UNITED STATES
DEPARTMENT OF THE INTERIOR
US GEOLOGICAL SURVEY

Rocks and structure of the Quartz Spring area northern Panamint Range, California

By James F. McAllister

The new stratigraphic names proposed in this preliminary report have not been officially adopted by the U. S. Geological Survey and should not be quoted for publication.

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northern Panamint Range, California

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Abstract

The Quartz Spring area covers about 50 square miles in the northern part of the Panamint Range, Inyo County, California. It lies near the southwestern border of the Basin and Range Province. The paper describes the stratigraphy, igneous petrology, and the main structures of the area. The formations, as defined by the stratigraphy, and the structure are shown on a large scale topographic map and in structure sections.

The stratigraphy, except for Quaternary deposits that cover about one fourth of the area, consists of Paleozoic sedimentary rocks preponderantly dolomite and limestone, representing each system from Cambrian to Carboniferous, as outlined below. No surface of erosion (unconformity) has been recognized between any of the formations or systems within the area.

	Feet
* Tihvipah limestone—Pennsylvanian. Limestone, somewhat shaly	200 ±
* Rest Spring shale—Pennsylvanian(?). Olive-gray shale, siltstone, and local quartzite	310 ±
* Perdido formation—Mississippian. Brownish siltstone, dark-gray limestone and chert, some conglomerate and shale	610 ±
* Tin Mountain limestone—Mississippian. Very dark gray limestone, shaly partings in lower part, a little chert	475
* Lost Burro formation—Upper and Middle Devonian. Light- and dark-gray dolomite and limestone, thin sandstones at top and bottom	1,525
* Hidden Valley dolomite—Lower Devonian (65 feet) and Silurian. Dolomite, cherty in lowest part	1,365
Ely Springs dolomite—Upper Ordovician. Light-gray dolomite in upper part; lower part very dark gray dolomite, cherty	940
Eureka quartzite—Middle Ordovician. Upper part massive vitreous quartzite; lower part somewhat shaly and ferruginous quartzite	400
Pogonip limestone—Lower Ordovician. Dolomite and limestone, some shale, chert, and sandy beds	1,440
Nopah formation—Upper Cambrian. Light- and dark-gray dolomite, shaly at base	1,600
* Racetrack dolomite—Middle(?) Cambrian. Gray dolomite	1,900 ±
Total thickness	10,765 ±

* New names.

The Paleozoic rocks have been deformed by thrust faults, folds related to the thrusts, normal faults, and small intrusions. The age of the structures cannot be determined here closer than that they are younger than early Pennsylvanian and older than Quaternary. The only discernible effect of the structures on the present topography has been to influence differential erosion.

The largest exposures of intrusive alkalic rocks in the northeastern quadrant of the area are not more than half a mile wide or 2 miles long. The alkalic rocks, in dikes, sills, and chonoliths, are characterized by abrupt changes in texture and in the proportion of mafic minerals. Most of the textural variations, whether granular or porphyritic-granular, are also trachytoid. The proportion of mafic minerals ranges from 3 percent in leucosyenite to 42 percent in the groundmass of porphyritic aegirine-augite syenite. The degree of saturation by silica ranges from undersaturated nepheline-syenite, through saturated syenite, to quartz-bearing rocks. The most abundant type is trachytoid leucosyenite, which consists of about 97 percent microperthite. Much of the microperthite, which is the most prevalent mineral in the entire suite of rocks, is a late partial replacement of orthoclase by albite. The other rocks described are: melanite nepheline-syenite, hastingsite nepheline-syenite, aegirine-augite monzonite, aegirine-augite monzonite-porphyry, aegirine-augite syenodiorite, syenite pegmatite, nordmarkite, and aplites. The most favored theory of origin of the alkalic rocks in the Quartz Spring area is that a late differentiate from an adamellite batholith was desilicated on passing through much carbonate rock, and late magmatic fluids deuterically added soda.

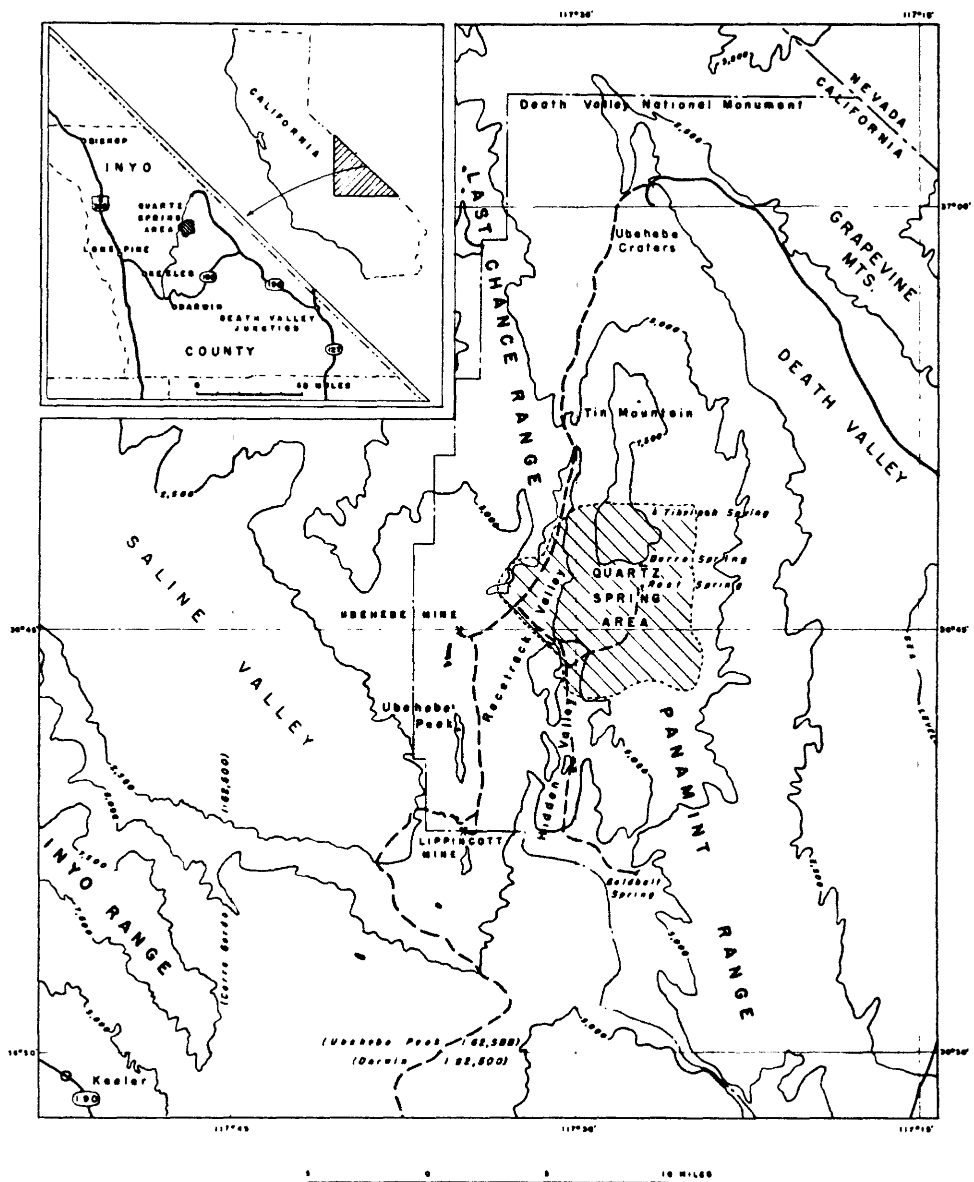

Figure 1. Index maps showing location of the Quartz Spring area, Inyo County, California.

Introduction

The Quartz Spring area lies about 4 miles south of Tin Mountain on the northern tip of the Panamint Range in Inyo County, eastern California, and is just within Death Valley National Monument (fig. 1). The area, (pl. 1)

Figure 1. Index maps showing location of the Quartz Spring area, Inyo County, California.

Plate 1. Geologic and topographic sketch map of the Quartz Spring area, Panamint Range, California.

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irregular in outline, covers about 50 square miles, and extends from the upper part of the eastern slopes of the Panamint Range westward across the rolling summit, and beyond Racetrack Valley into the foothills of the Last Chance Range (pls. 2 and 3A). The maximum relief of the area is 4,200 feet,

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Plate 2. Western front of Panamint Range at Quartz Spring.

Plate 3A. Southeastern foothills of Last Chance Range from Racetrack Valley showing the stratigraphy from Racetrack dolomite to Ely Springs dolomite.

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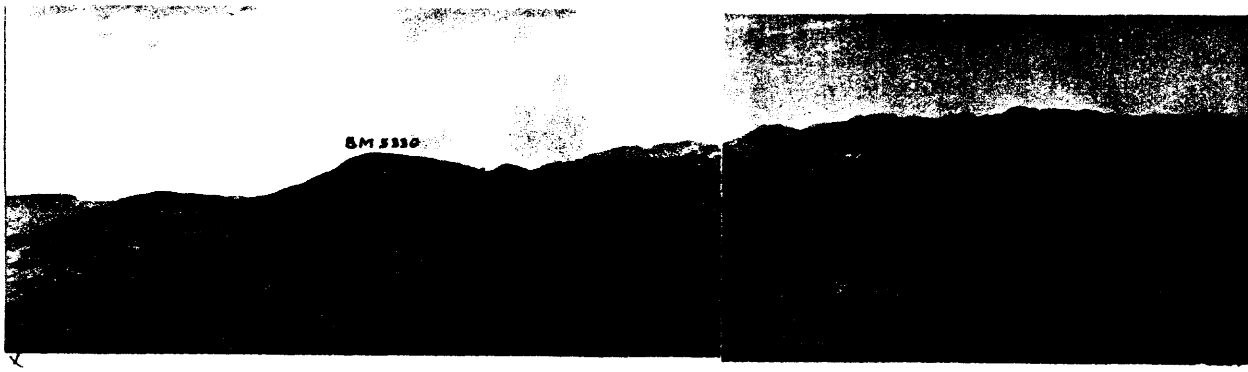
rising from 4,200 feet above sea level in Racetrack Valley to 8,400 feet north of Burro Spring. (See pl. 1).

Western front of Panamint Range at Quartz Spring.



A. Southeastern foothills of Last Chance Range from Racetrack Valley showing the stratigraphy from Racetrack dolomite to Ely Springs dolomite. Racetrack dolomite, Ꞓr; Nopah formation, Ꞓn; Pogonip limeston, Op; Eureka quartzite, Oe; Ely Springs dolomite, Oes. Photograph by Ward Smith.

B. Crepe structure in a siliceous limestone member of the Pogonip limeston.

C. Eureka quartzite about $2\frac{1}{2}$ miles north of Ubehebe Peak. Pogonip limestone, Op, below Eureka quartzite, Oe, and Ely Springs dolomite, Oes, above.

The road leading from the Death Valley paved highway is unimproved from Ubehebe Craters for 20 miles to the junction of the Hidden Valley and Racetrack roads (see fig. 1). This was the only road to the area at the time of the principal field work from 1937 to 1939. Subsequently a southwestern access from the Lone Pine-Darwin highway was opened by a steep, narrow, and rough road through the southern end of Saline Valley and up to Racetrack Valley. Over this much more direct route from Owens Valley it is advisable to use special equipment for rough mountain roads. At times the northern road is roughened by a torrential runoff, and the southern road is made impassable. Miners, intermittently active in the Ubehebe district, have kept the roads open. Within the area in 1937-39 it was possible to drive through Racetrack Valley, into Hidden Valley, and with difficulty past Rest Spring to within 2,000 feet of Burro Spring. A side road from the Racetrack road was passable 1½ miles to a campsite near Quartz Spring (see pl. 1).

The arid climate accounts for a lack of streams and a scarcity of springs. There are only four springs in the area—Quartz, Rest, Burro, and Tihvipah. They are unusable seeps except when cleaned and protected from abuse by wild burros. No water is available between Grapevine Springs in Death Valley and Quartz Spring. The nearest water to the south is at Goldbelt Spring, which is easily reached by a road through Hidden Valley (see fig. 1). Mendenhall (1909, pp. 32-33) reported that Rest Spring and Burro Spring each yield about 3 barrels daily and Goldbelt Spring about 20 barrels daily. Precipitation from summer showers and winter snowfall is highly erratic from year to year, and is somewhat greater in the higher places. No measurements of precipitation are available.

Because of the climate and relief, vegetation is sparse, soil is poorly developed, and exposures of bedrock are excellent. The vegetation at lower altitudes consists of unobtrusive widely spaced desert shrubs rarely more than knee-high, and of some low cactus. A few stunted Joshua trees grow at intermediate altitudes. Where snow remains longest at high altitudes and on shady slopes in the northeastern part of the area, there are some junipers and piñons.

Previous work

Earlier geologic work in the area was cursory. The earliest reference to the geology of the Panamint Range is in the report by Whitney (1865, p. 474), "......of their geology little is known except that the rocks are crystalline metamorphic." Gilbert in the U. S. Geographical Survey West of the 100th Meridian described the range merely as "mountains of upheaval" (Gilbert, 1875, p. 125). Fairbanks (1894, p. 473) added little to the knowledge of its geology in recording "limestone, quartzite, slate, and mica schist form the predominating rocks. Areas of granite are, however, found in places." He also noticed there had been intense diastrophism (Fairbanks, 1896, p. 67). Mineral deposits and types of associated rocks in the Ubehebe district, southwest of the Quartz Spring area, were described very briefly in Copper Resources of California (Aubury, 1908).

No maps that include the Quartz Spring area have been published with more information than was on the early reconnaisance maps by Spurr (1903, pl. 1) and Ball (1907, pl. 1). Spurr called all the rocks there Silurian, which then included Ordovician; Ball mapped them as the Pogonip limestone of Ordovician age, and a little quartz-monzonite porphyry. Ball's map is the source of the geology of the northern Panamint Range as shown on the latest geologic map of California (Jenkins, 1938). Other reports that mention or describe the Panamint Range do not include the northern end of the range.

More recently published material refers only to the central and southern parts of the Panamint Range. Murphy (1932, pp. 329-355) mapped and described an area in the south central part of the range, and White (1940, pp. 307-325) published on the antimony deposits of the Wildrose Canyon area, entirely in pre-Cambrian rocks. Hopper (1947, pp. 393-432) in his geologic section from the Sierra Nevada to Death Valley included a strip across the central part of the Panamint Range, and earlier published an abstract of the stratigraphic information (Hopper, 1939).

Other reports on adjacent regions have been more applicable. Some of the formations of Death Valley described by Noble (1934, pp. 173-178) occur in the Quartz Spring area, and a part of Hazzard's (1937, pp. 273-339) stratigraphic sequence in the Nopah and Resting Springs Mountains is similar to the sequence in the area. Hazzard's descriptions of rock units were useful, whereas the descriptions of the Paleozoic rocks in the much closer Inyo Range (Kirk, 1918, pp. 19-48) could not be applied.

Prior to 1937 Mr. H. D. Curry, while Ranger Naturalist of Death Valley National Monument, made reconnaissance trips through the Quartz Spring area and recognized some of the essential details of stratigraphy and structure. His work, although unpublished, is by far the most important previous work within the area.

Purpose

The purpose of the investigation was to map in detail the geology of the Quartz Spring area and to describe the stratigraphy, structure, and igneous petrology. The principal results presented in this report, therefore, are the following: a large-scale topographic and geologic map showing a sample of the complex structure of the region, a description of the Paleozoic stratigraphy from Cambrian to Pennsylvanian, and a study of some intrusive alkalic rocks. Fossils, many of them poorly preserved, were collected from every Paleozoic system except Permian. The collections, deposited at Stanford University, have not been described, although some of the fossils were used to determine several key horizons in the stratigraphic column. Some fossils collected later in the adjacent Ubehebe Peak area have been identified by paleontologists of the U. S. National Museum and the U. S. Geological Survey. Permission was granted to use the information, and credit to the paleontologists is given with the data.

Field work

Field work in the Quartz Spring area was started by a brief reconnaissance during several weeks in the summer of 1937, and a week in the spring of 1938. The main field work was done from August 1938 to January 1939, and the final field checking was concluded during two weeks in April 1940 and several days in 1948 and 1949.

A topographic map prepared by enlarging the relevant part of the U. S. Geological Survey's Ballarat quadrangle map was entirely inadequate as a base for the geologic mapping. A topographic sketch map (pl. 1) therefore was made without assistance by triangulating on a lightweight improvised plane table with a Brunton compass attached to a metal straightedge. The difficulty of measuring, unaided, a base line over hilly ground was met by using a Brunton clinometer as a hand level to measure the vertical distance from valley to hilltop, and the clinometer also to measure the vertical angle, so as to calculate trigonometrically the horizontal distance. The base line thus measured between two hills near Rest Spring, when drawn to a scale of 2,000 feet to an inch, was slightly less than 3 inches on the map, which was somewhat short for the triangulation network about 20 inches in diameter. The accuracy was checked later with alidade and stadia rod on the Racetrack Valley road, near one edge of the map area, and it was within the error due to reading the rod, plotting the points, and the method of triangulation. Altitudes used in sketching contour lines at a 100-foot interval were determined with an aneroid barometer, although there was no control for atmospheric changes in pressure. The magnitude of error in altitude, based on random checking, was considered to be generally within one-half contour interval. The datum is approximately sea level. On the map (pl. 1) most names of topographic features were applied for convenience in reference and have not been sanctioned by the Division of Geographic Names, so they must be considered a temporary expedient required by a dearth of names on published maps. Hidden Valley, a name assigned to a new formation, is not on the Ballarat quadrangle map but is used by the National Park Service on its map of the Death Valley National Monument (Office of the Chief Engineer, San Francisco, Calif., 1937) and is listed by T. S. Palmer in his compilation of <u>Place Names of the Death Valley Region</u> (1948, p. 36). It is hoped that Lost Burro Gap, Perdido Canyon, and Tihvipah Spring are accepted, as they are sources of formation names.

Acknowledgments

The National Park Service, through an appointment as Student Technician in Geology to assist Ranger Naturalist D. H. Curry in Death Valley Monument during the summer of 1937, provided the opportunity to select an adequate area. Mr. Curry proposed the Quartz Spring area, among several others, and was generous with his knowledge of regional geology. It is a pleasure also to acknowledge innumerable courtesies that officials of the National Park Service extended during the seveveral seasons of independent field work.

During field work 10 years later in the adjacent Ubehebe Peak quadrangle the writer, assisted at different times, by W. R. Eames, A. F. Agnew, E. M. MacKevett, Jr., M. W. Ellis, and R. F. Johnson, measured some of the sections and collected some of the fossils that have been used in this report. This work was part of the U. S. Geological Survey's program in cooperation with the California State Division of Mines, and was under the helpful supervision of Ward Smith of the U. S. Geological Survey.

At Stanford University the earlier part of the work in the Quartz Spring area was planned and discussed with Dr. Eliot Blackwelder and Dr. A. O. Woodford. Dr. S. W. Muller was helpful with the paleontologic and stratigraphic aspects of the work, and Dr. A. C. Waters, the petrologic part. Dr. Waters arranged for W. H. Herdsman's chemical analysis of the nepheline-syenite. Drs. Muller and Waters critically read the entire report and made greatly appreciated suggestions for improvement.

Sedimentary rocks

Sedimentary rocks compose somewhat more than 90 percent of the area shown on the geologic map (pl. 1). Except for Quaternary deposits, which cover about one fourth of the area, limestone and dolomite constitute by far the major part of the stratigraphic column (pl. 4). Shale, although it

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Plate 4. Columnar section of Paleozoic rocks in the Quartz Spring area, Panamint Range, California.

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constitutes a small proportion of the stratigraphic sequence, crops out extensively, and like the equally small proportion of quartzite, makes good stratigraphic markers. Chert, conglomerate, and breccia are minor constituents of the sedimentary sequence.

Formations were established primarily by selecting persistent and easily distinguishable lithologic units that could be mapped on a scale of 1:24,000 to show adequately the stratigraphy and structure of the region. Previously named formations were used when it was possible to recognize them by advice of H. D. Curry, by limited personal observation in some areas where they had been described, or by comparison with published descriptions. The age of some of the formations has been assigned tentatively, as diagnostic fossils have not been found in them or the fossils have not been precisely identified. Some of the formations that are primarily good mappable lithologic units may cross systemic boundaries.

Rocks older than Quaternary range in age from probably Middle Cambrian to Pennsylvanian (fig. 2). Those from Cambrian to Upper Devonian can be

Figure 2. Tentative correlation of the formations in the Quartz Spring area with the formations in the Roberts Mountains region and the Nopah Range.

correlated reasonably well with formations that have been established in the Death Valley region and eastern Nevada (see Nolan, 1943, pp. 148-156). Mississippian and Pennsylvanian units, however, are more difficult to compare with those in published stratigraphic sections.

Pre-Cambrian rocks, which are well-represented in the central and southern parts of the Panamint Range (Murphy, 1932, p. 337, pl. IV; Hopper, 1947, pp. 402-403, pl. 1), do not crop out in the Quartz Spring area. The area also lacks exposures of most of the great thickness of Cambrian rocks that occurs southward in the central part of the Panamint Range (Hopper, 1947, pp. 403-407), eastward in the Grapevine Mountains of the Amargosa Range (Curry, 1937, oral communication), northwestward in the Inyo Range (Kirk, 1918, pp. 25-28), and probably northward in the Last Chance Range.

		Roberts Mountains Region, Nevada (Merriam, 1942)	Quartz Spring Region, Calif. (This report)	Nopah Range, Calif. (Hazzard, 1937)
CARBONIFEROUS	"Pennsylvanian"	(discontinuity)	(Eroded) Tihvipah limestone 200 ± ft.	? Bird Spring(?) formation 780 + ft.
		Diamond Peak beds (greater part unrecognized)	Rest Spring shale 310 + ft.	?
	Mississippian		Perdido formation 610 ± ft.	Monte Cristo(?) limestone 987 ± ft.
			Tin Mountain limestone 475 ft.	Stewart Valley limestone 1,180 ft.
DEVONIAN	Upper	Devils Gate formation 2,065 ft.	Lost Burro formation 1,525 ft.	?
	Middle	Nevada formation (restricted) 2,400 ft.		Sultan dolomite 890 ± ft.
	Lower			(Missing)
SILURIAN		Lone Mountain formation (restricted) 2,200 ft.	Hidden Valley dolomite 1,365 ft.	Silurian(?) dolomite 335 ft.
		Roberts Mountains formation 1,900 ft.		
ORDOVICIAN	Upper	Hanson Creek formation 560 ft.	Ely Springs dolomite 940 ft.	Ely Springs(?) dolomite 800 ft.
	Middle	Eureka quartzite 500 ft.	Eureka quartzite 400 ft.	Eureka quartzite 265 ft.
	Lower	(discontinuity) Pogonip group (undifferentiated Lower Ordovician and Upper Cambrian)	Pogonip limestone 1,440 ft.	Pogonip(?) dolomite 1,040 ± ft.
CAMBRIAN	Upper		Nopah formation 1,600 ft.	Nopah formation 1,740 ± ft.
	? Middle		Racetrack dolomite 1,900 ± ft.	Cornfield Springs formation 2,975 ft.

Figure 2. Tentative correlation of the formations in the Quartz Spring area with the formations in the Roberts Mountains region and the Nopah Range.

Rocks younger than those remaining in the area occur nearby. Upper Pennsylvanian and Permian limestones continue the stratigraphic sequence several thousand feet upward, between Racetrack Valley and Saline Valley, only 5 miles west of the area (McAllister, 1946-49, unpublished data of the Geological Survey); and at least part of the same sequence lies faulted against the eastern front of the Panamint Range (Ball, 1907, p. 203, fig.17, pl. 1), about 10 miles southeast of the area. Triassic rocks are extensively exposed in the Inyo Range (Kirk, 1918, pp. 47-48, pl. II). Continental Tertiary deposits starting with fossiliferous Oligocene beds (Stock and Bode, 1935, pp. 571-579) are exposed in the Grapevine Mountains east of Death Valley. The absence of sedimentary rocks from Permian to Pliocene age in the Quartz Spring area not only leaves a wide gap in the history of sedimentation but also produces difficulties in dating events in the structural history.

No unconformity, representing any sort of erosional gap in the sedimentary sequence, has been recognized at the boundaries of the Paleozoic systems in the Quartz Spring and adjacent areas, where every boundary is well exposed. A disconformity marked by local conglomerate without noticeable angular discordance below it may occur in the Perdido formation, but within the Mississippian. Discontinuities in the sedimentary record, either disconformities or angular unconformities of such low angle of discordance that the discordance is not obvious, or some other types of hiatus, are to be expected in the local Paleozoic sequence. The known faunas are widely spaced through the sedimentary sequence. The fact that fossils of intermediate ages have not been found, however, is insufficient basis for postulating a corresponding absence of sedimentary rocks of those ages. The existence of significant gaps perhaps may be recognized after much more extensive mapping and correlation.

Racetrack dolomite (Middle(?) Cambrian)

Name and occurrence.—The oldest rock unit in the sedimentary sequence of the Quartz Spring area is named here the Racetrack dolomite for Racetrack Valley, which is the long depression draining southward to the Racetrack playa from a low divide between Tin Mountain and Dry Mountain. The valley separates the northern end of the Panamint Range from the southern foothills of the Last Chance Range. The type locality of the Racetrack dolomite is in the Last Chance foothills on the western side of Racetrack Valley, about 3 miles west of Quartz Spring. More precisely, the type locality extends from the southern tip of the spur west of the Hidden Valley road junction, for roughly 7,000 feet to the saddle north of the U. S. Geological Survey bench mark at 5,330 feet above sea level (see pl. 3A). The bench mark is shown on the Ballarat quadrangle.

The base of the Racetrack dolomite cannot be defined satisfactorily in the Quartz Spring area because alluvium overlaps the lowest exposures. The top is limited by the Nopah formation. The Racetrack dolomite crops out at no other place in the mapped area.

Lithology.--Gray dolomite is the conspicuously predominant rock of the formation. The gray varies from dark gray to very light gray or grayish yellow, producing from a distance a salient effect of thick bands (see pl. 3A). Closer inspection reveals that bedding is very much thinner than the color bands, and thinner than the spacing of well-developed joints which run parallel to the stratification. Many of the beds have minutely wavy bedding planes, and have small blotches of lighter or darker gray. Obvious variations in lithology are slight: there is some rather platy silty dolomite in a lower unit and some brown-weathering gray nodular chert in the lowest unit.

The following section was measured at the type locality:

Nopah formation.

Conformable contact.

Racetrack dolomite:	Feet
7. Somewhat streaky light-gray dolomite grades into darker gray near base....................	450
6. Light grayish buff dolomite contains a few thin dark-gray beds.........................	150
5. Very dark gray dolomite contrasts sharply with lighter dolomite above and below; in detail, very irregular lighter mottling extends in all directions; some small vugs of diagenetic(?) quartz....................................	200
4. Light-gray dolomite weathers creamy gray somewhat mottled by tan; a few irregular streaks of darker gray do not detract from its conspicuousness as a marker...............	30
3. Medium-gray dolomite; closely spaced sinuous mottling along bedding; widely spaced joints..	690
2. Somewhat platy dolomite that weathers pale yellowish brown, includes a very little pale reddish brown silty dolomite. About 30 feet from the base a massive bed of gray dolomite, 5 feet thick, lies within the brownish zone...	55
1. Dark-gray medium-grained dolomite, irregularly banded with lighter gray dolomite in layers about 1 inch thick, for about 220 feet above the base; in upper part some masses of chert up to 2½ feet long, ovoid in section; possible faults..................	325 ±
	1,900 ±

Thickness.—The stratigraphic thickness of the Racetrack dolomite in the Last Chance foothills is about 1,900 feet. Possible unmapped faults make questionable the measurement of the lowest units.

Age and correlation.—Although no fossils have been found in the Racetrack dolomite, the formation is presumably Middle Cambrian in age, if not early Upper Cambrian. No detectable stratigraphic break separates it from the overlying Nopah formation of probable Upper Cambrian age. In stratigraphic position and lithology the Racetrack dolomite corresponds to the upper part of Hazzard's Cornfield Springs formation in the Nopah Range. The entire Cornfield Springs formation was provisionally assigned by Hazzard (1937, p. 319) to the Middle Cambrian, with the reservation that the unfossiliferous upper part could be early Upper Cambrian.

Nopah formation (Upper Cambrian)

<u>Name and occurrence</u>.--The Nopah formation in the Quartz Spring area is considered to be essentially the same unit that Hazzard (1937, p. 320) named in the northern half of the Nopah Range in the southeastern corner of Inyo County, California. In the Quartz Spring area it is underlain by light-gray Racetrack dolomite and overlain by the Pogonip limestone. The Nopah formation ~~forms~~ makes cliffs or steep slopes that tend to become smooth, except in detail, in a manner indistinguishable topographically from that of the underlying Racetrack dolomite. In the mapped area the only exposures of the Nopah formation are on the ridge north of bench mark 5,330 in the Last Chance foothills (see pl. 3A).

<u>Lithology</u>.--The Nopah formation rather uniformly consists of dolomite, except for minor quantities of shale, limestone, and chert. The color ranges from cream through light gray to very dark gray, the dark gray predominating. Cream-colored dolomite, although subordinate, crops out in conspicuous bands that can be traced continuously across the area of exposure. In general aspect the banding is similar to that of the Racetrack dolomite.

The lowest part of the formation consists of medium dark gray dolomite, which at the base contains medium- to light-gray limestone interbedded with light-olive shale and brown-weathering silty and cherty limestone. On closer examination, some shaly partings in the limestone appear tan or pinkish. Locally the shaly partings contain some primitive brachiopods, and some of the limestone in this basal unit contains trilobites.

Above the basal unit of the Nopah formation there is a prominent layer of cream-colored dolomite, about 30 feet thick, overlain by a succession of dark- and light-colored dolomites, which crop out as conspicuous bands across the hills. The following generalized tabulation of the sequence of light and dark layers of dolomite was derived from a structure section that lacked details, and was later verified on aerial photographs that clearly showed the banding. The thickness of each layer therefore is only approximate.

Pogonip limestone.

Conformable contact.

Nopah formation:	Feet
9. Dark-gray dolomite	120
8. Cream-colored dolomite	30
7. Medium-gray to dark-gray dolomite; small gastropods about 3 millimeters in diameter	535
6. Cream-colored dolomite	30
5. Dark-gray dolomite	125
4. Very light gray dolomite	225
3. Dark-gray dolomite	125
2. Cream-colored dolomite	30
1. Medium dark gray limestone; lower 250 feet containing limestone, in places silty or cherty, weathering brown, interbedded with light-olive shale; trilobites in limestone and primitive brachiopods in tan or pinkish shaly partings	380
	1,600

Conformable contact.

Racetrack dolomite.

Thickness.--The thickness of the Nopah formation in the Last Chance foothills was calculated in a structure section to be approximately 1,600 feet.

Age and correlation.--The meager fauna in the Nopah formation occurs principally in the lowest unit, which is somewhat silty, and in gray dolomite about 500 feet below the upper contact. From the lower zone, G. Arthur Cooper of the U. S. National Museum reported the following fossils:

Lingula sp.
Obolus sp.
Acrotreta cf. A. idahoensis Walcott

Trilobites collected later have not been identified.

Small silicified fossils in the dark-gray dolomite of unit 7 of the Nopah formation were identified by Josiah Bridge of the U. S. Geological Survey, as follows:

Matherella cf. M. saratogensis Walcott
Sinuopea 3 or 4 spp. -- all undescribed.
Strepsodiscus sp.
New genus - new species - a small uncoiled curved form with a triangular cross section.
Unidentified plates.

"This fauna appears to correlate with a fauna in the upper part of the Eminence formation of Missouri particularly the so-called Proctor horizon and also with the Hoyt limestone of New York. The rather distinctive sinistrally coiled genus Matherella is common to all three areas. The fauna is very high Upper Cambrian."

The Nopah formation in the Quartz Spring area has been correlated with the Nopah formation of Upper Cambrian age at the type locality in the Nopah Range (Hazzard, 1937, pp. 320-321) chiefly by its stratigraphic position below the Pogonip limestone and partly by its lithology. Whereas the details of light and dark banding appear to be local, the basal shaly unit of the formation at the two localities appears to be a good marker of the lower limit. The upper limits of the formation in the Nopah and Quartz Spring areas may not be strictly equivalent.

Upper Cambrian rocks in the Inyo Range 30 miles northwest of the Quartz Spring area were described by Kirk (1918, pp. 31-32) as consisting largely of arenaceous limestones and shales that weather to bright colors, sandstones, and impure limestones, similar to Turner's Emigrant formation in the Silver Peak Quadrangle, Nevada (Turner, 1902, p. 265). The Upper Cambrian rocks in the Inyo Range on the basis of lithologic description cannot be correlated with the Nopah formation in the Quartz Spring area. The Upper Cambrian age of the formation in the Inyo Range has been questioned by Hazzard (1937, p. 322).

Other Upper Cambrian formations in the Great Basin are equally difficult to correlate with the Nopah formation by the described lithology. In the Pioche District the Mendha limestone (Westgate, 1932, pp. 11-12) is like the Nopah formation.

Pogonip limestone (Lower Ordovician)

Name and occurrence.--Pogonip limestone is the name applied originally by King (1878, pp. 187-195) to all beds between the Prospect Mountain quartzite (Lower Cambrian) and the Eureka quartzite (Middle Ordovician), as at Pogonip Ridge, Hamilton, Nevada, which is the type locality. Hague (1883, pp. 253-263) limited the Pogonip limestone to the beds between what is now called Dunderberg shale (Upper Cambrian) and the Eureka quartzite. Walcott proposed restricting Pogonip further, but the U. S. Geological Survey uses the name in the broader sense (Wilmarth, 1938, pp. 1689-1690).

The Pogonip limestone in the Quartz Spring area comprises the rocks above the Nopah formation and below the Eureka quartzite. Although the Pogonip here contains a variety of rocks among which limestone may not predominate, limestone is retained in the name rather than changed to formation because the Committee on Geologic Names, U. S. Geological Survey, has adopted Pogonip limestone for use in Survey publications/. The change at this time, furthermore, is inadvisable in that the Pogonip probably is destined to become a group. A typical section is exposed in the Last Chance foothills, about 2½ miles west of Quartz Spring (see pl. 3A).

/ Personal communication November 15, 1950.

Lithology.--The general aspect of the Pogonip is mouse-gray limestone and dolomite containing several more or less conspicuous dark reddish brown bands. Closer observation shows that it contains considerable siliceous material, both chert and sandy dolomite, and three well-marked zones of buff-weathering shaly beds. The reddish brown-weathering zones consist of thin cherty beds that appear crinkled or wavy, and merge at points of greatest irregularity, producing a structure that resembles piles of crepe; nodules and minute flat lenses of limestone remain isolated in the cherty rock (pl. 3B). These beds make diagnostic markers of the Pogonip limestone

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Plate 3B. Crepe structure in a siliceous unit member of the Pogonip limestone.

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throughout the region, as even through contact metamorphism the crepe-structure persists. The other distinctive feature of the formation is a conspicuous zone of large gastropods, which in outcrops appear as spirals sufficiently persistent to be considered a lithologic characteristic of that part of the formation.

Isolated outcrops of some parts of the Pogonip limestone may be confusingly similar to some other formations. Some beds in the Nopah and Racetrack formations are similar to the darker lowest dolomite of the Pogonip, which is distinguished, however, by light-gray chert and the somewhat mouse-gray color of the weathered rock. The uppermost Pogonip, the part that is above the gastropod zone and that lacks the usual brown streaks and lenses of sand, may be indistinguishable from mouse-gray dolomite in the Hidden Valley dolomite. Despite these exceptions, the Pogonip limestone is a distinctly mappable unit.

The following detailed section, except the bottom unit (no. 1), was measured with a tape along a spur on the west side of Racetrack Valley opposite Quartz Spring (see pl. 3A). The lowest unit was measured on the next ridge to the west, about 4,000 feet from the first:

Eureka quartzite.

Conformable contact.

Pogonip limestone:	Feet
8. Gray dolomite, in general medium gray althouth some beds are dark gray, weathering mouse gray; fine grained to medium grained; sandy dolomite in irregular streaks somewhat contorted in detail, expanding here and there into sandy pockets, especially characteristic of upper part. The sandy element weathers brown. A zone of _Mitrospira_ and _Maclurites_ is so exceptionally persistent that the gastropod spirals can be considered a lithologic characteristic...........................	485
7. Light-buff or yellowish shaly limestone, sparsely fossiliferous; very poorly exposed; forms shoulders on spur...........................	50
6. Brown-weathering siliceous beds, largely chert, tend to predominate over the gray limestone, which remains in nodules and lenses where the thin siliceous layers touch at undulations, producing a crepe structure. The proportion of siliceous material decreases gradually upward; and decreases abruptly at the base, where the lowest 35 feet is a platy gray limestone with ochreous irregular partings, and contains fragments of poorly preserved fossils. The shaly rock at the base emphasizes the cliff-forming quality of the unit, which makes it one of the most conspicuous of the Pogonip........................	185
5. Float of light-brown shale containing fossil fragments; does not crop out along line of section..	145

4. Light-gray limestone and dolomite, weathering brownish gray, contains many siliceous beds, up to 4 inches thick, that tend to merge at crenulations making a crepe structure, especially in lower half, which from a distance is browner than the mouse gray of the upper half. About 70 feet from the base of the unit there is some intraformational breccia of particles about one-half inch thick in a clastic matrix; some cross-bedding; numerous veinlets of white clacite.........	120
3. Buff-weathering shaly dolomite crops out poorly.....	60
2. Light-gray dolomite, much of which weathers light brown or light brownish gray, contains brown-weathering sandy streaks and a little chert in the lower part, where there are also scattered clusters of small but conspicuous quartz crystals which in some places make an open network pattern..................................	150
1. Medium-gray dolomite, locally limestone, weathers a mouse gray, and contains some flat lenses of light-gray chert, especially about 80 feet above the base of the formation. The mouse-gray color, the chert, and occasional limestone distinguish this basal unit of the Pogonip from the underlying Nopah formation.........	245
	1,440

Conformable contact.

Nopah formation.

Thickness.—The stratigraphic thickness of the composite section described in detail above is 1,440 feet. The measured section is a single continuous sequence except for the basal unit of 245 feet, which is buried in alluvium at that locality. The basal unit was measured in an excellent sequence extending unbroken from the Racetrack and Nopah formations below the Pogonip limestone and continuing into the Pogonip so that unit no. 2 of the Pogonip was matched at the two localities.

Age and correlation.—The most distinctive fauna of the formation is in the uppermost unit (no. 8) and consists of abundant Receptaculites and Maclurites, which have been considered good markers of the Chazyan part of the Lower Ordovician in the Great Basin. Few fossils have been collected from lower beds so that it is not yet known whether the Pogonip limestone as mapped here includes rocks of Upper Cambrian age as well as Lower Ordovician.

The following fossils from the Pogonip limestone were identified by G. Arthur Cooper. The lowest fossil collected, from no. 3 of the measured section, is Obolus sp. From an intermediate shaly unit, no. 5, fragments of a trilobite, collected by C. W. Merriam, were identified as an "Asaphid trilobite suggestive of Ptychopyge." The top unit, no. 8, contains the following:

Mitrospira longwelli Kirk
Maclurites sp.
Receptaculites sp.
Porambonites sp.

Unidentifiable Bryozoa were collected above the Mitrospira zone at the top of the Pogonip limestone.

Spurr (1903, p. 188) was the first to report on Pogonip in this region. He was informed by F. B. Weeks that rocks probably corresponding to the Pogonip formation of Eureka, Nevada, occur at Grapevine Peak at the northern end of the Amargosa Range and probably continue to Pyramid Peak in the central part of the range. The Amargosa Range is the first range east of the Panamint Range, on the opposite side of Death Valley. Weeks reported Pogonip fossils also from the northern part of the Panamint Range (Spurr, 1903, p. 202). At a later date Ball (1907, pp. 164-165) described the extensive occurrence of Pogonip limestone in the Amargosa Range. His reconnaissance map, however, includes under the symbol for Pogonip what is now known to be much more of the Paleozoic section. Ball's map is even more generalized at the northern end of the Panamint Range, where all the Paleozoic rocks from Cambrian to Pennsylvanian are shown as Pogonip limestone. The description (Ball, 1907, pp. 202-203) shows that Ball did observe Pogonip in the present sense of the term, but he failed to separate it from Eureka quartzite and higher formations.

Most of the Pogonip limestone of the Quartz Spring region closely resembles the Pogonip(?) in the Nopah area described by Hazzard (1937, p. 324). But the lowest part in the northern Panamint area, especially the lower boundary, has not been correlated precisely with the Pogonip elsewhere. The two lowest units, 1 and 2 of the section described above, as nearly as can be determined from Hazzard's (1937, p. 276) descriptions, correspond more closely to 400 feet of the uppermost member (80 in Hazzard's section) of the Nopah formation rather than to the basal part of the Pogonip(?) in the Nopah-Resting Springs region. These two units are included in the Pogonip here on the basis of lithology and of ease in mapping. Their mouse-gray color and chert lenses are characteristic of the Pogonip and not of the Nopah formation.

At the eastern base of the Panamint Range about 40 miles southeast of Quartz Spring, Hopper (1947, p. 407) recognized but did not map Hazzard's Pogonip (?) dolomite. Hopper included it in a unit, approximately 9,000 feet thick, of undifferentiated Cambrian and lower Ordovician dolomite and limestone.

In the Inyo Range rocks of the same age and lithology as the Pogonip limestone in the northern part of the Panamint Range were described by Kirk (1918, pp. 34-35), but he declined to call them Pogonip because he considered that the term was too loosely used. Kirk did not subdivide the Ordovician rocks for the reconnaissance map of the Inyo Range.

The Tank Hill limestone in the Pioche district (Westgate, 1932, pp. 14-15), which was considered to be essentially the same as the upper part of the Pogonip limestone of the Eureka district, seems equivalent to the upper part of the Pogonip limestone in the Panamint Range. The Yellow Hill limestone at Pioche (Westgate, 1932, p. 14) probably corresponds to part of the lower Pogonip in the Panamint area. The lithology of the Pogonip limestone in the Ely quadrangle (Spencer, 1917, p. 24) was described in too general terms to correlate it on that basis.

Eureka quartzite (Middle Ordovician)

Name and occurrence.—The Eureka quartzite was named by Hague (1883, pp. 253, 262; from Wilmarth, 1938, p. 706) in the Eureka region. Kirk (1933, in Wilmarth, 1938, pp. 706-707), with the approval of the Geological Survey, designated "....the exposures on southwest slope of Lone Mountain as the type section of the formation, because here it is completely exposed, together with overlying Lone Mountain limestone and underlying Pogonip limestone, while it is not exposed at Eureka, although it is poorly exposed in Eureka region. The Lone Mountain section is about 18 miles northwest of Eureka, and was know to Hague......." A stratigraphic section of Lone Mountain, showing the position and thickness of the Eureka quartzite, was published by Merriam (1940, p. 20).

Exposures of Eureka quartzite are widely distributed in the Quartz Spring area, but nowhere is it as continuous or well exposed in cross section as on the mountain scarp about 3 miles southwest of the area, where the thickness was measured for the local standard (pl. 3C). Within the

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Plate 3C. Eureka quartzite about 2½ miles north of Ubehebe Peak.

Quartz Spring area the quartzite crops out in Andy Hills near the southern border, on the southern flank of Whitetop Mountain near the eastern border, on the steep slopes east of Quartz Spring, and in the Last Chance foothills. The Eureka quartzite lies stratigraphically above the Pogonip limestone and below the Ely Springs dolomite.

Where the erosion has reduced the topography to a late stage the Eureka quartzite forms rough hills, and in areas where the topography is less subdued it makes blocky cliffs. The more massive upper part of the quartzite breaks into large angular joint blocks commonly 1 or 2 feet thick but as much as 6 feet thick.

Lithology.--The Eureka quartzite is perhaps the most conspicuous formation in the region. From a distance it appears as a light band emphasized by the nearly black Ely Springs dolomite on top of it. The lower half of the light band is somewhat darker, weathering tan, brownish, or pinkish brown, and is much less homogeneous in color. The quartzite in the upper part is uniformly vitreous, white, or tinged with pink, and is composed of quartz sand grains cemented by quartz that is indistinguishable from the grains except where they are outlined with faint coloring. In the lower quartzite unit there are some intercalated silty or shaly beds, and much of the unit is limonitic or hematitic.

A thin section of a random sample of the vitreous quartzite had quartz grains commonly 0.25 to 0.30 millimeter in diameter, falling within a range of 0.015 to 0.55 millimeter. Most of the grains were well rounded. The original shapes of the grains were faintly outlined by specks, although the quartz cement was in optical continuity with the grains, making a completely interlocking mosaic.

The general aspect of the Eureka quartzite varies little throughout the region. The Eureka has been the most distinctive formation of the area and was mapped with the greatest confidence. The lithology of quartzite beds interstratified in the lowermost part of the Devonian Lost Burro formation at some places is similar to that of the Eureka quartzite, but the quartzite beds of the Lost Burro are only a few feet thick in contrast to the 250 feet of vitreous quartzite in the Eureka. The sandy part of the Mississippian Perdido formation, where metamorphosed to quartzite near igneous intrusions, also can resemble Eureka quartzite except for the thinness of the quartzitic unit in the Perdido (only about 50 feet) and its distinctive stratigraphic position. The black Ely Springs dolomite lying on vitreous quartzite at once distinguishes the quartzite as Eureka.

The best exposure for detailed measurement of the Eureka quartzite lies southwest of the area, on the eastern front of a mountain 2½ miles due north of Ubehebe Peak and northwest of The Racetrack playa (see Ballarat quadrangle and pl. 3C). The following section was measured there with a tape:

Ely Springs dolomite.

Conformable contact.

Eureka quartzite:	Feet
2. White vitreous quartzite weathers white or faintly tinted pink or limonite yellow; in places the weathered surface is sugary. Some cross-bedding is discernible under close inspection; jointing parallel to stratification is rather widely spaced, up to about 5 feet. The contact with the overlying dolomite is sharp..................................	250
1. Interbedded dark hematitic quartzite, light, vitreous quartzite, and some platy quartzite and siltstone. Some of the siltstone is dull gray, contrasting with the reddish gray and light-colored quartzite. Iron-stained quartzite greatly predominates. Cross-bedded......	150
	400

Contact concealed along line of section. (Float-covered saddle; presumably a shaly part of the Pogonip limestone about 70 feet thick.)

Pogonip limestone.

Thickness.--The stratigraphic thickness of the Eureka quartzite as measured with a tape north of Ubehebe Peak is 400 feet. Where measured at the southern end of Andy Hills 6 miles due east it is also about 400 feet thick.

Age and correlation.--No fossils were found in the Eureka quartzite. The silty beds in the lower part should be examined more extensively for them. By lithology and stratigraphic position the formation has been correlated with the Eureka quartzite that crops out so extensively elsewhere in the Great Basin, where it has been designated Middle Ordovician.

The first published correlation of the quartzite in the Death Valley region with the Eureka quartzite was by Spurr (1903, pp. 188, 202), who wrote that F. B. Weeks had observed Eureka quartzite overlying the Pogonip formation south of Shaw Peak in the northern part of the Panamint Range. Spurr tentatively identified the Eureka quartzite also at Pyramid Peak in the Amargosa Range. Ball at a later date did not recognize that much of the quartzite at the northern end of the Panamint Range was Eureka quartzite, although at a locality where it does occur he described it as a "white or pinkish white fine-grained quartzite outcrop on the western side of the playa 4 miles north of Goldbelt Spring" (Ball, 1907, p. 203). He mapped Eureka quartzite in the Grapevine Mountains. Eureka quartzite is one of the few established formations that Hopper (1947, p. 407; fig. 1; pl. 1) distinguished without question at the eastern base of the Panamint Range about 40 miles southeast of Quartz Spring. In the Nopah Range Hazzard (1937, pp. 324-325) measured Eureka quartzite and correlated it with the formation at the type locality as redefined by Kirk (1933), with the Ordovician quartzite called the Eureka in the chart of the Geological Survey's "Tentative Correlation of the Named Geologic Units of Nevada," by M. G. Wilmarth, in the Spring Mountains region (Las Vegas quadrangle), and with the Eureka quartzite in the Pioche district (Westgate, 1932, p. 15). In the Inyo Range none was mapped (Knopf, 1918); but typical Eureka quartzite between Pogonip and Ely Springs has been observed by the writer at the southeastern tip of the range and near Barrel Spring in Mazourka Canyon on the western side of the range.

Ely Springs dolomite (Upper Ordovician)

Name and occurrence.--The Ely Springs dolomite was named originally by Westgate (1932, p. 15) from its exposures in the Ely Springs Range, about 12 miles west of Pioche, Nevada. In the northern Panamint Range the Ely Springs dolomite is bounded by the Eureka quartzite below and by the Hidden Valley dolomite, largely of Silurian age, above.

In the Quartz Spring area the Ely Springs dolomite crops out at the same localities as the Eureka quartzite (see p. 39). It is exposed more continuously southwest of the area, along the eastern front of the mountains north of Ubehebe Peak.

Lithology.—The Ely Springs is mostly dolomite, but it contains considerable dark-brown and black nodular chert. At most places chert is restricted to the lower part, but the proportion of chert to dolomite varies notably from place to place. The chert nodules tend to merge, and at exposures that are along the plane of bedding it is evident that they merge into extremely irregular networks which are parallel to the bedding. From the Eureka quartzite at the base to slightly beyond halfway to the top of the Ely Springs the dolomite is conspicuously dark gray, nearly black. In the upper part it is medium gray to light gray except for one noticeable dark-gray layer. In detail much of the dolomite is mottled somewhat lighter in the dark beds and darker in the medium-gray and light-gray beds. The mottling is so close in some layers that the effect is of wavy bands. Another type of color difference consists of lines of white grains, forming an irregular network through the darker rock. The lines at some places converge into ill-defined whitish blotches. At other places the lines and blotches are of pinkish dolomite. In the lower part of the black dolomite quartz-lined vugs 1 or 2 inches in diameter are common.

The following section of Ely Springs dolomite, measured with a tape, is taken as the standard for comparison in the region. It is a part of the long section measured on the east front of the mountains about 2½ miles north of Ubehebe Peak, southwest of the Quartz Spring area.

Hidden Valley dolomite.

Conformable contact.

Ely Springs dolomite:	Feet
2. Light-gray dolomite grades downward into about 100 feet of medium-gray dolomite at the base of this member. Some darker mottling and wavy streaks do not detract from the general effect of being much lighter than the lower unit of the Ely Springs dolomite. About 100 feet from the top a conspicuous dark layer 15 feet thick lies in the light-gray dolomite..........................	380
1. Conspicuously dark-gray or black dolomite containing lighter mottling, and some white dolomite grains and threadlike lines; near the base, there are some quartz-lined vugs about 1 to 2 inches in diameter. Abundant flat nodules of chert, from dark brown to black, tend to lie parallel to the bedding, starting 30 feet from the base, and diminishing in proportion to the dolomite up to a level about 250 feet above the base of the formation. Brachiopods and corals.............................	560
	940

Conformable contact.

Eureka quartzite.

The following section was measured at the southern end of the central long ridge of Andy Hills on the east side of Hidden Valley:

Hidden Valley dolomite.

Conformable contact.

Ely Springs dolomite:		Feet
2(b).	No outcrops through talus on the upper 65 feet of the top unit. Thin transitional beds of light and dark dolomite mottled in streaks parallel to the bedding; some lumpy chert also tends to be parallel to the bedding....................................	90
2(a).	Light-gray dolomite, grading into medium gray especially toward the bottom, where there is light-colored mottling about 1 inch in diameter................................	250
1(b).	Dark smoke-gray or black dolomite contains network and clusters of coarser grains of very light-gray and pink dolomite grains; no chert....................................	75
1(a).	Dark-gray and black dolomite contains abundant chert which becomes prominent about 25 feet above base. The chert is dark gray, weathering dark brown, and forms irregular plates that appear as brown streaks and lenses in outcrops across the bedding. Small fragments of fossils are in the basal 25 feet of dolomite. Gray dolomitic sandstone lies on the Eureka quartzite at the base.................	325
		740

Conformable contact.

Eureka quartzite.

Thickness.--The stratigraphic thickness of the Ely Springs dolomite is 940 feet on the west side of Racetrack Valley and only 740 feet on the east side of Hidden Valley, 6 miles east of the first section.

Age and correlation.--A few fossils from the Ely Springs dolomite in this region have been identified. Those listed below, collected by Miller W. Ellis for the Geological Survey, were identified by G. Arthur Cooper. The following fossils are from the base of the dark-gray dolomite at the locality north of Ubehebe Peak:

Streptelasma sp.
Resserella sp.
Dinorthis aff. D. Subquadrata (Hall)
Rhynchotrema aff. R. Capax (Conrad)

and from a place higher in the same unit:

Streptelasma
Halysites sp.
Rhynchotrema cf. R. argenturbicum (White)
Zygospira cf. Z. modestus (Say)

The fauna is consistent with the Upper Ordovician age of the original Ely Springs dolomite.

On the basis of lithology and of stratigraphic position above the Eureka quartzite the formation can be correlated with the Ely Springs (?) dolomite of the Nopah Range (Hazzard, 1937, pp. 325-326), which has been correlated tentatively with the original Ely Springs dolomite in the Pioche district, Nevada (Westgate, 1932, pp. 15-16). A similar dark-gray dolomite, though unnamed, has been observed by Hazzard (1937, p. 326) and Noble (1934) at several localities in the southern Great Basin. Ely Springs dolomite, associated with Eureka quartzite, was seen by the writer at the southeastern end of the Inyo Range. At the eastern base of the Panamint Range, Hopper mapped Ely Springs (?) dolomite and tentatively correlated it with the Ely Springs dolomite at Pioche (Hopper, 1947, p. 407, pl. 1).

Hidden Valley dolomite (Silurian and Lower Devonian)

Name and occurrence.--The Hidden Valley dolomite is named here for the good exposure on the eastern side of Hidden Valley (fig. 1), about 3 miles east-southeast from bench mark 5980 (Ballarat quadrangle map and pl. 1) near Lost Burro Gap. The name Hidden Valley, although not on the old Ballarat quadrangle map, appears on the map of Death Valley National Monument (National Park Service, 1937) and is listed by Palmer (1948, p. 36). It is anticipated that Hidden Valley will be used on the new map of the Ubehebe Peak quadrangle. The best exposure of the formation, however, is not in Hidden Valley but at the type locality about 3 miles westward.

The type locality of the Hidden Valley dolomite is on the eastern flank of a nameless mountain about 2½ miles north of Ubehebe Peak, and about three-fourths of a mile west of the road in Racetrack Valley. The formation is limited below by the Ely Springs dolomite and above by the Lost Burro formation.

The best exposure is at the type locality, southwest of the Quartz Spring area. Within the mapped area the entire section of the Hidden Valley dolomite occurs in the Andy Hills on the eastern side of Hidden Valley. A more accessible exposure, bearing conspicuous silicified fossils, crops out along the Hidden Valley road south of Lost Burro Gap. Here the section is incomplete but is representative of the formation. The Hidden Valley dolomite crops out also along the top of the ridge east of Quartz Spring, and on Whitetop Mountain.

The topographic expression of the Hidden Valley dolomite is like that of the great thickness of dolomite and limestone above and below it; all these units tend to make steep rather blocky slopes, slightly more prominent at cherty zones.

Lithology.--The Hidden Valley dolomite contains considerable chert in the lowest part, and very little limestone. The color of the dolomite in the lowest and highest units is a medium gray that weathers light olive gray or yellowish gray; in the middle it is very light gray or creamy. At most places it lacks black beds except on Whitetop Mountain on the main crest of the Panamint Range due east of Rest Spring, where the basal beds containing Silurian fossils are black. The chert is light gray or light brown and weathers to a darker brown. It forms nodules, which tend to join into coarsely branching masses or irregular beds. Fossils are abundant in the lower part, and at one locality they occur near the top of the formation.

In samples of the lowest unit, as seen under the microscope, the dolomite is pure, without grains of quartz or other minerals. The grain size is commonly about 1 millimeter and rarely over 1.7 millimeters in diameter; however, some grains are very minute, and a few are large--as much as 3 millimeters. The largest tend to be euhedral and form clusters. The creamy dolomite of the middle part of the formation is somewhat coarser grained, as grains are as much as 4 millimeters in diameter. The grain size in the creamy dolomite varies more erratically.

The section measured with a tape at the type locality 2½ miles north of Ubehebe Peak follows:

Lost Burro formation.

Conformable contact.

Hidden Valley dolomite:

		Feet
3.	Medium dark gray, fine-grained dolomite; lacks sandy or cherty beds, except for a 15-foot zone of brownish-weathering silty beds at the base of the unit........................	200
2.	Massive, very light gray (nearly white) dolomite, weathering creamy; becomes slightly darker and in places faintly mottled with darker gray, in upper part. At 450 feet from base of unit are the first beds of intraformational dolomite breccia, and these occur also higher in the section at irregular intervals. The angular fragments of the breccia tend to be elongate, commonly 2 to 4 inches long. The only trace of fossils was seen near the base of the unit, where the cellular structure of favositoids survived the rather coarse crystallization of the dolomite...................	730
1.	Medium-gray and medium light gray dolomite, weathering light olive gray, contains conspicuous chert. The basal beds are banded gray and lighter gray from a fraction of an inch to several inches thick, having rather wavy contacts. The chert is light gray to light brown and forms nodules that in section are round or oblate, if not more irregular; in places the nodules join to form chert beds 2 to 4 inches thick. The proportion of chert decreases above a zone 250 feet from the base of the formation. This unit is one of the most fossiliferous zones in the region. Small rather globular Favosites cf. F. niagarensis occurs in the basal beds and	

upwards; higher it is associated with solitary tetracorals and a few brachiopods; at 330 feet the _Favosites_ in the commoner discoidal form 1 to 2 feet in diameter, and is associated with _Syringopora_. Abundant _Halysites_ occur in a highly fossiliferous zone about 15 feet thick starting 325 feet above the base. Near the top of the unit there are many specimens of well-preserved cylindrical sponges.................... 435

1,365

Conformable contact.

Ely Springs dolomite.

Near the southern end of the central ridge in the Andy Hills the following section of the Hidden Valley dolomite was measured:

Lost Burro formation.

Conformable contact.

Hidden Valley dolomite:		Feet
3(b).	Medium dark gray dolomite, weathering light olive gray; thin-bedded; lower 50 feet fossiliferous (Spirifer kobehana zone of Merriam)........................	65
3(a).	Medium-gray dolomite weathers grayish buff or medium gray; thin-bedded. About 5 feet of brown-weathering quartzite occurs 35 feet above the base of the unit.........	450
2.	Very light gray, nearly white, rather coarse grained dolomite weathers light creamy buff; no discernible bedding; only traces of fossils such as the honeycomb structure of favositoids.....................	635
1(b).	Brownish-gray dolomite, weathering yellowish brown, contains light-gray chert. Fossils..	125
1(a).	Medium-gray dolomite, weathering medium buff gray, contains abundant dark-gray or dark-brown chert, constituting up to a half but more usually a third of the rock. The chert forms irregular nodules, many of which appear like branching somewhat flat masses or irregular sheets 1 to 2 inches thick, in general parallel to the bedding. Many well-preserved fossils including abundant Halysites......................	90
		1,365

Conformable contact.

Ely Springs dolomite.

The poorly defined threefold nature of the formation—that is, medium-gray dolomite containing much chert in the lower part, then creamy chert-free coarser-grained dolomite, overlain by somewhat darker thinner-bedded fine-grained dolomite—is persistent through the area.

Other chert-bearing dolomites in the Paleozoic section, such as the Ely Springs dolomite, could be mistaken for the Hidden Valley dolomite, especially if they are sufficiently metamorphosed to obscure characteristic colors. The dark-gray Tin Mountain limestone has considerable chert but the carbonate rock is distinctly limestone. In isolated outcrops where stratigraphic relationships are not known, the upper part of the Hidden Valley dolomite could be mistaken for the massive dolomite in the Pogonip limestone, upper Ely Springs, and parts of the Lost Burro formation.

Thickness.—At the type locality on the west side of Racetrack Valley and on the eastern side of Hidden Valley, 6 miles from the first locality, the thickness of the Hidden Valley dolomite is 1,365 feet.

Age.—The lowest fossiliferous part of the Hidden Valley dolomite is Silurian, probably equivalent to beds at the top of the Clinton group in the Niagaran series. Certain diagnostic forms were identified early in the work. *Halysites catenularia* (Linné) and *H. microporus* (Whitfield), typical of the Niagaran series, are abundant. *Favosites* cf. *F. niagarensis* of Niagaran age, though much less abundant, is also characteristic of the Hidden Valley dolomite. Excellent specimens of *Porpites porpita* (Linné) were found on Whitetop Mountain. Comparison with three good specimens of *P. porpita* from Gotland, the type locality of the species, shows that the species from Sweden and California are identical (McAllister, 1940, pp. 1984-1985). The morphologic characters of the specimens from the Panamint Range of *P. porpita* vary widely and include the features shown by *P. rotuloides* (Hall) and *P. michiganensis* (Bassler).

The stratigraphic range of *P. porpita*—including the above synonyms—when correlated according to the Silurian chart compiled by the National Research Council (Swartz, et al, 1942; chart 3) is essentially the same in North America (upper part of the Clinton and in the Manistique dolomite) as it is in Europe (upper part of the Llandoverian series and the lower part of the Wenlock series). The species, therefore, is a good marker of the middle part of the Niagaran series.

Fossils from the lowest unit of the Hidden Valley dolomite at the type locality were submitted to G. Arthur Cooper for identification. He reported, "Corals, mostly unidentifiable. The collection contains Halysites with numerous cup corals, possibly including Amplexus among others. One good Silurian index present is Favosites like F. gothlandica. Also present are corals resembling Ptychophyllum. The sponge Hindia is present."

Fossils in uppermost unit of the Hidden Valley dolomite, from a zone 50 feet thick lying 65 to 15 feet below the top of the formation in the Andy Hills were identified by Mr. Cooper as follows:

"Favosites sp.
Papiliophyllum elegantulum Stumm
Amplexus lonensis Stumm
A. invaginatus Stumm
Unidentifiable cup corals
Branching Cladopora
Heliolites sp.
Acrospirifer kobehana (Merriam)
Platyceras sp.

"This collection is Lower Devonian in age, the Oriskany portion of the Nevada limestone of Merriam."

This fauna contains some of the distinctive forms of the "Spirifer" kobehana zone at the base of Merriam's restricted Nevada limestone (Merriam, 1940, pp. 52-53, fig. 7, tables 2 and 4). In addition to Acrospirifer (Spirifer) kobehana, it has the diagnostic species Papiliophyllum elegantulum and Meristella robertsensis. Charles W. Merriam (written communication April 1950) later found that the fauna from this unit contains in some abundance a large Spirifer of the Spirifer arenosa (Conrad) group, confirming the Oriskany age. It should be noted that Heliolites sp. here occurs in the Lower Devonian fauna, whereas in the restricted Nevada formation, it occurs in the Middle Devonian "the only position in which Heliolites was found to occur in the Devonian of Nevada" (Merriam, 1940, p. 58).

The Silurian-Devonian boundary thus falls within the uppermost part of the Hidden Valley dolomite. Unfortunately for systematic stratigraphy, the distinctive persistent lithologic change is above the Lower Devonian fossils, in contrast to the minor variations in lithology below the fossiliferous beds. These minor variations are poorly defined and cannot be correlated acceptable from place to place. The distinctive formational boundary has been readily mapped over a broad region.

Correlation.—Rocks containing Niagaran fossils long have been known in the Great Basin. The Lone Mountain formation, named by Hague in 1883 in the Eureka region, contains Niagaran fossils in the upper part and Upper Ordovician fossils in the lower part. Spurr (1903, p. 86) in the Hot Creek Range, Nevada, identified fossils probably of Niagaran age, including "*Halysites catenulatus*, large variety" and "*H. catenulatus*, small variety" in the Lone Mountain. He noted the occurrence of "Upper Silurian" rocks above the Eureka quartzite near Cottonwood Canyon in the northern Panamint Range, without describing the rock, so that he may have meant Ely Springs rather than the Hidden Valley dolomite. Spurr's descriptions are apt to confuse readers because he includes Ordovician in Silurian, except when he quotes other geologists. The Lone Mountain formation in the original sense was used by Ball to include strata of Trenton and Niagaran age—that is, the Ely Springs as well as the Hidden Valley. From the descriptions of occurrences in the Amargosa Range it is impossible to judge whether Ball (1907, p. 165) recognized the equivalent of the Hidden Valley. No Lone Mountain was described in the Panamint Range.

Later publications on the Great Basin describe Silurian rocks without a name, such as in the Pioche region (Westgate, 1932, p. 16), the Spring Mountains region (Nolan, 1929), the Nopah Range (Hazzard, 1937, p. 326), and questionably south of Pinto Peak in the Panamint Range where they were grouped with Devonian rocks (Hopper, 1947, p. 408). These Silurian rocks in the Pioche district were correlated by Kirk (Westgate, 1932, p. 16) with the Fusselman limestone of the El Paso region and New Mexico, as well as with the Niagaran part of the Lone Mountain limestone.

The Lone Mountain formation in the Roberts Mountains region was restricted by Merriam (1940, p. 13) to the uppermost part of the original Lone Mountain limestone, which "is largely dolomitic and barren of determinable fossils with the exception of a single specimen of a poorly preserved Syringopora found within a few feet of the base at Lone Mountain. The determination of age rests therefore on position of the formation between the fossil-bearing Roberts Mountains formation and the Nevada formation." Merriam's restricted Lone Mountain formation is approximately equivalent to the middle and some of the upper part of the Hidden Valley dolomite (see fig. 2), and his Roberts Mountains formation (the middle unit of the original Lone Mountain formation) is equivalent to the lower part of the Hidden Valley dolomite. The lowest unit in the original Lone Mountain, of Upper Ordovician age, was called Hanson Creek formation by Merriam, and it is equivalent to the Ely Springs dolomite as used in the Panamint region.

The uppermost part of the Hidden Valley dolomite corresponds in age to the lowermost part of the Nevada formation as defined by Merriam (1940, pp. 13-14). The S. kobehana zone, which is the first persistent faunal zone of Lower Devonian age in the Roberts Mountains region, lies 100 to 150 feet above the base of the Nevada formation at Lone Mountain (Merriam, 1940, p. 52). The base of the same faunal zone in the Quartz Spring area, where the zone is 50 feet thick, lies 65 feet below the top of the Hidden Valley dolomite.

A. Lost Burro formation at type locality. Western side of Lost Burro Gap at southern end. Lost Burro formation, Dlb, is above Hidden Valley dolomite, Shv, and below Tin Mountain limestone, Ctm.

B. Contact of Lost Burro formation, Dlb, with overlying Tin Mountain limestone, Ctm. Eastern side of Lost Burro Gap near northern end. Cyrtospirifer zone in brown sandstone outcropping from lower left to top of view.

Lost Burro formation (Middle and Upper Devonian)

Name and occurrence.--The Lost Burro formation is here named for exposures at Lost Burro Gap, through which the road passes from Racetrack Valley to Hidden Valley. The type locality is on the western side of the gap at the southern entrance; it extends from the Hidden Valley dolomite at the base of the slope to the Tin Mountain limestone near the top (pl. 5A).

Plate 5A. Lost Burro formation at type locality.

The Lost Burro formation is exposed extensively, although not continuously from bottom to top, in the Quartz Spring area. The best outcrops are in Lost Burros Gap, Andy Hills, and along the flanks of West Crest. The formation is widespread also in the surrounding region between Death Valley and Saline Valley. It tends to form conspicuous cliffs, and high steps in canyons.

Lithology.—The general appearance of the Lost Burro formation is of a very light gray dolomite prominently striped with nearly black limestone and dolomite. The color alone is not a reliable indicator of whether the rock is limestone or dolomite, but the limestone where not metamorphosed is dark. The lower part is entirely dolomite. Sandy beds that weather brownish gray mark the base of the formation. At some places the sand forms layers of vitreous quartzite 2 or 3 feet thick, which weather into massive blocks but show thin bedding and cross-bedding. Throughout the rest of the formation up to the quartzite and sandy shale at the top, the quantity of sand in the rocks is negligible. Midway in the section conspicuous black limestone beds consist of masses of stromatoporoids, of which the peculiar concentric cellular structure is sufficiently persistent to be considered a lithologic characteristic of that part of the formation. In the same way spaghettilike outlines of masses of cladoporoids in several beds can be considered another characteristic of the lithology. Within the region the combination of these two structures of organic origin occurs in none of the other formations and is an excellent indicator of the Lost Burro formation.

The following section was measured by tape at the type locality of the Lost Burro formation, south of Lost Burro Gap (pl. 5A):

Tin Mountain limestone.

Conformable contact

Lost Burro formation:	Feet
5. Very light gray sandy dolomite and quartzite; upper part weathers brown; uppermost part, somewhat shaly, weathers slightly pinkish brown; contains excellent *Cyrtospirifer* in outcrops at lower end of Lost Burro Gap......................	35
4. Very light gray dolomite and some interstratified medium gray dolomite, producing a banded effect similar to the underlying unit but in general much lighter gray...............	335
3. Dark-gray dolomite mottled by white forms resembling broken spaghetti; beds of stromatoporoids in very dark gray limestone or dolomite, interbedded with light- and dark-gray dolomite and limestone..................	530
2. Light-gray dolomite mottled and streaked with cream-colored dolomite; dark-gray or black dolomite; dark-gray dolomite mottled with lighter gray................................	470
1. Light gray sandy dolomite, weathering mouse-gray, containing abundant chert in very irregular nodules; sand weathers dark brown, making rough surface, and in some places forms quartzite............................	155
	1,525

Conformable contact.

Hidden Valley dolomite.

The lower units, 1, 2, and 3, of the following section were measured along the central north-trending ridge of the Andy Hills, and the upper units, 4 and 5, were measured up the southern slope of the hills north of the Andy Hills.

Tin Mountain formation

Conformable contact

Lost Burro formation:	Feet
5. Very light gray sandy dolomite grading into quartzite; platy brown-weathering calcareous sandstone at top; fossiliferous....................	40
4. Very light gray dolomite, and some interbedded medium gray dolomite........................	295
(Gap in measured section, where covered by alluvium that may conceal complicating structures)	
3. Dark-gray or black dolomite, some a mass of stromatoporoids, and some mottled by spaghetti-like forms; medium-gray and light-gray dolomite interstratified with the darker, which is predominant (top of this unit covered by alluvium)......................................	1,400 ?
2. Medium-gray dolomite grading into layers of lighter or somewhat darker dolomite; lacking stromatoporoids and spaghettilike markings; basal 150 feet, coarse-grained light-gray dolomite marked by indistinct wavy bands roughly parallel to the bedding..........	260
1. Medium-gray sandy dolomite; 20 feet of massive very light gray sandstone 175 feet above base, separated by 15 feet of mudstone from underlying dark-weathering chert zone 35 feet thick................................	250
	2,245 ?

Conformable contact.

Hidden Valley dolomite.

Stratigraphic details at the boundary between the Lost Burro formation and the Hidden Valley dolomite in the Andy Hills are listed below. The numbers correspond to units in the complete sections on page 55 (Hidden Valley dolomite) and page 65 (Lost Burro formation).

Lost Burro formation:	Feet
1. Medium-gray dolomite, more or less sandy in lenses and in poorly defined discontinuous beds; a few inconspicuous pebbles of light-gray dolomite in some of the sandy layers............	55
Very light gray sandstone; a little dolomite cement in massive layer.....................	20
Light-gray mudstone (nonfissile shale)...............	15
Gray chert; weathering brownish black; in medium light gray dolomite; less chert in sandier base.......................................	35
Medium-gray dolomite containing brownish-weathering sand and silt in poorly defined lenses and beds, and outlining conspicuous sinuous branching forms............................	125
	250

Conformable contact.

Hidden Valley dolomite:	
3(b). Medium dark gray dolomite, weathering light olive gray; thin bedded....................	15
Same medium dark gray dolomite, containing abundant silicified fossils; *Spirifer kobehana* zone...........................	50
	65

Thickness.—At the type locality on the western side of the southern entrance to Lost Burro Gap the stratigraphic thickness of the Lost Burro formation is 1,525 feet. The total thickness of the section measured in the Andy Hills, owing to structural uncertainties in units 3 and 4, is questionable.

Age and correlation.—The age of the Lost Burro formation is Upper Devonian and probably Middle Devonian. As shown by excellently preserved brachiopods, the sandy beds within 35 feet of the top of the formation correspond to the Conneaut group in the upper part of the Cassadaga stage of the Upper Devonian (see Cooper et al, 1942, chart 4). There is little definitive faunal evidence for assigning much of the formation to the Middle Devonian, but abundant stromatoporoids and cladoporalike forms suggest that it is correlative with the Great Basin Middle Devonian. This age determination is supported by the stratigraphic position of the formation, without obvious depositional breaks, between Upper Devonian and Lower Devonian fossiliferous zones.

Fossils collected from the sandy uppermost 35 feet of the Lost Burro formation, at the lower end of Lost Burro Gap (pl. 5B), were identified and

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Plate 5 B. Contact of Lost Burro formation, Dlb, with overlying Tin Mountain limestone, Ctm.

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correlated by G. Arthur Cooper as follows:

Cyrtospirifer cf. C. monticola Haynes
C. cf. C. disjunctus (Sowerby)
Tylothyris? cf. T.? raymondi Haynes
"Camarotoechia" aff. "C." duplicata (Hall)
Cleiothyridina cf. C. devonica Raymond
Productella sp.

These "... are clearly related to Three Forks shale species. The species however of '*Camarotoechia*' cf. 'C.' *duplicata* indicates correlation with the upper part of the Cassadaga Stage in New York." This confirms the opinion earlier expressed in the field by Charles W. Merriam (oral communication, 1947) that the fauna was of Three Forks age and that much of the Lost Burro formation was similar to the Devils Gate formation in Nevada.

Specimens from the middle of the formation, starting 475 feet below the top and continuing 225 feet lower, were too poorly preserved to name other than as "Unidentifiable Bryozoa and corals; *Atrypa* sp.; branching *Cladopora*; silicified and unidentifiable *Stromatopora*."

The upper part of the Lost Burro formation can be correlated with the Sultan limestone as established by Hewett (1931, pp. 13-16) in the Goodsprings quadrangle, but the lower part, which extends well below the stromatoporoid beds similar to the Ironside member of the Sultan limestone, may continue into the underlying Goodsprings formation. The lower part of the Lost Burro formation seems equivalent to the Sultan dolomite as redefined by Hazzard (1937, pp. 328-331) for the Nopah Range, but the sandy top of the Lost Burro formation is lithologically similar to the lower part of Hazzard's Stewart Valley limestone(see fig. 2). The designation of the lowest member of the Stewart Valley limestone as Mississippian is on the meager faunal basis of one collection (No. P.B. G-5) containing "Corals and Stromatopora possibly Mississippian age." The Lost Burro formation also contains corals and stromatoporoids, which though of undetermined age lie under the diagnostic Cyrtospirifer zone of Upper Devonian age. The sandy base of the Lost Burro formation is similar to the base of the redefined Sultan dolomite, which Hazzard placed lower than that of the original Sultan limestone. The Lost Burro formation thus probably includes beds below the Sultan limestone in the Goodsprings quadrangle and above the redefined Sultan dolomite in the Nopah Range.

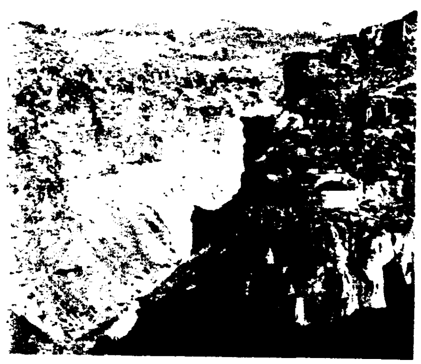
In east-central Nevada the Devils Gate formation in the Roberts Mountains region appears equivalent to the upper part of the Lost Burro formation, and the restricted Nevada formation—all but the basal part—apparently corresponds to the remainder of the Lost Burro. This correlation makes the Lost Burro formation approximately equivalent to all but the base of the original Nevada limestone. Even if nearly the entire Devonian succession falls thus into a single formational division, the Lost Burro formation is nevertheless the appropriate lithologic unit for mapping in the Quartz Spring region. This does not force the Devonian rocks there into a single time-rock unit; the number of time-rock units within it depends on the number of diagnostic faunas that can be correlated with those in established time-rock units, or that are suitable bases for new ones. In the Pioche district the Silverhorn dolomite and part of the West Range limestone (Westgate, 1932, pp. 16-19) in lithology and age seem at least roughly equivalent to the Lost Burro formation.

Tin Mountain limestone (Mississippian)

Name and occurrence.--The Tin Mountain limestone is named here for the northernmost peak in the Panamint Range (see Ballarat quadrangle), where it forms prominent cliffs near the top on the eastern and southern sides of the mountain. As the top of Tin Mountain is somewhat inaccessible, the type locality of the Tin Mountain limestone is designated as the southern slope of the hills about 2½ miles southeast of Quartz Spring and about 3,000 feet north of the road to Rest Spring, where the entire sequence is exposed from the underlying Lost Burro formation to the overlying Perdido formation. A still more accessible exposure, which lacks, however, the upper contact of the formation, is at the northern end of Lost Burro Gap (pl. 5B). The Tin Mountain limestone crops out widely and conspicuously at many places throughout the Quartz Spring area. It forms steep-walled canyons and cliffs on mountainsides more readily than any of the other formations (pl. 6A).

Plate 6A. Tin Mountain limestone, Ctm, above Lost Burro formation, Dlb, and below Perdido formation, Cp, on northeastern side of Bighorn Gap.

A. Tin Mountain limestone, Ctm, above Lost Burro formation, Dlb, and below Perdido formation, Cp, on northeastern side of Bighorn Gap.



B. Siltstone and silty limestone in Perdido formation, north of Bighorn Gap.

C. Rest Spring shale, Crs, faulted down against Perdido formation, Cp, south of Rest Spring.

Lithology.--The lower part of the Tin Mountain limestone consists of dark-gray limestone in beds 2 to 6 inches thick, separated by much thinner beds of light brownish gray to pale-red shale. The upper part consists of medium-gray limestone that from a distance appears to be a single massive layer, but actually the limestone is in beds that range in thickness from a few inches to 2 feet (pls. 5B and 6A). In some places mere traces of the shale remain as pale-red partings. Some beds of limestone are made up of crinoid stems. An abundance of Syringopora is distinctive; favositoids and horn corals are common. Both the lower and upper parts of the formation contain a little dark-gray chert, which weathers dusky brown or dark yellowish brown, in elongate nodules.

Features that distinguish the Tin Mountain limestone from the other formations of the region are the persistence of dark limestone, the thin pale-red shaly beds and partings, chert only in nodules, and the abundance of Syringopora. The only dark limestone stratigraphically lower--the limestone in the Lost Burro formation--is thinner, interstratified with dolomite, and is marked by stromatoporoid and cladoporoid structures. Stratigraphically higher, the only massive dark limestone is in the Perdido formation, which though gradational from the Tin Mountain, is distinguished by beds of chert and thick layers of shale and siltstone interbedded with the limestone. The distinctiveness of the Tin Mountain limestone makes it and excellent marker.

The following section was measured at the type locality:

Perdido formation.

Conformable contact.

Tin Mountain limestone:	Feet
2. Medium-gray limestone in beds a few inches to 2 feet thick but resisting as a unit to form cliffs; pale-red partings are faint; some nodules of dark-gray chert; poorly preserved horn corals and segments of crinoid stems scattered throughout..................	200
1. Medium dark gray limestone in beds 2 to 6 inches thick; thinner beds of calcareous shale, light brownish gray to pale red; some nodules of dark-gray chert; weathering dusky brown or dark yellowish brown; locally somewhat concealed by rubble from same unit......................................	275
	475

Conformable contact.

Lost Burro formation.

West of the Quartz Spring area another section showing the two characteristic units of the Tin Mountain limestone was measured in the canyon draining from the Ubehebe mine (see fig. 1) westward into Saline Valley, at a prominent constriction in the canyon about a mile in a straight line N. 70° W. of the mine and about 7 miles in a straight line due west of the type locality of the Tin Mountain limestone.

Perdido formation.

Tin Mountain limestone:	Feet
2. Dark bluish gray limestone, containing dark-weathering chert lenses 2 to 12 inches long and 1 to 4 inches thick; although appears massive, composed of beds 6 inches to 2 feet thick........................	265
1. Thin beds of dark-gray or light brownish gray limestone, as much as 6 inches thick, separated by pale-red shaly limestone beds that become thinner and redder-gray upward to where they are mere red-tinged partings in the base of the overlying member; somewhat crenulated..................................	160
	425

Lost Burro formation.

Thickness.--At the type locality, about 2½ miles straight southeast of Quartz Spring, the thickness of the Tin Mountain limestone is 475 feet, and about 7 miles due west of that locality it is 425 feet. The true thickness of the lower incompetent unit is modified by crenulation and boudinage structure. A factor of uncertainty in comparing measurements of the upper unit is the gradational nature of the contact with the overlying Perdido formation.

Age and correlation.--The age of the Tin Mountain limestone, according to a qualified determination of the poorly preserved fossils, is early Mississippian. The alternate possibility that the Tin Mountain limestone is older than Mississippian has been favored by Charles W. Merriam (oral communication in the field, 1947; written communication, 1950). Two collections of fossils, U-183tm from the excellent exposure at the lower end of Lost Burro Gap and U-200 from the top of the mountain about 1,000 feet south of bench mark 5980, that is, 8,000 feet south of the first locality, were submitted in 1948 to the U. S. Geological Survey. James Steele Williams' report on the collection is fully quoted below:

> "Two collections are described as being from this formation, U-200 and U-183tm. Collection U-183tm is composed of corals, crinoid columnals, and several incomplete specimens of two species of brachiopods. The corals were studied by Miss Helen M. Duncan, who reports as follows:
>
> "'This collection contains several specimens of *Syringopora* of the *S. aculeata* and *S. surcularia* types and several much-weathered and silicified examples of small horn corals. One of the specimens shows a zaphrentoid arrangement of septa in early ephebic stage, but for identification, the lot as a whole is too poorly preserved.

"'This collection is probably of Mississippian age. Dr. Kirk does not recall having ever observed Syringopora in the Devonian of the West, though several species of the genus have been described from the Devonian of eastern North America. Most of the known Devonian species are characterized by much smaller and more closely associated corallites or are lax forms that appear to be close to other Devonian auloporoid genera. Kirk says Syringopora is rather common in the Silurian of the West, but that if these specimens are definitely known to occur above good Devonian, they almost certainly indicate Carboniferous rocks. The small zaphrentoids, though not generically identifiable, are one of the types common in the lower Mississippian in this country.'

"The brachiopods, though not specifically determinable, also suggest Mississippian age. They have been designated as Spirifer cf. S. centronatus Winchell and Composita? sp. indet.

"Collection U-200 consists mostly of brachiopods, but contains two fragmentary and silicified horn corals. Miss Duncan examined the horn corals, and the brachiopods were examined by Drs. Edwin Kirk, G. A. Cooper, Arthur Bowsher, and me. All agree that the brachiopods represent a fauna that is very probably of very early Mississippian age, but definitely diagnostic characters needed for positive identifications are preserved on so few of the individuals that a definite age of reference cannot be made. A qualified determination as early Mississippian is the best that can be made on the material available to us. The following is a list of identifications, insofar as they may be made, prepared by me.

Horn corals, 2 specimens
Crinoid columnals
Echinoid plates
Shumardella? sp. indet.
Spirifer cf. S. centronatus Winchell
Spirifer? sp. indet.
Spirifer or Brachythyris sp. indet.
Composita? sp. indet.
Productella? sp. indet., part of an interior
Schizophoria? sp. indet.
Punctospirifer? sp. indet.

"Regarding the two horn corals listed above, Miss Duncan states:

"'One specimen is a fragment from the calicular part of what is interpreted to be a zaphrentoid coral. There is too little of the corallum to tell what the genus might be. The larger specimen is incomplete and poorly preserved. It might be a Mississippian caninoid, but in some respects it seems to more like a Devonian coral. Data from the corals in this collection are inconclusive.'"

As a working hypothesis it is proposed that the Tin Mountain limestone is equivalent to the lower part of the Madison group. This is based not solely on these properly noncommittal identifications of fossils but also on the lithologic similarities in the sequence of rocks from the Devonian-Mississippian boundary well into the Mississippian, as described in areas between the Panamint Range and the localities of established Madison.

Correlation of the Tin Mountain limestone with the Mississippian rocks in the Death Valley and other adjacent regions is impossible because the Mississippian units there have not been named or defined. Probably some part of the Mississippian (and older?) rocks described by Hopper (1947, pp. 409-411) in the northern end of the Argus Range, about 30 miles in a straight line south of the Quartz Spring area, is equivalent in age, if not as a lithologic unit. In the Nopah Range, the lithologic description of only the highest unit (14C) of the Stewart Valley limestone (Hazzard, 1937, pp. 275 and 333) suggests equivalency to the Tin Mountain limestone; the two lower units appear to be more similar to the Devonian Lost Burro formation (see fig. 2). The Mississippian formation in the Goodsprings area, the Monte Cristo limestone (Hewett, 1931, pp. 17-19), is lithologically unlike the Tin Mountain limestone although the faunas suggest at least approximate equivalency in age. The Bristol Pass limestone in the Pioche district is similar in lithology and age to the upper unit of the Tin Mountain limestone, and in the section south of Silverhorn (Westgate, 1932, p. 17) the West Range limestone above the Devonian fossils near the bottom would then correspond to the lower unit of the Tin Mountain limestone. The remainder of the West Range limestone and underlying sandy part of the Silverhorn dolomite are not too dissimilar in rock type and age to be provisionally correlated with the top of the Lost Burro formation. In the Roberts Mountains region there seems to be no lithologic unit of Mississippian age equivalent to the Tin Mountain limestone. In the Ely area the dual combination of the nonresistant Pilot shale and the overlying cliff-forming Joanna limestone (Spencer, 1917, p. 26) suggests the sequence of lower and upper Tin Mountain limestone; the little that is known about their ages (Weller et al., 1948, p. 134) supports the suggestion.

Perdido formation (Mississippian)

Name and occurrence.—The Perdido formation is named here for Perdido Canyon (pl. 1), where the formation is exposed from the foot of the southern wall, about 9,000 feet southeast of Quartz Spring, over the hill to the underlying Tin Mountain limestone. A scarcity of geographic names requires using Perdido, which has not been established. In the canyon, a fault between the Perdido and Rest Spring formations cuts out the uppermost part of the Perdido, but this segment is well exposed south of Rest Spring. The type locality south of Perdido Canyon, therefore, is supplemented by a second locality, about 3,000 feet south of Rest Spring, for the uppermost part of the Perdido formation.

The most conspicuous exposures lie in a much-faulted strip that trends north from the Rest Spring road, through the middle of the area to the northern border (pl. 6A, 6B, and 6C). The southern part of the strip is

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Plate 6B. Siltstone and silty limestone in Perdido formation, north of Bighorn Gap.

Plate 6C. Rest Spring shale, Crs, faulted down against Perdido formation, Cp, south of Rest Spring.

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readily accessible, but except along steep gullies the exposures are relatively poor, and unmapped minor faults, largely concealed by slope rubble, obscure the stratigraphic sequence. Excellent but less accessible outcrops occur in the northeastern part of the area.

The upper part of the Perdido formation makes smooth rounded slopes covered with fine-sized rubble, or somewhat ribbed slopes (pl. 6C). At favorable locations the lowest part of the formation makes cliffs, which are less pronounced than the cliffs made by the underlying Tin Mountain limestone.

Lithology.--The Perdido formation lithologically is greatly diversified within one section and also from place to place, so that its heterogeneity is an outstanding characteristic. It is somewhat transitional from the Tin Mountain limestone to the Rest Spring shale, in that dark limestone in the lower part is predominant over interbedded chert, shale, and siltstone, and in that shaly calcareous siltstone or fine-grained sandstone in the upper part is predominant over limestone, conglomerate, and shale. The limestone, both fresh and weathered, is medium gray and tends to break down into small platy fragments but less readily than the interstratified silty limestone. Most of the limestone is fine grained, although some is coarsely clastic and is composed of crinoid columnals or a more varied assortment of shell fragments and pebbles. Some of the upper limestone contains considerable sand, which on weathering brown in the gray calcareous matrix may show cross-bedding. The chert ranges in color from grayish black to light gray and weathers from gray to brown. Much of it forms continuous beds, either sharply defined or appearing to grade into the adjacent dark limestone; some of it is a more or less incomplete replacement of crinoidal limestone, and a little forms elongate nodules. The clastic rocks, the most characteristic part of the Perdido formation, range from shale through siltstone and sandstone to conglomerate. Of these, siltstone is the most abundant. It is commonly light gray or pale red and weathers from yellowish to reddish browns. Near igneous intrusions it has been changed to vitreous quartzite, which also weathers brown. The coarse conglomerate occurs only locally, and consists of rocks from the Perdido formation. As exhibited south of Rest Spring, the 10-foot conglomerate layer may have been deformed while still unconsolidated. Its origin deserves further study.

The lithology of the Perdido formation at the type locality, as described below in the measured section, is representative rather than definitive of the formation, because at other localities, even nearby, the sequence varies greatly and the strata cannot be convincingly correlated. In general the siltstone is the most diagnostic feature of the Perdido formation. The lower part of the formation is distinguished from the Tin Mountain limestone by the siltstone, shale, or continuous beds of chert, in the preponderant limestone, although the two formations are somewhat gradational. Where poorly exposed the lower boundary may not be mapped at precisely the same stratigraphic position. The shaly character of the upper part may seem gradational with the Rest Spring shale, but the upper boundary is sharp and rarely questionable. The Rest Spring shale normally has no reddish tints and in this area consistently contains no limestone. The top of the Perdido formation in the Quartz Spring area, but not everywhere southwestward in the Ubehebe Peak quadrangle, invariably is marked by the grayish-red soft shale capped by a thin bed of fossiliferous limestone.

Section of the Perdido formation measured with a tape at the type locality starting south of Rest Spring:

Rest Spring shale.

Conformable contact.

Perdido formation:	Feet
11. Very soft shale, grayish red to grayish red purple, fossiliferous, at surface invariably breaks down to loose powdery material; capped by thin bed (about 6 inches to 1 foot) or lenses of dark-gray fine-grained limestone containing abundant excellently preserved *Cravenoceras*...................................	5±
10. Thin to medium beds of medium-gray limestone, in places conspicuously sandy and cross-bedded; uppermost bed contains productids; interbedded thin layers of calcareous siltstone or sandstone..........................	15±
9. Conglomerate of fragments up to boulder size (3 feet longest dimension), subangular to rounded, composed of limestone (some crinoidal, containing also horn corals and brachiopods), dark-gray chert, and grayish-red siltstone. The matrix is medium-gray limestone faintly tinged red, containing irregularly distributed silt, fine sand, and shell fragments, in places lenticular and channel-bedded. Local and essentially intraformational...............................	10
8. Calcareous siltstone, somewhat platy, pale red weathering reddish brown, but in places moderate yellowish brown to grayish orange weathering light to moderate brown..................................	85

Section continued at the type locality south of Perdido Canyon:

7. Interbedded chert, siltstone, and limestone; chert ranging from grayish black to light gray, acquiring brownish tinges on weathering, some clearly a replacement of crinoidal limestone; siltstone as in unit 8; limestone medium to light gray, subordinate to chert and siltstone; base marked by 2-foot light-gray clastic crinoidal limestone under 11-foot layer of grayish-black chert.............................	70

6.	Poor exposure of platy limestone, dark chert; at base, 5 to 10 feet of clastic limestone (limestone pebbles, shell fragments) containing chert lenses................................	85
5.	Limestone and chert float........................	41
4.	Light-gray shale, somewhat siliceous.................	20
3.	Impure limestone, silty and cherty, containing some fine-grained conglomerate; fossiliferous....................................	32
2.	Thin-bedded limestone and chert making massive unit...................................	22
1.	Interbedded limestone, siltstone, silty limestone, and chert; limestone medium gray, weathering into platy chips from layers 2 to 3 feet thick, which make ribs on moderate slopes; siltstone and silty limestone range from reddish brown to light gray, weathering yellowish brown; chert makes thin continuous beds in ribby limestone; about 20 feet from top, conspicuous 6-foot bed predominantly chert, brown-weathering...............................	225
		610 ±

Conformable contact.

Tin Mountain limestone.

A section of the Perdido formation was measured at the mouth of the prominent constriction in the canyon below Ubehebe mine (about 1 mile straight N. 70° W. of the mine), and about 7 miles in a straight line west of the section at Perdido Canyon. A brief description of it follows:

Rest Spring shale.

Possibly fault contact.

Perdido formation:	Feet
(Numbers of units do not correspond to numbers in previous section)	
5. Olive-gray and olive-brown argillaceous limestone, breaking into small angular fragments in slope rubble, which, starting 13 feet above base of unit, covers it for 46 feet; somewhat hornfelsic in places; upper part medium gray, weathering olive gray	115
4. Dark argillaceous limestone; abundant grayish-black chert in upper 8 feet; more argillaceous, weathering reddish brown in lower 12 feet; poorly exposed	20
3. Medium dark gray crinoidal limestone, weathering as massive unit	25
2. Medium dark gray conglomeratic limestone; scattered pebbles, cobbles, and boulders of dark-gray chert and of limestone distinct from matrix, up to 2 feet long and 1 foot thick, well rounded	10
1. Medium dark gray limestone, cherty in places; upper half preponderantly shale or siltstone, weathering into small platy fragments; also somewhat argillaceous near base, weathering into platy fragments	50
	220

Conformable contact.

Tin Mountain limestone.

Thickness.--According to the composite section measured with a tape at the type locality, the thickness of the Perdido formation is 610 feet. There is some doubt concerning the accuracy of matching the top of the part measured south of Perdido Canyon with the bottom of the part measured south of Rest Spring. The error, if actual, is in omitting about 75 feet of siltstone above unit 7. Despite uncertainties caused by the combination of lithologic changes and faults, it is believed that from place to place the thickness of the formation varies within a wide range, and that the greatest thickness in a large region between Death Valley and the Inyo Range occurs between Perdido Canyon and Rest Spring. In the canyon below Ubehebe mine, west of the Quartz Spring area, the Perdido formation is only 220 feet thick.

Age and correlation.--The fauna in the uppermost 5 feet of the Perdido formation has a close affinity to the White Pine shale fauna of eastern Nevada (Miller and Furnish, 1940; Youngquist, 1949) and of the Inyo Range (Kirk, 1918, pp. 38-39) and is similar to the Caney fauna in Oklahoma as described by Girty (1909). Some of the best-preserved fossils of the Quartz Spring area were collected from this zone, and in 1939 they were deposited in the paleontological collection of Stanford University. The fauna's most conspicuous form, which is unusually well preserved in a thin limestone and is abundant throughout the area, is a diagnostic goniatite, which in 1937 compared well with _Gastrioceras_ _richardsonianum_ Girty (1909, pp. 54-57, pl. XI) of the Caney and White Pine assemblages (Kirk, 1918, p. 39). The form has since undergone reclassifying (Plummer and Scott, 1937; Youngquist, 1949, etc.). It is closely related to the _Cravenoceras_ in the lower part of the Upper Carboniferous in England (Bisat, 1924), which corresponds to the top of the Mississippian in the United States (Weller et al, 1948, chart no. 5, pp. 107-109). Thus the top beds of the Perdido formation are Chesterian; that is, of late Mississippian age.

Meager collections of poorly preserved fossils from lower zones in the Perdido formation were collected in 1948 during work on the stratigraphy of the Ubehebe Peak quadrangle. These fossils were submitted for identification to the Paleontology and Stratigraphy Branch of the U. S. Geological Survey. The only collection (U-438) within the Quartz Spring area is from a locality 1 mile S. 15° W. of Rest Spring. The exact stratigraphic position is not known, but it is below the calcareous siltstone of unit 8 at the type locality, and probably in unit 7. Excerpts from the report by James Steele Williams are quoted:

> "U-438 is the lowest of the Perdido collections (at that time). It is also the most varied, but unfortunately none of the forms can be definitely identified. The corals and the bryozoans, as identified by Miss Duncan, consist of 'small zaphrentoid(?) corals, fragmentary and silicified so as to prevent identification, a very large horn coral that is unidentifiable because the axial part of the apical and ephebic regions is missing, and a few fragments of silicified bryozoans, probably stenoporoids and rhomboporoids.' In addition to the corals and bryozoans, there are crinoid columnals, several fragmentary or incomplete brachiopods, identified as *Dictyoclostus*?, possibly 2 sp. indet., *Rhynchopora*? sp. indet., *Composita*? sp. indet.; several gastropods preserved as internal molds that are indeterminable; and several coiled cephalopods. The gastropods include a high-spired form, several bellerophontid types, and a euomphalid type. It is impossible to identify gastropods such as these without the ornamentation being preserved, as the genera and species are based in part on features of the ornamentation. The nautiloids are also not determinable... One of the brachiopods identified as *Dictyoclostus*? sp. indet. resembles in some ways *D. inflatus* (McChesney), a common late Mississippian and early Pennsylvanian species, but no definite identification can be made.
>
> "Collection U-438 is definitely post-Devonian and, of course, pre-Mesozoic. Though a definite reference closer than that cannot be made, the faunal aspect suggests a late Mississippian fauna more than any other fauna known in this area."

All but one of the other collections sent to the U. S. Geological Survey from the Ubehebe Peak quadrangle contained even poorer specimens and were less diagnostic of age. The exception (U-541), although it is from a locality 22 miles southwest of Quartz Spring, deserves attention because it marks the lower limit of the Perdido formation. The fossils were collected from the basal bed of the Perdido formation lying on Tin Mountain limestone 2 miles due east of Cerro Gordo bench mark (see Ballarat quadrangle). The report by James Steele Williams follows:

> "U-541 is from the Perdido formation. It consists of horn corals and a few crinoid columnals. The crinoid columnals are of no age significance. Miss Duncan lists the corals as follows:
>
> Hapsiphyllum? sp. indet.
> Homalophyllites? sp. indet.
> Cyathaxonia? sp. indet.
> Caninia cf. C. cornicula (Miller)
> Other small zaphrentoid corals
>
> "Her remarks concerning the collection are as follows: 'This collection is somewhat more adequate than several of the others so far as the number of specimens is concerned; however, some of the specimens are fragmentary and all are somewhat silicified. Identification is therefore doubtful. The assemblage looks very much like what might be expected in the Kinderhook (Chouteau) or related faunas of the Mississippi Valley region.'"

In summary, the age of the Perdido formation is Mississippian which is shown by its stratigraphic position above the Tin Mountain formation and below the White Pine fauna. Based on doubtful identifications of inadequate collections of fossils, the formation ranges in age possibly from late Kinderhookian time into Chesterian. The completeness of the sedimentary record during that long interval will not be known until better fossils are collected, and the best answer lies in the Quartz Spring area rather than in the region for many miles around.

The difficulty of correlating the Perdido formation with other Mississippian formations is understandable on considering the diversity displayed by the formation in a small area. The White Pine shale of the Inyo Range, as described by Kirk (1918, p. 38) and as observed by the writer, is in part lithologically equivalent to the Perdido formation, but the White Pine includes also the Rest Spring shale. The Mississippian rocks in the Argus Range have not been named as formations and have been insufficiently described for an adequate comparison. The Monte Cristo limestone in the Goodsprings district and in the Nopah Range, although in an equivalent stratigraphic position, does not closely correspond in lithology to the Perdido formation. In central and eastern Nevada, the stratigraphic columns of the Roberts Mountains region and of the Ely district have no described lithologic equivalents of it. In the Pioche district, however, the Peers Spring formation and at least part of the Scotty Wash quartzite, as described by Westgate (1932, pp. 20-22), are convincingly similar to the Perdido formation.

Rest Spring shale (Pennsylvanian(?))

Name and occurrence.--The Rest Spring shale is named here from the extensive exposure around Rest Spring. The type locality extends from the head of the gulch 2,000 feet south of Rest Spring (see pl. 6C) northward to within 200 feet of the top of the hill that is 2,000 feet northwest of Burro Spring. The Perdido formation lies conformably below and the Tihvipah limestone above the Rest Spring shale.

The Rest Spring shale covers a large proportion of the Quartz Spring area, especially in the northeastern quadrant where it makes a continuous belt 4 miles long and 1 mile wide. Isolated patches are exposed along the major fault zone from Hidden Valley to Gap Hills on the northern boundary. This widespread occurrence, fortuitous in the small area that was mapped, is far from representative of the whole region in which the formation is found.

It is by far the most easily eroded formation in the Paleozoic sequence of the region; hence in places of active erosion it normally controls drainage lines. The seemingly anomalous occurrence of the Rest Spring shale in the highest part of the Quartz Spring area is explained by the protecting margin of resistant intrusive rock and of cherty limestone in the Perdido and Tin Mountain formations at a place recently exposed. The slopes that develop on the formation are smooth and rolling (pl. 6C).

Lithology.—The characteristic rock of the Rest Spring shale is argillaceous shale grading into siltstone. It is olive gray on the surface, but the fresh shale, as exposed in the excavation to develop Rest Spring, is grayish black. The basal shale contains discoidal concretions 2 to 6 inches in diameter, which are sufficiently persistent to be excellent markers of the lowest part of the formation. The nuclei of the concretions consist of calcite and pyrite or limonite; some are septaria. The shale grades upward into siltstone, fine-grained sandstone, and in some places thin isolated beds of light-gray quartzite. Some of the sandstone is conglomeratic, in thin, very inconspicuous beds. The conglomerate is further described below in the generalized stratigraphic section of the formation. The sandy and conglomeratic layers show the effects of channeling and cross-bedding, and in some exposures the siltstone displays ripple marks.

The incompetence of the Rest Spring shale has favored igneous intrusions and thrust faults. Thin sills of highly sericitized feldspathic rock, which at first glance may be taken for sedimentary layers, are locally common in the formation. Within the aureoles of larger intrusions the Rest Spring shale has been metamorphosed to chiastolite-bearing hornfels, and nearest the igneous contacts, to biotitic hornfels and schist. In thrust zones much of the shale is moderate red or reddish brown, a sharp contrast to the normal olive gray.

No complete stratigraphic section of the Rest Spring shale has been measured in the Quartz Spring area. Complex structures, generally covered by finely broken shale in slope rubble, could not be mapped and precluded measurement of the true stratigraphic sequence. A composite description of the two gradational units, largely without data on thickness, follows:

Tihvipah limestone.

Conformable contact.

Rest Spring shale:

2. Olive-gray siltstone and shale, sparsely fossiliferous; locally thin beds of light-gray or olive-gray quartzite, in places metamorphosed by sills to vitreous quartzite; thin local intraformational conglomerate of poorly sorted fragments rarely as much as 1 or 2 inches in diameter, mostly subangular, some fairly well rounded but others angular, composed of olive-gray siltstone or shale, white or gray quartzite, and gray dolomite, in a matrix of coarse sand or rarely in a matrix of fragmented shells. Some measured details at one locality follow:

	Feet
Light olive gray quartzite, grading into siltstone in upper 10 feet....................	15
Porphyry sill..................................	20
Light-gray quartzite, weathering reddish or yellowish brown; thin-bedded but breaking into blocks........................	4
Olive-brown siltstone, breaking into angular fragments 1 inch or less in diameter...........	20
Quartzite similar to the stratigraphically higher light-gray quartzite....................	6
Olive-gray siltstone..........................	63
Sill..	5

Olive-gray shale of underlying unit, not measured.

1. Olive-gray argillaceous shale, grayish black where completely fresh; very readily disintegrates into small incipiently lustrous chips; near base typically contains discoidal concretions around mineral nuclei including septaria; concretions commonly between 2 and 6 inches in diameter and as much as 2 inches thick.

Conformable contact.

Perdido formation.

Thickness.—In the Quartz Spring area the stratigraphic thickness of the Rest Spring shale could not be measured because of the complex structure and poor exposures. West of the area, 1.1 miles N. 75° W. of Ubehebe mine (fig. 1), the formation is somewhat more than 400 feet thick. At a better exposure 3 miles N. 70° E. of the southwestern corner of the Ubehebe Peak quadrangle (fig. 1) the Rest Spring shale is 310 feet thick. The extreme incompetence of the Rest Spring shale relative to the adjacent rock units permits the formation to pinch and swell in zones of folds and faults, so that little confidence can be placed in these measurements of thickness.

Age and correlation.—Fossils are very scarce in the Rest Spring shale. The few that were collected early in the field work and were deposited at Stanford University have not been identified. They include impressions of elongate reedlike leaves, which are the only fossil plants from the area. In the Ubehebe Peak quadrangle, fossils have been found in the formation at only one locality, at the southwestern margin of the quadrangle. These fossils (U-324) were collected for the U. S. Geological Survey by Raymond Douglass in 1947, from somewhat metamorphosed shale. Comments by James Steele Williams about this collection, from a locality about 2.8 miles N. 60° E. of the southwestern corner of the Ubehebe Peak quadrangle (see fig. 1), follow:

"Only one collection, U-324, has come from this formation. It is shown as coming from near but not at the base of the formation. The matrix is a hard, compact black shale or argillite and is so baked that none of the fossils is definitely determinable. Impressions or fragmentary remains suggest brachiopods belonging possibly to the genera Chonetes, Marginifera, and Composita, but even the generic identifications are uncertain. The resemblances of the fragmentary remains are slightly, but very slightly, more with Pennsylvanian species of these genera than with Mississippian species, but the age might as well be Mississippian as Pennsylvanian."

The uncertain identification of these poorly preserved fossils cannot be used to determine the age of the Rest Spring shale. The stratigraphic relationships are unequivocal: the formation lies above the late Mississippian fauna in the uppermost part of the Perdido formation and below the moderately early Pennsylvanian fauna in the lowest part of the Tihvipah limestone. Provisionally, the Mississippian-Pennsylvanian boundary is drawn arbitrarily at the base of the Rest Spring shale.

The Rest Spring shale corresponds to the black, fissile, noncalcareous, shaly part of the White Pine shale in the Inyo Range (Kirk, 1918, p. 38). There the White Pine shale includes also the Perdido formation. The Caney-White Pine fauna was reported to occur in black shale north of the Cerro Gordo mine in the Inyo Range, but it is not known if this fauna is at the base of the black shale, as it is in the Quartz Spring area, or well within the black unit. This fauna in the Quartz Spring area, containing Cravenoceras, was included in the Perdido formation because the thin limestone and reddish shale that have the fossils are lithologically consistent with the rocks in the Perdido formation and not with the dark shale and siltstone of the Rest Spring.

The description of the Chainman shale at Ely (Spencer, 1917, p. 27) fits the Rest Spring shale. There may be some difference in age of the two units, as fossils from the upper third of the Chainman shale, though containing a suggestion of Pennsylvanian affinity, were assigned tentatively to the upper Mississippian. At Devils Gate, south of Roberts Mountains in east-central Nevada, the dark shales and sandy interbeds that Merriam (Merriam and Anderson, 1942, pp. 1690-1691) describes in the Diamond Peak beds resemble the Rest Spring shale. Merriam includes these black shales in the Diamond Peak, although in the Eureka district they had been referred by Hague to the White Pine shale. The black fissile part of the White Pine shale of Nevada, as described by Youngquist (1949, pp. 276-283) in connection with his detailed description of the cephalopod fauna, appears to be lithologically equivalent to the Rest Spring shale. But if in Nevada the <u>Cravenoceras</u>-bearing limestone is confined to the top of the shale, ~~the shale,~~ the lithologies and ages of the two units are not strictly equivalent; there is no question about the position of the only <u>Cravenoceras</u>-bearing limestone being contiguously below the black shale in the Quartz Spring area.

Tihvipah limestone (Pennsylvanian)

Name and occurrence.--The limestone and associated rocks above the Rest Spring shale are named here the Tihvipah limestone from the exposure northwest of Tihvipah Spring, which is 2 miles N. 15° E. of Burro Spring. The name Tihvipah Spring does not appear on any previously published map, but in 1938 it was used by the rangers of the National Park Service in Death Valley. The dearth of published geographic names in the area requires the use of unofficial names. The type locality of the Tihvipah limestone is on the hill due east of Rest Spring, which is far more accessible than the exposure near Tihvipah Spring. In the Quartz Spring area the top of the Tihvipah limestone is eroded so that its upper limit cannot be satisfactorily defined. Between Racetrack Valley and Saline Valley it is the lowest unit of a thick sequence of limestones of Pennsylvanian age. The Tihvipah limestone caps hills in the central belt of Rest Spring outcrops and in Gap Hills, making smooth rounded slopes except where moderately ribbed by more resistant limestone beds.

Lithology.--The Tihvipah limestone consists mostly of platy light-gray limestone, interbedded with shaly limestone or calcareous shale and some beds, 1 to 3 feet thick, of fine-grained medium-gray limestone. The shaly rocks range in color from very light gray to pale red or grayish pink. Abrupt lenses of fusulinids and finely broken shells, most of which are dark fragments in a light-gray matrix, probably are filled channels. The most diagnostic widespread characteristic is spherically concretionary dark-gray chert in balls ranging from about 1/10 inch to 2 inches in diameter. Many of the chert speroids are about 1½ inches in diameter. In some places the nodules are somewhat flattened or coalesce, thus becoming less diagnostic of the formation. These concretions are readily distinguished from the rounded chert pebbles, 1 inch or less in diameter, which compose a local, inconspicuous, thin basal conglomerate.

Thickness.--No section of the Tihvipah limestone has been measured in the Quartz Spring area, where the exposures are incomplete or complicated by local structures. West of the area, 1.2 miles N. 76° W. of the Ubehebe mine (fig. 1), the Tihvipah unit of the still unnamed Pennsylvanian rocks is about 200 feet thick.

Age and correlation.--The fossils collected from the Tihvipah limestone, and now in the collection at Stanford University, have not been identified. The basal part of the formation contains fusulinids of moderately early Pennsylvanian age. A closer determination of the age by Lloyd G. Henbest of the U. S. Geological Survey is not ready for publication.

No correlation of the Tihvipah limestone with previously named formations is made here. It seems probable, however, that the formation will prove to be a small part of the thick formations now assigned to the Pennsylvanian and Permian. The Tihvipah limestone retains its lithologic identity in the southwestern corner of the Ubehebe Peak quadrangle and as far away as the western side of Mazourka Canyon along the foothills of the Inyo Range near Independence.

Older gravel (Pleistocene(?))

Remnants of continental deposits that are older than the Recent alluvium are exposed at the northern end of Hidden Valley, in the basin draining through Leaning Rock Canyon, on the eastern flank of the Panamint Range, and along the western foot of Gap Hills. On the geologic map (pl. 1) the older gravel has not been distinguished from Recent deposits. A considerable part of the older gravel consists of poorly sorted continental sediments similar to the Recent alluvium but it is somewhat more consolidated and in general slightly stained with limonite. In many places the dips are steeper than the greatest initial dips in the present-day alluvial fans.

The most distinctive characteristic of the older deposits is the volcanic material. White beds of pumice, commonly 2 to 4 feet thick, consist of fragments as much as 3 inches in diameter, although most are a fraction of an inch. Some of the pumiceous material is remarkably free of other rock constituents. Other beds in the gravel contain fragments of weathered basaltic material, which is much less conspicuous than the pumiceous material. Within the mapped area there is no evidence of the age of the gravel other than that it is younger than Pennsylvanian and older than Recent. The amount of deformation and erosion suggests that the age is Pleistocene. Other pumiceous gravels in the Death Valley-Owens Valley region have been called Pliocene or Pleistocene (Kirk, 1918, pp. 48-57; Hopper, 1947, pp. 415-416). No attempt, however, is made here to correlate any of these older gravels with the older gravel in the Quartz Spring area.

Structure

The structure of the area, which is complex in detail, is characterized by thrust faults and related imbricate structure, normal faults, folds, and intrusions. The relative shortness of each element of the structure contributes greatly to the areal complexity. Many of the structural details are not shown on the geologic map (pl. 1). The faults and folds are described briefly here, but the intrusive structures are considered in the description of the intrusive rocks.

Quartz Spring thrust complex

An exceedingly complex zone centering at Quartz Spring (see pl. 2) lies between thrust faults. One side of the zone extends from Gap Hills through Bighorn Gap and Perdido Canyon to the alluvium of Hidden Valley, and the other side is largely concealed by the alluvium in Racetrack Valley. Much of this zone, which is greatly simplified on the map (pl. 1), is a chaotic jumble.

The sole of the Quartz Spring fault complex is exposed between Gap Hills and the western front of the range, north of where the trace of the thrust makes a sharp bend into Bighorn Gap and joins an overlying thrust fault. The steep range front east of Gap Hills is essentially the sole from which the overlying thrust plate has been stripped by erosion (see pl. 7, sec. A-A').

Plate 7. Geologic structure sections, Quartz Spring area, Panamint Range, California.

The steepening of the sole at the range front, although possibly an initial curvature, probably is a post-thrust warp that breaks into normal faults through Bighorn Gap and Perdido Canyon. Below the sole southeast of Gap Hills the normal sequence of Lost Burro, Tin Mountain, and Perdido formations was dragged up and steeply overturned. The greatest stratigraphic throw is shown by Rest Spring shale lying on Lost Burro formation, and probably amounts to somewhat less than 1,500 feet of stratigraphic thickness. The sequence of Rest Spring and Tihvipah formations in the overriding block at Gap Hills is greatly crushed and faulted, but upright.

This block of Rest Spring and Tihvipah formations in turn is overridden by a plate of Tin Mountain limestone turned under Lost Burro formation. The fault surface, which dips west at a low angle, is intercepted to the northeast by the sole fault, and southwestward it is covered by alluvium. West of Bighorn Gap the first traceable thrust fault above the sole has Lost Burro lying on a complex mosaic of the Rest Spring and Perdido formations. This fault, for convenience, will be called the Bighorn Gap thrust. It extends eastward through Bighorn Gap into Perdido Canyon, where it abuts against a vertical fault. On the west the Bighorn Gap thrust is truncated by another fault, which placed Pogonip limestone on the Lost Burro formation. The thrust fault in the northwestern part of Gap Hills is considered to be a segment of the Bighorn Gap thrust.

In the block between the Bighorn Gap thrust and Quartz Spring, the beds are nearly on end or steeply overturned. The overturned part at the northern end is separated from the upright part by a thrust fault, which toward the south could not be traced because of the structural intricacies. In the whole block the formations range from Pogonip limestone eastward to the Perdido formation (see pls. 1 and 7, sec. B-B'). Sufficient lithologic characteristics and fossils remain to identify each formation in the correct order, but at many places the characteristics are too indefinite to outline the boundaries of the formations or to account for many anomalies. At Quartz Spring another thrust fault defines the western side of the block by placing upper Paleozoic rocks against it. These range from the Lost Burro formation to the Rest Spring shale. Great structural complexity occurs within the zone between the Quartz Spring thrust and the Racetrack thrust. In this zone the aggregate effect on the shattered rocks was to overturn the sequence from the Lost Burro formation to Rest Spring shale and to drag shale of the Rest Spring along the faults.

The shale outlines much of the Racetrack thrust, which placed steeply overturned Pogonip limestone along with a few slivers of Eureka and Ely Springs, over the Quartz Spring chaos of upper Paleozoic formations. The Racetrack thrust, which dips about 25° W., goes under the alluvium at the range front southwest of Quartz Spring, but southward the face of the mountain is substantially the stripped surface of the fault. The even face slopes about 25°, and beneath it the less competent beds are turned up. The Racetrack thrust probably curves southward under the alluvium, following the eastern side of Racetrack Valley about 4 miles to where low foothills of resistant Eureka quartzite are next to a mountain exposing Lost Burro and Tin Mountain formations. From there the fault is traceable by the Ordovician or Cambrian rocks thrust over Carboniferous rocks along the eastern side of the valley about 6 miles southward to where quartz monzonite truncates the beds and the fault. This southern part of the Racetrack fault is in the Ubehebe Peak quadrangle.

Leaning Rock reverse fault

Near the eastern margin of the mapped area (pl. 1) a reverse fault of considerable displacement extends from a syenitic stock southward along the western base of Whitetop Mountain and across Leaning Rock Canyon to the eastern flank of the range. The fault will be referred to as the Leaning Rock fault. Strata on Whitetop Mountain curve conspicuously down toward the upturned ends of the strata on the other side of the fault (pl. 7, sec. F-F'), Ely Springs dolomite was placed against Perdido formation, making the stratigraphic throw as much as 4,000 feet where well exposed; but under the alluvium to the south, where Pogonip limestone abuts on Rest Spring shale the stratigraphic throw is probably more than 5,000 feet. On the eastern flank of the range, in the southeastern corner of the mapped area, the Leaning Rock fault was displaced down on the east by a normal fault and was covered by gravel, a remnant of which still conceals it. The concealed part of the reverse fault accounts for the seeming anomaly of Pogonip limestone dropped down against Lost Burro formation, which is stratigraphically higher. (See pl. 7, sec. C-C'.)

On the highland between the Leaning Rock reverse fault and the Bighorn Gap thrust fault, various blocks of Tihvipah limestone were shoved over or into the Rest Spring shale. This is clear where the blocks are on brecciated Tihvipah formation, as exhibited east of Rest Spring, and where the topography exposes the structural breaks, as it does southeast of Burro Spring. The displacement of other blocks is inferred by the thinning or absence of Rest Spring shale between them and the underlying Perdido formation. No attempt has been made to show inferred structures through the incompetent and rubble-covered Rest Spring shale. These complexities may indicate that an overriding mass was not far above the present topography.

Folds

The folds are mostly drag along faults. A drag upward under the sole fault, well exposed between Bighorn Gap and Gap Hills, involves Lost Burro, Tin Mountain, and Perdido formations in an overturned syncline. Similar overturning of Perdido formation, exposed in a high basin between Quartz Spring and Lost Burro Gap, was produced by the drag of an overriding block. Southwest of Whitetop Mountain Eureka quartzite and Ely Springs dolomite clearly show the bending down to the Leaning Rock reverse fault, and on the other side of the fault Tin Mountain and Perdido formations as clearly show the upward fold (see pl. 7, sec. F-F').

A fold not made by drag along a fault is in the northeastern part of the mapped area, 1½ miles northeast of Burro Spring. It is a short anticline or dome elongated southward (see pl. 7, secs. A-A', B-B', and D-D'). A syncline on the eastern flank is obscured by intrusive masses and a thrust fault.

Normal faults

The normal faults of the Quartz Spring area can be grouped into three north-trending zones located as follows: in the Last Chance foothills, in the central part of the area from Bighorn Gap to Andy Hills, and along the eastern crest of the range. The only discernible effect on the existing topography has been to influence differential erosion.

A long fault in the Last Chance foothills shows the greatest displacement (see pl. 3A). As expressed by the eroded topography, the fault dips about 60° E. The effect on the Racetrack-Nopah contact was to displace it 3,000 feet horizontally and to produce a stratigraphic throw on the order of 1,000 feet. Two faults of small displacement are shown (pl. 1) branching northeastward, making a wedge in the downthrown block of the main fault. Other normal faults in the foothills west of the mapped area trend north.

In the central belt of normal faults, a set of faults through Bighorn Gap shifted the western side down. The displacement along this set diminishes northward to extinction at the range front, and southward it diminishes greatly to where it is lost in surface rubble of the Perdido formation. The same shift, however, is taken up by the essentially vertical fault through Perdido Canyon. These faults may be a subsidiary expression of the structural downwarp along the western front of the range. Thus the block that was warped down northeast of Gap Hills yielded by breaking around the re-entrant outlined by the Bighorn Gap and the Perdido Canyon faults. Other normal faults in the central zone are downthrown on the east and are of minor displacement.

The normal fault east of Whitetop Mountain and Leaning Rock Canyon, though poorly shown at the margin of the map (pl. 1), exhibits conspicuous downthrow to the east. The dip slip is possibly 1,000 feet, leaving uppermost Ely Springs dolomite opposite the base of the Eureka quartzite. The normal displacement is obscured in the southern part, where an old gravel that covers the Leaning Rock reverse fault is faulted down against the Lost Burro formation (see pl. 1 and pl. 7, secs. C-C' and F-F').

A fault along the western side of the same crest locally makes the crest-block a horst. Along the westward-dipping fault Tin Mountain limestone was dropped against Lost Burro formation. The northern end of the fault is concealed by an old gravel.

Igneous rocks

Intrusive alkalic rocks, largely leucosyenite, occur in the northeastern quadrant of the Quartz Spring area (pl. 1) and continue to crop out sporadically down the eastern slope of the Panamint Range to the foothills in Death Valley (McAllister, 1940, p. 1962). They form dikes, sills, and chonoliths. The largest masses in the mapped area are between 2,000 and 3,000 feet wide, and the longest is about 2 miles. The contacts are generally concordant with the Rest Spring shale and Perdido formation, but are intricately discordant across the Tin Mountain limestone, Lost Butto formation and the undifferentiated metamorphosed lower Paleozoic limestone and dolomite. In other parts of the area, sills and dikes of well-sericitized syenite-porphyry or monzonite-porphyry occur in the Rest Spring shale. Soda syenite about 11½ miles southeast of Tin Mountain, as described concisely by Ball (1907, pp. 207-208), appears to be the same as much of the syenitic rock in the Quartz Spring area. At both places the rocks are "characterized by abrupt and great changes in granularity and in the relative abundance of the constituent minerals" (Ball, 1907, p. 208).

Age and correlation

The age of the igneous rocks within the Quartz Spring area has not been fixed closer than that they are post-Pennsylvanian and that some of the thin, sericitized sills are older than the last thrusting, whereas the larger masses are younger than some of the major deformation. They are considered to be diaschistic offshoots from adamellite,_/ which is widely

_/ Adamellite is used in the sense that was recommended by Johannsen (1932, vol. 2, p. 308): a quartz-bearing plutonic rock which contains a ratio of orthoclase to plagioclase between 35:65 and 65:35.

exposed in the northern Panamint Range, in the Inyo Range, and almost continuously between the ranges. Although the adamellite is not exposed in the area, the relationship is shown by the melanite syenite in border facies and offshoots of the adamellite starting 10 to 15 miles southwestward in the Ubehebe Peak quadrangle (Ball, 1907, pp. 206, 208; McAllister, Geology of the Ubehebe Peak quadrangle, in preparation). The adamellite of the Inyo Range, which is clearly post-Triassic, was considered by Knopf (1918, p. 60) to be contemporaneous with the Cretaceous intrusions of the Sierra Nevada. The same intrusive complex in the Coso Range has been called Jurassic by Hopper (1947, p. 412), because he correlated it with the intrusions of the Sierra Nevada. In reviewing the age of plutonic rocks in California, Larsen (1948, p. 136) indicated that those in northern California, southern California, and Baja California are related to each other; and for the age of the batholith in southern California Larsen favored Lower Cretaceous, rather than the late Jurassic age assigned to the northern rocks, or the early Upper Cretaceous age assigned to those in Baja California.

Petrography

The texture of the rocks is varied, ranging in grain-size from 80 millimeters in syemite pegmatite to a common size of 0.05 millimeter in the groundmass of monzonite porphyry, and from nonporphyritic through many combinations of porphyritic texture. In the porphyritic rocks the volume of phenocrysts ranges from 20 to 60 percent, and some of the phenocrysts are as much as 70 millimeters long. Most of these textural variations are also trachytoid. The predominant elongate and tabular feldspar grains have a parallel or subparallel arrangement.

The composition also varies greatly, ranging in proportion of mafic minerals from slightly less than 3 percent in leucosyenite to 42 percent in the groundmass of porphyritic aegirine-augite syenite; and ranging in silica saturation from undersaturated nepheline-syenite, through saturated syenite, to quartz-bearing aplitic rock. The quantity of quartz-bearing rock is greatly subordinate to that of saturated and undersaturated rocks. Pegmatitic diaschists contain no quartz. A characteristic of composition that the rocks have in common is the relative abundance of soda, which is shown by the large proportion of albite in the ubiquitous microperthite, by aegirine-augite, and in some rocks, by nepheline.

Trachytoid leucosyenite.—The most abundant intrusive rock in the Quartz Spring area is trachytoid leucosyenite. It occurs in sills and dikes starting about half a mile northeast of Burro Spring. Much of it is in contact with the Rest Spring shale or the silty calcareous Perdido formation. The typical trachytoid leucosyenite (3010)_/ is grayish orange (10 YR 7/4)_/

_/ Numbers refer to specimens at Stanford University.

_/ Symbols and names of colors are according to the "Rock-Color Chart," by E. N. Goddard and others, National Research Council, 1948.

and only slightly grayer where it is freshest. Most of the grains are subhedral microperthite between 3 and 5 millimeters long and 1 to 2 millimeters wide in a subparallel arrangement. A micrometric analysis along 161 millimeters shows that about 45 percent of the rock is orthoclase, 52 percent is albite, and 3 percent is accessory and secondary minerals. The albite and orthoclase are combined in microperthite, which thus constitutes 97 percent of the leucosyenite. Albite makes up a large part of some microperthite grains, leaving ragged islands of orthoclase. Most of the albite appears to be a replacement of orthoclase rather than a product of exsolution. The accessory and secondary minerals are biotite, aegirine-augite, magnetite, sphene, melanite, chlorite, muscovite, and calcite. A little of the biotite is a deuteric alteration of pyroxene, and some is in clots of melanite, sphene, aegirine-augite, and magnetite, Chlorite altered some of the biotite, and muscovite replaced a very little of the microperthite.

Muscovite leucosyenite (3011) is one of the variants of the trachytoid leucosyenite. Where it crops out about 1½ miles east-northeast of Burro Spring, it is a grayish-yellow (5Y 8/4) coarse-grained rock of conspicuously trachytoid fabric. It consists of microperthite, a little albite not intergrown with orthoclase, and muscovite. Most of the rock is made up of highly albitized orthoclase in grains 10 to 20 millimeters long, 5 to 10 millimeters wide, and 1 to 2 millimeters thick. Clusters of muscovite fill interstices among the closely packed feldspar grains. Only in the most favorable places is the interstitial muscovite in pockets as much as 3 millimeters thick, and in most places it is less than 1 millimeter or absent. The diameters of the pockets in the plane of the trachytoid fabric are as much as 5 millimeters; they are connected, however, in an irregular network. Some of the muscovite forms clusters having a subhexagonal outline within the microperthite, where it may be a replacement of early euhedral nepheline.

Very coarse grained leucosyenite (3012) is a nontrachytoid variant that crops out on the ridge 2¼ miles northeast of Burro Spring. It is a medium light gray (N 6) rock of microperthite, some of which has a bluish iridescence. The accessory minerals were estimated to be less than 1 percent of the volume. The microperthite grains are on the order of 20 millimeters long and 5 millimeters wide, whereas the mafic grains are commonly 1 to 2 millimeters in diameter. The proportion and coarseness of the microperthitic albite varies greatly from grain to grain of orthoclase. Some of the intergrowth is very fine. A small quantity of albite forms separate grains, some of which are interstitial, whereas others are randomly oriented inclusions in the orthoclase, distinct from the albite of the microperthite. The accessory minerals are biotite, partly altered to chlorite, aegirine-augite, sphene and ilmenite, apatite, magnetite, and muscovite. A little melanite is visible in the hand specimen.

In the porphyritic leucocratic rocks the proportions of phenocrysts and groundmass are widely different. The extreme low in the proportion of phenocrysts is a trachytoid porphyritic syenite (3021), which is exposed on the southeastern part of a spur nearly 3 miles east-northeast of Burro Spring. The yellowish-gray (5 Y 6/2) groundmass constitutes about 80 percent of the volume. Light bluish gray (5 B 6/1) Carlsbad twins of orthoclase form well-alined phenocrysts about 70 millimeters long and 12 millimeters thick, in a groundmass of feldspar grains, many of which are about 7 millimeters long, and a few mafic grains of about 1 millimeter. The orthoclase of the phenocrysts is incipiently microperthitic, but in the groundmass it has a high percentage of intergrown albite. Andesine, which is abundant in the groundmass, is rimmed with albite. Accessory sphene, apatite, and magnetite are more abundant and commonly in larger grains than the biotite and amphibole.

The other extreme among the porphyritic rocks is a trachytoid porphyry of altered nepheline syenite (3022), which crops out on a hill 2 miles N. 80° E. of Burro Spring. The groundmass constitutes only 40 percent of the volume, as estimated from a measurement of 428 millimeters normal to the trachytoid fabric in hand specimens. The pale grayish orange (10 YR 8/4) rock consists of large tabular euhedral microperthite in a fine-grained groundmass. The tabular phenocrysts, which lie roughly parallel, in places are so closely packed that they touch, but in other places in the same hand specimen they are well isolated in the groundmass. The largest phenocrysts are as much as 70 by 40 by 8 millimeters, but most are about 50 by 25 by 5 millimeters; average grains of the groundmass are less than 1 millimeter. The direction of the trachytoid orientation changes within short distances. Some of the microperthite has clear cores of orthoclase. The groundmass contains microperthite, and clusters of muscovite and calcite. Some of the clusters are subhexagonal in outline and are probably altered feldspathoid. All the mafic minerals, in accessory amounts, also were altered to finer-grained aggregates of iron oxides and calcite.

Melanite nepheline-syenite.—Although of very limited occurrence in a spur 2½ miles N. 70° E. of Burro Spring, melanite nepheline-syenite (3013) is noteworthy because it contains the only coarse-grained, fresh nepheline that has been seen in the area. When found in 1937, nepheline had not yet been reported as occurring in place in California (Murdoch and Webb, 1948, p. 22). The nepheline-syenite is similar to the preceding leucosyenite (3012) and to other melanite-bearing syenites in the Ubehebe Peak quadrangle, except that it contains a slightly greater quantity of dark minerals and some interstitial nepheline. It is light gray (N 7) or medium light gray (N 6), spotted by black garnet. Some of the feldspar iridesces very pale blue (5 B 8/2). Weathering has little effect on the color of the rock, but it pits the surface by decomposing the interstitial nepheline. The texture is coarse-grained hypidiomorphic, varying abruptly in grain size. Most tabular grains of microperthite are 10 to 20 millimeters long and few are more than 40 millimeters long. Exceptionally large nepheline grains are 20 millimeters long, whereas common sizes are 2 to 5 millimeters. Grains of melanite range in diameter from less than 1 millimeter to about 10 millimeters where elongate or possibly in aggregates; most are about 3 millimeters.

The coarse texture forestalled determining adequately in thin sections the proportions of mineral constituents. A megascopic analysis based on a linear measurement of 245 centimeters follows:

	Percent volume
Alkalic feldspar........................	81
Nepheline (fresh and altered)..........	16
Melanite...............................	3

Accessory biotite, augite, and magnetite, as seen in thin section, constitute a small fraction of 1 percent and are included with melanite in the mode.

Most of the feldspar is microperthite, in which albite occurs in many degrees of coarseness, starting exceedingly fine, and as several types of intergrowth, depending on distribution and shape. The proportion of albite is notably different from grain to grain. It has replaced more than half of some grains, leaving irregular patches of orthoclase, and in other grains it is scarcely present. Some albite ($Ab_{92}An_{08}$), not intergrown with orthoclase, forms large separate grains. Clear orthoclase is moderately sodic, about $K_{72}Ab_{28}$, which is shown by the extinction angle of 9° between X and (001) normal to Z (Winchell, 1933, fig. 284).

Fresh nepheline in the hand specimen is pale grayish orange (10 YR 7/2) and has a greasy luster. The powder gelatinizes with hydrochloric acid. It is negative uniaxial, of low relief in balsam, and of weak birefringence. Some of the nepheline has altered to zeolites. In thin section the zeolite aggregates having hexagonal outline within microperthite may be altered nepheline, but the dodecahedral shape of pits of the same size (about 0.5 millimeter) on weathered surfaces suggests that the altered mineral may have been sodalite.

The black or brownish black garnet is called melanite because of the color and its typical occurrence in nepheline-syenite and other syenitic rocks. The high indices of refraction have not been determined and there is no chemical analysis of it to show whether it is titaniferous. In some syenite of the area the garnet is associated with abundant accessory sphene and some leucoxene-rimmed ilmenite. The color in thin section magnified 20 times (a daylight microscope lamp was used when determining colors in thin sections) ranges from light olive gray (5 Y 6/1) to dusky yellow (5 Y 6/4). The garnet is euhedral or subhedral, isotropic, and high in relief.

Analyses and norms of melanite nepheline-syenite from the Quartz Spring area and of nepheline-syenite from some other areas

	Analyses 1	2	3	4
SiO_2	59.14	54.63	58.27	52.53
Al_2O_3	21.72	19.89	23.75	19.05
Fe_2O_3	0.98	3.37	1.86	4.77
FeO	0.71	2.20	n.d.	2.10
MgO	0.94	0.87	Trace	1.99
CaO	2.42	2.51	1.89	5.75
Na_2O	5.69	8.26	6.90	4.03
K_2O	6.28	5.46	5.17	7.30
H_2O+	1.54	1.35	2.30	1.49
H_2O-	0.32	----	----	0.13
TiO_2	0.12	0.86	----	0.07
P_2O_5	Trace	0.25	----	0.28
MnO	Trace	0.35	----	0.13
CO_2	Trace	----	----	----
	99.86			
Norms				
or	37.25	32.80	31.14	43.37
ab	39.30	28.82	43.49	11.53
an	11.95	0.56	9.45	12.23
ne	4.83	22.44	7.95	12.21
C	1.12	----	3.16	----
di	----	4.97	----	10.86
wo	----	2.32	----	0.23
ol	1.88	----	2.45	----
mt	1.39	5.57	----	6.96
il	0.30	1.67	----	0.15
ap	----	----	----	0.67
	98.02			
Position	I.5.1.4			

1. Melanite nepheline-syenite (3013), Quartz Spring area, W. H. Herdsman, analyst.
2. Average nepheline-syenite, mean of 42 analyses (Daly, 1933, p. 14).
3. Nepheline-syenite, Peterborough County , Ontario (Washington, 1917, pp. 292-293).
4. Biotite-melanite nepheline-syenite, Kruger Mountain, British Columbia (Washington, 1917, pp. 564-565).

The chemical analysis and norm of a specimen of melanite nepheline-syenite (3013) are shown in the first column of the table, where they may be compared with the analyses and norms of average nepheline-syenite (Daly, 1933, p. 14), of a nepheline-syenite from Peterborough County, Ontario, selected for its similarity, and of biotite-melanite nepheline-syenite from Kruger Mountain, British Columbia (Washington, 1917, pp. 292-293; 564-565). In the Quartz Spring and Peterborough rocks much more of the soda is in normative albite than in nepheline, in contrast to the more nearly equal distribution in the average nepheline-syenite and the Kruger Mountain melanite nepheline-syenite, both of which contain a considerably larger proportion of femic minerals. Modal nepheline of the Quartz Spring melanite nepheline-syenite is 16 percent (volume), whereas the normative nepheline is only 5 percent (weight); also modal plagioclase is about $Ab_{92}An_{08}$, whereas normative plagioclase is $Ab_{77}An_{23}$. Much of the lime that appears in salic anorthoclase actually occurs in melanite, for which the norm makes no provision.

A melanite syenite (3014) that is finer-grained and somewhat darker contains large patches of natrolite, which probably are zeolitized nepheline. The mafic minerals are augite and green biotite. Sphene and magnetite are accessory. Corundum, although also in accessory quantity, is particularly noteworthy.

Aegirine-augite monzonite and monzonite-porphyry.—Aegirine-augite monzonite (3015), which crops out on the hill three-quarters of a mile north of Burro Spring and south of the leucosyenite (3010) is one of the most abundant of the less leucocratic rocks. It also is trachytoid, but lacking the orange tint of the leucosyenite; it is medium light gray (N 6). Slender feldspar grains are commonly 2 to 5 millimeters long and many of the aegirine-augite grains in the hand specimen are between 1 and 2 millimeters, although in thin section a more usual size is about 0.5 millimeter. Microperthite and plagioclase (near the division between oligoclase and andesine) are in nearly equal proportions. Micromeasurements along 107 millimeters gave the following volume percentages:

Microperthite	48
Plagioclase	44
Aegirine-augite	6
Accessories	2

The accessory minerals are sphene, magnetite, biotite, and apatite. Some anhedral magnetite is closely associated with the aegirine-augite. Near aplitic dikes the aegirine-augite monzonite is somewhat epidotized and sericitized.

Aegirine-augite monzonite-porphyry (3017) crops out 2½ miles northeast of Burro Spring. The rock is medium light gray (N 6) and weathers light or pale brown (5 YR 6/4 or 5 YR 5/2). Phenocrysts of microperthite are 20 to 30 millimeters long and 10 to 15 millimeters wide; another generation of microperthite and plagioclase phenocrysts, as measured in thin section, range in length from about 0.5 millimeter to 1.5 millimeters; and aegirine-augite crystals are seriate up to 1 millimeter long. The groundmass of roughly equal quantities of orthoclase and plagioclase is hypidiomorphic in grains generally about 0.05 millimeter long. The plagioclase in phenocrysts is andesine ($Ab_{58}An_{42}$), except in rims, whereas in the groundmass it is probably oligoclase. In a micromeasurement of 100 millimeters, 9 percent of the volume is aegirine-augite. Euhedral magnetite, sphene, and apatite together form much less than 1 percent of the rock.

Aegirine-augite syenodiorite.—An increase in the proportion of plagioclase forms aegirine-augite syenodiorite (3018), which occurs locally near the melanite nepheline-syenite (3013), close to marble. The texture is medium- or fine-grained granitic, which in thin sections appears moderately trachytoid. In hand specimens the largest grains of feldspar commonly are 5 millimeters long, but in the thin sections few grains are 1.5 millimeters and most are 0.5 to 1.0 millimeter long. Many of the mafic grains are about 0.3 millimeter in diameter, and where elongate, about 1.0 millimeter in length; however, sphene is as much as 2.5 millimeters long.

The mineral composition of a specimen is shown approximately by the following micrometric analysis along lines aggregating 86 millimeters:

	Percent volume
Orthoclase (variably microperthitic).....	24
Andesine..............................	53
Aegirine-augite.......................	14
Hastingsite...........................	4
Magnetite.............................	3
Sphene................................	1
Melanite..............................	1

Some of the orthoclase is nearly free of albite intergrowth but some is highly perthitic. The andesine ($Ab_{67}An_{33}$) tends to form elongate grains approximately the same size as the orthoclase grains. The alkalic feldspar is 31 percent of total feldspar, making the rock syenodiorite. Pleochroic green aegirine-augite is rimmed by more strongly pleochroic darker green to bluish green hastingsite, which is described more fully under the altered nepheline syenite (3019) that follows. Sphene and melanite, although accessory, are conspicuous. Biotite and apatite are scarce.

Hastingsite nepheline-syenite.--Another darker rock is hastingsite hepheline-syenite (3019), in which the nepheline has been altered to natrolite. It occurs locally, near the contact with marble at the head of the canyon about 2½ miles east-northeast of Burro Spring. The texture is hypidiomorphic medium-grained. A micrometric analysis based on a traverse 118 millimeters long gave the following mineral composition:

	Percent volume
Microperthite	60
Natrolite after nepheline	10
Hastingsite	11
Augite	8
Biotite	6
Melanite	4
Apatite	1

There are also a few crystals of sphene and fewer of zircon. Some of the microperthite contains a large amount of albite, but as in other rocks of the area, the proportions and form vary from grain to grain. No fresh nepheline remains in the thin sections; however, natrolite in well-defined masses is considered to be an alteration of nepheline. The hexagonal outline of some of the masses may be the shape of original euhedral nepheline, or possibly of sodalite, as suggested for the previously described melanite nepheline-syenite (3013).

The hastingsite, which in thin section shows good amphibole cleavage, has a very small axial angle, weak birefringence, is optically negative, and is strongly pleochroic as follows:

X : dark greenish yellow (10 Y 6/6)

Y : dusky yellowish green (10 GY 3/2)

Z : grayish green (5 G 5/2)

Absorption : Y > Z > X

$c \wedge Z$: 35°

The distinctive characteristics of this hastingsite are the conspicuously small axial angle, weak birefringence, intense pleochroism, and large extinction angle. The same optical properties were emphasized in the first descriptions of hastingsite from the type locality in Hastings County, Ontario (Adams, 1894, p. 13; Adams and Harrington, 1896, pp. 210-211; and Graham, 1909, pp. 540-543). Later, recognizing that the properties of hastingsite vary considerably Quensel (1914, p. 152) redefined hastingsite to include "...hornblende with small axial angle, with a probably indefinite position of the axial plane..., low birefringence, ...with Y or Z lying nearest c, forming large extinction angles, and with strong axial dispersion." In some more recent usage of the term (Larsen and Berman, 1934, p. 225; Larsen, 1942, p. 49) the axial angle is large and the other distinctive optical properties have been lost. The hastingsite, however, of the Kruger alkaline syenites in British Columbia, as described by Campbell (1939, p. 532) and of the Oroville malignite in Washington (Krauskopf, 1941, pp. 25, 27) is similar to the hastingsite of the Quartz Spring area.

The biotite is pleochroic in similar but much paler colors, and likewise has a very small axial angle, but it is distinguished by the cleavage, birefringence, and clearly lower relief. It is the third in a deuteric reaction series from augite through hastingsite. Nevertheless, most of the three minerals form grains that are free of the others.

The darkest rock is a mesotype porphyritic altered nepheline-syenite (3020), which is nearly 35 percent mafic, and conspicuously trachytoid. Only a small quantity occurs near the last rock described (3019). Phenocrysts of orthoclase commonly are about 15 millimeters long and 5 millimeters wide. They enclose small grains of mafic and accessory minerals. The dark gray (N 3) groundmass, according to a megascopic measurement 650 millimeters long, constitutes 82 percent of the rock's volume. Grains in the groundmass commonly range from 0.2 to 1.0 millimeter, except orthoclase grains, which commonly are about 0.5 by 2.5 millimeters. Phenocrysts and grains of the groundmass are well alined.

The approximate mineral composition of the groundmass, calculated from a microscope traverse 90 millimeters long, follows:

	Percent volume
Orthoclase..................................	52
Altered nepheline............................	5
Hastingsite and aegirine-augite...............	33
Melanite....................................	8
Biotite, apatite, sphene, magnetite...........	2

The orthoclase is slightly microperthitic. Fine-grained masses of zeolites and muscovite are considered to be altered nepheline. There is somewhat more hastingsite than aegirine-augite, and some of it poikilitically encloses euhedral aegirine-augite. The hastingsite is an amphibole similar to that of the hastingsite nepheline-syenite (3019) in that the axial angle is very small, the birefringence weak, and the extinction angle ($c \wedge Z = 30^{\circ}$) is large for an amphibole, but the similar pleochroism is slightly more olive, as follows:

X : light olive (10 Y 5/4)

Y : grayish olive green (5 GY 3/2)

Z : grayish green (5 G 5/2)

absorption : Y > Z > X

The aegirine-augite has the optical characteristics of pyroxene, a maximum extinction angle of 67° between c and Z, and is pleochroic from dusky yellow (5 Y 6/4) to pale bluegreen (5 BG 6/2). Some has a colorless augite core, showing a smaller extinction angle. Isotropic melanite in thin section is light brown (5 YR 5/4). Some of the accessory apatite is unusually large.

Syenite pegmatite.--Pegmatitic and aplitic rocks also show an alkalic affinity. The pegmatite contains no quartz, whereas many of the aplitic rocks do have quartz. A syenite pegmatite (3023), which occurs in a small irregular dike about $2\frac{1}{2}$ miles N. 60° E. of Burro Spring, is the coarsest rock found in the area. Yellowish gray (5 Y 8/1) anhedral microperthite crystals, oriented at random, are commonly 70 by 50 by 5 millimeters and are as much as 80 millimeters long. The microperthite contains a large proportion of albite, and it is slightly replaced by muscovite and calcite. Spaces between the large microperthite grains are filled with finely granular muscovite, clacite, less albite, both euhedral and anhedral magnetite, and very little pyrite. In syenite near the pegmatite there are some veinlets of blue crocidolite.

Nordmarkite.--Quartz-bearing alkalic leucosyenite, or nordmarkite (3024), has a medium-grained hypidiomorphic texture, which contrasts sharply with the nearby trachytoid coarsely porphyritic altered nepheline-syenite (3022). Many grains in the nordmarkite are elongate microperthite as much as 5 millimeters long and 2 millimeters wide, although the more equidimensional grains are about 1.0 millimeter across. Most mafic grains are 0.5 or somewhat less, and few of the irregular interstital quartz grains are as much as 0.5 millimeter in the longest dimension.

The mineral composition of the nordmarkite is shown by the following micrometric analysis based on a measurement 146 millimeters long:

	Percent volume
Microperthite......................	76
Plagioclase (not in microperthite)..	16
Quartz............................	3
Aegirine-augite....................	5 -

Sphene, apatite, and magnetite together form much less than 1 percent; of these sphene is the least scarce. The microperthite contains a large proportion of albite in patches, veins, and rims; in some grains the orthoclase is subordinate. The quartz is clearly interstitial, sharply angular in outline between faces of microperthite crystals, which it does not transect or replace. The quartz, though late in the sequence of crystallization, is not hydrothermal. Aegirine-augite is accessory but it is conspicuous because of the brilliant greens in thin section and the peppery aspect in the hand specimen. The color and the large extinction angle ($c \wedge Z = 77^{\circ}$) indicate that it is high in aegirine.

Aplites.--The finer-grained hypidiomorphic, leucocratic, largely quartz-bearing rocks that occur in dikes through the other intrusive rocks are aplites in the broadest sense of the term but not in the stricter sense that requires a saccharoidal texture and always quartz. The close genetic relationship of the aplites to the coarser-grained alkalic rocks is indicated by the prevalence of albite as a separate mineral in some or as an abundant constituent of microperthite in most, and by a little aegirine-augite. In the proportions between the feldspars some of the aplites are equivalent to the coarser-grained syenite, and others to the coarser-grained monzonite. The principal difference is the oversaturation with silica.

Granitic aplite (3026) is closely associated with the abundant trachytoid leucosyenite (3010) on the eastern side of the mountain about a mile north-northeast of Burro Spring. The granitic aplite, which more precisely is fine-grained leucogranite, is yellowish gray (5 Y 7/2) and has a few brown specks as if from weathered pyrite. The texture is fine-grained hypidiomorphic, in which most grains are about a millimeter or somewhat less in diameter, although microperthite grains are seriate up to 2.5 millimeters, and interstitial quartz grains are commonly about 0.5 millimeter. The mineral composition, as derived from a micrometric measurement 221 millimeters long, consists of 83 percent microperthite, 16 percent quartz, and somewhat more than 1 percent iron oxides and apatite. The microperthite contains a large proportion of albite, which replaces also a few grains of more calcic plagioclase, which were counted with the microperthite.

Another granitic aplite (3027), or fine-grained leucogranite, is associated with the muscovite leucosyenite (3011). The aplite is medium light gray (N 6), becoming light olive gray (5 Y 6/1) where specked with limonite. The texture is fine-grained hypidiomorphic, consisting of subhedral microperthite grains mostly between 0.5 and 1.0 millimeter excepting those that are elongate as much as 1.5 millimeters, of anhedral albite grains 0.5 millimeter or less, and of anhedral quartz mostly about 1 millimeter across.

The mineral constituents are predominant microperthite, abundant quartz, and less--though still abundant--plagioclase in distinct grains that are not part of the microperthite. The sparse accessory minerals, aggregating a small fraction of 1 percent, include aegirine-augite, sphene, pyrite largely weathered to hematite and limonite, and violet fluorite. The proportions of the constituents are shown in the following micrometric analysis from a traverse 72 millimeters long:

	Percent volume
Microperthite..................................	51
Oligoclase....................................	21
Quartz..	28

The microperthite, 71 percent of total feldspars, contains a large proportion of albite, which rims and irregularly patches the microperthite and predominates in some grains. Oligoclase about $Ab_{84}An_{16}$, as determined by the indices of refraction of cleavage fragments, makes fine-grained aggregates among the microperthite grains, and a little in microperthite forms inclusions without the systematic orientation of the perthite albite. Some of the quartz is interstitial, having straight edges in contact with microperthite faces, but some transects microperthite. Individual grains under crossed nicols show a faint mosaic. The interstitial quartz is considered to be an original constituent of the rock, but some of the other quartz may be a replacement formed during a stage that was essentially hydrothermal, if that term is used in a general sense without commitment as to the phase of the mineralizing fluid. Pyrite and fluorite are also products of the late stage.

Adamellitic aplite (3016), or fine-grained albite leucoadamellite, forms dikes in aegirine-augite monzonite-porphyry (3017) 2½ miles northeast of Burro Spring. In the hand specimen it is very light brownish gray (5 YR 7/1) weathering light brown (5 YR 6/4), and appears saccharoidal from the abundant equidimensional anhedral quartz. The texture, however, as shown by thin section is hypidiomorphic rather than saccharoidal, and consists of grains commonly 0.5 to 1.0 millimeter across. The mineral composition of a specimen is shown by the following micrometric analysis based on a traverse 170 millimeters long:

	Percent volume
Orthoclase..........................	35
Albite..............................	39
Quartz..............................	26

The orthoclase, some of which is incipiently microperthite, is 47 percent of the total volume of feldspars, making the rock adamellitic. The albite is an original constituent of the rock, the first grains having crystallized before some of the quartz. A very small quantity of accessory minerals consists of magnetite and biotite. Some sericite and muscovite are secondary.

Origin of the alkalic rocks

The origin of the undersaturated alkalic rocks of the Quartz Spring area involves a controversial subject that has been treated extensively in geologic literature. Rather than review what has been written (see Shand, 1947, for references) and attempt to make generalizations in the light of this one occurrence, what seems to be a reasonable explanation of only the Quartz Spring rocks will be presented without the slightest claim to originality. At a late stage in the crystallization of an adamellite batholith, small masses of residual magma were injected relatively far into predominantly carbonate rock, which desilicated the small masses as they passed through the limestone and dolomite. The nearly solidified syenitic offshoots then were altered by highly sodic emanations. The relatively small quantity of quartz-bearing aplitic rocks on passing through earlier igneous rock had less opportunity to be desilicated.

The emplacement of at least some of the intrusive rocks was by injection. Three-dimensional exposures in gulches about 500 feet deep show well that thick dikes and sills crumpled back incompetent beds and bowed the more competent beds. A wedging effect together with marginal crumpling, made by a large sill, is exposed near the canyon junction in the northeastern corner of the area. In massive country rock, as along the eastern crest of the Panamint Range, the irregular intrusions were much less obviously injected, and they may have been controlled by irregular joints.

Piecemeal stoping was a subsidiary result of the forceful injection and not the main process of emplacement. All stages in piecemeal stoping, from large masses of limestone nearly surrounded by tongues of syenite to small blocks of quartzite several inches in diameter, are exposed in O'Brien Canyon. The small inclusions of quartzite, although more than 100 feet from exposed sedimentary rock, are probably near the base of the sill, which is visible farther down the canyon. Within small areas near contacts, limestone xenoliths show an arrested series of digestion: some xenoliths are nearly pure metalimestone, others are rimmed with ferromagnesian minerals, or they are fine-grained aggregates of light-colored ferromagnesian minerals, or finally, clots of coarse-grained mafic minerals. The small total amount of stoping and assimilation in the exposed region is indicated by the low proportion of basic minerals in the rocks as a whole, and by the leucoratic rocks that are sufficiently well exposed in small masses to show that crystal settling does not account for the scarcity of heavier minerals.

For the same reasons most of the desilication of the leucocratic rock is not the result of assimilating carbonates, in the final position that now is exposed. Yet the presence of melanite, as in the fresh nepheline-syenite (3013), according to Shand (1947, p. 307) proves assimilation of limestone. Possibly the melanite-bearing rocks and the more basic rocks near margins are from diaschistic magma that was reduced from oversaturation to saturation in transit through carbonate rock, and in the present position locally assimilated sufficiently more carbonate rock to reduce it further to undersaturation. There is no evidence to show which process was more effective in reducing the proportion of silica during passage through carbonate rock, desilication by assimilating carbonate or by losing silica through additive contact-metamorphism of the carbonate country rock.

The alkalic nature of the rocks is partly an original characteristic and partly a late acquisition. The normal late differentiates around the margins of adamellite in the Ubehebe Peak quadrangle are pegmatites and aplites rich in orthoclase and albite and poor in mafic minerals. The Quartz Spring rocks originally were similar to these but for the loss of silica, as orthoclase and microperthite formed much of the original rocks. At least some of the orthoclase is moderately sodic, about $K_{72}Ab_{28}$ (3013), and probably a large part was originally microperthitic. Some of the albite in interstitial grains also appears to be primary. Euhedral feldspathoids, as inclusions in microperthite and as interstitial grains, crystallized early. Then soda-rich solutions greatly increased the quantity of albite in microperthite, rimming many grains, leaving isolated ragged patches of orthoclase in some, and entirely replacing others, forming an aggregate of completely oriented fine-grained albite within the outline of the grain. (See Anderson, 1937, pp. 59-61.) Albite formed replacement rims on more calcic plagioclase and in some grains left only irregular cores. The sodic solutions reacted with augite to form coronas or entire grains of aegirine-augite. The amphibole, some of which is a deuteric alteration of pyroxene, is hastingsite. The active role of late solutions is shown further by muscovite replacement of some feldspathoid, orthoclase, and biotite, and by traces of fluorite.

In summary, the regional distribution of saturated and undersaturated rocks with respect to oversaturated adamellite and the carbonate rocks favors the theory of desilication by the carbonate rocks. Syenite was produced from a somewhat pegmatitic differentiate of adamellite at a few places along carbonate contacts where lack of circulation from the parent magma impeded equilibrium, and nepheline-syenite was formed where small satellite masses passed through carbonate rock, permitting further desilication and virtually no cirulation with the source. The pegmatitic aspects, the trace of fluorite, and the deuteric addition of soda to the minerals suggest that the alkalic rocks of the Quartz Spring area were produced during the late stage of crystallization of a residual magma containing abundant fugitive constituents, which were rich in soda.

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Plate I.

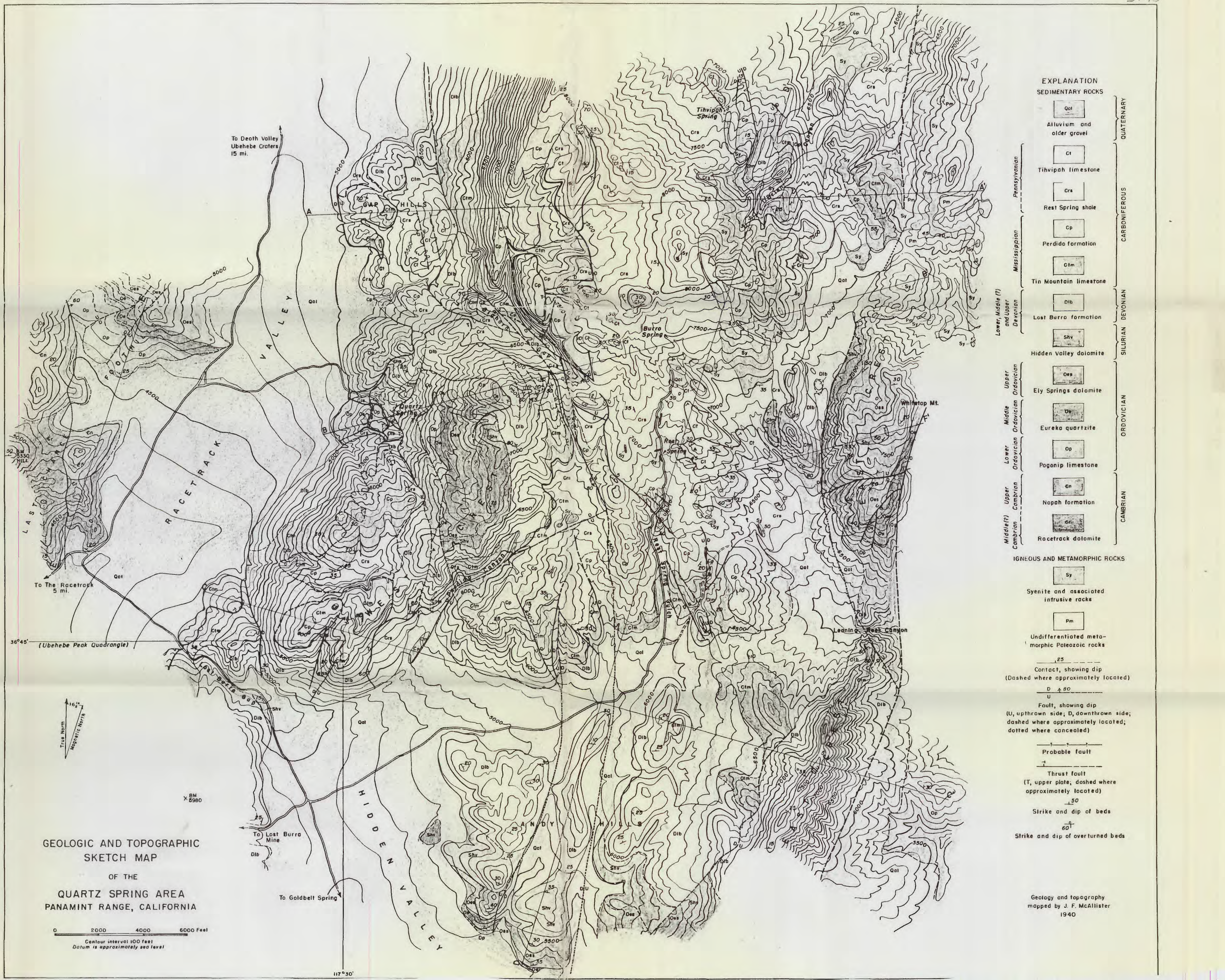
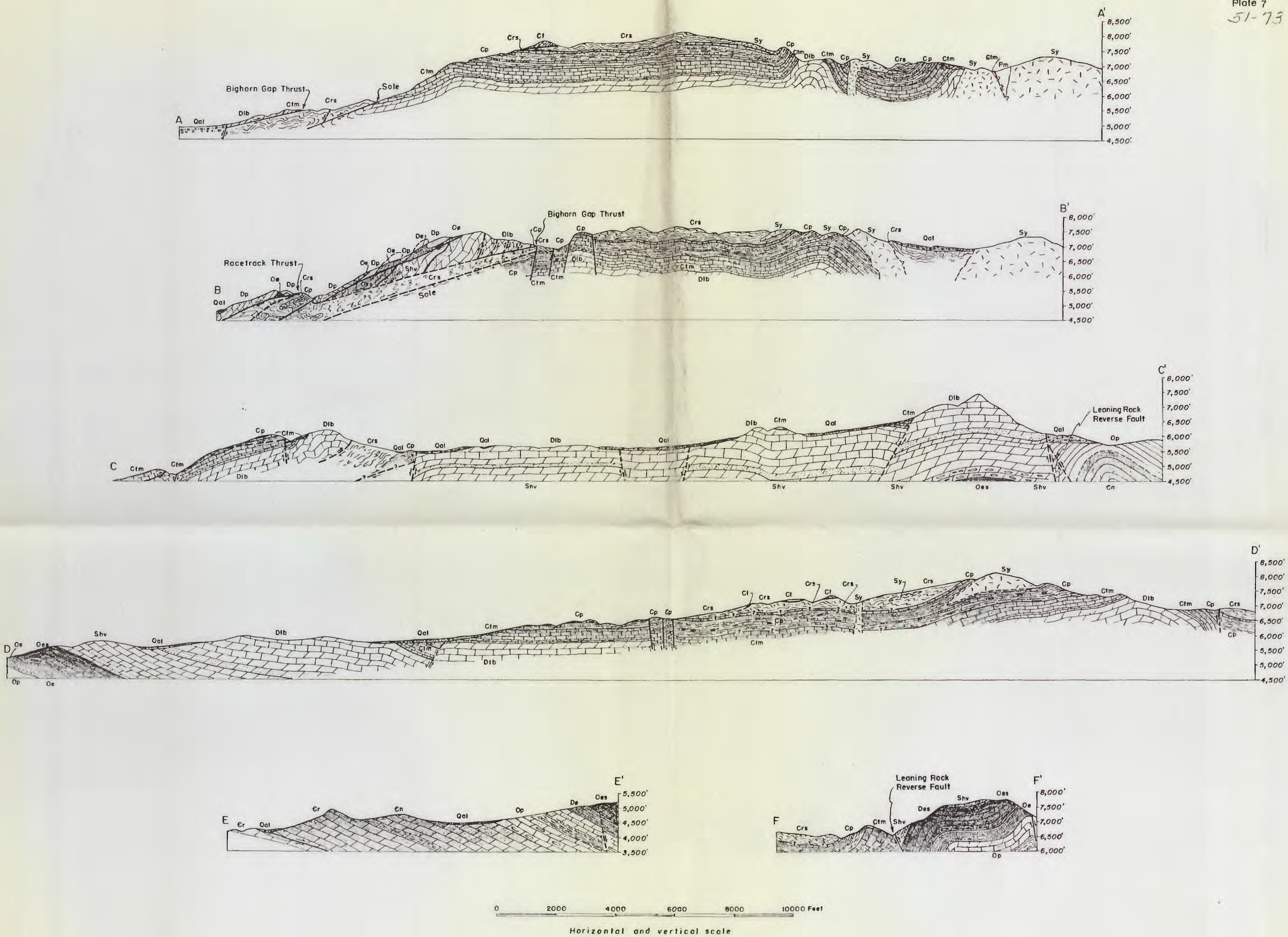

GEOLOGIC AND TOPOGRAPHIC
SKETCH MAP
OF THE
QUARTZ SPRING AREA
PANAMINT RANGE, CALIFORNIA
0 2000 4000 6000 Feet
Contour interval 100 feet
Datum is approximately sea level
EXPLANATION
SEDIMENTARY ROCKS
Qal Alluvium and older gravel
QUATERNARY
Ct Tihvipah limestone
Crs Rest Spring shale
Pennsylvanian
Cp Perdido formation
Ctm Tin Mountain limestone
Mississippian
CARBONIFEROUS
Dlb Lost Burro formation
Lower, Middle (?) and Upper Devonian
DEVONIAN
Shv Hidden Valley dolomite
SILURIAN
Oes Ely Springs dolomite
Upper Ordovician
Oe Eureka quartzite
Middle Ordovician
Op Pogonip limestone
Lower Ordovician
ORDOVICIAN
Cn Nopah formation
Upper Cambrian
Cr Racetrack dolomite
Middle (?) Cambrian
CAMBRIAN
IGNEOUS AND METAMORPHIC ROCKS
Sy Syenite and associated intrusive rocks
Pm Undifferentiated metamorphic Paleozoic rocks
Contact, showing dip
(Dashed where approximately located)
Fault, showing dip
(U, upthrown side; D, downthrown side; dashed where approximately located; dotted where concealed)
Probable fault
Thrust fault
(T, upper plate; dashed where approximately located)
Strike and dip of beds
Strike and dip of overturned beds
Geology and topography
mapped by J. F. McAllister
1940
To Death Valley
Ubehebe Craters
15 mi.
To The Racetrack
5 mi.
To Lost Burro
Mine
To Goldbelt Spring
36°45' (Ubehebe Peak Quadrangle)
117°30'
True North
Magnetic North
RACETRACK
VALLEY
HIDDEN VALLEY
SANDY HILLS
GAP HILLS
Tihvipah Spring
Burro Spring
Quartz Spring
Rest Spring
Rest Spring Gulch
Whitetop Mt.
Leaning Peak Canyon
BM 5980

Plate 4.
51-73

Age		Formation		Lithology	Fossils	Locality of measured section
CARBONIFEROUS 1,595 FT.	Pennsylvanian	TIHVIPAH LIMESTONE 200± FT.		Limestone, shaly limestone, calcareous shale: mostly platy and light gray; some massive, medium gray chert in spheroidal concretions, very dark gray.	Fusilinids	1-2 miles N. 80° W. of Ubehebe mine
	?	REST SPRING SHALE 310+ FT.		Siltstone, shale, a little quartzite: olive gray to olive brown. Shale; grayish black, weathering olive gray; discoidal concretions.	Poorly preserved Brachiopods suggestive of Chonetes Marginifera Composita	3 miles N. 70° E. of southwest corner of Ubehebe Peak quad.
	Mississippian	PERDIDO FORMATION 610± FT.		Siltstone, shale, limestone, chert, conglomerate: pale red to dark gray, weathering reddish brown, brown or gray; siltstone predominant in upper part, limestone predominant in lower part, characterized also by bedded chert.	Cravenoceras Dictyoclostus? sp. indef. Rhyncopora? sp. indef. Composita? sp. indef. Caninia cf. C. cornicula (Miller)	Upper part: 3,000 feet south of Rest Spring. Remainder: 9,000 feet south-east of Quartz Spring.
		TIN MOUNTAIN LIMESTONE 475 FT.	2	Limestone: medium gray; pale red shaly partings; some chert nodules.	Spirifer cf. S. centronatus Winchell Syringopora cf. S. aculeata S. cf. S. surcularia	About $2\frac{1}{2}$ miles southeast of Quartz Spring
			1	Limestone: medium gray; in thin beds; interbedded with calcareous shale: light brownish gray to pale red; some chert nodules.		
DEVONIAN 1,590 FT.	? Upper	LOST BURRO FORMATION 1,525 FT.	5	Sandstone, quartzite, sandy dolomite: very light gray, sandy parts weathering brown	Cyrtospirifer cf. C. monticola Haynes C. cf. C. disjunctus (Sowerby) Tylothyris? cf. T.? raymondi Haynes "Camarotoechia" aff. "C." duplicata (Hall) Cleiothyridina cf. C. devonica Raymond Productella sp. Bryozoa and corals Atrypa sp. Cladopora Stromatopora	Type locality west side of south end of Lost Burro Gap between Racetrack Valley and Hidden Valley starting about 3 miles S. 25° W. of Quartz Spring
			4	Dolomite: very light gray; some medium gray, interbedded.		
	Middle		3	Dolomite and limestone: very dark gray and light gray, alternately.		
			2	Dolomite: light gray, mottled and streaked creamy; very dark gray, some mottled with lighter gray.		
	Lower		1	Sandy and shaly dolomite: light gray, weathering mouse gray to brown.		
SILURIAN 1,300 FT.		HIDDEN VALLEY DOLOMITE 1,365 FT.	3	Dolomite: medium dark gray, weathering light olive gray; fossils in upper 65 feet in Andy Hills, Hidden Valley.	Papiliophyllum elegantulum Stumm Amplexus lonensis Stumm A. invaginatus Stumm Acrospirifer kobehana (Merriam) Meristella robertsensis Merriam	Type locality about $2\frac{1}{2}$ miles north of Ubehebe Peak
			2	Dolomite: very light gray, massive.		
			1	Dolomite: medium gray and medium light gray; cherty.	Halysites catenularia (Linné) H. microporus (Whitfield) Favosites cf. F. niagarensis Hall F. aff. F. gothlandica Porpites porpita (Linné)	
ORDOVICIAN 2,780± FT.	Upper	ELY SPRINGS DOLOMITE 940 FT.	2	Dolomite: light gray, grading downward to medium gray; some darker mottling.		About $2\frac{1}{2}$ miles north of Ubehebe Peak
			1	Dolomite: conspicuously dark gray; in detail, mottled lighter gray; chert nodules.	Streptelasma sp. Halysites sp. Resserella sp. Dinorthis aff. D. subquadrata (Hall) Rhynchotrema cf. R. argenturbicum (White) R. aff. R. capax (Conrad) Zygospira cf. Z. modestus (Say)	
	Middle	EUREKA QUARTZITE 400 FT.	2	Quartzite: vitreous, weathering light tints of yellow and pink.	No fossils	About $2\frac{1}{2}$ miles north of Ubehebe Peak
			1	Quartzite, hematitic, limonitic and vitreous, interbedded with a little siltstone, dull light gray.		
	Lower	POGONIP LIMESTONE 1,440 FT.	8	Dolomite, some sandy dolomite and dolomitic sandstone in local beds: generally medium gray, some dark gray.	Bryozoa Mitrospira longwelli Kirk Maclurites sp. Receptaculites sp. Porambonites sp.	Lost Chance foot-hills, $2\frac{1}{3}$ miles N. 75° W. of Quartz Spring
			7	Shaly limestone: light buff or yellowish.	Fragments	
			6	Siliceous (largely cherty) limestone: gray, weathering brown.		
			5	Shale: light brown.	Fragments	
			4	Siliceous limestone and dolomite: light gray, weathering brown.		
			3	Shaly dolomite: gray, weathering buff.		
			2	Dolomite: light gray, weathering in general light brown or light brownish gray.		
			1	Dolomite: medium gray; limestone, local; chert, light gray, in thin lenses.		
CAMBRIAN 3,500± FT.	Upper	NOPAH FORMATION 1,600 FT.	9	Dolomite: dark gray.		Lost Chance foot-hills about 3 miles west of Quartz Spring
			8	Dolomite: cream colored.		
			7	Dolomite: medium to dark gray.	Matherella cf. M. saratogensis Walcott Sinuopea spp. Strepsodiscus sp.	
			6	Dolomite: cream colored.		
			5	Dolomite: dark gray.		
			4	Dolomite: light gray.		
			3	Dolomite: dark gray.		
			2	Dolomite: cream colored.		
			1	Dolomite: dark gray; lower part silty, some shaly partings, weathering to light browns.	Lingula sp. Obolus sp. Acrotreta cf. A. idahoensis Walcott	
	? Middle	RACETRACK DOLOMITE 1,900± FT.	7	Dolomite: light gray, grading into darker gray at base.	No fossils	Type locality Last Chance foothills about 3 miles west of Quartz Spring
			6	Dolomite: light grayish buff; a few thin dark beds.		
			5	Dolomite: very dark gray, irregular lighter mottling.		
			4	Dolomite: light gray, weathering creamy.		
			3	Dolomite: medium gray; closely spaced sinuous mottling.		
			2	Dolomite: silty in part; weathering pale yellowish brown.		
			1	Dolomite: dark gray, irregularly banded lighter gray in layers about 1 inch thick. Some chert masses in upper part.		

COLUMNAR SECTION OF PALEOZOIC ROCKS IN THE QUARTZ SPRING AREA
NORTHERN PANAMINT RANGE, CALIFORNIA

Plate 7
51-73



GEOLOGIC STUCTURE SECTIONS, QUARTZ SPRING AREA, PANAMINT RANGE, CALIFORNIA

Qal, alluvium and older gravel; Ct, Tihvipah limestone; Crs, Rest Spring shale; Cp, Perdido formation; Ctm, Tin Mountain limestone; Dlb, Lost Burro formation; Shv, Hidden Valley dolomite; Oes, Ely Springs dolomite; Oe, Eureka quartzite; Op, Pogonip limestone; Cn, Nopah formation; Cr, Racetrack dolomite; Sy, syenite and associated intrusive rocks; Pm, undifferentated metamorphic Paleozoic rocks.