Stratigraphy, structure, and metamorphism in the central Panamint Mountains (Telescope Peak quadrangle), Death Valley area, California

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INTRODUCTION

The Telescope Peak quadrangle encompasses the central Panamint Mountains which from the western boundary of the central part of Death Valley, California (Figure 1). The Panamint Mountains are a north-trending range with great relief. Telescope Peak, 11,049 feet above sea level, is the highest point, and it lies only about 25 km west of the lowest point in Death Valley, 282 feet below sea level. The lowest elevations within the quadrangle are in Panamint Valley at approximately 1040 feet above sea level. The topography is rugged along the east side of the range crest and along the western margin, but the canyons widen toward the divide, and the heads of many drainages occur in broad, high parks.

The climate in the Death Valley region is desert and the vegetation at the lower elevations is sparse and is characterized by creosote, desert holly, and plants of the buckwheat family. The higher elevations of the Panamint Mountains receive substantial precipitation, and the west-draining, spring-fed streams flow nearly year-round. Mesquite and willow occur in the canyons and near springs. At higher elevations, sagebrush, mountain mahogany, pinyon, juniper, limber pine, and bristle-cone pine grow. In general, the rugged topography, dry climate, and sparse vegetation allow good exposures of rock.

Access to the range is principally from the west. A gravel road occurs along the east side of Panamint Valley, and jeep trails are located in Tuber, Surprise, Happy, and Pleasant Canyons. Most are washed out by the frequent, summer flash floods and are rebuilt only when there is sufficient interest in a mining venture in the mountains. A paved road serves Wildrose Canyon

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and is maintained by the National Park Service. A gravel road occurs along the west side of Death Valley and jeep trails run up Hanaupah Canyon and Butte Valley.

Settlements in the Telescope Peak quadrangle are not permanent; a few miners live in Ballarat, a once active mining town, and in Happy, Pleasant, and Jail Canyons. Indian Ranch, a reservation at the mouth of Hall Canyon, caters to the occasional tourist, and a ranger station is located in Wildrose Canyon.

The Panamint Mountains have elicited considerable economic interest because of the numerous silver and gold deposits, and Panamint City, located in upper Surprise Canyon, was a major silver mining district in the 1870's. The Panamint Mountains hold considerable geologic attention because they contain the westernmost exposures of known Precambrian rocks in central California and contain the easternmost Sierra Nevada-type plutonic rocks. In addition, the tremendous relief across the mountains is maintained by Quaternary faulting.

Murphy (1930, 1932) carried out the first detailed studies of the geology of the Panamint Mountains. He described the geology of the Panamint City Mining District and reconnoitered the geology of the Telescope Peak area. Murphy divided the late Precambrian strata into several formations with local names.

White (1940) mapped two small areas in Wildrose Canyon because of the presence of possibly economic antimony deposits. Hopper (1947) mapped a strip of the Emigrant Canyon quadrangle to the north and recognized the presence of the Johnnie Formation, Stirling Quartzite, and Wood Canyon Formation, as well as younger formations which are not exposed in the Telescope Peak quadrangle. Maxson (1950) investigated the physiography of the Panamint Range and described an old erosion surface of moderate relief, later uplifted by displacement on the Panamint Valley fault zone and severely dissected.

Johnson (1957) mapped a portion of the Manly Peak quadrangle to the south and recognized the presence of the Kingston Peak Formation and Noonday Dolomite in the Paniment Mountains. Albee and Lanphere (1962) correlated the rock units described by Murphy (1932) with the Pahrump Group and Noonday Dolomite of Hewett (1940), and Labotka and Albee (1976, 1977) outlined the depositional environment of the Pahrump Group exposed in the Telescope Peak quadrangle.

Detailed geologic mapping in the Telescope Peak quadrangle began in 1958 when Lanphere (1962) mapped the Wildrose Canyon area. In 1962, A. L. Albee directed the California Institute of Technology Geology Summer Field Camp and he, with B. Carter, S. Curtis, and R. Hooke, mapped the upper Pleasant and Happy Canyons area. Lanphere, Wasserburg, Albee, and Tilton (1964) described the geology and strontium isotopic characteristics of the World Beater Dome. R. Smith (1976) mapped in Panamint Valley and described the deformation of shorelines of Pleistocene Lake Panamint, and Hooke (1965) estimated the amount of eastward tilting of Death Valley based in part on alluvial fan morphology on the east side of the Panamint Mountains. McDowell (1967) mapped the Little Chief stock and its environs, and Albee, Lanphere, and McDowell (1971) provided a generalized geologic map of the Telescope Peak quadrangle for the revised edition of the Death Valley Sheet of the Geologic Atlas of California (1977).

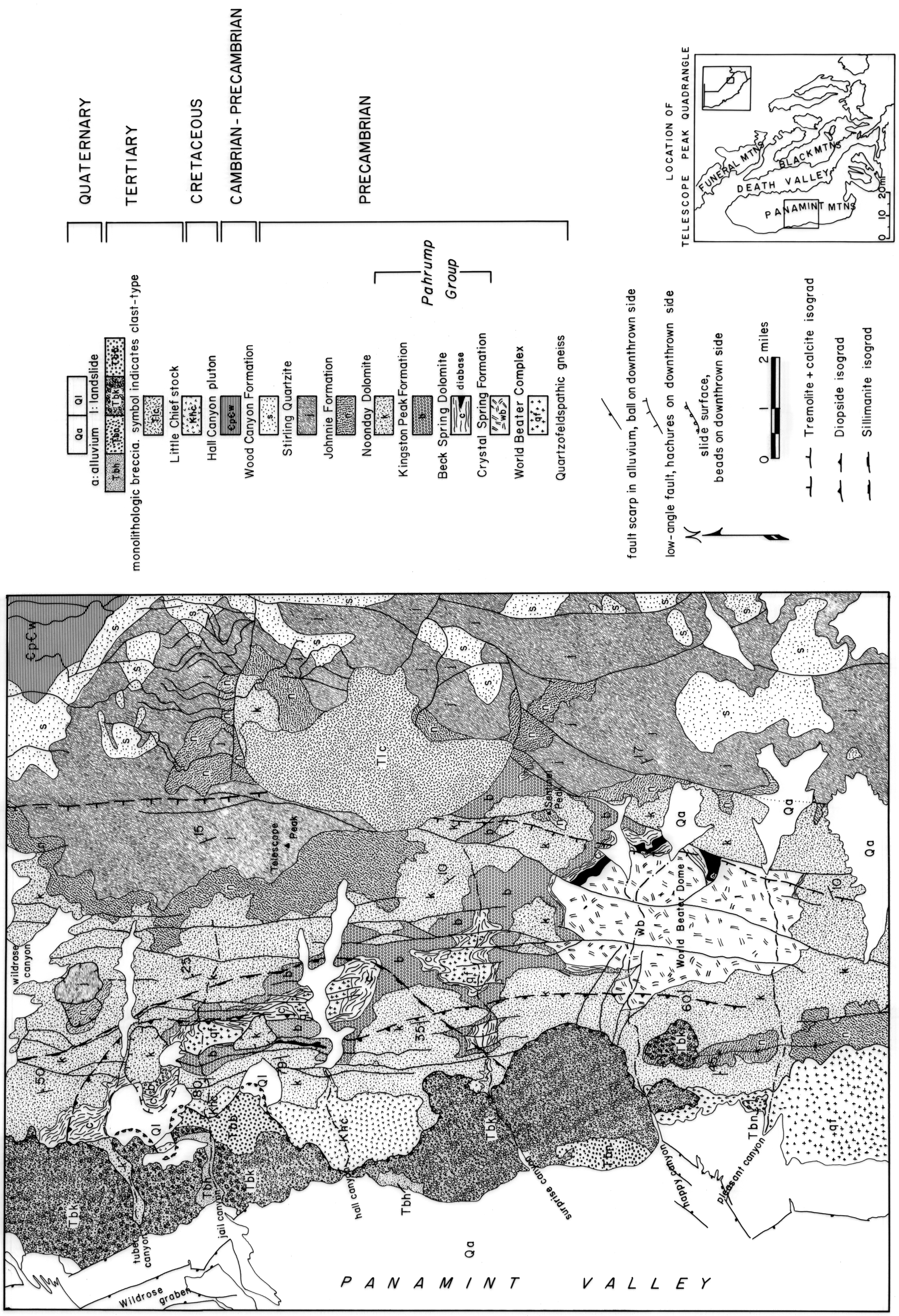

Figure 1. Location and generalized map of the Telescope Peak quadrangle, California.

Additional mapping by Labotka (1978) was carried out in the northwest part of the area to resolve structural and stratigraphic complexities. This report synthesizes the geologic history of the central Panamint Mountains, and Albee, Labotka, Lanphere, and McDowell (in press) present the geology of the Telescope Peak quadrangle.

ACKNOWLEDGMENTS

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STRATIGRAPHY

LOWER PRECAMBRIAN ROCKS

The oldest rocks exposed in the Telescope Peak quadrangle are crystalline gneiss, schist, and granite which crop out in the core of a north-northwest-trending anticline and along the western margin of the Panamint Mountains south of Happy Canyon (Figure 1). These old crystalline rocks consist of three principal types. The first, and possibly oldest type, is a sequence of metasedimentary micaceous schist and leucocratic, quartzofeldspathic gneiss. The second is grey, biotite +rich augen gneiss which contains inclusions of micaceous schist. The third rock type if grey porphyritic quartz monzonite which has intruded the augen gneiss in the World Beater Dome area.

The lower Precambrian micaceous schist and quartzofeldspathic gneiss are exposed along the western margin of the range south of Happy Canyon and occupy the core of a major anticline in Surprise, Hall, and Jail Canyons (Figure 1). Murphy (1932) included these rocks in his Panamint Metamorphic Complex. Schistose rocks predominate in the western margin area and also occur in Surprise Canyon. The dominant lithology in these areas consists of light-grey, micaceous quartzite and feldspathic quartzite. The rocks have a well developed foliation which is principally defined by the parallel alignment of flattened or sheared quartz grains. This cataclastic texture is particularly evident in the vicinity of the west-dipping fault that separates the lower Precambrian rocks from later Precambrian strata along the southwest margin of the range (the South Park Canyon fault of Johnson, 1957). Elsewhere, the parallel alignment of mica defines the foliation. Dark, biotite-rich schist and local hornblende-schist layers are interbedded with the quartzite. These dark schist layers dominate the layer Precambrian metasedimentary rocks in Surprise Canyon. In Surprise Canyon, where the lower Precambrian biotite schist sequence dips steeply east, the sequence lies beneath quartzofeldspathic gneiss. This leucocratic gneiss comprises the outcrops of lower Precambrican rocks in Hall and Jail Canyons. The gneiss exhibits a moderately developed foliation, and the stratiform appearance of the gneiss suggests that it may have been bedded. The major mineral phases that constitute the leucocratic gneiss are quartz, microcline, plagioclase, and muscovite. The apparent bedded nature of the gneiss suggests that the protolith may be felsic, volcanic rock, but deformation and recrystallization have obliterated the original texture of the rock.

Visually estimated modes of representative samples of the metasedimentary rocks and quartzofeldspathic gneiss are listed in Table 1.

The two other lower Precambrian rock types, the augen gneiss and the porphyritic quartz monzonite, occur in World Beater Dome in Happy and Pleasant Canyons. Murphy (1932) originally called these rocks World Beater Porphyry, but Lanphere and others (1964) distinguished the augen gneiss and the quartz monzonite and renamed the rocks which occur in this dome the World Beater Complex. Lanphere and others (1964) described in detail the petrography and structural characteristics of these two rock types in their study of the isotopic characteristics of the World Beater Complex. The augen gneiss is medium to dark grey, biotite-rich, quartz monzonitic orthogneiss. Augen up to 4 cm in length of potassium feldspar megacrysts and of quartz + plagioclase segregations, a high biotite content (10 to 25 vol percent), and inclusions of quartz-biotite-muscovite schist distinguish this unit from all other Precambrian rocks (Figure 2a). The relative age relations between the augen gneiss and the metasedimentary rock sequence are unclear, but inclusions of mica schist in the augen gneiss suggest that it intrudes are unclear, but inclusions of mica schist in the augen gneiss suggest that it intrudes the paragneiss and schist.

The grey augen gneiss was intruded by light grey, equigranular to porphyritic quartz monzonite. The rock has a non-foliated, hypidiomorphic granular texture and contains megacrysts of tabular potassium feldspar. This granite crosscuts the foliation in the augen gneiss, and in many places the augen gneiss is pervasively invaded by the granite (Figure 2b). Augen gneiss and granite are combined into one map unit, the World Beater Complex. Modes and chemical analyses of representative samples of the augen gneiss and the quartz monzonite are taken from Lanphere and others (1964) and listed in Table 1.

Uranium-lead ages were determined by Lanphere and others (1964) from zircon separates from the augen gneiss and the grey quartz monzonite. The isotopic systems were greatly disturbed during Mesozoic time, but they indicate that the augen gneiss is approximately 1790 m.y. old and the cross-cutting quartz monzonite is about 1350 m.y. old. Potassium-argon and rubidium-strontium ages obtained from pegmatites which cut across metarhyolite in the Warm Spring area (outside the quadrangle on the southeast side of the Panamint Mountains) give ages ranging from 1660 to 1730 m.y. (Wasserburg and others, 1959). ^{207}Pb/^{206}Pb ages obtained from zircon separates from the metarhyloite and granitic gneiss in the same area are 1720 and 1780 m.y. respectively (Silver and others, 1961). No isotopic age data are available from the metasedimentary sequence, but the inclusions of mica schist in the augen gneiss suggest that the quartzite-schist sequence is older than the augen gneiss.

Table 1. Modes and compositions of lower Precambrian rocks

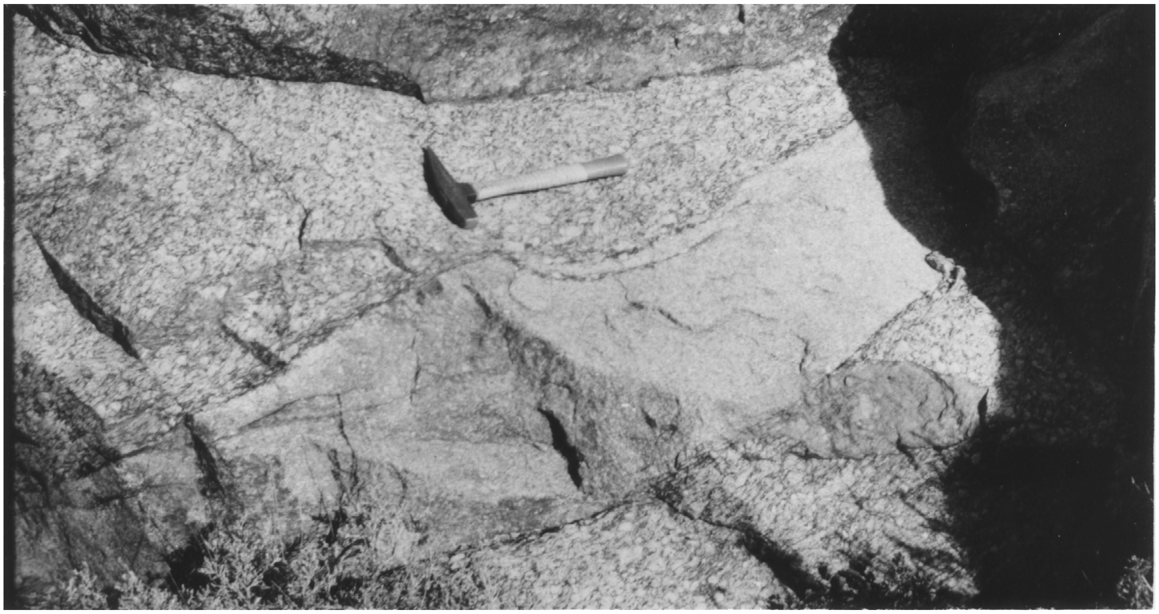
	Metasedimentary rocks			Quartzofeldspathic gneiss	Quartz monzonite	Augen gneiss
	Mouth of Pleasant Canyon	South Park Canyon	Surprise Canyon	Surprise Canyon	Upper Pleasant Canyon	Upper Pleasant Canyon
	CP 117*	CP 427*	PML 273*	PML 271*	CP 346†	CP 93R†
Quartz	88	54	30	10	39	36
Plagioclase	40	25.5	21	5	0	20
Microcline–microperthite	40	13.5	25	5	15	0
Biotite	tr	8	5	0	10	35
Muscovite	tr	12	12	1	10	0
Hornblende	0	0	0	0	0	10
Other minerals	ep, ap, sph, z	ap, op, z	ap, op, z	op	z, ch, op, ap	ep, op, ap t
SiO_2		73.40	71.72			
TiO_2		0.20	0.51			
Al_2O_3		13.60	13.68			
Fe_2O_3		0.42	0.77			
FeO		1.81	2.99			
MnO		0.03	0.04			
MgO		0.49	0.87			
CaO		0.40	0.79			
Na_2O		2.21	2.36			
K_2O		5.94	4.38			
P_2O_5		0.13	0.13			
H_2O^+		0.67	1.05			
H_2O^-		0.04	0.05			
Total		99.34	99.33			

* Visually estimated mode

† Mode calculated from chemical composition

ch = chlorite, op = opaque, ap = apatite, ep = epidote, sph = sphene, z = zircon, t = tourmaline

(a) Biotite augen gneiss (about 1,800 m.y. old).



(b) Intrusive relation between quartz monzonite (about 1,400 m.y. old) and augen gneiss.

Figure 2. Lower Precambrian World Beater Complex. Pleasant Canyon.

UPPER PRECAMBRIAN ROCKS—PAHRUMP GROUP

Introduction

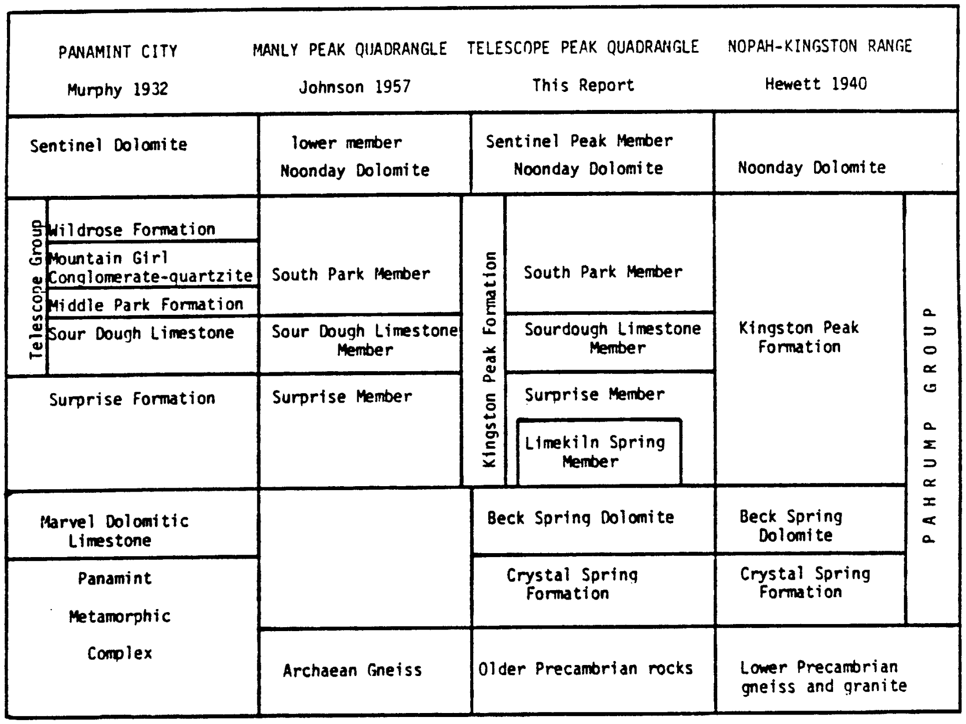
The upper Precambrian Pahrump Group occupies a unique position in the stratigraphic sequence of the Death Valley area, California. These are the oldest deposits in the southwest Great Basin which were not metamorphosed and strongly deformed prior to late Paleozoic and Mesozoic tectonic events. The Pahrump Group marks the inception of grossly continuous sedimentation through the Paleozoic Era, and because the Pahrump is extensively exposed in the Panamint Mountains an opportunity is provided to study the environment of the initial deposits in the Cordilleran Geosyncline.

These upper Precambrian sedimentary rocks were first described in the Panamint Mountains by Murphy (1932). He applied the term Panamint Metamorphic Complex to the oldest and more highly metamorphosed rocks in the Panamint Mountains (Figure 3). He assigned overlying rocks to Marvel Dolomitic limestone, Surprise Formation, and Telescope Group (Figure 3). Subsequently, Hewett (1940) defined the Pahrump Group in the Kingston Range (approximately 110 km to the southeast and divided the group into Crystal Spring Formation, Beck Spring Dolomite, and Kingston Peak Formation. The Kingston Peak Formation was recognized in the southern Panamint Mountains by Johnson (1957), and he correlated this formation with the Surprise Formation and the lower part of the Telescope Group of Murphy (1932). Albee and Lanphere (1962) recognized the presence of lower Precambrian basement rocks and the Pahrump Group in the Telescope Peak quadrangle, and they correlated the lower Precambrian rocks and the Crystal Spring Formation to the Panamint Metamorphic Complex, and the Beck Spring Dolomite to the Marvel Dolomitic Limestone. Widespread use of Hewett's (1940) nomenclature has led to the abandonment of Murphy's formational names.

The detailed mapping which allowed the correlation of the Panamint Metamorphic Complex of Murphy (1932) with the Pahrump Group and lower Precambrian basement revealed a complex change in the lithologies and thicknesses of the Pahrump Group over relatively small distances. Late Mesozoic and Tertiary folds and faults are superimposed on the Precambrian rocks, and these structures confuse the stratigraphic relations. (Structural and geographic features frequently referred to in the following descriptions are indicated in Figure 4.) Stratigraphic sections are incomplete and highly faulted on the west side of the north-northwest trending anticline.

Unfaulted sections are rare even on the east flank of the structure. Measured sections on the east flank are derived from Albee and Lanphere (1962) (Pleasant Canyon and Sentinel Peak), Johnson (1957) (a South Park–Redlands Canyon composite), and Murphy (1932) (Surprise Canyon). Additional sections were measured in Tuber and Jail Canyons, and the descriptions of the sections in Surprise Canyon and on Sentinel Peak were supplemented.

Stratigraphic sections on the west flank of the anticline are incomplete. Partial sections were measured in lower Surprise Canyon but most thicknesses are calculated from the map distribution. Errors are difficult to estimate because many contacts are gradational and because many units change in thickness over very small distances. Calculated thickness is also subject



PANAMINT CITY Murphy 1932	MANLY PEAK QUADRANGLE Johnson 1957	TELESCOPE PEAK QUADRANGLE This Report	NOPAH-KINGSTON RANGE Hewett 1940
Sentinel Dolomite	lower member Noonday Dolomite	Sentinel Peak Member Noonday Dolomite	Noonday Dolomite
Telescope Group Wildrose Formation	South Park Member	Kingston Peak Formation South Park Member	Kingston Peak Formation PAHRUMP GROUP
Mountain Girl Conglomerate-quartzite			
Middle Park Formation			
Sour Dough Limestone	Sour Dough Limestone Member	Sourdough Limestone Member	
Surprise Formation	Surprise Member	Surprise Member Limekiln Spring Member	
Marvel Dolomitic Limestone		Beck Spring Dolomite	Beck Spring Dolomite
Panamint Metamorphic Complex		Crystal Spring Formation	Crystal Spring Formation
	Archaean Gneiss	Older Precambrian rocks	Lower Precambrian gneiss and granite

Figure 3. Stratigraphic nomenclature for the Pahrump Group.

to errors in contact locations and in dip. However, the arguments are based on large changes in thicknesses and errors as large as 20 percent (in the worst cases) are tolerable.

The late Mesozoic metamorphism makes textural analysis difficult, but the metamorphic rocks do preserve many primary sedimentary structures, particularly millimeter-scale bedding and graded bedding. Despite later metamorphism and deformation, the changes in thicknesses and in the overall lithologies of the constituent units allow a first-order determination of the paleogeography during late Precambrian time.

Crystal Spring Formation

The Crystal Spring Formation is the oldest of the formations that constitute the Pahrump Group. The Crystal Spring Formation was defined by Hewett (1940) for exposures in the Kingston Range and was correlated to part of the Panamint Metamorphic Complex by Albee and Lanphere (1962). Like most of the lithologic units in the central Panamint Mountains the thickness of the Crystal Spring Formation is variable. The Crystal Spring Formation is 200 to 300 m thick in most places, but in Tuber Canyon where the base is not exposed the formation appears to be greater than 1000 m thick. The formation thins toward World Beater Dome and is absent on the west and southwest flanks of the dome.

A complete section is exposed on the southwest side of Sentinel Peak (Figure 5). The formation

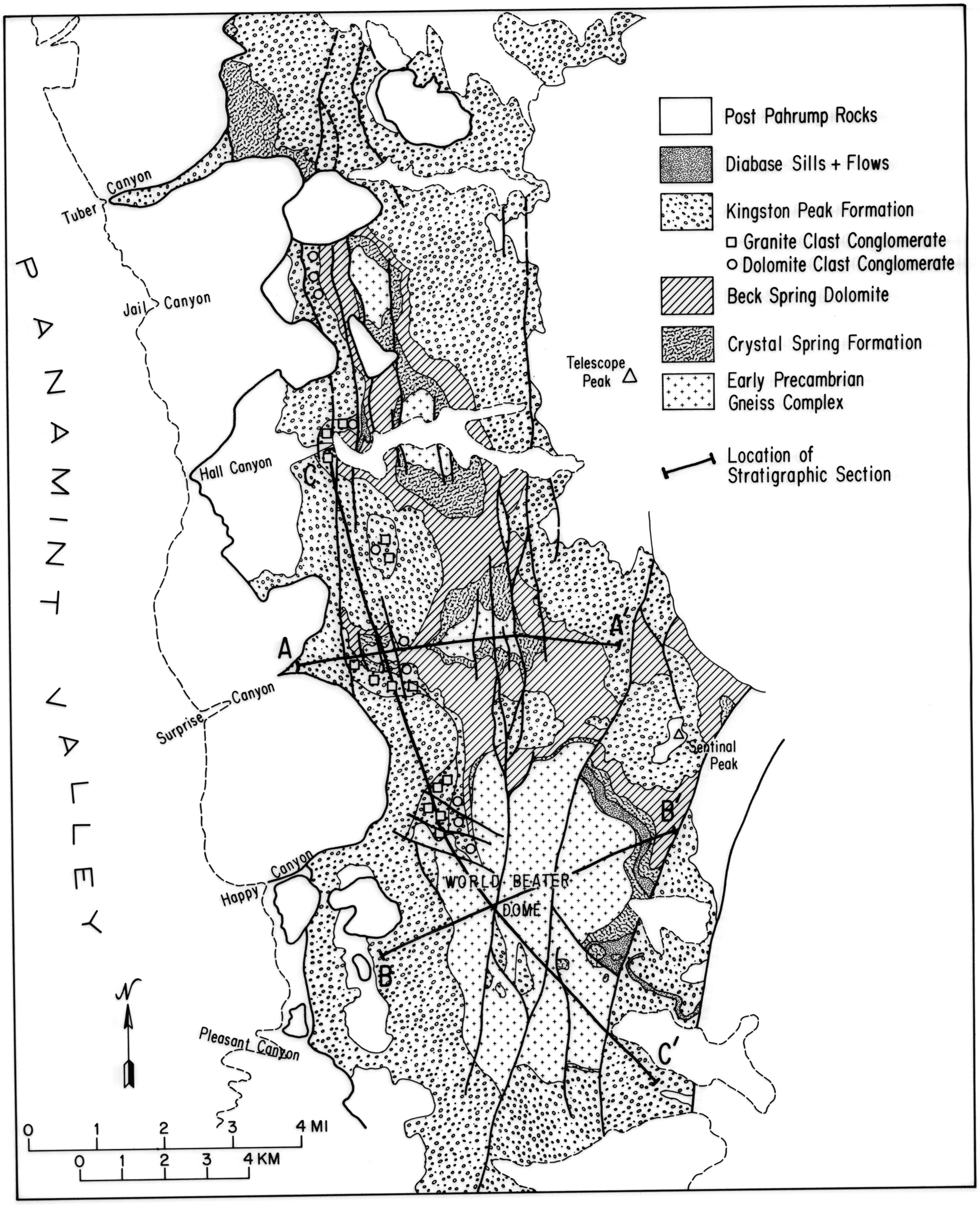


Figure 4. Generalized geology of the Pahrump Group showing the locations of stratigraphic cross sections of Figure 16.

contains 18 m of light grey quartzite which contains quartzite clasts at the base. The quartzite is overlain by about 60 m of light grey dolomite and 200 m of blue-grey micaceous quartzite which is interbedded with argillite and dolomite in the upper 15 m. The section was intruded by a 180 m thick diabase sill and its feeder dike.

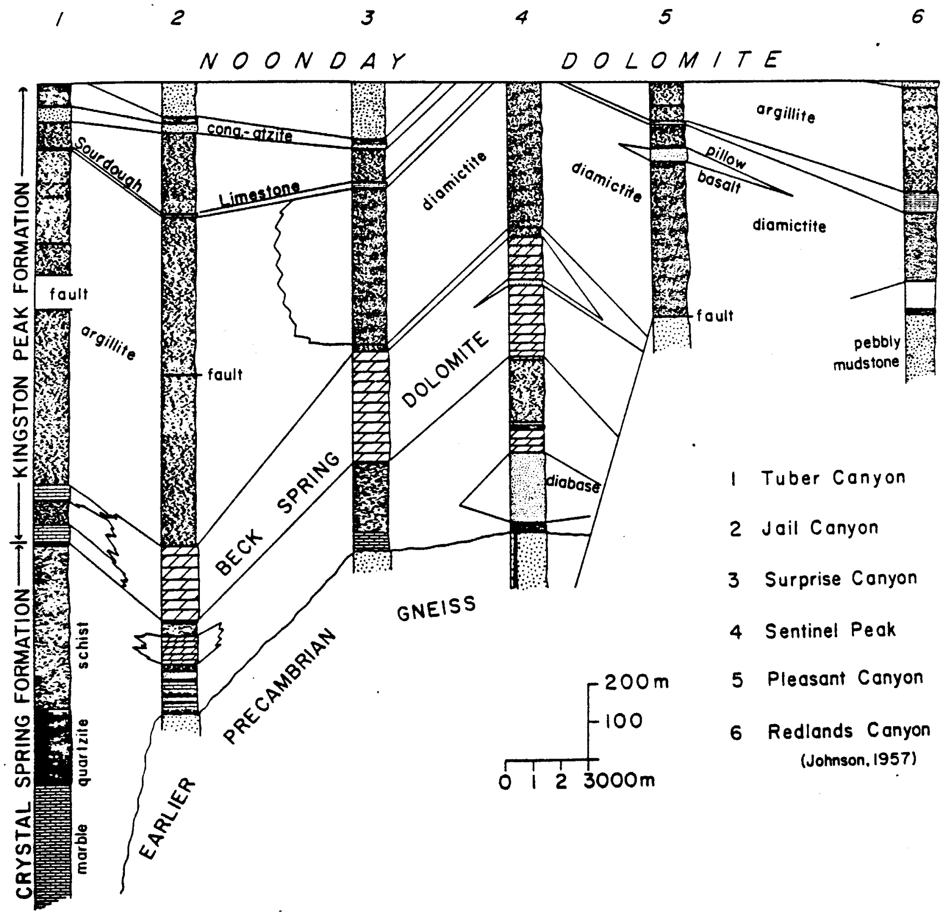


Figure 5. Stratigraphic sctions of the Pahrump Group from Tuber Canyon (north) to Redlands Canyon (south; from Johnson, 1957) on the east side of the north-northwest-trending anticline.

Between Surprise and Jail Canyons the Crystal Spring Formation is characterized by dark brown-weathering, micaceous calcite marble overlain by dark grey argillite, quartz-rich arenite, and muscovite-biotite schist. The marble makes up approximately the lower third of the formation.

In the Crystal Spring section measured in Jail Canyon (Figure 5) a lower unit, about 130 m thick, consists of rock types similar to those found to the south and includes interbedded dark-weathering micaceous marble, micaceous arenite, dark biotite shcist, and amphibolite. This unit is overlain by 75 m of light tan dolomite marble. The marble is medium-bedded and contains thin interbeds of siliceous dolomite marble and arenite. The marble is overlain by 30 m of quartz-rich schist and 6 to 10 m of quartzite.

In Tuber Canyon, rocks which are here correlated with the Crystal Spring Formation comprise a section which is more than three times as thick as the Crystal Spring section exposed immediately to the south. The base is not exposed but the lowest unit consists of at least 305 m of dark brown-weathering marble similar to the dark brown marble in the lower part of the Crystal Spring Formation. The marble contains what appear to have been chert nodules (nodular quartz segregations which have tremolite reaction rims) and massive amphibolite layers in the upper part. The marble unit is overlain by a southward thinning wedge which consists of quartz arenite, amphibolitic schist, and white calcite marble. A middle unit consists of 210 m of flaggy micaceous quartzite. Blue-grey graphitic schist and quartzite occur at the top of the section. These rocks occur in the core of the north-northwest trending anticline, and folding may have exaggerated the true thickness.

In contrast to the apparently thick section of Crystal Spring Formation in Tuber Canyon, the formation is very thin or absent on the west and south flanks of World Beater Dome. Here the only rocks recognized as Crystal Spring Formation are white quartzite and quartzite-clast conglomerate which in most places are less than 5 m thick. Rocks assigned to the Kingston Peak Formation lie unconformably over the quartzite or rest on the lower Precambrian basement. The 200 to 300 m of Crystal Spring Formation exposed on the east side of the dome thin and pinch out westward over the dome.

Beck Spring Dolomite

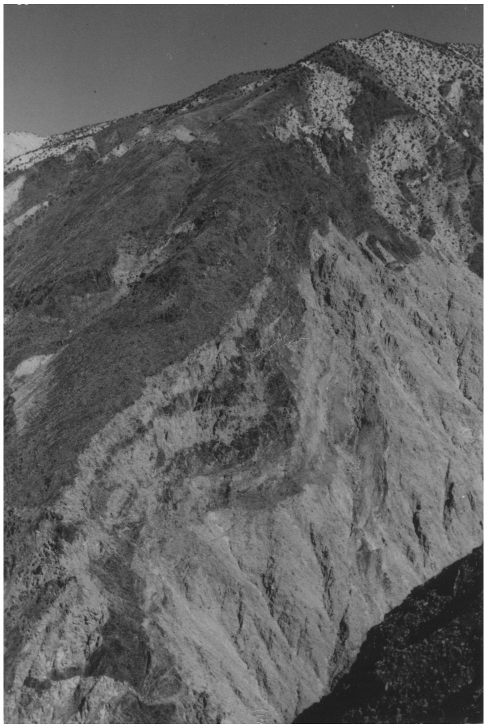
The Marvel Dolomitic Limestone of Murphy (1932) was correlated to the Beck Spring Dolomite by Albee and Lanphere (1962), and it lies conformably on the Crystal Spring Formation throughout most of the Telescope Peak quadrangle. Like the Crystal Spring Formation, the thickness of the Beck Spring Dolomite varies considerably. On the east flank of the anticline 200 to 300 m are exposed, but on the northwest side of World Beater Dome the formation is only about 30 m thick and it is absent of Happy Canyon.

Beneath Sentinel Peak, the Beck Spring Dolomite consists of generally massive-bedded, blue-grey sandy dolomite. Oolitic dolomite is common in the massive-bedded sequence, but near the top thinly laminated and a stromatolitic dolomite, intraformational dolomite breccia, and intertongues of quartz-rich arenite and argillite are abundant (Figure 5). Similar interfingering of dolomite and siliceous clastic rocks occur in the upper part of the Beck Spring Dolomite along the western margin of the anticline. In many places no suitable continuous carbonate horizon serves to separate Beck Spring Dolomite from the overlying, dominantly noncarbonate-bearing Kingston Peak Formation. This leads to the definition of a transitional “Limekiln Spring Member” of Kingston Peak Formation, described below.

In contrast to the gradational nature of the upper contact on the margins of the anticline, the upper contact of the Beck Spring Dolomite is sharp on top of the structural high. In Surprise Canyon, Beck Spring Dolomite is in angular discordance with the overlying Kingston Peak Formation on top of a structural high, but it interfingers with the Kingston Peak Formation on the flank of this same structure (Figure 6).

In and south of lower Happy Canyon, Beck Spring Dolomite is less than 30 m thick, laps over the Crystal Spring Formation and rests directly on rocks of the World Beater Complex. Here the Beck Spring Dolomite is dominantly breccia which pinches out just south of Happy

(a) Angular unconformity between Beck Spring Dolomite (light) and overlying Kingston Peak Formation (dark).



(b) Beck Spring Dolomite (light) interfingering with dark clastic rocks of the Kingston Peak Formation.

Figure 6. Stratigraphic relations between Beck Spring Dolomite and Kingston Peak Formation, lower Surprise Canyon.

Canyon. Breccia that occurs on top of World Beater Dome consists of angular dolomite clasts set in a dolomitic matrix and is suggestive of a shoal breccia.

Beck Spring Dolomite is also absent in the Tuber Canyon section where Crystal Spring rocks are overlain by thinly laminated, siliceous calcite marble interbedded with quartz arenite and fine-grained metagreywacke. This metalimestone and arenite sequence is continuous upward into the Kingston Peak Formation with no apparent stratigraphic break. Isolated outcrops in the floor of Tuber Canyon show Beck Spring Dolomite interbedded with quartz-rich arenite and grey limestone and suggest a facies change from dolomite to the clastic sequence.

Kingston Peak Formation

The lithology of the Kingston Peak Formation (Hewett, 1940) varies considerably within the Death Valley area although conglomerate and pebbly mudstone units are ubiquitous. Within the Telescope Peak quadrangle lateral lithologic heterogeneity occurs with respect to distribution, size and composition of clasts in conglomerates.

This lithologic heterogeneity and variations in thickness are particularly acute in the lower Kingston Peak Formation. Johnson (1957) divided the Kingston Peak Formation into the Surprise, Sourdough Limestone, and South Park members which he correlated to the Surprise Formation, Sourdough Limestone, Middle Park, Mountain Girl Conglomerate-Quartzite, and Wildrose Formations of Murphy (1932) (Figure 3). In addition, the Limekiln Spring Member is defined here as a unit which is transitional to the underlying Beck Spring Dolomite.

Limekiln Spring Member The Limekiln Spring Member encompasses the greatest variation in lithology and thickness in the Kingston Peak Formation and records a rapid change in the environment of deposition. The unit is here named for the exposures near Limekiln Spring in Surprise Canyon. The unit is extensively and almost exclusively exposed along the western margins of the anticline and World Beater Dome. However, the arenaceous rocks which interfinger with Beck Spring Dolomite on Sentinel Peak are also included in this member.

The lower contact intertongues with the Beck Spring Dolomite except in lower Surprise Canyon and south of Happy Canyon where the Limekiln Spring Member rests unconformably on Beck Spring Dolomite, Crystal Spring Formation, and lower Precambrian rocks. The upper contact is defined as the top of a calcareous quartzite that is extensively exposed in the western part of the range. This definition of the Limekiln Spring Member is largely operational because the unit is isolated from most of the rest of the Kingston Peak Formation by the anticline. Time-equivalent strata probably exist on the east side of the anticline and in Tuber Canyon, but the lateral gradation to these equivalents is unknown. Certainly, the axis of the present anticline and dome separated an eastern from a western depositional environment, and arguments based on the first appearance of overlying diamictite suggest that although there is a great accumulation of Limekiln Spring strata, equivalent rocks east of the anticline are quite thin.

The Limekiln Spring Member has been subdivided into several lithologic units which are shown in Figure 7, a larger scale detail of Figure 1. The three major units are an arkosic unit which occurs at the base of the member in the Hall Canyon area, a heterogeneous unit which consists predominantly of pelitic and amphibolitic schists and metagreywacke, and a quartzite and calcareous quartzite unit which occurs at the top of the member. The volumetrically abundant argillaceous layer contains within it conglomerate, breccia, and dolomite beds whose distribution is also indicated in Figure 7.

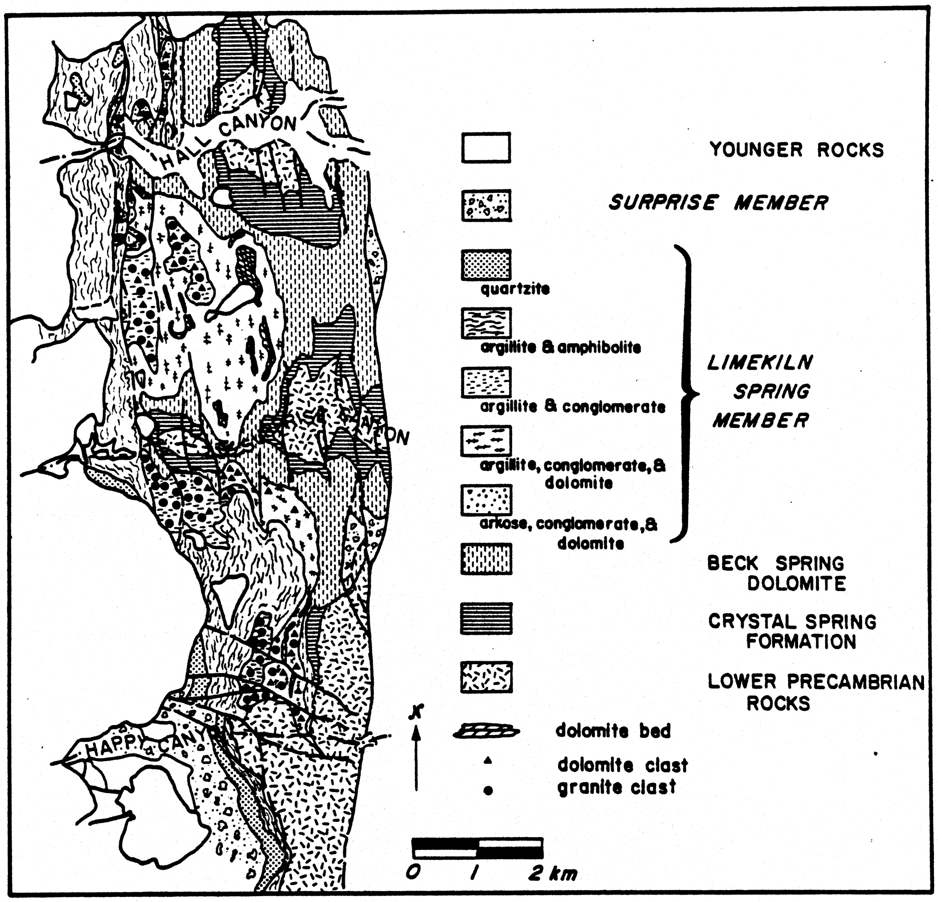
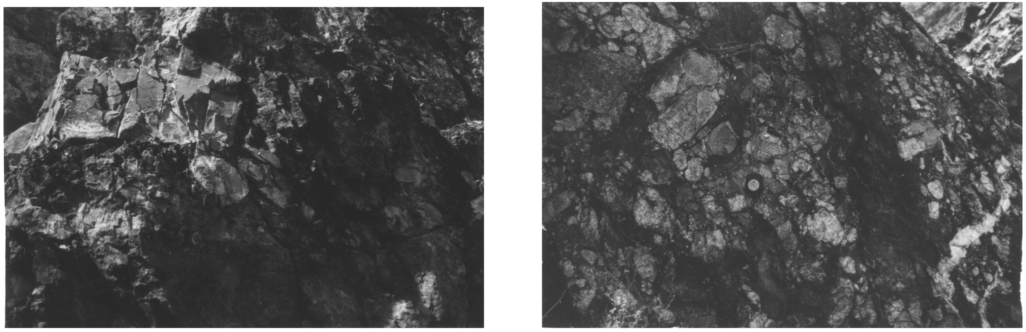


Figure 7. Distribution of the lithologies within the Limekiln Spring Member of the Kingston Peak Formation, west-central Panamint Mountains.

The arkosic unit occurs at the base of the Limekiln Spring Member in the Hall Jail Canyon areas. The unit is about 170 m thick in Jail Canyon and it pinches out just north of Surprise Canyon. The arkosic unit comprises dolomite, breccia, amphibolite, feldspathic quartzite, arkose, and arkosic conglomerate (Figure 8). The strata occur in 5 to 10 m thick layers which are intimately interbedded. The breccia consist of blocks of dolomite up to several meters across, set in a green amphibolitic matrix (presumably calcareous mud), and is interbedded with dolomite similar in appearance to the Beck Spring Dolomite. A second type of conglomerate consists of leucocratic granitic pebbles and cobbles set in a dark arenaceous matrix, interbedded with dark arenite (Figure 8). This conglomerate is considerably more abundant to the south and is described below. The third rock type is arkose or arkosic conglomerate; a component which distinguishes the arkosic unit from the rest of the Limekiln Spring Member. The arkose is coarse-grained and contains boulders of granite in an arkosic matrix. The arkose is restricted to the west side of the anticline and pinches out to the south. The north and west limits are unknown, but it does not occur in the Tuber Canyon section.

(a) Arkosic unit, Hall Canyon. Dark layer at bottom of cliff is a mafic sill; cliff consists of interlayered dolomite, dolomite-clast conglomerate, and arkose.

(b) Granitic clast conglomerate, Hall Canyon. Large boulder is about 0.5 m across.



(c) Dolomite breccia, Surprise Canyon. Large white block is about 2 m long.

(d) Granite-clast conglomerate, Surprise Canyon. Unit dips steeply to the right.

Figure 8. Lithologies within the Limekiln Spring Member.

Except for the arkose, the rock types that occur in the argillaceous unit are similar to those in the arkosic unit. The predominant rock type is dark brown-weathering, fine-grained metgreywacke, amphibolitic schist, and pelitic schist. This unit also interfingers with Beck Spring Dolomite, and dolomite layers are common in the lower part of the section. Conglomerate and breccia layers are unevenly distributed within this unit. Dolomite-clast breccia layers are unevenly distributed within this unit. Dolomie-clast breccias, similar to the ones described above, are interbedded with intertongues of Beck Spring Dolomite (Figure 8) in the trough between the two structural highs in Surprise Canyon and in the adjacent region to the south. Granite-clast conglomerate occurs in great abundance in the region between Happy and Surprise Canyons (Figure 8), and some clasts of granitic rock are several meters across. By and large, conglomerate is absent from the argillaceous unit north of Surprise Canyon except in the uppermost exposed section. Figure 7 details the distribution of these rock types and clast types in the Limekiln Spring Member.

The thickness of the argillaceous unit ranges from about 900 m between Happy and Surprise Canyon to 530 m in Hall Canyon. In most places, the total thickness is not exposed but irregularities in thickness are readily observed.

The uppermost unit in the Limekiln Spring Member is a 120 to 140 m, thin- to medium-bedded quartzite and calcareous quartzite whose upper contact appears to be conformable with the overlying Surprise Member. The quartzite is light grey but the more calcareous layers weather yellowish-brown.

Surprise Member The Surprise Member contains one of the most enigmatic rock types in the Death Valley area. Diamictite and associated rocks constitute the Surprise Member in Surprise Canyon and to the south. Approximately 400 m of this member are exposed in Surprise Canyon and near Sentinel Peak, more than 530 m occur in upper Pleasant Canyon, and Johnson (1957) reports more than 500 m in Redlands Canyon where the best is not exposed.

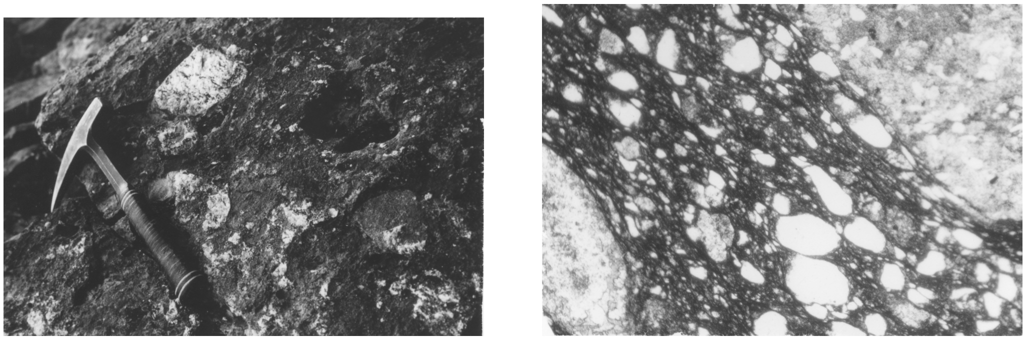
The lower part of the member south of Surprise Canyon east of World Beater Dome consists of 10 to 25 m of very fine-grained dark argillite and pelite which is probably equivalent to the Limekiln Spring Member. The argillite is overlain by diamictite which consists of massive conglomeratic greywacke and pebbly mudstone. The texture is generally trimodal and consists of angular cobbles, 5 to 10 cm in diameter, sand-sized quartz and lithic grains, and clay-sized dark matrix (Figure 9). Clasts as large as several meters in diameter have been observed and consist of dolomite, quartzite, argillite, granite and granitic gneiss, and diabase. Much of the dolomitic and gneissic clasts have local sources (see discussion).

The matrix is dense black, and the rock resembles basalt, particularly on surfaces where carbonate clasts have weathered out so that the diamictite has a vesicular appearance. Sulphides are abundant and megascopically recognizable pyrite and pyrrhotite are characteristic of the diamictite.

Interspersed within the diamictite section are fine-grained argillite beds which contain graded beds and a few exotic cobbles.

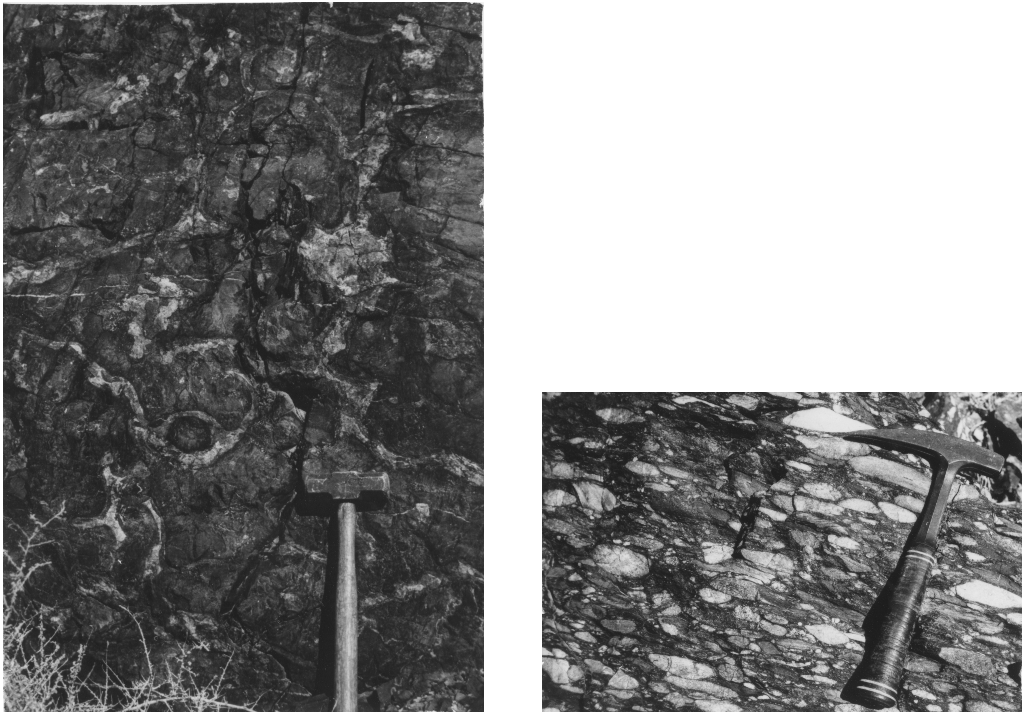
North of Surprise Canyon, the Surprise Member consists almost entirely of a monotonous sequence of thin bedded argillite, micaceous arenite, and fine-grained metagreywacke. Granitic pebble-bearing layers are rare and only three layers were encountered in the section measured in Jail Canyon. Dolomite-clast conglomerate is also uncommon and occurs principally in the Kingston Peak Formation exposed in Tuber Canyon.

Thinly laminated siliceous limestone is an important component of this Surprise Member north of Hall Canyon. In Hall Canyon a 30 m thick limestone (marble) unit that contains clasts of the underlying Beck Spring Dolomite occurs at the base of the Kingston Peak Formation. This carbonate type is very abundant in Tuber Canyon where at least three units of this thinly laminated siliceous marble 30 to 50 m thick occur in the lower part of the Surprise Member. The marble is characterized by carbonate-rich layers 5 to 10 m thick interbedded with quartz-rich layers equally as thick and is distinct from the Sourdough Limestone which does not contain abundant quartzose layers. The carbonate is moderately to strongly deformed and fold hinges and boudins are common. The limestone marble rests on the schist unit of the Crystal Spring Formation and is overlain by the dark arenite which is common in the Surprise Member. The structure of the rocks in this area is complex and the stratigraphy is consequently poorly known. As indicated above, isolated outcrops suggest that this limestone-arenite sequence in



(a) Diamictite, Sourdough Canyon.

(b) Photomicrograph of diamictite from Sentinel Peak (plane polarized light); consists of dolomitic and granitic clasts, 3 to 5 mm in size, about 0.25 mm diam quartz sand, and very fine-grained black matrix.



(c) Pillow structures in mafic lava flow in Surprise Member, lower Pleasant Canyon.

(d) Stretched pebble conglomerate, South Park Member, lower Tuber Canyon.

Figure 9. Lithologies in upper members of the Kingston Peak Formation.

the lower Kingston Peak is the stratigraphic equivalent to the Beck Spring Dolomite, but the transition from the massive dolomite to a clastic carbonate-arenite sequence is obscured as a result of younger tectonic events.

The thickness of the Surprise Member north of Surprise Canyon is difficult to determine directly because the section is faulted. In Jail Canyon 457 m have been measured from the base of the member to a fault. A calculated 427 m of section occur east of the fault to the Sourdough Limestone. The lack of suitable marker horizons in this monotonous section prevent determination of the actual thickness, but the west-side up normal faulting in this region indicates that 884 m is a minimum estimate for the thickness of the Surprise Member.

Faulting and folding is more intense in Tuber Canyon and the estimate of 1000 m shown in Figure 5 is crude and is based on an estimate of the amount of missing section and of the stratigraphy of the lower 200 m. There are at least 700 m of continuous, non-repeated section present.

In upper Pleasant Canyon and in lower Pleasant, Happy, and Tuber Canyons, mafic volcanic rock or its metamorphosed equivalent are interbedded within the diamictite and micaceous arenite of the Surprise Member 100 m below the Sourdough Member. The mafic rock contains abundant pillow-like structures (Figure 9), and in part of the mafic unit consists of a volcanic breccia with quartzfeldspathic clasts in a basaltic matrix and angular fragments of basalt in a siliceous matrix. Whatever the origin of the diamictite, the extrusion of baslatic pillow indicates that at least part of the unit was deposited in a subaqueous environment.

Sourdough Limestone Member The Sourdough Limestone is generally a thin, but persistent unit which separates the Surprise Member from the South Park Member. The unit consists of a thinly-laminated, light- and dark-grey, micaceous limestone, and varies in thickness from 50 m in the Manly Peak Quadrangle (Johnson, 1957) to less than 10 m. Much of this change in thickness may be due to later deformation; the laminae are often spectacularly folded in the thicker sections. Penecontemporaneous folds and slumps occur in places at the top, and dark clastic rocks from the overlying South Park Member are folded into the Sourdough Limestone.

South Park Member The stratigraphy of the South Park Member is considerably more uniform than any of the lower units of the Pahrump Group, although thickness varies due to the unconformity at the top. From 80 to 250 m of thin-bedded argillite and pelitic schist rest on top of the Sourdough Limestone (Middle Park Formation of Murphy, 1932). Locally, the rock has a spotted appearance due to the presence of altered cordierite prophyroblasts. Scattered pebbly layers occur near the top of the argillite.

This argillite is overlain by 30 to 100 m of what Murphy (1932) called Mountain Girl Conglomerate-Quartzite. The lower part is dominated by conglomerate that comprises quartzite clasts in a reddish to black matrix. The rock is clast-supported and clasts are generally no larger than 10 cm. Far from the anticline axis, the cobbles are well rounded and spherical, but in most places the conglomerate is deformed. The stretched, white quartzite clasts in a dark matrix give the rock a spectacular appearance (Figure 9). Granule conglomerate and lithic greywacke are interbedded within the conglomerate, and the conglomerate unit grades upward into fine- to medium-grained, white to pink micaceous, feldspathic quartzite. This conglomerate-quartzite unit is locally overlain by up to 150 m of pebbly mudstone and calcareous argillite (Wildrose Formation of Murphy, 1932). The unconformity at the base of the overlying Noonday Dolomite has cut out this upper unit in most places and the conglomerate-quartzite unit typically occurs at the top of the Pahrump Group.

Upper Precambrian rocks—Noonday Dolomite

Noonday Dolomite rests disconformably on the Kingston Peak Formation in the Telescope Peak Quadrangle. Angular discordance is slight, and is observed only by the truncation of upper units in the Kingston Peak Formation. This truncation is most marked on Sentinel Peak where Noonday Dolomite appears to rest on the Surprise Member of the Kingston Peak Formation. Elsewhere in southern Death Valley area the disconformity is marked by Noonday Dolomite resting on Beck Spring Dolomite, Crystal Spring Formation, and lower Precambrian rocks (Wright and others, 1974).

The age of the unconformity is probably late Precambrian because the lowest occurrence of lower Cambrian fossils is in the upper part of the Wood Canyon Formation, about 2000 m above the base of the Noonday Dolomite (Diehl, 1974). Noonday Dolomite, Johnnie Formation, and Stirling Quartzite are considered to be Precambrian in age because there is no convenient stratigraphic marker nor diagnostic fossils to separate probable Precambrian rocks from probable Paleozoic rocks.

The rocks here recognized as comprising the Noonday Dolomite of Hazzard (1937) were first described by Murphy (1932) as the Sentinel Dolomite, Radcliff Formation, and Redlands Dolomitic Limestone. The Noonday Dolomite is extensively and nearly continuously exposed just west of the crest of the range where the threefold subdivision is easily recognized. Outcrops also occur on Tuber Ridge, in Hanaupah Canyon, and along the western flank of the World Beater Dome.

A complete section of Noonday Dolomite was measured in Hanaupah Canyon (McDowell, 1967). The lowest member of the Noonday Dolomite, the Sentinel Peak Member (after the Sentinel Dolomite of Murphy, 1932), consists of 30 m of medium grey, very siliceous limestone which occurs in beds 5 to 15 cm thick, overlain by 30 m of massive, grey to white dolomite. Thin irregular laminae, tubes and eyes filled with sparry calcite, and small mounds of possible algal origin are common in this member.

The middle part of the Noonday Dolomite is named the Radcliff Member (after the Radcliff Formation of Murphy, 1932) and lies conformably on top of the Sentinel Peak Member. In Hanaupah Canyon the Radcliff Member is approximately 225 m thick and consists of thinly laminated, grey, pink, green, or brown crystalline limestone interlaminated with dark greenish grey or grey argillaceous limestone and argillite. The proportion of argillite is greater in the lower part of the member where lenses of conglomerate also occur. The conglomerate consists of argillite clasts in an argillaceous matrix.

The upper member of the Noonday Dolomite is called the Redlands Member (after the Redlands Dolomitic Limestone of Murphy, 1932), and in Hanaupah Canyon the Redlands Member consists of massive, light grey dolomite, about 160 m thick.

Several sections of Noonday Dolomite in the Panamint Mountains are shown in Figure 10 (from McDowell, 1967) and illustrate the lateral variations in lithologies within the formation. The Sentinel Peak Member consists of massive dolomite of probable algal origin throughout the Panamint Mountains, but the thickness ranges from about 140 m in the Pleasant Canyon area to less than 50 m in the Wildrose Canyon area. A massive dolomite unit everywhere occurs at the base of the Noonday Dolomite but in many places near Wildrose Canyon the Sentinel Peak Member is too thin to map separately.

The Radcliff Member comprises a variety of lithologies. In the southern part of the area, near Butte Valley, the member consists almost entirely of thinly laminated limestone and only a small proportion of argillite. In the exposures of the Radcliff Member north of Happy Canyon, argillite is a major lithology and in many places the interlaminated argillite and limestone are spectacularly deformed into tight, passive-flow folds. Conglomerate in which dolomite clasts and minor argillite clasts are embedded in a dark green, calcareous, argillaceous matrix occurs at the base in exposures near Wildrose Canyon. The thickness of the Radcliff Member ranges from 100 to 250 m.

The Redlands Member ranges in thickness from 130 to 260 m, and the relative proportion of clastic debris varies from south to north. North of Surprise Canyon and in the upper reaches of Hanaupah Canyon the Redlands Member is massive dolomite and contains abundant algal structures, but in Johnson and Pleasant Canyons quartz and carbonate sandstone, commonly crossbedded, is abundant, and some layers are locally conglomeratic. The size of clastic carbonate grains ranges from silt to medium sand, and quartz grains, generally well rounded, range in size from fine sand to pebble. In places the sandstones are composed of 85% quartz grains. The lateral gradation from dolomite to sandy dolomite is often observed, and in the Pleasant and Johnson Canyons region where sandy dolomite and calcareous sandstone are abundant, the distinction between the Noonday Dolomite and the overlying Johnnie Formation is nebulous. The lower part of the Johnnie Formation contains dolomite beds similar in appearance to the dolomite in the Noonday Dolomite, and in some places there is no practical mappable boundary between the two formations.

The distribution of Noonday Dolomite and equivalent strata in the southern Death Valley region is outlined by Williams and others (1974) and Wright and others (1978). There the Noonday Dolomite comprises a lower, algal dolomite member and an upper dolomite member. The lower dolomite member contains mound-like structures which had as much as 200 m of relief across them. The upper dolomite member consists of a great variety of lithologies. Thin-bedded dolomite and argillite filled the deep areas between the mounds of the lower member. The majority of the member consists of algal dolomite which contains abundant stromatolites, tubes, and eyes. Farther south, clastic debris becomes abundant, and a transition from the platform facies Noonday Dolomite to a basinal equivalent occurs. The basinal equivalent comprises breccia, arkosic sandstone, siltstone, and shale, interbedded limestone and dolomite and dolomite-quartz sandstone (Williams and others, 1974). Tentative correlation of Noonday Dolomite in the Panamint Mountains to the southern Death Valley area suggests that the

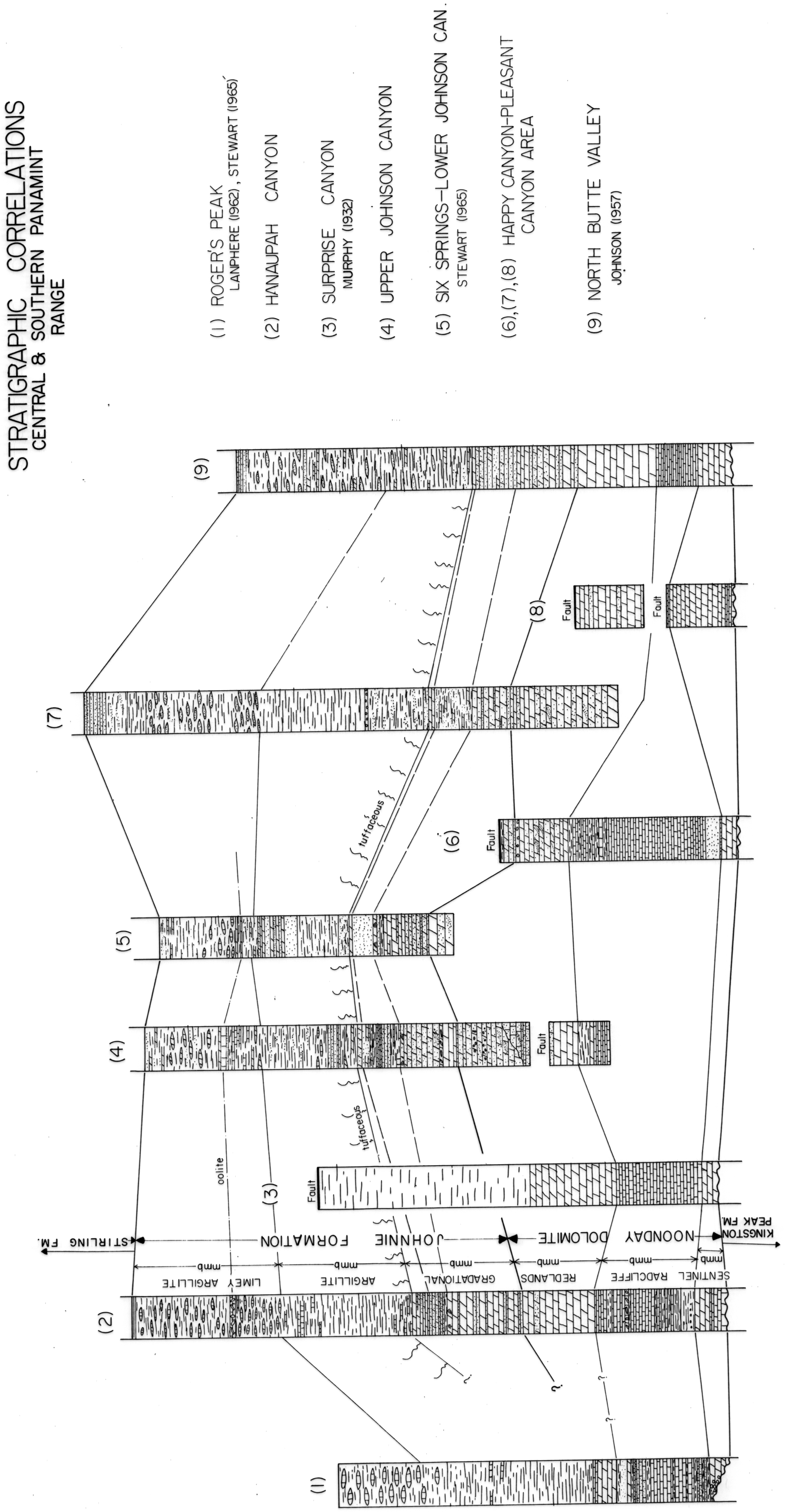


Figure 10. Stratigraphic sections of the Noonday Dolomite and Johnnie Formation, east-central Panamint Mountains.

Sentinel Peak Member corresponds to the lower dolomite member, and the Redlands Member corresponds to the upper dolomite member. It is not certain whether the Radcliff Member correlates to the thin-bedded part of the upper dolomite member which fills the intermound areas or whether it correlates to the basinal clastic wedge.

UPPER PRECAMBRIAN ROCKS—JOHNNIE FORMATION

The Johnnie Formation of Nolan (1929) is correlated by Stewart (1970) to rocks which Murphy (1932) termed Hanaupah Formation and Death Valley Formation. The Johnnie Formation has been divided into two mappable units in the Telescope Peak Quadrangle, a 150 to 330 m thick gradational member overlain by a 400 to 650 m thick argillaceous member. In addition, the argillaceous member can be divided into a lower, green argillite unit and an upper calcareous argillite unit throughout most of the quadrangle. The lower contact is gradational to the Noonday Dolomite, and the Johnnie Formation is conformably overlain by arkose and quartzite of the Stirling Quartzite. A complete section of Johnnie Formation if exposed in Hanaupah Canyon and is described in detail (McDowell, 1967) (Figure 10).

The basal part of the gradational member is 185 m thick and consists of 20 to 30 m intervals of light yellow-brown or brown weathering, massive gray dolomite with some sandy dolomite containing quartz grains of silt- or fine-sand size, and rare limestone beds, alternating with 2 to 3 m intervals of dark red-brown weathering, cross-bedded, coarse-grained gray orthoquartzite or dolomitic quartzite. Algal-like heads occur in the uppermost dolomite beds of this unit.

The middle part consists of 40 m of dark red-brown weathering, brown, gray or blue-gray, 1 to 2 m cross-bedded quartzite beds and rare medium red-brown weathering, brown sandy dolomite. The member forms a distinctive dark band in outcrop and makes an excellent mapping horizon.

The upper part of the gradational member is 45 m thick and consists of less than 3 m thick beds of light brown or yellowish-brown weathering, medium gray or blue-gray dolomite, sandy dolomite, limestone, and sandy limestone. The quartz sand beds are cross-bedded. One dark gray thinly laminated, limestone bed occurs 30 m from the top of the member.

The argillite unit of the argillaceous member is 360 m thick and is made up dominantly of gray-green weathering, gray, green or gray-green very thinly laminated micaceous argillite. In the basal 80 m, 20 to 30 percent of the rock is dark yellow-brown weathering, gray or red-gray quartz-sand, crystalline limestone and dolomite. The lower 100 m of the argillite tends to weather red-brown rather than gray-green, and has scattered rusty spots after pyrite (?); its general appearance is suggestive of a rock of tuffaceous origin. A 15 to 45 m thick lamprophyre (sodic minette) sill was emplaced just below the top of the argillite unit in the Hanaupah Canyon area. The development of breccia lenses and pipes above the sill suggests that it was emplaced into wet sediments, soon after deposition of the shale. In the upper 70 m of the gray-green argillite member, numerous dark brown or medium red-brown weathering, medium-light red-gray crystalline limestone beds and dark gray aphanitic limestone beds are interbedded with the argillite in 2.5 to 10 mm laminations.

The calcareous argillite unit of the argillaceous member is about 300 m thick and consists dominantly of a ripple marked and flute-casted unit in which medium red-gray and rare green, gray-green and purple crystalline limestone lenses less than 20 mm thick or laminations less than 7 mm thick are interbedded with micaceous purple, blue-gray, very thinly-laminated argillite beds less than 12 mm thick. The argillite beds are draped over the elongate limestone lenses, producing sections which look like typical aircraft wing cross-sections. There are also zones in which only the strongly ripple-marked micaceous blue-gray argillite occurs.

In the top 70 m red-brown weathering, gray or light brown 2 to 20 cm quartzite beds occur and increase in abundance as the Stirling contact is approached. A discontinuous yellow-brown weathering 2 to 3 m dolomite bed often occurs just below the Stirling contact. This dolomite is considerably thicker (about 10 m) north of Hanaupah Canyon. At a distance of 210 m below the Stirling contact, a 16 m conglomerate bed occurs that contains slabby pink crystalline limestone clasts up to 15 to 60 cm in dimension in a medium-dark gray siliceous limestone matrix. This is present throughout the Hanaupah Canyon area and is used locally as a marker bed as it forms a massive dark-brown weathering cliff in the otherwise slabby to platy, lighter-weathering section. The upper contact of the Johnnie Formation with the Stirling Formation is sharp and marks the abrupt break between the darker, finer-grained quartzites and argillites of the Johnnie and the very light-colored, coarses-grained quartzites of the Stirling Formation.

Stewart (1970) divided the Johnnie Formation which occurs in the Nopah Range into several members. The “transitional member” encompasses the lower 162 m of Johnnie Formation and consists of dolomites and sandy dolomites interbedded with quartzite; the “transitional member” corresponds to the lower part of the gradational member in the Panamint Mountains. In the Nopah Range a quartzite member 160 m thick overlies the transitional member and this quartzite appears to correspond to the middle part of the gradational member.

The dolomite in the upper part of the gradational member corresponds to the “lower carbonate-bearing member” in the Nopah Range where the member consists of 5 m of argillite and micaceous sandstone overlain by a 3 m dolomite bed. The “siltstone member” is 230 m thick, of micaceous sandstone, shale, and minor quartzite, and appears to be equivalent to the lower part of the argillite unit of the argillaceous member in the Panamint Range. The upper part of the argillite unit corresponds to the “upper carbonate-bearing member” which consists of 160 m of interbedded quartzite, sandy dolomite, and argillaceous sandstone. In the Nopah Range the uppermost 120 m of the Johnnie Formation is called the “Rainstorm Member” and consists of grey-green to maroon, cross-bedded, ripple-marked, micaceous argillaceous sandstone and minor sandy dolomite. The “Rainstorm Member” corresponds to the calcareous argillite unit in the Panamint Mountains.

A distinctive and persistent oolite bed occurs in the lower part of the “Rainstorm Member” and this oolite occurs in the same relative stratigraphic position in all described sections east of the Panamint Mountains (Wright and Troxel, 1966; Stewart, 1970). In the Panamint Mountains the oolite bed that occurs near the base of the calcareous argillite unit as a very erratic distribution. A 1 m bed of thinly laminated dolomite with 0.5 to 2 mm oolites occurs in lower Johnson Canyon. In middle Johnson Canyon the ooilte bed is represented by clasts of oolitic dolomite in a conglomerate. Elsewhere the same stratigraphic horizon is represented by conglomerate with non-oolitic clasts.

The basal 200–300 feet of the argillite member of the Johnnie Formation in the mapped area is characterized by rusty red-brown or yellow-brown weathering, cliff-forming beds which contain minute cubic cavities in the more argillitic portions which appear to be hematite after pyrite. Within this section, several distinctive light gray or blue-gray, massive, dense "argillite" beds occur which often have irregular close-spaced fractures filled with a dark brown material to produce a rock with a mosaic texture. These break with an almost concoidal fracture, and produce fracture surfaces which in detail are quite hackly and irregular. Their general appearance is that of fine-grained tuffaceous sediments.

Lateral variations in thickness and lithology of the Johnnie Formation are illustrated in Figure 10. The threefold subdivision can be recognized throughout most of the Telescope Peak Quadrangle, but the two units within the argillaceous member are not distinguished in the Butte Valley area.

Variations within the calcareous argillite unit of the argillaceous are slight. On the east slope of the range, the small red-gray lenses which give the member its distinctive ripple-marked appearance are almost wholly of crystalline limestone, while on the west side of the range these same lenses are wholly quartzose and consist of fine to medium-grained quartz grains in a siliceous matrix. Carbonates are very rare to the west of the range divide. The thickness ranges from 265 to 400 m.

The argillite unit of the argillaceous member ranges from 230 to 400 m thick. The unit thickens southward and the grain size increases from silt to medium sand. Pebble conglomerate occurs locally. Where the unit is more highly metamorphosed a weak slaty cleavage is developed and 1 mm spherical chlorite segregations and cordierite porphyroblasts occur. The tuffaceous portion of the member appears the same throughout the range.

The gradational member ranges from 125 to 250 m in thickness. Dolomite layers contain greater proportions of quartz-rich clastic debris to the south and this increase in debris parallels the change from massive dolomite to quartzose dolomitic sandstone in the underlying Redlands Member of the Noonday Dolomite. In regions west of the range crest where metamorphic grade is greater, the sandy dolomitic layers contain tremolite and the pelitic layers contain andalusite and biotite.

Upper Precambrian rocks— Stirling Quartzite

The Stirling Quartzite (Nolan, 1929) conformably overlies the Johnnie Formation and the contact between them is sharp. The lower 100 to 150 m of Stirling Quartzite consists of medium- to coarse-grained feldspathic quartzite and conglomerate. The quartzite is massive and white at the base but reddish brown-weathering in the upper part of the section. The remainder of the Stirling Quartzite consists almost entirely of crossbedded quartzite which contains minor siltstone and thin bedded dolomite near the top. About 130 m to 200 m above the base are two 25 m thick argillite units separated by 15 m of quartzite. The argillite is purple in color and it stands out against the reddish brown quartzite. In the northeast corner of the quadrangle the unit contains 5 to 10 mm andalusite porphyroblasts and the unit is cut by veins of andalusite and pyrophyllite.

The top of the Stirling Quartzite is exposed only in the northeast corner of the quadrangle where the thickness of the Stirling Quartzite is approximately 500 m. Stewart (1970) measured 850 m of Stirling Quartzite in the Emigrant Canyon Quadrangle and Johnson (1957) reports at least 300 m of quartzite in the Manly Peak Quadrangle.

UPPER PRECAMBRIAN TO CAMBRIAN ROCKS—WOOD CANYON FORMATION

In the northeast corner of the quadrangle an incomplete section of Wood Canyon Formation (Nolan, 1929) overlies the Stirling Quartzite. The lower part of the formation consists of greenish brown and yellowish brown, thin bedded shale and sandstone which are interbedded with 0.5 to 1 m thick dolomite beds. The lower contact is gradational with the top of the Stirling Quartzite in which thin shale and dolomite beds occur. Most of the Wood Canyon Formation consists of thin- to medium-bedded quartzite which is interbedded with minor, thin shale and dolomite beds. The Wood Canyon Formation in the Telescope Peak Quadrangle is incomplete and faulted, but Hunt and Mabey (1966) estimate a thickness of 860 m in Blackwater Wash, approximately 17 km to the north.

TERTIARY ROCKS

Monolithologic Breccia

The west face of the Panamint Range from Wildrose Canyon to Happy Canyon is composed of great masses of breccia. Smaller masses to breccia also occur on the crests of west trending ridges south of Surprise Canyon and south of Pleasant Canyon. These deposits consist of material derived primarily from the Kingston Peak Formation, although Beck Spring Dolomite, Noonday Dolomite, and Cretaceous granitic rock are also represented. The deposits which form the gateway to Surprise Canyon consist of finely crushed and pulverized Kingston Peak Formation and support a badlands-type topography that consists of knife-sharp ridges and steep-walled gullies. Although the rocks are extremely crushed, there is no great mixing of different rock types, and in places ghost bedding occurs. The source location of the breccia landslides (see section on structure). The larger masses rest on a surface that dips from about 40° west to horizontal, and this surface is believed to be a slide surface upon which the breccia developed.

The monolithologic breccia is believed to be Pliocene in age. Between Jail and Hall Canyons a desert pavement surface of low relief has been developed on the breccia, and the breccia must have formed prior to the more recent uplift indicated by the deep incision of west-draining canyons. Additionally, near Wildrose Canyon the breccia is unconformably overlain by the Pliocene Nova Formation (see below) and an upper age limit for the breccia of Pliocene is indicated. The lower age limit for breccia is not well constrained, the youngest rocks which occur as clasts within the breccia are Cretaceous. The breccia is believed to be younger than Miocene because there is no evidence that the breccia was ever mantled by volcanic rocks that would have been derived from the Little Chief stock. A small patch of breccia north of Hall

Canyon rests on top of a dacite sill which if the sill is related to the Little Chief stock also suggests that the breccia formed later than 12 m.y. ago (see section on Little Chief stock).

Monolithologic breccia that is composed of Noonday Dolomite clasts occurs in isolated remnants on top of west-trending ridges south of Pleasant Canyon and in the Manly Peak quadrangle (Johnson, 1957). The breccia nearly everywhere rests on Sourdough Limestone, and the breccia is locally overlain by old alluvial deposits. This breccia may be correlated to the larger, range front breccia masses, particularly if the overlying alluvium was deposited during the formation of the uplifted erosion surface. The Noonday Dolomite breccia must have been much more extensive because no immediate source for the breccia now exists.

Nova Formation

The monolithologic breccia in the Wildrose Canyon area is overlain disconformably by alluvial fan deposits which Hopper (1947) called the Nova Formation. A 1 to 2 m thick dark grey limestone occurs at the base, and the limestone is overlain by an undetermined small thickness of alluvial silt, sand, and gravel. The unit is much more extensively exposed north of the Telescope Peak quadrangle where the fanglomerates are titled as much as 30° to the east. Hall (1971) divided the Nova Formation into three units and called the lower part Fanglomerate #3. Hall (1971) noted that the fanglomerate is intercalated with monolithologic breccia which is similar to, but not as volumetrically abundant as the breccia in Telescope Peak Quadrangle. He also recognized fresh-water limestone beds which appear to have filled depressions in the fan. Hall (1971) describes basalt flows which are interbedded near the top of Fanglomerate #3 and which have an age of 5 million years. An early Pliocene age for the fanglomerate is indicated.

QUATERNARY ROCKS—LANDSLIDE DEPOSITS, ALLUVIUM, AND PLAYA LAKE DEPOSITS

Young landslide breccia masses are abundant in the Telescope Peak quadrangle and are commonly superimposed on the older breccia masses. The distinction between Pliocene breccia and younger landslide breccia is based on the nature of the lower contact and the “texture” of the brecciated material. The older breccia masses have planar, west-dipping contacts and are comprised of finely crushed but unmixed rock. Younger landslide deposits have irregular lower contacts which dip down the present slope, the parent rocks are broken into angular fragments, and diverse lithologies are commonly mixed.

Unconsolidated alluvial deposits of interbedded silt, sand, and gravel are divided into older and younger deposits. The older alluvium is distinguished from presently accumulating alluvium by the degree of dissection of the older deposits. The older alluvium occurs along the easter side of Panamint Valley where it was uplifted by Quaternary faulting the Panamint Valley fault zone. Older dissected alluvium also occurs in the canyons as elevated terrace remnants. Alluvium and playa-lake silt and clay are accumulating in Panamint Valley and in the broad upper reaches of most of the west-draining canyons.

INTRUSIVE ROCKS

METADIABASE DIKES AND SILLS

Mafic dikes and sills intrude the older Precambrian rocks and the Pahrump Group in the Telescope Peak quadrangle where they are metamorphosed to greenstone and amphibolite. Most of the sills intruded along sedimentary contacts and the sills are generally less than 50 m thick. A sill of diabase approximately 200 m thick was intruded into the Crystal Spring Formation on the east flank of World Beater Dome, and metamorphosed basaltic pillow lava occurs within the Surprise Member of the Kingston Peak Formation. Although no crosscutting relations which might indicate more than one age of intrusion were observed, the presence of diabase clasts in the Kingston Peak Formation below the pillow lava indicates at least two periods of igneous activity during Precambrian time in the Death Valley region.

Throughout the Death Valley region, diabase sills and dikes intruded the carbonate rocks of the Crystal Spring Formation. The contact metamorphic aureoles contain talc-bearing assemblages, and the Death Valley area is a leading talc-producing region (Wright, 1968). The age of diabase emplacement is believed to be pre-Kingston Peak Formation and possibly pre-Beck Spring Dolomite (Wright, 1968), but radiometric age determinations have been unsuccessful because the diabase is considerably altered. A sample of diabase from a dike in the World Beater area gave a K–Ar date of 377 m.y. (Lanphere and others, 1964) which reflects alteration during the Mesozoic metamorphism. Wrucke and Shride (1972) suggested a correlation of the Pahrump diabase sills were emplaced at the same time over this large region, the diabase may be 1100 m.y. old (Silver, 1960).

HALL CANYON PLUTON

The prominent cliff-forming unit exposed on the west slope of the Panamint Mountains at the mouth of Hall Canyon is a leucocratic, muscovite-bearing granitic rock and is informally named Hall Canyon pluton (Figure 11). This particular granitic rock is most extensively exposed at the mouths of Hall Canyon and Jail Canyon, but small, isolated masses crop out in Wildrose Canyon, Tuber Canyon, and Surprise Canyon as well. The contacts with the country rocks, invariably the Kingston Peak Formation, are nearly everywhere concordant and dip slightly west in Hall Canyon and steeply west in Jail Canyon. The western contact of the pluton is obscured by monolithologic breccia, and so the form of the pluton is not well known. The smaller exposures in Surprise, Tuber, and Wildrose Canyons generally have discordant, crosscutting contacts with apophyses of granitic rock injected into the host rock.

Plagioclase, quartz, and microcline-microperthite comprise 90 percent of the rock. Plagioclase is typically the most abundant phase and occurs both as phenocrysts and as matrix grains. Phenocrysts reach 1 cm in size and locally exhibit oscillatory zoning. Plagioclase composition ranges from An_0 Ab_{99} Or_{01} to An_{18} Ab_{81} Or_{01}. Microcline also occurs as a phenocryst phase but the proportions of microcline and plagioclase are variable. Microcline generally constitutes less than 20 percent of the rock, but microcline phenocrysts are much more

(a) Hall Canyon pluton (light), near mouth of Hall Canyon.

(b) Little Chief stock at the head of Surprise Canyon.

Figure 11. Granitic rocks in the Telescope Peak quadrangle.

abundant in the smaller bodies in Wildrose Canyon. The composition of microcline is An_0 Ab_{05} Or_{95}. Approximately 7 percent of the granitic rock is composed of muscovite with the composition $K_{0.95}Na_{0.05}Fe_{0.25}Mg_{0.11}Al_{1.83}$ $(Al_{0.81}Si_{3.19})O_{10}(OH)_2$. Muscovite occurs as subhedral to euhedral books ranging from 1 mm to 10 mm in diameter and appears to be a primary magmatic phase. Secondary white mica also occurs in altered rocks and appears to be replacing plagioclase. Mafic phases generally constitute less than 3 percent of the rock. Brown biotite (Table 2) occurs in most localities but small rounded garnet grains are also present in some of the smaller, isolated exposures. The biotite is commonly altered to chlorite and trace amounts of epidote are also observed. Modes, phase compositions, and normative mineral compositions of several samples of the Hall Canyon pluton are listed in Table 2.

Near the margins of the large plutonic exposure, the granitic rock is strongly foliated parallel to the contact. The foliation is defined by the parallel alignment of muscovite plates and planar orientation of long axes of feldspar phenocrysts set in a fine-grained quartz-rich matrix. Phenocrysts are somewhat rounded, some show possible rotation, and the matrix is a granular mosaic of equant grains which have some interlocking boundaries as well as straight, polygonal boundaries. Coarser-grained quartz is invariably flattened parallel to the foliation, and edges appear to be recrystallizing to the fine-grained matrix. The well developed foliation indicates that deformation accompanied or followed intrusion, but the small, isolated body of granitic rock in Surprise Canyon is unfoliated and preserves a fine-grained, primary igneous texture. Thus, a complex sequence of intrusion, deformation, and continued intrusion may have occurred.

Gravity data of Hunt and Mabey (1966) indicate a positive gravity anomaly centered over the Wildrose–Nemo Canyons area, that is lower than topographically comparable areas in which Precambrian rocks are exposed. They suggested the presence of granitic rock underlying this portion of the Panamint Mountains. A cursory examination of the granitic pluton exposed in the Skidoo region in the Emigrant Canyon quadrangle showed that this pluton is also composed of a leucocratic, muscovite-bearing granite which has concordant intrusive contacts. It is possible that the Skidoo pluton and the Hall Canyon pluton are related, and that much of the Harrisburg Flat area may be underlain by this granitic rock.

Muscovite separated from an exposure of this granite in Wildrose Canyon is used as an internal standard for potassium-argon analysis (P-207) and has yielded ages of 81 to 83 m.y. derived by K–Ar and Rb–Sr techniques (Lanphere and Dalrymple, 1967; Dalrymple and Lanphere, 1971).

LITTLE CHIEF STOCK AND RELATED DIKES

The Little Chief stock (Murphy, 1932) is exposed near the crest of the range between Hanaupah and Johnson Canyons. The structure, mode of emplacement, and crystallization history of the stock are described by McDowell (1967, 1974, 1978).

The Little Chief stock is composite and consists of south and north intrusive phases. The north phase has a chilled margin at the border of the south phase, and both phases contain inclusions of an older intrusive phase near their mutual contact. Stock-country rock contacts are almost everywhere steep, and vary from vertical to steeply outward or inward dipping. The country

Table 2. Mode, phase compositions, and calculated bulk compositions of PML 179 and P 101, Hall Canyon pluton

PML 179, Lower Surprise Canyon

	Quartz	Plag	Micr	Musc	Gar	Ap	Other	Bulk Composition
(2178 pts)								
Vol %	27.5	45.8	18.7	7.5	tr	0.3	0.2	100
ρ	2.65	2.63	2.56	2.77				
Wt %	28.1	46.2	18.4	7.4				100.1
SiO_2	100.0	70.18	64.80	48.15	38.07			76.1
TiO_2				0.0	0.07			0.0
Al_2O_3		19.78	17.92	29.15	21.35			14.25
FeO		0.11	0.19	5.42	23.61			0.4
MnO				1.42	19.52			0.1
MgO				0.0	0.0			0.0
CaO		0.21	0.0	0.0	0.58			0.1
Na_2O		11.49	0.62	0.60				5.2
K_2O		0.05	16.07	10.81				3.8
H_2O				4.43				0.3
Total		101.83	99.60	100.0	103.20			100.25
	q	28.3		cor	1.5			
	or	22.3		hy	0.8			
	ab	46.6						
	an	0.5						

P 101, Lower Tuber Canyon

	Quartz	Plag	Micr	Musc	Gar	Ap	Other	Bulk Composition
(1455 pts)								
Vol %	35.9	46.9	10.2	6.7	0.2	0.1	100.0	
ρ	2.65	2.63	2.56	2.77	4.30	3.20		
Wt %	36.0	46.7	9.8	7.1	0.3	0.1	100.0	
SiO_2	100.0	68.57	65.11	46.76	37.49		77.8	
TiO_2				0.22	0.05		0.0	
Al_2O_3		22.02	18.33	34.34	21.18		14.6	
FeO		0.0	0.16	3.04	22.25		0.3	
MnO				0.0	18.08		0.1	
MgO				0.17	0.35		0.0	
CaO		2.24	0.0	0.0	1.39	54.19	1.1	
Na_2O		10.72	0.06	0.83			5.1	
K_2O		0.08	16.12	10.60			2.4	
H_2O				4.04			0.3	
Total		103.63	99.78	100.0	100.79		101.7	
	q	33.4		cor	1.9			
	or	13.9		hy	0.6			
	ab	45.0						
	an	5.1						

rock is deformed by the intrusion of the stock, and in many places, the stock is sheathed by carbonate rocks of the Noonday Dolomite.

The stock is composed of hornblende-biotite granite porphyry which contains phenocrysts of plagioclase and sanidine up to 10 mm in diameter set in a fine-grained groundmass of quartz, alkali feldspar, and plagioclase. Sanidine phenocrysts are coated with a rim of plagioclase which gives the rock a Rapikivi texture. Table 3 lists representative modes of the Little Chief stock. McDowell (1978) describes the complex rimming relations observed in feldspar phenocrysts, and he interpreted the complex zoning in terms of the history of crystallization. At an early stage of crystallization the magma assimilated dolomitic wall rocks and the liberated CO_2 elevated the fluid pressure and caused fracturing of the roof rocks and formation of a set of shallowly west-dipping normal faults now preserved northeast of the stock. After emplacement of a swarm of rhyolite-porphyry dikes along these faults, the magma ascended into its present position which was approximately one kilometer below the surface and crosscut the faults and dike swarm. At this time the magma probably vented to the surface. High angle "trap door" faults which formed during the intrusion of the stock also offset the low angle faults. Stern and others (1966) report a 12 m.y. age obtained from a granite porphyry boulder collected from the mouth of Hanaupah Canyon and believed to have been derived from the north phase of the Little Chief stock. The cluster of late Tertiary ages reported by Stern and others (1966) obtained from dike and volcanic rocks near the mouth of Hanaupah Canyon is consistent with a Tertiary age for the stock.

Table 3. Typical modes of the major phases of the little chief stock

	North phase interior	North phase exterior	South phase
PHENOCRYSTS			
Sanidine	10	15	12
Sodic oligoclase replacing sanidine	0	10	6
Oligoclase rims on sanidine	11	0	0
Plagioclase	21	6	7
Hornblende	3	1	4
Biotite	2	3	1
Other minerals	2	1	1
Total phenocrysts	49	36	31
GROUNDMASS			
Alkali feldspar	28	29	37
Quartz	19	32	24
Plagioclase	3	2	7
Other minerals	1	1	1
Total groundmass	51	64	69

Note: Values in volume percent. Data from McDowell (1978).

STRUCTURE

The structure of the central Panamint Mountains is dominated by a north-northwest-trending fold system which includes World Beater Dome and an asymmetric anticline north of the dome. Rocks on the west flank of the anticline dip steeply west whereas on the east flank rocks dip gently east, and the east slope of the Panamint Mountains is a dip slope, interrupted by the Little Chief stock. The anticline is cut by numerous faults of several ages. The oldest are a series of north-trending, high angle faults which in part probably predate the development of the anticline. Younger faults include shallow-dipping normal faults, faults associated with the intrusion of the Little Chief Stock, and faults which form the Panamint Valley fault zone.

PRE-LATE TERTIARY STRUCTURES

North-Trending Faults

The dominant fault system in the quadrangle is that of a series of steeply dipping, north-trending faults. Deviations in trend occur in some faults in the southern and southeastern part of the quadrangle where faults strike north-northeast and north-northwest. In addition, a set of faults which strike west-northwest occurs in lower Happy Canyon.

This network of north-trending faults extends the length of the quadrangle and continues south in the Manly Peak quadrangle (Johnson, 1957). One fault which runs through the middle of World Beater Dome has been mapped for approximately 25 km along strike.

Offsets across these faults are primarily dip-slip although the absolute displacement is complex. Many faults have a reversal in the sense of displacement along strike. The north-trending faults cut across the north-northwest-trending anticline, and a south-to-north change in offset from east-side-up to west-side-up occurs along many faults. The maximum stratigraphic separation observed is about 800 m.

The north-trending fault that separates lower Precambrian rocks along the west face of the range near the mouths of Pleasant and Happy Canyons from upper Precambrian rocks has a much shallower west-dip than the other north-trending faults. Johnson (1957) called this fault the South Peak Canyon fault, and the shallow west-dip with lower Precambrian rocks on the hanging wall gives a reverse fault geometry. It is suggested below the the present geometry may be due to folding after faulting.

Because the north-trending faults have reversal in the sense of offset, these faults are believed to predate the development of the north-northwest-trending anticline. Some direct evidence supports this contention. On top of trending anticline. Some direct evidence supports this contention. On top of the western structural high in Surprise Canyon a north-trending fault displaces Beck Spring Dolomite and older rocks, but the displacement is truncated at the Kingston Peak contact, and the Kingston Peak Formation buries the faulted rocks. Thus, at least one north-trending fault is Precambrian in age. These high-angle faults are presumed to be inherited from an old fracture pattern in the basement which were activated during late Precambrian time, reactivated during the formation of the north-northwest-trending anticline, and even during the intrusion of the Little Chief stock (McDowell, 1974).

North-Northwest-Trending Anticlines, Domes, and Associated Faults

The structural culmination of the Panamint Mountains trends approximately 20 west of north and consists of a series of anticlines and domes. The core of the structural high is occupied by lower Precambrian rocks, except in Tuber Canyon where Crystal Spring Formation occupies the core. The anticline is cut by the north-trending faults, and canyons that cut across the anticline give the outcrop pattern the appearance of being en echelon domes.

The domes and anticlines are asymmetric; east flanks dip gently east, but west flanks dip steeply west and are locally overturned (Figure 12). This asymmetry is repeated on a smaller scale south off lower Hall Canyon where Beck Spring Dolomite occupies the cores of smaller domes. On the west flank of World Beater Dome the steeply dipping sedimentary mantle is thrown into a complementary open syncline. In the Manly Peak quadrangle, this broad anticline-syncline couple dominates the structure (Johnson, 1957). The west flank of the broad syncline is truncated by the west-dipping South Park Canyon fault. The moderate dip of this fault sets it apart from the other north-striking faults, and the timing of its displacement relative to the formation of the folds is not clear (see below).

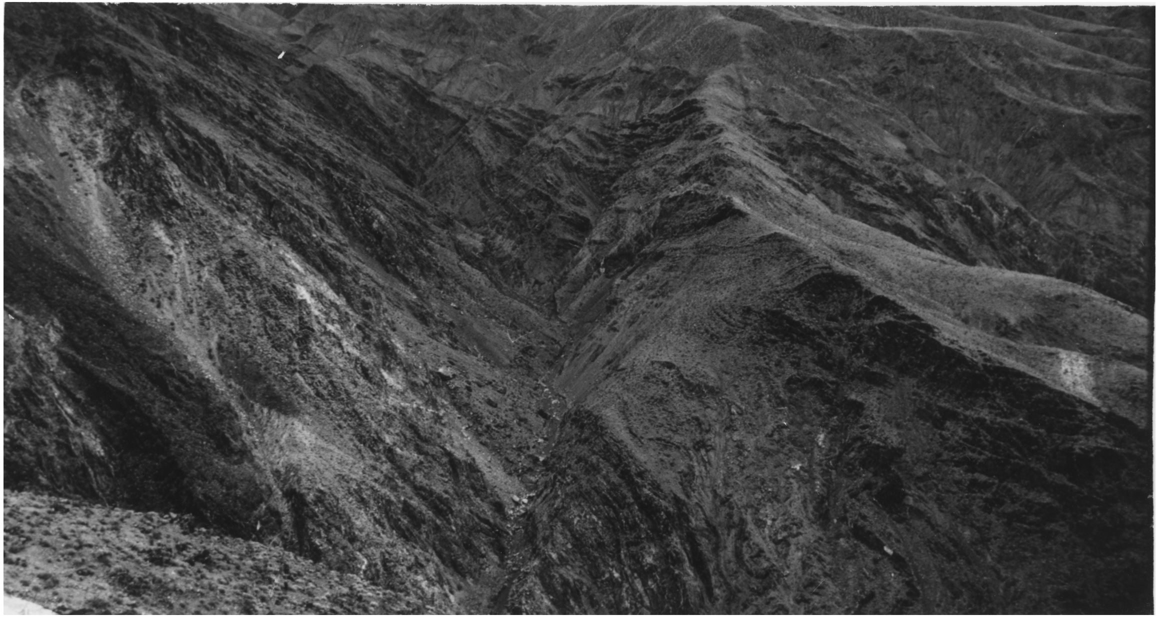
Numerous minor folds are associated with the north-northwest anticline, particularly on the west flank of the structure. A zone of disharmonic folding is developed along a north trend, between the structural high and the Cretaceous Hall Canyon pluton (Figure 13). Within this zone which is up to 100 m wide amphibolitic layers in the lower Kingston Peak Formation are disharmonically folded along north-northwest axes and roughly horizontal axial planes. This zone separates steeply west-dipping strata on the east from more gently west-dipping strata on the west, but the stratigraphic separation is confined within the Limekiln Spring Member of the Kingston Peak Formation.

Lineation is also well developed along the west flank of the anticline. Cobbles within the lower Kingston Peak Formation are stretched and have lengths up to about 10 times the diameter. The long axes of cobbles plunge in the range 20°/N10W to 40°S. Mineral lineation is also well developed and is defined by the parallel alignment of hornblende and white mica pods. The plunge of the lineation ranges from 15°/N20W to 15°/S20E.

The lower limit of the time of folding is the 80 m.y. age of the Hall Canyon pluton. Tangible evidence for this lower limit is minimal; the granite is deformed along its margin and it is displaced in a few places by faults associated with folding which suggest that intrusion predated deformation. The principal argument stems from the recognition of two periods of metamorphism. The older is related to the intrusion of the granite, and the second is a retrograde event during which rocks in the cores of the folds show the greatest degree of recrystallization. Hence, folding occurred after intrusion of the granite and regional metamorphism of the country rock.

It is possible that folding occurred soon after the primary metamorphic event because the small

(a) Gently dipping east flank of the anticline, Hall Canyon. From lower right to upper left: Beck Spring Dolomite, Kingston PEak Formation, Noonday Dolomite, Johnnie Formation.



(b) Steeply dipping west flank of the anticline, Surprise Canyon. Steeply dipping Limekiln Spring strata separated from less steeply dipping strata by a zone of disharmonic folding. Tertiary slide mass in background.

Figure 12. Geometry of the north-northwest-trending anticline.

(a) Zone of disharmonic folding, Surprise Canyon.

(b) Fold in Crystal Spring Formation, Tuber Canyon.

Figure 13. Smaller scale structures on the west flank of the anticline.

unfoliated bodies of granite cross-cut strata deformed during the folding event. Such an effect could arise by deformation prior to the complete consolidation of the Hall Canyon pluton during which the folding reactivated intrusion of late stage liquids. No crosscutting relations within the granitic pluton were observed and such a mechanism and timing sequence can only be postulated.

The upper limit for the time of folding is the age of low-angle faulting. Low-angle normal faults cut the folds, and the development of these faults is related to the intrusion of the Little Chief stock.

Reactivation of old, north-trending faults during the folding event is suggested, but the reverse fault (South Park Canyon fault) exposed along the west front of the range south of Happy Canyon complicates this simple structural history. In the Manly Peak quadrangle this fault is intruded by granodiorite that has been thoroughly metamorphosed (Johnson, 1957). Johnson suggested a Triassic age for the granodiorite and indicated that all contacts are intrusive; this fault was not reactivated during post-metamorphic folding. The fault dips 30 west where it cuts Noonday Dolomite (south of Pleasant Canyon), but steepens down dip to 40 west in and north of Pleasant Canyon where the fault cuts the Surprise Member of the Kingston Peak Formation. This down dip steepening is consistent with the folding of an originally steeply dipping fault on the limb of a syncline. These relations imply that there was a post Noonday Dolomite (youngest rock cut by the fault), pre-Triassic (?) granodiorite faulting episode, and that the present reverse fault geometry may be the result of post-Cretaceous folding.

Late Tertiary structures

Low-Angle Normal Faults

Low-angle normal faults crop out extensively along the east slope of the Panamint Mountains in the northeast corner of the quadrangle. In addition several isolated fault blocks occur on the ridges on the west slope of the range.

The low-angle faults on the east slope have dips which range from 45° west to nearly horizontal. One individual fault even changes dip along strike from moderate to low. Displacement across these faults is nearly everywhere normal; even where the faults are nearly flat, younger rocks are placed over older. Offsets across the faults are generally less than 200 m. These low angle faults have no apparent stratigraphic control; the faults dip west, but the rocks dip east. The flat faults are not confined to bedding planes.

Low-angle faults crop out extensively along the east foot of the Panamint Range, to the east and northeast of Telescope Peak Quadrangle, and Hunt and Mabey (1966) called this extensive fault network the Amargosa Thrust Compex. Hunt and Mabey (1966) believed that these faults had a complex history which started with Cretaceous or Jurassic thrusting, early Tertiary intrusion, and Late Tertiary folding and gravity sliding. The Mesozoic thrusting was believed to be large scale, east to west, gravity sliding of rock off of a high eastern plateau. In the Telescope Peak quadrangle these low angle faults are invaded by rhyolite dikes and are cut by structures related to the intrusion of the 12 m.y. Little Chief stock at its present level of emplacement. The low-angle faults are reinterpreted to be Tertiary structures which were active after the Late Cretaceous folding episode and are related to regional extension and the intrusion of the Little Chief stock.

Several relatively small, isolated fault blocks occur on the ridges on the west slope of the range. These "klippen" occur on each major ridge north of Hall Canyon, and south of Memo Canyon in Emigrant Canyon quadrangle (Lanphere, 1962). The faults which bound the blocks are generally gently west-dipping, but in places (particularly on Tuber Ridge- the faults appear to have a spoon shape in which fault planes are curved and dip east at the western edge of the fault block. The individual blocks may have once been part of one large fault block, but the elevations of the flat faults are not the same and the rocks on the hanging walls are of different ages (middle Kingston Peak Formation near Hall Canyon, Crystal Spring, Beck Spring, and lower Kingston Peak in Jail-Tuber Canyon area, and Noonday Dolomite and Johnnie Formation on Tuber Ridge). These blocks are probably the remnants of several, once-large fault blocks. The sense of displacement across the faults is hanging wall down to the west (Figure 14), and the locations of source regions for the blocks suggest displacements of approximately 1500 m. The isolated fault blocks cut the structures formed during the Late Cretaceous folding event, and if they are of the same generation as the low angle faults to the east, they are older than the Little Chief stock at its present level of emplacement.

Little Chief Stock

Structures related to the intrusion of the Little Chief stock are described in detail by McDowell (1974). The most conspicuous effect of the intrusion on the country rocks is the development of a trapdoor bordered by vertical faults which ring the stock. The rocks within the bounding faults are uplifted relative to the rocks outside. The greatest displacement is on the west side of the trapdoor, and a hinge line of zero displacement is located near the east edge. The trapdoor opens to the west where most of the country rock above the stock has been removed. The stock and the trapdoor faults either crosscut or displace the earlier north-trending vertical faults. Dike swarms and low-angle faults related to an earlier phase of intrusion are also offset by the trapdoor fault which indicates that the trapdoor formed during the last stages of intrusion.

The east side of the trapdoor is offset by an east-trending tear fault which extends from an inclusion-rich zone in the stock. The displacement across this fault is scissors-like; north side is up near the stock, and a pivot occurs about 3 km east of the stock, east of which the south side is up. This tear fault and some of the trapdoor faults were probably preexisting faults along which the stock was intruded.

Nearly everywhere carbonate rocks sheathe the stock. In many places, particularly on the southeast side of the stock, the rocks are folded sympathetically and greatly thinned with upward emplacement of the stock.

(a) Tuber Ridge (north of Tuber Canyon). Fault places Noonday Dolomite and Johnnie Formation on top of Kingston Peak Formation. Sourdough Limestone is cut by the fault.

(b) Jail Canyon. Fault places Kingston Peak Formation on top of Beck Spring Dolomite and Crustal Spring Formation. Note drag fold in Beck Spring–Crystal Spring contact.

Figure 14. Tertiary low-angle, normal faults.

Slide Masses

Great masses of monolithologic breccia form the western foot of the Panamint Mountains from Wildrose Canyon to south of Happy Canyon. The breccia is composed predominantly of material derived from the Kingston Peak Formation, and the Kingston Peak Formation forms the footwall of the surface that bounds the breccia throughout much of its length. Where exposed, the slide surface is well defined.

The structural setting of the monolithologic breccia shows characteristics similar to those of the low-angle normal faults. In general, the breccia was developed on a surface which dips approximately 45° west at the head of the slide and flattens westward to about 5° west. The surface on which the breccia developed has some irregularities. The slide surface dips 45° to 50° where the breccia rests on granite, but the surface dips less than 30° elsewhere. Between Tuber and Jail Canyons a west-trending bedrock ridge appears to perturb the west-dipping surface. A confused mass of younger landslide material obscures the relations between bedrock, an older fault block ("klippe"), and the monolithologic breccia, but there appears to be a window into bedrock on this ridge. It is probable that the geologic relations on this bedrock ridge are more complex than depicted, and in particular the ridge may divide the breccia into two separate masses.

The slide surface along most of its extent does not appear to have utilized any one particular bedding plane or other anisotropy during its development. The underlying strata generally dip west and consist of thin-bedded argillite and metagreywacke (Limekiln Spring Member of Kingston Peak Formation). The granitic rock of the Hall Canyon pluton has steeply west-dipping foliation planes, particularly near Jail Canyon, and the slide apparently took advantage of these various planes of weakness to develop. Farther to the south, particularly in the Manly Peak quadrangle, monolithologic breccia masses (generally of Noonday Dolomite) rest on Sourdough Limestone, and here the top of the limestone may have acted as the weak "break-away" surface along which the breccia developed.

The source and approximate amount of displacement is readily identified in these breccia masses. Between Happy and Surprise Canyons, brecciated Noonday Dolomite is embedded in crushed Kingston Peak Formation. These rocks are the counterpart to the syncline south of Happy Canyon in which Noonday Dolomite occupies the core. Between Surprise and Hall Canyons the breccia contains crushed granitic rock which is overlain with an approximately horizontal contact by Kingston Peak breccia. This relation corresponds to the contact about 2500 m to the east between the Hall Canyon pluton and Kingston Peak Formation. In Jail Canyon the breccia contains a steeply dipping contact between Kingston Peak debris and Beck Spring debris, analogous to a similar contact exposed in bedrock about 2000 m up the canyon. The identified source regions for the breccia indicate that the horizontal displacement of the breccia is approximately 2000 m, down to the west (absolute displacement is approximately 2800 m down the dip of the slide surface).

The shattered and brecciated nature of the material on the hanging wall of the slide surface indicates that although the geometry and sense of displacement is similar to that of the low-angle normal fault blocks, formation of the slide mass probably occurred under a shallow cover. The breccia is younger than the displacement on the low angle normal faults, and probably younger than the emplacment of the Little Chief stock. The breccia is at least in part older than the Pliocene Nova Formation.

Quaternary Structures

Young faults are well developed along the east side of Panamint Valley at the margin of the mountain front. This fault network is part of the marginal Panamint Valley fault zone. North and south of the Telescope Peak quadrangle the Panamint Valley fault zone is a comparatively well defined linear array of north-northwest-trending high angle faults (G. I. Smith and others, 1968; R. Smith, 1976) across which vertical warping occurred during Quaternary time (R. Smith, 1976). Evidence for right lateral slip is abundant in northern Panamint Valley and in southern Saline Valley further northwest (R. Smith, 1976).

The Panamint Valley fault zone is poorly defined in the Telescope Peak Quadrangle where discontinuous, en echelon, and often antithetic faults are common. The most impressive feature related to the fault zone is Wildrose Graben where older Quaternary gravels are vertically offset about 100 m (Figure 15). An impressive north-facing scarp is exposed at the mouth of Pleasant Canyon and just south of Ballarat where older gravels are uplifted about 120 m.

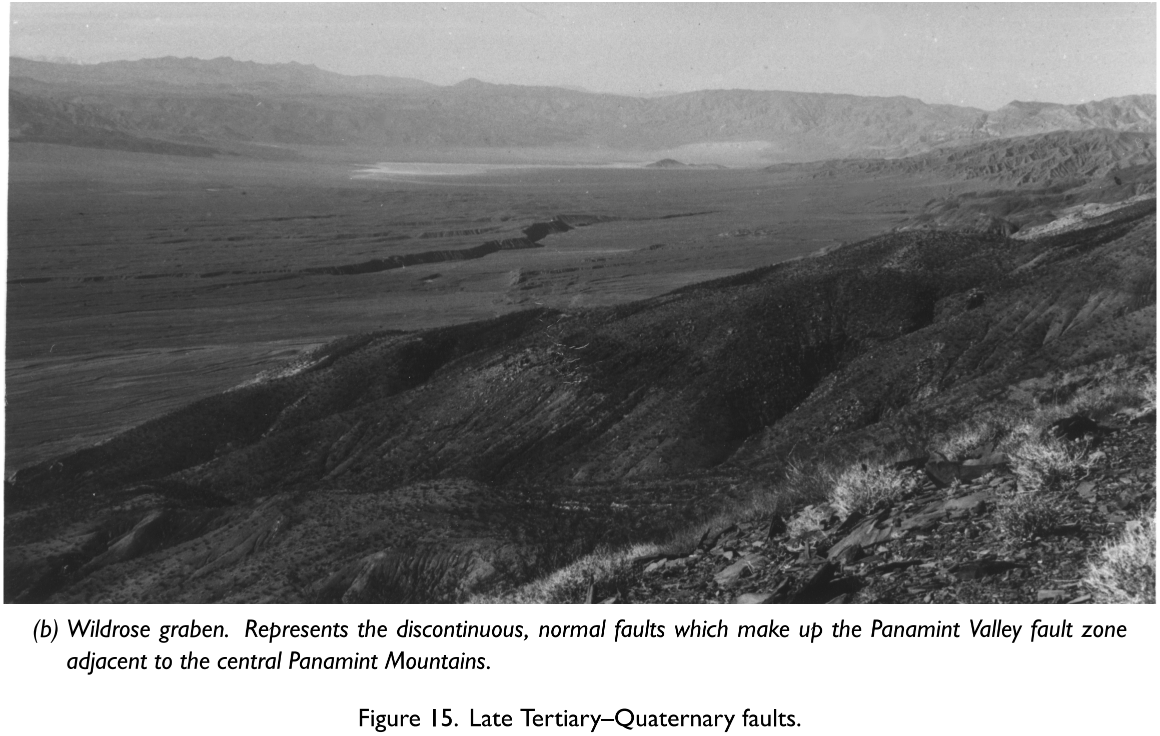
The prominant reentrant in the mountain front between Pleasant and Wildrose Canyons (Ballarat embayment), the en echelon and often northwest-dipping fault scarps, and common antithetic faults and grabens are attributed by R. Smith (1976) to recent right-lateral shear along the Panamint Valley fault zone. A “pull apart” origin for the central portion of Panamint Valley is suggested (Burchfiel and Stewart, 1966; Smith, 1976).

The dominant, overall vertical component of offset across the Panamint Valley fault zone is east side up. The Fanglomerate #3 of Hall (1971) (equivalent to the lower part of the Nova Formation) in the Panamint Butte Quadrangle is tilted 20° to 40° east, Hooke (1965) estimated an eastward tilting rate of approximately 0.018/1000 y on the Panamint block based on alluvial fan morphology.

METAMORPHISM

The rocks that crop out in the central Panamint Mountains have undergone multiple periods of metamorphism. The lower Precambrian gneiss complex was formed about 1700 to 1800 m.y. ago. Late Precambrian sedimentary rocks were regionally metamorphosed at least twice, and a narrow contact metamorphic aureole was developed at the margins of the Little Chief stock. The detailed petrology of the regionally metamorphosed terrain is described by Labotka (1978, 1979), and the overall characteristics of the metamorphism are only summarized here.

(a) Late Tertiary slide mass near the mouth of Surprise Canyon. Contact between Kingston Peak Formation (dark) and Hall Canyon pluton (light) is displaced from upper left to lower right.



(b) Wildrose graben. Represents the discontinuous, normal faults which make up the Panamint Valley fault zone adjacent to the central Panamint Mountains.

Figure 15. Late Tertiary–Quaternary faults.

POST-PRECAMBRIAN REGIONAL METAMORPHISM

Effects of regional metamorphism in the Panamint Mountains are recognized over a wide area, from Tucki Mountain in the north to Coyote Canyon in the south (Johnson, 1957). Within the Telescope Peak area argillaceous rocks in the Stirling Quartzite at the northeast edge of the quardangle show the effects of incipient metamorphism, and the degree of recrystallization increases to the west. The metamorphic grade reaches sillimanite grade, but despite the high grade of metamorphism gross recrystallization did not occur. The grain size of most of the rocks, particularly metagreywacke, is small. Small-scale sedimentary structures, especially centimeter-scale bedding, graded bedding, slump folds, and locally ripples, crossbedding, raindrop impressions are well preserved. Evidence for metamorphic differentiation and metamorphic veins is rare.

The characteristic assemblages developed in pelitic rocks are andalusite + biotite + staurolite and andalusite + biotite + cordierite. However, pelitic rocks are relatively rare, and the most common assemblage developed in the abundant metagreywackes is quartz + biotite + epidote + plagioclase. Amphibole is an additional constituent in many mafic assemblages. Carbonate rocks contain tremolite- and diopside-bearing assemblages.

The intensity of metamorphism is delineated by isograds based on the stable association of tremolite + calcite at the expense of quartz + dolomite and on the occurrence of diopside relative to quartz + calcite + tremolite. In addition, the transition from andalusite to sillimanite is also observed. These isograds depicted on Figure 1 indicate a westward increase in metamorphic grade toward the vicinity of the Hall Canyon pluton. The coincidence of the highest grade of metamorphism and the position of the Hall Canyon pluton suggest that metamorphism and intrusion occurred simultaneously.

The occurrence of andalusite- and cordierite-bearing assemblages are indicative of low pressure-intermediate metamorphism (Miyashiro, 1961). An estimate of the stratigraphic cover at the time of metamorphism was derived from Hall (1971) and Johnson (1957), and the prevailing lithostatic pressure was about 2.5 to 3.0 kb. Temperature estimates range from about 400 °C near the tremolite isograd to about 675 °C adjacent to the Hall Canyon pluton (Labotka, 1978).

A younger regional metamorphic event has affected most of the Telescope Peak area. This second metamorphic event is manifested primarily by chloritization of mafic minerals and sericitization of aluminous minerals. Recrystallization during the second metamorphism was most complete in the core of the anticline. Here, a garnet + chlorite assemblage was superimposed on an earlier sillimanite-bearing assemblage, and amphiboles have well-developed secondary rims. A b-axis lineation was developed by the growth of elongate pods of secondary muscovite which formed at the expense of andalusite and sillimanite. This secondary metamorphic event appears to have occurred during the post-intrusive folding episode.

Direct field evidence for the age of metamorphism is lacking; the intensity of metamorphism decreases so that Lower Cambrian Wood Canyon formation is essentially unmetamorphosed. In the Wildrose Canyon area Lanphere (1962) made age determinations on muscovite, biotite, and hornblende separated from the Pahrump Group and Noonday Dolomite by the K-Ar method and reported ages in the range 79 to 115 m.y. for the metamorphic rocks. Lanphere and others (1964) investigated the strontium isotopic characteristics of the lower Precambrian World Beater Complex. Despite the Precambrian geologic age of the gneiss, Rb-Sr biotite-total rock isochrons indicated ages ranging from 64 to 156 m.y. The high ^{87}Sr/^{86}Sr in apatite from these gneisses indicated nearly complete isotopic homogenization during metamorphism, and the range in ^{87}Sr/^{86}Sr and ^{87}Rb/^{86}Sr for total rock samples indicated that this homogenization had occurred over a large volume of rock. The range in age values for the metamorphic rocks may be due to the superposition of two relatively young metamorphic events. The earlier metamorphism is believed to have occurred about 80 million years ago during the intrusion of the granite, and the second metamorphism occurred during the slightly later folding episode.

Tertiary contact metamorphism

Intrusion of the Little Chief stock was accompanied by contact metamorphism of the country rock. The contact metamorphism aureole is extremely narrow around most of the stock, and contact metamorphism generally affected less than a few centimeters of rock. In the region of the dike swarm, northeast of the stock, the contact metamorphic effects extend about 0.5 km from the stock. Country rocks are predominantly carbonate rocks and diopside- and wollastonite-bearing assemblages occur. Locally, amphibole-bearing assemblages are observed in Kingston Peak Formation.

Mineralization

The Panamint Mountains were a major silver mining district in the 1870's and Murphy (1930) estimated that approximately $2 million in silver was produced in Panamint City from 1875 to 1877. Most of the commercially successful mining operations were located in upper Surprise Canyon (Hemlock, Wyoming, and Stewarts Wonder mines), but the Radcliff mine in lower Pleasant Canyon was a major producer around 1900. Today intermittent mining ventures occur in Happy, Surprise, and Pleasant and Jail Canyons.

Murphy (1930) described the principal ore-producing veins in the Panamint Silver District and he divided them into three types. Two occur principally in the Kingston Peak Formation and consist of quartz-pyrite-galena veins and quartz-pyrite-pyrrhotite veins. The major silver-producing veins consist of quartz, tetrahedrite, galena, sphalerite, pyrite, and chalcopyrite. These veins are vest developed in Beck Spring Dolomite, but they also occur in the Kingston Peak Formation. The major producing veins occur in Beck Spring Dolomite and appear to fill fractures which are oriented either approximately east and steeply dipping or parallel to the regional north-trending fault pattern.

The diamictite in the Surprise Member of the Kingston Peak Formation is very dense, black, and contains abundant pyrite, pyrrhotite and chalcopyrite. Although Murphy (1930) believed that the ore deposits are genetically related to the intrusion of the Little Chief Stock, the spatial relation between major ore-producing veins and sulphide-rich Kingston Peak diamictite suggests that the ore may have been derived from the Kingston Peak Formation. Murphy (1930) suggested that ore deposition occurred during the emplacement of the Little Chief Stock (determined to be Miocene), but no conclusive arguments are made which indicate whether mineralization occurred during emplacement of the granite, or during perhaps one of the earlier metamorphic events.

Minor deposits of antimony occur in the Wildrose Canyon area (White, 1940) and exploration for possibly economic deposits of uranium is presently underway.

Geologic history and regional setting of the Telescope Peak Quadrangle

The rocks in the Telescope Peak Quadrangle record a complex geologic history which involves the deposition of the late Precambrian Pahrump Group in a tectonically active environment, regional metamorphism and folding of these rocks during the late Mesozoic, and large-scale gravity sliding during the Tertiary. However, much of the geologic history of the western Great Basin, particularly the early and middle Mesozoic, is recorded only in the surrounding mountain ranges. Here, the geology of the Telescope Peak area is summarized and integrated with the geology of surrounding regions to provide a coherent picture of what is known and what is unknown about the tectonic evolution of the western Great Basin.

Precambrian History

The outcrop area of lower Precambrian rocks is too limited to provide a clear picture of geologic history prior to the deposition of the Pahrump Group. The pre-Pahrump history involves deposition of sedimentary and possibly volcanic rocks on an unknown basement and intrusion of the proto-augen gneiss. Grey quartz monzonite was intruded in the World Beater area approximately 1400 m.y. ago, but only after the development of the texture in the augen gneiss.

Depositional Environment of the Pahrump Group

The most striking features of the Pahrump Group in the central Panamint Mountains are the stratigraphic changes from east to west across the axis of the anticline and from north to south in the Jail–Tuber Canyon areas. The variation in thickness and lithology over short distances and the presence of locally derived clasts argue for the antiquity of the structural high now represented by domes and for tectonic activity during the deposition of the Pahrump Group.

Both the Crystal Spring Formation and Beck Spring Dolomite thin toward World Beater Dome and dolomite shoal breccia occurs on top of the dome. Despite the erosion that occurred during the initial Kingston Peak deposition, the World Beater area must have stood above sea level during early Pahrump time (World Beater Island). However, in Tuber Canyon, the great increase in thickness of the Crystal Spring Formation and the apparent facies change from Beck Spring Dolomite to a clastic carbonate–arenite sequence suggest a deeper water environment and a large amount of relief on the lower Precambrian basement.

The pre-Kingston Peak geography envisaged in the Telescope Peak area consists of a relatively stable platform underlain by lower Precambrian basement. The platform stood above sea level at World Beater Island; supported a carbonate shelf during Beck Spring Dolomite time; and had a northern margin in the vicinity of Tuber Canyon. The northern margin may have been a scarp in the basement, but the lack of coarse detritus in the Crystal Spring Formation suggests that the increase in the sedimentary thickness may be due to a differential rate of subsidence.

Near the end of Beck Spring time, the platform was rejuvenated. World Beater Island and much of the carbonate shelf to the north were uplifted while the region to the west sank. This geography provided a complex depositional environment for the Limekiln Spring Member. Figure 16 illustrates the geometry of the lower Kingston Peak depositional basin. The datum for Figure 16 is intended to be the base of the diamictite, but the facies change from diamictite to argillite north of Surprise Canyon and the absence of the Surprise Member on top of and west of the anticline necessarily renders Figure 16 a cartoon. The uplift of the platform provided a local source for dolomite and granitic clasts to the adjacent down-dropped areas. These depressions are largely filled with argillaceous material, although local stabilization must have occurred to allow the development of the dolomite interbeds. Argillite lapped over the conglomerate and eventually the positive areas, and the deposition of the quartzite appears to have eliminated the topographic irregularities on the west side of the high.

The first appearance of the unusual diamictite and associated rocks may represent a time line, and thus, rocks east of the anticline which are equivalent to the Limekiln Spring Member are thin.

The depositional environment of the upper units in the Kingston Peak Formation is not adequately assessed. In particular, the origin and environment of the Surprise Member are unknown, but the peculiar texture and bedding characteristics of the diamictite are suggestive of glacial till (Johnson, 1957). A few thin, graded beds of argillite (commonly containing exotic "lonestones") do occur, and the presence of pillow structures in basaltic lava indicate that the Surprise Member is at least in part subaqueous and probably marine. The south to north change from diamictite to argillite and greywacke shows that a complex depositional environment must have existed.

The map view of the geography and geology at the end of Beck Spring Dolomite time is shown in Figure 17. Attempts to present quantitative structure contours were fruitless because of the lack of complete sections and the later deformation of the Pahrump Group. The contours shown in Figure 17 are arbitrary, although zero is intended to represent sea level, and are used to show only the interpretation of the topography. Source areas and drainage divided are inferred from the distribution of clasts (Figure 7). Sources for the dolomite clasts are particularly obvious in the recognition of the angular unconformity on top of the western high in Surprise Canyon (Figures 7, 15). The granitic clasts are identical to the quartzofeldspathic gneiss which crops out extensively in the basement terrain, but no clasts of the distinctive World

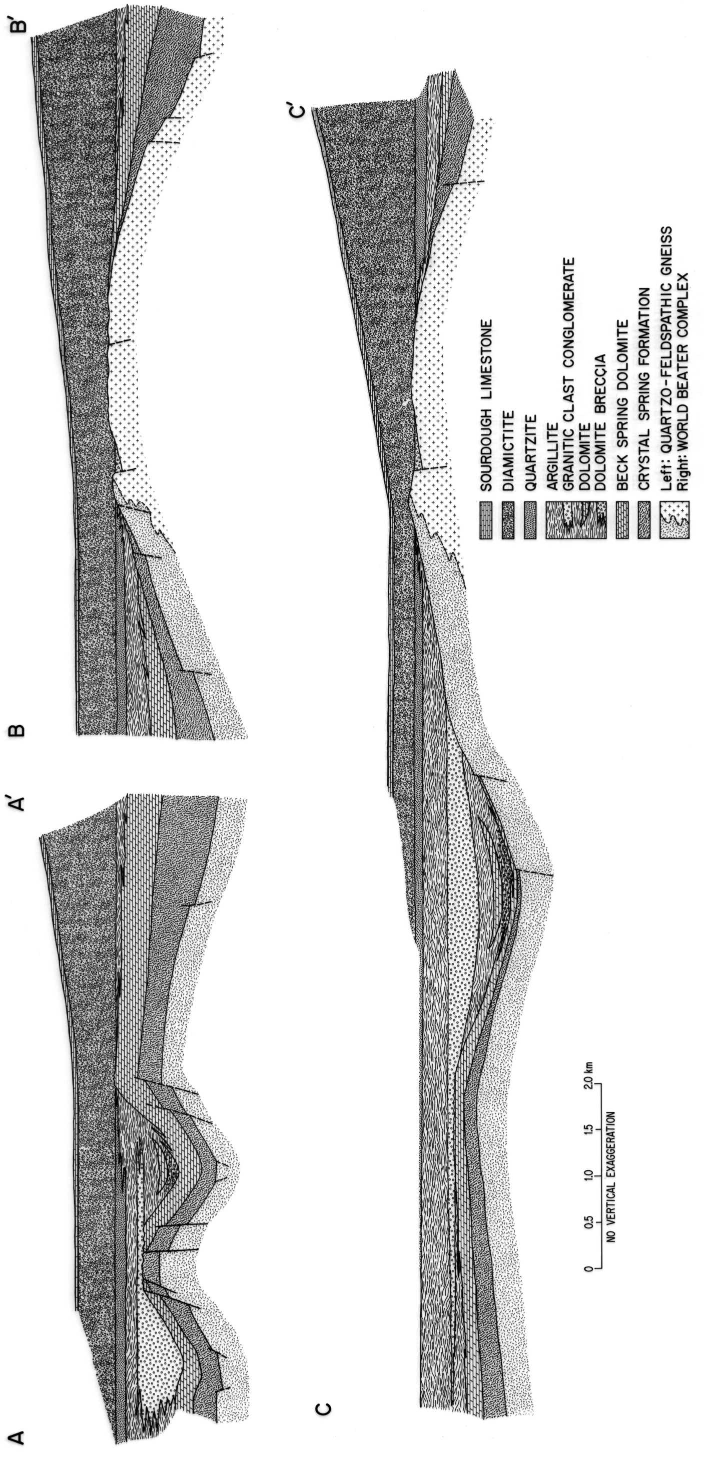


Figure 16. Stratigraphic cross sections of the Pahrump Group. Section locations are shown in Figure 4.

Beater Complex were observed. Either the terrain underlain by the World Beater Complex remained covered, or more likely, a drainage divide separated the World Beater Complex from the quartzofeldspatic gneiss complex.

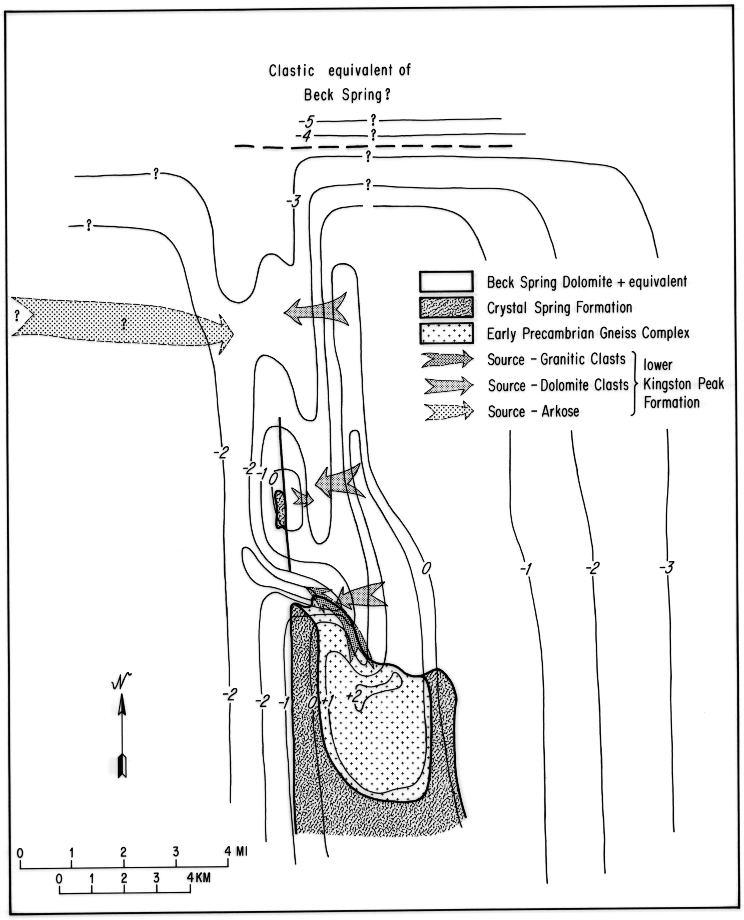


Figure 17. Paleogeography and paleogeology in the Telescope Peak area at the end of Beck Spring deposition. Contours are arbitrary and show only the interpretation of topography; 0 represents sea level.

A similar divide is postulated which prevented the delivery of granitic clasts to the trough between the two highs in Surprise Canyon.

Deformation of the basement occurred along the north- and northwest-trending faults which are prominent in the geology. At least one north-trending fault was buried by lower Kingston Peak rocks. All other faults were reactivated during younger folding.

A source terrain external to the Telescope Peak Quadrangle is indicated for the arkose component in the lower Kingston Peak Formation. The arkose occurs only west of the anticline and it pinches out to the south. A west or northwest source is proposed. The presence of Beck Spring Dolomite clasts up to 3 m in diameter and of clasts of the distinctive World Beater gneiss in the diamictite indicate that World Beater Island continued to be a source after the deposition of the quartzite, but most of the upper Kingston Peak clastic units must have had sources external to the Telescope Peak Quadrangle.

Intrusion of mafic sills occurred at least as late as earlier Kingston Peak time, and extrusive pillow lava flows occur in the lower Kingston Peak Formation. The presence of diabase clasts in the Kingston Peak below the lava flows indicates that igneous activity must have occurred over a significant period of time.

Regional Significance of the Pahrump Group

The gross stratigraphy exposed in the Telescope Peak Quadrangle records a history of deposition in a Precambrian basin which contained a substantial amount of relief and which was tectonically active during middle Pahrump time. The paleogeography consisted of a deep water basin in the north, a shallow water platform–carbonate shelf, and an island, or the northern part of a peninsula in the south.

The regional extent of the "Panamint platform" is imprecisely known. Johnson (1957) reported that a relatively thin Kingston Peak section rests on lower Precambrian basement in Goler Wash in the southern Panamint Mountains, and thus, the platform-with-islands probably extended throughout the southern Panamint Mountains.

East and west positive areas are also indicated. An eastern positive area, called the Nopah Upland by Wright and others (1974) occurs in the present site of the Black Mountains. A western positive area is postulated as the source of the arkose in the lower Kingston Peak and was also suggested by L. A. Wright (personal communication) as a source for conglomerates in the Crystal Spring Formation south of Golar Wash.

The regional, pre-Kingston Peak paleogeography in the Death Valley area is illustrated in Figure 18. There is still much uncertainty regarding the paleotectonic elements in this region. Wright and others (1974) outlined evidence for a west-trending trough in the southern Death Valley region which they call the Amargosa Aulacogen. The northern margin of this trough (equivalent to southern edge of Nopah Upland) is well documented, but the southern "Mojave" upland is postulated on the basis of isopachous maps of Crystal Spring Formation (Roberts, 1974) and transport directions for detritus in Crystal Spring Formation (Roberts, 1974) and Noonday Dolomite (Williams and others, 1974). Isopachous maps presented for the Kingston Peak Formation (Wright and others, 1974) and Crystal Spring Formation (Roberts, 1974) suggest that the Amargosa trough shallows to the east and to the west. It is possible that the Panamint Platform extended even farther south than Golar Wash.

Pahrump Group and possibly equivalent rocks also occur in the Tucki Mountain area (Hunt and Mabey, 1966) and in the northern Funeral Mountains (Troxel and Wright, 1968), but the stratigraphy of these rocks is largely unknown.

Figure 18 shows the uplands, shallow water platform areas and deeper water basins suggested by this and other studies.

It is quite apparent that the late Precambrian paleogeography is very irregular and that the relatively simple aulacogen-geosyncline relation originally proposed by Wright and others (1974)

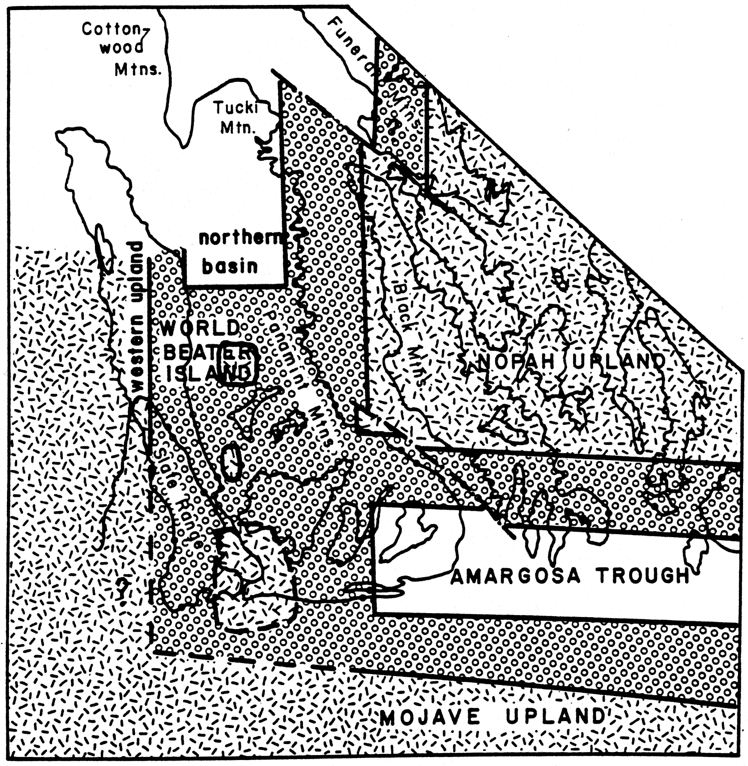


Figure 18. Regional paleogeography during late Precambrian time in Death Valley, California. Represents a synthesis of the present work with the work of Williams, Wright, and Troxel (see text).

is not viable.

Stewart (1972) argued that the initiation of the Cordilleran Geosyncline occurred after the deposition of Belt Supergroup and equivalent strata, and with the deposition of Windermere and equivalent rocks. Lithologic similarities of the Pahrump Group and overlying strata to Belt Supergroup and Windermere group and equivalents have often been noted (e.g. Stewart, 1972; Crittenden and others, 1971), and in particular the presence of diamictite within these sections is often cited. Diamictite in the Windermere Group and equivalents occurs above an unconformity over the underlying Belt equivalent rocks. Argument by analogy places a major stratigraphic break between Kingston Peak and Beck Spring Dolomite. Rocks equivalent to the Belt Supergroup would be Crystal Spring Formation and Beck Spring Dolomite; Windermere equivalents would be Kingston Peak Formation, Noonday Dolomite, Johnnie Formation, and Stirling Quartzite. Such a correlation does not seem justified for four reasons.

The local unconformity observed between Kingston Peak and Beck Spring rocks occurs well below diamictite-bearing strata, and the intertonguing Beck Spring Dolomite and Kingston Peak strata indicate the local nature of the unconformity and no real absence of time-rock record.

Diamictite first appears above the quartzite unit in the Limekiln Spring Member. Although the diamictite and quartzite appear conformable, the contact may represent a hiatus. However, the distribution of diamictite is capricious, and north of Surprise Canyon the entire lower Kingston Peak consists of monotonous, thin-bedded argillite and fine-grained greywacke. The Pahrump exposed in Tuber Canyon also suggests continuous sedimentation from the top of the Crystal Spring to the Noonday Dolomite.

Diamictite is unevenly distributed within the Kingston Peak Formation throughout Death Valley. True, massive diamictite and possible tillite occurs in the Panamint Mountains. Elsewhere the conglomerates are fan deposits (Kingston Range, Hewett, 1956) or turbidites with occasional exotic clasts (Sperry Wash, personal observation). Hence, the first appearance of diamictite is difficult to assess.

The major, regional unconformity which is observed in the Death Valley area occurs between the Kingston Peak Formation and Noonday Dolomite, and not below the Kingston Peak.

The stratigraphic relations within the Pahrump Group indicated by this study are shown in Figure 19a. If the correlation of the Tuber Canyon section to the Pahrump Group is in error, a diastemic relation between Beck Spring and Kingston Peak may exist as shown in Figure 19b. However, the lack of a recognized regional unconformity beneath the Kingston Peak Formation casts doubt on such an interpretation, and a more or less continuous history of sedimentation punctuated with local tectonic uplift is a more accurate description of the Pahrump Group.

The age of the Pahrump Group is not well constrained. The top of the group lies about 2000 m below the lowest occurrence of lower Cambrian fossils in the upper Wood Canyon Formation (Diehl, 1974). The Crystal Spring Formation rests depositionally on the World Beater Complex which is about 1400 m.y. old (Lanphere and others, 1964). Wrucke and Shride (1972) have correlated the diabase sills which occur in the Crystal Spring Formation to those in the Apache

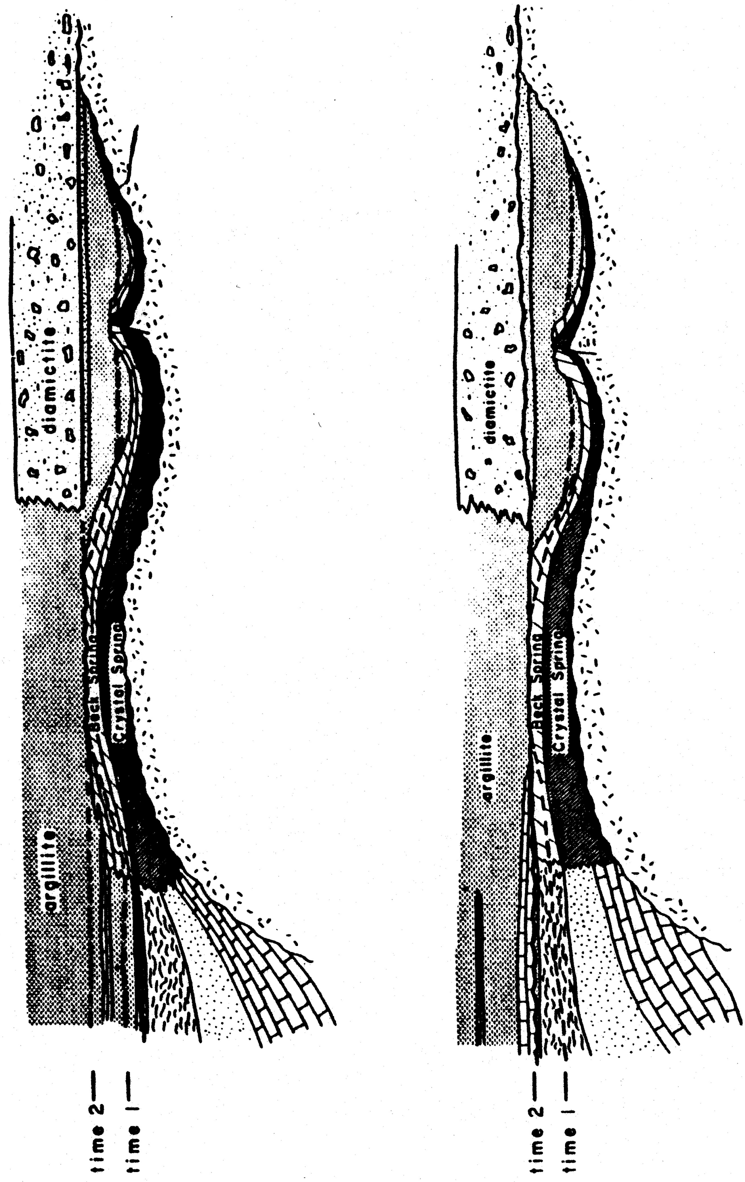


Figure 19. Time–stratigraphic relations between the Kingston Peak Formation and lower formations in the Pahrump Group. (A) Local unconformity, but no marked hiatus between the Kingston Peak Formation and the lower part of the Pahrump Group. (B) Possible, but unsubstantiated alternative if the correlation of the section in Tuber Canyon is in error.

and Unkar Groups of Arizona, and they suggested regional diabase sill emplacement at about 1200 m.y. Such a correlation indicates that the Crystal Spring Formation is greater than 1200 m.y. old (Silver, 1960).

In the Telescope Peak area, mafic sills and dikes occur as high as the Beck Spring-Kingston Peak contact and basalt flows are interbedded within the Surprise Member of the Kingston Peak Formation. The occurrence of basalt flows in diamictite sections is summarized by Stewart (1972) and this association may represent a single time (850 m.y.–Ryan and Belkinsop, 1971).

Such correlations imply that the grossly continuous sedimentation in the Pahrump encompasses a time from greater than 1200 m.y. to less than 850 m.y. old, but these more than 350 m.y. are represented by only 3000 m of rock, at most. Alternatively, one or both of the age correlations may be in error, or a significant, but unrecognized hiatus may be present in the section.

Stewart (1972) contends that the initiation of the Cordilleran Geosyncline is marked by the deposition of diamictite, extrusion of basaltic lava, and the formation of the northwest paleoslope characteristics of Paleozoic sedimentary trends. If the opening of the Cordilleran ocean was accomplished by continental rifting, as proposed by many people (e.g. Stewart, 1972; Burchfiel and Davis, 1975; Gabrielse, 1972), the initial deposits are most likely to record a microenvironment dominated by local provenance and irregular basins of deposition. Only when the local environments are integrated can the overall northwest paleoslope be established. It is believed that the initiation of the Cordilleran geosyncline occurred after the intrusion of the 1400 m.y. granitic rocks (Silver and other, 1977) when ensialic basins were developed in which Crystal Spring, Belt, Apache, Big Cottonwood rocks were deposited (Silver and others, 1977; Stewart, 1972; Harrison and others, 1974). Harrison and Reynolds (1976) believed that the Belt Supergroup was deposited at the edge of an ancient continental margin. Episodic, vertical deformation, compatible with rifting, occurred at the end of the Beck Spring Dolomite time, and at the end of Kingston Peak time.

Paleozoic and Mesozoic history

Regional uplift occurred after the deposition of the Pahrump Group and the disconformity at the base of the Noonday Dolomite truncates some of the upper units in the Kingston Peak Formation. Rocks of the upper Precambrian Noonday Dolomite, Johnnie Formation, Stirling Quartzite, and Cambrian Wood Canyon Formation were deposited on top of this disconformity. There is no evidence for any disconformities within this stratigraphic section.

Evidence for the Paleozoic history of the Telescope Peak area is lacking, but relatively complete Paleozoic sections are entensively exposed to the north (Hall, 1971, Hunt and Mabey, 1966) which indicate a relatively quiescent period of dominantly carbonate sedimentation after middle Cambrian time.

The next geologic event recorded in the Telescope Peak Quadrangle occurred in late Cretaceous time when the Precambrian rocks were regionally metamorphosed and intruded by a muscovite-bearing granite. This regional metamorphism was followed by a deformational event which produced the north-northwest-trending anticlines and World Beater Dome. The formation of these structures was accomplished in part by reactivation of the older north-trending faults, and was accompanied by a second metamorphic event.

The Mesozoic history of the Death Valley region is considerably more complex than the geology exposed in the Telescope Peak Quadrangle indicates. Prior to the Late Cretaceous metamorphism one or more periods of thursting and intrusion occurred. An extensive network of thrust faults crops out in the White and Inyo Mountains and in the Last Chance Range (Last Chance thrust of Stewart and others, 1966), in the Hunter Mountain area (Racetrack thrust of McAllister, 1958), in the Cottonwood Mountains (Lemoigne thrust of Hall, 1971), in the Argus Range (Argus–Sterling thrust of Moore, 1974), and the Slate Range (Layton Well thrust of Smith and others, 1968). Most of these faults either displace or are intruded by Mesozoic granitic rocks (Figure 20). Dunne and others (1978) summarized the Mesozoic history of the White–Inyo Mountains region. At least two periods of thrusting are separated by an episode of intrusion. The Last Chance, Racetrack, Lemoigne thrusts displace Permian strata but are intruded by granitic rocks of the Hunter Mountain pluton (approximately 175 m.y.). The more westerly Swansea and Argus–Sterling thrusts displace Triassic marine and Triassic to lower Jurassic volcanic strata as well as granitic rocks approximately 160 to 180 m.y. old. The upper age limit on the younger thrust system is placed by the 150 m.y. old Independence dike swarm which intrudes the Swansea thrust (Dunne and others, 1976).

Burchfiel and Davis (1971 and 1977) described an extensive history of thrusting and intrusion in the eastern Mojave Desert which commenced in the Triassic and continued into the Cretaceous. Stevens and others (1974) suggested that the Panamint Mountains rest on the upper plate of a thrust fault, the Butte Valley thrust, and this implies that the Precambrian rocks in the Death Valley area are allochthanous. The Butte Valley fault is nearly everywhere intruded by 150 m.y. granitic plutons, but where it is not, the Butte Valley fault is a high angle normal fault (Johnson, 1957).

Thus, after the depositions of Triassic marine strata (as suggested by Johnson, 1957, and Stewart and others, 1966) and before the late Cretaceous metamorphism in the Panamint Mountains, the Telescope Peak area was involved to an unknown extent in a late Triassic thrusting episode, an early to middle Jurassic period of intrusion, a middle to late Jurassic thrusting episode, a late Jurassic period of intrusion, and perhaps an even younger thrusting episode.

Late Mesozoic regional metamorphism and the intrusion of leucocratic granitic rocks in the Panamint Mountains may have occurred during the Jurassic when most of the granitic rocks in the Argus–Inyo–White mountains area were emplaced. However, if the 80 m.y. age for the Hall Canyon pluton is the emplacment age, then regional metamorphism must have occurred during the Cretaceous when most of the Sierra Nevada was emplaced (Evernden and Kistler, 1970). Regional metamorphism of probable Mesozoic age has affected upper Precambrian strata in the Panamint Mountains, Tucki Mountain, and Funeral Mountains (see Labotka, 1978), but the time and space relations of the metamorphic terrane to the Sierra Nevada batholith are not adequately determined. Subsequently, the regionally metamorphosed rocks were folded along northwest and north-northwest-trending axes, and domes and anticlines of probable late Mesozoic–early Tertiary age dominate the structures of the Panamint Mountains, Tucki Mountain (Hunt and Mabey, 1966), the Funeral Mountains (Troxel and Wright, personal

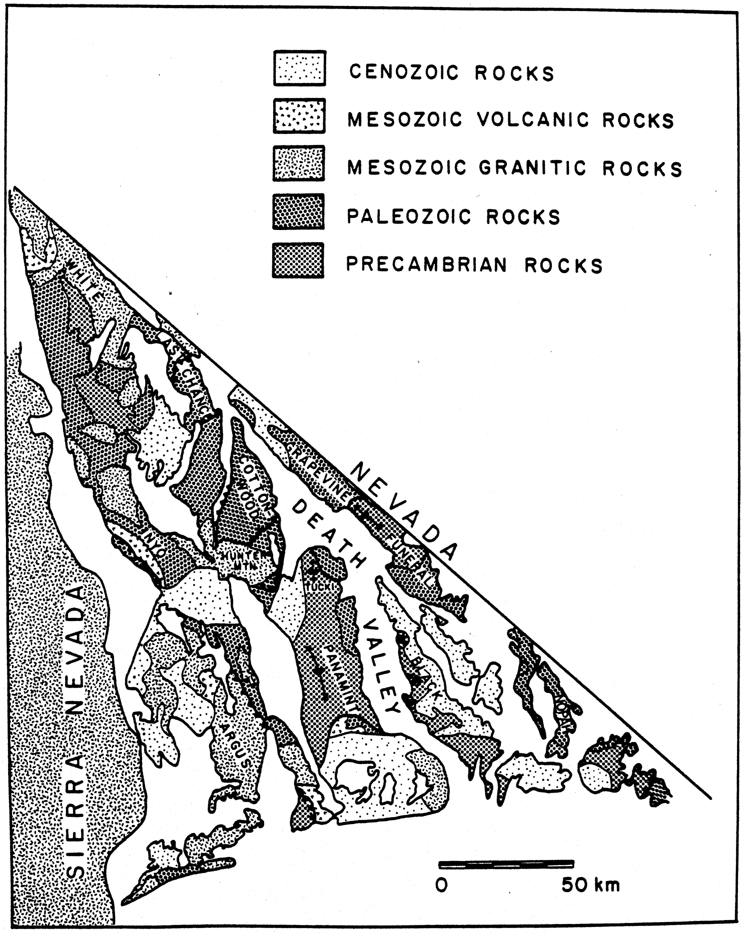


Figure 20. Regional geology of the southwest Great Basin, and the relation of the Panamint Mountains to neighboring ranges.

communication, and Labotka, 1978), and Black Mountains (Otten, 1974).

Tertiary and Quaternary history

In contrast with earlier styles of deformation, deformation occurred during Tertiary time along low-angle normal faults. The younger monolithologic breccia may have formed in response to the inception of displacement along the Panamint Valley fault zone. A relatively stable period after the formation of the monolithologic breccia allowed the development of topography of relatively low relief. Renewed displacement along the Panamint Valley fault zone uplifted the Panamint Range and caused dissection of this old surface. Substantial uplift had occurred prior to the development of late Pleistocene Lake Panamint (R. Smith, 1976).

The setting of the Panamint Mountains during Tertiary time and the relations between the Panamint Mountains and adjacent mountain blocks are not clear. The Tertiary history is dominated by uplift and denudation of the metamorphic terrains in the Panamint, Black, and Funeral Mountains (Hunt and Mabey, 1966). This uplift is coupled with the inception of extensional tectonics as exemplified by the hypabyssal intrusion of felsic igneous rocks and great eastward tilting of blocks along rotational faults (Wright and Troxel, 1973). The great east-west extension appears to be coupled in turn with the beginning of regional right-lateral shear which is manifested in the Panamint Valley and Death Valley fault zones (Burchfiel and Stewart, 1966).

This extensional tectonic regime is represented in the central Panamint Mountains by low angle normal faults, Little Chief stock, and monstrous late Tertiary landslides. Late Tertiary and Quaternary deformation involved uplift and eastward tilting of the Panamint Mountains along the Panamint Valley Fault Zone, but the degree to which the central Panamint Mountains was affected by this deformation is unclear. In the Panamint Butte quadrangle Pliocene Nova Formation is tilted 20 to 40 east, but these rocks appear to be in a block which is separated from the central Panamint Mountains by an old strand of the Panamint Valley fault (R. Smith, 1976). R. Smith (1976) indicated that the maximum present uplift rate of the Panamint block is about 1.5 mm/y, but the amount of eastward tilting is not determined. The principal deformation across the Panamint Valley Fault Zone occurs as right-lateral displacement and is probably responsible for the present geometry of Panamint Valley (R. Smith, 1976).

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