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GEOLOGIC RECONNAISSANCE OF THE SLATE RANGE, SAN BERNARDINO AND INYO COUNTIES, CALIFORNIA

SPECIAL REPORT 96

California Division of Mines and Geology
Ferry Building, San Francisco, 1968

GEOLOGIC RECONNAISSANCE OF THE SLATE RANGE, SAN BERNARDINO AND INYO COUNTIES, CALIFORNIA

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ABSTRACT

The Slate Range is a 30-mile-long north-trending range that lies near the southwest corner of the Great Basin and just north of the Mojave Desert. As a result of reconnaissance geologic mapping, the rocks and sediments have been divided into 24 units that probably range in age from Precambrian to Recent.

Rock units assigned to the Precambrian include schist, metaplutonic rocks, metasedimentary rocks, and an undivided complex that includes all three types; lead-alpha and isotopic dates on two of these units are discordant but suggest Precambrian ages. Paleozoic rock units include limestone of probable Mississippian age in the northern part of the range, quartzite and dolomite of Cambrian age along the edge of the adjoining Panamint Range, and well-bedded marine sedimentary rocks assumed to be of Paleozoic age just south of the Slate Range. Early Mesozoic volcanic rocks and shales that are metamorphosed crop out in the south half of the range. Late Mesozoic quartz monzonitic rocks crop out in the north-central and southern parts of the range and in the Panamint Range; a lead-alpha date indicates an age of 120 $\pm$ 20 m.y. for one unit. Tertiary lavas, pyroclastic rocks, and sedimentary epiclastic rocks occur on the flanks and crest of the range. Quaternary deposits lie on the flanks of the range and in the adjoining valleys.

A gravity survey consisting of 33 stations within the range was combined with published data from surrounding areas; it reveals no large deviation in the regional gravity field associated with the Slate Range. Two gravity highs within the range and one south of the Garlock fault seem to indicate areas of bedrock having higher average density. Gravity lows occur over zones of lower density quartz monzonitic rock. A steep gradient along the northwest edge of the range probably coincides with a fault.

This mapping has shown the Slate Range to be an area of structural complexity. The Garlock fault forms its south boundary, and the Panamint Valley fault zone forms part of its eastern edge. Several west- or northwest-dipping low-angle faults of late Mesozoic or Tertiary age are inferred to be thrust faults, although the evidence of actual displacement is inconclusive; of these, the Sand Canyon, Layton Well, and Straw Peak thrusts are the most extensive. The northwest-trending New York Canyon fault and the north-trending Manly Pass fault are vertical and trend diagonally across the range; their displacements are also of late Mesozoic and (or) Tertiary age but are of uncertain sense. Displacements along the Garlock fault and the Panamint Valley fault zone are in part of Pleistocene and Recent ages. A graben and several normal faults displace gravels of late Pleistocene and Recent ages along the edges of the Slate Range. Warping, which occurred after deposition of the basal member of the Tertiary rock sequence, is responsible for much of the present relief of the range. The physiography too appears to be partly determined by this warping inasmuch as some anomalous topographic surfaces preserved on the crest and western flank of the range are interpreted as the exhumed soles of warped thrust faults.

None of the mines in the Slate Range is active. Past mining has produced gold, silver, lead, zinc, copper, and limestone. Their recorded production is about $2 million, but total production greatly exceeds that amount.

GEOLOGIC RECONNAISSANCE OF THE SLATE RANGE, SAN BERNARDINO AND INYO COUNTIES, CALIFORNIA

BY GEORGE I. SMITH, BENNIE W. TROXEL, CLIFFTON H. GRAY, JR., AND ROLAND VON HUENE *

INTRODUCTION

The Slate Range is a 30-mile-long north-trending range that lies near the southwest corner of the Great Basin physiographic province and just north of the Mojave Desert physiographic province, California (fig. 1). Its south half is in San Bernardino County

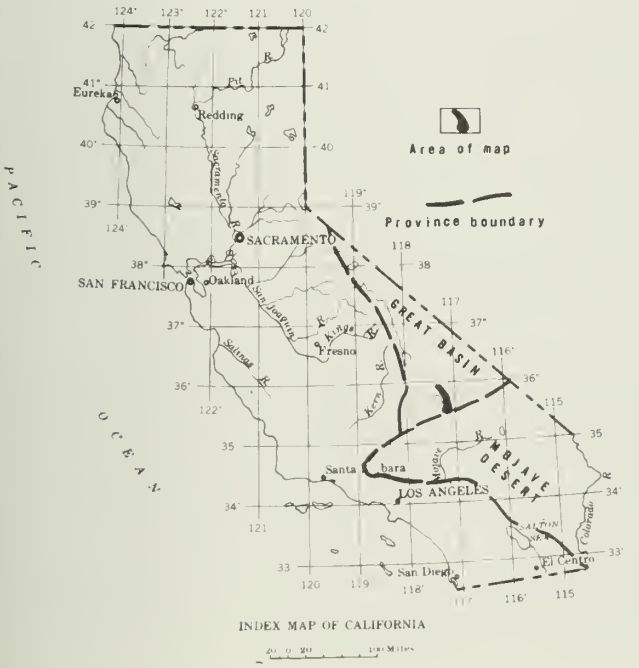

Figure 1. Index map of California showing location of Slate Range and boundaries of nearby physiographic provinces.

and its north half is in Inyo County. The range occupies parts of the Trona, Manly Peak, Searles Lake, and Wingate Pass 15-minute quadrangles. These show that the highest point within it is Straw Peak with an elevation of 5,578 feet—about 4,000 to 4,500 feet above the floors of Searles and Panamint Valleys. Nearby towns are Trona, Argus, Westend, and Pioneer Point on the west side of Searles Lake.

Precipitation in Searles Valley averages 3.8 inches per year, and precipitation in the Slate Range is probably only a little higher. Summers are hot and dry, and winters are cool and relatively wet. Consequently, the vegetation is mostly that of the lower Sonoran zone, *Larrea* and *Franseria* being among the dominant types. Upper Sonoran zone floras occur in some of the canyons and at higher elevations. The fauna consists of native desert animals such as jackrabbits, lizards, rattlesnakes, and kit foxes, plus wild burros.

Reconnaissance geologic mapping of the Slate Range was started in 1960 by Troxel and Gray for use on the 1:250,000-scale Trona sheet of the Geologic Map of California. At about the same time, Smith began mapping the west flank of the Slate Range as part of a study of the Quaternary geology of Searles Valley. After combining the results for the State map, we agreed that it would be profitable to resume field work and compile a reconnaissance map at a larger scale. This was partly because of the unusual nature of the geology that had been mapped, and partly because it is unlikely that a detailed map of the range will be made in the near future inasmuch as its south half lies within the U.S. Naval Ordnance Test Station Mojave B Range to which access is limited. The gravity survey was made by von Huene. The final map (pl. 1) represents about 80 man-days in the field.

We are grateful to the U.S. Navy for permitting access to the restricted area and for services provided in part of this work; to the U.S. Marine Corps for providing us with two helicopters and crews for 4 days; to R. L. Langenheim, Jr., and J. D. Ridlon for their assistance in the field during these 4 days; and to Robert Streitz of the California Division of Mines and Geology for 2 days of field assistance. The radiometric dates were provided by T. W. Stern, the fossil molluscs were studied by Dwight Taylor, and the terrain corrections for the gravity survey were made by D. L. Peterson, all of the U.S. Geological Survey; we wish to thank them for their contributions.

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STRATIGRAPHY

The following descriptions of the lithology, composition, and texture of the major rock units in the Slate Range are based chiefly on field observations, but about 65 thin sections of the crystalline rocks were also studied.

The rock units were assigned ages on the basis of several criteria. Lithologic similarity of some units to dated sections from other nearby areas was the basis for most age assignments; tentative correlations with specific formations were possible for some units, fossils helped identify the ages of two, and radiometric dates added support to the ages inferred for three more.

The radiometric ages of zircon concentrates from four samples of rocks from this range were made by T. W. Stern. Ages by the lead-alpha method were obtained on three samples, and ages based on the lead-thorium-uranium isotopic ratios were obtained on one of these plus one other. These dates are listed in table 1. All of the ages on Precambrian rocks are discordant and must be considered as minimums.

Precambrian rocks

METAMORPHIC ROCKS

Metamorphic rocks, undivided. Metamorphic rocks of diverse types crop out in a large part of the south half of the Slate Range. They are especially well exposed in Layton and New York Canyons. Most are fine to coarse grained and are medium- to dark-gray shades of orange, pink, or green. Many have been extensively crushed and altered. Massive textures are most common, but some are gneissic and schistose. These rocks are most conspicuously crushed and leached near the tops of the ridges and surfaces that were close to a thrust surface.

The rocks included in this map unit are composed chiefly of feldspar, quartz, and altered hornblende, biotite, and pyroxene, plus secondary epidote, chlorite, and a little calcite. Many are leucocratic. Most were probably plutonic rocks before metamorphism, but some were apparently sedimentary and volcanic in origin.

In Layton Canyon and other nearby areas, this unit includes many dikes of fine-grained dark rocks that may be related to the Mesozoic metavolcanic rocks or plutonic rocks.

Isotopic ages of zircon concentrates from two samples are strongly discordant and range from 80 m.y. to 588 m.y.; a lead-alpha age for one of these samples is 190 ± 20 m.y. (table 1). However, by projecting the discordant isotopic ages on the two samples back to their concordant point, true ages of about 700 ± 100 m.y. are indicated (T. W. Stern, written communication, 1964). The lead loss has been so great, though, that this projection is very inaccurate, and the geologic history of the surrounding areas suggests that a true age of at least twice this figure is more likely.

Table 1. Radiometric ages of rocks from the Slate Range, California.

[*Age determinations by T. W. Stern. Pb-alpha ages calculated from the following equation: $t = C$ Pb/alpha, where t is the calculated age in millions of years, C is a constant based upon the U/Th ratio, Pb is the lead content in parts per million, and alpha is the alpha counts per milligram per hour. The following constants were used: Assumed U/Th ratio, 1.0; C, 2485. Age is rounded off to nearest 10 m.y. The error quoted here is that due to uncertainties in analytical techniques. Uranium, thorium, and lead concentrations were determined by isotope dilution, and the isotopic ages were calculated by standard methods*]

Map unit	Rock lithology	Field no.	Lab. no.	Alpha/mg-hr	Zircon concentrate			Calculated ages (m.y.)				
					Pb (ppm)	U[2] (ppm)	Th[2] (ppm)	Pb-alpha	Pb^{206}/U^{238}	Pb^{207}/U^{235}	Pb^{207}/Pb^{206}	Pb^{208}/Th^{232}
Plutonic rocks (unit 1)	Coarse-grained quartz monzonite	CQ773-1	526Z	1476	74[1]			120 ± 20				
Metaplutonic rocks	Medium- to fine-grained gneissic granodiorite	CQ770-17	528Z	154	32[1]			500 ± 60				
Metamorphic rocks, undivided	Crushed metagranodiorite (?)[4]	CQ772-11			15.2[2]	393	194		130	149	474	80
Do	Leucocratic metamorphosed quartz monzonite	PTK4088-7	383Z	7379	553[1]			190 ± 20				
Do	do[4]	do		7392[3]	618[2]	11,500[5]	36,600[5]		184	217	588	133

[1] Spectrochemical analysis by Harold Westley.
[2] Isotope dilution analysis by M. F. Newell and T. W. Stern.
[3] Calculated alpha activity from U and Th concentrations measured by isotope dilution.
[4] The isotopic composition of the zircon lead in atom percent is:

Field No.	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
CQ772-11	0.589	55.86	11.79	31.76
PTK4088-7	0.231	50.40	6.37	43.00

The common lead used to correct for the presence of nonradiogenic lead was:
$Pb^{206}/Pb^{204} = 18.51$ $Pb^{207}/Pb^{204} = 15.72$ $Pb^{208}/Pb^{204} = 38.44$
The following constants were used in the age calculations:
$U^{238}\lambda = 1.54 \times 10^{-10}\ yr^{-1}$; $U^{235}\lambda = 9.72 \times 10^{-10}\ yr^{-1}$; $Th^{232}\lambda = 4.88 \times 10^{-11}\ yr^{-1}$; $U^{238}/U^{235} = 137.7$

[5] Abnormally high U and Th contents suggest presence of minerals containing those elements in zircon concentrate.

The inferred time of lead loss is estimated to be about 70 m.y. ago.

Metasedimentary rocks. Metasedimentary rocks crop out near the Gold Bottom and Ophir mines. They are mostly schist, hornfels, phyllite, silicated marble, and fine-grained quartzitic or felsitic rock, and cannot be correlated lithologically with sedimentary sections of other nearby areas. They could be an unrecognized facies of Mesozoic or Paleozoic rocks, but are more likely Precambrian in age.

Metaplutonic rocks. Medium- to fine-grained metaplutonic rocks form the upper plate of the Sand Canyon thrust fault, and rocks tentatively assigned to this unit also crop out along the southwest corner of the range and northwest of the Gold Bottom mine. The rocks are mostly medium to dark gray, and consist of fine- to medium-grained quartz monzonite or granodiorite. Locally they are foliated and fractured and most are slightly altered to chlorite and other minerals.

A lead-alpha age on zircon indicates 500 ± 60 m.y. (Cambrian or Ordovician) (table 1). However, according to the geologic history of this area, metaplutonic rocks of Cambrian or Ordovician age are unlikely and the calculated lead-alpha age is thought to be substantially younger than the true age because of late Mesozoic metamorphism. A true age of Precambrian is inferred.

The degree of discordance between the probable true ages and the lead-alpha ages of the two dated Precambrian units is quite different. The undivided metamorphic rock unit has been strongly metamorphosed, and its calculated age is nearly as young as the event that caused the loss of radiogenic lead. The metaplutonic rock unit, however, has lost less lead because of metamorphism, and its calculated lead-alpha age is closer to its probable true age. This difference probably means that the two units have had very different thermal histories, and for this reason we infer that even though they now form the upper and lower plates of the Sand Canyon thrust fault, they were an appreciable distance apart at the time this lead loss occurred.

Schist. Schist, along with some gneiss and slate, crops out in the south part of the range. The thickness of this unit is uncertain, but 200 to 300 feet is exposed in the canyons on the west side of the range. In many places, the schist consists of very thin distinct layers that are light to very dark gray in color, but in other places, the rocks are less distinctly layered and grade into gneissic or slaty rocks. In outcrop (fig. 2), hand specimens (fig. 2a), and thin section, these rocks have shear and imbricate structures suggesting extensive deformation and cataclasis. The rocks are composed mostly of sericite, chlorite, and quartz, and the quartz grains are commonly stretched. Some rocks contain plagioclase, opaque minerals, and secondary carbonate.

The contacts of schist with Mesozoic plutonic rocks are gradational over vertical distances of several feet; some contacts grade over as much as 50 feet and are notably contorted and complex. The contacts with the Precambrian undivided metamorphic rocks along the west side of the range are similarly gradational. Both are interpreted as fault contacts. The unit is mapped as a discrete rock unit caught between these faults, but it may be entirely composed of sheared and recrystallized rock derived from one or both of the adjoining units and thus be a phyllonite.

Paleozoic rocks

MARINE SEDIMENTARY ROCKS

Sedimentary rocks. Sedimentary rocks of probable marine origin crop out south of the Garlock fault. Most are well-bedded, medium- to dark-gray siltstone and sandstone, but some beds consist of conglomerate or limestone and many contain chert. Their ages are unknown, but are considered most likely to be Paleozoic.

Quartzite and dolomite. Thick sections of marine quartzite and dolomite are exposed in the Panamint Range east of the Panamint Valley fault. Most of them are probably of Cambrian age and correlative with part of the Wood Canyon Formation and Bonanza King Formation (Hazzard, 1937).

Limestone and marble. Limestone and marble crop out in the north part of the Slate Range. Most exposures consist of fine- to coarse-grained marble that is cherty and locally silicified. The typical colors are medium to dark gray or brown, but near intrusive contacts the rocks are bleached to lighter colors. Most sections are well bedded. In the limestone quarry near the north end of the range, crosscutting reddish-brown siliceous veinlets form about 10 percent of the unit.

The unit is generally unfossiliferous, but crinoid stems are locally abundant a quarter of a mile northwest of the limestone quarry. The thickness of the section was not measured, but probably exceeds 500 feet. The rocks along the lower slopes and north of the limestone quarry are considered by R. L. Langenheim, Jr. (written communication, December 1962) to be in part similar to the Perdido Formation and Tin Mountain Limestone of Mississippian age (McAllister,

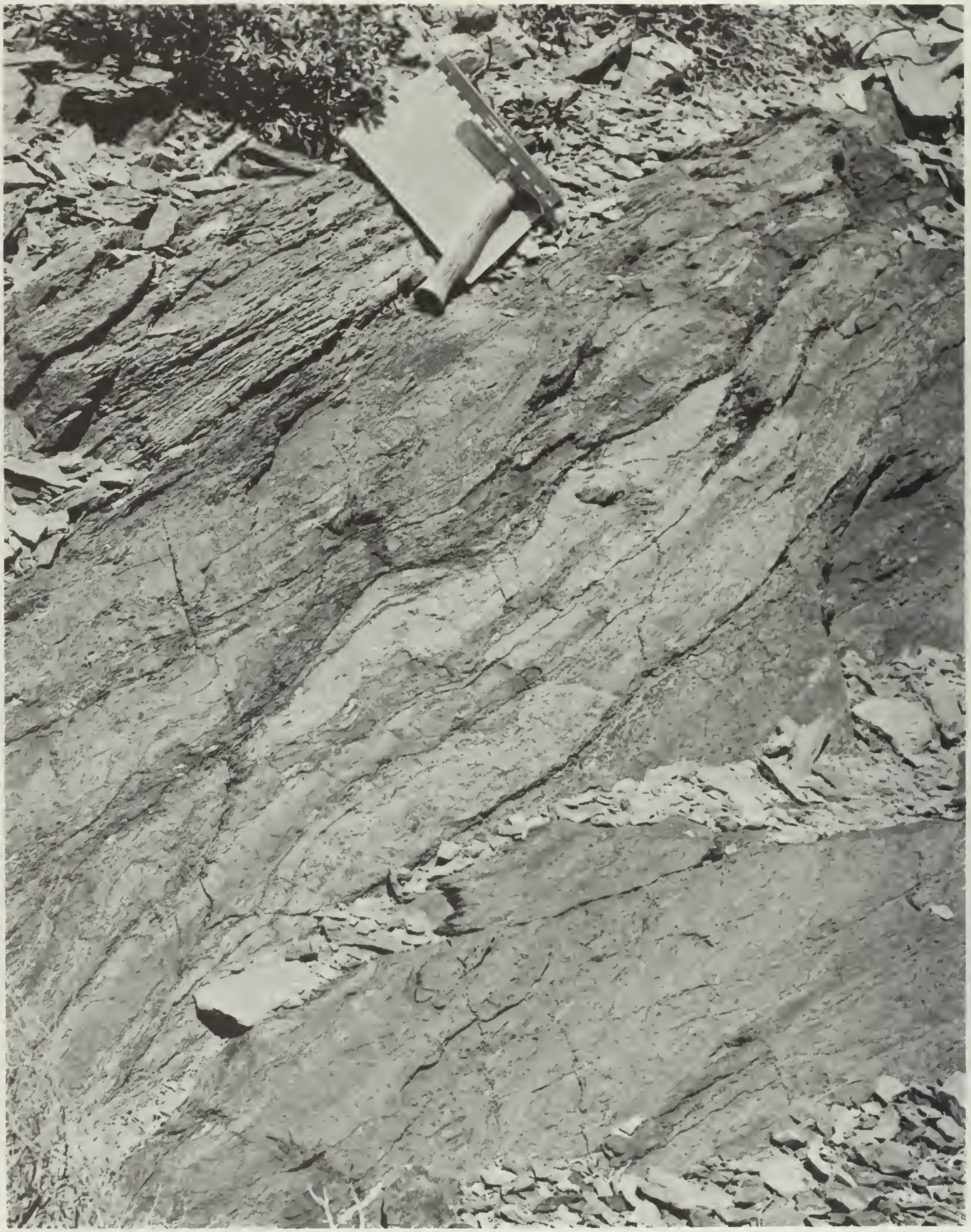

Figure 2. Contorted gneissic rocks included in schist rock unit. Outcrop in canyon bottom, E½ sec. 33 along sec. D–D′. Photograph toward north.

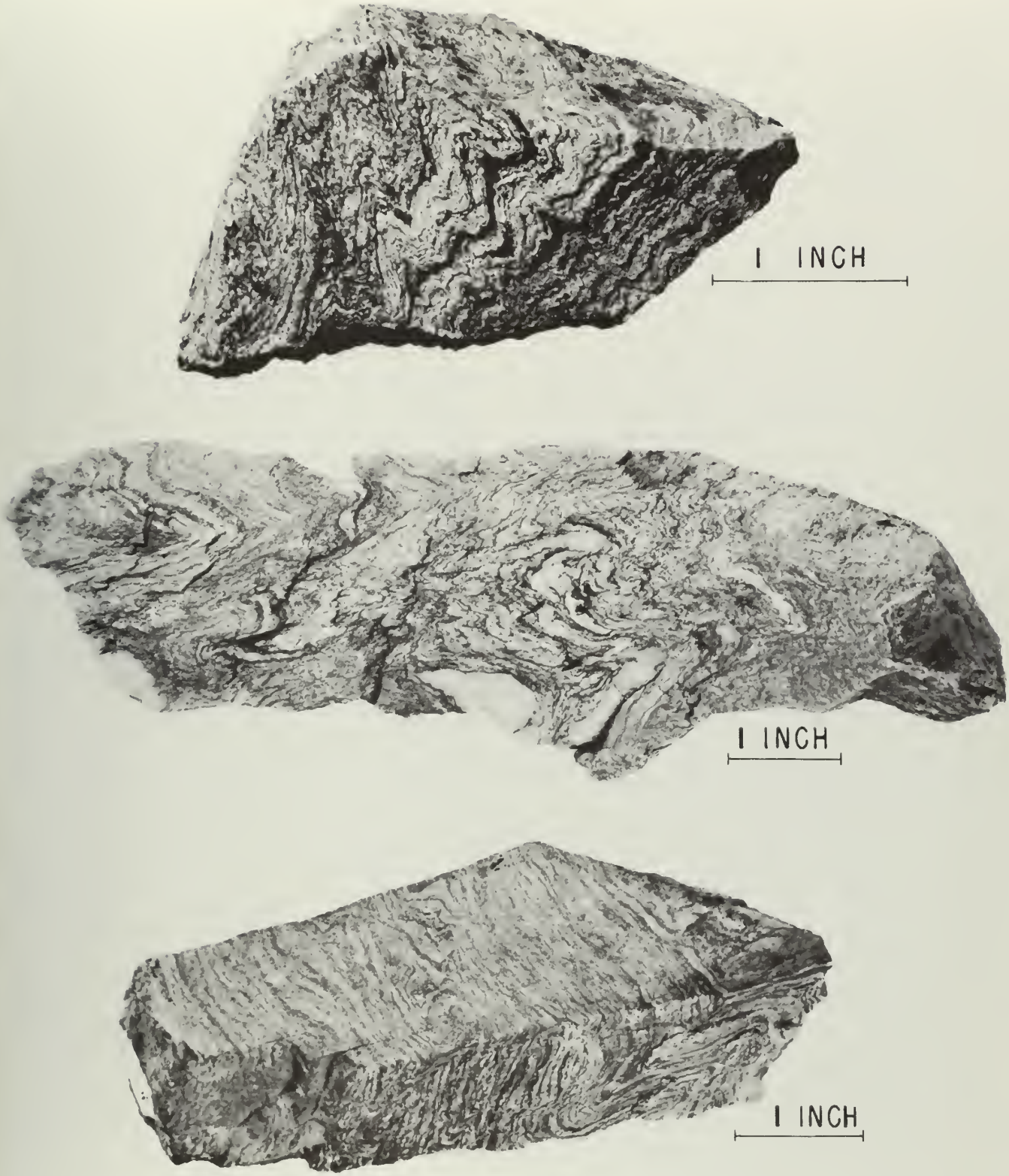

Figure 2a. Hand specimens of schist showing textures indicative of deformation and shearing.

1956). An apparently thick sequence of interbedded clastic rocks and limestone higher in the Slate Range was considered by J. F. McAllister (written communication, June 1966) after a brief inspection to be possibly in the Keeler Canyon (Pennslyvanian and Permian) and Owens Valley (Permian) Formations.

Mesozoic rocks

SHALE

Tuffaceous shale, characterized by light colors and pronounced cleavage along thin layers, crops out in an area of complex structure in the middle of the range and in one thin fault slice near the southwest corner of the range. It ranges in color from white or tan to light hues of green or red. Near faults, the rocks of this unit are contorted and changed to material that is indistinguishable from gouge. The unit appears to be within the section composed chiefly of metavolcanic rocks, and for this reason is considered to be of about the same age.

METAVOLCANIC ROCKS

Metavolcanic rocks crop out in the south half of the Slate Range. They are considered on lithologic grounds to be correlative with the early Mesozoic metavolcanic rocks of other nearby ranges, but pronounced differences in shearing between areas may mean that some of the included rocks are significantly older or younger. The metavolcanic rocks consist chiefly of lavas and massive to faintly bedded pyroclastic rocks that have been metamorphosed. Most of these rocks are light to dark green; some are reddish or purple. The unit includes some chloritized tuffaceous(?) sandstone and breccia or conglomerate that contains clasts of plutonic rocks. The feldspar and mafic phenocrysts of the original rocks are now mostly altered, but a few euhedral to anhedral quartz phenocrysts remain unaltered. The groundmass is composed of fine-grained secondary quartz, sericite, chlorite, epidote, and opaque minerals.

In the area north of Layton Pass, schistose metavolcanic rocks have been mapped separately. They are mostly very light gray to green, conspicuously schistose, and appear to be altered bedded tuffs.

PLUTONIC ROCKS

Plutonic rocks in the Slate Range consist mostly of quartz monzonite, but there are large areas of rocks with other compositions. The rocks included in this unit may be of both late Mesozoic and older ages.

The northernmost exposures of plutonic rocks are in intrusive contact with limestone, probably of Mississippian age (fig. 3). They also are lithologically similar to other plutonic rocks of eastern California that are known to be of late Mesozoic age, and a lead-alpha age on zircons from one sample indicates an age of 120 ± 20 m.y. (table 1).

The ages of the plutonic rock units in the central and southern parts of the range are problematical. The plutonic rocks that are 1 mile north of the New York mine intrude metavolcanic rocks that are correlated on lithologic grounds with rocks of early Mesozoic age in other areas. However, similar plutonic rocks are also found as fragments in these metavolcanics, so some of the exposed plutonic rocks in this part of the range may thus be older and possibly of Precambrian age.

The plutonic rocks near the south end of the Slate Range are in fault contact with Precambrian and lower Mesozoic rocks. Their lithology is slightly different from the units known to be of late Mesozoic age in the north end of the range, and it is possible that the plutonic rocks of the south end of the range are older.

These plutonic rocks are divided into five map units on the basis of areal extent, composition, and texture.

Unit 1 consists chiefly of light-colored, coarse-grained, equigranular quartz monzonitic rock, but large variation in composition and texture is evident, especially near the intrusive contacts with limestone, where several small masses of felsite occur, and along the shear zone bordering the Manly Pass fault.

Unit 2 is mostly a light- to medium-gray, medium-grained granite or quartz monzonite composed of an estimated 30 to 45 percent K-feldspar, 20 to 45 percent plagioclase, 20 to 35 percent quartz, and 1 to 5 percent mafic minerals (mostly biotite). Some parts are monzonitic to dioritic. The north half of this unit is composed of nearly flat sheets, tens to hundreds of feet thick, of light and dark facies of these rocks.

Unit 3 is mostly a medium-gray, coarse-grained, equigranular quartz monzonite composed of an estimated 30 to 40 percent K-feldspar, 30 to 40 percent plagioclase, 20 to 30 percent quartz, and 5 to 10 percent mafic minerals.

Unit 4 is mostly light-gray, medium- to coarse-grained granite or quartz monzonite. It is composed of an estimated 30 to 40 percent K-feldspar, 20 to 30 percent plagioclase, 25 to 35 percent quartz, 1 to 5 percent mafic minerals (mostly biotite and magnetite), and a little secondary sericite and epidote.

Unit 5 is composed of quartz monzonitic rocks which are probably related to the quartz monzonite of probable Late Jurassic age in the Manly Peak area (Johnson, 1957).

Tertiary rocks

VOLCANIC AND SEDIMENTARY ROCKS

Sedimentary rocks. Rock types included in the map unit described as sedimentary rocks include siltstone, sandstone, cobble and boulder conglomerate, tuffaceous sandstone, and lacustrine limestone and siliceous limestone containing fossil snails and plant stems(?). The rocks that contain the snails are probably late Tertiary in age, and the conglomerates beneath them may be significantly older.

Siltstone and sandstone are most common in the northern part of the range. They are generally tan, alluvial-type deposits that are poorly sorted and bedded. Conglomerate is exposed locally on the western and eastern slopes of the range and near the crest of Layton Pass, and is characterized by a large proportion of very well rounded boulders of quartzite. The quartzite is a distinctive type that was clearly derived from the Precambrian to Cambrian Stirling and Wood Canyon Formations of Hazzard (1937) that are exposed in the Panamint Range to the east. Conglomerate beds in the Layton Canyon area also contain boulders of gray crinoidal limestone; these boulders resemble the limestone in the north end of the Slate Range but more likely were derived from an unknown locality to the east, the direction from which the quartzite boulders came. The siltstone and sandstone sections are locally several hundred feet thick, especially those north of Manly Pass. Most of the conglomerate sections are less than 100 feet thick.

White, tan, or deep-red limestone and siliceous limestone crop out as distinctly thin bedded sections from 5 to 25 feet thick. Fair to poorly preserved fresh-water snails contained in the silicified limestone were identified by Dwight W. Taylor (written communications, 1953 and 1962) as belonging to the genus *Coretus*. This form lived in shallow-standing waters of California, the northern Great Basin, and Idaho, and is not known in rocks younger than middle Pliocene or older than middle Miocene.

Pyroclastic rocks. Thick sections of pyroclastic rocks crop out in the north and east parts of the range, and thinner sections are present along the west edge and near the summit of Layton Pass. The rocks are mostly white, gray, pink, or light green. In general, they are poorly sorted and contain many fragments of different rock types. The pyroclastic rocks in the northern Slate Range contain fragments of welded tuff, pumice, lava, and euhedral crystals of volcanic origin, all in a matrix of fine to coarse tuffaceous material. Some sections contain a high proportion of clastic material. The unit ranges abruptly in thickness from as

Figure 3. Intrusive contact of Mesozoic quartz monzonite (Mzp_1) and Paleozoic limestone (Pzl) on west side of Slate Range, north of Manly Pass. Dark Tertiary volcanic rocks (Tv) crop out along the crest of the range. View looking east; Panamint Range along skyline.

little as a few feet to several hundred feet. It apparently was deposited on surfaces that were uneven but more subdued than those of the present range.

The pyroclastic rocks east of Panamint Valley and south of the Garlock fault were not studied in detail, but they consist mostly of light-colored coarse pyroclastic debris.

Volcanic rocks. Volcanic rocks of probable late Tertiary age crop out along both flanks and on the crest of the Slate Range (fig. 3). The largest areas of exposure are along the northeast and east sides of the range; smaller masses are on the central crest and west side of the range. The largest areas are flows, but some smaller outcrops appear to be plugs. The layered sections of these rocks are commonly a few hundred feet thick.

The rocks are mostly basaltic and andesitic, but some are dacitic. Those studied in thin section are vesicular, contain 5 to 35 percent plagioclase megaphenocrysts (An_{45-60}), 10 to 75 percent plagioclase microphenocrysts, 1 to 5 percent clinopyroxene, 0 to 2 percent orthopyroxene, 0 to 1 percent quartz, 0 to 2 percent biotite, 2 to 10 percent opaque minerals, and 20 to 60 percent submicroscopic crystalline to glassy material. Some contain oxyhornblende or olivine.

The volcanic rocks south of the Garlock fault are included in this map unit; they are probably mostly andesite or dacite but were not studied in detail. The volcanic rocks east of the Panamint Valley fault zone are also included; they are probably similar, but appear less deformed and may be younger than those in the Slate Range.

Quaternary deposits

CHRISTMAS CANYON FORMATION

Deposits correlated with the Christmas Canyon Formation, a Pleistocene(?) formation exposed south of the Garlock fault in the Lava Mountains (Smith, 1965), are exposed along the low south edge of the Slate Range. They are mostly well-layered lake silts and sands with some interbedded tuff layers; some beds contain gypsum, small quantities of sodium chloride, and sodium sulfate (Noble, 1931, p. 10–13). Toward the east and north, sand and gravel layers become more common. The fine-grained beds in this area generally crop out to form smooth, light-colored slopes that are free of vegetation. Most slopes are light tan to yellow, but the easternmost outcrops tend to be green and red. Bedding in the fine-grained material is commonly 2 to 5 feet thick, and is recognized chiefly by the slight variations in color. Bedding in the coarser material is indistinct. Several thousand feet of these deposits are exposed in the southwest corner of the Slate Range.

The lithology and mineral content of the Christmas Canyon Formation, both in the Slate Range and in the Lava Mountains, show that it was formed in closed basins that were elongate parallel to the Garlock fault and thus probably related to the fault.

UNCONSOLIDATED SEDIMENTARY DEPOSITS

Older gravels. Older gravels crop out on the east, west, and south flanks of the Slate Range (fig. 4). They consist of pebbles, cobbles, and boulders in a sandy matrix. The maximum exposed thickness of these gravels is about 400 feet. The deposits are mostly medium to dark tan or gray, and are poorly bedded and sorted. The matrix consists of poorly sorted fine to coarse sand. The larger fragments form 2 to 10 percent of the material and are mostly derived from older rocks now exposed nearby. Gravels exposed in the southwest corner of the map area, however, contain fragments of bluish agate which is probably derived from outcrops near Blue Chalcedony Spring—an area long known to mineral collectors that lies 10 to 15 miles to the southeast. This inferred source area is south of the Garlock fault, and a large part of the distance between the source area and these gravel fragments may be accounted for by left-lateral displacement along the Garlock fault.

In the canyon leading to the Standard mine, at an elevation of 2,400 feet, two beds of lake gravels, 1 to 3 feet thick, are interbedded in the deposits of this unit.

Pleistocene lake deposits. The Pleistocene lake deposits in Searles Valley are mostly of Wisconsin age (Smith, in press). They extend up the sides of the valley to an elevation of about 2,260 feet, and are composed of tan to yellow calcareous silt and sand at the lower levels, tan to gray sand and subangular gravels at intermediate levels, and well-rounded gravels near the highest levels.

In Pilot Knob Valley, lake deposits of probable very late Pleistocene or Recent age are composed of light-tan silt and sand. They apparently were deposited in a lake that formed behind a scarp of the Garlock fault.

In Panamint Valley, the lake deposits are inferred to be of Wisconsin age and possibly of Illinoian age on the basis of evidence obtained from the related deposits in Searles Valley. They are composed of tan to gray silt, sand, and pebble gravel, and are overlain in most areas by more recent alluvial gravels.

Alluvial deposits. Alluvial deposits on the slopes surrounding the Slate Range consist of poorly sorted

pebble to boulder gravel on the upper levels, and pebbly sand on the lower levels. The surfaces of these deposits are commonly veneered by a lag gravel composed of the larger fragments in the deposit. The map unit includes alluvium of Recent age plus some older and slightly dissected gravels that may be of late Pleistocene age.

Windblown sand. Windblown sand covers much of the surface between the mouths of Sand and New York Canyons. The sand is composed largely of fault-gouge material blown eastward from the alluvial fans which originally received it from the fault zones exposed in the upper parts of those canyons. The windblown sand near the Ophir and Standard mines is mostly derived from the surface of Searles Lake.

Playa lake surface deposits. Playa lake surface deposits occupy the floors of most of the closed basins in this area. Three such deposits lie within the mapped area, two in Panamint Valley, and one within the Slate Range. The large playa in the northeastern part of the mapped area consists of fine sand and silt; the playa is a light-tan color in its center where dry, and dark gray to brown around the edges where moist. The playa deposit 5 miles northeast of Layton Pass is entirely dry and consists of yellowish-tan silt. That playa is in the initial stages of being dissected because overflow from it has lowered the drainage divide

Figure 4. Uplifted gravels (G) on the west flank of the northern Slate Range. Note shorelines (S) cut into foot of gravel slopes and in lower alluvial slopes. View toward north-northwest, Argus Range in left background, Panamint Valley in upper right.

Table 2. Measured densities of weathered rocks from the Slate Range, California.

Map unit	Lithology	Density (g/cc)
Volcanic rocks	Vesicular basalt	2.45
	Nonvesicular andesite	2.54
		(2.50 average)
Plutonic rocks (unit 1)	Quartz monzonite or granite	2.58
Do	Quartz monzonite	2.60
		(2.59 average)
Plutonic rocks (unit 2)	Diorite (segregation?)	2.92
Do	Quartz monzonite	2.65
Do	do	2.68
Do	do	2.59
Do	Granite	2.56
Do	Quartz monzonite	2.56
		(2.66 average)
Plutonic rocks (unit 3)	Quartz monzonite	2.65
Plutonic rocks (unit 4)	Quartz monzonite	2.68
		(2.65 average of 10 plutonic rocks)
Metavolcanic rocks	Metatuff	2.68
	Metatuff(?)	2.71
	Metapyroclastic rock	2.49
	Meta-andesite	2.83
	Meta-andesite	2.85
	Metatuff	2.61
	Metatuff	2.66
	Arkosic metavolcanic rock	2.75
	Metapyroclastic	2.74
	Metabasalt	2.85
		(2.72 average)
Limestone and marble	Limestone	2.68
Metaplutonic rock	Gneissic granodiorite	2.81
Metamorphic rocks, undivided	Metaplutonic rock	2.65
	do	2.61
	do	2.58
	do	2.65
		(2.62 average)

along its north side below the playa level. Small playas composed of tan silt have formed in fault depressions near the crest of the northern Slate Range and near the south edge of the bedrock portion of the range.

GRAVITY SURVEY

Procedures and accuracy. Thirty-three gravity stations were established in the Slate Range. Stations 1 to 29 were with Worden gravity meter No. 226 (dial constant 0.4738 mgal per meter scale division); stations 30 to 33 were established with Worden meter No. 558 (dial constant 0.09774 mgal per meter scale division). During the closed traverses of 2 to 3 hours, the maximum drift of Worden meter No. 226 was 0.38 mgal per hour, and that of Worden meter No. 558 was 0.1 mgal per hour. This drift was distributed linearly with respect to time among the observations in a traverse. Transit between stations was made by U.S. Marine Corps helicopters. All readings were based on an absolute value at the U.S. Naval Air Facility, China Lake, which has been tied to the Woolard network with a certainty of ± 0.3 mgal. Stations were established at points of known position and elevation shown on 15-minute topographic quadrangle maps of the area.

The gravity observations were reduced to Bouguer gravity anomalies using the International Gravity Formula and an elevation adjustment factor of 0.05960 mgal per foot. This factor corresponds to a density of 2.70 g/cc which is probably somewhat less than the average of fresh rock densities from the Slate Range and other nearby ranges, though a little greater than the average densities of weathered rocks in the Slate Range (table 2). The datum is sea level, and terrain corrections through zone 0 were made using the Coast and Geodetic Survey system (Swick, 1942, p. 67–68). To make all values positive, 1,000 mgals have been added to the complete Bouguer anomalies (table 3).

A rigorous analysis of errors was not made because of time limitations and the nature of the problem. Observational errors are probably no greater than 0.3 mgal; position and elevation uncertainties could contribute up to 0.1 and 0.3 mgal of error, respectively. The terrain corrections vary between 2.0 and 22.1 mgals, and, in spite of the good topographic control, reading uncertainties may result in as much as 2 mgals

Table 3. Observed gravity and terrain correction data.

Station number	Observed gravity (979.0000 + gals)	Elevation (in feet)	Terrain correction (in mgals)
1	3383	5578	17.9
2	3605	5260	15.7
3	3603	5304	13.4
4	4779	3493	4.2
5	5012	3207	4.3
6	4669	4244	6.9
7	4384	4222	5.7
8	4545	3954	9.7
9	4222	4314	12.9
10	3608	5244	15.8
11	4374	4029	5.3
12	5154	3135	2.2
13	3752	5181	18.4
14	4392	4468	11.9
15	3992	4847	15.3
16	4409	4069	14.0
17	3988	4708	20.0
18	4465	4094	11.5
19	4906	3362	8.5
20	5499	2362	5.4
21	5831	1908	4.3
22	5379	2701	6.7
23	3803	5093	22.1
24	3817	4823	20.7
25	4843	3518	8.9
26	5407	2702	4.7
27	5154	3128	5.1
28	4535	3955	13.1
29	5193	3029	3.9
30	4931	2975	3.6
31	4738	3407	3.6
32	4605	3646	4.1
33	5376	2487	2.0

of error at stations in very rugged terrain where the larger corrections occur.

Gravity anomalies in the more accessible areas around the Slate Range and in Layton Canyon have been established by Mabey (1963), and a repeat observation at Mabey's Layton Spring station during one of our traverses differs by only 0.4 mgal from his value. Although observations in mountainous terrain are not as accurate as observations in the surrounding valleys, the two surveys appear compatible, no obvious discrepancies occurring where our present work joins that of Mabey.

Interpretation of gravity data. The density of twenty-eight rock samples was measured with a Jolly balance and water immersion (table 2). No determination of feldspar alteration was made, and all densities may therefore be somewhat low in relation to densities encountered in unweathered rock.

The density range of nearly 0.4 g/cc within a single mapped rock unit is not unusual for metamorphic and plutonic rocks in this area. Plutonic rock units mapped in the Rademacher Hills and Argus Mountains (west and southwest of the Slate Range) have comparable fresh rock-density variations; the larger variations in those areas occur in general near contacts of the plutonic rocks with carbonate-rich metasedimentary rocks (von Huene, unpublished data). Variations of this magnitude, however, reduce the quantitative significance of the average densities obtained from the small number of samples in table 2 and preclude a highly quantitative interpretation of the gravity data. A sizable topographic gravity residual is also possible from the elevation correction.

If anomalies produced by near-surface density variations are graphically smoothed, no large deviation of the regional gravity field appears to be associated with the Slate Range. However, the uncertainties resulting from the reconnaissance nature of the gravity and surface rock-density data are great, and a small anomaly caused by significant deep crustal density variations might be obscured.

Three areas are characterized by pronounced gravity highs associated with them. In the north half of the range, a general correspondence of high gravity values with areas of Precambrian metasedimentary rocks and Paleozoic limestone probably indicates a higher than average density for rocks in these units. The configuration of contours on the west side of this high suggests a steep frontal fault between lower density valley fill and bedrock.

An elongate zone of high gravity values lies along the west edge of the range in the vicinity of Layton Canyon. The maximum values are near the north end of this high, an area of extreme geological complexity. The remaining part of this high largely coincides with the area of Precambrian undivided metamorphic rocks, and may reflect a higher density of these rocks at depth or an incomplete topographic correction.

The third area characterized by high gravity values lies south of the Garlock fault and seems to indicate a higher average density of the bedrock south of this segment of the fault.

A gravity low just north of the San Bernardino County line, over the east-central part of the large area of plutonic rock, may be a result of lower rock densities away from the contact zones to the north, west, and south where mixing with carbonate and metavolcanic rocks has occurred; further density sampling is needed to check this interpretation. The gravity low near the south end of the range probably reflects the concealed extent of the Mesozoic granitic pluton. The northward projection of this low may indicate a shallow continuation of the pluton along a zone that lies just west of the exposed trace of the Layton Well thrust fault, and suggests that the thrust fault existed at the time of the intrusion and helped localize it.

STRUCTURE

The Slate Range is one of the northward-trending ranges characteristic of the Great Basin physiographic province. It is bordered on the south by the Garlock fault which forms the south boundary of this portion of the province, and is only about 40 miles from the Sierra Nevada which forms the west boundary. Structurally, though, the Slate Range is different from many of the other northward-trending ranges in the province because its present topographic expression is largely a result of warping rather than displacement along high-angle boundary faults.

The Slate Range also differs from other ranges in the province because it appears to lie along a zone of significant change in the earth's crust. This is indicated by differences in the character of the basement rocks that lie to the east and west of the range. To the west, late Mesozoic rocks of the Sierra Nevada batholith make up most of the pre-Tertiary basement; early Mesozoic metavolcanic rocks are absent; Paleozoic rocks are few and highly metamorphosed; and crystalline rocks known to be Precambrian are not present. To the east, late Mesozoic plutonic rocks form only small intrusive bodies; Mesozoic metavolcanic rocks are found; Paleozoic and late Precambrian strata are abundant and only mildly metamorphosed; and crystalline rocks of early Precambrian age are common (Smith, 1963).

The transitional zones between areas having contrasting basement rock types are linear though indistinct. They are nearly superimposed in the Slate Range although divergent to the north. The Garlock fault offsets them to the south, and they can best be reestablished in the Avawatz Mountains, 40 miles to the east; it seems probable that this offset is due to activity along the Garlock fault which is inferred from other evidence (Smith, 1962) to have a comparable displacement.

The Slate Range is bounded on the south by the Garlock fault and for a short distance on the east by a fault related to the Panamint Valley fault zone. Both are major crustal features that extend many miles beyond the limits of the mapped area. Five other major faults are exposed within the range, and some of these may also extend beyond its limits. The Sand Canyon, Layton Well, and Straw Peak faults are low-angle faults that dip west or northwest in the southern part of the range; they are inferred to be thrusts although evidence of actual displacement is inconclusive. The vertical New York Canyon fault strikes northwest through the middle of the range. The vertical Manly Pass fault strikes northward diagonally through the northern part of the range; this fault probably continues northward diagonally across Panamint Valley and may underlie Towne Pass in the Panamint Range.

The southwestern part of the Slate Range is structurally the highest; this may be due partly to uplift along the Layton Well and Sand Canyon thrust faults, and partly to uplift along the Garlock fault. The north end of the range is structurally the lowest, with Cenozoic rocks forming most of the outcrops.

Warping has played an important role in the development of the Slate Range, and, in general terms, the range may be considered as a north- to northwest-

Figure 5. Garlack fault scarp, view taward nartheast. Sedimentary depasits of the Christmas Canyan Formatian and Quaternary gravels constitute the higher block.

plunging anticline. The present attitudes and positions of the Tertiary sedimentary rocks show that upwarping measurable in thousands of feet has occurred since the sediments were deposited. The curved surfaces along the bases of the Sand Canyon and Straw Peak thrusts seem also to reflect this warping.

Garlock fault

The Garlock fault is about 160 miles long, and the segment that forms the south boundary of the Slate Range is about 130 miles east of the western end of the fault. Its trend here is east-northeast. In contrast to many parts of the fault zone, its late Cenozoic activity is here confined to a narrow zone consisting of a few fractures (fig. 5). In some segments, it consists only of a single mappable scarp, suggesting either that displacements have repeatedly been along the same trace or that only one displacement has occurred recently enough to still have topographic expression.

Horizontal displacement on the Garlock fault is left lateral and is estimated to be as much as 40 miles (Smith, 1962). A large horizontal displacement is indicated in the Slate Range area by the total dissimilarity of pre-Tertiary rocks on the two sides, and the contrast in gravity values. A left-lateral sense to this displacement is implied by the apparent drag on faults that join it, and by stream offsets which are measurable in hundreds of feet.

Relative vertical displacement, as indicated by the present regional topography and the position of the fault scarp, is up on the north block. Dips in the late Cenozoic sedimentary deposits of the Christmas Canyon Formation, though, suggest that the north block has moved down since their deposition. The earliest age of displacement on the fault is not indicated in this area. The latest displacement occurred after deposition of the Quaternary gravels but before deposition of the youngest alluvium, and probably occurred immediately before deposition of the Quaternary lake deposits immediately south of the fault scarp; these sediments apparently were deposited behind a dam created by vertical displacement of gravels along the Garlock fault where the fault crosses the south entrance to Panamint Valley.

Panamint Valley fault zone

The Panamint Valley fault zone is a major tectonic feature that trends north-northwest for at least 60 miles, and young fractures along it form a nearly continuous trace across the older gravels and upper parts of the fans that border the Panamint Range. For a few miles north and south of the point where it crosses the county line, the fault trace borders the west side of several masses of Quaternary gravel and a small block of Cambrian quartzite and dolomite. This part of the zone is expressed by several parallel faults, the westernmost of which cuts Tertiary volcanic rocks and Quaternary gravels that slope from the east side of the Slate Range. The southward projection of the fault zone seems to join the Brown Mountain fault which curves southeastward toward the Garlock fault (Jennings, Burnett, and Troxel, 1962).

The vertical component of relative displacement along the Panamint Valley fault zone is predominantly up on the east side, and this displacement is responsible for the steep west scarp of the Panamint Range. A few of the Panamint Range fans cut by the fault, however, were displaced up on the west side, and other exposures provide evidence of Quaternary right-lateral offset. The dissimilarity between the pre-Tertiary rocks on the two sides of this fault suggests that the displacement along it has been large, and may provide evidence of major lateral displacement.

The longest trace of the fault shown on the map is probably the most recent. Within this area, it elevates Quaternary gravels over a hundred feet. It also makes several small scarps in the alluvium, and in some areas these can be traced across all but the more recent alluvium of the washes and thus must have been formed in very late Quaternary time.

Manly Pass fault

The Manly Pass fault is the name applied to the broad fault zone that trends northward diagonally through the north half of the range. The zone is in many areas 2,000 to 3,000 feet wide, and consists of crushed and brecciated rock fragments that are rarely larger than 1 foot across. The fault zone loses its identity to the south, approximately where it meets the Sand Canyon thrust fault, but the geology in this area is complex, and the relation between these two faults could not be determined satisfactorily. To the north, the Manly Pass fault probably continues under the area of Tertiary rocks and is represented by shear zones in the plutonic rocks exposed in the deeper canyons. It may be related to the relatively minor north-trending faults that displaced the Paleozoic and Tertiary rocks and caused the small sag pond containing a playa on the top of the range, and may be responsible for the fractures in the alluvium at the north edge of the map. The northeast-trending fracture shown on the map near Manly Pass seems to offset the fault; it may be a branch of the Manly Pass fault or be part of a younger set.

Displacement on the Manly Pass fault is problematical. It seems most likely to be large because of the

Figure 6. View of the Sand Canyon thrust fault (SCT); nearest segment craps out over 2½ miles; distant segment mostly concealed under gravels. Note graben (G) in Quarternary lake gravels and normal fault (F) in alluvium. View toward south.

very wide and complex shear zone, and to have been vertical during late Cenozoic time, as indicated by the 2,000-foot scarp on its east side which is capped by a remnant of a preserved surface. Evidence against large displacement is provided by the alignment of the north-dipping contacts between Paleozoic limestone and late Mesozoic plutonic rocks on the east and west sides of the fault. This alignment suggests a virtual lack of either vertical or horizontal displacement, but probably should be disregarded because the Paleozoic limestones are somewhat dissimilar, and the lines of evidence indicating major displacment seem stronger.

Most of the displacement along this fault occurred after emplacement of the late Mesozoic plutonic rocks but before deposition of the Tertiary volcanic and sedimentary rocks. These younger rocks, though, have also been offset a few hundred feet by faults with similar trends, and a sag pond has formed along one

of these faults. The Quaternary gravels near Manly Pass are not faulted, but apparently are warped along this line. These criteria suggest intermittent activity that extends into Quaternary time.

Sand Canyon thrust fault

The Sand Canyon thrust fault is exposed along the west edge of the Slate Range (fig. 6). The southern half of its known extent is mostly covered by Quaternary deposits, but it can be seen in the more deeply dissected washes, and a 1,500-foot segment is exposed 1 mile south of Layton Canyon. To the north, about 2½ miles of its trace is exposed; beyond this, it becomes obscure in an area of extreme structural complexity. The thrust fault separates megascopically distinct Precambrian rocks, and the fault zone generally consists of a layer of chlorite-rich gouge 10 to 20 feet thick. In most places the fault dips 25° W. However, a klippe on the top of the range, just south of Layton Spring, is apparently a product of this fault, indicating that its dip flattens to the east (see cross section C-C′). Displacement on this thrust fault is not adequately known, but presumably was up on the west side, bringing Precambrian rocks with different thermal histories into contact (see section on Metamorphic rocks).

The age of main displacement on the thrust is clearly post-early Mesozoic inasmuch as it truncates the northwest-trending New York Canyon fault which displaces lower Mesozoic rocks. Two indirect lines of reasoning suggest an age of early Tertiary. First, the contrast in the degree of discordancy of the radiometric dates on rocks from the upper and lower plates suggests that the displacement occurred since the thermal event that caused the discordancy, which is estimated to have been about 70 m.y. ago. Second, in the vicinity of Layton Pass, middle Pliocene or older rocks locally rest on material that looks like the fault gouge found at the base of the klippe, implying that displacement on the thrust was early enough in Tertiary time to have its upper plate eroded down to the level of the gouge before the Teritary rocks were deposited.

The latest displacement on this fault has apparently been normal, thus creating the tension responsible for the graben in the late Quaternary deposits west of Layton Canyon and the normal faults in these deposits to the north and south of the graben. These faults are thought to be related to the thrust fault because they are closely parallel over much of their length, and because their northern and southern limits coincide with the apparent limits of the thrust. It is possible that the Quaternary activity on the thrust fault was not a result of tectonic forces, but rather a compaction of valley fill due to the additional weight of the late Quaternary lakes in Searles Valley.

Layton Well thrust fault

The low-angle fault that extends from Layton Pass to the south edge of the Slate Range is designated the Layton Well thrust fault. Between Layton Well and Layton Pass, the fault is poorly exposed so its location is approximate. However, its trace is clearly and continuously exposed southward from a point about a quarter of a mile southeast of Layton Well where it is offset by a steep east-northeast-trending fault. This segment of the thrust fault dips gently to moderately westward, and its gouge is well indurated. The northern end of the Layton Well thrust fault near Layton Pass is truncated by the New York Canyon fault, but it may continue northward from a point slightly east of the northwest end of the offsetting fault. The southern end of the Layton Well fault is also truncated by a steeply dipping fault.

The footwall rocks are lower Mesozoic metavolcanic rocks. The hanging-wall rocks are Precambrian undivided metamorphic rocks. Bedding and other planar features beneath the Layton Well thrust fault diverge from the fault plane and locally are folded. Planar features in the overriding Precambrian rocks locally are strongly and tightly folded near the fault zone.

Movement along the Layton Well thrust fault is likely to be Mesozoic but could be of early Tertiary age. It involves lower Mesozoic rocks, but is truncated on the north by the New York Canyon fault which is overlain by Tertiary rocks. Gravity data suggest that it is also intruded at its south end by plutonic rock herein assigned a late Mesozoic age.

New York Canyon fault

The New York Canyon fault trends northwest along the north edge of the topographic saddle containing Layton Pass. It consists of a zone of sheared rocks that, in places, is over 1,000 feet across. The dip on most shears is approximately vertical. The southeastern part of the fault offsets the Layton Well thrust fault and the metavolcanic rocks beneath it. The northwestern end is truncated by the Sand Canyon thrust; it is possible that the north-trending west-dipping thrust fault just east of this junction is the offset extension of the Layton Well thrust fault, but relations between rock units are very obscure in this area. If this is the correct interpretation, though, the sense of

displacement on the New York Canyon fault is left lateral and/or up on the northeast side. Activity on this fault occurred since deposition of the lower Mesozoic rocks, which are offset, and was prior to deposition of the Tertiary sedimentary rocks which cover it.

The New York Canyon fault is the southernmost of a series of parallel faults that trend diagonally through this part of the range. In detail, this set of faults is exceedingly complex, and the mapped relations are approximations, at best, of the true structure. It is clear, though, that some of these faults are truncated by the Sand Canyon thrust fault and are covered by Tertiary rocks, so are no younger than about middle Tertiary. Possibly, this set of faults is related to the Wilson Canyon fault which crosses the Argus Range to the west and has a similar strike (see Jennings, Burnett, and Troxel, 1962).

Straw Peak thrust fault

The Straw Peak thrust fault is well exposed along the south slope of the Slate Range, especially southwest of Straw Peak.

It is nearly flat along the southwest-trending ridge that includes Straw Peak, but dips away from that ridge at attitudes that increase more or less in proportion to the distance from it. It thus makes a southwest-trending arch that may have been formed in that shape but seems more likely to be the result of warping.

The upper plate of the Straw Peak thrust fault is composed of schist inferred to be of Precambrian age, and the lower plate is plutonic rock of probable late Mesozoic age (fig. 7). The zone of most severely sheared rock along the fault zone is commonly several feet thick, but pronounced shearing and deformation extend upward through the entire section of schist (figs. 2 and 2a). The lack of a clearly defined upper limit to this shearing may mean that the entire schist unit is a product of cataclasis and thus a phyllonite.

Movement along this thrust fault occurred after intrusion of the late Mesozoic rocks that form the lower plate and before deposition of the Quaternary gravels that cover part of its trace.

Figure 7. Straw Peak thrust fault showing fenster of Mesozoic plutonic rock (Mzp_4) below Precambrian schist (pEmsc). Note discordance between foliation in schist (dotted lines) and underlying thrust surface (heavy dashed line). View toward east where section D–D′ crosses fenster on west side of range.

Other faults

North and east of the northern part of the Slate Range, north- to northeast-trending faults cut some of the older alluvial gravels bordering the range. These faults appear to be mostly tension features inasmuch as they commonly form grabens. The north-trending faults may be extensions of similar faults in the Tertiary rocks of the northern Slate Range, and both sets may reflect late Cenozoic activity along the Manly Pass fault zone.

On the east slope of the central part of the Slate Range, a northwest-trending steeply east-dipping fault extends through the Sandora mine. It is clearly exposed and is marked by a zone of brecciated and altered rocks several feet wide. This fault extends northwest and seems to join an east-dipping fault on the west side of the range. This fault dips east at a fairly low angle near their projected junction, and it is nearly flat at its northwestern end. These faults were not completely mapped during our study, but it seems reasonable to conclude that they join. Rocks on either side of these faults are plutonic, though dissimilar. The fault is thus younger than the late Mesozoic plutonic rocks and older than the Quaternary gravels that cover its southeast end. Its sense of movement is not known.

Along the west edge of the Slate Range, both north and south of the mouth of Layton Canyon, a graben and a series of subparallel normal faults offset lake gravels of Wisconsin age and younger alluvium. In overall pattern (pl. 1), these fault traces are strikingly

Figure 8. Oblique aerial photograph of graben and subparallel normal faults along west side of Slate Range. View toward north, alluvial wash at mouth of Layton Canyon in foreground.

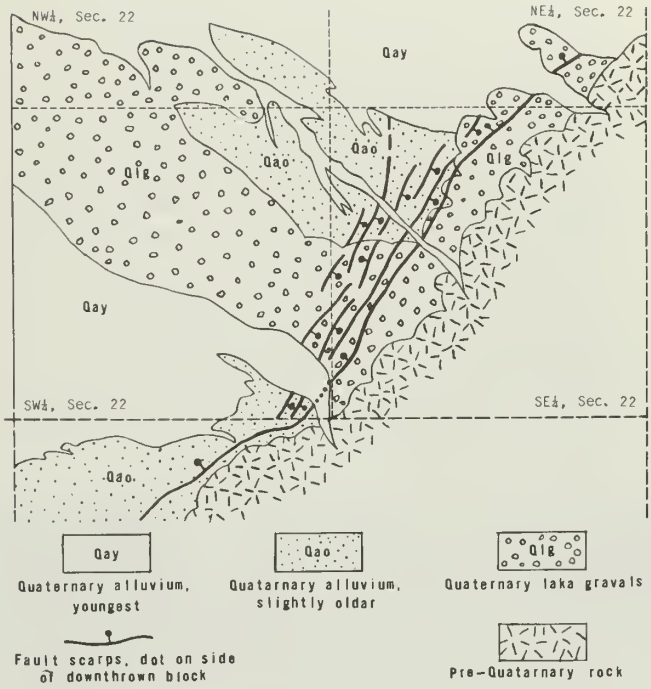

Figure 8a. Sketch map of faults in Quaternary deposits in S½ sec. 22, 1½ miles south of mouth of Layton Canyon.

linear, parallel to the mountain front, and systematic in displacement; in detail, though, some are sinuous (fig. 8), divergent, and inconsistent in displacement (fig. 8a). Displacements on these graben-forming faults are generally 5 to 15 feet. Displacement on the normal fault at the mouths of Sand and Tank Canyons is 10 to 20 feet, and the youngest segments of this fault displace all but the most recent alluvium (fig. 9); it is probably the most recent fault in Searles Valley and may have slipped within the last few hundred years. As noted in the description of the Sand Canyon thrust fault, these normal and graben faults are thought to be a consequence of the thrust fault and reflect normal displacement on it.

The thrust fault shown along the northwest boundary of the Precambrian schist unit near the south end of the Slate Range is not well supported by field evidence, but represents the more likely interpretation of the evidence observed. The transition from schist into rocks included in the Precambrian undivided metamorphic unit is generally gradational over distances of 10 to 50 feet because it is coincident with extensive shearing. Similar relations were observed near the crest of the range and in the canyons near

Figure 9. Normal fault in alluvium and older deposits. Canyon on right is Sand Canyon; canyon near left is Tank Canyon. Note shorelines from Pleistocene Searles Lake on slopes above fault.

the west edge, although the mapped relations just north of the cross-section line (D-D′) on the west slope of the range were not adequately checked.

The branching set of northeast-trending faults in the southern part of the range all dip steeply. They are younger than the Layton Well thrust fault and older than the northwest-trending faults to the southwest. Their displacements vary.

The northwest-trending faults at the southwest corner of the range have created a crushed zone several hundred feet across, where they separate Precambrian undivided metamorphic rocks, Precambrian schist, and late Mesozoic plutonic rocks from Precambrian metaplutonic rocks. They truncate the northeast-trending faults and continue southeast in a gradual arc toward the Garlock fault; one reaches and is truncated by the Garlock fault, and the other is truncated by a fault parallel to it. These faults and the slickensides on them dip southwest at about 60° and the southwest block is downdropped. The rocks of the downdropped block are lithologically similar to, and have been tentatively correlated with, the Precambrian metaplutonic rocks that form the upper plate of the Sand Canyon thrust fault. It is therefore possible that they are part of the southern extension of this upper plate, and that the thrust fault has been displaced downward by this northwest-trending set of faults. If so, these faults are probably younger than early Tertiary. The latest displacement is of Quaternary age inasmuch as the faults cut beds of the Christmas Canyon Formation and Quaternary gravels, but most of the displacement is probably older.

Although not shown on the geologic map, a set of buried faults may extend north-northwest along the east side of the north half of the Slate Range and merge to the south with the Panamint Valley fault zone near the county line. Evidence for the postulated fault zone is the steep and straight alignment of the east edge of the Slate Range north-northwest of the county line. These faults would form the west side of a deep graben occupied by this part of Panamint Valley. The lack of surface expression would mean that the latest movements on them were prior to the latest movements on the Panamint Valley fault zone.

Warping

The Slate Range can be considered a north- to northwest-plunging anticline that formed during late Tertiary time. This configuration is indicated by the distribution and attitude of the Tertiary sedimentary rocks that are composed mostly of quartzite clasts, and possibly also by the warped surfaces at the bases of the Sand Canyon and Straw Peak thrust faults.

Tertiary conglomerates composed of quartzite clasts occur in many parts of the range, and the nearest known bedrock source for these clasts is in the Panamint Range to the east. The surface on which these deposits rest is thus interpreted as a plane that predates most of the deformation responsible for the Slate Range and the south part of Panamint Valley. At present, outcrops of conglomerate on the east slope of the Slate Range dip east, those on the crest west of Layton Pass are nearly flat, and those on the west slope dip west. Inasmuch as no faults lie between outcrops having contrasting dips in the northern or the Layton Pass parts of the range, warping must be responsible for both their present attitudes and differences in present elevation. The distribution of Quaternary gravels suggests that warping has continued since their deposition.

It is also likely that this warping is responsible for much of the curvature of the bases of the Sand Canyon and Straw Peak thrusts. On the crest of the range, both thrusts lie nearly flat, although the depression that includes Layton Pass appears to be the expression of a gently west-plunging trough in this part of the surface (fig. 10). On the flanks of the range, these thrust surfaces dip at attitudes that closely parallel the probable surface of the upwarped range prior to its latest dissection, an unlikely configuration if the curvature now found at the bases of these thrust faults was formed at the time of thrusting.

North of Manly Pass, the axis of Cenozoic warping lies along the west edge of the range. The east-dipping Tertiary section forms the eastern and crest parts of the range, and Paleozoic limestone that crops out along the anticlinal axis extends to the alluvium on the west. However, east-dipping basalt and pyroclastic rocks crop out just west of the highway in Searles Valley and on the flanks of the nearby Argus Range, indicating either the presence of an adjoining parallel synclinal axis or a fault such as suggested by gravity data.

Most of the recorded warping and folding in the Slate Range is younger than the Tertiary rocks which were involved in it. Quaternary gravels exposed along the east and west edges of the Slate Range also appear tilted toward the nearby valleys at attitudes greater than likely initial dips. There is, however, no apparent warping of the Wisconsin age shorelines cut on the flanks of the Slate Range in Searles Valley, although the levels of these shorelines cannot generally be established more accurately than 10 or 20 feet.

Figure 10. View of Layton Pass (left foreground) showing surface that is interpreted as an exhumed sole of the Sand Canyon thrust fault. Fault zone of the older New York Canyon fault (NYC zone) is truncated by this surface. View toward north-northwest.

PHYSIOGRAPHY

The Slate Range is an elongate range that has steep to moderately steep slopes incised by very steep sided canyons. Its crest is undulating and has three high portions separated by two lower saddles. The two saddles—Manly Pass and Layton Pass—are preserved or exhumed older surfaces, and small remnants of a third older surface are found 2 to 3 miles north of the county line, on top of the middle high segment of the range.

The east side of the central part of the range is notably steep and straight and may reflect activity along a concealed frontal fault related to the Panamint Valley fault zone. The west side of the northern part of the range is also steep, and gravity data suggest a fault along that side. The other flanks of the range are moderately steep but not linear, and their characteristics appear to be chiefly the result of warping.

The topographic saddle containing Manly Pass is probably a result of erosion along the Manly Pass fault zone which cuts through it. Downwarping seems precluded by the dips and relations between the Quaternary gravels in this part of the range which, if anything, suggest eastward tilting and upwarping since their deposition.

The broad saddle containing Layton Pass is a west-plunging surface that extends northward across the trace of the New York Canyon fault (fig. 10). The surface is inferred to be part of the exhumed sole of the Sand Canyon thrust fault (which is younger than the New York Canyon fault), and its saddlelike shape is presumed to be a result of the same episode of warping that affected the rest of this thrust fault. The inferred origin of this part of the surface is based upon its alignment with the base of the klippe, the presence of fault gouge(?) at the base of some of the Tertiary deposits on it, and its continuity with the surface of that origin which lies along the nearby west slope of the range.

That surface (fig. 11) is deeply dissected, but its remnants clearly define a uniformly dipping plane that can be traced downward and laterally into the

Sand Canyon fault zone. Its continuation into the fault zone is visible in several of the more deeply dissected canyons, but is especially evident where the upper plate of the thrust is preserved 1 mile south of Layton Canyon (visible near the left end of the dissected surface shown in figure 11) and just north and south of Sand Canyon (shown in the foreground of figure 6).

The broad bulge in the map outline of the Slate Range south of Layton Canyon is a striking topographic feature. The bulge may be a compressional feature developed along the Garlock fault or a feature related to the Layton Well thrust fault, but the evidence is inconclusive.

Landslides are common in the range. A large mass (possibly as much as a cubic mile) of fractured plutonic rocks from the oversteepened east side of the central part of the range slid northeast and apparently blocked a segment of Panamint Valley. Since then, the slide has been largely destroyed by erosion and elevated between branches of the Panamint Valley fault, suggesting that it formed in middle or even early Quaternary time. Many smaller landslides occur in the area of early Mesozoic metavolcanic rocks and shales in the vicinity of upper Sand Canyon. These have masked much of the structure of the underlying rocks, and appear superficially as thrust faults. On one ridge, landsliding has created a small closed depression that now contains a playa lake (not shown on geologic map); this slide, at least, is probably late Quaternary in age. The small playa lake deposit near the southwest part of the Slate Range lies in a basin closed by a landslide.

Shorelines are prominent along much of the west edge of the range(figs. 2 and 9). The most prominent one, at an elevation of about 2,260 feet, was formed

Figure 11. View of uniform (though deeply dissected) west slope of the Slate Range south of Layton Canyon (foreground). Note linear base of slope; this line coincides with trace of Sand Canyon thrust fault, and, because of this and other reasons, the slope is considered to be the exhumed fault surface of the Sand Canyon thrust fault.

during the Wisconsin age stands of Searles Lake that reached the level of its spillway (Smith, in press). Less-pronounced shorelines are preserved on some of the lake deposits at lower levels. A few scattered shorelines occur at levels below 2,000 feet along the Panamint Valley side of the northern Slate Range. They are probably of early Wisconsin age but might be older.

ECONOMIC GEOLOGY

Metallic minerals that have been mined in the Slate Range include gold, lead, manganese, silver, zinc, and copper; the only nonmetallic commodity mined to date is limestone. Since about 1955 there has been no significant mineral production.

Early prospecting concentrated on metallic minerals following the discovery of gold near the mouth of New York Canyon about 1870. This was extensively mined through the 1880's, and almost certainly was the largest and most productive metal mining operation in the Slate Range. During the same period, silver was mined at the head of New York Canyon. Shortly before 1900, gold was discovered in Goff Canyon (Stockwell mine), and at about the same time several lead-silver-zinc properties were opened along the northwest margin of the range. During World War I, the Mature group of mines was explored for manganese. The most recent significant metal mining was at the lead-silver-zinc properties during World War II, but some work continued until about 1950. Considerable prospecting for gold was done at many points during the 1930's, and although several small mills were erected, only minor production resulted. Such activity terminated during World War II.

Nonmetal mining assumed importance in 1926 when West End Chemical Co. opened a deposit of Paleozoic limestone at the northwest end of the Slate Range and ended when quarrying ceased in 1955.

Gold claims have been located chiefly in shear or fracture zones that occur in rocks assigned here to three units, the Precambrian undivided metamorphic rock unit, the Mesozoic metavolcanic rock unit and the Mesozoic plutonic rock unit. Shear zones in Precambrian schist have been prospected in a few places, and the zone along the Layton Well thrust fault has been explored where vein quartz and traces of copper minerals occur. Free gold in quartz veins is reported at several prospects, but more commonly it is associated with iron oxides, pyrite, and minor chalcopyrite. Gold apparently occurs as mesothermal veins and wallrock replacements adjacent to veins. The mineralization may be related to the intrusion of the Mesozoic plutonic rocks, but its abundance in Precambrian rocks suggests that an earlier period of mineralization is responsible for some deposits.

Lead and silver, with minor proportions of zinc, gold, and copper, have been mined at about half a dozen localities along the northwest margin of the range. Some of these deposits are associated with steeply dipping fault zones in Paleozoic limestone and marble; however, the two largest mines—the Gold Bottom and Ophir—are in a limestone zone of the Precambrian metasedimentary rocks. In these, replacement lenses and cavity fillings of galena, oxidized lead, zinc, iron, copper, and manganese minerals occur as disconnected ore shoots along the fissures. The only silver deposit not associated with carbonate rocks is at the New York mine in a shear zone, apparently containing mesothermal veins in early Mesozoic metavolcanic rocks and shale. The lead and silver mineralization may be related to the intrusion of late Mesozoic plutonic rocks.

Manganese and iron enrichment appears to be localized along fault zones in the extreme southwest end of the Slate Range, but none of these concentrations has been successfully mined. Manganese also occurs in a gossan zone in Paleozoic limestone along the northwest margin of the range; tactite is developed locally along contacts of plutonic rocks.

The total value of metal production from the Slate Range is undetermined, but the Gold Bottom mine alone is reported to have yielded nearly $1 million, and by 1938 the Ophir mine is stated to have yielded $800,000 (Tucker and Sampson, 1938). Much of the mining activity occurred before production records were kept; total production from the area substantially exceeds $2 million.

The southern part of the Slate Range that is in San Bernardino County is also within the U.S. Navy's Mojave "B" Range or Randsburg Wash Test Range. These lands were acquired by the Navy in 1943 and 1950. They are, of course, closed to public entry, and no mining has been done since the mines were purchased and closed by the Navy. The northern part of the area is in Inyo County and thus outside the restricted area, but it has had little mining activity since World War II.

Gold mines

Colorado (Old Glory) mine. SW¼ sec. 36 (proj.), T. 25 S., R. 44 E., M.D.M., north of New York Canyon. Mineralized zones in Mesozoic schistose metavolcanic rocks. Gold property formerly productive as Old Glory mine. Period of greatest activity probably about 1880. Developed by 450-foot adit,

several short adits, and gopher-drifts. E. R. Wilson, Trona, held the property in 1937. About 1943 owned by J. C. Peters, 311 W. 93rd St., Los Angeles, leased to James T. Pierson, 1220½ South Plymouth Blvd., Los Angeles. Very little record available for this property, long idle.

Daily Dozen (January Jones) mine. NE¼ sec. 22 (proj.), T. 24 S., R. 44 E., M.D.M., east slope of the Slate Range. Mineralization occurs in hydrothermal fissure veins along local faults in pale-gray medium-grained granite or quartz monzonite of the Mesozoic plutonic rock map unit. Both walls are slickensided granite with gouge. Vein material consists of quartz, pyrite, and iron oxides. Gold occurs in or with the iron and panning shows little free gold. Veins dip 50° to 75°. Assays for gold and silver from 25 samples collected throughout the workings ranged from $4.26 across 4 inches to $193.35 for a 3-foot chip sample; silver values are rather constant and exceeded 5 oz in only a few samples. Underground exploration work totals about 400 feet and includes drifts, crosscuts, one raise, and one shaft 70 feet deep. Reported to have been discovered in 1901 and $75,000 to $80,000 in high-grade gold ore packed out by mules. Little, if any, work done after 1910 until the property was examined in 1965 by the present owners, Ray G. Brown, 402 E. Alamar Ave., Santa Barbara, and Norman Riggle, Trona (Brown, 1965).

Early Spring prospect. SW¼ sec. 22 (proj.), T. 26 S., R 45 E., M.D.M., east side of Slate Range. Several adits at Early Spring explore mineralized zones in Mesozoic metavolcanic rocks. The largest adit is driven N. 70° E. in a mineralized dike-like body of rock with granitic texture within metavolcanic rocks that strike N. 40°–60° W. and dip 15°–40° S. The dike-like body is stained with iron oxide and is about 300 feet wide; it appears to be similar to the body explored at the Johnson mine, half a mile to the northeast. Rocks on the dump are also iron-oxide stained and have granitic texture; they contain vein quartz and numerous limonite cubes (altered pyrite). Probably a gold prospect of the 1930's; no record of activity found.

Ghost mine. NW¼ sec. 29 (proj.), T. 26, S., R. 45 E., M.D.M., 1 mile southwest of Layton Well. A deep two-compartment shaft inclined 63° N. is sunk on a narrow zone of east-striking iron-oxide-stained thin quartz stringers at the mineralized contact of Precambrian undivided metamorphic rocks and a lens of schist. The schist lens has a general strike of N. 80° E., and dips 50°–60° N. The schist is highly sheared at the contact and forms the hanging wall of the vein material. Most of the dump material is medium-grained metaplutonic rock and contains milky quartz veins and epidote veinlets; some is greenish-gray sheared schist showing sparse sulfides, and minor sheared metavolcanic(?) rocks. There is also much iron-oxide-stained vein quartz on the dump, some vuggy quartz, and some vein material composed of stained quartz and brown calcite. The shaft contains water at a depth of about 100 feet; the size of the dump suggests at least several hundred feet of workings. A collapsed head frame, hoist house, mess hall, and office remain on the property. Apparently a gold prospect active in the 1930's, but no record was found.

Jennie B. lode. Location uncertain, not shown on geologic map. Reported to be in secs. 4 and 5, T. 25 S., R. 44 E., M.D.M. This location is at the mouth of Copper Queen Canyon in Mesozoic coarse-grained plutonic rocks. One lode claim (20.68 acres) for gold was patented to Leo D. Hirschfield in 1920. No record of activity was found. Last known owners (1943), L. D. Hirschfield, J. A. Rea, and (or) E. M. Rea, Commercial Bldg., San Jose.

Johnson mine. Center sec. 22 (proj.) T. 26 S., R. 45 E., M.D.M., east side of Slate Range. Several inclined adits and pits explore a quartz-bearing dike-like body of rock that has a granitic texture, strikes about east, is 50 to 100 feet wide, and is mineralized sporadically across its width and at least 200 feet along its length. The dike is enclosed by platy sheared Mesozoic metavolcanic rocks that strike east to northeast and dip 25° to 50° S. In the mine area, the northernmost 10 feet of the dike is the most mineralized and in places is a honeycomb of quartz with some iron-oxide stain. The principal workings consist of several shafts inclined 25° S. in a quartz and gouge zone along the footwall. At the portal of the main incline is a 5-foot face composed almost entirely of quartz. Several of the shafts have been stoped to each side and may have 50 to 100 feet of workings in each. The vein quartz area has been prospected by a number of shallow pits and trenches across the vein material 20 to 30 feet long. In places solid quartz vein material is 3 to 5 feet thick. Remnants of a hoist and small mill, and a small pile of mill tailings remain on the property. The geologic setting resembles that at Early Spring, half a mile to the southwest, although there is much more vein quartz at the Johnson mine. This property was probably a gold prospect active in 1930's, but no record was found.

Lake View mine. Center sec. 25 (proj.), T. 25 S., R. 44 E., M.D.M., upper Sand Canyon. Several adits explore a fault contact between probable Mesozoic plutonic rocks and schistose metavolcanic rocks. Fault

strikes northwest, dips 70° SW. No record of activity was found.

Layton Well mine. W½ sec. 20 (proj.), T. 26 S., R. 45 E., M.D.M. A number of shafts, adits, and shallow pits explore iron-oxide stained quartz stringers along a northeast-trending shear-zone contact between Precambrian undivided metamorphic rocks and Mesozoic metavolcanic rocks. Most of the openings are shallow, but some may have 100 feet or more of underground workings. Remains of several buildings and a small improvised mill are on the property which apparently was a gold prospect active in the 1930's, but no record was found.

Lone View and San Francisco mines. S½ sec. 2 (proj.), T. 26 S., R. 44 E., M.D.M., south side of the mouth of New York Canyon. Several quartz veins occur in shear zones in Precambrian undivided metamorphic rocks. Deposits were developed by a number of shafts and adits and worked by George Hearst and associates in the 1870's and 1880's. Ore, which was milled at the Slate Range Millsite (Deans Mill), was reported to contain $5 to $12 per ton in gold. Two lode claims (Lone View and San Francisco) were patented as part of the Alta Silver Group to D. L. Reese and others, 1890; in 1943 they were owned by Owsley, Oberteuffer, and Austin, of Trona. Long idle.

Mature group of mines (Lillie). NW¼ sec. 36 (proj.), T. 23 S., R. 43 E., M.D.M., west slope of the Slate Range on the north side of a steep canyon. The workings, which include several adits, open cuts, and shafts, explore the contact of Paleozoic limestone and Mesozoic plutonic rocks. The bottom of the canyon is quartz monzonite, which is in contact with gray crystalline limestone up the slope to the north. Irregular apophyses of quartz monzonite and several quartz veins cut the metamorphic rocks. Apparently most of the exploration on this property was done on northwest-trending fissures in limestone and was for lead, silver, and zinc, and perhaps for gold and copper. Two lode claims (Mature and Los Angeles) totaling 43.32 acres were surveyed for patent (Survey no. 4180) in 1903 and patented to Peter B. Mathiason. The largest working is the lower adit driven north about 800 feet from near the bottom of the canyon. This adit may be the development known as the Silver King mine (see below).

The property was explored for manganese during World War I and was then known as Mature Consolidated. In 1937, the Lillie claim No. 1 was located in the manganese-bearing area. According to Wilson (1950, p. 82-83), who describes the deposit in some detail, the manganese occurs in a gossan zone in irregular areas, mostly at the footwall of the limestone, which here strikes east and dips 30° N. The gossan includes manganese and iron oxides, with brown jasper and quartz vein material. Gossan areas are about 20 to 30 feet long and 1 to 3 feet thick. Much of the manganese is in the form of crusts and stains, but ore piled on the dump at the bottom of the canyon includes psilomelane, in part botryoidal, and pyrolusite. Assays from World War I investigations showed 28 percent manganese, 14 percent iron, and 23 percent silica. Development for manganese consists of a few shallow cuts. In 1942, the largest was an L-shaped cut, 3 feet wide and as much as 12 feet deep at the face, extending northward into the hill across the strike, and eastward following the strike, about 20 feet in both directions. The property was idle in 1942 and appeared to have been for some time (Tucker and Sampson, 1938; Trask and others, 1943, p. 121; Wilson, 1950; Norman and Stewart, 1951). Reported to have been sold in a tax sale in 1965.

Sandora (Hafford) mine. SE¼ sec. 19 (proj.), SW¼ sec. 20 (proj.), T. 25 S., R. 45 E., M.D.M., east slope of the Slate Range west of Wingate Pass. One patented claim (Hafford, 20.66 acres; surveyed 1900, patented to L. H. Manning, 1905) located along "Moore's Canyon" and six claims held by location (1943). J. McDonald Manning, Tucson, Arizona, owner; leased to R. M. Sanderson, South Pasadena (1943). Mine located in a zone of brecciated and altered granitic rocks several feet wide; it is associated with a major northwest-trending steeply east-dipping fault between Mesozoic plutonic rock map units 2 and 3 that extends through the central Slate Range. Gold-bearing vein reported to occur on contact of schist and granite; granite footwall and schist hanging wall. Vein strikes N. 30° W., dips 85° E., ranges from 2½ to 5 feet in width. It is reported that 10,000 tons of ore were developed, averaging $25 per ton in gold. Workings consist of a shaft sunk on the vein to a depth of 100 feet, with levels at 50 and 100 feet. On 50-foot level is a drift north 40 feet and south 40 feet; on 100-foot level, drift north 65 feet. Now idle. (Tucker and Sampson, 1943; Wright and others, 1953.)

Slate Range Millsite (Deans Mill). NE¼ sec. 10, NW¼ sec. 11 (proj.), T. 26 S., R. 44 E., M.D.M., west margin of Slate Range, between Layton Canyon and New York Canyon. Surveyed for patent in 1877 and patented in 1890 to D. L. Reese and others as part of Alta Silver Group. Before 1900 ore from the Lone View and San Francisco was treated. For 12 years prior to 1944, J. C. Dean, Trona, operated a 5-ton cyanide mill at this site; treated old tailings from the original milling of ore from the Lone View and San

Francisco claims. Four wells in the wash furnished water for milling. Apparently idle since 1944.

Standard mine. NE¼ sec. 10 (proj.), T. 25 S., R. 44 E., M.D.M., west side of Slate Range. Fault strikes north, dips 70° W. in Mesozoic plutonic rocks. Explored by several adits. No record of activity was found.

Stockwell mine. NW¼ sec. 17 (proj.), T. 24 S., R. 43 E., M.D.M., in Goff Canyon; mill and camp in sec. 14, 3 miles west. Shear zone in Mesozoic plutonic rock strikes north to N. 20° W., dips 60° to 70° NE; contains crushed quartz, talc, and altered quartz monzonite; ranges from 3 to 30 feet in width. Gold is associated with pyrite and some chalcopyrite, and a few pockets of high-grade ore are reported. More than 7,500 feet of workings include crosscuts, drifts, and shafts. Discovered about 1897 and operated intermittently until 1942. In 1937 shipped 400 tons of ore to Selby Smelting Co., stated to have an average value of $25 per ton in gold and 2 percent in copper. In 1950 the Stockwell Gold Mining Co., E. E. Teagle, president, began rehabilitation of the property and although not in production they continue to maintain the mine in standby condition (Eric, 1948; Tucker and Sampson, 1938; Norman and Stewart, 1951).

Tank Canyon mine. SE¼ sec. 23 (proj.), T. 25 S., R. 44 E., M.D.M., south side of Tank Canyon. Fault strikes east-southeast, dips 80° N.; contact between Mesozoic plutonic and metavolcanic rocks. Contact explored, presumably for gold, by means of adits, shafts, and pits. No record of activity was found.

Virginia Ann mine. NW¼ sec. 26 (proj.), T. 25 S., R. 44 E., M.D.M., north edge of lower Sand Canyon. Mineralized fault zone strikes northwest, dips 45°–70° SW. in Precambrian undivided metamorphic rocks, very close to thrust fault that separates these rocks from probable plutonic rocks and schistose metavolcanic rocks. Developed by surface work and 10-foot shaft. Owned and operated in 1940 and 1941 by Dick Gilbert, Trona. Ten tons of gold and silver ore were mined in 1940 and 8 tons in 1941. Idle since 1941.

Lead, silver, and zinc mines

New York mine. NE¼NW¼ sec. 31 (proj.), T. 25 S., R. 45 E., M.D.M., near crest of the Slate Range at head of New York Canyon. Quartz veins occur along shear zone that involves lower Mesozoic metavolcanic rocks and shale; shear strikes northwest, dips 70° S. Explored by one long adit, several small adits, and prospect pits. Two lode claims (Alta Silver and New York Silver) surveyed for patent in 1877 and patented as part of Alta Silver Group to D. L. Reese and others in 1890. Mined for silver and lead ore in the 1870's and perhaps as late as 1900. Owners in 1943 were R. Lueck and Lillian L. Lueck. Long idle.

Gold Bottom mine (American Group, Copper Queen Group, Slate Range mines). E½ sec. 36 (proj.), T. 24 S., R. 43 E., M.D.M., sec. 31 (proj.), T. 24 S., R. 44 E., M.D.M., northwest of Copper Queen Canyon. Replacement lenses of galena, oxidized lead, zinc, and iron minerals occur along fissures which parallel the strike of the bedding and contact of limestone and schist included in Precambrian metasedimentary rock map unit. Fissures trend N. 50° W., dip 65° SW.; one fissure dips 35°–45° NE. Ore shoots average about 200 feet in length and 5 feet in width. Worked by a series of adits as follows: Annex, elev. 2,230, ore 0.36 to 0.74 oz gold, 16.60 to 20.26 oz silver; Marble Halls, elev. 2,245; Mill, elev. 2,298, ore 0.17 oz gold, 2.4 to 6.10 oz silver, 5.7 to 11.5 percent lead; Queen, elev. 2,370; Truman, elev. 2,480. Underground workings total more than 7,500 feet. Discovered in the 1880's, present claims located 1906–1917; upper ore bodies mined before 1900 and lower after 1900. Includes six patented (1920) claims (American, Annex, Copper Queen, Mountain Beauty, Rosalind, Sylvia) and the Copper Queen millsite. Operated by Slate Range Consolidated Mining Co., 1916–1935; intermittently by Gold Bottom mines, 1935–1943. Ore shipments during 1936–1937 averaged 0.63 oz gold, 14.5 oz silver, 15.9 percent lead, and 0.6 percent copper. Total production between $900,000 and $1 million. Idle since 1943 (Tucker, 1926, 1938; Tucker and Sampson, 1938, 1940; Eric, 1948; Norman and Stewart, 1951).

Kane group of mines. Location doubtful, probably includes all or part of the workings shown in secs. 25, 26, and 35 (proj.), T. 23 S., R. 43 E., M.D.M. Galena and lead carbonate occur in a series of parallel fissures in Paleozoic limestone which strike N. 30° W., and dip 30°–40° W. Width of ore was reported as 1 to 2 feet, containing lead 12 to 30 percent, silver 12 to 30 ounces. Mines were worked by a series of short adits, shallow open cuts, and two vertical shafts, 50 feet and 120 feet deep in 1926. The vein observed in 1965 is 1½ to 2 feet wide, strikes northwest, and contains green copper minerals; the largest working is a shaft about 350 feet deep. Discovered in 1920. In 1926, 15 claims were under development by Belcher Extension Consolidated Mines Co. Became idle prior to 1938 (Tucker, 1926; Tucker and Sampson, 1938; Norman and Stewart, 1951).

Ophir mine. NE¼ sec. 24, T. 24 S., R. 43 E., M.D.M., north side of Bundy Canyon. Galena, lead carbonate, and lead vanadate occur in a fissure zone in limestone included in Precambrian metasedimentary

rock map unit. Zone strikes N. 30° W., dips 60°–70° W., has been developed for more than 1,000 feet along strike; ore bodies range from 2 to 20 feet in width. Some ore shipped contained 30 percent lead, 3 percent zinc, 20 percent iron, 5 to 7 oz silver; some contained 0.04 oz gold. Workings consist of three shafts, the main one 500 feet deep, and more than 2,500 feet of drifts and crosscuts; 120-ton mill on the property. The Ophir and Uncle Sam claims totaling 41.32 acres were located in 1912 and 1917 and patented to J. A. Otto in 1926; 13 unpatented claims are included in the property. Periods of operation include 1915–1916, 1926–1930, 1936–1939, 1943–1946, and some work in 1948–1949. Idle since 1950, owned by Gold Bottom mines who acquired the property in 1943. By 1938, production total $800,000 (Waring and Huguenin, 1919; Tucker, 1926; Tucker and Sampson, 1938; Tucker and Sampson, 1940; Eric, 1948; Norman and Stewart, 1951).

Silver King mine. Location uncertain, not shown on geologic map, but reported to be 9 miles northeast of Trona on the west slope of the Slate Range. The description by Tucker (1926, p. 500) suggests that the Silver King is one of the workings shown in NW¼ sec. 36 (proj.), T. 23 S., R. 43 E., M.D.M., and described herein as the Mature group of mines. This area is near the contact of Paleozoic limestone and Mesozoic plutonic rocks. Country rock is reported by Tucker (1926, p. 500) to be limestone, granodiorite, and quartzite; lead carbonate and galena ore occurs in a vein in limestone; the vein trends N. 40° W. and dips 40° NE. Adit was driven north 800 feet to intersect ore showings that outcrop. Under active development in 1926, but apparently idle since then (Tucker, 1926, p. 500).

Iron prospect

Iron prospect (unnamed). SE¼ sec. 9 (proj.), T. 27 S., R. 45 E., S.B.M., low ridge north of Pilot Knob Valley. Brecciated iron-rich Mesozoic metavolcanic rocks. Breccia fillings of magnetite and other iron oxides exposed by several shallow prospect trenches and pits over a narrow zone several hundred feet long.

Limestone

West End limestone quarry. NW¼SE¼ sec. 15, T. 23 S., R. 43 E., M.D.M., north end of Searles Lake valley. Gray to black Paleozoic limestone; in places the deposit contains thin black chert bands, and reddish-brown siliceous veinlets cut most parts of the deposit. Quarry-run rock averaged 11 percent silica but was much less by selective quarrying. Quarry opened by West End Chemical Co. about 1926 and was mined until 1955. Most of the rock was used by the company in their plant at Westend. Some aggregate for railroad ballast and concrete and minor amounts of high-grade limestone were occasionally sold. Total production about 1,500,000 tons of limestone, in 1953 rate was 75,000 tons per year. Idle since 1955.

Water

The Slate Range has very few springs. Rainfall in Searles Valley averages 3.8 inches per year, most of which falls in the winter; the rainfall in the Slate Range is probably a little higher. Springs occur along the west edge of the central part of the range, and shallow wells have been dug near some of the cabins occupied by those working the mines. A few springs occur along the east edge of the range. The flow in all of these is small, though, and at most would support only a few families. Slightly larger water supplies have been developed at Layton Spring and Layton Well, Amity Spring, and Early Spring.

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