.

dolomite of the Hidden Valley Dolomite. Either the top of a dark-gray dolomite band in the light-gray dolomite or a brown thinly bedded sandy dolomite, where present, is used as the upper contact of the Ely Springs.

The following section of Ely Springs Dolomite was measured 2.55 miles N. 31° E. of BM 2081:

Hidden Valley Dolomite.
(Gradational contact.)

Ely Springs Dolomite:	*Thickness (ft)*
Dolomite, brown, thinly bedded, sandy	5
Dolomite, light-gray, sugary-grained, thickly bedded, shattered	10
Dolomite, medium-gray; beds 1–10 ft. thick; somewhat shattered	215
Dolomite, light-gray thickly bedded, shattered	45
Dolomite, medium-gray, with irregular brown chert lenses and nodules; beds 1–3 ft. thick	210
Dolomite, dark-gray, with abundant dark-gray and brown chert lenses and nodules; beds 6–24 in. thick; abundant brachiopod fragments (USGS colln. D545–CO)	185
	670

(Sharp conformable contact.)
Eureka Quartzite.

AGE

The Ely Springs Dolomite is Middle and Late Ordovician in age. USGS colln. D545–CO is from the base of the lower unit in the measured section. It is described by R. J. Ross, Jr., (written commun., 1960) as follows:

Brachiopods, silicified, include:
- *Lepidocyclus*? sp.
- *Sowerbyella*? sp. or *Thaerodonta*? sp.
- *Zygospira* sp.

This collection is fairly typical of the Ely Springs or Hanson Creek. Whether it is later Middle Ordovician or Late Ordovician in age would require a larger collection, a little better preserved.

Conodonts were collected from about 10 feet above the base of the Ely Springs and were described by W. H. Hass (written commun., 1957) as follows:

USGS colln. D 421–CO. Ely Springs Dolomite. Panamint Range 4 miles S. 88° E of VABM 2030, Lake Hill:
- *Belodus ornatus* Branson and Mehl
- *Paltodus* spp.
- *Plectodina* sp.
- *Zygognathus*? sp.
- New genus A

The above listed association of genera and species indicates a Middle to Late Ordovician age.

Reuben J. Ross, Jr., identified rhynchonellid brachiopods (*Lepidocyclus?* and (or) *Rhynchotrema*), *Paucicrura* sp., *Sowerbyella* sp., and *Plaesiomys* sp. from USGS colln. D421–CO (written commun., 1957). Ross (written commun., 1956) also studied a collection of fossils (USGS colln. D396–CO) from the lower Ely Springs on Lake Hill 400 feet southwest of VABM 2030 and reported as follows:

> This collection contains the cephalopod *Armenoceras* and several very poor specimens referrable to the brachiopod genus *Lepidocyclus*.
> *Armenoceras* ranges from Ordovician into Silurian.
> *Lepidocyclus* is an Upper Ordovician genus as far as is known at present.

SILURIAN AND DEVONIAN SYSTEMS

HIDDEN VALLEY DOLOMITE

Name and Distribution

The Hidden Valley Dolomite was named by McAllister (1952, p. 15) for exposures in the Quartz Spring area. The formation is exposed in the eastern part of the Panamint Butte quadrangle between North Panamint Canyon and Dolomite Canyon. The most readily accessible exposures are near the head of Dolomite Canyon. The most continuous exposure is a band about 1.4 miles long 4.5 miles N. 12° E. of BM 2081 on State Highway 190 (pl. 1); here the topography is very steep, and access is difficult.

Thickness and Stratigraphic Relations

The Hidden Valley Dolomite is approximately 400 feet thick on the west face of the Panamint Range 4.5 miles N. 12° E. of BM 2081, and it is about the same thickness on the ridge 4.60 miles N. 29° E. of BM 2081 (pl. 1). This is considerably thinner than the 1,365 feet at the type locality in the Quartz Spring area (McAllister, 1952, p. 15), the more than 1,000 feet in the Darwin quadrangle (Hall and MacKevett, 1958), or the 1,500 feet in the Inyo Mountains (Merriam, 1963, p. 11). Hazzard (1937, p. 326) described 335 feet of Silurian(?) dolomite in the Nopah Range.

The thickness of the Hidden Valley Dolomite apparently varies so greatly within a few miles that the difference suggests a period of erosion prior to Middle Devonian time. An erosional surface cannot be identified, however, because metamorphism of the carbonate rocks has made it difficult to distinguish the upper Ely Springs from the Hidden Valley Dolomite. The upper Ely Springs is a recrystallized light- to medium-gray dolomite that resembles the medium-thick-bedded light-gray Hidden Valley Dolomite. The contact was placed at the top of a dark-gray band in the Ely Springs. Where this band has been destroyed by metamorphism, or where it is absent, a brown sandy dolomite bed was used as the top.

Lithology

The Hidden Valley Dolomite consists of medium- to thick-bedded light-gray dolomite. The lower part is somewhat cherty and locally has sparse white vitreous quartzite beds, most less than 3 feet thick. Light-gray chert nodules that weather brown are present near the base.

Age

No well-preserved fossils were found in the Hidden Valley Dolomite in the quadrangle. Some very poorly preserved solitary corals, crinoid columnals, and probable favositids are present near the base of the formation 3.75 miles N. 12° E. of BM 2081. Brown-weathering chert nodules near the base of the formation are probably silicified favositids. Fossil evidence collected by McAllister (1952, p. 16–17) indicates the lower part of the Hidden Valley Dolomite in the Quartz Spring area is Silurian and the uppermost part is Lower Devonian.

DEVONIAN SYSTEM

LOST BURRO FORMATION

Name and Distribution

The Lost Burro Formation was named by McAllister (1952, p. 18) for exposures of carbonate rocks of Middle(?) and Late Devonian age at Lost Burro Gap in the Quartz Spring area. The formation is exposed in both the Argus and Panamint Ranges. It crops out in the northern part of the Argus Range on the north side of Stone Canyon at an altitude of 3,080 feet, and it underlies most of Lookout Mountain just south of the quadrangle on the south side of Stone Canyon (Hall and Stephens, 1963, pl. 2). In the Panamint Range it crops out between North Panamint and Dolomite Canyons in several outcrops displaced by faults and at the foot of the range on the north side of North Panamint Canyon.

Thickness and Stratigraphic Relations

The only complete sections are on the west and south flanks of hill VABM 7287 on the west face of the Panamint Range (pl. 1). The formation is 1,500 feet thick a mile southwest of VABM 7287 and apparently 1,170 feet thick along the ridge 1 mile south of the bench mark. The rocks are shattered in the latter section and may be thinned structurally. The Lost Burro Formation is 1,535 feet thick at the type locality in the Quartz Spring area (McAllister, 1952, p. 18), 1,500 feet thick in the Panamint Range east of the Panamint Butte quadrangle (Sears, 1953, p. 140), and 1,600 feet thick in the Inyo Mountains (Merriam, 1963, p. 15).

The Lost Burro Formation is overlain conformably by the Tin Mountain Limestone of Early Mississippian age. The contact is sharp and is marked by a change in color and in places by a sandy bed at the top of the formation.

Lithology

The Lost Burro Formation consists generally of dolomite in the lower part and limestone, in large part recrystallized to marble, and some dolomite in the upper part. The lower dolomitic part is exposed only in the Panamint Range. It is 200–300 feet thick and consists of interbedded light- and dark-gray banded dolomite. The dark-colored dolomite commonly is mottled with light-gray dolomite. The underlying Hidden Valley Dolomite is uniform light gray or light brownish gray, in contrast to the banded and mottled appearance of the Lost Burro Formation. The lower brownish quartzitic Lippincott Member of the Lost Burro Formation, described by McAllister (1955, p. 12) in the Ubehebe Peak quadrangle and by Hall and MacKevett (1962) from the Darwin quadrangle, is not well developed except for a 3-foot-thick brown quartzite bed at the base of the formation east of Towne Pass.

Dark limestone predominates in the middle part of the Lost Burro, and light-bluish-gray limestone in the upper part. The limestone is relatively pure. The dark limestone bands commonly contain poorly preserved stromatoporoids that have been partially replaced by chert. Locally, some dolomite is interbedded in the upper part of the formation. Tan sandy dolomite about 25 feet thick is at the top of the Lost Burro Formation in both the Argus and Panamint Ranges.

The upper part of the formation crops out in the Argus Range only at the south edge of the quadrangle along the ridge on the north side of Stone Canyon 3.4 miles east of the southwest corner of the quadrangle (pl. 1). There the Lost Burro is a light-gray thin- to medium-bedded marble, except for the top 25 feet.

Age

The Lost Burro Formation is Middle and Late Devonian in age. No fossils were found in the lower part of the formation, but the middle part contains poorly preserved but abundant stromatoporoids and cladoporoid corals, which are characteristic of the Middle Devonian of the Great Basin (for example see Nolan and others, 1956, p. 49–50).

Four collections of *Amphipora* were made from the vicinity of the Modoc mine on Lookout Mountain just south of the quadrangle (for location of collections see Hall and Stephens, 1963, pl. 2) and were described by W. A. Oliver, Jr., (written commun., 1959) as follows:

The age of the four *Amphipora* collections is most likely Middle or early Late Devonian. The range of this stromatoporoid genus is variously given, but Silurian and post-Devonian occurrences are not well authenticated anywhere, and none are known from North America. At the present time *Amphipora* is considered to be a good index of Middle and early Late Devonian age.

Amphipora and *Stromatopora* were collected from the middle part of the Lost Burro Formation on the south side of Dolomite Canyon at an altitude of 3,240 feet from medium-bedded gray dolomite 5,500 feet S. 51° E. of Towne Pass. Richard S. Boardman (written commun., 1957) reported a probable Middle or Late Devonian age for both.

MISSISSIPPIAN SYSTEM

TIN MOUNTAIN LIMESTONE

Name and Distribution

The Tin Mountain Limestone was named by McAllister (1952, p. 20) for a sequence of dark-gray limestones of Early Mississippian age in the Quartz Spring area. The formation is widespread in both the Panamint and Argus Ranges (pl. 1). It crops out for about 1.5 miles along the axis of a major anticline in the Argus Range in the southwestern part of the quadrangle. In the Panamint Range it is well exposed near the foot of the range on the north side of North Panamint Canyon and near the crest of the range between North Panamint and Dolomite Canyons (pl. 1). The most easily accessible exposure in the Panamint Range is three-quarters of a mile S. 65° E. of Towne Pass. This exposure is an excellent fossil locality for the Tin Mountain Limestone, but the top of the formation is eroded.

Thickness and Stratigraphic Relations

The Tin Mountain Limestone is 380 feet thick in the Argus Range in a measured section along the ridge 3.4 miles east of the southwest corner of the quadrangle. In the Panamint Range between Dolomite and North Panamint Canyons, it is about 450 feet thick. These thicknesses are comparable with the 425- and 475-foot measured sections in the Quartz Spring area (McAllister, 1952, p. 21) and 435 feet in the Darwin quadrangle (Hall and MacKevett, 1962). The thickness of at least 4,500 feet given by Hopper (1947, p. 409) for Mississippian (and older?) limestone in the northern Argus Range includes Devonian and Mississippian strata and strata that are duplicated by folding in an overturned anticlinal structure.

The Tin Mountain Limestone is conformably overlain by the Perdido Formation of Mississippian age. The contact between the two is gradational and is marked by the presence of bedded brown-stained chert in the overlying formation.

Lithology

The Tin Mountain Limestone is a thin- to medium-bedded fine-grained gray limestone that locally contains dark-brown chert lenses and nodules. Bedded chert, however, is absent, which distinguishes the Tin Mountain from the overlying Perdido Formation. In the Argus Range much of the Tin Mountain Limestone is bleached and recrystallized to marble and thus is difficult to distinguish from the marble of the Lost Burro Formation or from the Lee Flat Limestone.

The Tin Mountain Limestone is the most fossiliferous formation in the Paleozoic sequence. Syringoporoid corals, cup corals, and crinoid columnals are widespread and can be considered a lithologic characteristic that helps to distinguish the formation from similar limestone in the Devonian.

The following section was measured in the Argus Range along the ridge 3.4 miles east of the southwest corner of the quadrangle:

Perdido Formation.
(Conformable contact.)

Tin Mountain Limestone:	*Thickness (ft)*
Limestone, medium-gray; beds 6–48 in. thick; brachiopods, syringoporoid corals, and cup corals	20
Limestone, medium-gray, thinly bedded; some chert lenses and nodules; syringoporoid corals and cup corals are present locally	75
Limestone, medium-gray; beds 6–12 in. thick; sparse chert lenses; cup corals, syringoporoid corals, and crinoid columnals are abundant at the top of the unit	175
Limestone, medium-gray; beds 6–36 in. thick; some crinoid columnals and syringoporoid corals 25 ft above the base	110
	380

(Conformable contact.)
Lost Burro Formation.

Age

The age of the Tin Mountain Limestone is Early Mississippian. The upper part of the formation is abundantly fossiliferous, and fossils were observed nearly everywhere the formation crops out. *Syringopora surcularia* Girty and *Zaphrentites* sp. are particularly characteristic of the formation.

Two localities of Tin Mountain Limestone in the quadrangle contain an abundant Early Mississippian fauna. One is near the crest of the Panamint Range 4,200 feet S. 65° E. of Towne Pass, and the other is a tiny isolated hill of Tin Mountain Limestone in Panamint Valley 9,000 feet N. 69° W. of VABM 2030 on Lake Hill. The following faunas were identified from these two localities by J. Thomas Dutro, Jr., and Ellis L. Yochelson (written commun., 1959):

Corals (identified by W. J. Sando):

Amplexus sp.

Aulopora sp.

Corals (Identified by W. J. Sando)—Continued
- *Beaumontia*? sp.
- *Caninia* sp.
- *Cyathaxonia* sp.
- *Enygmophyllum* sp.
- *Homalophyllites* sp.
- *Lithostrotionella* sp.
- *Menophyllum*? sp.
- *Rylstonia* sp.
- *Syringopora surcularia* Girty
- *Syringopora* aff. *S. surcularia* Girty
- *Vesiculophyllum* sp.
- *Zaphrentites*? sp.

Bryozoans (identified by Helen Duncan):
- Branching bryozoans, indet.
- *Cystodictya* sp.
- *Fenestella* sp.

Brachiopods:
- *Buxtonia*? sp.
- *Camarotoechia* sp.
- *Chonetes* sp.
- *Cleiothyridina* cf. *C. obmaxima* (McChesney)
- *Cleiothyridina* sp.
- *Composita* sp.
- *Cyrtina* sp.
- *Dielasma*? sp.
- orthotetid brachiopod, genus indet.
- *Productella* sp.
- *Punctospirifer*? sp.
- *Rhipidomella* sp. aff. *R. michelini* (Leveille)
- *Rhynchopora*? sp.
- *Schizophoria* sp.
- *Spirifer* sp. (*centronatus*-type)
- *Spirifer* sp.
- terebratuloid brachiopod, genus indet.
- *Torynifer*? sp.

Pelecypods:
- *Allorisma*? sp.
- *Parallelodon*? sp.

Gastropods:
- cf. *Anomphalus* sp.
- *Baylea*? sp.
- *Bellerophon* sp.
- *Ianthinopsis*? sp.
- cf. *Loxonema* sp.
- *Mourlonia* sp.
- *Murchisonia* sp.
- *Naticopsis* sp.
- *Platyceras* (*Platyceras*) sp.
- pleurotomarian gastropod, genus indet.
- *Rhineoderma* sp.
- *Straparollus* (*Euomphalus*) *utahensis* (Hall)

Gastropods—Continued
- *Straparollus* (*Euomphalus*) *subplanus* (Hall and Whitefield)
- *Straparollus* (*Euomphalus*) sp. indet.
- subulitid gastropod, genus indet.

Cephalopods:
- goniatite cephalopod, undet.
- orthoceroid cephalopod, undet.

Trilobite:
- phillipsid trilobite, genus indet.

Worms (phylum Annelida):
- cf. *Spirorbis* sp.

W. J. Sando (written communication, 1959) reported as follows:

> The coral assemblage is very similar to that of the middle and upper Lodgepole Limestone (of the Madison Group) of Montana, Wyoming, and Utah. The Lodgepole is of Early Mississippian age.

J. Thomas Dutro, Jr., and Ellis L. Yochelson (written commun., 1959) reported

> The fauna [of F–223A and F228] is clearly related to that found in the upper part of the Lodgepole in the northern Rocky Mountains.

PERDIDO FORMATION

The Perdido Formation was named and described by McAllister (1952, p. 22) for a heterogeneous sequence of silty and cherty limestones, siltstone, and shale of Late Mississippian age in Perdido Canyon in the Quartz Spring area. The formation is present in both the Panamint and Argus Ranges in the Panamint Butte quadrangle. It crops out on the north side of the north-plunging anticline in the Argus Range. It is present near the crest of the Panamint Range between North Panamint Canyon and Dolomite Canyon and near the foot of the range north of North Panamint Canyon (pl. 1).

The formation is 370 feet thick in the Argus Range along the ridge north of Stone Canyon, 3.4 miles east of the southwest corner of the quadrangle. The contact with the overlying Lee Flat Limestone is a fault, but because this fault has a small displacement, the 370 feet is about the total thickness. In the Panamint Range, the formation is 350 feet thick near the crest of the range on the south side of North Panamint Canyon. The formation is 610 feet thick at the type locality (McAllister, 1952, p. 23), 200–335 feet thick in the Darwin quadrangle (Hall and MacKevett, 1962), and less than 200 feet thick in the southern Inyo Mountains (Merriam, 1963, p. 19).

The Perdido Formation is conformably overlain by the Lee Flat Limestone of Mississippian and Pennsylvanian(?) age. The contact between the two is marked by a sharp change from a dark-brown-weathering cherty limestone of the Perdido to white marble in the

Lee Flat Limestone (fig. 5). The Rest Spring Shale, which overlies the Perdido Formation in the Ubehebe Peak quadrangle (McAllister, 1956), is not present in the Panamint Butte quadrangle.

LITHOLOGY

The Perdido Formation is a dark-brown cliff-forming unit that makes a conspicuous marker bed. It consists of thinly bedded fine-grained bluish-gray limestone with abundant thin brown-weathering beds, lenses, and anastomosing veinlets of chert. The lithology of the Perdido changes southward considerably from that described at the type locality by McAllister (1952, p. 22–23), but is comparable with that described by Hall and MacKevett (1958, p. 8) in the Darwin quadrangle. The Perdido in the Panamint Butte quadrangle resembles the cherty units 1–7 of the type locality (McAllister, 1952, p. 23), but the upper clastic units are missing.

The following section of Perdido was measured along the ridge 3.4 miles east of the southwest corner of the quadrangle:

Lee Flat Limestone.
(Fault contact, displacement small.)

Perdido Formation:	Thickness (ft)
Limestone, medium-gray; in part dolomitized; beds 6–12 in. thick; crinoid columnals locally abundant	85
Limestone, medium-gray; brown-weathering chert; beds 2–6 in. thick	285
	370

(Conformable contact.)
Tin Mountain Limestone.

AGE

Very few fossils, except for crinoid columnals and a few poorly preserved solitary corals, were found in the Perdido Formation. The age in the report area can be given only as Mississippian because it is younger than the Early Mississippian Tin Mountain Limestone and older than the basal Keeler Canyon Formation of Pennsylvanian age.

McAllister (1952, p. 24–25), on the basis of fossil evidence in the Quartz Spring area, has shown that the Perdido is of Mississippian age, ranging possibly from late Kinderhook or Osage into Chester.

MISSISSIPPIAN AND PENNSYLVANIAN(?) SYSTEMS

LEE FLAT LIMESTONE

NAME AND DISTRIBUTION

Lee Flat Limestone is the name given a sequence of limestones of Mississippian and Pennsylvanian(?) age overlying the Perdido Formation at the south end of Lee Flat in the Darwin quadrangle (Hall and MacKevett, 1958, p. 8). The formation is present in both

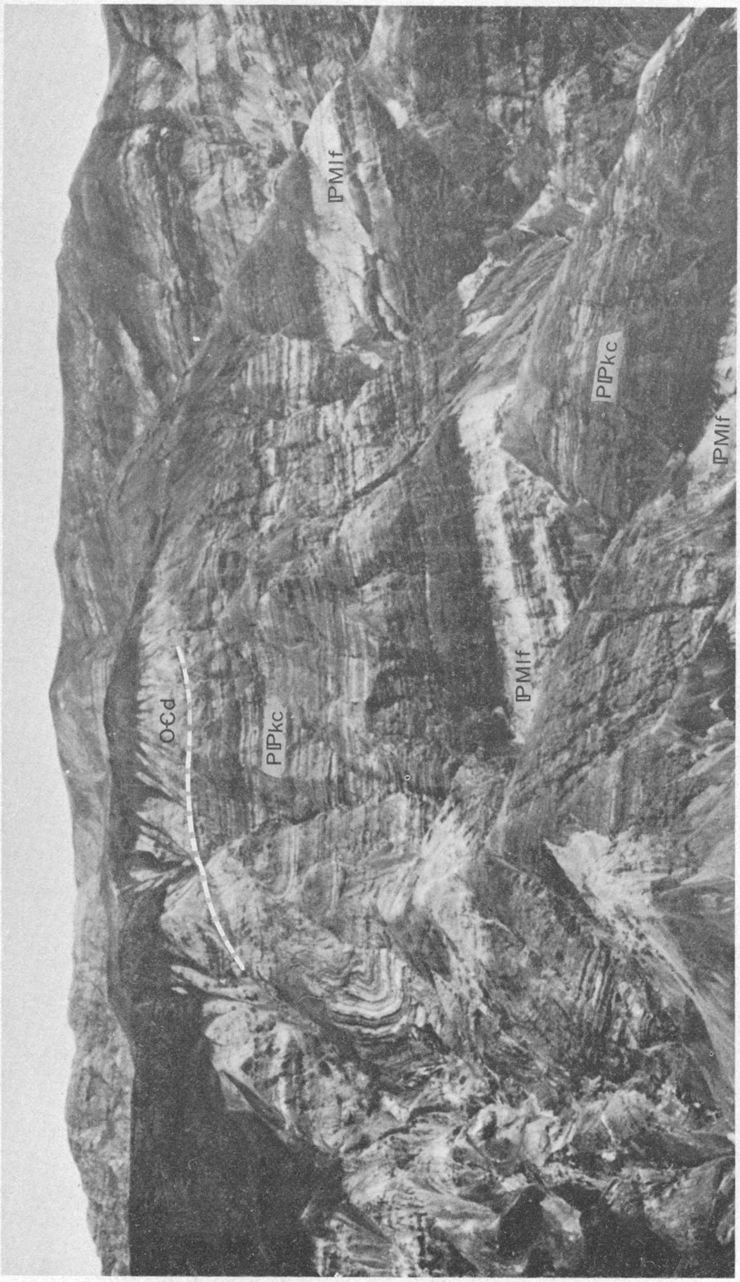

FIGURE 5.—West face of the Panamint Range on the north side of North Panamint Canyon. The Lee Flat Limestone (ℙMlf) is displaced by left-lateral N. 70° E.-striking faults. At the top of the range is the Lemoigne thrust (white line) with Cambrian and Ordovician dolomite (O€d) thrust over the Keeler Canyon Formation (PℙKc). Note the drag in the Keeler Canyon Formation. Photograph by H. G. Stephens.

the Argus and Panamint Ranges within the Panamint Butte quadrangle (pl. 1). It crops out around the nose of the plunging anticline in the Argus Range in the southwestern part of the quadrangle, and it forms the prominent white bands north of Dolomite Canyon on the west face of the Panamint Range (fig. 5).

Thickness and Stratigraphic Relations

The Lee Flat Limestone has a minimum thickness of 650 feet along the ridge on the north side of Stone Canyon, 3.4 miles east of the southwest corner of the quadrangle, but the lower contact is a fault of small displacement. The formation is 650 feet thick on the west face of the Panamint Range near the crest of the range between North Panamint and Dolomite Canyons.

The Lee Flat Limestone is overlain conformably by the Keeler Canyon Formation of Pennsylvanian and Early Permian age. The contact between the white marble of the Lee Flat Limestone and the thinly bedded dark limestone of the Keeler Canyon Formation in the Argus Range is sharp. In the Panamint Range the contact is obscured by alteration of the lower Keeler Canyon.

Lithology

The Lee Flat Limestone consists of white to light-gray marble with an average grain size between 1 and 2 millimeters. Beds commonly are less than 1 foot thick, but the uniform white color gives the formation a more massive appearance. Dolomitization of the marble is common in the Argus Range, but not in the Panamint Range. The following section of Lee Flat Limestone was measured in the Argus Range along the ridge 3.4 miles east of the southwest corner of the quadrangle:

Keeler Canyon Formation.
(Conformable contact.)

Lee Flat Limestone:	*Thickness (ft)*
Marble, white and light-gray locally dolomitized; beds 4–6 in thick; crinoid columnals locally abundant	400
Marble, white, thickly bedded; in part altered to light-brown dolomitic marble	250
	650

(Fault contact, displacement small.)
Perdido Formation.

A composite sample taken across the measured section of Lee Flat Limestone had the following analysis:

	Percent
SiO_2	0.32
Al_2O_3	.1
Total Fe as FeO	.10
MgO	.42
CaO	55.4
Na_2O	.06
K_2O	.02
TiO_2	.01
P_2O_5	0
MnO	0
H_2O	.08
CO_2	43.8
	100.2

The analysis of the sample of Lee Flat Limestone indicates about 2 percent dolomite and half a percent of limonite and quartz in the marble.

Age

No fossils other than abundant crinoid columnals were found in the Lee Flat Limestone. The same is true for the Lee Flat Limestone in the Darwin quadrangle (Hall and MacKevett, 1958, p. 9). The formation is considered Mississippian and Pennsylvanian(?) in age in the Panamint Butte quadrangle because it lies conformably between the Perdido Formation and the Keeler Canyon Formation. It is probable that the Lee Flat Limestone is the time-stratigraphic equivalent of the upper part of the Perdido and the Rest Spring Shale of the type section in the Quartz Spring area, because the Lee Flat lies conformably upon rocks equivalent to the middle nonclastic part of the Perdido Formation of the type locality. The age of the middle Perdido is not well documented, but J. S. Williams (in McAllister, 1952, p. 24) stated the faunal aspect suggests a Late Mississippian age. Furthermore, the basal part of the overlying Keeler Canyon Formation in the Argus Range contains fusulinids of Middle Pennsylvanian age.

PENNSYLVANIAN AND PERMIAN SYSTEMS

KEELER CANYON FORMATION

Name and Distribution

The Keeler Canyon Formation was named by Merriam and Hall (1957, p. 4) for a thick section of thinly bedded limestones of Pennsylvanian and Early Permian age in the southern Inyo Mountains. It is the most widely distributed Paleozoic formation in the Panamint Butte quadrangle. It is exposed on the flanks of the major north-plunging anticline in the Argus Range in the southwestern part of the quadrangle (pl. 1). In the Panamint Range the Keeler Canyon underlies the Lemoigne thrust sheet and crops out over most of the west face of the range north of North Panamint Canyon (pl. 1).

Thickness and Stratigraphic Relations

The thickness of the Keeler Canyon Formation differs widely over short distances within the quadrangle. A measured section in the Argus Range 3.3 miles N. 81° E. of the southwest corner of the quadrangle is 1,825 feet thick. Another section on the west flank of the anticline about 2.5 miles to the west is 2,600 feet thick. In the Panamint Range the formation is 2,685 feet thick on the west side of hill VABM 7287. The thickness of the Keeler Canyon Formation also differs widely in adjacent areas. It is 4,000 feet thick in the Darwin Hills (Hall and MacKevett, 1958, p. 9) and 1,300–2,500 feet thick in the New York Butte quadrangle at the type locality (Merriam and Hall, 1957, p. 5).

The Keeler Canyon Formation is conformably overlain by the Owens Valley Formation of Permian age. The contact between the formations is transitional, and the upper contact is difficult to define because of the great lateral variations within the Keeler Canyon Formation. It is placed, in general, at the base of abundant siltstone, lenses of pure limestone or limestone breccia, and crossbedded calcarenite in the overlying Owens Valley Formation.

Lithology

The Keeler Canyon Formation consists of thinly bedded bluish-gray silty and sandy limestone, clean limestone, limestone breccia, shale, and locally minor siltstone. The appearance of the formation in the Argus Range differs considerably from that in the Panamint Range.

In the Argus Range the formation is thin bedded and a uniform bluish-gray color. The lower part of the formation consists of thinly bedded gray and bluish-gray silty limestone that contains round chert nodules ¼–2 inches in diameter and is referred to as the "golf ball" horizon. Sparse small fusulinids are present locally. This unit is widespread at the base of the formation, as indicated by its occurrence at the type locality in the southern Inyo Mountains (Merriam and Hall, 1957, p. 5), in the Darwin quadrangle (Hall and MacKevett, 1962), and in the equivalent Tihvipah Limestone in the Quartz Spring area (McAllister, 1952, p. 26). Locally, northwest of the Surprise mine, a massive basal unit 500 feet thick consists of dark-gray fine-grained crinoidal-rich limestone. Much of this basal unit is limestone breccia or conglomerate; sparse tiny fusulinids of Middle Pennsylvanian age were found near the base.

The upper part of the Keeler Canyon Formation in the Argus Range is more shaly than the lower part. Black siliceous shale, pink shale, and some limestone conglomerate are interbedded with the predominant shaly limestones. Pink shales, which are abundant in the upper part of the Keeler Canyon in the Darwin quadrangle (Hall and MacKevett, 1962), are scarce in the Keeler Canyon on the east side of the Argus Range, but are abundant on the west side.

The following section of the Keeler Canyon Formation was measured 3.3 miles N. 81° E. of the southwest corner of the quadrangle:

Owens Valley Formation.
(Conformable contact.)

Keeler Canyon Formation:	*Thickness (ft)*
Limestone, blue-gray, medium- to thick-bedded, shaly and silty	180
Limestone, blue-gray, thin-bedded	105
Limestone, light-gray, shaly, thin-bedded; pure limestone beds 3–6 in. thick are commonly conglomeratic	410
Limestone, bluish-gray, and silty limestone; thin bedded; locally poorly preserved fusulinids	40
Shale; black, siliceous	5
Limestone, bluish-gray, thin-bedded; abundant crinoid columnals; contains disseminated tremolite needles 4–10 mm long	160
Limestone, bluish-gray, and gray silty limestone; thin bedded	35
Limestone, blue-gray, thin- and medium-bedded; a few thin beds and lenses of chert	100
Silty limestone, brown-weathering, thin-bedded; interbedded with bluish-gray limestone	175
Limestone, bluish-gray, thin-bedded	50
Limestone, bluish-gray with thin brown iron-stained partings; thin bedded; contains some round chert nodules ½–1½ in. in diameter	390
Limestone, bluish-gray; in beds 2–6 in. thick; contains round chert nodules ¼–1 in. in diameter and minor thin beds of brown shaly and silty limestone; locally contains *Fusulinella*	175
	1,825

(Conformable contact.)
Lee Flat Limestone.

In the Panamint Range the Keeler Canyon Formation has a banded appearance formed by alternating bluish-gray limestone and thin white or light-gray bands of marble (fig. 5). The limestone, particularly in the middle part of the formation, is much purer than to the west in the Argus Range or in the Darwin quadrangle and lacks the abundant fusulinids found elsewhere in the formation. The basal part of the formation contains chert nodules ½–1½ inches in diameter, similar to those in other described sections.

A partial section of the Keeler Canyon measured on the south side of North Panamint Canyon N. 70° W. from VABM 7287 is as follows:

Olivine basalt.
(Nonconformable contact.)

Keeler Canyon Formation:	*Thickness (ft)*
Limestone, bluish-gray, medium-bedded; locally contains *Rhomboporella*	580
Marble, white; interbedded with bluish-gray medium-bedded limestone and thin chert and siltstone; marble beds are as much as 25 ft thick	360
Limestone, bluish-gray, thin bedded; 1–2 in. thick chert beds	5
Marble, white, buff and light-gray; interbedded with bluish-gray medium-bedded limestone; contains ellipsoidal chert nodules 2½–3 in. in diameter; beds 2–15 ft thick; striped appearance because of dark and light bands	440
Silty limestone, bluish-gray, medium-bedded; at 405 ft contains brachiopods of probable Middle Pennsylvanian age	475
Silty limestone, thin- to medium-bedded; contains chert nodules ½–1½ in. in diameter ("golf ball" horizon)	825
	2,685

(Conformable contact.)
Lee Flat Limestone.

Age

The Keeler Canyon Formation ranges in age from Middle Pennsylvanian to Early Permian. Fusulinids are the most abundant part of the fauna in the Argus Range. They were found only in the upper part of the formation in the Panamint Range, where bryozoans are most abundant.

In the Argus Range fusulinids were found within 100 feet of the base and in the upper half of the formation. The basal part of the formation contains sparse tiny fusulinids in thin-bedded limestone containing chert nodules ¼–2 inches in diameter. R. C. Douglass (written commun., 1958) reported on a collection from this zone as follows:

Collection F12373. Location: base of Keeler Canyon Formation, S. 16° E., 5.75 miles from Panamint Springs at an altitude of 3,680 ft.

Climacammina sp.
Fusulinella sp.

This sample contains only a few recrystallized specimens of fusulines. These are probably assignable to *Fusulinella*, although all the characters cannot be determined. Middle Pennsylvanian (early Des Moines) is suggested.

This basal *Fusulinella* zone of probable early Des Moines age associated with chert nodules is present at the base of the Keeler Canyon Formation at the type locality in the southern Inyo Mountains (Merriam and Hall, 1957, p. 6), in the Darwin quadrangle (Hall and MacKevett, 1962), and in the Quartz Spring area in the Tihvipah Limestone (McAllister, 1952, p. 26–27), which correlates with the lower part of the Keeler Canyon Formation.

In the lower part of the upper unit *Triticites* is the characteristic fusulinid. *Pseudofusulinella*, *Schwagerina*, and primitive forms of *Parafusulina* are other common genera from this part of the section. R. C. Douglass (written commun., 1958) stated this fauna is of Early Permian age, probably middle and late Wolfcamp equivalent.

The uppermost part of the Keeler Canyon Formation contains predominantly *Schwagerina*, *Paraschwagerina*, *Pseudofusulinella*, *Triticites*, and possibly *Pseudoschwagerina*. The following description by R. C. Douglass (written commun., 1958) is based on a collection several feet from the top of the Keeler Canyon:

Collection F12378. Location: top of Keeler Canyon Formation, crest of Argus Range S. 20° W., 4.5 miles from Panamint Springs at an altitude of 5,280 ft.

Climacammina sp.
Bradyina sp.
Triticites sp.
Schwagerina sp.

This sample has fair preservation and a good fusuline fauna. It is of Early Permian age, probably late Wolfcamp equivalent. It appears to be younger than F12377 but not latest Wolfcamp.

In the Panamint Range fusulinids were found only in the uppermost part of the Keeler Canyon Formation. The middle part contains bryozoans and some brachiopods, while the lower part is apparently unfossiliferous. Correlation of the base of the Keeler Canyon in the Panamint Range with that in the Argus Range is based on lithology and stratigraphic succession. In both ranges the basal part of the Keeler Canyon consists of thinly bedded limestone with dark spheroidal chert nodules—the "golf ball" horizon. In the Argus Range this unit is Middle Pennsylvanian in age.

In the Panamint Range the lowest fossils that were sufficiently well preserved to be collected are about 1,000 feet above the base of the Keeler Canyon Formation. They were described by J. Thomas Dutro, Jr., (written commun., 1959) as follows:

Collection F18312–PC: Keeler Canyon Formation, 2,200 ft N. 48° W. of VABM 7287 at an altitude of 6,540 ft.

orthotetid brachiopod, indet.
Mesolobus? sp.
Lissochonetes? sp.

This collection is most likely of Middle Pennsylvanian age. Only the relatively poor preservation of the material prevents a more positive assignment.

Brachiopods were collected about half a mile south of collection F18312–PC and approximately 1,400 feet above the base of the formation. They were described by J. Thomas Dutro, Jr., (written commun., 1959) as follows:

Collection F18313–PC (Field No. F316). Keeler Canyon Formation, 1,000 ft S. 67° W. of VABM 7287 at an altitude of 7,120 ft.

The single collection F–316 (USGS 18313–PC) contains *Rhipidomella nevadensis* Meek. This species, according to Mackenzie Gordon, Jr., characterizes a zone in the uppermost Mississippian and lowermost Pennsylvanian in the Great Basin. Gordon considered it more likely to be uppermost Mississippian but pointed out that the species ranges 'a couple of hundred feet up into Lower Pennsylvanian strata.' Your collection F–600 from 50 ft above F–316 (F18313–PC) is definitely of Pennsylvanian age, probably Middle Pennsylvanian.

A collection of bryozoans and brachiopods collected 50 feet stratigraphically above F–316 is considered to be of probable Middle Pennsylvanian age by Helen Duncan and J. T. Dutro, Jr., (written commun., 1959). They reported the following:

USGS 18460–PC. Keeler Canyon Formation, ridge crest about 600 ft S. 70° W. of VABM 7287.

Fusulines
Crinoid columnals
Rhomboporella sp.
Polypora sp.
Orthotetid brachiopod, indet.
Crurithyris sp.
Hustedia sp.

Most of the blocks in this collection contain the bryozoan *Rhomboporella* but no indications of other fossils. One piece exhibited a few silicified brachiopods and was therefore dissolved in acid. A few fusulines as well as the brachiopods and other types of bryozoans were obtained. The brachiopods were examined by Dutro and the bryozoans by Duncan. The *Crurithyris* is a large species, unlike any known to Dutro from pre-Pennsylvanian rocks. The association of brachiopods, fusulinids, and *Rhomboporella* indicate a probable Middle Pennsylvanian age.

Bryozoans were collected 2,100 feet above the base of the formation on the northwest side of hill VABM 7287. They were identified as *Rhomboporella* by Helen Duncan (J. Thomas Dutro, Jr., written commun., 1959), who stated that this genus ranges from early Middle Pennsylvanian into Early Permian and considers it an appropriate component of the Keeler Canyon fauna.

PERMIAN SYSTEM

OWENS VALLEY FORMATION

NAME AND DISTRIBUTION

The Owens Valley Formation was named by Merriam and Hall (1957, p. 7) for a thick section of limestone, siltstone, and shale of Permian age in the southern Inyo Mountains. The formation is exposed in the Panamint Butte quadrangle in the northern part of the Argus Range, where it crops out in a northwest-plunging anticline. In the Panamint Range the Owens Valley Formation is exposed for 4 miles under the Lemoigne thrust, 3 miles north-northwest of Towne Pass.

Thickness and Stratigraphic Relations

A partial section of Owens Valley Formation 1.5 miles southwest of Panamint Springs is 2,400 feet thick. The formation conformably overlies the Keeler Canyon Formation of Middle Pennsylvanian to Early Permian age. The lower contact of the Owens Valley is gradational, but is placed at the base of a brown siltstone unit 400 feet thick that crops out 1.3 miles west of the Surprise mine (pl. 1). The Owens Valley Formation is intruded by quartz monzonite 1 mile southwest of Panamint Springs, so only a partial, contact-metamorphosed section of the formation is present. In the Panamint Range the upper contact is covered by basalt and by the Lemoigne thrust.

Lithology

Only the lower unit of the Owens Valley Formation, described in the Darwin quadrangle by Hall and MacKevett (1962, p. 26), is present in the Panamint Butte quadrangle. It consists mainly of thin- to medium-bedded limestone, shaly and silty limestone, siltstone, and lenses of pure limestone and limestone breccia. A siltstone unit 400 feet thick is at the base of the formation in the Argus Range. The basal siltstone unit contains brown-stained siliceous siltstone beds interlayered with bluish-gray beds of limestone 1–3 inches thick. Much of the Owens Valley Formation is metamorphosed to a brown-stained calc-hornfels in the Argus Range, and the identification of the formation, where metamorphosed, is based mainly on stratigraphic position.

Age

Only the lower part of the Owens Valley Formation is exposed; fusulinids are abundant in parts of the formation, and solitary corals, bryozoans, and gastropods are present locally. The fusulinids are considered to be Early Permian (late Wolfcamp equivalents) by R. C. Douglass (written commun., 1958). Two collections of fusulinids from the Owens Valley in the Argus Range were reported by Douglass as follows:

Collection F12381. Location: lower member of Owens Valley Formation, 1.55 miles S. 20° W. of Panamint Springs at an altitude of 3,200 ft.

Climacammina sp.
Pseudofusulinella sp.
Schwagerina spp.
Parafusulina sp. (primitive form)

This sample has some of the best preserved specimens in the samples in this shipment. The sample is of Early Permian age, probably late Wolfcamp.

Collection F12374. Location: top of lower member of Owens Valley Formation, S. 21° W., 5.0 miles from Panamint Springs at an altitude of 2,640 ft in Osborne Canyon.

Schwagerina spp.

?*Pseudoschwagerina* sp.

Paraschwagerina sp. (primitive form)

This sample represents Early Permian age, probably late Wolfcamp equivalents.

Two collections of fusulinids from the Owens Valley Formation in the Panamint Range were reported by Charles A. Ross (written commun., 1959) as follows:

Collection F–301. Owens Valley Formation, Panamint Range, 3.6 miles N. 3° W. of Towne Pass.

Of the two silicified specimens sent, one is a bryozoan; the other a fusulinid probably belonging to the genus *Schwagerina*. The presence of this genus suggests a Wolfcamp or Leonard age for the collection.

Collection 302. Owens Valley Formation, Panamint Range, 3.1 miles N. 15° W. of Towne Pass.

The fusulinids in this collection include *Schwagerina* cf. *S. hessinsis* Dunbar and Skinner and *Pseudoschwagerina* cf. *P. moranensis* Thompson. These two species are common in the upper part of the Wolfcamp Series and the fauna in this collection represent approximately the same faunal zone.

MESOZOIC ROCKS

PLUTONIC ROCKS

Granitic rocks crop out over approximately 14 square miles in the Panamint Butte quadrangle. They include two main rock types: a biotite-hornblende-quartz monzonite and a leucocratic quartz monzonite. These are the same rock types described in the Darwin quadrangle by Hall and MacKevett (1962). Locally, granodiorite and syenodiorite constitute hybrid border zones, and small dikes and irregular bodies of aplite and leucogranite are common near the borders of plutons. The biotite-hornblende-quartz monzonite in the northern part of the quadrangle extends into the Ubehebe Peak quadrangle, where it has been named the Hunter Mountain Quartz Monzonite (McAllister, 1956).

The granitic rocks intrude Paleozoic sedimentary rocks. Much material was assimilated by the magma, particularly where it was in contact with silty limestones. Consequently the borders of plutons are commonly hybrid quartz-poor rocks that include monzonite, syenodiorite, diorite, and hornblende gabbro.

Fresh exposures of granitic rocks are not abundant, as most hills underlain by granitic rocks are well rounded and grus covered. Small dikes and bodies of leucogranite and aplite are much more resistant and form the best exposures.

BIOTITE-HORNBLENDE-QUARTZ MONZONITE

Biotite-hornblende-quartz monzonite is the dominant granitoid rock type (fig. 6). It crops out in the northern part of the quadrangle and forms the south end of the quartz monzonite described by McAllister (1956). It is present in the Argus Range in a stock 1 mile west of Panamint Springs. It is typically a medium-grained light-gray rock speckled with 10–20 percent mafic minerals. Texture ranges from equigranular to porphyritic, with the porphyritic texture being 10–20 percent phenocrysts of pink feldspar as much as 1½ cm in diameter in a hypidiomorphic granular groundmass of 1–3 mm grain size.

The centers of intrusives are predominantly quartz monzonite. Essential minerals are quartz, potassium feldspar, and plagioclase. Feldspar of about equal amounts plagioclase and potassium feldspar makes up 65–79 percent of the rock. Plagioclase is calcic oligoclase or andesine and is strongly zoned An_{43}–An_{28}. Potassium feldspar is mostly orthoclase microperthite; microcline is less common. Quartz varies greatly in amount. The center of intrusives has 10–15 percent quartz, but only 2–3 percent may be present in hybrid border facies.

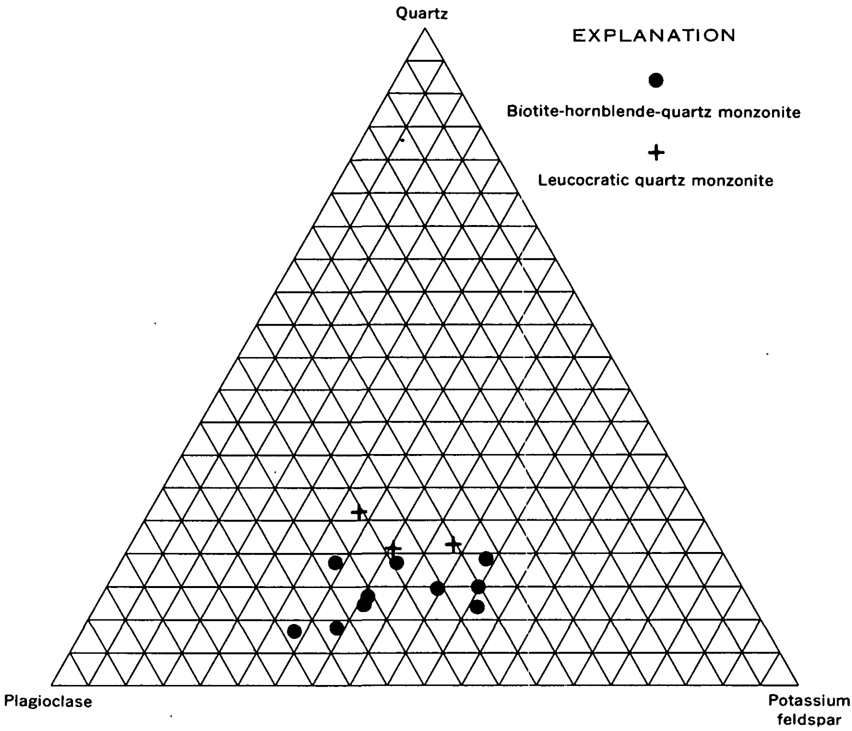

FIGURE 6.—Modal analyses: biotite-hornblende-quartz monzonite and leucocratic quartz monzonite.

The mafic mineral content increases near the contacts, and composition approaches monzonite or syenodiorite.

Varietal minerals, biotite and hornblende, constitute 10–20 percent of the rock; hornblende is more abundant. Accessory minerals are apatite, sphene, magnetite, and zircon.

LEUCOCRATIC QUARTZ MONZONITE

Leucocratic quartz monzonite crops out over an area of about 2 square miles near the head of Osborne Canyon and in the vicinity of Zine Hill. It is a medium-grained light-gray to light-pinkish-tan granitoid rock that commonly has pink potassium feldspar phenocrysts as much as 1 cm in diameter in a hypidiomorphic granular groundmass averaging 2 mm in grain size. Biotite-rich inclusions as much as 2 feet long are present locally. Plagioclase, orthoclase, and quartz are essential minerals. Plagioclase is calcic oligoclase or sodic andesine (An_{23}–An_{33}) and is strongly zoned. Potassium feldspar is microperthitic orthoclase; grid twinning is rare. Quartz is more abundant than in the biotite-hornblende-quartz monzonite (fig. 6).

Biotite is the predominant mafic mineral and constitutes 2–5 percent of the rock. The biotite is in large part altered to chlorite. Apatite, sphene, magnetite, and zircon are accessory minerals.

Age

The biotite-hornblende-quartz monzonite is Early Jurassic in age. It intrudes the Keeler Canyon Formation of Middle Pennsylvanian to Early Permian age and is overlain by late Cenozoic deposits. Two intrusions of biotite-hornblende-quartz monzonite in the Argus Range were dated by the lead-alpha and potassium-argon methods as approximately 180 million years. One sample was collected from the pluton in Darwin Canyon 1 mile west of Panamint Springs at an altitude of 2,120 feet; the other was collected in Thompson Canyon 1.4 miles S. 85° W. of the Minnietta mine at an altitude of 3,910 feet. (See Hall and Stephens, 1963, pl. 2 for location.) The latter locality is just south of the Panamint Butte quadrangle and is in the pluton that underlies Maturango Peak. Data for the samples and the constants used are given in Hall and MacKevett (1962, p. 31).

The relative age of the biotite-hornblende-quartz monzonite and leucocratic quartz monzonite is uncertain, as they are not in contact with each other; however, the leucocratic quartz monzonite is presumed to be slightly younger (Hall and MacKevett, 1962, p. 31).

ANDESITE PORPHYRY DIKES

A swarm of altered andesite porphyry dikes striking about N. 70° W. cuts the Paleozoic sedimentary rocks and quartz monzonite at the north end of the Argus Range (pl. 1). This dike swarm extends from the Argus Range northwest at least 30 miles to the southern Inyo Mountains. Moore and Hopson (1961) have described a dike swarm in the Sierra Nevada and Inyo Mountains that they consider to be a continuation of the same swarm. If so, the length of the dike swarm is 85 miles. The dikes are as much as 1 mile long and 10 feet thick; in places, mineral deposits are adjacent to them (Hall and Stephens, 1963).

The andesite porphyry is greenish gray on fresh surfaces and weathers brownish. It invariably is highly altered and consists of phenocrysts of plagioclase with saussuritic alteration in a fine-grained groundmass of plagioclase, hornblende, clinozoisite, chlorite, and calcite. Plagioclase is mainly albite with occasional relict andesine.

The dikes intrude quartz monzonite, but are older than the lead-silver deposits. The dikes are younger than Early Jurassic and are considered Cretaceous(?) in age.

CENOZOIC ROCKS

No early Cenozoic deposits are known in the quadrangle. Late Cenozoic deposits include both sedimentary and volcanic rocks. Sedimentary rocks are mostly fanglomerates, but also include lacustrine clastic deposits, fresh-water limestone and tufa, sand dune deposits, and monolithologic breccias. Old fanglomerate and monolithologic breccias are present mainly in the Panamint Range, although some are exposed in roadcuts along State Highway 190 at the north end of the Argus Range (pl. 1). Volcanic rocks include olivine basalt flows and dikes, basaltic tuff, tuff-breccia, agglomerate, quartz-olivine basalt, and welded rhyolite tuff. Olivine basalt is the most abundant volcanic rock type and forms extensive dip slopes on the east slopes of both the Panamint and Argus Ranges. A correlation chart for the Cenozoic rocks is given in table 2.

PLIOCENE

FANGLOMERATE NO. 3

Fanglomerate No. 3, of Pliocene age, is present in both the Argus and Panamint Ranges, particularly in the vicinity of Towne Pass. The fanglomerate is red or buff in color and is moderately well cemented by a clayey matrix. The more highly indurated parts commonly are cliff forming, and in canyons they tend to develop dry falls and vertical-walled ravines. Fanglomerate No. 3 is tilted 20°–40° E., and it lies unconformably on Paleozoic rock of Cambrian to Permian age. Part of this fanglomerate was included with

TABLE 2.—*Correlation chart of volcanic and sedimentary rocks of Cenozoic age*

Era	Period	Epoch	Volcanic rocks	Sedimentary deposits
Cenozoic	Quaternary	Holocene		Alluvium: includes fanglomerate (essentially untilted, but may be elevated and dissected), playa deposits, grus, slope debris, talus deposits, and sand dunes.
		Pleistocene		Fanglomerate No. 1: dissected unconsolidated gravel that is slightly tilted. Lacustrine deposits and tufa and fresh-water limestone in Panamint Valley.
	Tertiary or Quaternary	Pleistocene or Pliocene		Fanglomerate No. 2: tilted, moderately consolidated, dissected.
	Tertiary	Pliocene	Olivine basalt (forms extensive dip slopes) Basaltic pyroclastic rocks Quartz-olivine basalt and tuff-breccia Rhyolite tuff	Fanglomerate No. 3: red conglomerate and monolithologic breccia tilted to dips of 20°-40° E. Included in part in Nova Formation by Hopper (1947).

younger tilted fanglomerate in the Nova Formation by Hopper (1947, p. 414). The name Nova Formation has not been used here because of uncertainty about what it includes. No complete section is exposed, but east of Towne Pass, fanglomerate No. 3 is more than 7,800 feet thick.

In the lower part fanglomerate No. 3 is iron stained and well consolidated. It contains subrounded pebbles and boulders of quartzite, schist, gneiss, diorite, and phyllite, but it contains no olivine-basalt clasts. Basalt agglomerate, basalt, monolithologic breccias, and fine-grained sediments are interbedded near the top of the fanglomerate. Fine-grained beds in the fanglomerate are white, bluish-gray, green, and reddish-brown layers of clay, silt, and sand.

Monolithologic breccias are abundant in the fanglomerate and are well exposed 1.5 miles east of Towne Pass (fig. 7). The breccias are from shattered dolomite and quartzite formations of Paleozoic age and have a local source, whereas most of the clasts in the fanglomerate came from Precambrian terrane farther to the southeast in the Panamint Range. The bottom of a monolithologic breccia lens has subangular fragments mostly less than a quarter of an inch in diameter in a clay- and sand-size matrix which extends about 4 feet above the base; the matrix is about 50 percent of the rock. The size of the fragments increases upward and the amount of matrix decreases. Individual breccia lenses are as much as 250 feet thick and 2 miles

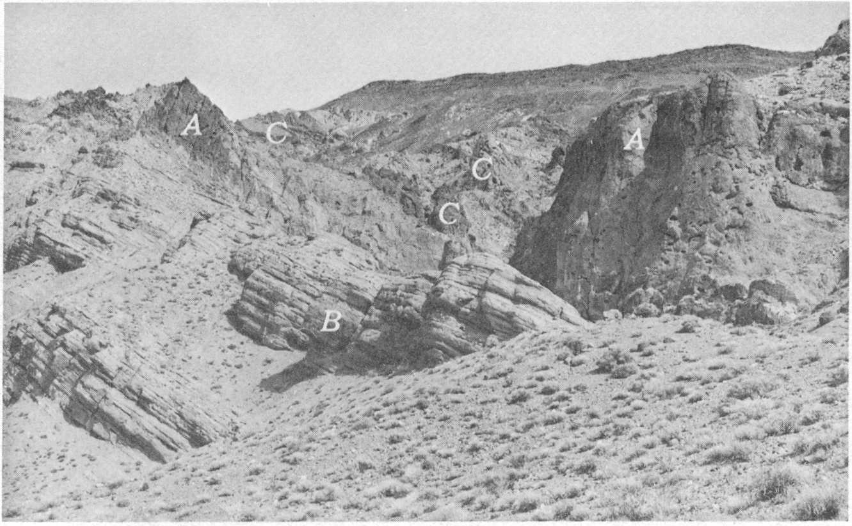

FIGURE 7.—Monolithologic breccia of Paleozoic dolomite (*A*) interbedded in red conglomerate (*B*), east of Towne Pass. Other monolithologic breccias (*C*) can be seen in the distance.

in length. The breccias slid by gravity onto the fanglomerate during the late Pliocene and thus formed concordant lenses.

Fresh-water limestones were deposited in local ponds in the fanglomerate in the Argus Range. One such limestone is exposed 1 mile east of the west border of the quadrangle on the north side of State Highway 190.

QUARTZ-OLIVINE BASALT

Quartz-olivine basalt flows and minor intrusive rocks and some basalt tuff-breccia and agglomerate are interbedded near the top of fanglomerate No. 3 on the west slope of the Panamint Range. These are grouped as quartz-olivine basalt on plate 1. Many good exposures of the quartz-olivine basalt are readily accessible in canyons cutting fanglomerate No. 3 south and east of California State Highway 190, for example, in the canyon that intercepts Highway 190 at BM 3863. Here the basalt has a maximum thickness, in two units, of about 430 feet. The two units are separated by several hundred feet of fanglomerate and monolithologic breccia. Both units are similar lithologically and consist predominantly of quartz-olivine basalt and agglomerate.

The quartz-olivine basalt is much less continuous than the younger olivine basalt, which forms extensive dip slopes in the Argus and Panamint Ranges. The lack of continuity is due both to original lenticularity and to later erosion. There is a marked angular unconformity between fanglomerate No. 3 and the overlying fanglomerate No. 2. Because the quartz-olivine basalt forms a resistant unit, it commonly forms the erosion surface and protects the underlying, less resistant Pliocene gravels from erosion.

The quartz-olivine basalts are red, purple, green, or gray and are commonly conspicuously porphyritic or amygdaloidal. Where the basalts are associated with fine-grained lacustrine deposits, the color is generally greenish, and the rock is thoroughly shattered. Palagonitic alteration and conspicuous amygdaloidal structure are prevalent in the shattered flows. The shattering is limited to certain flows or bottoms of flows overlying lacustrine deposits, and shattered flows may be overlain by unshattered flows. The shattering is attributed to rapid cooling due to extrusion over wet sediments.

The quartz-olivine basalt contains abundant phenocrysts of olivine and plagioclase and fewer phenocrysts of augite, orthoclase, and quartz, in a glassy or fine-grained pilotaxitic groundmass. Olivine forms euhedral phenocrysts approximately 2 mm in diameter and is present as tiny anhedral grains disseminated through the groundmass. In the grayish flows the olivine is unaltered, but in the purplish and reddish basalts it is largely altered to iddingsite. The olivine has the indices $n\alpha=1.673$ and $n\gamma=1.712$, which indicate a fayalite content of about 23 molecular percent.

Plagioclase (An_{45}–An_{55}) occurs in the groundmass as subhedral phenocrysts commonly 1–2 mm long and as subhedral laths. Usually the plagioclase phenocrysts exhibit albite and in some cases Carlsbad twinning. The plagioclase phenocrysts generally have zonal growths that have abundant unconnected inclusions oriented along cleavage, similar to those described by Larsen, Irving, Gonyer, and Larsen (1938, p. 232) in mainly quartz basalts of the San Juan volcanics, by Kuno (1950, p. 968) in the Hakone volcano, Japan, and by Schmidt (1957, p. 133) in andesites of Saipan. In a few plagioclase crystals, the inclusions are distributed throughout the phenocrysts, are coarser, and are vermicular in shape. The inclusions in most phenocrysts are glass; in some, the inclusions are opaque and apparently are glass mixed with iron oxides. The plagioclase phenocrysts nearly always have a clear core, an intermediate zone containing abundant glass inclusions, and a thin clear outer rim. The clear core and the intermediate zone with inclusions show evidence of corrosion; the outer clear zone is everywhere of uniform thickness and shows no corrosive effects. It seems probable that the clear core was an early phenocryst formed while the basaltic magma was deep seated. The zone with inclusions probably developed during initial eruption of the basaltic lava when gases were first being given off; this period was one of rapid growth. The outer clear rim has the same composition as the plagioclase laths of the groundmass and formed when the flow was virtually in place.

Small amounts of quartz and orthoclase xenocrysts are present. The quartz is always rounded, strained, and invariably has a thin reaction rim of diopsidic pyroxene rods oriented perpendicular to the grain boundary. Small amounts of orthoclase are distributed irregularly as corroded phenocrysts as much as 1 cm long in the quartz-olivine basalt. Both the quartz and orthoclase presumably are foreign, although no local source is known except the Precambrian basement complex, which is under a thick sedimentary cover. Table 3

TABLE 3.—*Chemical analyses and norms, in weight percent, of quartz-olivine basalt*

[Analysts: P. L. D. Elmore, Hezekiah Smith, Lowell Artis, Gillison Chloe, James Kelsey, and J. L. Glenn]

Sample	WH-68-2	WH-68-3	Sample	WH-68-2	WH-68-3
Chemical analyses			**Norms**		
SiO_2	50.6	56.5	Q	3.6	6.2
Al_2O_3	16.1	16.7	or	8.3	13.0
Fe_2O_3	7.2	2.5	al	26.3	30.5
FeO	1.0	4.2	an	25.9	22.9
MgO	7.7	5.7	di	3.4	3.1
CaO	8.4	5.9	hy	17.6	16.5
Na_2O	3.1	3.6	mt	.2	3.6
K_2O	1.4	2.2	il	2.3	2.5
H_2O^-	.40	.28	ap	.3	.7
H_2O^+	.90	.55	cc	3.3	.2
TiO_2	1.2	1.3			
P_2O_5	.39	.29			
MnO	.14	.12			
CO_2	1.4	.10			
Sum	100	100			

gives the analysis and norm of two samples of quartz-olivine basalt. Both samples are from the Panamint Range on the southeast side of State Highway 190 in the canyon that intercepts the highway at BM 3863. Sample WH-68-2 is purplish amygdaloidal olivine basalt from the top of the lower unit. Sample WH-68-3 is gray massive quartz-olivine basalt from the top of the upper unit. Sample WH-68-2 has a very low ferrous iron content that probably is due to deuteric alteration. Sample WH-68-3 contains xenocrysts of potassium feldspar, and the analysis shows an anomalous content of potash.

AGE

The quartz-olivine basalt is late Pliocene in age. Jarel Von Essen (written commun., 1969) dated sample WH-68-3 as 5.13 ± 0.35 million years. This sample is from the upper unit of quartz-olivine basalt in the Panamint Range 800 feet southeast of State Highway

190, in the canyon that intersects the highway at BM 3863. Data for the calculations are given below:

[Potassium analyses by Lois B. Schlocker]

Field No.	*Rock name*	*Percent* K_2O	Ar^{40}_{rad} (*moles per g*)	$\frac{Ar^{40}_{rad}}{Ar^{40}_{total}}$	*Age (m.y.)*
WH-68-3	Quartz-olivine basalt.	2.23	1.700×10^{-11}	0.19	5.13 ± 0.35

NOTE.—Constants used: $\lambda_\beta = 4.72 \times 10^{-10}$ per year, and $\lambda_\epsilon = 0.585 \times 10^{-10}$ per year.
Abundance ratio: $K^{40}/K = 1.19 \times 10^{-4}$ atom percent.

RHYOLITE TUFF

A welded rhyolite tuff, the oldest volcanic unit in the Argus Range, is exposed discontinuously over a distance of 6 miles from the south end of Ash Hill along the foot of the Argus Range. It probably was continuous originally, but the tuff is friable and easily eroded. Best exposures are along the west side of Ash Hill south of Osborne Canyon and at an altitude of 2,800 feet on the ridge on the north side of Osborne Canyon.

The welded tuff has a maximum thickness of 150 feet on the ridge north of Osborne Canyon, where it is overlain by olivine basalt and underlain by the Keeler Canyon Formation. It consists of a lower light-colored unit about 100 feet thick and an upper darker unit about 50 feet thick. The lower unit consists of white and light-gray rhyolite tuff with abundant gray subrounded glassy inclusions ⅛–½ inch in diameter and crystals and crystal fragments of sanidine and quartz. A layering shown by flattened shards is evident locally. The upper unit is reddish or pinkish and is more pumiceous than the lower unit. The bulk specific gravity of the lower unit is 1.73–1.84, as compared with that of the upper unit, which is 1.1.

The rhyolite tuff contains 5–10 percent phenocrysts of sanidine, oligoclase, and minor quartz and reddish biotite in a glassy or very finely crystalline groundmass. Sanidine is predominantly euhedral to subhedral. Locally, glassy shards are in part flattened and welded.

The groundmass is predominantly glass. Tridymite is present in the coarser grained parts of the groundmass, on the margins of shards, and as the lining of cavities. X-ray diffraction patterns were made of the groundmass of two specimens of rhyolite tuff. The patterns are similar and indicate that tridymite, sanidine, and oligoclase (An_{18}) are the dominant minerals.

BASALTIC PYROCLASTIC ROCKS

A separate pyroclastic unit of basaltic to andesitic composition was mapped mainly in the Argus Range. The unit consists of agglomerate, tuff-breccia, and lapilli tuff. It crops out discontinuously in the western part of the quadrangle, under olivine basalt on Ash Hill, and in many canyons leading into Panamint Valley. The unit in the Argus Range has a maximum thickness of 480 feet on the north side of Osborne Canyon. It is thickest near vents and thins rapidly away from them.

At Ash Hill, the basaltic pyroclastic rocks overlie rhyolite tuff or nonconformably overlie Paleozoic sedimentary rocks where tuff is absent. The pyroclastics are overlain by olivine basalt. Minor agglomerate and tuff-breccia in the quartz-olivine basalt interbedded in fanglomerate No. 3 in the Panamint Range may indicate consanquinity of these two volcanic units, although they are mapped as separate units owing to lack of certainty of correlation.

OLIVINE BASALT

Olivine basalt flows crop out extensively in both the Argus and Panamint Ranges, where they cap ridges and form dip slopes (fig. 8). The unit has a maximum thickness of 400 feet in Rainbow Canyon (pl. 1). Individual flows cover many square miles. Dikes of olivine basalt, which are in part feeders for the extensive flows, cut all the older rocks. Two olivine basalt dikes cutting fanglomerate are exposed in a roadcut on Highway 190 a short distance west of the quadrangle boundary.

In the Argus Range the olivine basalt overlies basaltic pyroclastic rocks, Paleozoic sedimentary rocks, and Mesozoic quartz monzonite. In the Panamint Range it overlies Mesozoic quartz monzonite,

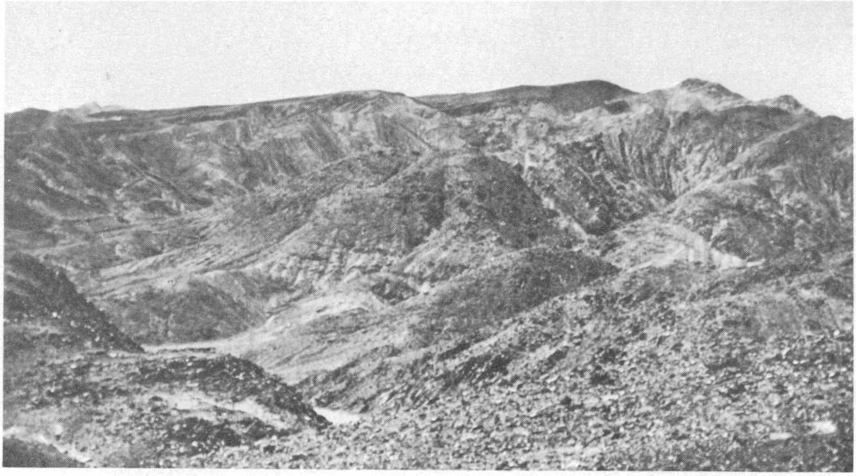

FIGURE 8.—View south along east slope of Argus Range; an east-tilted fault-block range shown by dip slope of olivine basalt flow on skyline.

Paleozoic sedimentary rocks, and quartz-olivine basalt. In general, olivine basalt forms dip slopes of less than 20°, whereas the underlying quartz-olivine basalt dips mainly about 30°. Without question, there is an angular unconformity between the two. Olivine basalt is overlain unconformably by fanglomerate No. 2 (pl. 1).

The olivine basalt is dense in the centers of flows, but scoriaceous at the top. The scoriaceous rock may be purplish or reddish. Amygdaloidal structures are not nearly as common as in the quartz-olivine basalt.

The basalt is mostly dark gray on fresh surfaces, but on weathered surfaces is commonly blackened by desert varnish. The olivine basalt contains phenocrysts of olivine, plagioclase, and augite in a pilotaxitic groundmass. Several percent of quartz xenocrysts are present in some of the basalt. The quartz is embayed and corroded and has reaction rims of pyroxene needles oriented perpendicular to the border of the grains. Plagioclase is in laths 0.1 – 0.5 mm long of composition An_{50} – An_{65}. The plagioclase commonly has an intermediate zone or rim with inclusions of glass that forms a sieve texture in the plagioclase. Table 4 gives an analysis of the capping olivine basalt. The sample is from the east side of the Argus Range at the north end of Ash Hill. The analysis is very similar to WH–68–3, from the upper unit of quartz-olivine basalt.

TABLE 4.—*Chemical analyses and norms, in weight percent, of olivine basalt*

[Analysts: P. L. D. Elmore, Hezekiah Smith, Lowell Artis, Gillison Chloe, James Kelsey, and J. L. Glenn]

Chemical analyses					
SiO_2	55.3	Na_2O	3.5	MnO	.12
Al_2O_3	18.0	K_2O	1.8	CO_2	<.05
Fe_2O_3	3.3	H_2O^-	.38		
FeO	3.8	H_2O^+	.11	Sum	100
MgO	4.5	TiO_2	1.2		
CaO	7.5	P_2O_5	.34		
Norms					
Q	6.7	di	5.2	ap	.8
or	10.6	hy	11.2	cc	.1
al	29.6	mt	4.8		
an	28.1	il	2.3		

AGE

The olivine basalt is late Pliocene in age. Jarel Von Essen (written commun., 1969) dated sample WH–68–1 as 4.05±0.15 million years. This sample is from the Argus Range at the north end of Ash Hill. Data for the calculations are given below:

Field No.	*Rock name*	*Percent* K_2O	Ar^{40}_{rad} (*moles/g*)	$\frac{Ar^{40}_{rad}}{Ar^{40}_{total}}$	*Age (m.y.)*
WH–68–1	Olivine basalt	1.77	1.058×10^{-11}	0.27	4.05±0.15

Constants used are the same as given for the quartz-olivine basalt.

A 20-foot-thick intrusive basaltic breccia, or peperite, is well exposed on the north side of Darwin Canyon at the west edge of the quadrangle (fig. 9). The breccia consists of calc-hornfels, limestone, and basalt fragments in a fragmental basaltic matrix .The fragments range in size from ¼ to 1½ inches in maximum dimension; most are quite angular. The calc-hornfels fragments have sharp, smooth contacts with the basalt; the limestone fragments tend to be irregular, and some have gradational contacts with the basaltic matrix.

The basaltic matrix is largely fragmental. The basalt is aphanitic and has some phenocrysts of olivine, augite, and plagioclase; much of the basalt is altered to greenish clay minerals.

The basalt is interpreted as having intruded a wet, buried talus. The viscosity of the basalt must have been very low to permit the complete mixing of fragments and basalt. The fragments are uniformly distributed through the basalt except in thin dikes of olivine basalt that cut the breccia. The fragmentation of the basalt is due to the vapor pressure from the matrix water.

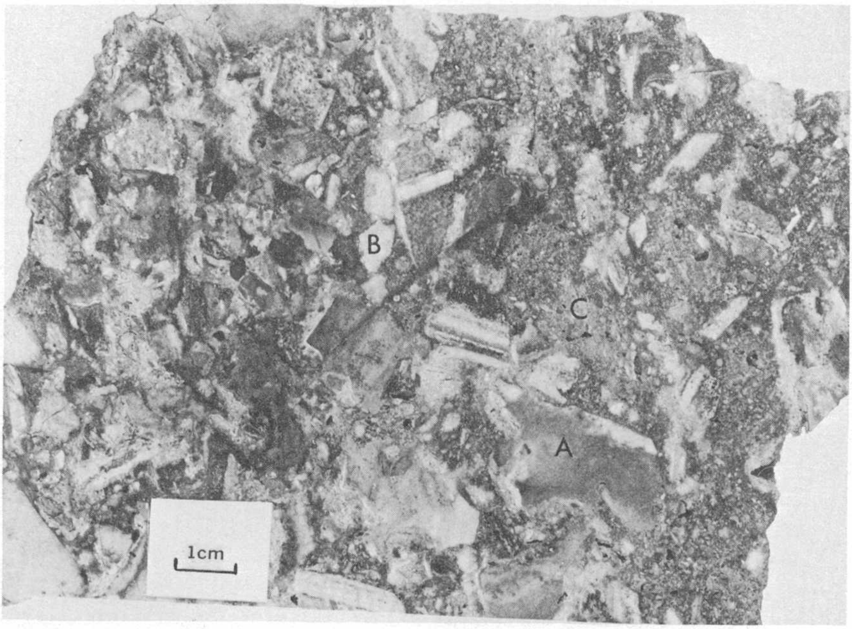

FIGURE 9.—Peperite from Darwin Canyon. The fragments are limestone (*A*) and calc-hornfels (*B*) in a fragmental basaltic matrix (*C*).

CORRELATION OF OLIVINE BASALT BY FUSED SAMPLES

In some isolated exposures it was impossible to recognize whether olivine basalt was part of the quartz-olivine basalt or part of the younger olivine basalt. As an aid in correlation, the refractive indices of fused basalts were determined as described by Mathews (1951), and a curve was drawn for index of refraction plotted against specific gravity. The curve is similar to curves of Rinehart and Ross (1964, p. 60), representing volcanic units in the Mount Morrison and Casa Diablo Mountain quadrangles. The method proved useful in places in differentiating the two basalts. Fused glass of quartz-olivine basalt ranged in index of refraction from $n = 1.555$ to 1.579 and averaged 1.560. The younger olivine basalt ranged in index from 1.579 to 1.592 and averaged 1.587.

MAGNETIC POLARITY OF OLIVINE BASALT

The magnetic polarity of both the quartz-olivine basalt units and the younger olivine basalt was determined by J. F. McAllister (written commun., 1969), using the technique described by Doell and Cox (1962, p. D105–D108). The lower unit and the lowermost flow of the upper unit of quartz-olivine basalt in the Panamint Range in the canyon that intercepts California State Highway 190 at BM 3863 are reversed. The uppermost flow of the upper unit on the southeast side of the canyon is normal. The polarity of olivine basalt in the Argus Range at the north end of Ash Hill is also reversed.

PLIOCENE OR PLEISTOCENE

FANGLOMERATE NO. 2

Fanglomerate No. 2 is an old, elevated, tilted, and dissected fanglomerate of late Pliocene or early Pleistocene age forming extensive exposures on the west side of the Panamint Range. The fanglomerate lies unconformably on fanglomerate No. 3 and on olivine basalt. It dips 4°–20° E., whereas the older fanglomerate No. 3 dips as much as 40° E, and it is slightly less consolidated and lacks the red or reddish-brown colors of fanglomerate No. 3. Fanglomerate No. 2 is also exposed over large parts of Nova Canyon and was included with part of the older fanglomerate in the Nova Formation (Hopper, 1947, p. 414). It probably correlates with the Funeral Formation in the Death Valley area (Hunt and Mabey, 1966, p. 63).

Fanglomerate No. 2 is moderately to poorly indurated. It consists of rounded to subrounded fragments of dolomite, quartz monzonite, quartzite, phyllite, vein quartz, schist, and basalt. The type and size of clasts are similar to fanglomerate No. 3, except that clasts of olivine basalt are present in small amounts throughout fanglomerate No. 2.

PLEISTOCENE

LACUSTRINE DEPOSITS

Panamint Valley includes two basins separated by a constriction of the valley at the south end of the quadrangle. The northern basin, which lies mostly within the quadrangle, contains a number of isolated dissected remnants of a former Pleistocene lake. Deposits left by the former lake include (1) calcareous tufa deposits at an altitude of 1,560 feet at the north end of the valley, (2) lake beds at an altitude of 1,800–1,840 feet a half mile east of Panamint Springs, (3) calcareous tufa at an altitude of 1,680–1,730 feet at the north end of Ash Hill, and (4) lake deposits at an altitude of 1,840–2,000 feet in the southeastern part of the quadrangle. Gale (1914, p. 313) found the highest water level of the old lake in Panamint Valley to be 1,977 feet; this was determined by the altitude of the outlet at Wingate Pass.

Some lake beds at altitudes of 2,080–2,160 feet on the east side of Panamint Valley, about 2,000 feet south of State Highway 190, are tilted as much as 18° E. These beds are undoubtedly older and correlate with the Pliocene fanglomerate No. 3.

The Pleistocene lake beds consist of white, greenish-white, and tan soft friable clay and silt. They are estimated to be 200 feet thick in the southeastern part of the quadrangle.

AGE

The lake beds have been cut and tilted by basin and range faults. They underlie at least part of fan No. 1 and are younger than the extensive olivine-basalt flows. Diatoms and small gastropods were collected from lake beds half a mile east of Panamint Springs. K. E. Lohman (in Hall and Stephens, 1963, p. 20) reported

> Although only 32 percent of the diatoms in this assemblage also occur in the Darwin Wash lake beds, the same age assignment of middle to late Pleistocene is most reasonable.

FAN NO. 1

Fan No. 1 is a high, dissected, unconsolidated, and only slightly tilted fan that occurs as widespread remnants on the lower slopes of the Panamint and Argus Ranges. This fan contains the same type of clasts as fanglomerate No. 2 and was derived predominantly from eroded debris of the older fanglomerates. In the southeastern part of the quadrangle, fan No. 1 overlies the middle and late Pleistocene lacustrine deposits.

HOLOCENE

UNCONSOLIDATED GRAVELS AND ALLUVIUM

Holocene deposits consist mostly of untilted or slightly tilted alluvial fan material marginal to the Argus and Panamint Ranges and playa deposits and sand dunes in Panamint Valley, but include slope wash and stream gravels. Also included is some older alluvial fan material in both the Argus and Panamint Ranges which has been uplifted and dissected or cut by basin and range faults but which is essentially untilted.

The alluvial fill in the northern Panamint basin is quite shallow. In 1953 a 375-foot core hole was drilled near the center of this basin for the U.S. Geological Survey (pl. 1). A log of the hole is given by Smith and Pratt (1957, p. 54–57). The core was predominantly interbedded sand and silt to a depth of 80 feet and below that was interbedded clay, gravel, marl, sand, and silt to a depth of 365 feet. The last 10 feet of core was in Paleozoic limestone. Although all the Pliocene and early Pleistocene deposits in the Argus and Panamint Ranges dip eastward and the range front faults are down on the east, or mountain side, Mabey's (1963) Bouguer anomaly map shows no gravity evidence for thick accumulations of sediments along the Panamint Range front where they might be expected. In the northern part of Panamint Valley, the basin fill is generally less than 500 feet thick, and the gravity low is near the center of the valley.

STRUCTURE

GENERAL FEATURES

Rocks in the Panamint Butte quadrangle have been broken into many structural blocks through a complex history of folding, intrusion, faulting, and landsliding (pl. 1). In general the sedimentary rocks strike north and dip toward the east. The Paleozoic strata were intruded by quartz monzonite plutons in both the Panamint Range and the Argus Range and were disrupted and shattered by thrust faults and steeply dipping strike-slip faults during a Mesozoic orogeny. During the Cenozoic the rocks were again thrust and shattered, were disrupted by steep faults to form the present basin and range topography, and were moved locally by landslides. The several periods of orogeny have formed a chaos structure in the Paleozoic rocks in the Panamint Range southwest and southeast of Towne Pass like that described by Noble (1941). In general the formations are present in their proper sequence, but they are thoroughly shattered and have an imbricate structure that indicates they have been displaced toward the northwest.

No major unconformities are recognized in the Paleozoic section, but three younger major unconformities are recognized. The oldest of these three truncates the Paleozoic strata and the Mesozoic intrusive rocks. It formed a surface of low relief that was covered by thick deposits of fanglomerate No. 3 of Pliocene age. These deposits now dip 25°–40° E. The second oldest unconformity truncates fanglomerate No. 3 and is overlain by younger thick deposits of fanglomerate No. 2 of late Pliocene or early Pleistocene age. Fanglomerate No. 2 is tilted to dips of 15°–20° E. and is truncated by a surface of probable late Pleistocene age that is uplifted and deeply incised. Both these old clastic units have well-developed smooth surfaces with desert varnish.

A reinterpretation is made of Hopper's (1947, p. 408) unconformity at the base of dolomite and limestone of Middle Devonian age in Nova Canyon. He described 1,000 feet of Devonian conglomerate overlying Silurian(?) dolomitic limestone without angular discordance. In this area the well-consolidated red-stained fanglomerate No. 3 of Pliocene age lies with little angular discordance upon limestone and dolomite of Cambrian(?) to Mississippian age. The fanglomerate contains abundant monolithologic breccias derived from fossilferrous dolomite of Paleozoic age. Probably one of these breccias forms the limestone and dolomite unit 300 feet thick that he described as overlying Devonian conglomerate. The whole sequence is Pliocene in age.

MESOZOIC STRUCTURE

The strata from Death Valley 60 miles west to Owens Valley strike predominantly north and dip east. This area includes the Inyo Mountains, Coso Range, Darwin Hills, and Panamint Range. The dips of the late Cenozoic strata are mostly 15°–30° E. By restoring the structure prior to the late Cenozoic deformation, the Paleozoic strata show broad open folds except near intrusive contacts. The major deformation during the Mesozoic is related to forceful intrusion of the quartz monzonite. In the Argus Range, Early Jurassic intrusion of the quartz monzonite pluton that underlies Maturango Peak deformed the Paleozoic rocks into a broad, locally overturned anticline that has an axis that strikes N. 20° W. and plunges to the north. The anticline was further deformed by continuing forceful intrusion that pushed the south end of the anticline toward the northeast so that its axis strikes N. 70° W. in the vicinity of the Modoc mine (Hall and Stephens, 1963, pl. 2). The east limb of the anticline is overturned near the small quartz monzonite pluton in Osborne Canyon (pl. 1).

There is little evidence of a major anticlinal structure in the Panamint Range during the Mesozoic. The structure there is controlled predominantly by faulting, and during the Mesozoic Era the strata were only gently folded. The Panamint Range is probably largely a Cenozoic feature.

Thrust faults and strike-slip faults were formed during the Mesozoic. The Lemoigne thrust fault in the northeastern part of the quadrangle thrust Middle and Upper Cambrian and Ordovician dolomite southeast over the Keeler Canyon and Owens Valley Formations of Pennsylvanian and Permian age (fig. 5; pl. 1). The stratigraphic displacement is over 6,000 feet. The direction of movement toward the southeast is shown by drag of the underlying thinly bedded shaly limestones in the Keeler Canyon Formation (fig. 5). The Lemoigne thrust sheet was lifted up and thrust southeast by the injection of the Hunter Mountain batholith. During the final stages of its emplacement, the batholith intruded the thrust sheet, tightly folded and overturned the sole of the thrust sheet, and metamorphosed the Paleozoic strata it intruded. The Talc City and Davis thrusts in the Darwin quadrangle are examples of similar displacement (Hall and MacKevett, 1962).

Steeply dipping left-lateral strike-slip faults, striking about N. 70° W., are a late phase of the Mesozoic orogeny (pl. 1). In the Argus Range a strike-slip fault about 1,900 feet north of the Surprise mine has a displacement of 2,000 feet, the north side moving west relative to the south side (pl. 1). The direction of displacement is shown by offset of the Lee Flat Limestone in the core of the major anticline. These faults are locally intruded by andesite porphyry dikes in the Modoc district and are mineralized (Hall and Stephens, 1963, p. 2).

MIDDLE(?) TERTIARY STRUCTURES

The chaos structure of the Paleozoic strata in the vicinity of Towne Pass is a tectonic feature younger than the Mesozoic thrust faults but older than the basin and range faults and fanglomerate No. 3. The chaos structure is probably part of a much more extensive thrust sheet of Paleozoic strata thrust over the Precambrian in the Death Valley area, but the thrust is not exposed. The foreground of figure 10 shows the thoroughly shattered nature of the chaos in the Paleozoic rocks. The carbonate rocks and quartzite, which dominate the Paleozoic section, are shattered to blocks commonly about 6 inches on a side. The shattering is caused by the intersection of a steep, predominantly northerly striking cleavage with a gently

FIGURE 10.—West face of Panamint Range with intense shattering of the Paleozoic strata due to thrusting under shallow cover. Photograph by H. G. Stephens.

dipping cleavage or small thrust faults; however, cleavages and other small faults of many orientations are present.

The chaotic complex at Towne Pass has an imbricate structure that dips in general gently toward the northwest. Many faults and fracture surfaces are parallel to bedding, but locally they crosscut or have curving surfaces that have tens of feet to a few hundred feet of displacement and cut out parts of the section. The flat-lying faults may be only a few hundred feet long, whereas others, like those on the north side of Dolomite Canyon, are continuous for a mile or two. The detail of fracturing and movement cannot be mapped at any reasonable scale of quadrangle mapping. Bedding, however, is generally distinct, and the stratigraphic units are sufficiently continuous to be generally recognized. Much detail of faulting, though, is not shown on plate 1.

The shattered elongate Paleozoic block 1.5 miles southeast of Towne Pass is in proper sequence from the Ely Springs Dolomite of Late Ordovician age to the Tin Mountain Limestone of Mississippian age (pl. 1). The Middle Ordovician Eureka Quartzite, however, is minutely shattered and is irregularly distributed within the steep Towne Pass fault zone.

The southern part of this chaotic complex, 3–7 miles south-southeast of Towne Pass, is a predominantly dolomitic section that consists probably of Upper Cambrian and Ordovician formations.

The dolomite is shattered by a steeply dipping cleavage and flat-lying faults. Beneath a gently north-dipping thrust fault near the south end of this chaotic complex is a unit of white, red, and reddish-brown quartzite and micaceous quartzite that may be of either Precambrian or Early Cambrian age.

Similarly shattered dolomite occurs in the upper reaches of Dolomite Canyon, 3 miles west-southwest of Towne Pass. The dolomite is also disrupted by numerous small flat-lying faults that dip to the north or northwest. The shattering is developed in the Ordovician part of the section near the contact with fanglomerate No. 3.

The chaotic complex shows the following features:

1. The shattering is restricted to brittle rock types, dolomite and quartzite.
2. Bedding is generally preserved.
3. Stratigraphic succession is generally maintained, although parts of sections are cut out.
4. There is no evidence of large movement, although many north-dipping faults have small displacements and form an imbricate structure.
5. The sole of the chaotic complex is not exposed.
6. Dolomite is broken into tightly packed angular blocks generally about 6 inches in maximum dimension.
7. The chaos is overlain by a very thick section of Pliocene fanglomerates containing monolithologic breccias.
8. The chaos is on a domal structure.

Chaos complexes have been described in the Death Valley area in a belt extending over 100 miles in a north-northwest direction. The areas include Tucki Mountain (Hunt and Mabey, 1966), Copper Canyon (Drewes, 1959), Virgin Spring area (Noble, 1941), and Silurian Hills (Kupfer, 1960).

The Towne Pass chaos is postulated to be a thrust sheet on an domal structure that plunges north-northwest. The sole of the thrust is not exposed. Small thrusts or flat-lying faults within the shattered Paleozoic block indicate direction of movement was toward the northwest off a highland of Precambrian rocks to the southeast. The pattern of shattering appears to have two sources. The rocks were first shattered by tension from vertical uplift. As the strata were uplifted, they must have slid locally toward the northwest to form an imbricate structure. The large north-striking faults—the Towne Pass and Nova faults—although younger than the chaos, have large normal displacements and further shattered the rocks.

The time of formation of the chaos structure is difficult to place. It is younger than the thrusting related to the Hunter Mountain batholith, as the shattering has not been rehealed where the complex is near an intrusive contact, and it is older than the Pliocene fanglomerate No. 3, which unconformably overlies the chaos complex. The chaos may have formed in the middle Tertiary during the intrusion of the middle Tertiary porphyritic plutons of the Death Valley area (Stern and others, 1966).

LATE CENOZOIC STRUCTURES

FAULTS

The Cenozoic basin and range structure from Death Valley to Owens Valley indicates substantial extension of the crust. The volcanic and sedimentary rocks of Cenozoic age in this distance of 40 miles all dip to the east from a few degrees to a maximum of about 40°. The valleys as well as the Inyo Mountains and the Coso, Argus, and Panamint Ranges are all east-tilted fault blocks. The Sierra Nevada is the west-tilted limb. Section *A–A′* (pl. 1) illustrates the extension in the Panamint Range. The normal faults are well exposed (fig. 5; pl. 1) and dip to the west mostly between 45° and 70°. The extension shown in section *A–A′* is 2.4 miles. This is an extreme amount for the Death Valley–Owens Valley area, and the amount in the Argus Range is much smaller (section *C–C′*, pl. 1; Hall and MacKevett, pl. 1, 1962). It appears that most of the extension in this broad Death Valley–Owens Valley warp occurred at its eastern extremity and at its crest in Owens Valley.

The late Cenozoic was a period of intensive faulting in the Panamint and Argus Ranges. The faults can be divided into groups with the following trends: (1) steeply dipping north-striking faults, (2) steeply dipping northeast-striking left-lateral strike-slip faults, (3) spoon-shaped northwest-striking gravity faults, and (4) steeply dipping N. 30° W.-striking normal faults.

STEEPLY DIPPING NORTH-STRIKING FAULTS

The Towne Pass fault is exposed in the Panamint Range 4,000 feet east of Towne Pass (fig. 11). The fault separates Paleozoic rocks on the east and old tilted fanglomerates and interbedded volcanic rocks on the west. The fault dips 45°–80° W.; the west side has moved down at least 7,800 feet relative to the east side. There is no evident strike-slip component of displacement. The fault is a highly iron-stained shear zone 50–60 feet thick. Dolomite as much as 1,000 feet from the fault has steep fractures and slips that roughly parallel the fault.

The Towne Pass fault is exposed for 8.5 miles in the quadrangle and undoubtedly extends north of Towne Pass under the alluvium

FIGURE 11.—Towne Pass normal fault. Note the wide shattered zone on the footwall of the fault. Photograph by H. G. Stephens.

and capping olivine basalt. The gravity map of the Death Valley region suggests the fault extends 30 miles north of Towne Pass and then merges with the Furnace Creek fault zone on the east side of Death Valley (Mabey, 1963). It also extends approximately 30 miles south through the Wildrose graben and along the east side of Panamint Valley to the Slate Range. It is the same as the Panamint Valley fault zone of Smith, Troxel, Gray, and Von Huene (1968, p. 19).

Most of the displacement on the Towne Pass fault is older than the capping olivine basalt of late Pliocene age. Movement on this fault accounts for most of the elevation in the Panamint Range southeast of Towne Pass and is responsible for the highland that was the source for the extensive Pliocene fanglomerates.

The Nova fault, 2 miles west of the Towne Pass fault, is a normal fault that dips 45°–85° W. The west side has moved down an estimated 2,000 feet relative to the east side. The fault extends from 2 miles north to 6 miles south of State Highway 190 and then passes under Holocene alluvium. The fault is poorly exposed and is indicated mainly by the repetition of fanglomerates Nos. 1 and 2 immediately west of fanglomerate No. 3.

Near Nova Canyon other steeply dipping north-striking faults are exposed cutting fanglomerates Nos. 2 and 3 between the Towne Pass and Nova faults (pl. 1). Exposures, however, are too poor between canyons to be sure of their continuity.

The Ash Hill fault is a steeply dipping north-striking fault in the Argus Range on the west side of Ash Hill. It is a normal fault wherein the mountain or west side has moved down 200 feet relative to the east side since the late Pliocene. The fault has had very recent movement, as the fanglomerate in the present drainage north of Ash Hill is displaced (pl. 1).

Some north-striking basin and range faults cut the Paleozoic strata in the vicinity of the Big Four mine south of the Hunter Mountain batholith, but the strata are so shattered that faults are difficult to follow unless they separate distinctive lithologies. The basalt flow that extends from the Big Four mine east to the top of the Panamint Range is step-faulted by a series of basin and range faults as well as further disordered by landslides (fig. 12). The displacement of these faults, however, is only evident where there is a distinctive bed, like the capping olivine basalt.

NORTHEAST-STRIKING LEFT-LATERAL STRIKE-SLIP FAULTS

The Paleozoic strata on the west face of the Panamint Range are broken by northeast-striking left-lateral strike-slip faults that dip 35°–70° NW. (pl. 1). The faults are all located between Dolomite

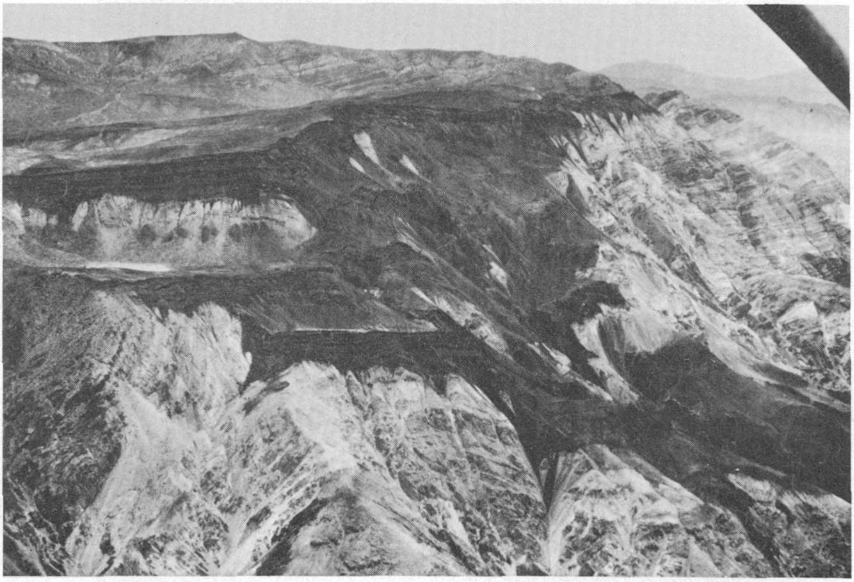

FIGURE 12.—West face of the Panamint Range 1.4 miles N. 70° E. of the Big Four mine where a step-faulted olivine basalt flow is further disordered by slumping.

Canyon and the Big Four mine. Figure 13 is a photograph of horizontal mullion structures on the fault plane in North Panamint Canyon. Figure 5 shows disruption of the white marble of the Lee Flat Limestone of Mississippian and Pennsylvanian(?) age by the northeast-striking faults. The horizontal separation in these faults ranges from 500 to 7,000 feet. These faults broke the Paleozoic rocks into five unstable blocks, which later moved on gravity faults, probably during the Pliocene and Pleistocene.

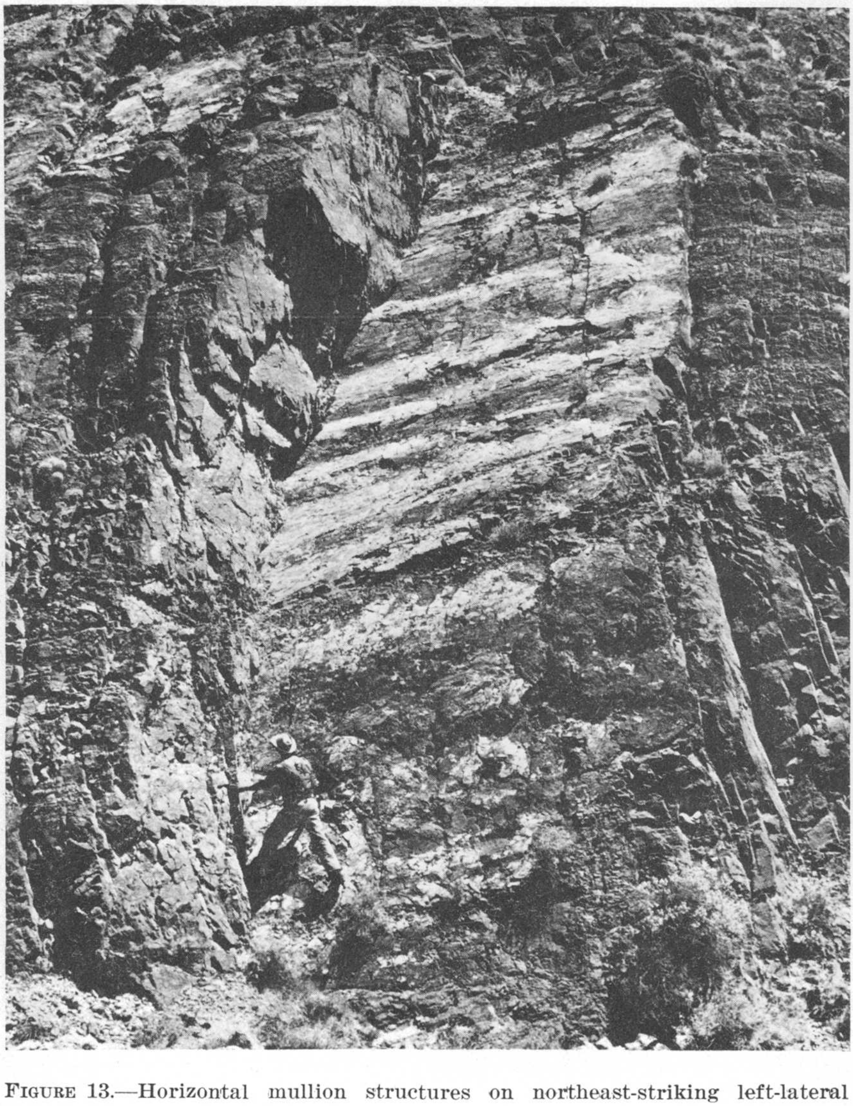

FIGURE 13.—Horizontal mullion structures on northeast-striking left-lateral strike-slip fault in North Panamint Canyon. Photograph by H. G. Stephens.

GRAVITY FAULTS

The northeast-striking structural blocks south of the Big Four mine are further broken by northwest-striking normal faults that dip 40°–70° SW. The faults tend to be spoon shaped and flatten with depth. These faults cause repetition of the section toward the southwest (pl. 1). These are gravity faults that moved the shattered, unstable blocks during the Pliocene and Pleistocene when the relief in the area was great and the precipitation was much heavier than at present.

STEEPLY DIPPING N. 30° W.-STRIKING FAULTS

Steeply dipping faults that strike about N. 30° W. are present along the range front on the east side of Panamint Valley (pl. 1). Two prominent ones that have topographic expression in the Holocene fans crop out between Lake Hill and the range front (fig. 14). Both have the valley side moved up about 30 feet relative to the mountain side. The range-front faults have a right-lateral strike-slip component of displacement that is shown by drag in the Tin Mountain Limestone 2 miles east of Lake Hill and by right-lateral displacement of drainages at the mouths of canyons south of State Highway 190.

LANDSLIDES

Landslides were common in the Panamint-Death Valley area during the Pliocene and Pleistocene. In areas of steep topography the shattered Paleozoic rocks were particularly susceptible to sliding, which has been characteristic of this area since at least the Pliocene. The landslides range vastly in size and in the amount of disorder of the slide. On the steep west face of the Panamint Range north of North Panamint Canyon, blocks of Devonian and Mississippian

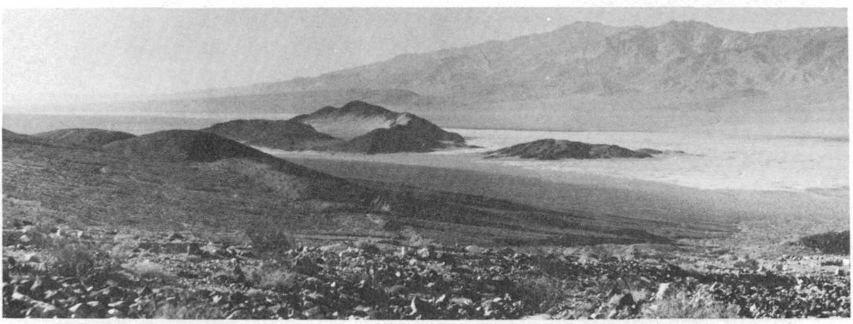

FIGURE 14.—View south from the Big Four mine road over Panamint Valley. In the foreground the unconsolidated fan has been displaced valley side up by recent movement on a N. 30° W.-striking fault. Lake Hill is in the playa. Photograph by H. G. Stephens.

limestone a few feet to several hundred feet long have slid with little internal disorder. These slides are too small to be shown on the geologic map. The "islands" in Panamint Valley are interpreted as much larger gravity slides that have little internal disorder (pl. 1). The monolithologic breccias interbedded in fanglomerate No. 3 are landslides in which there has been large internal movement.

LAKE HILL

Lake Hill, in Panamint Valley, is interpreted as a slide block that has moved from an area of shattered Ordovician strata 3.3 miles to the east (pl. 1). Lake Hill has a normal stratigraphic sequence of Pogonip Group, Eureka Quartzite, and Ely Springs Dolomite. No gravity evidence for a fault's bounding Lake Hill is available to account for its position in the valley (Mabey, 1963), and an origin by sliding is more probable. The much smaller hills 2.5 miles north of Lake Hill near the mouth of the canyon to the Big Four mine definitely have a landslide origin. Dolomite breccia of fanglomerate No. 3 rests on olivine basalt and agglomerate. The dolomite breccia came from the thrust plate of Cambrian dolomite 0.6 miles to the northeast.

Another island of breccia within fanglomerate No. 3 occurs in Panamint Valley at the south edge of the quadrangle in sec. 28, R. 43 E., T. 19 S., where it is surrounded by lake deposits. The breccia contains fragments of dolomite, quartzite, and gneiss as much as 15 feet in diameter. The breccia is older than the lake beds which lap upon it and is probably the same age and origin as the monolithologic breccias interbedded in fanglomerate No. 3.

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