Geology of the Funeral Peak Quadrangle, California, on the East Flank of Death Valley

GEOLOGICAL SURVEY PROFESSIONAL PAPER 413

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By HARALD DREWES

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A description of the structural development of part of a large block including contributions on megabreccias, turtlebacks, and chaotic structure overlying the Amargosa thrust fault

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By Harald Drewes

ABSTRACT

The 15-minute Funeral Peak quadrangle straddles the ranges between Death Valley and the Amargosa Valley and contains parts of the Black Mountains, Greenwater Valley, and Greenwater Range. A small part of the adjacent Bennetts Well quadrangle is also described; Dantes View and Badwater lie in the northwestern part of the area.

The rocks comprise Precambrian metamorphic rocks, Cambrian and Ordovician sedimentary rocks, Tertiary plutonic rocks, and Tertiary and Quaternary volcanic and sedimentary rocks. The oldest Precambrian rocks are schist, gneiss, and marble. These are intruded by diabase of Precambrian age, now metamorphosed to metadiorite. The youngest Precambrian rocks are small remnants of the virtually unmetamorphosed Pahrump series(?).

In the Funeral Peak quadrangle Cambrian and Ordovician rocks occur only as chaotic structural blocks that are commonly hundreds to thousands of feet long, although the full Paleozoic section in other parts of the Death Valley region is about 4 miles thick. These blocks include parts of many formations and form broken sheets that are at most a few hundred feet thick. Some of these rocks resemble the Noonday dolomite, Sterling quartzite, Wood Canyon formation, Pogonip group, or Eureka quartzite. Other rocks are unidentified dolomites similar to those common among the Cambrian and Ordovician rocks in adjacent areas.

Quartz monzonite, porphyritic quartz latite, and porphyritic quartz monzonite of Tertiary age form at least two stocks. The quartz monzonite has a border zone as wide as 2 miles that contains numerous xenoliths. It probably was passively injected into the metadiorite. Primary copper minerals occur only in these rocks or older ones.

The other Tertiary and Quaternary rocks comprise widespread and thick older rhyolite and rhyodacite volcanic rocks and sedimentary rocks, locally thick younger rhyolite and rhyodacite volcanic and sedimentary rocks, and still younger more widespread thin andesite and basalt and sedimentary rocks. The older volcanic rocks contain abundant tuff and agglomerate and are intruded by many red felsite bodies. Many felsite bodies contain veins of barite and secondary copper minerals. The younger Copper Canyon formation filled a small basin with more than 10,000 feet of playa and fan deposits, which contain some gypsum and the only identifiable Tertiary fossils found in the area. A similar, but larger, basin was filled with playa beds of the Furnace Creek formation. These beds also contain gypsum, and just northeast of the area they also contain borates. The Greenwater volcanics form several volcanic domes, on the flanks of which vitrophyre flows alternate with pumiceous tuff and conglomerate. A few andesite and basalt dikes and irregular bodies intrude the three older formations at shallow depths, and a few flows are intercalated with them. The Funeral formation of Pliocene and Pleistocene age forms a widespread thin veneer of conglomerate with andesite and basalt flows and local siltstone playa beds. Younger gravels form abundant fan and alluvial deposits and scarce beach deposits of Lake Manly, of late Pleistocene age, in Death Valley.

The geologic structural features of the quadrangle are chiefly normal faults, a few folds, and a thrust fault, the Amargosa thrust fault of Cenozoic age, but include some folds of Precambrian age. These features are typical of the Black Mountains fault block, a block extending from Death Valley eastward to Amargosa Valley (in the Eagle Mountain quadrangle) and from the Furnace Creek Ranch to a point (in the Ryan quadrangle) about 70 miles southward. The block is probably bordered by large strike-slip fault zones, which have shifted recurrently since at least early Tertiary time.

In Precambrian time the metasedimentary rocks were folded. Most folds are open; but one is tight, and all plunge gently northwestward. Parts of some of these folds were stripped to form the turtleback surfaces on the flanks of Death Valley.

After the intrusion of the monzonitic magma in early Tertiary time, the Black Mountains block was raised and internally jostled. In middle Tertiary time the thick Paleozoic section was thrust over the metamorphic and monzonitic rocks along the Amargosa thrust fault, which followed bedding planes near the base of the thick Paleozoic sequence. Much of the rock above the Amargosa thrust fault was broken into blocks hundreds to thousands of feet wide. The blocks within the quadrangle are randomly oriented and consist chiefly of wholly or unordered parts of Cambrian and Ordovician formations that are preserved beneath a major unconformity of Tertiary age. In the region south of the quadrangle, the chaotic blocks form a more extensive sheet and the blocks are somewhat systematically oriented and ordered. Many of the features of the distribution and appearance of the chaotic blocks can be explained just as satisfactorily by a hypothesis of rootless bedding-plane thrust faulting as by a more conventional hypothesis of rooted thrust faulting, or even landsliding. The thrust fault may have been formed within the Black Montains fault block through repeated adjustments to large movements on the steep faults bordering the block. Before the eruption of the older volcanic rocks, the Black Mountains fault block was lifted perhaps as much as 4 miles, and most of the 20,000 feet of Paleozoic rock was eroded.

Later, during Cenozoic time, the Black Mountains block was uplifted, tilted, and broken many times by normal faults. The times of movement on these faults are poorly dated, for fossils are scarce, but a succession of events is recognizable. The largest and best exposed faults, the Black Mountains fault system comprising a set of north-northwest-trending faults

connected by a set of northeast-trending faults, lie at the east age (turtleback surfaces) were stripped and then rapidly buried fault since the early Tertiary is at least 4,000 feet and very likely is about 10,000 feet. In response to one of the earlier movements on the fault, some of the folds of Precambrian age (turtleback surfaces) were stripped and then rapidly buried by fan deposits. During a later uplift of part of the Black Mountains block, a large mass from the raised block slid along the turtleback faults across the adjacent fans and into the playa beyond them to form the megabreccia member of the Funeral formation. Further movement along the Black Mountains fault system left the deposits on the turtleback surfaces unsupported. These deposits slid down the turtleback surfaces along the turtleback faults and partly across the Death Valley fault system. Still later movement on this fault system truncated the blocks that slid along the turtleback faults. These movements along the fault system offset the various gravel bodies different amounts. The latest of these movements offset all but the youngest gravel on the fans.

INTRODUCTION

LOCATION

The Funeral Peak quadrangle lies between the Mojave Desert of southeastern California and the Nevada boundary (fig. 1). It comprises about 240 square miles between parallels 36°00′ and 36′15′N. and meridians 160°30′ and 116°45′W. A narrow strip of the Bennetts Well quadrangle adjacent to the Funeral Peak quadrangle to the west is also described in this report. The area straddles the mountain ranges between Death Valley and the Amargosa Valley, the next major valley 15 miles to the east. About half of the area lies within Death Valley National Monument, and the scenic lookout of Dantes View lies in its northwest corner.

OBJECTIVES AND METHODS

The description of geologic features of part of the Black Mountains and Greenwater Range and interpretation of the geologic development of the area from these features is intended to help clarify the geologic development of four adjacent areas, which are being studied more intensively by C. B. Hunt, J. F. McAllister, C. S. Denny, and by L. F. Noble, L. A. Wright, and B. W. Troxel. The geologic map of this area also fills one of the few gaps in the geologic section between the Sierra Nevada near Lone Pine, Calif., and the Colorado Plateau near Boulder City, Nev.

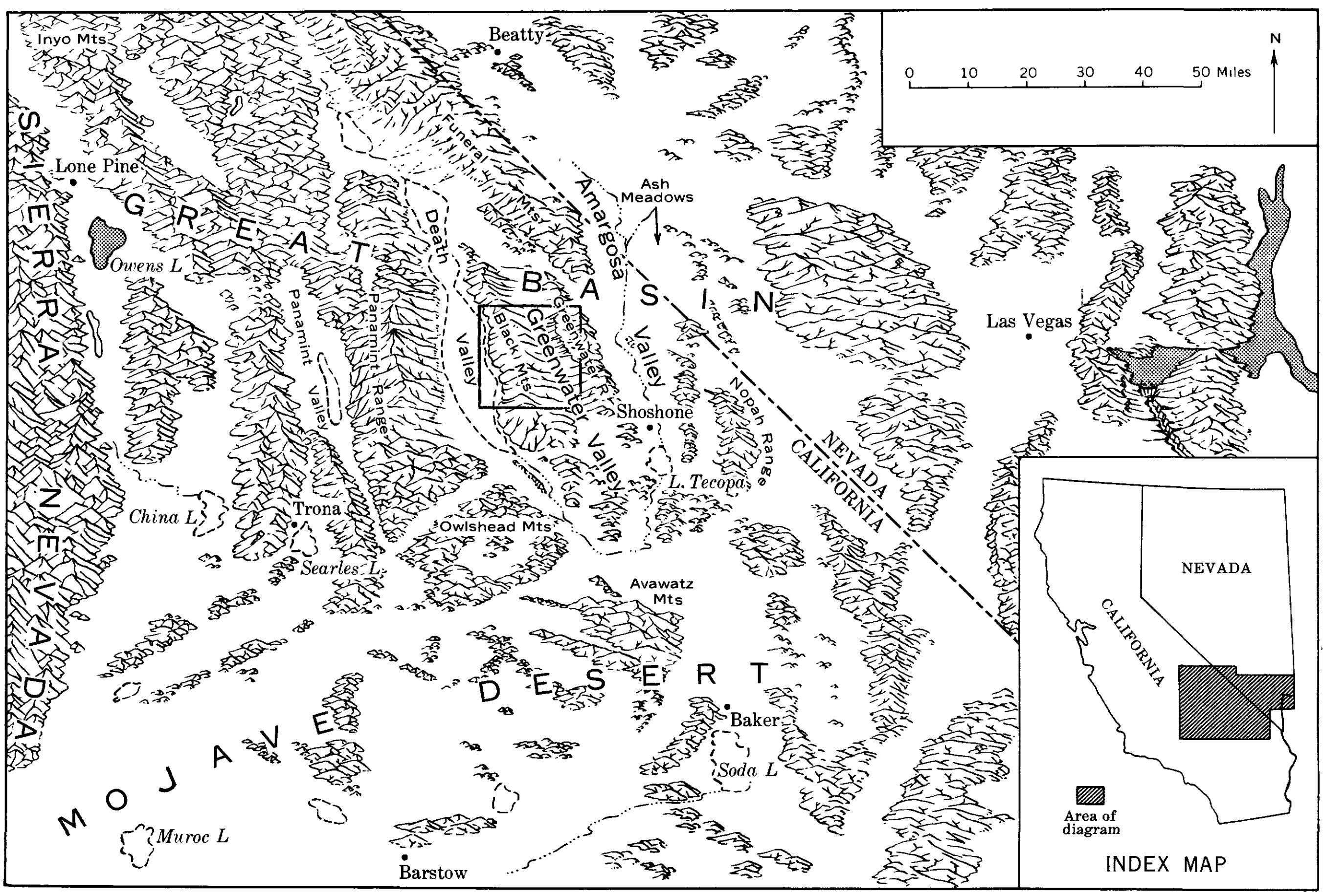

FIGURE 1.—Physiographic diagram of parts of the Great Basin, Sierra Nevada, and Mojave Desert, showing the location of the Funeral Peak area.

Particular emphasis was placed on gathering information concerning the deformation associated with the Amargosa thrust fault, the succession of the normal faults and possible strike-slip faults, and the relation between playa sediments, conglomerate, and volcanic rocks of Tertiary and Quaternary age (pl. 1).

The report is based on 133 days of fieldwork in the spring and fall of 1956, the spring of 1957, and the spring of 1958. H. C. Crandell, Jr., J. P. D'Agostino, H. B. Dyer, D. V. Lewis, and H. J. Moore assisted with the fieldwork.

The geologic map was made chiefly with a planetable and open-sight alidade upon a topographic base at a scale of 1:48,000. Vertical black-and-white aerial photographs and low-angle oblique aerial color transparencies were extensively used to augment reconnaissance mapping in the relatively inaccessible areas on the west flank of the Black Mountains.

Little geologic work had been done in the quadrangle before 1956, and the results of most of that work are unpublished. Levi Noble (1941, p. 942–997) mapped the chaotic structure in the Virgin Spring area a few miles south of the Funeral Peak quadrangle, and many of his observations and interpretations extend into the quadrangle. H. D. Curry (1938a, p. 1874–1875; 1938b, p. 1875; 1941, p. 1979; 1949, p. 1882; and 1954, p. 53–59) presented some of his ideas of the geology of parts of the western flank of the Black Mountains. T. P. Thayer also contributed to the understanding of the Tertiary stratigraphy north of the quadrangle, and his notes were available. This geologic work was summarized by Noble and Wright (1954, p. 143–160) and was illustrated by their generalized map (pl. 7) of the Black Mountains fault block and adjacent areas.

ACKNOWLEDGMENTS

On many occasions C. B. Hunt offered helpful suggestions about the structure and stratigraphy of the rocks and offered excellent criticisms of my interpretations. I have also benefited from the advice and questions proffered me during several field trips by C. S. Denny, H. G. Ferguson, James Gilluly, D. F. Hewett, J. F. McAllister, Levi Noble, B. W. Troxel, and L. A. Wright. The friendly cooperation of Fred Binnewiess, superintendent of Death Valley National Monument, and of the park rangers and naturalists is also gratefully acknowledged.

GENERAL GEOGRAPHIC FEATURES

Rugged mountains and the scarcity of water, vegetation, and roads have hindered the economic development of the area and have affected the rate and method of fieldwork. The western flank of the Black Mountains is steeper over a larger area than most other mountains in this region, and the vegetation is scantier on the floor of Death Valley than on the floors of most other valleys.

The Black Mountains and the Greenwater Range trend north-northwestward through the quadrangle. Between them lies the comparatively narrow Greenwater Valley. East of the Greenwater Range and somewhat below the level of Greenwater Valley is the broad Amargosa Valley. West of the Black Mountains lies Death Valley, whose floor is as low as 279 feet below sea level, at Badwater, a few hundred feet from the foot of the Black Mountains. Funeral Peak in the Black Mountains, the highest point in the quadrangle, has an altitude of 6,384 feet. The west flank of the Black Mountains has relief exceeding 6,000 feet; it is cut by deep canyons, all but two of which are impassable. The lower few hundred feet of the west flank of the Black Mountains is the steepest; it exceeds 40° over large areas that form little-dissected facets facing Death Valley. In some places the floor of Death Valley abuts directly against the steep foot of the Black Mountains (figs. 3 and 10), but in most places small well-defined alluvial fans and cones with radii commonly shorter than 1 mile lie at the foot of the mountains. The fans are small in proportion to the drainage area that lies above them. Interesting physiographic details of the floor of Death Valley and of the flanking alluvial fans are described by C. B. Hunt (written communication).

Walking over the steep slopes and up the canyons generally is challenging. Most rocks are sheared near the foot of the mountains and the slope is steeper than the angle of repose of debris; so the footing is treacherous. All canyons but Sheep Canyon and the lower half of Copper Canyon contain dry impassable waterfalls. Trails of mountain sheep and cairns, presumably built largely by prospectors, are reliable guides to get around these obstacles.

The steep west flank of the Black Mountains, without foothills and with only narrow canyons breaking the mountain front, contrasts markedly with the other more gentle mountain fronts and their irregular fringe of rolling foothills and broad valley embayments. The relief on the east flank of the Black Mountains and in the Greenwater Range rarely exceeds 1,000 feet, and over large areas is less than 500 feet.

The climate is very dry and water is scarce. No precipitation measurements were made in the area, but the annual precipitation in this part of Death Valley, judging from the records made at Furnace Creek Ranch, probably is less than 3 inches, and the precipitation on the higher mountains probably is only 6 or

7 inches. The amount of water in springs and "tanks," natural rock basins in which water collects and is stored, and the condition of plants vary much from year to year, for the difference of one or two showers is a significant or even critical difference in the annual precipitation. Most rain falls in summer thunderstorms, and some snow falls on the higher mountains between November and April. Summer temperatures are uncomfortably hot in the high areas and are dangerously hot in Death Valley. Winter temperatures in the mountains sometimes are uncomfortably low.

Permanent springs are scarce, and the quality of the water is poor—the pools and seeps in Death Valley, one at Badwater, and several along the road near the southern border of the area are not potable by humans but are used by mountain sheep. Small seeps lie about 30 feet above the valley floor on the north side of the middle part of Sheep Canyon, and a row of springs feed Willow Creek, which rarely flows as far as the lowest waterfall in the canyon. The potability of these waters is untested, but their salt content in undoubtedly high. Greenwater Spring and Hidden Spring flow only part of the year. Several canyons between Funeral Peak and Copper Canyon contain small tanks (rock basins in which water collects and is stored for weeks or months) near the contact between the monzonitic rocks and the metadiorite. Another larger tank lies in a shady corner 1,500 feet up the north fork of the lowest tributary canyon entering the west side of Greenwater Canyon, 2¾ miles from the north edge and 3½ miles from the east edge of the map. This tank was much used by nomadic Indians.

Most of the Funeral Peak area is covered with plants of salt-desert shrub formation (Shantz, 1925, p. 15–23). No plants grow on the salt flat on the floor of Death Valley. Shrubs and grasses which prefer or tolerate salt from a broken band along the eastern edge of Death Valley where the ground water rises close to the surface, and salt-tolerating shrubs are sparsely scattered across the alluvial fans and in the washes. Shrubs and herbaceous plants of the greasewood-shadscale association cover the high valleys, and the surrounding hills are covered by some plants of the northern desert shrub formation. The shrubs in Greenwater Valley are commonly 1–5 feet high and are spaced a few feet apart. Those on the adjacent hills are rarely higher than 2 feet and are spaced many feet apart.

The Funeral Peak quadrangle is uninhabited, and the nearest communities are many miles distant. Shoshone is 14 miles southeast of the area, and Furnace Creek Ranch is 17 miles north of the area. However, during 1906 and 1907 about 1,500 people lived in Greenwater, Furnace, and the neighboring unnamed mining camps in the north-central part of the quadrangle. These towns had telephone service and, at one time, were less than 10 miles from a railroad. However, the high cost of hauling water from Ash Meadows, then a 2-day drive, and the lack of ore curtailed their existence.

A paved road follows the eastern edge of Death Valley and another runs from Highway 190, about 7 miles north of the quadrangle, to the lookout at Dantes View. A graded gravel road runs the length of Greenwater Valley. Ungraded roads in good condition run down Greenwater Canyon to the abandoned townsites of Furnace and Greenwater and to Gold Valley and include many shorter roads shown on the topographic quadrangle map. Unmapped jeep trails extend up both major forks of Copper Canyon, up the valley north of Funeral Peak, and down the drainage leading to Virgin Spring Canyon between Gold Valley and the southeast corner of the quadrangle.

GENERAL GEOLOGIC FEATURES

The rocks of the Funeral Peak quadrangle are metamorphic and sedimentary rocks of Precambrian age, sedimentary rocks of Paleozoic age, plutonic rocks of Tertiary age, and volcanic and sedimentary rocks of Cenozoic age. They are generally typical of those in the Black Mountains block, a lozenge-shaped structural block trending north-northwestward and about 70 miles long and 35 miles wide at a maximum (fig. 2). Such rocks are common in structural blocks adjacent to the Black Mountains block, and in much of this part of the Basin and Range province, but their relative abundance differs greatly. In the Black Mountains block, rocks of Precambrian and of Cenozoic ages are abundant, and rocks of Paleozoic age are scarce, whereas the reverse is true in many adjacent structural blocks. The geologic history of the Black Mountains fault block differs considerably from that of adjacent blocks. Furthermore, it alone appears to contain the Amargosa thrust fault, and it was structurally high during much of Cenozoic time.

The distribution of the rocks within the Black Mountains block is not uniform. Many thousand feet of volcanic and sedimentary rocks of Cenozoic age underlie the northern part of the block. The central part, including the Funeral Peak quadrangle, consists of abundant metamorphic rocks of Precambrian age and plutonic rocks of Tertiary age, scattered blocks of sedimentary rocks of Paleozoic age, a thin but widespread sheet of volcanic rocks, and thick local deposits of sedimentary rocks both of Cenozoic age. The southern part of the Black Mountains block is underlain by abundant metamorphic and sedimentary rocks of

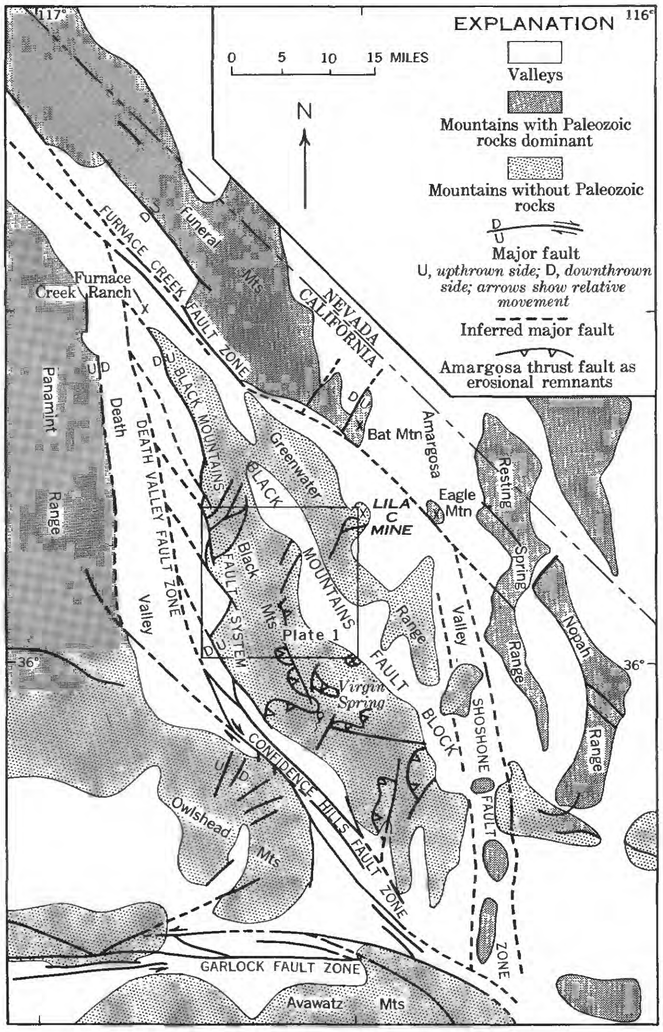

FIGURE 2.—Generalized geologic map of the Black Mountains fault block and vicinity, adapted, in part, from Noble and Wright (1954, pl. 7).

Precambrian age, a discontinuous sheet of sedimentary rocks of Paleozoic age, and a thin discontinuous sheet of volcanic and sedimentary rocks of Cenozoic age.

The rocks in the Funeral Peak quadrangle are divided on the geologic map (pl. 1) into 23 units, many of which are only local informal lithologic units. The rocks of Precambrian age comprise a metasedimentary unit containing schist, gneiss, and marble, a metadiorite unit, and a sedimentary unit. Rocks of Cambrian and Ordovician age are mapped as one unit but contain blocks of many formations recognized outside the Black Mountains block. The plutonic rocks of Tertiary age include a unit of fine-grained monzonitic rocks and a unit of coarsely porphyritic quartz monzonite. The rocks of Cenozoic age comprise five major volcanic and sedimentary units of Tertiary age, one sedimentary and volcanic unit of Tertiary and Quaternary age, and six units of Pleistocene and Recent age.

The rock were variously folded, faulted, and intruded at intervals from Precambrian to Recent time. Lack of fossils prevents accurate dating of the orogenic events of the area and leads to a chronologic sequence of events with only two radiogenic age determinations and a few generalized estimates of the age of specific events. During Precambrian time the rocks were folded and faulted and were intruded by a pluton that was later altered to metadiorite. Monzonite plutons were emplaced in early or middle Tertiary time, with little deformation of the surrounding rock. Paleozoic rocks were thrust over metamorphic and monzonitic rocks and were broken into chaotic blocks a few hundred feet to a few thousand feet long during early or middle Tertiary time. Later during Cenozoic time the rocks were broken along normal faults, were intruded by volcanic rocks, and were gently folded. The master faults of the area, including the mapped Furnace Creek and Confidence Hills fault zones and the inferred Death Valley and Shoshone fault zones, which border the Black Mountains fault block, were active during Cenozoic time and may have a large component of strike-slip displacement. Most high-angle faults in the quadrangle are subsidiary structural features, related to the master faults. The fault trough of Death Valley probably was initiated in middle Tertiary(?) time and certainly has been a major trough since Pliocene or early Pleistocene time. The turtleback faults are low-angle normal faults formed in response to a dropping of the floor of Death Valley trough in early or middle Pleistocene time.

The mineralization of the area occurred in early or middle Tertiary time and consists mostly of secondary copper minerals, a little gold, silver, and barite. A little gypsum and much pumice was deposited in local basins.

PRECAMBRIAN ROCKS

Rocks of Precambrian age include a dominant older group of highly metamorphosed sedimentary and igneous rocks and a subordinate younger group of little metamorphosed sedimentary rocks. The older rocks comprise abundant metadiorite and smaller bodies of metasedimentary schist, gneiss, and marble. All the older rocks are cut by feldspathic dikes and by basaltic or andesitic dikes probably also of Precambrian age. The younger rocks are dolomite and argillite.

METASEDIMENTARY ROCKS

GENERAL DESCRIPTION

Schist, gneiss, and marble underlie the lower parts of northwest-trending prominent spurs descending from Smith Mountain to Mormon Point and from the ridge southeast of the mouth of Copper Canyon. Schist and gneiss also appear in hills south of Gold Valley and in the Greenwater Range about 4 miles south of the upper end of Greenwater Canyon, and gneiss is exposed on the west side of Smith Mountain high above Mormon Point. Small unmapped masses of faintly gneissic rock in metadiorite may be either inclusions of partly transformed schist and gneiss or merely an early phase of the metadiorite.

Schist and gneiss in about equal amounts constitute more than 90 percent of the metasedimentary rocks. They are the only types present in the areas south of Gold Valley and in the Greenwater Range. Southeast of Mormon Point and of the mouth of Copper Canyon, the metasedimentary rocks include marble. Marble is most abundant near Mormon Point, where it constitutes 25–50 percent of the rock and appears to be even more abundant because it forms conspicuous resistant sheets parallel to the surface of the ridge. In the spur south of Copper Canyon, marble does not exceed 25 percent of the exposed metasedimentary rocks. A little pegmatitic granite in the Greenwater Range and some migmatite and augen gneiss near Smith Mountain and near Gold Valley are mapped with metasedimentary rocks.

Steplike terrain of small cliffs alternating with benches is developed on many of the schist and gneiss units, which are medium dark gray from a distance, and on the marble, which is pale yellow brown. Streambeds across them have many falls. These steplike features are poorly developed, however, where the average slope is very steep, as along the front of the range. Steplike topography is especially characteristic of slopes cut on a mixture of marble and schist, as in part of the Mormon Point area. By contrast, less conspicuous or irregular breaks in slope are formed on the more weakly foliated metasedimentary rocks. The adjacent slopes of metadiorite are also dark gray but do not form small cliffs and benches. Slopes on the younger monzonitic rocks are generally distinguished by being lighter pinkish gray and having smoother, more rounded slopes with more extensive areas covered by fine rubble.

The thickness of the metasedimentary rocks is unknown because their top and bottom are covered. The exposed thickness in the ridges south of Copper Canyon and Mormon Point is probably several hundred feet, considerably less than the local relief, for the rocks form broad plunging arches (Drewes, 1959, fig. 3 and pl. 1) with axes roughly following the ridge crests. The thickness of these rocks exposed in Gold Valley and the Greenwater Range is probably much less than on the two ridges. The stratigraphic relations between separate masses of metasedimentary rocks are unknown. The metasedimentary rocks are everywhere faulted against younger rocks or are intruded by them.

PETROGRAPHY

The schist is greenish gray on both fresh and weathered surfaces and readily breaks into platy or small slabby fragments an inch to a few inches thick. Less schistose migmatitic or gneissic rocks break into thicker slabs and blocks. Lamellae of quartz and feldspar, generally less than 3 mm thick, separate sheets of mica; in some schist they form thicker lenses and augen. The lamellae and the alined mica between them make the strong foliation, which in some places is deformed into small-scale drag folds. Pods and veins of chlorite and epidote generally are less prominent in these rocks than in the other Precambrian rocks.

The schist generally comprises quartz, plagioclase, chlorite, biotite, and sericite and has minor amounts of magnetite, sphene, and possible potassium feldspar. The texture is commonly schistose, less commonly is cataclastic; locally there are other textures. For example, the schist from Gold Valley has scattered grains and faint layers of larger biotite and quartz grains surrounded by smaller ones. Also, the schist in Copper Canyon has abundant layers and pods of quartz and feldspar with a hypidiomorphic-granular texture, and some patches with a cataclastic texture. Furthermore, certain schistose layers have weak mortar texture formed by scattered rounded feldspar grains.

Quartz forms 10–25 percent of the rock and occurs as anhedral grains ranging in average size from 0.05 to 0.2 mm. Some quartz is strained and has grown around edges of feldspar grains; other quartz is unstrained, forms a mosaic pattern, and is embayed by the chlorite-rich groundmass. Plagioclase forms 15–25 percent of the rock and occurs as rounded grains as large as 2 mm. It is probably in fine-grained pods with quartz. In one thin section the large grains of plagioclase are probably oligoclase. Biotite forms 10–20 percent of the rock and occurs in alined plates 2–3 mm long. In some places these grains are surrounded by an aggregate of fine mica flakes, some of which may also be biotite. Biotite is partly altered to chlorite. Chlorite forms 30–60 percent of the rock, and sericite, 10–20 percent of the rock. Together they form a fine-grained strongly sheared matrix between the less sheared minerals and replace to some extent all the other minerals, with the exception of the interlocking quartz aggregate in the pods. None of the secondary minerals, except sericite and chlorite, exceeds 2 percent.

Gneiss is gray on both fresh and weathered surfaces. Surfaces cutting the foliation are very light gray to dark gray; those parallel to the foliation are dark gray. The rock consists largely of quartz, feldspar, and biotite. The quartz and feldspar together form light-colored layers generally less than an inch thick, which alternate with comparatively thin dark-colored layers of biotite. The gneiss has less mica than the schist; these two rock types are probably gradational at Copper Canyon and at Mormon Point. The layering in some gneiss is even and distinct; in others it is less regular, with the light-colored layers forming alined pods and lenses. Still other gneiss contains feldspar augen ½–1 inch long. Veins and irregular masses of epidote are locally conspicuous.

Most gneiss contains quartz, plagioclase, potassium, feldspar, biotite, and muscovite, with a hypidiomorphic to idiomorphic texture. Small amounts of chlorite, apatite, magnetite, sphene, and zircon are also present. Locally, the gneiss has a cataclastic texture with sheared mica flakes and subrounded, granulated feldspar grains. Some large crystals of potassium feldspar are poikiloblastic.

The plagioclase constitutes 15–40 percent of the rock; it is commonly sodic andesine or oligoclase, but in a few rocks it is albite. Potassium feldspar constitutes as much as 40 percent of the rock; most of it is probably orthoclase, but the larger grains are perthite. Quartz makes up 20–40 percent of the rock. Biotite and muscovite each constitute as much as 20 percent of the rock but do not appear in the same rock. Many of these grains are sheared, and the biotite alters to two types of chlorite, one a penninitic chlorite, which together constitute as much as 5 percent of the rock.

The marble is white to light olive gray and weathers to yellowish gray and pale yellowish brown. Some weathered surfaces of the rock have many small sharp pinnacles. Weathered fragments form small irregular plates. The marble forms beds and lenses a few feet thick to a few tens of feet thick that are intercalated in the schist and gneiss. This lithologic alternation probably represents former bedding in the metasedimentary rocks. Much of the marble is coarsely crystalline calcite marble, but some at Mormon Point is dolomitic. Clastic impurities are more common in the rock at Copper Canyon than in that at Mormon Point. Small carbonate veins cut the marble lenses and adjacent rock.

Calcite or dolomite is the dominant mineral. A few percent of chlorite and limonite occur in marble from Copper Canyon, and the accessory minerals in one specimen from Mormon Point include 10 percent clinopyroxene (diopside?), 5 percent talc(?), 2 percent quartz, 1 percent graphite, and a trace of sphene. Tiny grains in the marble from Copper Canyon form a brown mylonite in thin section, but those from Mormon Point are elongate interlocking anhedral crystals about 0.5 mm long. The diopside(?) forms clear subhedral grains; the graphite forms flanky or granular aggregates; the muscovite is generally tabular, but some grains are bent; quartz grains are rounded, and sphene occurs in large euhedral crystals.

ORIGIN AND AGE

The schist, marble, and possibly some of, or all, the gneiss are sedimentary rocks that were metamorphosed at moderately high temperature and pressure and were later recrystallized at a lower temperature. The alternating marble and schist were probably derived from limestone or dolomite, and shale; the gneiss was probably derived from siliceous and argillaceous clastic rocks. The assemblage of biotite, oligoclase, quartz, and some clinopyroxene places these rocks in the almandine-diopside-hornblende subfacies of the amphibolite facies (Turner and Verhoogen, 1951, p. 459). Most rocks were slightly sheared during metamorphism, for a little cataclastic texture occurs at the edges of the quartz-feldspar lamellae but is less conspicuous than the hypidiomorphic-granular texture. However, some gneiss was more strongly sheared and developed cataclastic texture and, rarely, mortar texture. Biotite and chlorite in the gneiss with mortar texture, and possibly also that between the slightly sheared quartz-feldspar lamellae, are undeformed or less deformed than the other grains and seem to have recrystallized to the greenschist metamorphic facies after the shearing.

The metamorphic rocks in the Black Mountains cannot be dated directly, but the rocks are similar to the older Precambrian (locally called Archean) rocks of nearby areas, for example the classic area of the Grand Canyon (Noble and Hunter, 1916). The metamorphism of the schist unconformably beneath the sedimentary rocks and diabase sills of the Pahrump series of younger Precambrian age in the southern Nopah Range is dated as 1,670 m.y. (million years) by K/A potassium argon and 1,720 m.y. by strontium-rubidium methods by Wasserburg, Wetherill, and Wright (1959). The metamorphic age of this schist is anomalously younger than that of mica from a pegmatite vein cutting the schist. In spite of some details in need of explanation, the schist is probably older Precambrian.

METADIORITE

GENERAL DESCRIPTION

Largely unfoliated or very subtly foliated metadiorite, consisting largely of hornblende and feldspar, forms the bulk of the lower Precambrian rocks in the quadrangle. The rock is distributed along the crest and west flank of the Black Mountains and is exposed in a zone 1–2 miles wide between Coffin Canyon and the northern edge of the area near Badwater.

FIGURE 3.—West flank of Black Mountains north of peak 4214, just south of Sheep Canyon, lower right. The skyline ridge dropping to Death Valley, left and center, is approximate profile of surface of Copper Canyon turtleback and is underlain near the crest by broadly arched metasedimentary rocks that grade into metadiorite near Sheep Canyon.

Abundant blocks are included in the fault wedge at the mouth of Coffin Canyon. A larger zone of metadiorite is exposed in upper Coffin Canyon, extends east of lower Copper Canyon and the adjacent ridge of metasedimentary rocks, and is nearly 5 miles wide south of Sheep Canyon. Farther south the zone is 1–2 miles wide between the front of the range and the metasedimentary rocks of Mormon Point to the west and the porphyritic quartz monzonite to the east.

Slopes underlain by metadiorite are medium dark gray except locally near the felsite intrusive rocks of the older volcanics, where both rocks are dark red. The rock forms abundant steep slopes and cliffs, which are generally more prominent than those formed on adjacent monzonitic rocks, but much less prominent than those formed on the felsite. Weathered fragments are generally coarse and blocky to irregular.

The metadiorite appears to intrude the metasedimentary rocks and is intruded by monzonitic and felsitic rocks, but in a few places the contacts are faulted. From the gneiss toward the metadiorite, the banding of the gneiss becomes gradually less distinct, the foliation gradually weaker and discontinuous (fig. 3), and the biotite and quartz content smaller. Gneiss is mapped wherever the foliation is continuous and sufficiently strong to be seen easily in the outcrop. On the southern ends of the three areas along the east flank of Death Valley underlain by metasediments the gradation takes place over thousands of feet, but east of Mormon Point the gradation occurs over a few tens of feet, and the metadiorite appears to truncate the folds in the metasedimentary rocks.

PETROGRAPHY

Metadiorite is medium dark gray to dark greenish gray on fresh and weathered surfaces alike. Grains of plagioclase, hornblende, and, in some rocks, biotite are visible. The rock is commonly massive and moderately coarse, but locally it is fine grained and uniformly gray or coarse grained and mottled black on very light gray. In some places lenses or pods of fine-grained metadiorite a few inches to many feet wide are surrounded by the coarser grained variety, and in others the coarse-grained rock dilates the fine-grained one. Slightly elongate and alined grains give some rocks a weak, discontinuous foliation; these may be inclusions of gneiss or local flow structure. Epidote-rich veins and pods, and some small bodies of highly feldspathic rock cut the metadiorite, as do the more mafic dikes that are discussed as follows:

TABLE 1.—*Modal analyses of metadiorite*

Specimen No.	25	26	27
Field No.	56D56c	56D62b	56D83
Mode points	2135	2184	2000
Plagioclase composition	An_{25-70}	An_{35-50}	An_{30-40}
Plagioclase	60.0	47.8	54.2
Hornblende	37.2	36.9	39.2
Biotite	1.5	9.4	1.4
Sphene	.7	.4	.7
Magnetite	.3	.1	3.5
Apatite	.1	.2	.7
Clinopyroxene	0	5.3	.2

The mineralogy of the metadiorite is relatively simple and uniform. Andesine or oligoclase, common hornblende, and biotite are the dominant minerals; and sphene, titaniferous magnetite, apatite, and, rarely, quartz and pyroxene are the accessory minerals. The modes of three moderately coarse specimens are given in table 1.

The microscopic texture of metadiorite is hypidiomorphic granular with the dominant minerals commonly 0.3–2 mm in diameter. In some rocks the dominant minerals are weakly alined and in others a cataclastic texture appears. Still other rocks have an ophitic texture of ferromagnesian minerals, particularly horneblende, in a crude felty network of subhedral plagioclase. In other rocks the ferromagnesian minerals are clustered.

Plagioclase constitutes 40–65 percent of the rock and ranges in composition from labradorite to oligoclase. It occurs in three habits: some plagioclase forms stubby, subhedral grains with a length-to-width ratio between 3:1 and 5:1; others are anhedral and equidimensional; still others are large and poikilitic. Grains with the first two habits occur together in different proportions and constitute nearly all the feldspar. Considerably more than half of the subhedral grains are twinned, but comparatively few of the others are twinned. The large, crudely poikilitic plagioclase grains occur as broadly zoned grains, widely scattered among the other plagioclase types, but scarcer among the subhedral grains than among the anhedral ones. The margins of some of the poikilitic grains are ragged, for plagioclase of the outer composition zones wraps partly around the smaller adjacent grains; however, the inner zones maintain the subhedral shape of the grains. Plagioclase is slightly altered to sericite and possibly to kaolin. Twinning and sericite alteration are more common in the cores than in the outer zones of the broadly zoned grains. Most twins of all types of plagioclase grains are polysynthetic albite, pericline, and a few other twins. Untwinned plagioclase that veins some of the large plagioclase grains is as free of sericite alteration as the outer zones of the large grains, and hence probably also with a relatively sodic composition.

Common hornblende constitutes 20–40 percent of the rock and is pleochroic with X=pale olive, Y=grayish olive green, and Z=grayish blue green. It generally occurs in clusters associated with biotite and is subhedral or euhedral. In the coarser grained rocks some grains are poikilitic. The birefringence is about 0.024, $Z \wedge C$ is 20°–24°, and n_z=1.64–1.65. Hornblende alters to chlorite in a few rocks, possibly by way of a very pale green slightly pleochroic amphibole such as actinolite.

Biotite makes up 3–15 percent of the rock and is pleochroic in pale brown to moderate brown or dark brown. The grains are subhedral and are alined in the weakly foliated rocks. In some specimens biotite alters to chlorite.

Of the accessory minerals, sphene forms 2 percent of the rock and appears as conspicuous, large euhedral or subhedral grains with a very high birefringence and relief. Titaniferous magnetite forms 1–3 percent of the rock and is commonly anhedral, but some grains are subhedral, and some are intimately intergrown with other ferromagnesian minerals. It is commonly associated with apatite and sphene. Apatite generally constitutes less than 1 percent of the rock. The pyroxene is probably diopside or augite and forms colorless anhedral to euhedral grains, with moderately high relief, a birefringence of about 0.029, and a $Z \wedge C$ of 40°–45°. In two specimens it appears as irregular cores in hornblende, which replaces it. The few zircon grains are subhedral and colorless or faintly pinkish. Quartz is rare.

ORIGIN AND AGE

The structure and texture of the rock suggest that it had an igneous origin, and the mineralogy points to a rock almost entirely without quartz and of dioritic or even gabbroic composition. The ophitic habit is a peculiar one for hornblende but is common to pyroxene in diabase. The poikilitic texture of other hornblende suggests secondary growth from the pyroxene cores. Perhaps the subhedral and much-twinned plagioclase grains and, of the other plagioclase grains, the outer zones which are wrapped around adjacent grains are also secondary. This replacement is the chief metamorphic process that has affected the original diorite or gabbro; the metamorphism could have occurred at the same temperature and pressure as the metamorphism of the metasedimentary rocks.

The metadiorite is younger than the metasedimentary rocks, and it possibly also is younger than the folding of the metasedimentary rocks, for it is virtually unfoliated, and it intrudes and appears to truncate the foliated rocks. In degree of metamorphism it has a far greater resemblance to the older Precambrian rocks of the Funeral Peak quadrangle than to the

Pahrump series of late Precambrian age; therefore the metadiorite is tentatively assigned to early Precambrian.

FELDSPATHIC AND ANDESITIC DIKES

Abundant small unmapped feldspathic dikes and others of basalt or andesite cut the metasedimentary rocks and the metadiorite. They are metamorphosed to a degree more nearly comparable with the older Precambrian metamorphic rocks than with younger rocks, but many are less deformed than their host rocks.

The feldspathic dikes are probably of several varieties and ages. They form locally conspicuous, light-colored streaks on the gray slopes underlain by the metamorphic rocks. Most of them are less than 30 feet wide and have sharp borders. Plagioclase and possibly potassium feldspar are the dominant minerals, and together with their alteration minerals, they constitute more than 95 percent of the rock. Quartz and biotite are the chief accessory minerals. Some dikes near the quartz monzonite pluton have the appearance and composition of that rock; others are more feldspathic and contain no quartz and less ferromagnesian minerals and are more altered than the quartz monzonite of the plutons. The more altered and sheared dikes are probably early Precambrian. Some of the monzonitic dikes near the monzonitic pluton are probably of the same age as the pluton. The age of most other dikes is unknown.

The andesitic dikes are fairly uniform, and all are probably of the same age. At a distance they are inconspicuous, but on outcrops they are a darker gray than their host rocks. Most dikes are a few feet wide, but one body, a few hundred yards east of hill 5172 on the southern edge of the map area, is at least several tens of feet wide. The contacts are sharp. Plagioclase is the most abundant mineral; where alteration is not too severe, the plagioclase is andesine or labradorite, but in one altered rock some of the andesine is albitized. Hornblende(?) and biotite are the usual ferromagnesian minerals; in one rock there is a little clinopyroxene, and in another there are chlorite pseudomorphs after olivine. Magnetite, apatite, sphene, and, rarely, quartz are accessory minerals; pyrite occurs in the rocks of two dikes and may be primary. Chlorite is the most common alteration mineral and hematite, limonite, uralite, epidote, calcite, and kaolin(?) also appear. The rock is generally porphyritic, and the groundmass feldspar laths have a felty texture to a flow texture with intergranular ferromagnesian minerals. The age of these dikes is uncertain; they cut the metadiorite but do not intrude the allochthonous blocks of Paleozoic sedimentary rocks. Conceivably they have a late Precambrian age, for during that time abundant diabase was injected into the Pahrump series several miles south of the quadrangle (Wright, 1952, p. 1347–1348), and perhaps these andesitic dikes are associated with them.

PAHRUMP SERIES(?)

Rocks very tentatively correlated with the Pahrump series underlie several small areas. One group forms structural blocks, just large enough to map on plate 1, at the mouth of Coffin Canyon; the other group forms inclusions in the monzonitic rocks northeast of Gold Valley. None of these blocks has a distinctive lithology of rocks of Paleozoic or of Precambrian age, but they are either slightly metamorphosed or mixed with abundant blocks of Precambrian age. Conceivably, some of the blocks mixed with the chaotic blocks of Paleozoic age in other parts of the quadrangle are also of this series. In these places, too, blocks without diagnostic lithology are tentatively correlated through the blocks with which they are most abundantly associated.

In the Gold Valley area the rocks of questionable age are largely dark-gray hornfels or argillite with some crystalline limestone, cherty limestone, and quartzite. They are surrounded and in places intruded by fine-grained quartz monzonite. The hornfels or argillite has much limonite stain on closely spaced fracture surfaces. The occurrence of hornfels or argillite below a well-marked relatively continuous flat-lying fault suggests that they are part of the lower plate of the Amargosa thrust fault. The rocks are more likely of Precambrian than of Paleozoic age because the Pahrump series of Precambrian age forms part of the lower plate to the south and in no place do the Paleozoic rocks underlie the thrust fault.

Near the mouth of Coffin Canyon, there is a mixture of rocks similar to that occurring northeast of Gold Valley, except that a larger proportion of blocks are metadiorite, gneiss, and quartz monzonite near the mouth of Coffin Canyon. Among the larger blocks, which are vertical slabs parallel to the front of the range and which straddle the canyon near its middle, is a dark-brown crystalline dolomite. Other small unmapped blocks include limestone and shaly limestone. The mixture of blocks resembles the structure of the chaotic blocks described in the following section. The absence of distinctive Paleozoic blocks, coupled with the abundance of metamorphic blocks and brown dolomite, suggests that the sediments may be of the Pahrump series; however, they could be younger.

The Pahrump series south of the quadrangle includes many thousands of feet of slightly metamorphosed or unmetamorphosed arkose, quartzite, conglomerate, diabase, as well as greenish-gray shale and grayish-brown dolomite. It is not reported north of the southern end of the Nopah Range, the Virgin Spring area, and the Panamint Range across Death Valley from Mormon Point. The rocks of the Pahrump series commonly lie unconformably between the older Precambrian rocks and the Paleozoic rocks; however, in the Nopah Range and the Virgin Spring area, they form structural blocks in thrust(?) faults. Thus the presence of a few blocks of the Pahrump series in the Funeral Peak quadrangle is not surprising. The series was apparently deposited or preserved in a trough elongate northwestward and not extending southwest of the Garlock fault zone or its southward extension. The rocks are accepted as late Precambrian rocks because of the position unconformably between older Precambrian and Paleozoic rocks.

CAMBRIAN AND ORDOVICIAN ROCKS

GENERAL DESCRIPTION

Sedimentary rocks largely of Cambrian age, but including rocks of Ordovician age and possibly even younger Paleozoic rocks, form many small scattered outcrops between Funeral Peak near the center of the quadrangle and the southern border of the area. The total area of exposure is less than 2 square miles. One belt of these rocks trends from the southwest flank of Funeral Peak along the northeastern edge of Gold Valley to northeast of hill 5021. Scattered outcrops of Paleozoic sediments also occur in the southeastern corner and near the southern border of the area. The outcrops near hill 5172 are the northernmost ones of a belt which continues southward beyond the quadrangle to the Virgin Spring area (fig. 2).

The Cambrian and Ordovician rocks are everywhere in fault contact with the monzonitic rocks and the old metamorphic rocks; in many places they are intruded by Tertiary volcanic rocks, and in other places they are unconformably overlain by the volcanic rocks or are in fault contact with them. The rocks along these faults, however, are much less sheared than those along the faults between the older metamorphic rocks and the Cambrian and Ordovician rocks, and those between adjacent blocks of Cambrian and Ordovician rocks.

The continuity of the patches of Cambrian and Ordovician rocks generally decreases northward. South of the quadrangle in the Virgin Spring area (fig. 4), they form a continuous thick sheet; but in the southern third of the Funeral Peak quadrangle, they

FIGURE 4.—Cambrian and Ordovician sedimentary rocks, Pzs, on the Amargosa thrust fault. The large knobby outcrops are Noonday dolomite, which is separated from the Precambrian metasedimentary rocks, p€s, underlying the gentle slopes by a gouge sheet many feet thick. Between the arrows the gouge sheet contains rounded fragments. The smaller knobby outcrops in the foreground are typical of Tertiary tuffaceous rocks, Tv, and intrusive rhyolite, Ti. View of east side of hill 5172 south of Gold Valley.

are relatively small and discontinuous. In the rest of the quadrangle, they are absent or covered.

A once greater extent of these Paleozoic rocks is suggested by inclusions in the volcanic rocks, by thick carbonate veins, and by fragments in the conglomerate members of the Funeral formation and the Copper Canyon formation. Most carbonate veins and inclusions of sedimentary rock occur near exposed Cambrian and Ordovician rocks; however, quartzite of Paleozoic age and monzonite fragments of Tertiary age occur in several of the older volcanics intrusive east of Greenwater Canyon. The dike largely northeast of section *A–A′* of plate 1, for example, contains such inclusions. The abundant cobbles of quartzite and dolomite of Paleozoic age in the Funeral formation in the northeastern corner of the area also suggest that these rocks were once exposed nearby. Furthermore, the former presence of quartzite of Cambrian or Ordovician age near the mouth of Copper Canyon is indicated by the abundant coarse angular quartzite fragments in the very light gray beds in the conglomerate member of the Copper Canyon formation at altitude 1,300 feet on the main spur of the ridge 1 mile east of the mouth of Copper Canyon. Several small blocks of carbonate rocks were found only after thick gray carbonate veins indicated that the small gullies should be examined more carefully.

Areas underlain by Cambrian and Ordovician rocks attract attention with their patchwork of gray, brown, red, and yellow colors, which are more varied than those of the other rocks. The knobby-weathering habit of the carbonate rocks is generally distinctive, although some of the intrusive rhyolitic rocks have a similar appearance but more restricted color range.

The mapped areas of Cambrian and Ordovician rocks do not form a simple bedded sedimentary sequence but consist of more than 150 discrete large blocks that are separated from each other and from the underlying rocks by crushed and sheared rock a few feet to a few tens of feet thick. Most blocks are monolithologic, but a few consist of a mixture of the major rock types. In some places where exposures are poor, abrupt changes of orientation of the bedding between outcrops suggest that they are separate blocks. In a few places the limits of a block are unknown; this is most common where the blocks are composed of shale. Most of the blocks are shorter than 500 feet; about 20 are between 500 and 1,000 feet long; 9 are longer than 1,000 feet; and 1 is about 6,000 feet long. The blocks are mapped as a single stratigraphic unit because many of them cannot be correlated with particular Paleozoic formations. Only the larger blocks are shown on plate 1.

PETROGRAPHY

More than 40 percent of the blocks are dolomite, 25 percent limestone, 20 percent quartzite, 10 percent shale, and less than 1 percent are quartz monzonite.

Very pale orange dolomite, dark-gray and grayish-brown dolomite, and medium-gray or mixed medium- and light-gray dolomite are about equally abundant. Very pale orange fine-grained dolomite is the most conspicuous of these. It is fine grained and slightly pinkish on fresh surfaces; it forms, along with the other carbonate rocks, some of the most rugged knobs in the area. Weathered surfaces are cracked by a network of fractures along which the rock weathers more rapidly than farther from the fractures. The two large blocks south of Gold Valley are largely or wholly of this dolomite.

Dark-gray and grayish-brown dolomite forms many of the smaller knobs of Cambrian and Ordovician rock. Many of these knobs are near quartzite blocks, and some are a breccia of fragments of dolomite mixed with fragments of quartzite or are a dolomite containing grains of quartz sand. Some of these dolomites are mixed with limestone, and some contain siliceous bands or chert pods. Mixed light-gray and medium-gray dolomite is also common and in places forms a layered rock, with silty beds or chert pods. One such block about three-quarters of a mile west of the head of the road to Hidden Spring (pl. 2) contains clastic material and fragments of a sponge resembling *Receptaculites* and fragments of algae or Bryozoa. It has a strong organic odor when struck.

Limestone blocks are generally dark gray and resemble the unbanded gray dolomites at a distance. About one-third of them have siliceous or cherty pods and stringers. Some are mixed with dolomite, are silty or shaly or are coarsely saccharoidal. Silty and shaly limestone weathers a reddish gray or yellowish brown and is commonly platy. The platy limestones and the coarsely crystalline ones do not form prominent knobs like the dolomite outcrops. One block contains some unidentified high-spired gastropods.

Most quartzites are moderately coarse to coarse grained, are gray or brown, and have beds 1 foot thick or thicker. Some quartzites have dolomite cement and micaceous shaly partings. The quartzite and shale of one block contain swash marks and fucoidal markings. A conspicuous type of grayish-purple quartzite occurs in minor amounts. Pebbly quartzite and conglomeratic quartzite with granules and small pebbles are found around a large dark-grayish-brown dolomite block north of Gold Valley. About one-quarter of the quartzite blocks are distinctive very fine grained white to pale-pink massive rocks, which lie adjacent to quartzitic shales.

Shaly rocks generally are mixed with quartzite, limestone, or dolomite and in a few places are phyllitic. In large blocks interbedded shale, quartzite, argillite, and minor amounts of carbonate rocks are most common. Shaly limestone and thin platy limestone with interbedded shale are also common. A few shale blocks are grayish and dark grayish green, but most are light to medium olive gray and pale yellow brown. One block of phyllitic shale and mottled gray limestone contains some flat pebble chips, possible trilobite fragments, and *Girvanella*-like markings. Most small shaly blocks are sheared, and in these the mixed lithologies may have a tectonic rather than a depositional origin.

Two quartz monzonite blocks lie among Paleozoic sedimentary blocks. Of these, one is interpreted as lying either beneath a thrust fault and raised to its position among the sedimentary blocks of the upper plate along normal faults (pl. 2) or lying above that thrust fault. The other, along the east side of Gold Valley, is interpreted as overlying a thrust fault because in this locality the thrust fault follows a nearly flat surface, broken only in a few places by rhyolite of Tertiary age and broken nowhere by normal faults, below the base of the monzonitic block.

The rocks between some blocks are only moderately sheared, but others are a thoroughly sheared and crushed gouge. The more deformed shale zones are most common between Cambrian(?) blocks and the basement rocks. A well-exposed gouge zone about 6 feet thick underlies the pinkish-gray to light-brown dolomite block at the southern border of the area. There the gouge is a reddish-gray compact mixture of silty and clayey material locally containing as much as 15 percent subangular to subrounded fragments of dolomite, schist, quartzite, conglomeratic quartzite, granite gneiss, and altered porphyritic felsite and containing fragments of crystals common to these rocks. Many of these rocks do not occur in the rocks either above or below the gouge.

AGE AND CORRELATION

The few fossils in some of the blocks are inadequate for identification, but the occurrence of possible trilobite fragments and *Girvanella*-like markings indicate an early Paleozoic age and possibly a Cambrian age. If the sponge is a *Receptaculites*, it also suggests an early Paleozoic age, and perhaps even an Ordovician age. This age is supported by the lithologic correlations, taken as a whole, with the Paleozoic section in the Nopah and Resting Springs Ranges (Hazzard, 1937).

Only the dolomite that weathers very pale orange is correlated with much assurance; it is probably part of the Noonday dolomite of Early Cambrian age. The other dolomites could be Middle Cambrian to Middle Devonian but are probably Upper Cambrian or Lower Ordovician rocks, for the Middle Cambrian rocks of the surrounding region contain more limestone, and the younger carbonate rocks contain more chert and fossils. A few dolomite blocks could even be correlative with the Pahrump series. The fine-grained white quartzite closely resembles Hazzard's Zabriski quartzite member of the Wood Canyon formation of Early Cambrian age or the Eureka quartzite of Middle to Late(?) Ordovician age. The grayish-purple quartzite and the conglomeratic quartzites are possibly equivalents of the Stirling quartzite of Early Cambrian age, and the shaly quartzites may be Johnnie(?) formation of Early Cambrian age or the Wood Canyon formation. Taken as a whole, the blocks are probably of Cambrian or Ordovician age, although the quartz monzonite blocks may be equivalent to the Tertiary rocks immediately underlying much of the area, and few blocks may be of late Precambrian age.

TERTIARY PLUTONIC ROCKS

Monzonitic rocks are the youngest rocks underlying the volcanic veneer, and in the southern half of the quadrangle they are probably more abundant under this veneer than are the metamorphic rocks. Monzonitic rocks are extensively exposed near the crest of the Black Mountains and in the southern part of the Greenwater Range. They probably also underlie part of the northern part of the Greenwater Range because fragments of these rocks are included in some dikes of the older volcanics.

The monzonitic rocks consist of two major groups, a quartz monzonite and porphyritic quartz latite group (in the sense of a latite with quartz phenocrysts), and a porphyritic quartz monzonite group. The quartz monzonite and porphyritic quartz latite group form about 75 percent of the monzonitic rock and is exposed north and east of Gold Valley. The porphyritic quartz monzonite is exposed southwest and east of Gold Valley. The contact between these groups is covered by alluvium in Gold Valley, possibly they are separate stocks of one plutonic complex. The stocks probably were emplaced in the same manner and at about the same time; they are dated as Tertiary by two zircon age determinations.

664503 O—63——2

QUARTZ MONZONITE AND PORPHYRITIC QUARTZ LATITE

GENERAL DESCRIPTION

Quartz monzonite is more abundant than porphyritic quartz latite, and a little monzonite, latite, granodiorite, and granite are also present. Quartz monzonite underlies more than 20 square miles, and the porphyritic quartz latite underlies about 4 square miles, chiefly in one poorly defined body in the high hills north and west of Funeral Peak, but also as small bodies of unknown size and shape that may intrude the quartz monzonite.

Areas underlain by quartz monzonite and porphyritic quartz latite are fairly uniform pinkish gray or grayish orange pink. They commonly have a cover of chips and blocks less than 2 inches long, which is interrupted by small, discontinuous outcrops and scattered larger blocks that break readily into small blocks. Adjacent slopes underlain by Precambrian rocks are darker and grayer and are broken by more numerous and larger outcrops. The intrusive rocks of the older volcanics of Tertiary age form redder slopes and more massive outcrops, and the extrusive rocks of this formation, which are also pinkish gray, are commonly interbedded with lava flows.

The quartz monzonite and porphyritic quartz latite is generally separated from its metamorphosed host by a broad zone of mixed rock; the rocks are less commonly separated by faults. The zone of mixed rock grades from the one extreme of a host rock with scattered monzonitic dikes, through an area in which the host rock and sheets of monzonitic rock are volumetrically equal, to the other extreme in which the monzonitic rock contains small and widely scattered metadiorite inclusions. The mixed border zone is more than 2 miles wide in the area between Sheep Canyon and Copper Canyon. West of Dantes View it is relatively wide, but in the area east of Coffin Canyon and in the Greenwater Range it is comparatively narrow. Most of the contacts between the quartz monzonite or porphyritic quartz latite and the wallrock are sharp in detail. Fine-grained border rocks against the host rock are scarce but do occur on the margins of some quartz monzonite dikes inferred to be apophyses of the main body. The contact is mapped along the line of equal volumes of host rock and intruded rock; where the gradational border zone is broad, the contact location is generalized.

The exposures of quartz monzonite and porphyritic quartz latite constitute a nearly horizontal section of a broad elongate pluton that underlies an area about 8 by 20 miles and continues northwestward and southeastward beyond the borders of the quadrangle. The border of the pluton is exposed only along a part of its southwestern edge. Where the narrow contact zone is exposed east of Coffin Canyon, its orientation with respect to topography suggests that it is steep.

The margins of the bodies of monzonitic rocks form a fairly regular, although unmapped, structural pattern in two places. Between Dantes View and Badwater monzonitic rock forms closely spaced north-trending, vertical dikes adjacent to the pluton. North of Sheep Canyon septa and tabular inclusions of metadiorite dip gently southwestward. The host rock commonly appears unfoliated, but near the mouth of the canyon and a few miles east of the border area, the host rock has a faint southwest-dipping foliation. Perhaps these features are more common but difficult to observe, for in few places are the local relief as large and the exposures as excellent as in these two places.

Locally, the rocks of the older volcanics intrude or unconformably overlie the quartz monzonite and porphyritic quartz latite; elsewhere the volcanic rocks are faulted against the plutonic rocks. Pyroclastic rocks lie unconformably on the monzonitic rocks between Funeral Peak and Furnace.

PETROGRAPHY

Fresh surfaces of the monzonitic rocks are light gray to grayish pink and weathered surfaces and fracture surfaces are a slightly darker pink or orange. The porphyritic quartz latite east of upper Coffin Canyon is pale red and lies above a grayer quartz monzonite. Outcrops are irregular and are cut by many closely spaced fractures. Small blocky fragments lie on the surface. Inclusions make dark areas in the rubble or dark spots on the outcrop. The shadowy outlines of clusters of altered ferromagnesian minerals, such as occur in the southern part of the Greenwater Range, may be relicts of similar inclusions. Lamprophyre dikes that rarely are more than 3 feet wide are scattered throughout the body, but are possibly more abundant near the southwestern border of the pluton than near the center. Some rhyolite dikes cut the quartz monzonite, but only the more conspicuous bodies are mapped with the older volcanics.

The mineralogy of the quartz monzonite and porphyritic quartz latite is simple, but the modes are variable. The rocks contain chiefly sodic plagioclase, potassium feldspar, quartz, and a little biotite, and accessory amphibole, magnetite, apatite, sphene, and zircon. The modes of seven coarse-grained rocks, stained for potassium minerals, show (table 2) that, as a whole, the two feldspars are about equally abundant, and that quartz is slightly subordinate to either of the feldspars.

TABLE 2.—*Modal analyses of monzonitic rocks*

Specimen No	28	29	30	2a	2b	31 [1]	32 [1]
Field No	56D66	56D71	56D99	56D106a [2]	56D106b [2]	56D112	56D200
Mode points	978	2069	2001	2009	2025	2000	1108
Plagioclase composition	An_{2-25}	An_{26}	An_{4-10}	An_{10-28}	An_{10-28}	An_{7-17}	An_{18}
Orthoclase	29.2	36.6	43.3	34.6	31.7	11.6	39.5
Plagioclase	40.5	34.2	23.6	32.9	38.8	60.4	18.9
Quartz	23.7	24.8	29.4	28.6	23.5	21.1	39.0
Biotite	5.0	2.6	3.0	1.8	3.4	2.1	.9
Amphibole	.6	.7	Tr.	1.1	1.1	3.1	.4
Magnetite	.5	1.0	.7	1.0	1.1	.7	1.4
Apatite	.1	.1	Tr.	Tr.	.2	.2	Tr.
Sphene	.1	--------	Tr.	.1	.1	.8	Tr.
Zircon	.2	Tr.	Tr.	Tr.	----------	Tr.	Tr.
Quartz in granophyric texture	0	16.9	18.1	22.9	20.4	0	6.8
Plagioclase [3] in granophyric texture	0	0	0	0	2.4	0	0
Orthoclase and perthite in granophyric texture	0	19.5	13.6	24.8	23.9	0	3.4
Total minerals in granophyric texture	0	36.4	31.7	47.7	46.7	0	10.2

[1] Specimen 31 is a granodiorite, either a variety of the monzonitic rocks, or conceivably a feldspathic dike of Precambrian age. Specimen 32 is a granite variety of the monzonitic rocks.
[2] Two thin sections from adjacent hand specimens.
[3] A three-mineral intergrowth of orthoclase and plagioclase, probably in coarse perthite, and of quartz.

Most quartz monzonite is moderately coarse grained and has a xenomorphic-granular and granophyric texture. The average grain size is about 0.5 mm, and the maximum grain size is about 3 mm. Some rocks have a hypidiomorphic-granular texture. The common combinations of minerals with granophyric texture are quartz and perthite, quartz and orthoclase, quartz and plagioclase, in decreasing order of abundance. They occur in more than half the rocks and constitute nearly half of some rocks. Hypidiomorphic-granular rocks have a coarser granophyric texture than other rocks. Fine-grained granophyre typically forms rods or elongate triangular prisms of quartz in perthite or orthoclase. Some granophyre forms a plumose or radial pattern. Coarse granophyre, with quartz patches larger than 0.3 mm wide, has less geometric regularity, and some is completely vermicular. The coarser granophyre has more quartz than the fine granophyre.

Less commonly, grains with granophyric texture are zoned from core to rim as follows: Calcic plagioclase, albite, orthoclase, perthite, fine-grained granophyre, and coarse-grained granophyre. More than four zones seldom occur together, but different combinations with this order are common. The calcic plagioclase cores are subhedral, twinned, and moderately altered; the albite zones are untwinned and less altered. Orthoclase zones form around many plagioclase grains or groups of plagioclase grains with an irregular boundary. Orthoclase also forms the cores of some grains. Perthite has an irregular boundary with the orthoclase or plagioclase, if any, inside it. In one specimen perthite around a group of plagioclase grains embayed them most deeply along the boundary between plagioclase grains. The boundary between the two sizes of granophyric texture is generally sharp.

Albitized plagioclase phenocrysts and, less commonly, quartz phenocrysts and phenocryst clusters, generally smaller than 4 mm, constitute 10–35 percent of the porphyritic quartz latite. Alteration material obscures most of the groundmass, but a few rocks have a felty or granular texture with grains 0.03–0.06 mm long. Granophyric and spherulitic textures also appear.

Orthoclase grains are generally anhedral, but in some rocks they are subhedral and anhedral. Some perthite appears in all quartz monzonite except that which is included in the older volcanic rock. These inclusions are laced by very fine grained veins of quartz or albite. Vein perthite appears with either a braided perthite similar to that shown by Gates (1953, pl. 7, figs. 6–7) or with film perthite (Gates, 1953, fig. 1). Film perthite with broad films resemble patch perthite. Rims of clear plagioclase, probably albite, with polysynthetic twins border some perthitic grains and are continuous with the plagioclase veins in the perthite. Abundant very fine grained clay minerals give orthoclase and perthite a mottled appearance, but the alteration is least intense in the inclusions in volcanic rock. Potassium feldspar is inferred to make up a large part of the groundmass of the porphyritic quartz latite; it is granular or mixed with quartz in the micrograno-phyre.

Plagioclase is anhedral, or both anhedral and subhedral, and some of its veins perthite or other more calcic plagioclase grains. Most large plagioclase grains have a broad normal compositional zone; oscillatory zones are absent or relatively inconspicuous. The composition of cores of grains is generally calcic oligoclase or sodic andesine; rims are sodic oligoclase to albite. Alteration material is more scattered in plagioclase than in orthoclase and perthite. Sericite plates commonly form patches in more calcic parts of the grains, and the brownish mottling of clay minerals is abundant.

Quartz is anhedral and subhedral, and in granophyre it forms rods or vermicular intergrowths. It also occurs in the fine-grained veins in the inclusions in the older volcanic rocks. In the porphyritic quartz latite, the quartz anhedra and clusters are less than 0.5 mm across and are more abundant than the embayed subhedral grains, possibly xenocrysts, which are as large as 2 mm. Quartz also lines some small cavities and occurs in the spherulites.

A small amount of biotite occurs in more than 90 percent of the rocks. In the quartz monzonite it forms subhedral plates with a yellow-brown to dusky-brown pleochroism, which are associated with amphibole. Biotite of the porphyritic quartz latite is represented by calcite and sericite pseudomorphs.

Amphibole occurs in about one-third of the quartz monzonite and in slightly less of the porphyritic quartz latite. It forms euhedral to subhedral grains as long as 3 mm in which pleochroism generally is in very pale yellowish green and very pale bluish green. Other grains lack pleochroism, and in one rock a bright-green amphibole is surrounded by pale-green amphibole. In the bright-green amphibole $N_x - N_z = 0.023$ and in the pale amphibole $N_x - N_z = 0.023$–0.015. In both types $Z \wedge C = 21°$. The amphibole in the porphyritic quartz latite is pseudomorphosed by penninitic chlorite, granular sphene, and a spherulitic olive-brown mineral with a radial fibrous structure.

A small quantity of accessory magnetite anhedra and subhedra, generally 0.05–0.1 mm long is always present. Some grains are rounded and are as large as 0.7 mm. Magnetite dust rims the ferromagnesian grains in the quartz monzonite inclusions in the volcanic rock. Magnetite alters to or is associated with hematite, limonite, and possibly to leucoxene.

Sphene, zircon, and apatite are the other accessory minerals. Euhedral sphene forms distinctive lozenges 0.08–0.8 mm long or is a granular replacement of other minerals. It is commonly associated with a small amount of leucoxene. Generally less than 10 grains of zircon occur in each thin section; these are euhedral to elliptical anhedral grains smaller than 0.2 mm. The yield of a zircon separate is largest and purest in the 100–300-mesh size; recrushing and reprocessing the magnetic separate of the heavy minerals increases the zircon yield about 30 percent. Euhedral apatite forms rods generally about 0.01 mm long but in some rocks 1 mm long. Much sphene, zircon, and apatite are associated with magnetite.

PORPHYRITIC QUARTZ MONZONITE

GENERAL DESCRIPTION

The porphyritic quartz monzonite underlies about 7 square miles of the top of Smith Mountain and an additional 10–15 square miles of the Confidence Hills quadrangle to the south. Its composition is similar to that of the other monzonitic rocks, but it is slightly coarser than they are and contains many feldspar phenocrysts which are longer than 3 inches. The porphyritic quartz monzonite probably forms a separate stock of the same plutonic complex, and possibly the porphyritic quartz monzonite is younger than the other monzonitic rocks, for it looks fresher; however, critical data on the field relations between these rocks have not been obtained.

Slopes developed on the porphyritic quartz monzonite are broken by relatively few and small outcrops, except on the steep slope facing Death Valley, and are light gray to pinkish gray, and resemble slopes on the other monzonitic rocks. A few large inclusions or pendants of metadiorite or gneiss are conspicuously darker gray, but a few inclusions of marble resemble the monzonitic rock at a distance.

The border of the porphyritic quartz monzonite in the more accessible northwest and east parts of the body forms a relatively narrow mixed zone a few hundred feet wide. Monzonitic dikes intrude the gneiss and metadiorite host rocks, and inclusions of the host rocks are most abundant near the border of the pluton. Younger rocks other than alluvium are nowhere in contact with the porphyritic quartz monzonite.

The stock has a shape similar to that of the larger monzonitic body; it is elongate northwestward parallel to the other body, with which it may be contiguous. The area underlain by most of the stock, including its extension south of the quadrangle, is a crude ellipse 2–3 miles wide and 7 miles long, to which the area underlain by porphyritic quartz monzonite east of Gold Valley forms an appendage. The less accessible western border of the stock appears to be steep for several thousand feet of altitude.

PETROGRAPHY

Fresh porphyritic quartz monzonite is light gray to medium gray and weathers brownish gray or pinkish gray. Outcrops are moderately massive, and debris on steep slopes is fairly coarse, for joints are widely spaced. The debris abundantly covering most slopes is a mixture of small chips and grus disaggregated from the blocks. Lamprophyre dikes and small inclusions are generally few and widely scattered.

Essential minerals are quartz, orthoclase, plagioclase, and biotite; accessories include magnetite, apatite, zircon, and sphene. Alteration minerals comprise a large amount of clay minerals and small amounts of sericite, chlorite, calcite, hematite, and limonite. Modes of four rocks stained with sodium cobaltinitrite are given in table 3.

The rock is coarse grained, hypidiomorphic granular, and conspicuously porphyritic. Many groundmass grains are longer than 4 mm, and some exceed 6 mm. Most phenocrysts are orthoclase; some are plagioclase or quartz. Granophyric texture is absent in the porphyritic quartz monzonite, unlike the other monzonitic rocks.

Quartz anhedra make up about 25 percent of the rock, largely as interlocking grains in the groundmass. They are interstitial between the larger groundmass feldspar and are sutured against other quartz grains.

TABLE 3.—*Modal analyses of porphyritic quartz monzonite*

Specimen No	33	1	34	35
Field No	237	240a	241	243
Mode points	944	2001	1077	1035
Plagioclase composition	An_{6-9}	An_{4-10}	An_{23}	An_{10-27}
Orthoclase	36.1	27.0	20.4	24.3
Plagioclase	29.1	31.4	40.2	39.1
Quartz	29.5	35.1	29.8	28.6
Biotite	3.1	4.0	8.0	6.9
Amphibole	.6	.8	.6	.3
Magnetite	1.4	1.0	.8	.8
Apatite	.2	.1	Tr.	Tr.
Sphene	.1	Tr.	----------	Tr.
Zircon	.1	Tr.	Tr.	Tr.
Chlorite	----------	.6	----------	----------
Calcite	Tr.	.1	----------	----------

Anhedral to subhedral plagioclase grains, constituting 30–40 percent of the rock, are commonly polysynthetically twinned and are altered to sericite and clay minerals. Normal composition zones are more conspicuous than oscillatory zones. Most of the plagioclase is albite, but one comparatively unaltered rock contains oligoclase.

Orthoclase phenocrysts or possible porphyroblasts are subhedral, and groundmass grains subhedral to anhedral. They are nearly as abundant as plagioclase. Perthitic intergrowths are most conspicuous in the larger grains, in which they form a delicate braid pattern or a vein pattern. Some included perthite patches are optically continuous with some adjacent patches of albite. The large orthoclase crystals contain many inclusions of plagioclase, quartz, and biotite.

Of the other minerals, biotite constitutes about 5 percent of the rock and forms subhedral crystals as long as 2 mm, with a pleochroism of X = yellow brown, Y and Z = dark brown. Titaniferous magnetite forms anhedra and subhedra about 0.1 mm wide. The ubiquitous small apatite euhedra and the granular or euhedral sphene are associated with ferromagnesian minerals. Zircon euhedra are about 0.05 mm long.

DIKES ASSOCIATED WITH THE MONZONITIC ROCKS

Two groups of dikes are associated with the monzonitic rocks: monzonitic and latitic dikes near the margins of the pluton, and lamprophyre dikes well within the pluton. Those of the first group form irregular pods and gently dipping sheets a few feet to a few tens of feet wide. Their texture and mineralogy resemble that of the plutonic rocks except that small amounts of sanidine and muscovite occur in a few of them. Some of these dikes resemble a few of the porphyritic dikes in the older volcanics that lack the conspicuous red color.

The swarm of dikes on the high ridge south of Copper Canyon differs from the majority of the monzonitic dikes in that they are long and straight and as wide as 60 feet. They contain 20–35 percent phenocrysts as long as 6 mm in a granular cryptocrystalline or granular-xenomorphic groundmass. Ferromagnesian minerals, of which biotite and chlorite are most common, form about 5–10 percent of the rock. Plagioclase composition is calcic oligoclase to sodic andesine, and potassium feldspar is abundant in the groundmass. Inclusions of fine-grained dark rock occur in the widest dike.

These dikes are distinguished from the feldspathic dikes of probable Precambrian age by their lack of alteration and by their regular structural habit and from the lamprophyre by their more alkalic composition.

The lamprophyre dikes are generally only a few feet thick and are moderate dark gray to dark greenish gray. Many are porphyritic and contain dark minerals in clusters a few millimeters in diameter. The groundmass texture of most rocks is obscured by abundant alteration material, but some have felty or intergranular vestiges with a grain size of about 0.1 mm. They are andesitic and contain 25–50 percent ferromagnesian minerals. Andesine or labradorite, amphibole, and altered pyroxene are the dominant primary minerals; and magnetite, sphene, and apatite are the subordinate ones. Chlorite, including penninitic chlorites with anomalous blue and green interference colors, is the most abundant mineral in the altered rock, replacing amphibole and pyroxene; epidote and calcite also replace them. Sericite commonly replaces plagioclase. Some of the dark mineral clusters are secondary minerals replacing amphibole and pyroxene, but others are porphyroblastic epidote and calcite replacing the groundmass material.

PETROLOGY OF THE MONZONITIC ROCKS

The monzonitic rocks were probably emplaced by a relatively quiet intrusion of magma, largely by piecemeal stoping and perhaps partly by assimilation of the metadiorite and gneiss host rocks. Quiet intrusion of a magma and piecemeal stoping are indicated by the absence of deformation of the adjacent host rocks and by the broad borders of monzonitic dikes and abundant metadiorite inclusions in the pluton near these borders. The magma probably advanced with little tectonic stress into a thoroughly heated host rock as shown by gently dipping sheets of monzonitic rocks alternating with alined tabular blocks of metadiorite north of Sheep Canyon and the scarcity of chilled margins. The gradual decrease in size of the inclusions toward the center of the quartz monzonite and porphyritic quartz latite stock suggests that some assimilation occurred. The northwest trend of the long axes of the two stocks of the pluton possibly was controlled by folds of Precambrian age in the adjacent metasedimentary rocks.

Changes within the magma chamber interrupted the regular crystallization of the quartz monzonite and permitted material to move locally. The feldspar grains of the quartz monzonite have an outer shell of granophyre, which probably formed by the simultaneous crystallization of quartz and feldspar; the inner zones were all formed during initial crystallization rather than solely by alteration. Irregularities in the texture and sequence of the zones include: (a) the clustering of some plagioclase crystals before orthoclase or perthite were deposited; (b) the embayed albite-orthoclase and orthoclase-perthite contacts; (c) the crystallization of albite first as an independent zone and possibly later with orthoclase, with which it later formed as perthite, and (d) the succession of granophyre of two different grain sizes separated by a sharp contact. The dominantly euhedral biotite, amphibole, and accessory minerals crystallized with or prior to the calcic plagioclase. The clustering of plagioclase grains may have taken place during a brief pause in crystallization prior to the deposition of the albite. The partial resorption of albite prior to orthoclase deposition also requires a pause in crystallization. This resorbed albite and the albite possibly not yet crystallized either was mixed with orthoclase after a considerable amount of relatively pure orthoclase was deposited or replaced only some of the orthoclase after the granophyre zones crystallized. The crystallization of granophyre began abruptly and was interrupted once, during which time conditions affecting the degree of dispersion of the centers of quartz and orthoclase growth and possibly affecting the rate of crystallization changed, so that the outer granophyre crystallized coarser than the inner granophyre. Very locally, plagioclase and quartz crystallized simultaneously. Albite, either exsolved from the outer zone of orthoclase rich in albite, or not yet crystallized from the melt, or both, moved through the rock and was deposited in minute veins in the plagioclase cores, possibly in the perthite zone, and between grains through-

TABLE 4.—*Chemical and spectrographic analyses, modes*

	Monzonitic rocks			Older volcanic rocks							Greenwater volcanics
Specimen No.	1	2	3	4	5	6	7	8	9	10	11
Rock name [1]	Porphyritic quartz monzonite	Quartz monzonite	Quartz monzonite	Rhyolite vitrophyre	Rhyodacite vitrophyre	Rhyolite vitrophyre	Rhyolite vitrophyre	Rhyolite vitrophyre	Rhyolite vitrophyre	Rhyolite glass	Rhyodacite vitrophyre
Field No.	56D240	56D106	56D146	57D293	56D105	56D177	57D297	56D131	56D255	56D131a	56D155
Chemical [Analysts, P. L. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack;											
SiO_2	69.1	71.3	72.7	67.7	67.8	68.4	68.5	68.8	69.8	73.7	66.0
Al_2O_3	15.1	15.1	14.7	15.3	15.4	15.8	14.9	15.1	15.0	13.3	15.8
Fe_2O_3	1.1	1.3	1.1	1.3	2.7	1.3	1.0	1.7	1.0	.45	1.6
FeO	1.6	.82	.66	1.0	.56	1.4	1.3	.64	1.3	.21	1.3
MgO	.63	.64	.53	.54	.78	.58	.44	.78	.43	.18	1.0
CaO	2.2	1.3	1.4	1.8	3.0	2.6	1.6	2.5	1.7	1.2	3.2
Na_2O	4.0	4.0	3.9	3.8	3.9	3.9	4.1	3.9	4.1	3.5	3.7
K_2O	4.4	4.9	4.8	4.3	3.7	3.6	4.5	3.5	4.2	4.1	3.6
H_2O	.54	.53	.50	4.0	1.5	1.9	3.3	2.8	2.4	3.3	2.8
TiO_2	.40	.34	.26	.30	.45	.32	.36	.32	.31	.11	.47
P_2O_5	.10	.10	.10	.06	.15	.10	.08	.12	.06	.08	.16
MnO	.05	.02	.02	.06	.06	.06	.08	.06	.06	.04	.06
CO_2	.31	<.05	<.05	.11	.42	.11	.06	<.05	.10	<.05	.29
F	.04	.04	.04	.03	.04	.04	.03	.04	.03	.01	.05
Total	100	100	100	100	100	100	100	100	100	100	100
Norms											
Q	23.66	25.54	27.86	25.58	24.82	25.98	23.73	26.93	25.89	36.07	23.58
or	26.40	29.02	28.33	26.58	21.97	21.57	27.63	21.13	25.59	25.32	21.81
ab	34.42	34.19	32.97	33.29	33.38	33.71	35.70	33.91	35.30	30.39	33.60
an	9.00	6.42	6.94	8.68	12.67	12.50	8.32	12.85	7.95	6.04	14.67
C	.41	.82	.51	1.38	.42	1.04	.31	.32	.84	.95	.63
di											
hy	2.95	1.61	1.30	1.73	2.03	2.47	2.09	2.06	2.20	.52	2.86
wo											
ol											
mt	1.64	1.63	1.16	1.93	.47	1.90	1.44	1.18	1.42	.72	2.40
il	1.17	.61	.61	.64	.92	.62	.79	.63	.62		.94
hm		.16	.32		2.43			.99			
ap											
ca				.21	.91	.20			.20		
ne											
ti											
Symbol	I.4."2.3	I.4.(1)2.3	I.4.(1)2.3	I.4."2.3	I."4.2.3	I.4.2.3	I.4."2.3	I.4.2.3	I.4."2.3	I.(3)4.(1)2.3	I.4.2.3
CIPW name	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Toscanose
Rittmann (1952) name				Quartz latite	Quartz latite	Quartz latite	Rhyolite	Quartz latite	Quartz latite	Rhyolite	Quartz latite

See footnotes and explanation of numbered heads at end of table.

out the rock after the granophyre crystallized. The variations in the modal amounts of some of the major constituents are about 10 percent of that constituent, which, if they represent true inhomogeneity in the rock, need not require more than local movement of material.

The rocks of the pluton were slightly altered not long after crystallization, probably by late fluids of the magma itself. Feldspar was sericitized and changed to clay minerals; amphibole, once probably hornblende, was changed to a lighter colored amphibole and was replaced by chlorite. Biotite was replaced by chlorite and sericite.

AGE OF THE MONZONITIC ROCKS

The monzonitic rocks are early or middle Tertiary according to two lead-alpha determinations from zircon made in 1959 by H. J. Rose, Jr., H. W. Worthing, and T. W. Stern. Specifically, the age of specimen 1 of table 4 is calculated as 45±10 millions years and that of specimen 2 is calculated as 30±10 million years.

These ages fall within the broad range of time from Precambrian to Tertiary available for the intrusion, as bracketed by geologic data. It is particularly interesting that the calculated ages fall close to the youngest age permitted by geologic data and that the extrusion of monzonitic rocks probably preceded the intrusion of rhyolite by only millions to a few tens of millions of years. Perhaps additional strontium-rubidium age determinations from biotite in both the monzonitic rocks and the older volcanic rocks could provide valuable information on the relations between these plutonic and volcanic rocks. It is also interesting that, as far as these two calculated ages are concerned, the quartz monzonite and porphyritic quartz latite are older than the porphyritic quartz monzonite, as suspected but by no means proved in the field, because the porphyritic quartz monzonite is much less altered than the other monzonitic rocks.

and norms of rocks from the Funeral Peak quadrangle

Greenwater volcanics—Continued					Andesite and basalt of Tertiary age				Andesite and basalt of the Funeral formation			
12 Rhyodacite vitrophyre 56D93	13 Rhyodacite vitrophyre 56D165	14 Rhyodacite vitrophyre 56D164	15 Rhyolite vitrophyre 56D159	16 Rhyolite vitrophyre 56D171	17 Porphyritic alkali andesite 56D2	18 Porphyritic alkali basalt 56D96	19 Porphyritic andesite 56D12	20 Porphyritic andesite 56D144	21 Porphyritic "central" basalt 56D257	22 Porphyritic "central" basalt 56D210	23 Porphyritic andesite 56D153	24 Porphyritic andesite 56D150
analyses												
fluorine of 2, 3, 8, 10–20, 23, 24 by S. M. Berthold, and others, P. M. Montalto]												
66.5	66.6	66.8	67.3	71.0	47.0	47.2	51.3	56.8	47.1	49.3	56.9	57.6
15.6	15.4	15.8	15.3	14.9	16.2	15.3	16.2	16.5	15.6	16.7	19.0	16.4
2.5	1.7	2.7	1.4	2.1	3.9	4.4	4.7	1.7	3.1	3.4	2.7	2.3
.66	1.4	.74	1.3	.21	8.6	4.6	4.6	4.7	6.8	6.2	3.0	4.2
1.2	1.2	1.3	1.0	.62	6.3	10.2	4.7	4.7	9.5	7.9	3.6	4.2
3.0	3.2	3.5	2.4	2.1	8.1	8.9	8.4	7.5	9.2	9.7	7.8	7.5
3.8	3.7	3.7	3.8	3.7	3.2	3.2	3.3	3.9	3 0	3.3	3.5	3.5
3.4	3.5	3.9	3.6	4.2	1.8	1.2	2.0	2.1	1.6	.82	1.8	2.2
2.6	2.6	.62	2.9	.65	1.9	2.9	2.2	.45	1.6	1.0	1.1	.48
.50	.50	.54	.44	.34	2.4	1.4	1.8	1.1	1.6	1.4	.97	1.1
.14	.18	.20	.22	.14	.65	.56	.56	.34	.70	.32	.23	.34
.06	.06	.08	.05	.06	.16	.15	.14	.12	.17	.16	.08	.12
.18	<.05	.28	.06	.12	.05	.19	<.05	<.05	.19	.40	<.05	<.05
.05	.04	.06	.03	.03	.16	.08	.11	.05	.07	.04	.04	.06
100	100	100	100	100	100	100	100	100	100	100	100	100
Norms—Continued												
24.41	23.77	21.80	25.18	28.20			3.49	4.46			8.76	8.26
20.55	21.16	23.01	22.00	25.19	10.74	7.43	11.91	12.29	9.65	5.06	10.66	12.85
32.87	32.37	31.75	33.36	31.64	27.80	28.02	28.28	33.21	24.61	28.13	29.58	29.52
14.29	15.44	15.15	12.46	9.79	24.92	24.34	24.20	21.54	24.96	28.74	31.11	22.92
.63			.85	.61								
	.24	.20			4.45	5.90	5.51	5.55	5.84	6.01	2.96	10.90
3.08	3.01	3.13	3.16	1.61	2.25	1.10	8.44	11.62		8.29	7.85	3.63
	.36	.23			4.72	6.71	6.16	5.95	6.39	6.58	3.28	5.83
					13.11	15.51			18.70	8.83		
.72	2.62	.70	2.18		5.66	6.79	6.88	2.56	4.49	4.93	3.98	3.27
.93	.93	1.07	.79	.46	4.64	2.82	3.75	2.14	3.10	2.78	1.84	2.14
2.13		2.26		2.09								
					1.71	1.38	1.37	.67	1.72	.67		.67
.41		.70		.21								
									.58			
				.20								
I''.4.2.3	I''.4.2.3	I''.4.2.3	I.4.2.3	I.4.2.3	II(III).5.3.(3)4	(II)III.5.3.4	II''.5.3.3(4)	II.5.''3.(3)4	(II)III.5.3.(3)4	(II)III.5.3''.4	IV.2.3.2.3	II.4(5).3.3(4)
Toscanose	Toscanose	Toscanose	Toscanose	Toscanose	Andose	Camptonose	Shoshonose	Andose	Camptonose	Camptonose	Texase	Harzose
Quartz latite	Quartz latite	Quartz latite	Quartz latite	Quartz latite	Olivine-andesine trachybasalt	Olivine-andesine basalt	Olivine-andesine trachybasalt	Trachyandesite	Olivine-andesine trachybasalt	Olivine-andesine basalt	Bandaite	Dark rhyodacite

TABLE 4.—*Chemical and spectrographic analyses, modes,*

	Monzonitic rocks			Older volcanic rocks							Greenwater volcanics
Specimen No.	1	2	3	4	5	6	7	8	9	10	11
Rock name [1]	Porphyritic quartz monzonite	Quartz monzonite	Quartz monzonite	Rhyolite vitrophyre	Rhyodacite vitrophyre	Rhyolite vitrophyre	Rhyolite vitrophyre	Rhyolite vitrophyre	Rhyolite vitrophyre	Rhyolite glass	Rhyodacite vitrophyre
Field No.	56D240	56D106	56D146	57D293	56D105	56D177	57D297	56D131	56D255	56D131a	56D155

Modes

[modes of vitrophyric rocks are visually estimated;

	1	1	2	2	3	3	4	5	6	7	8	9	10	11
Thin section No.[3] (from same specimen).	a	b	a	b	a	b	---	---	---	---	---	---	---	---
Points counted	2001	1237	2009	2025	1104	1029	---	---	---	---	---	---	---	---
Quartz	35.1	27.8	28.6	23.5	27.2	30.1	---	---	---	---	---	---	---	---
Quartz xenocryst	---	---	---	---	---	---	---	3	10	---	3	---	---	---
Orthoclase	27.0	20.8	34.6	31.7	33.8	34.0	---	---	---	---	---	---	---	---
Plagioclase	31.4	42.8	32.9	38.8	34.0	30.3	5	12	35	9	7	3	---	24
(An content) [2]	(5–15)	(15–30)	(10–30)	(5–30)	(5–25)	(2–30)	(25–35)	(30–50)	(30–45)	(30–40)	(25–40)	(30–40)	---	(35–45)
Plagioclase xenocryst	---	---	---	---	---	---	1	---	---	1	---	1	---	---
(An content) [2]	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Biotite	4.6	5.3	1.8	3.4	3.4	4.1	2	2	3	1	3	2	---	4
Hornblende	.8	1.7	1.1	1.1	.8	.7	1	2	2	---	2	1	---	2
Augite	---	---	---	---	---	---	---	---	---	1	---	---	---	---
Hypersthene	---	---	---	---	---	---	---	<1	---	<1	---	---	---	---
Olivene	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Magnetite	1.0	1.0	1.0	1.1	.5	.5	<1	1	<1	<1	<1	<1	---	<1
Sphene	<.1	.2	.1	.1	.1	<.1	---	---	<1	---	---	---	---	---
Apatite	.1	.4	<.1	.2	.1	.1	<1	<1	<1	<1	<1	<1	---	<1
Zircon	<.1	<.1	<.1	<.1	---	<.1	---	---	---	<1	<1	---	---	---
Other minerals and groundmass.	---	---	---	---	---	<.1	Cryptocrystalline, 35; microlites, 2; glass, 53	Tridymite and opal(?), 20; microlites, 25; glass, 35	Microlites, 15; glass, 35	Microlites, 2; glass, 85	Microlites, 3; glass, 80	Microlites, 20; glass, 70	Microlites, 4; glass, 96	Cryptocrystalline, 5; microlites, 5; glass, 60

Spectrographic analyses

	1	2	3	4	5	6	7	8	9	10	11
Ag	[5] 0.00003	[4] 0	[4] 0	[5] 0.00003	[5] 0.00003	[5] 0.00003	[5] 0.00003	[4] 0	[5] 0.00003	[4] 0	[4] 0
B	.003	.002	.003	.007	.003	.007	.007	.002	.007	.003	.002
Ba	.07	.2	.1	.07	.07	.07	.07	.1	.07	.1	.1
Be	.0003	0	0	.0003	.0003	.0003	.0003	0	.0003	0	0
Co	.0007	0	.0007	.0007	.0007	.0007	.0003	.0005	.0003	0	.0009
Cr	.0007	.0004	.0009	.0007	.0007	.0003	.0003	.0004	.0003	.0002	.002
Cu	.0007	.001	.02	.0015	.0015	.0015	.003	.0008	.0015	.0003	.002
Ga	.003	.001	.001	.003	.003	.003	.003	.002	.003	.001	.001
La	.007	.006	.003	.007	.007	.007	.007	.004	.007	.004	.004
Mo	.0003	0	0	.0007	.0007	.0007	.0007	0	.0007	0	0
Nb	.0015	0	0	.0015	.0015	.0015	.0015	0	.0015	0	0
Ni	.0003	.0006	.0009	.0003	.0007	.0003	.0003	.0006	.0003	0	.0009
Pb	.003	0	.002	.007	.007	.007	.007	.002	.007	.002	.003
Sc	.0007	.0003	.0006	.0007	.0007	.0007	.0007	.0003	.0007	.0002	.0003
Sr	.03	.03	.02	.015	.03	.03	.03	.06	.015	.02	.09
V	.003	.002	.002	.0007	.0015	.0015	.0015	.003	.0007	0	.003
Y	.0015	.002	.002	.0015	.0015	.0015	.0015	.002	.0015	.002	.002
Yb	.00015	---	---	.00015	.00015	.00015	.00015	---	.00015	---	---
Zr	.03	.02	.02	.03	.03	.01	.03	.01	.03	.01	.02

[1] Rock names based on Nockolds' (1954) revision of analyses of Daly.
[2] An content of plagioclase obtained from extinction angles of mp sections (010∧001) applied to Tröger's graph (1956, p. 111). Ranges in An content generally obtained from 5 readings, but in some thin sections as many as 10 or as few as 3 readings were made.
[3] a and b are two thin sections from adjacent specimens.

1. Porphyritic quartz monzonite (affinity toward granite) from pluton intruded into metasedimentary rocks from Smith Mountain southwest of Gold Valley, 0.4 mile northeast of knob 5873, alt 5,440 ft. Pinkish gray to light gray; grains disaggregate readily. Hypidiomorphic granular, porphyritic; plagioclase phenocrysts as long as 12 mm constitute about 10 percent of the rock; groundmass grains shorter than 3 mm. Orthoclase is vein perthite and delicate braid perthite, intensely altered to kaolin(?). Plagioclase phenocrysts slightly poikilitic; most plagioclase partly altered to albite and sericite. Some magnetite is poikilitic. Amphibole and biotite partly replaced by peninitic chlorite and sericite. A few veinlets of calcite and sericite cut the rock.

2. Quartz monzonite typical of pluton intruded into metadiorite; from north side of knob 5357, between Furnace townsite and Coffin Canyon, alt 5,000 ft. Pale red to grayish pink; much altered along closely spaced fractures. Hypidiomorphic granular to granophyric; grains commonly about 0.6 mm long but as long as 3.5 mm. Plagioclase partly altered to minute grains of sericite and kaolin(?); some is albitized. Some cores of tabular plagioclase have intermediate zones of more sodic plagioclase and outer zones of granophyre with radial orientation of quartz and feldspar. Other plagioclase forms granophyre in place of perthite. Orthoclase strongly altered to minute crystals of kaolin(?). Biotite slightly altered to chlorite.

3. Quartz monzonite from pluton intruded into rocks of Precambrian age; near Funeral Peak, 0.8 mile north of knob 5315, alt 5,110 ft. Pale red to pinkish gray; weathers dark yellow brown. Hypidiomorphic granular to granophyric; grains about 2.5 mm long. Vein and lace perthite common; patch perthite rare. Some perthite and plagioclase have granophyre rims with radial orientation of quartz and feldspar. Some plagioclase has normal zoning; some has orthoclase rims. Hornblende partly altered to biotite.

4. Rhyolite vitrophyre (affinities towards quartz latite and alkali rhyolite) from lava flow southeast of Greenwater Canyon, from uppermost flow on nose 0.2 mile west of peak 4982, alt 4,810 ft. Medium-gray glass; weathers dusky brown. Phenocrysts and crystal fragments as long as 4 mm and lie in groundmass of perlitic glass containing a few microlite rods. Glass cut by veinlets of dusky-red cryptocrystalline material with abundant crystal fragments; veinlets cut by others of coarser cryptocrystalline material, probably of silica and feldspar. Glass slightly devitrified along fractures. Plagioclase vermicular and embayed. All hornblende and biotite oxidized.

5. Rhyodacite vitrophyre (affinity toward quartz latite) from lava flow near Dantes View, alt 4,320 ft on a knob 0.9 mile northwest of hill 4443. Pale red gray; strongly flow layered. Phenocrysts and crystal fragments, as long as 2 mm, and a few rock fragments lie in groundmass of dark glass and fine-grained devitrified glass interlayered with coarse-grained devitrified glass. Quartz euhedral to rounded. Plagioclase subhedral and vermicular. The tridymite is in the coarse-grained layers and in vugs.

6. Rhyolite vitrophyre (affinities toward quartz latite and alkali rhyolite) from lava flow or sill 2 miles southeast of Funeral Peak and 0.7 mile east of knob 5780, alt 4,850 ft. It is dark-gray glass; some reddish-gray layers of crystalline material. Phenocrysts and crystal fragments as long as 3 mm and lie in groundmass of glass containing strongly alined microlite plates, rods, laths, and tiny dark specks. Quartz embayed. Plagioclase has broad normal zones; some is vermicular.

7. Rhyolite vitrophyre (affinities toward quartz latite and alkali rhyolite) from base of lava flow, second flow beneath flow of specimen 4. From nose 0.3 mile west of peak 4982, alt 4,800 ft. Rock is dark-gray glass. Phenocrysts and fragments as long as 2 mm; lie in groundmass of light-brown perlitic glass containing a few microlite rods. Plagioclase forms tabular crystals and rounded fragments; some is vermicular; some has oscillatory or normal zoning.

8. Rhyolite vitrophyre (affinity toward quartz latite) from lava flow near Greenwater Spring, on north side of knob 0.2 mile southwest of spring, alt 5,400 ft. It is medium-gray glass; weathers dusky brown. Phenocrysts as long as 2 mm and are crudely alined in groundmass of perlitic glass containing microlite laths and rods. Plagioclase forms tabular crystals and laths; some slightly vermicular. Zircon included in plagioclase.

9. Rhyolite vitrophyre from an agglomerate flow with abundant vitrophyre boulders in tuffaceous matrix. Collected near southeast corner of quadrangle, from knob 0.1 mile north of road and 1.5 miles southeast of knob 4335, alt 3,280 ft. It is light-gray glass. Phenocrysts and crystal fragments as long as 3 mm and lie in groundmass of perlitic glass containing alined microlite rods. Some plagioclase has strong normal zoning, other is embayed. Glass is of three types: an early perlitic

and norms of rocks from the Funeral Peak quadrangle—Continued

Greenwater volcanics—Continued					Andesite and basalt of Tertiary age				Andesite and basalt of the Funeral formation				
12 Rhyodacite vitrophyre 56D93	13 Rhyodacite vitrophyre 56D165	14 Rhyodacite vitrophyre 56D164	15 Rhyolite vitrophyre 56D159	16 Rhyolite vitrophyre 56D171	17 Porphyritic alkali andesite 56D2	18 Porphyritic alkali basalt 56D96	19 Porphyritic andesite 56D12	20 Porphyritic andesite 56D144	21 Porphyritic "central" basalt 56D257	22 Porphyritic "central" basalt 56D210		23 Porphyritic andesite 56D153	24 Porphyritic andesite 56D150

others are based on Chayes point count]

										a	b		
					1000	1012	1042	1104	1100	1128	1108	1009	1133
							1.5	2.7				0.5	0.4
15 (35-45)	11 (30-50)	11 (35-50)	10 (30-40)	7 (35-55)	49.3 (50-65)	47.0 (50-65)	55.3 (50-60)	47.1 (45-65)	46.0 (55-75)	62.5 (50-65)	65.3 (50-65)	51.5 (45-70)	49.7 (45-70)
			2				1.5	10.0 (30-45)				4.0 (35-50)	7.0 (35-50)
2	1	1	5	2						.1			
2	3	3	3	1									
	1	2			24.8	27.1	20.1	33.6	28.6	15.0	17.6	23.3	31.2
	1	1											
					6.8	16.8	5.9	1.8	18.7	16.4	12.7	3.3	2.5
1	1	<1	<1		12.3	7.0	4.9	3.4	6.0	4.6	3.3	5.1	4.0
<1	<1	<1	<1	<1	4.6	<.1	3.2	1.0	.3	1.5	.9	1.1	1.3
Cristobalite, 1; microlites, 15; glass, 65	Microlites, 5; glass, 75	Tridymite, 2; cryptocrystalline, 10; microlites, 20; glass, 50	Microlites, 10; glass, 75	Opal(?), <1; microlites, 20; cryptocrystalline and glass, 70	Altered glass, 2.2	Zeolite, 1.0	Altered glass, 9.1	Altered glass, 0.4	Cristobalite, 0.1; glass, 0.3		Glass, 0.1	Glass, 11.3	Cristobalite, 1.1; glass, 2.8

of minor elements

[4] 0	[4] 0	[4] 0	[4] 0	[4] 0	[4] 0	[4] 0	[4] 0	[4] 0	[5] 0.00007	[5] 0.00007	[4] 0	[4] 0
.002	.002	.001	.001	.002	0	0	.003	0	.003	.003	0	0
.2	.1	.1	.1	.1	.09	.09	.07	.09	.07	.03	.1	.1
0	0	0	0	0	0	0	0	0	.00015	.00015	0	0
.0006	.0008	.001	.0008	.0007	.003	.003	.002	.002	.003	.003	.002	.002
.0006	.002	.002	.0009	.001	.006	.04	.006	.006	.03	.015	.006	.008
.004	.002	.003	.001	.001	.01	.009	.002	.004	.007	.003	.008	.01
.002	.001	.002	.001	.001	.002	.002	.002	.002	.003	.003	.002	.001
.004	.007	.005	.004	.007	.004	.004	.005	.004	.007	.003	.005	.005
0	0	0	0	0	0	0	0	0	.0015	.0007	0	0
0	0	0	0	0	0	0	0	0	.0015	.0003	0	0
.0006	.0008	.001	.0006	.0007	.006	.02	.003	.004	.03	.007	.006	.005
.001	.002	.002	.002	.002	.002	.002	.001	.002	.0015	.0003	.001	.002
.0004	.0003	.0003	.0003	.0002	.002	.002	.002	.002	.003	.003	.002	.003
.1	.04	.08	.1	.03	.1	.1	.1	.1	.07	.07	.1	.1
.004	.003	.004	.003	.002	.03	.04	.02	.02	.015	.015	.01	.01
.002	.002	.002	.002	.002	.004	.003	.004	.003	.003	.003	.003	.003
									.0003	.0003		
.01	.01	.01	.01	.01	.02	.01	.02	.01	.01	.01	.02	.01

[4] Quantitative. Looked for but not found: As, Au, Be, Bi, Cd, Ce, Ge, Hg, Ir, P, Pt, Sb, Ta, Th, Tl, U, W, Zn. As much as 0.01 percent Zn could be missed in the samples containing as much as 0.1 percent Ti. Analyst J. D. Fletcher.

[5] Semiquantitative. Looked for but not found: As, Au, Bi, Cd, Ce, Cs, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Nd, Os, Pd, Pr, Pt, Rb, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn. Analyst H. W. Worthing.

type dark with abundant microlites, a slightly later perlitic type with fewer microlites, and a much later nonperlitic type.

10. Rhyolite glass, estimated 98 percent pure, separated from specimen 8. Heavy minerals separated from 100–200 mesh fraction of ground rock by heavy liquids; feldspar separated with Franz magnetic separator.

11. Rhyodacite vitrophyre (affinity toward quartz latite) from top of lava flow from northern part of Greenwater Range, 0.4 mile southwest of peak 5148, alt 4,265 ft. Medium light gray; weathers brownish black. Phenocrysts and crystal fragments as long as 3 mm and lie in groundmass of perlitic glass containing microlite laths and rods. Plagioclase forms tabular crystals and laths; some is vermicular; some has normal zoning.

12. Rhyodacite vitrophyre from middle or top of lava flow from knob 5484 between Dantes View and Coffin Peak. Medium light gray; crudely layered. Phenocrysts and crystal fragments as long as 2.5 mm and alined in slightly vesicular groundmass of glass and cryptocrystalline material containing microlite laths and rods. Plagioclase forms tabular crystals and laths; some has normal zoning; some is vermicular. Hornblende and biotite oxidized. Cristobalite lines vesicles.

13. Rhyodacite vitrophyre (affinity toward quartz latite) from base of lava flow, separated from underlying flow of specimen 14 by about 30 ft of pumiceous lapillae beds. Collected 0.3 mile south of peak 5148, alt 4,840 ft, from flow overlying that from which specimen 14 was collected. Grayish black; weathers brownish black. Phenocrysts and crystal fragments as long as 3 mm and alined in groundmass of light-brown glass containing a few alined microlite rods and tiny dark specks. Plagioclase has normal zoning; some is vermicular. Hornblende and biotite partly oxidized.

14. Typical rhyodacite vitrophyre from center of lava flow 0.2 mile southwest of peak 5148, alt 4,850 ft above specimens 11 and 15. Blackish red with pale-red layers; moderately vesicular. Phenocrysts and crystal fragments as long as 3.5 mm and set in groundmass of brown mottled glass containing abundant microlite laths. Plagioclase forms tabular crystals; some is vermicular. Hornblende and biotite oxidized. Tridymite lines vesicles.

15. Rhyolite vitrophyter (affinities toward quartz, latite and rhyodacite) from base of lava flow, which is separated from underlying flow of specimen 11 by about 100 ft of agglomerate, tuff, and tuffaceous to pumiceous grit and conglomerate. Alt 4,365 ft, above specimen 11. Medium gray; weathers brownish gray. Phenocrysts as long as 2mm and alined in groundmass of glass containing small brown-mottled microlite rods that radiate from abundant local centers. Plagioclase forms tabular crystals and laths; some is embayed and vermicular. Normal and oscillatory zoning common; reverse zoning rare.

16. Rhyolite vitrophyre (affinity toward quartz latite) from center of lava flow underlying flow of specimen 11. Collected 0.5 mile west of peak 5107 and 0.8 mile northwest of peak 5148, alt 4,000 ft. Grayish red to moderate red. Phenocrysts and crystal fragments as long as 2 mm and set in groundmass of murky brownish glass and cryptocrystalline material containing abundant alined microlite laths, some shadowy spherulite and abundant hematite specks. Plagioclase forms tabular crystals; some is vermicular; some has normal zoning. Some hornblende and biotite are oxidized. Opaline material lines some cavities.

17. Porphyritic alkali andesite (affinity toward alkali basalt) from a small dike intruded into conglomerate of Copper Canyon formation, from near mouth of Copper Canyon, in bottom of large tributary canyon joining Copper Canyon from north, alt 440 ft. Dark gray; weathers grayish olive to grayish olive green. Has intergranular to ophitic flow texture. Olivine phenocrysts make up less than 1 percent of the rock; as long as 1 mm; set in groundmass of crudely alined plagioclase laths about 0.2 mm long, with interstitial granular ferromagnesian minerals and finer plagioclase laths. Olivine probably has high magnesia content; partly altered to serpentine(?). Plagioclase forms abundant laths and few tabular crysrals. Pyroxene partly altered to chlorite.

18. Porphyritic alkali basalt (affinities toward alkali andesite and "central" basalt) from lava flow or sill near top of older volcanic rocks, 0.2 mile southwest of Coffin Peak in northwest corner of quadrangle, alt 5,040 ft. Very dark gray; weathers grayish red purple; largely vesicular. Porphyritic, messy intergranular to ophitic, felty to flow texture. Phenocrysts make up about 5 percent of the rock and include 4 percent olivine and 1 percent plagioclase; as long as 4 mm; set in groundmass of plagioclase laths shorter than 0.1 mm and interstitial granular ferromagnesian min-

(Continued on following page)

erals and finer plagioclase laths. Olivine altered to iddingsite(?) and chlorite or bowlingite(?). Two types of zeolites fill cavities.

19. Porphyritic andesite (affinities toward alkali andesite and "central" basalt) from lava flow in rocks of Copper Canyon formation, from lower end of large basin along Copper Canyon, about 150 ft above canyon floor, alt 1,160 ft. Dark gray; weathers dark brownish gray; largely vesicular. Porphyritic, ophitic to intergranular, felty texture. Phenocrysts and xenocrysts make up about 5 percent of the rock and include 1.5 percent plagioclase phenocrysts and xenocrysts, 1.5 percent quartz xenocrysts, and 1 percent olivine phenocrysts; as long as 2 mm; set in groundmass of plagioclase 0.1 to 0.2 mm long, with a little interstitial glass, with interstitial granular ferromagnesian minerals and finer plagioclase laths. Plagioclase forms tabular crystals and abundant short laths; some has oscillatory or normal zoning; some has zones of dusty inclusions. Quartz xenocrysts strongly embayed, with some glass in cavities, and with rims of magnetite and clinopyroxene. Ferromagnesian minerals partly altered; interstitial glass largely altered to unidentified orange material.

20. Porphyritic andesite (affinity toward alkali andesite) from lava flow or small intrusive body near top of older volcanic rocks, from hill south of Greenwater townsite, on western spur of knob south of canyon cutting hill, alt 4,525 ft. Medium gray to purplish gray; largely vesicular. Porphyritic, intergranular flow texture. Phenocrysts and xenocrysts constitute about 18 percent of rock and include 10 percent plagioclase xenocrysts, 4 percent plagioclase phenocrysts, 2.7 percent quartz xenocrysts, and less than 1 percent olivine phenocrysts; as long as 3 mm; set in groundmass of plagioclase as long as 0.4 mm and interstitial granular ferromagnesian minerals and smaller plagioclase. Plagioclase forms tabular crystals and laths; some has vermicular zones; some has oscillatory or normal zoning. Olivine partly altered to iddingsite(?). Quartz xenocrysts embayed and rounded, with intermediate rims of brown glass and outer rims of clinopyroxene.

21. Porphyritic olivine basalt (or "central basalt" of Mull; affinities toward alkali basalt and alkali andesite) from lava flow near southeast corner of quadrangle, from northwest side of knob 4,456, alt 4,000 ft. Dark gray; weathers brownish gray to brownish black. Porphyritic, intergranular, flow texture. Phenocrysts make up about 15 percent of the rock and include 8 percent olivine, 3 percent augite, and 4 percent plagioclase; as large as 2 mm and lie in groundmass of plagioclase about 0.1 mm long. Plagioclase forms only laths, without zoning or vermicular zones. Olivine euhedral and fragmental, partly altered to iddingsite(?).

22. Porphyritic olivine basalt ("central basalt" of Mull; affinities toward alkali basalt and alkali andesite) from lava flow east of Gold Valley, from north slope of knob 5021, alt 4,460 ft. Medium gray. Porphyritic ophitic texture. Phenocrysts constitute about 4 percent of the rock with augite predominant over olivine; as long as 2.5 mm; set in groundmass of plagioclase as long as 1 mm, interstitial pyroxene grains intergrown with plagioclase, and other minor granular ferromagnesian minerals. Plagioclase forms tabular phenocrysts, some with oscillatory zoning, some with vermicular zones, and abundant groundmass laths. Olivine partly altered to iddingsite(?). Biotite associated with magnetite.

23. Porphyritic andesite from lava flow near south end of Greenwater Canyon, from floor of canyon, alt 3,760 ft. Medium gray; weathers light brownish gray. Porphyritic intergranular to ophitic flow texture. Phenocrysts and xenocrysts constitute about 11 percent of the rock and include 7 percent plagioclase phenocrysts, 3 percent plagioclase xenocrysts, and less than 1 percent each of quartz xenocrysts and olivine phenocrysts; as long as 3 mm; set in a groundmass of plagioclase about 0.1 mm long, and interstitial granular ferromagnesian minerals, finer plagioclase laths, and a little glass and cryptocrystalline material. Plagioclase forms tabular and rounded grains and abundant laths; some has vermicular zones. Olivine partly altered to hematite and iddingsite(?). Quartz embayed, has intermediate rims of brown glass and outer rims of clinopyroxene.

24. Porphyritic andesite (affinities toward latite and "central basalt") from lava flow near Funeral Peak, 0.7 mile southeast of knob 5315, alt 4,720 ft. Medium gray to medium bluish gray; weathers dark yellowish brown to reddish black. Porphyritic ophitic to intergranular felty texture. Phenocrysts and xenocrysts make up about 9 percent of the rock and include 6 percent plagioclase xenocrysts, 2 percent plagioclase phenocrysts, and less than 1 percent each of quartz xenocrysts and olivine phenocrysts; as long as 2.5 mm; set in groundmass of plagioclase about 0.03 mm long, and interstitial abundant smaller plagioclase laths and some granular ferromagnesian minerals. Plagioclase forms tabular and rounded grains and abundant laths; some has vermicular zones. Olivine partly altered to iddingsite(?). Quartz embayed and rounded, with intermediate rims of brown glass and outer rims of clinopyroxene.

TERTIARY VOLCANIC AND SEDIMENTARY ROCKS

Tertiary volcanic and sedimentary rocks are distributed in a belt, certainly longer than 50 miles and probably longer than 100 miles, that centers about the Black Mountains fault block and apparently extends slightly onto adjacent blocks. The sedimentary formations are restricted to local deep basins. The volcanic formations are less restricted and may have formed and added to the topographic barriers between the basins of sedimentation. They also were an important source of clastic material deposited in the basins.

In the Funeral Peak quadrangle, rocks of Tertiary age younger than the monzonitic rocks consist chiefly of two rhyolite and rhyodacite units, plus two sedimentary units, and one unit of andesite and basalt. Three of these are formal units: the Furnace Creek formation, the Greenwater volcanics, and the Copper Canyon formation, which is a new formation proposed in this report. Two units, the older volcanics and the andesite and basalt, remain informal, for their distribution, stratigraphic variations, and relations to other units are not as well known as those of the other three formations. In addition, three units are divided into two members each.

The eight mapped formations and members are stratigraphically superposed or are separated by lateral facies changes or diffuse intrusive contacts. Both sedimentary and igneous units are local, and facies changes are abrupt. This is a function partly of the igneous history and partly of the depositional environments. Rigid correlation between formations and members is difficult and perhaps is even unrealistic. Nevertheless, the distinctions made between units, and the general relations inferred between them, are useful in preparing a reasonable and internally consistent picture of the geologic development of the area.

The fine-grained igneous rocks of the Funeral Peak quadrangle are classified by both the CIPW and the Rittmann systems on table 4, but the preferred classification is derived from the averages of rock analyses of Daly, as revised by Nockolds (1954). Ideally, the chemical analyses of rocks of a specific area should be compared with all other "good" analyses, on which an empirical classification is based. However, lists of such analyses are old, as those of CIPW (Washington, 1917) or not available from the classifiers of such rocks. Therefore, Nockolds' averages are used as the most accessible and up-to-date substitute, even though they are averages rather than original analyses. The most useful guides for a general comparison of rock analyses with those of Nockolds' averages are, in decreasing order of usefulness: CaO/Na_2O, $MgO+CaO$, and SiO_2. The comparison is simplified by graphing the averages. In this manner basalt is easily distinguished from andesite, and rhyodacite from rhyolite, two distinctions in which the CIPW and Rittmann classifications give significantly different results. A more specific name, and the tendencies toward similar rocks with other specific names (indicated parenthetically below table 4), is derived by comparing other oxides with those of the averages. The name derived from the Nockolds' averages lies between the more extreme names of Rittmann and those used by most geologists for rocks, the analyses of which are listed by CIPW. For instance, specimen 23 is called bandaite, essentially a labradorite dacite, by Rittmann and is called some variety of basalt by geologists whose rocks are listed by CIPW, whereas andesite is preferred here.

The general classification of fine-grained igneous rocks of the Funeral Peak quadrangle obtained from the Nockolds' averages is better supported by the modes of the rocks than are the other systems. For example, the modal olivine of the analysed basalts is more than 15 percent and that of andesite is less than 7 percent. Also, the An content of plagioclase phenocrysts of analysed rhyodacite vitrophyres is 40 percent or more and that of rhyolite is less than 40 percent.

OLDER VOLCANICS

Moderately deformed older volcanics and clastic rocks derived from them form in many places a relatively thin sheet overlying the Precambrian metamorphic rocks and the Cambrian and Ordovician rocks and the Tertiary monzonitic rocks. The volcanic rocks comprise a dominant group of rhyolite and rhyodacite and related porphyritic felsites and a very subordinate group of andesite and basalt. The rhyolite and rhyodacite rocks are divided into two members: rocks largely extrusive or sedimentary and rocks largely intrusive. The andesite and basalt are probably both intrusive and extrusive; they are mapped as a separate unit and are described with the unnamed andesite and basalt unit because identical rocks occur with other formations of Tertiary age.

The older volcanics underlie part of the crest and most of the east flank of the Black Mountains and are also extensively exposed in the Greenwater Range from upper Greenwater Canyon to the east edge of the area. Another prominent belt of older volcanic rocks extends from the crest of the Black Mountains at Dantes View to the lower part of Coffin Canyon on the west flank of the range. The felsite intrusive rocks are most abundant along the western edge of the volcanics, in the Coffin Canyon area, and in a few large areas in the Greenwater Range.

Slopes underlain by the older volcanics are mixed very pale orange and reddish brown. In the area of intrusive felsites, reddish-brown slopes and abundant knobs form irregular patches; elsewhere the slopes are banded by a more subdued shade of reddish brown, cliff-making lava flows, alternating with bands of very pale orange bench-making tuffaceous rocks. The reddish colors of the rhyolitic rocks contrast strongly with the more somber color of the metamorphic and monzonitic rocks and the more varied color of the Cambrian and Ordovician blocks. The older volcanic rocks resemble closely the Greenwater volcanics but are distinguished by their thinner units of pale-reddish-brown rocks, by their steeper dips, and by their patches of brighter reddish-brown intrusive rocks.

The felsites associated with the older volcanics intrude the monzonitic and older rocks, and the volcanic rocks lie unconformably on them, but locally they are faulted against them. The older volcanics are overlain with a less pronounced unconformity by the Furnace Creek formation and younger rocks.

The formation is estimated to be more than several hundred feet thick, possibly several thousand feet thick. The uniformity of the rocks and the abundance of intrusions and of faults makes such estimates very unreliable.

EXTRUSIVE AND SEDIMENTARY ROCKS

GENERAL DESCRIPTION

The extrusive and sedimentary rocks of the older volcanics include rhyolite and rhyodacite lava flows, with interbedded tuff-breccia and agglomerate, and relatively small amounts of reworked tuffaceous sandstone and conglomerate. Lava flows constitute 20–80 percent, but generally less than 50 percent of the unit. Sandstone and conglomerate rarely exceed 1 percent of the rocks in areas as large as 1 square mile and are absent from large areas. The proportion of lava flows to other rocks is highest north of Dantes View and in the Greenwater Range, and sedimentary rocks are most common in the Greenwater Range south of Greenwater Canyon, and a mile southeast of Funeral Peak.

Together, these three rock types underlie the lightest colored slopes in the area and generally weather more rapidly than the associated felsite intrusive rocks. Most slopes are very pale orange with scattered broken pinkish-gray to pale-red bands. Striped slopes are more pronounced where the flows are relatively abundant, as on peak 4982 south of Greenwater Canyon. Here slopes weather to small cliffs and alternating benches. The places with relatively irregular distribution of color or of slope weathering habit are near the base of the formation or are more complexly faulted, or both.

The gradation between lava flow and pyroclastic rocks and between pyroclastic and epiclastic rocks is more apparent in the Black Mountains than in the Greenwater Range. The tops and possibly the edges of some lava flows grade over a zone a few feet to many tens of feet wide from slightly vesicular aphanitic rock, by way of more vesicular rock, to a faintly layered tuff-breccia. Some highly vitric flows appear to grade laterally into vitrophre agglomerates and on into tuff-breccias rich in vitrophyre fragments, but this change is more difficult to demonstrate in this formation than in the Greenwater volcanics. Massive tuff-breccia grades into, or alternates with, thickly and crudely bedded tuff-breccia and less commonly grades into a bedded rock rather than flow-layered rock. Well-bedded epiclastic deposits grade vertically into less well bedded tuffs over a few tens of feet to more than 100 feet.

The thickness of different pyroclastic units is probably more variable than that of different lava flows or epiclastic beds. Most tuff-breccia units are less than 150 feet thick, but a few exceed 300 feet. Lava flows are generally 10–80 feet thick and extend laterally less than a mile, but a few flows south of Greenwater Canyon are thicker and more extensive. Along the western exposures of the volcanics the continuity of the units is poor, possibly because faults are more abundant there than elsewhere.

LAVA FLOWS

The lava flows of the older volcanics are more variable than the younger rhyolite and rhyodacite flows in the area. Fresh and weathered surfaces of the rocks are pinkish gray to pale red or, less commonly, are pale red purple, moderate orange pink, or moderate red. Most rocks break into small platy chips less than an inch thick, but some break into thicker irregular blocks. Some of the thinner plates make a distinct tinkling when knocked against each other. Vugs, generally less than an inch in diameter, constitute a few percent of most flows and are lined with quartz or amorphous forms of silica. Some of the lighter colored flows which superficially resemble the tuffaceous rocks contain 10–40 percent of minute cavities. Some flows contain a few percent of angular fragments 1–2 inches across that resemble the rocks of flows and intrusives of the older volcanics. Phenocrysts of feldspar are ubiquitous but not abundant, and phenocrysts of amphibole and quartz also occur. Veinlets of quartz and opal are common.

The vitrophyres are mostly medium light gray, but some are grayish black, brownish black, or olive gray. Vitrophyre sheathes many felsite flows, and some flows, on their thin edges, are wholly vitrophyre. The vitrophyre sheath is less continuous on the flows in most parts of the Black Mountains than they are on most flows in the southern Greenwater Range. The basal vitrophyre of some of the flows in the Greenwater Range is darker than the top vitrophyre. Perlitic structures are fairly common, possibly more common than in the vitrophyres of the Greenwater volcanics.

The relations between vitrophyre flows, pale-orange felsite, and pale-red felsite are complex in some places. About 1¼ miles northwest of Greenwater townsite and one-fourth of a mile northeast of peak 4967, for instance, gray vitrophyre pods a few feet wide and about 10 feet long are surrounded by a pale-orange felsite. The contacts between the vitrophyre pods and the felsite are sharp, and where silica veins cut the vitrophyre and felsite, the felsite forms continuous narrow borders to the veins. Red spherulites, layers of spherulites, and unbroken layers of pale-red felsite generally less than half an inch thick and a few inches apart occur in both gray vitrophyre and pale-orange felsite. Some layers cross the border between the gray vitrophyre and the pale-orange felsite.

The rocks are very fine grained or glassy and are generally severely altered. Phenocrysts and identifiable secondary minerals make up less than half the rock. The data obtained from thin sections of the vitrophyre and from some felsite fragments in the pyroclastic rocks are presented with the data from thin sections of the lava flows. The specific gravity and index of refraction of some glasses are listed in table 5.

TABLE 5.—*Some properties of the older volcanics*

Specimen No.[1]	Field No.	Plagioclase phenocryst composition	n	Specific gravity[2]		Remarks
				Rock	Glass	
4	57D293	An_{33-35}	1.498	2.38	(2.33)	
5	56D105	An_{36-50}	1.518	2.54	(2.51)	
6	56D177	An_{31-50}	1.496	2.46	(2.44)	
8	56D131	An_{40-44}	1.496	2.46	[3] 2.38	
9	56D255	An_{31-41}	1.496	--------	--------	Fragment in agglomerate.
36	56D88	An_{33}	1.498	(2.34)	2.33	Specific gravity of spherulites=2.40.

[1] See desription in table 4.
[2] Specific gravity was obtained, except as noted in footnote 3, by averaging that of five selected chips essentially free of crystals and vesicles weighed on a Berman balance. Values of specific gravity in parentheses are corrected for the estimated amount of vesicles and amount and type of crystals still present in the chips.
[3] Measured by S. M. Berthold, U.S. Geol. Survey, using powdered sample and a pycnometer.

The type of phenocrysts and xenocrysts, their frequency of occurrence, and their abundance is given in table 6. The term "xenocryst" is used throughout the report in a descriptive sense; that is, markedly embayed crystals or crystals with reverse zoning. Groundmass minerals include abundant plagioclase microlites, tridymite, and cristobalite. Secondary minerals include much quartz or chalcedony, devitrified glass, hematite, sericite, and clay minerals.

TABLE 6.—*Frequency of occurrence and abundance of phenocrysts and xenocrysts in the extrusive rocks of the older volcanics*

Minerals	Percent of 19 thin sections containing mineral	General percent of thin section	Maximum percent of thin section
Plagioclase [1]	100	5–10	35
Biotite	100	2–3	4
Amphibole	70	1–2	4
Quartz [1]	40	<5	10
Magnetite	90	<1	2
Apatite	80	<1	<1
Sphene	10	<1	<1
Zircon	20	<1	<1
Orthopyroxene	20	<1	4
Clinopyroxene	<10	<1	7

[1] Includes some xenocrysts.

Porphyritic and vitrophyric textures are most common. Phenocrysts, generally stubby laths and clusters of crystals, make up about 15 percent of most rocks and rarely make up more than 30 percent. Most phenocrysts are less than 2 mm long. Microlites are commonly less than 0.01 mm long and constitute 5–20 percent of the rock. Some rocks contain several types of vitrophyre that differ in color, microlite content, or fracture habit. Alined microlites and, less commonly, layers of rock with different amounts of quartz, or hematite, or of different colored glass are conspicuous features in the groundmass and parallel the macroscopic flow layers. Microlite layers are unbroken by the pale-red spherulites, which have a radially fibrous and cryptocrystalline texture. About half of the glassy rocks have perlitic fractures. In one rock two types of intimately mixed vitrophyre with strong perlitic fractures are cut by a penecontemporaneous nonperlitic vitrophyre. Small pods and lenses of quartz and chalcedony occur in a few rocks.

Plagioclase phenocrysts generally form stubby laths, but anhedral rounder, anhedral fragmental, embayed, and vermicular grains, many of them xenocrysts, are also common. More than 90 percent of the phenocrysts are andesine, but they range in composition from calcic oligoclase to calcic labradorite. Broad normal composition zones are conspicuous, and oscillatory zones, although commonly present, are inconspicuous.

Biotite and amphibole are generally euhedral, but a few bent biotite and flaky or crushed amphibole grains are commonly present. Biotite, amphibole, or both of them are oxidized in about one-third of the rocks. The biotite normally is pleochroic with X= yellow brown to pale yellow brown, Y=blackish brown, and Z=blackish brown, but Y and Z are reddish brown in oxybiotite. In a few rocks both types of biotite appear. Most amphibole is pleochroic with X=pale yellow brown, Y=moderate olive brown, and Z=grayish green; however, some is X=yellow brown, Y=moderate red, and Z=very dark red. The extinction angle of the red hornblende is 5°–8°; that of the olive hornblende is 17°–21°. The red hornblende is much more severely altered to an opaque red material, probably hematite, than the other hornblende.

The other phenocrysts and xenocrysts have a relatively uniform character. Quartz is commonly anhedral rounded to embayed. Magnetite and ilmenitic magnetite are subhedral or form clusters of small grains and are associated with amphibole and biotite. Apatite and zircon form small euhedra, and sphene forms euhedra or fragments. Orthopyroxene and clinopyroxene are subhedral to euhedral.

The groundmass is severely altered and is obscured by a reddish to very pale orange material, which probably is hematite and clay minerals. The matrix of the pyroclastic and epiclastic rocks is probably similar material. Small amounts of calcite are interstitial or replace plagioclase. Quartz, tridymite, cristobalite, chalcedony, and opal occur in small pods, or disseminated grains. No indisputable signs of welding are found in rocks that looked most promising in the field.

PETROLOGY

The rhyolite and rhyodacite flows of the older volcanics are at least slightly contaminated, and they are much devitrified and altered. Many of the large crystals, the xenocrysts, are foreign to the surrounding rock and probably were introduced prior to extrusion. Some textural features, such as the embayed quartz and the vermicular plagioclase suggest partial resorption of the crystals by the magma. The crystals must have been added or crystallized prior to ejection, for the groundmass is largely glassy and was probably chilled rapidly upon extrusion. The composition of the phenocrysts or xenocrysts of plagioclase may, therefore, have little or no bearing on the composition of the rock.

The lava probably continued to be mixed at the surface by inclusions of rock fragments similar to the flows. Some lava flows contain two vitrophyre types that were physically mixed before they were chilled; others, with truncation of flow structure, mixed after one type chilled but before the other did. These mixtures are normal occurrences in flows and are caused by the infalling of pyroclastic rocks, inrolling of underlying fragments, or stoping or infalling of volcanic material from the walls of the vent, and by local turbulence in otherwise lamellar flow currents.

Some amphibole and biotite may have been oxidized in the vents. Dissociation temperatures of hornblende were reported at 750°C by Kōzu, Yoshiki, and Kani (1927), and those for biotite were reported at 900° by Day and Allen (1925, p. 49–53). However, the oxidation may have continued on the surface while the iron of the red spherulites was oxidized.

After chilling, but probably while the temperature was still high and fluids abundant, the rocks were partly devitrified, altered to clay minerals, and oxidized. The available information suggests that possibly two types of devitrified rocks occur, or, alternately, devitrification occurred at two times. The first type produced the red spherulite and pale-red felsite layers in vitrophyre. This change was accompanied by a gain in weight of the spherulites (see table 5, No. 36) that was probably due to loss of water in the devitrified areas and oxidation of iron. This devitrification occurred after the microlites were alined in the glass, for the spherulites overlap microlite bands. It probably occurred while the temperature was sufficiently high to oxidize the iron. About this time cristobalite crystallized in cavities in the rock and at least some of it was converted to tridymite.

The second type of devitrification produced a pale-orange felsite and probably is associated with abundant opal veins. The red spherulites were not affected by this change, for they extend through both the vitrophyre and the surrounding felsite. This devitrification was accompanied by alteration to clay minerals, and hematite dust. The temperature at which this devitrification occurred was below that at which the oxidation of minerals takes place, and favored the deposition of opal rather than tridymite.

The flows are believed to have had the following composite history. Physical contamination probably occurred during and shortly after extrusion. They were at temperatures of about 800°C only long enough for some hornblende and biotite crystals to oxidize. During cooling, some glass was devitrified and oxidized, and tridymite was deposited in cavities. At considerably lower temperature more glass was devitrified, much of the rock was altered to clay minerals, and opal was deposited in veins.

PYROCLASTIC ROCKS

Pyroclastic rocks consist of tuff-breccia, which is the most abundant and most uniform rock type in the older volcanics, and of agglomerate, which is less abundant than the lava flows. Tuff-breccia forms massive grayish-yellow to very pale orange outcrops and broad rubble zones. Locally, tuff-breccia is pinkish gray or pale reddish brown. It breaks into small angular fragments rarely more than a few inches long. Outcrops of tuff-breccia are generally small and form rounded bosses or ledges thinly covered with rubble, but on steep slopes outcrops are massive. Bedding is either absent or appears in units a few tens of feet thick, which are separated by large fractures but in which there rarely is any size sorting. Crude size sorting and orientation of fragments are more common close to well-bedded tuffaceous sediments. Some tuff-breccia is faintly and thinly layered by darker and better indurated layers alternating with others. In the vicinity of unquestioned bedding, they are parallel to the beds and are inferred to have a similar origin. In other places their origin remains unknown, and their structural usefulness is questionable.

The dominant constituents of the tuff-breccia are gritty fragments of tuff and secondary clay minerals; less than 25 percent of the rock consists of angular fragments of felsite ranging in size from sand to small cobbles. Most of the rock is highly porous. The felsite fragments include abundant dark-red rocks similar to the intrusive rocks in the formation, moderate amounts of rock resembling the lava flows in the same formation, and small amounts of pumice, other tuff-breccia, and locally, quartz monzonite and dolomite. Fragments of biotite are ubiquitous. Opal, chalcedony, and clay minerals, probably derived from devitrification and other alteration of the tuff-breccia, form the chief cementing material. Small amounts of calcite are present in most of the rocks.

Agglomerate is less abundant than tuff-breccia and grades into it through tuff-breccia rich in vitrophyre blocks. Agglomerate is light gray to pale red and pale orange, depending on the chief constituents. The rock is massive and is generally as poorly resistant to weathering as other clastic rocks in the formation, but in some places, as on the low spurs extending eastward into Greenwater Valley near Greenwater townsite, or on the spurs east of Hidden Spring, agglomerate forms a resistant cap over tuffaceous rocks. Some weathered vitrophyre agglomerate forms a thick blanket of boulders difficult to distinguish from weathered vitrophyre flows.

Agglomerate contains more than 50 percent of boulders and blocks set in a gritty, tuffaceous matrix similar to the tuff-breccia. Some agglomerate contains blocks of gray vitrophyre; others have porphyritic rhyolite or porphyritic latite blocks which resemble some of the more massive flows of the older volcanics. Angular granules and pebbles of red porphyritic felsite are generally absent from the matrix of the agglomerate. The cementing material is probably the same as that of the tuff-breccia.

The microscopic characters of the fragments in the tuff-breccia and the agglomerate are described in the sections on the lava flows and intrusive rocks which they resemble. The character of the groundmass is obscured by clay minerals.

EPICLASTIC ROCKS

Tuffaceous sandstone and conglomerate form a minor, but stratigraphically important part of the formation. They are generally pale orange to pale red, and contain abundant porphyritic felsite fragments; they resemble the tuff-breccia except that they are well bedded and sorted. Beds of silt and fine sand are commonly pale red, and the coarse sand and grit beds are pale orange. The rocks are easily eroded and weather into fragments ranging in size from slabs about an inch thick to small blocks, and break more readily along the coarse-grained beds than the fine-grained beds. In addition to the porphyritic felsite fragments, scoriaceous, amygdular, and vesicular olivine basalt pebbles occur in the sediments near the basalt bodies in the older volcanics. Beds range in thickness from fine lamellae thinner than one-sixteenth of an inch to units several inches thick. The less well sorted tuff-breccias are even thicker. Crossbedding and lenticular bedding is common to the laminated beds. No fossils were found.

Microscopic examination reveals little more than the outcrops. Grains are poorly rounded and are crudely alined. The groundmass is very fine and is generally obscure, but some secondary silica and sericite are present, and pervasive hematite colors some rocks. The petrography of the larger fragments is described with the rocks that probably were their source.

ORIGIN AND ENVIRONMENT

The extrusive and sedimentary rocks of the older volcanics indicate that the origin was largely by explosive effusion, secondarily by quiet effusion, and subordinately by sedimentation, for tuff-breccia and agglomerate are most abundant, lava flows are less abundant, and epiclastic rocks are least abundant. It is also probable that explosive activity was greater in the Black Mountains than in the Greenwater Range, for tuff-breccia and agglomerate are more abundant in the Black Mountains, and lava flows are least continuous there. Furthermore, the incidence of included fragments of older rocks is restricted to pyroclastic rocks in the Black Mountains. The comparatively regular alternation of tuff-breccias and lava flows in the Greenwater range shows that in this area the strength of explosions and abundance of effusion had a constant relation. Each outburst is marked by a sequence: basal tuff-breccia, lava flow, and capping tuff-breccia. The interim between explosions, if any, is marked by the epiclastic rocks. It is alternatively possible that the bulk of the rocks in the Greenwater Range is younger than those in the Black Mountains and that, after initial irregularly spaced and larger explosions, the activity settled down to more regular eruptions of relatively uniform and smaller size, coupled with more abundant lava effusion. This alternative is less favored because no volcanic rocks mixed with intrusive rocks like the volcanic rocks in the Black Mountains occur in the corner of the Greenwater Range where basement rocks are exposed. However, high-angle faults are sufficiently abundant to make general correlation of flows from major block to major block very uncertain.

The epiclastic rocks were deposited by small streams and in ponds. Neither streams nor ponds had a long life, as indicated by the small lenticular bodies of coarse sediments, before being buried by the next tuffbreccia sheet; so drainage probably never formed a well-integrated system. Very likely ponds formed locally were new irregularities occurred in the surface just modified by eruptions. The absence of fossils may reflect the frequency and destructiveness of the explosive eruptions, or an arid climate, or just conditions unfavorable to the preservation of fossils. Certainly arid climates prevailed during later times.

INTRUSIVE ROCKS

GENERAL DESCRIPTION

Porphyritic felsite, largely rhyolite and rhyodacite, forms about a third of the mapped area of the older volcanic rocks. It underlies many irregularly shaped areas near the crest of the Black Mountains and several large areas in the Greenwater Range. A fairly continuous belt of outcrop along the high ridges northwest of Coffin Canyon is also underlain by intrusive rhyolite. Similar rocks are abundant in the quadrangles immediately to the north and south of the Funeral Peak quadrangle and also occur elsewhere.

In most places the felsites form dark-red knobs that rise above the surrounding volcanic rocks or older rocks, but in a few places the red felsites form lowlands. The prominent red boss northeast of the mouth of Coffin Canyon and many of the abundant knobs east of Gold Valley are typical of the more resistant intrusive felsite, whereas extensive areas of intrusive felsite in the southern part of the Greenwater Range are not conspicuous topographically.

Most of the outcrops are relatively small and irregular, but they make three slightly different patterns. Most of the red felsite in the Black Mountains is a composite of several rocks that have different phenocryst or breccia content and form ellipitical patches, short bands, and irregular areas. East of Gold Valley one conspicuous yellow-brown to light-gray igneous breccia with rhyolite, carbonate, and quartz monzonite fragments forms a broad belt of alined outcrops. Near Coffin Canyon the felsite forms a relatively uniform and large lens or sheet between the metamorphic and monzonitic rocks, and the tuffaceous rocks of the older volcanics. In the northern part of the Greenwater Range the felsite forms parallel bands trending northeast and alternating with tuffaceous rocks; the southernmost exposure of felsite in this range also makes a northeast-trending linear pattern. The other exposures of felsite in the southern part of the range trend more easterly and are too poorly exposed to show whether they are composite or single bodies. Septa or irregular pods of tuffaceous rocks a few feet to many tens of feet wide, some of which are bedded, are common within many felsite bodies. On the other hand, many tuffaceous rocks of the formation contain small intrusive bodies of felsite. Contacts are much generalized in areas of mixed rocks, and only the dominant rock type is mapped. Red felsites of unknown origin are mapped with the intrusive rocks rather than the extrusive rocks.

Most felsite bodies are intruded into, or are faulted against other units of the older volcanic rocks, or older rocks. Felsite cuts the monzonitic rocks; it forms dikes and pods within the monzonite in many places, as for example 2½ miles north-northeast of Funeral Peak, and forms plugs in the monzonitic rocks just east of Gold Valley. In many places, such as the west corner of plate 2, felsite, here probably a rhyolite, also engulfs blocks of sedimentary rocks of Paleozoic age. In other places, such as just west of bend in section *A–A′*, plate 2, and also just east of Gold Valley, plate 1, it disrupts segments of the Amargosa thrust fault along very irregular contacts. The felsite contacts that cut the Amargosa thrust fault are too poorly exposed to show details, but they are so irregular in plan that normal faulting does not adequately explain them. However, in other places such as the center of plate 2, normal faults with relatively narrow sheared and brecciated zones compared to those of the Amargosa thrust fault, separate a rhyolite(?) from the sedimentary rocks of Paleozoic age. Locally, tuffaceous rocks of the older volcanic bodies are altered to a dark-red rock, are much faulted, and are erratically tilted at high angles near the felsite. The faults between pyroclastic rocks and felsite are strongly grooved and accompanied by breccia, but few faults extend far from the felsite. These faults are probably contemporaneous with intrusion, or represent minor jostling between rocks of greatly different strengths within the major blocks as they were tilted along major faults.

One elliptical patch of red porphyritic felsite on a low knob just north of Gold Valley has in plan an outer ring, about ¼ by ½ mile in outside diameter, of felsite with large feldspar phenocrysts. Within this ring is a crescent of tuff-breccia and tuffaceous conglomerate dipping 45°–80° toward the center. In the center of the crescent, and surrounded by prominent shear surfaces, is a breccia with a porphyritic felsite matrix. Cross section *C–C′*, plate 1, cuts this felsite body but is generalized.

PETROGRAPHY

The red color, the feldspar phenocrysts, and the common occurrence of breccia are the most distinctive features of the felsite. Most rocks are pale red, grayish red, reddish brown, or dusky red, but a few rocks are medium light gray, pale purple, or yellow brown. Some weathered surfaces are unchanged, others are blackish red, or are altered to shades of orange. The rock weathers to irregular or blocky fragments generally 3–4 inches long. Many rocks are shattered or brecciated and unevenly rehealed or recemented so that some outcrops have a rounded, resistant cap with cavities and weathered-out pockets a foot to many feet long. Fractures in shattered and brecciated rock are very close together; in the others they are seldom more than 4 inches apart. A second abundant type of breccia has an igneous matrix and is thoroughly healed. The fragments are usually less than a few inches long, but some are a foot across; they are porphyritic felsite types similar to the matrix or to the lava flows of the older volcanics, but south of Funeral Peak and along Greenwater Canyon, the breccias include lesser amounts of quartz monzonite, tuff, metadiorite, quartzite, dolomite, and limestone. The igneous breccias along Greenwater Canyon, which contain, among others, fragments of quartzite and quartz monzonite, are particularly noteworthy, for no rocks older than the older volcanics are exposed for 5 miles around. More rarely the felsite is vesicular or vuggy. Quartz fills many of the veins and lines some of the vugs; other veins contain calcite.

Phenocrysts generally make up 10–25 percent of the rock, although in one rock they constitute 40 percent. They usually range in length from 0.1 to 0.3 mm but some exceed 3 mm. One conspicuous type of felsite has phenocrysts as long as 10 mm. Many phenocrysts are alined or clustered. They are set in an altered or cryptocrystalline groundmass, commonly with a strong layering marked by changes in color or microlite content. Pods and veins of quartz and calcite are common, and spherulites, vesicules, and calcite-filled amygdules also occur in a few rocks.

Mineralogical details are few and are reported mostly from phenocrysts and xenocrysts because the rocks are severely altered. Plagioclase phenocrysts are ubiquitous and form stubs, laths, or clusters in about equal abundance. Their composition generally falls in the andesine or albite ranges. Most of them are altered to sericite and clay minerals, and a few are replaced by calcite or hematite. Biotite and amphibole each occur in about half the rocks, but occur together in less than one-quarter of them. Biotite and hornblende are commonly anhedra or are pseudomorphosed by various combinations of uralite, chlorite, calcite, sericite, and hematite. A few rocks contain oxybiotite or oxyhornblende with thick rims of granular hematite. Quartz is anhedral or embayed. Phenocryst composition and abundance are tabulated below. Some primary quartz is difficult to distinguish from secondary quartz, and some phenocrysts may be xenocrysts; so the reported frequency is somewhat less than shown. Accessory apatite, sphene, and zircon occur as phenocrysts and in the groundmass; all are included with phenocrysts in table 7. The original groundmass mineralogy could be determined from fewer than 20 percent of the rocks; the minerals in the groundmass are chiefly plagioclase, magnetite, and cristobalite, all in unknown quantity. Cristobalite lines some cavities. Glass is probably a major constituent of many rocks and is probably present in them all.

TABLE 7.—*Frequency of occurrence and abundance of phenocrysts and xenocrysts in the intrusive rocks of the older volcanics*

Mineral	Percent of 34 thin sections containing mineral	Percent of thin section	Maximum percent of thin section
Plagioclase	80	5–15	30
Biotite	50	1–2	3
Magnetite	50	<1	2
Amphibole	40	3–4	6
Quartz	20	1	2
Potassium feldspar	<10		7
Pyroxene	<10	5	5
Olivine	<10		1
Apatite	50	<1	<1
Sphene	<10	<1	<1
Zircon	<10	<1	<1

The felsites are severely altered, and secondary minerals include hematite, limonite, quartz, calcite, uralite, chlorite, sericite, clay minerals, and chalcedony or opal and other unidentified minerals. The distribution of the alteration has no apparent pattern, although locally it is distinctly associated with one particular intrusive body, or one particular breccia variety within an intrusive body. Plagioclase is commonly albitized. Some red felsites are thoroughly bleached to very pale orange, and some of these rocks are stained red on fracture surfaces. The bleached rock probably has a high clay-mineral content and may be silicified. Random chips immersed for several days in concentrated nitric acid were bleached in a similar manner, whereas others immersed in concentrated sodium hydroxide were not affected, so that at least the color change may have been caused by an acid solution. Other rocks are stained dark with iron oxides and possibly with manganese oxides. Specularite appears in some veins, but sulfides are absent. Manganese, copper, barium, and possibly gold and silver occur in small quantities with some of the felsites, and may be related to the altered rocks.

ORIGIN AND ENVIRONMENT

The red porphyritic felsites are contemporaneous with the flows and tuffs of the older volcanics and were intruded at shallow depths as a complex of sills, dikes, vent plugs, and other plutons. Contemporaneity is suggested by the abundant intrusive contacts of red felsite into volcanic rocks containing abundant fragments of similar red felsite. In addition, fragments and pods of tuffs and flows are included in some of the red felsite intrusive bodies. Intrusion at shallow depths is inferred from the contemporaneity of host and intrusive rocks, and it is also suggested by the abundance of red oxidation, by the abundance of igneous breccia, and by the local rupturing rather than warping of the host rocks about the intrusive bodies. The large sheet or lens of relatively uniform red felsite at Coffin Canyon may have been injected at the base of the volcanic bodies as an irregular sill or a laccolith, and probably represents the deepest exposed part of the intrusive rocks. This depth is as least 2,000 feet, the estimated local thickness of the volcanic rocks plus the thickness of the felsite exposed beneath them. The dike swarms, mapped in the Greenwater Range as large areas along and just south of Greenwater Canyon, possibly were feeders for the abundant flows east of them. The small elliptical felsite body with the crescent of tuffaceous conglomerate and igneous breccia core north of Gold Valley is interpreted as a volcanic throat with minor collapse structure. Several other volcanic throats, most without collapse structure, occur nearby.

The inclusions in the red felsite can be correlated in the underlying rocks where the underlying rocks are known, and they are used as an indicator of the underlying rocks elsewhere. Fragments of Cambrian and Ordovician rocks in igneous breccias were successfully used as indicators of the proximity of small isolated blocks of these rocks in the southern Black Mountains. Presumably, where igneous breccias with exotic fragments are unaccompanied by exposure of such rocks, they occur at shallow depths. Fragments of quartzite of Paleozoic age and quartz monzonite felsite dikes east of Greenwater Canyon suggest that these rocks lie beneath the volcanic rocks, and the particular combination of exotic rocks suggests that the Cambrian and Ordovician rocks are thin or perhaps form chaotic blocks, and lie on quartz monzonite.

AGE AND CORRELATION

The older volcanics are older than the Furnace Creek and the Copper Canyon formations of Miocene and Pliocene age and are younger than the monzonitic rocks of early or middle Tertiary age. They lie unconformably beneath the Copper Canyon formation and

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were the source of much of the clastic fragments in the Copper Canyon and Furnace Creek formations. They are therefore assigned to the middle(?) Tertiary.

The older volcanics are correlative with part of or all the Artists Drive formation of the Furnace Creek area north of this quadrangle (Noble, 1941, p. 955–956; Noble and Wright, 1954, p. 149; and this paper). Noble and Wright correlated the Artists Drive formation with the well-dated, but distant, Titus Canyon formation of Stock and Bode (1935, p. 571–579), but they accepted the possibility that the Artists Drive formation might be partly younger than the Titus Canyon formation by assigning the Artists Drive formation an Oligocene or Miocene age. A similar conclusion of the age relations between the older volcanics and rocks similar to those at Titus Canyon was reached by me at Bat Mountain (fig. 2).

FURNACE CREEK FORMATION

GENERAL DESCRIPTION

The Furnace Creek formation comprises fine-grained clastic rocks and evaporites. The formation underlies less than 1 square mile of the northeastern corner of the area. It chiefly underlies lowlands and slopes beneath resistant caps of younger andesite and basalt that slump and weather to form a veneer over much of the formation. The bodies of andesite and basalt of Tertiary age that intrude into or extrude onto the formation will be described with other andesite and basalt bodies of Tertiary age.

The base of the formation is not exposed in the area, and the exposures are inadequate to provide a stratigraphic succession within the formation. It is unconformably capped by conglomerate or basalt of the Funeral formation. Some of the upper part of the Furnace Creek formation may intertongue with tuff-breccia of the Greenwater volcanics to the southwest, but most of it underlies the Greenwater volcanics. The base of a conspicuous tuff-breccia sheet, which lies with apparent local conformity over tuffaceous clastic rocks, is chosen as the contact between the formations about 1⅓ miles south and ¾ mile west of the northeast corner of the area, and also in the next canyon south of this area. The Greenwater volcanics overlie basalt of the Funeral formations (fig. 6). The formation is more extensively exposed along Furnace Creek to the north, where it is described by T. P. Thayer (written communication) and Noble (1941, p. 956).

PETROGRAPHY

The formation is largely composed of tuffaceous clastic rocks with subordinate evaporite deposits. Locally there are three general associations of sedimentary rocks: the shale-borate beds, the siltstone-shale beds, and the siltstone-limestone beds. The shale-borate beds lie just east of the map area near the Lila C mine (fig. 2). They are alternating beds of limy shale and siltstone containing gypsum and borates. The siltstone-shale beds occur southwest of the mine for the first half a mile west of the eastern border of the area. They include alternating beds of limy siltstone and shale, and tuffaceous beds. The siltstone-limestone beds lie farther southwest and consist of alternating limy tuffaceous siltstone and sandstone, limestone, and tuff-breccia. The rocks 3 miles west of the east edge of the quadrangle, and those just north of it, resemble the last group except the limestone is less abundant. These three types of beds appear to grade laterally into each other, but precise relations are obscured by the extensive colluvial cover.

Many of the lithologic features of the three facies are similar. Practically all the rocks are very pale orange to pale yellow brown. Most of them are limy and tuffaceous, and silt is the dominant grain size. Bedding thicknesses usually range from ⅛ to 1 inch but are thicker in sandstone and tuff-breccia beds. The rocks break into small platy chips and abundant limy and clayey silt. Rock fragments are well sorted and rounded except in the tuff-breccia. Probably less than 10 percent of the shale-borate beds and the siltstone-shale beds is tuff-breccia, but there is considerably more in the siltstone-limestone beds. The dissimilarities are discussed in the following description.

The shale-borate beds will be described in detail by J. F. McAllister upon the completion of his study of the borate deposits. In addition to abundant tuffaceous and limy shale and siltstone, there are tuffaceous sandstone and grit, and tuff-breccia containing abundant subangular pumice and angular vitrophyre fragments as large as half an inch. The glass of these fragments is light gray and relatively clear or dark gray with minute inclusions and microlites; the specific gravity of the clear glass is 2.36 and $n=1.502$. Some glass also appears as rounded beads as large as one-eighth of an inch in diameter; they are unabraded and appear to be perlite cores broken from vitrophyre. Beds of colemanite and finely granular gypsum, some several feet thick, are more resistant than the adjacent siltstone and shale. Vein gypsum, small-scale plastic deformation of shale beds, and high-angle faults of very small displacement are common.

The siltstone-shale beds just within the Funeral Peak quadrangle comprise about 70 percent limy and tuffaceous siltstone and shale, and 30 percent tuffaceous sandstone. They lack bedded colemanite, and gypsum is relatively scarce. Several massive very pale orange tuff-breccia beds contain cavities ¼–3 inches in diameter that are partly filled with pale-brown clay. In the alluviated area west of the Lila C mine, there are numerous small, isolated outcrops with rocks more varied than those of the siltstone-shale beds, but without the abundance of limestone common to the siltstone-limestone beds. These rocks include pale-reddish-brown to light-brown limy sandstone in platy beds 1–4 inches thick, sedimentary breccia beds resembling the beds of mudflow origin in the Copper Canyon formation (described below), very pale orange limy siltstone and shale with a trace of halite and with scattered quartzite pebbles, grit beds with basalt fragments, light-gray cherty limestone and bedded chert or opal, pale-green tuff-breccia, and the ubiquitous greenish-gray altered andesite and basalt. The pale-reddish-brown and yellow-brown rocks resemble those exposed in a hill a mile northwest of Ryan, about 5 miles north of the quadrangle, which may be older than the Furnace Creek formation (T. P. Thayer, written communication; Noble and Wright, 1954).

The siltstone-limestone beds contain more abundant and coarser epiclastic and pyroclastic beds than do the other two facies. Limestone beds in units a few feet to a few tens of feet thick constitute 10–30 percent of the sequence, but their distribution is irregular. Opaline beds as thick as 2 inches and opaline nodules occur in a few places, as about 3 miles south of the northeastern corner of the area. Some tufa limestone, oolitic limestone, and limestone conglomerate also occur there. The surfaces of other thin platy limestone beds contain round pits as large as 1 inch across and $\frac{3}{16}$ inch deep that resemble interference ripples. The depressions are partly filled with limestone cylinders less than one-eighth of an inch in diameter that may be fecal pellets of burrowing animals. The irregular crests of the ridges between the pits suggest that the pellets washed across the interference ripples, scoured away some of the crests of the ripples, and collected in the pits. Elsewhere the beds contain travertine limestone, algal(?) limestone, and flat-pebble limestone conglomerate. About 10 feet of platy limestone beds cap small domes a few hundred feet across and a few tens of feet high about 2½ miles southwest of the northeast corner of the area. A little halite and gypsum are associated with shale in this facies.

AGE AND CORRELATION

The age of the Furnace Creek formation is Miocene or Pliocene, based on meager fossil evidence collected north of the quadrangle near the mouth of Furnace Creek Wash. Axelrod (1940) reported *Lyonothamnus mohavensis* Axelrod, or Catalina ironwood, and unidentifiable grass or reeds in the upper part of the formation. By comparing present precipitation of areas in which this plant grows with the inferred precipitation rates during part of the Tertiary, obtained from larger floras in the Mohave area, he concluded that the *Lyonothamus* of Death Valley is most reasonably upper Miocene. T. P. Thayer (written communication) mentioned mammal and bird tracks from sandstone and mudstone of the Furnace Creek formation north of the Funeral Peak quadrangle. The tracks are poorly described, but they could be similar to those found in the Copper Canyon formation, and hence may be Pliocene. Fish fragments have also been found in rocks of the Furnace Creek formation (Levi Noble and J. F. McAllister, oral communication), but are nowhere described. I suspect that the fish fossils are either compatible with a Miocene or Pliocene age, or are undiagnostic.

Correlation of the Furnace Creek formation is difficult because fossils are scarce in the Tertiary rocks throughout the region and because deposits with similar lithologies occur in small widely separated patches. Some of the rocks in the Copper Canyon area and in the Confidence Hills in southern Death Valley are similar to the rocks of the Furnace Creek formation. At best, one can say that they were deposited in similar environments during roughly the same time, the late Tertiary. There is no evidence that they were deposited in the same basin or at precisely the same time.

Parts of the Furnace Creek formation are probably facies of parts of one or both of the volcanic formations, and part of the Furnace Creek formation was probably deposited contemporaneously with the erosion surface between the volcanic formations. These age relations are inferred from the following observations: First, the general dip of 20° of the Furnace Creek formation in the Funeral Peak quadrangle is intermediate between the general dip of 40° of the older volcanics and of 10° of the younger Greenwater volcanics. As exposures of these rocks are a few miles apart and as their lithologies and hence their response to given stresses differ, this criterion is not completely reliable. Nevertheless, the differences in the degree of deformation of rocks in a relatively small area is a good rough indication of the relative ages of the rocks. Second, the tuff-breccia beds at the edge of the exposures of the Furnace Creek formation thin away from a rhyolitic dome of the Greenwater volcanics toward the center of the lake in which the formation is inferred to have been deposited. Toward the center of the lake, and relatively high in the formation, tuff-breccia beds are thin and uniform and contain abundant little-worn pumice that apparently was airborne to the lake in which it sank rapidly. Since pumice is most common in the base of the Greenwater volcanics, is less common higher in that formation, and is rare in the older volcanics, the upper part of the Furnace Creek formation in this area may be contemporaneous with the base of the Greenwater volcanics. Third, some of the Furnace Creek formation is unconformably overlain by basal beds of the Greenwater volcanics in one small area, but it is impossible that the unconformity is localized along the base of one tongue of the Greenwater volcanics. The inferred relations of the Furnace Creek formation to the volcanic formations is illustrated in the interpretive columnar section on plate 1.

ENVIRONMENT

The beds of the Furnace Creek formation in the Funeral Peak quadrangle were deposited at the edge of and within a lake in a closed basin, in which abundant volcanic ash and less abundant coarser pyroclastic rocks were deposited. The laminated, thinly bedded, and well-sorted siltstone and the shale beds containing gypsum, borate, and a little halite indicate quiet subaqueous conditions, such as would be found in many undrained lakes in the Basin and Range area. The southwestern edge of the lake lay approximately along the northeast edge of the tuff-breccia member of the Greenwater volcanics, and trended northwestward. The lake level probably fluctuated widely, for lacustrine and fluvial deposits alternate throughout the siltstone-limestone facies. Subaerial features such as stream-scoured channels, and mudflows alternate with limestone. The absence of subaerial features in the shale-borate facies suggest that a lake rather than a playa occupied the center of the basin. The combination of a closed basin and a rainfall ranging from 13 to 15 inches a year in the hills to 10 inches on the playa flats, or about twice that of Death Valley today, as indicated by the Catalina ironwood (Axelrod, 1940, p. 30), also suggests that a permanent lake rather than a playa occupied the basin part of the time. The combination of the interference ripple marks, the oolites, and the travertine limestone, opal beds, and possibly tufa limestone that may have been deposited at springs along or near the shore of the lake, suggests that the lake was shallow along this edge.

The terrain adjacent to this margin of the lake was not particularly rugged; certainly there were no abrupt scarps, such as border Death Valley today, for coarse clastic debris is scarce, and faults with large displacement are unknown there. The area adjacent to the lake was, for at least part of the time, an active volcanic field supplying much rhyolite and rhyodacite, pumica and vitric fragments.

COPPER CANYON FORMATION

DEFINITION

A Pliocene(?) sequence of more than 10,000 feet of moderate-red conglomerate, yellowish-gray siltstone and evaporites, and intercalated basalt, which underlie the lower Copper Canyon area, informally referred to as the Copper Canyon beds by Curry (1941), are here named the Copper Canyon formation. They were deposited in a basin that was closed during part of its history, a basin that was probably separated from a similar basin near Furnace Creek north of the map area and was possibly separated from a similar basin to the south. The suggested type area of the formation is its full exposure in the basin, which is practical in view of the excellent exposure and the rapidly changing facies and thickness of the rocks. Copper Canyon furnishes easy access to part of the basin and cuts across most of the rock types.

GENERAL DESCRIPTION

The rocks underlie a rectangular area of about 5 square miles that is bordered by Death Valley on the west, and they also underlie a few small areas on top of the prominent red peak north of Coffin Canyon. The formation lies unconformably on tuffaceous rocks of the older volcanics and is faulted against intrusive felsite of the older volcanics along the north side of the basin. Conglomerate of the Funeral formation unconformably overlies the formation to the east, and locally the breccia member of the Funeral formation is faulted against the Copper Canyon formation. This fault is peculiar in that laterally it grades into the unconformity. It is described in more detail later. Fanglomerate and sedimentary breccia of the Copper Canyon formation are faulted over the Precambrian metasedimentary rocks on the south side of the basin on the Turtleback fault.

The sedimentary rocks of the Copper Canyon formation consist of a dominant conglomerate member and a subordinate siltstone and evaporite member. All the lower part of the formation, much of the middle part, and some of the top part is conglomerate that intertongues laterally with the siltstone and evaporite member that forms some of the middle and top parts of the formation. The largest tongues are a few hundred yards long and a maximum of a few hundred feet thick. In detail the contact between the members follows bedding planes that generally converge gradually toward the tip of a conglomerate tongue but in places converge abruptly.

Intercalated greenish-gray andesite and basalt form large tabular or lenticular bodies parallel to the beds and also form small pods and tabular bodies that cross the beds. They are described with similar rocks in the section on Tertiary andesite and basalt.

The scenery in the Copper Canyon area is among the most spectacular in Death Valley National Monument, for the conglomerate, siltstone, and basalt contrast strongly in color and erosional form. The conglomerate member underlies steep slopes and cliffs that are moderate red (fig. 5). The rock weathers to small benches and ledges or to rounded bosses with fluted or grossly pitted surface. Bedding is massive, and widely spaced joints and faults of small displacement cut the rock. The siltstone and evaporite member, on the other hand, underlies broad benches and basins that are yellowish gray, very pale yellow brown, or, locally, greenish gray. The type and distribution of the evaporites control most of the weathering habits of the member: fluted cliffs and steep-walled gullies are associated with gypsiferous sediments; hogbacks are typical of tilted siltstone containing thick limestone beds.

The thickest sections of the formation are exposed along the axis of a syncline that extends across the basin between knob 1591 southeast of the mouth of Coffin Canyon and knob 2410 about 2½ miles farther east. Tuffaceous rocks and small felsite intrusive pods of the older volcanics lie beneath the basal unconformity. The surface cut on these rocks slopes 10°–20° southeastward and has a relief of about 200 feet. The basal conglomerate contains larger amounts of tuffaceous fragments than the overlying conglomerate, and the ubiquitous red felsite fragments are particularly abundant. A small andesite or basalt sheet lies on the unconformity on the red peak north of Coffin Canyon and in the small fault block at the south end of the wedge of chaotic blocks. East of knob 1591 the red conglomerate at the base of the formation is only a few hundred feet thick, but a mile farther south it is several thousand feet thick. In the center of the basin and parallel to part of section *B–B′*, the conglomerate is overlain, successively, by about 200 feet of siltstone and evaporites, 100 feet of basalt, 200 feet of conglomerate, 1,500 feet of siltstone and evaporites, 500 feet of

FIGURE 5.—Copper Canyon formation exposed on the south wall of Copper Canyon near its mouth. The light-colored rock is a lens of siltstone about 200 feet thick enclosed by and intertonguing with dark conglomerate. The white bands in the small fluted cliffs are evaporites.

basalt, and 4,500 feet of siltstone and evaporites. The capping unconformity lies subparallel to the bedding of the conglomerate in the Copper Canyon formation along the edges of the basin, but toward the center the siltstone member is disrupted by the megabreccia member of the overlying Funeral conglomerate.

The thickness of the formation is highly variable. Along the axis of the syncline it is more than 7,000 feet thick; it is probably thinner along the northern and southern borders of the basin, and is at least 10,000 feet thick toward the southwest where the basal part is not completely exposed. The thickness is probably little affected by fault repetition and rock flowage of shale and gypsum. The siltstone and evaporite member does contain some normal faults that trend at right angles to the axis of the syncline and have their northwest sides down, but the displacements are small, and in the rest of the formation faults are few. The thickening of the siltstone and evaporite beds toward the center of the basin is probably due to deposition rather than rock flowage, for evidence supporting rock flowage is meager and large changes in thickness also occur in the less plastic conglomerate and basalt.

CONGLOMERATE MEMBER

The conglomerate is generally a uniform rock containing poorly sorted subangular pebbles and cobbles, dominantly of porphyritic felsite, from which it gets its pale-red, grayish-red, or pale reddish-brown color. Variations in fragment size and sorting are more conspicuous than color or composition.

Most of the fragments in the conglomerate are of rock types present in the surrounding mountains; others are derived from the andesite and basalt within the formation or from rocks not present nearby. Red porphyritic felsites are most abundant; monzonitic rocks, metadiorite and metasediments are common; and tuff, tuff-breccia, basalt, chalcedony, vein quartz, fine-grained white quartzite, and algal limestone are comparatively scarce. The felsites and the tuffaceous rocks resemble the rocks of the older volcanics. The common rocks are similar to the rocks of early or middle Tertiary age and of Precambrian age. Andesite and basalt fragments are abundant near the flows, which are their probable source. The quartzite and limestone of the rare fragment types are noteworthy, for they resemble the Paleozoic rocks, which are absent in the surrounding mountains. Some sedimentary rocks, but not these types, appear among the chaotic blocks in the fault wedge at the mouth of Coffin Canyon, and possibly the wedge also contained quartzite and limestone blocks. Both these blocks and the fragments in the Copper Canyon formation suggest that the Paleozoic rocks were more widespread, although not abundant, in Miocene or Pliocene time.

The size of the fragments decreases, and beds are better sorted and thinner toward the center of the basin. Most of the rock is a pebble-and-cobble conglomerate in beds one to several feet thick. Boulders and blocks larger than 10 feet across occur in the formation and locally are abundant. The matrix is granular and sandy material similar in composition to the larger fragments. Near the base of the formation and along its southern margin, unbedded coarse sedimentary breccia grades upward into the typical conglomerate. A few sheets of such breccia are interbedded with the conglomerate farther away from the edge of the basin. For example, a breccia bed a few feet thick of quartzite fragments a few inches across is interbedded in conglomerate at an altitude of 1,300 feet about 1 mile east of the mouth of Copper Canyon. Another sheet of much coarser breccia of metadiorite and quartzite lies near the siltstone tongues at an altitude of 700 feet just north of Copper Canyon.

The conglomerate is slightly better sorted and thinner bedded and contains some conglomeratic sandstone beds where the conglomerate member interfingers with the siltstone and evaporite member. These conglomeratic sandstones form single beds as thick as 6 feet, or groups of beds; they extend from well within the conglomerate member to well within the siltstone and evaporite member. Silt-sized and sand-sized fragments are dominant, but the sandstone beds contain a few percent of blocks about an inch across. Some beds are completely unsorted but others are graded.

SILTSTONE AND EVAPORITE MEMBER

Clastic rocks are dominant over evaporites in the siltstone and evaporite member and consist, in decreasing order of abundance, of siltstone, sandstone, shale, granule conglomerate, and pebble conglomerate. The evaporites are almost wholly limestone and gypsum; borate-bearing efflorescent material is rare, and sodium chloride was not recognized.

Evaporites are most abundant away from the intertonguing conglomerate. Most clastic beds are limy, and thin silty limestone beds are common throughout the member; but limestone is most abundant, and beds are thickest in the upper 1,000 feet of the member. There they constitute 40 percent of the member near the center of the basin and 10 percent near the edges. Gypsum occurs only below the upper limestone-rich unit, and probably nowhere constitutes as much as 10 percent of any unit 100 feet thick.

Most clastic rocks are yellow gray to very pale yellow brown on fresh and weathered surfaces; a few are greenish gray. The rocks weather to a clay-rich sheet that covers the slopes like frosting on a cake. Fragments of the more resistant beds and the pebbles of the few conglomerate beds within the siltstone and evaporite member locally form lag concentrates on the frosting. The clastic rocks are all limy and contain angular feldspar and quartz fragments and small amounts of biotite and magnetite. Oxyhornblende is also present in the few specimens checked optically. The pebbles in the coarser beds consist of the same rock types as those in the conglomerate member. The siltstone and shale beds are commonly about one-fourth of an inch thick, but some of the shale is much more finely laminated and contains mudrolls and nodules.

Gypsum is white to light gray (fig. 5); it generally occurs as thin beds in the shale, but some beds are as thick as 12 inches. The weathered surfaces on the thicker gypsum beds form brown hard crags a few inches high. However, this weathering habit is neither as craggy nor as dark a brown as that associated with borate beds in the Furnace Creek formation north of the area. Very locally, gypsum beds thicken abruptly and are contorted. A chalky mineral, possibly anhydrite, forms pods in some of these beds. Thin gypsum veins cut many of the clastic rocks.

Limestone is pale yellow brown to pale brown and weathers to a color that is slightly darker than the fresh rock. Beds in the upper part of the member are a few inches to a few feet thick and weather into plates or large slabs that veneer the dip slopes. Their surfaces are etched into pits and small sharp pinnacles. Most limestone is silty, and the thicker beds are moderately coarse crystalline. Mammal tracks, ostracodes, and gastropods are rarely abundant enough to be important lithologic features. Other organic markings resemble twigs with branching stems as thick as a quarter of an inch and as long as 2 feet.

Jasper beds are intercalated with intertonguing siltstone and conglomerate beds where they overlie a basalt flow at an altitude of 1,600 feet along the south edge of Coffin Canyon. The jasper is dusky red, blackish red, black, or dusky green and forms resistant beds that break into blocky debris. Beds range in thickness from fine laminae to several inches, and many bedding planes have a peculiar nodular surface. The laminae consist of microscopic quartz zones alternating with chalcedonic material that has a strong radial structure. Finely disseminated particles of iron oxides of various reddish and yellowish colors further emphasize the zones.

A sheet of very coarse breccia 6–15 feet thick and less than 200 feet long is interbedded with siltstone and limestone near the top of the formation. The sheet is exposed on the south side of the large knob surrounded by alluvium in the north fork of Copper Canyon at an altitude of 1,400 feet (Drewes, 1959, in center foreground of fig. 2, pl. 1). Its features are well exposed and are transitional between those of the isolated large blocks and sedimentary breccia sheets in this formation and those of the very large breccia sheet in the overlying formation. The breccia at this knob consists of porphyritic felsite, similar to the porphyritic quartz latite of the plutonic rocks, and metadiorite, all in angular blocks as large as 10 feet. These are set in a matrix of similar but more finely broken rocks, but near the base of the sheet some of the matrix is sandstone and shale. Internally the blocks are thoroughly fractured but are cemented. In most places the immediately underlying beds are little disturbed along the basal contact, but in other places the base of the breccia sheet is irregular and not parallel to the clastic beds. Locally, the deformation is strong, and large wedges of highly contorted and sheared beds are squeezed into the breccia sheet.

FAUNA

Fossils from the Copper Canyon formation fall into two groups, ostracodes and gastropods, which are more valuable indicators of environment than of age, and mammal and bird tracks. All occur in the siltstone and evaporite member. The gastropods, which occur in abundance in several limestone beds within 1,000 feet of the top of the formation, are described by D. W. Taylor (written communication) as narrow, high-spired species and as high-spired and medium-high-spired species, and are identified as Hydrobiidae indet. Their habitat was a permanent fresh-water lake, probably without much current action. Ostracodes that occur with gastropods at the northern margin of the member and about 3,000 feet below the top of the formation, are described by I. G. Sohn (written communication) as steinkerns, corroded carapaces, and clean valves showing hinge-and-muscle scar. They include indetermined genera; many are of one genus, which may be "Cytheridea," and lived in fresh or brackish water.

Artyodactyl tracks are the most common tracks; others include those of cats, birds, and a probocidian. Most tracks occur in a group of beds about 1,500 feet below the top of the formation, but those of the probocidian are more than 2,000 feet below the top of the formation. Tracks in much greater abundance and variety are mentioned but not described by Curry (1941). Since that time, according to the park rangers, many were removed. Of the remaining tracks many are probably depressions on several bedding planes below the surface on which the imprint was made. Details of the imprints are absent and this may indicate that they are enlarged. Many artyodactyl tracks or imprints are about 3½ inches long and 2⅝ inches wide. The cat track is about the size of that of a large bobcat. The six probocidian tracks are each about 1 foot in diameter, are depressed about 7 inches, and have a pace of about 7 feet. Horse tracks that could be useful in age determination, as reported by Curry (1941), were not found.

AGE AND CORRELATION

The Copper Canyon formation is accepted as Pliocene(?) on the basis of the report by Curry (1941). The invertebrates have either a long range or are nondiagnostic. The remaining tracks are only suggestive of a late Tertiary or Pleistocene age. Curry tentatively considered the horse tracks to be middle Pliocene, but without additional support Pliocene is a safer estimate.

The siltstone and evaporite member of the Copper Canyon formation is lithologically similar to the rocks in the Furnace Creek area, which appear in the northeast corner of the quadrangle. The conglomerate member also resembles a red conglomerate west of Jubilee Pass in the Confidence Hills quadrangle adjacent to the south. No firm age or age range has been assigned these rocks, but those in the Furnace Creek area are possibly Miocene or Pliocene.

In the Avawatz Mountains, about 75 miles south of Copper Canyon, the inferred tectonic, climatic, and faunal conditions of the lower Pliocene(?) Avawatz formation of Henshaw (1940, p. 5) resemble those inferred from the Copper Canyon and Funeral formations in the Copper Canyon area. Fluviatile conditions changed to pluvial conditions and were followed by another fluviatile time, during which coarse breccias were deposited. This sequence contains a fauna probably of early Pliocene age. A similar tectonic and environmental sequence, with one exception, occurs in Copper Canyon. The abundant mammalian fauna occurs beneath the sedimentary breccia of the second fluviatile episode. Neither the fauna nor the tectonic episodes leading to the deposition of the conglomerate of the Funeral formation in the Copper Canyon area need be the same as that in the Avawatz Mountains, but both are believed to be Pliocene episodes.

ORIGIN AND ENVIRONMENT

The Copper Canyon formation is the relatively complete record of a Pliocene basin and its later tectonic history. Very likely it provides in section a view of some types of rocks that may be found below the present surface of Death Valley. The overall picture is one of a tectonic basin in which playa sediments were deposited near the center and fanglomerate was deposited at the edges. Basalt was extruded several times in the history of the basin. The basin may have had a drainage outlet near the end of its history, for the saline deposits ceased and fresh-water limestones were deposited then. Faulting at the edges of the basin changed the local topographic conditions radically and brought to a close the deposition of the Copper Canyon formation. Conglomerate of the Funeral formation was later deposited in the basin, and all the rocks were synclinally folded and tilted to the southeast.

The lowest exposed rocks of the formation contain abundant fragments of the older volcanics—fragments that were deposited on alluvial fans adjacent to a highland capped by the older volcanic rocks. In a few places, as on the high knob north of Copper Canyon, a thin andesite or basalt flow was extruded before the deposition of the fanglomerate. The lateral sequence away from the base of the source area is sedimentary breccia, poorly bedded angular conglomerate, well-bedded conglomerate, and conglomerate with tongues of sand and silt; it is similar to the lateral sequence of the fans deposited along the foot of the Black Mountains today. Normal faults dropped a part of the area and produced a local relief comparable to that of today. At first the fans from the north and south sides of the basin met in the center, but silt and clay were gradually washed into the center and deposited in playas. The playa gradually covered a wider part of the basin, and gypsum and limestone accumulated with the silt and clay.

A thick basalt flow next spread across the playa, and was covered by more fans containing red felsite fragments. A minor renewed tectonic movement probably indicated by the record of the readvance of fans across the valley and the temporary obliteration of the playa following this thick basalt flow, but playa conditions returned for a time. Later, another small flow covered a small area along the northern edge of the basin. Jasper was deposited at the toes of fans, possibly by hot springs associated with this flow. Shortly thereafter the last thick flow of andesite spread across the entire playa. A longer, relatively stable time followed, and gypsum and silt were deposited between fans of almost constant size. Silt and sand washed out from toes of fans formed small mudflow sheets that carried a small amount of coarser debris over the edges of the playa silts, much as they do at the edges of some fans today.

The earliest signs of life are ostracodes that lived in pools of brackish or fresh water along the north side of the basin. Later, the abundant tracks of mammals and birds indicate that fresh water and food were abundant. But the adjacent topography was still high enough to send a small landslide of monzonitic and metamorphic rocks, now exposed beneath the partly stripped cover of older volcanics, across the fan and onto the playa, probably from the east side of the basin. The more fluid sediments were mixed with the base of the flow, but the other sediments were disturbed relatively little as the debris glided across them. The limestone beds with abundant ostrocodes and gastropods record several stands or spreads of a freshwater lake; most likely the basin had an outlet at this time, and almost certainly it had a more effective precipitation than the area receives today. The history of the basin continues with the deposition of the Funeral formation.

GREENWATER VOLCANICS

GENERAL DESCRIPTION

The Greenwater volcanics, here redefined from Noble (1941, p. 956), are dominantly rhyolite and rhyodacite vitrophyre lava flows with subordinate interbedded pumiceous tuff-breccia and slightly reworked pumiceous sediments. At and near the base of the formation, pyroclastic rocks form a thick and moderately extensive sheet that is mapped as the tuff-breccia member of the Greenwater volcanics. The flows and intercalated tuffaceous beds constitute the vitrophyre member.

The formation underlies a broad belt about 25 miles long extending probably from Brown Peak in the adjacent Shoshone quadrangle (about 10 miles southeast of the nearest exposures of the formation in the Funeral Peak quadrangle) northwestward at least as far as Lemonade Spring in the Ryan quadrangle about 3 miles north of the quadrangle. The central part of the belt crosses diagonally through the northeast corner of the quadrangle. The Greenwater volcanics are absent along two narrow transverse zones in the vicinity of Greenwater Canyon. The tuff-breccia member underlies the northeast edge of the belt and is less extensive than the vitrophyre member.

The name Greenwater volcanics was first used by T. P. Thayer (written communication) in the northern Black Mountains and Greenwater Range. The name was used by Noble (1941, p. 956), who briefly described formation. The formation is here redefined because more detailed information is now available.

The reference locality established for the Greenwater volcanics, as here redefined, is between Greenwater Canyon and the west side of the Greenwater Range 1–3 miles south of the northern edge of the Funeral Peak quadrangle. Here the Greenwater volcanics unconformably overlie the older volcanics or the Furnace Creek formation. In some places the underlying rocks are tuffaceous and dip 45°–70° southeastward. The basal rocks of the vitrophyre member of the Greenwater volcanics are also tuffaceous but dip less than 25° in the same direction. In some places the contact between the two tuff-breccias is obscure because both are massively bedded and are poorly exposed beneath cliffs of vitrophyre flows. Some of the difficulty may exist because the younger rocks have incorporated colluvial material formed on the surface of the older rocks. In other places, as along Greenwater Canyon, where the tuff-breccia member is well bedded and well exposed and where the underlying rock is not tuffaceous, the contact is sharp, and the angular unconformity between the two tuff-breccias is unequivocal. The lowest beds of the tuff-breccia member of the Greenwater volcanics lap around the exhumed hills cut on the older volcanics. This well-exposed part of the unconformity can be followed for several miles along Greenwater Canyon. East of Greenwater Canyon, as described in the section on the "Furnace Creek formation, General description," the Greenwater volcanics appear to intertongue with some beds of the Furnace Creek formation; yet the formation as a whole is less deformed than the Furnace Creek formation.

There is little stratigraphic variation within the two members of the Greenwater volcanics. The vitrophyre member appears to be centered about four or more volcanic piles or domes, which consist of thick rhyolite and rhyodacite vitrophyre flows, vitrophyre agglomerate flows and plugs, and less than 10 percent intercalated pyroclastic and epiclastic material (fig. 6). Two of these thick accumulations lie within the Funeral Peak quadrangle, one on each side of the Greenwater Canyon area, one around Brown Peak southeast of the quadrangle, and one around Lemonade Spring north of the quadrangle. The volcanic pile northwest of Greenwater Canyon consists of about six flows and interbedded tuffs with an estimated maximum combined thickness of about 1,500 feet; the pile southeast of the canyon has four or five flows totaling about 1,200 feet. The tuff-breccia member of the formation forms a lens as thick as 400 feet and 3 miles wide elongate northwest to southeast. Its southwestern margin underlies the lowest flows and is intercalated between them, and its northeastern margin probably

FIGURE 6.—Greenwater volcanics. Exposure in Greenwater Range just north of the quadrangle and two-thirds of a mile northwest of knob 3619. Agglomerate flow of the vitrophyre member (Tgv) of the Greenwater volcanics forms a wedge between 15 feet of pumice conglomerate (Tgt–t) and pumiceous tuff-breccia and conglomerate (Tgt–t) of the tuff-breccia member of the Greenwater volcanics. Here the Greenwater volcanics lie unconformably on a body of andesite or basalt of Tertiary age (Ta), associated with the Furnace Creek formation. Note the absence of alteration of basal beds of Tgt–c by basalt, and the dikes of Tgt–c in the basalt.

interfingers with and locally lies conformably over the Furnace Creek formation.

Part of the formation is unconformably overlain by the Funeral formation, but the highest parts of the volcanic piles probably have never been buried by other formations.

VITROPHYRE MEMBER

Steep slopes underlain by rocks of the vitrophyre member have a markedly different appearance than gentle slopes underlain by this rock. The steep slopes are colorfully banded in pale red, very light gray, reddish black, and pale orange and are broken by small ledges, which follow the thin tuffaceous beds. Gentle slopes underlain by vitrophyre are somber, grayish-brown block fields, which are broken by small and widely spaced ledges. On steep slopes the formation resembles the older volcanics and is distinguished from them by the slightly thicker and more continuous flows. On gentle slopes the formation resembles some andesite and basalt of the Funeral formation, but the blocks weather a little browner and are more platy than andesite and basalt blocks.

Flows are relatively thick and probably not extensive. In the plane of the cliffs facing Greenwater Valley west of Greenwater Canyon, the flows are as thick as about 250 feet and extend 1–2 miles. In the southern volcanic pile northeast of peak 4507, an agglomerate and vitrophyre flow is on the order of 1,000 feet thick but probably is not widespread. The dark bases of flows and the tuffaceous rocks intercalated between flows are useful marker zones around peak 5107 in the northern pile, but become difficult or impossible to find in the deeper canyons near the peak. Pyroclastic deposits are absent, and there is no sign of a gradation into welded tuffs. The flows either did not break into separate lobes or had a remarkable uniform cooling history throughout their thickness. These relations suggest that the vent of these flows was in the vicinity of peak 5107.

The flows of this member consist of massive vitrophyre, felsitic vitrophyre, vitrophyre agglomerate, or a combination of these rock types. In detail, a vitrophyre flow consists of three main zones—a basal dark vitrophyre, a felsitic vitrophyre core, and an upper light vitrophyre—which have distinctive appearances and which grade into each other over a few feet to many tens of feet.

The basal part of a typical flow, such as those fully exposed on the east side of Greenwater Valley north of Greenwater Canyon, is medium- to dark-gray fresh vitrophyre with a bright luster and conchoidal to hackly fracture. It is commonly 5–20 feet thick but is absent locally. The basal vitrophyre of the lowest flows in the volcanic pile northwest of Greenwater Canyon and of most flows in the volcanic pile southeast of Greenwater Canyon is only moderately dark, uniform, and thick, but the basal vitrophyre of the other flows in these areas is very dark and commonly is banded with light-gray vitrophyre or contains angular fragments a few inches long of slightly darker, but otherwise similar, vitrophyre. In a few places the basal vitrophyre consists of a breccia of black vitrophyre in a matrix of moderate-reddish-brown vitrophyre. Other inclusions are grayish-red felsite or resemble agglutinated vitric fragments. Some of the basal vitrophyre is perlitic. The top of this zone contains streaks and thin lenses of a grayish-red felsitic vitrophyre which increase upward in abundance and continuity and grade into the next overlying zone over a few tens of feet.

The central and largest part of many flows is felsitic vitrophyre, but others are gray vitrophyre indistinguishable from that at the top of a typical flow, or are an interlayered mixture of the two. The felsitic vitrophyre is grayish red on joint and foliation surfaces and brownish gray between them; it weathers reddish black or reddish brown. It is conspicuously foliated with weak zones ½–2 inches apart roughly parallel to the flows and is cut by several sets of widely spaced joints. Locally the foliation is irregular and forms small isoclines with vertical limbs. The rock breaks into large slabs that weather further into fragments with hackly or irregular surfaces and disintegrate into coarse grus. Along and near the foliation planes, there are many alined and flattened irregular cavities or vesicles that alternate with sheets of rock with fewer and smaller cavities. The rock is faintly streaked because the porous zones are lighter colored than the adjacent rock. Ridges and depressions with an amplitude of about one-quarter of an inch form a lineation on some foliation surfaces and are probably normal to the flow direction. The upper surfaces of some of the larger blocks and slabs of weathered vitrophyre from the central part of some flows are pitted. Commonly, the depressions are an inch to a few inches in diameter and in depth and have a widely flaring mouth. Most are watertight and contain a little fine sediment. The weathered surface or desert varnish is thinner in the cylindrical walls of the cavities than on the outer surface of the block. In rare cases the cavities are deep or run completely through the block like an undersized hole in an oversized doughnut. The top of the felsitic vitrophyre has irregular lenses and sheets of gray vitrophyre that are lighter colored than the basal vitrophyre and that increase upward in thickness and persistence, and thereby grade over many tens of feet into the third zone.

The third and topmost zone of a typical vitrophyre flow is generally a light- to medium-gray vitrophyre with a thickness between that of the other zones. The lower part of the zone contains sheets and lenses of reddish-gray felsitic vitrophyre; the central part is massive gray vitrophyre; and the upper part is either a vitrophyre agglomerate or a very pale orange rock resembling vitrophyre but without the glassy luster. The very pale orange rock resembles tuff but is less massive than tuff. Near the top of the third zone, the rock is more fractured and grades upward into the basal tuff-breccia of an intraflow unit. The gray vitrophyre adjacent to some felsitic dikes or siliceous veins is altered to a similar very pale orange rock, which probably is devitrified glass or possibly a finely frothy flow top analogous to scoria in basalt flows.

Agglomerate of subrounded blocks as large as 3 feet in diameter forms many of the flows or parts of them (fig. 6), and also forms small plugs. The lower flows west of Greenwater Canyon are largely agglomerate but the center of the flow which crosses the canyon has a massive vitrophyre core. The blocks are set in a matrix of smaller blocks and of very pale orange fragmental material that is tuffaceous or pumiceous. The lowest blocks are pressed into the uppermost beds of the underlying tuffaceous rocks and the tuffs overlying agglomerates are draped over the boulders. In the southern volcanic pile agglomerate flows are more abundant and are associated with the thicker flows. Blocks a few feet in diameter are most common, but some are as long as 12 feet. In one place near the canyon bottom, 1,300 feet east of knob 4272, a crudely sheeted massive vitrophyre flow grades laterally over a few hundred feet into a blockly vitrophyre flow and on into a vitrophyre agglomerate. The irregularity of the intertonguing of the vitrophyre flow and the vitrophyre agglomerate and its overall gradational character suggest an autoclastic fragmentation of a massive flow. The matrix, then, is not an airborne tuff, but probably was formed in place with minor internal movement. At peak 4507 southeast of Greenwater Canyon an agglomerate body too small to be mapped truncates a massive to platy felsitic vitrophyre flow, and a similar agglomerate tongue underlies the flow

TABLE 8.—*Frequency of occurrence and abundance of constituents in vitrophyres of the Greenwater volcanics*

Mineral (phenocrysts, xenocrysts, and glass)	Percent of 36 thin sections containing mineral	Percent of thin section	Maximum percent of thin section
Plagioclase	100	20	45
Biotite	97	3	8
Amphibole	93	3	5
Quartz	17	<1	3
Clinopyroxene	23	<1	2
Hypersthene	27	<1	3
Magnetite	97	<1	1
Apatite	90	<1	1
Cristobalite	13	<1	2
Tridymite	27	<1	20
Zircon	20	<1	<1
Glass or altered glass	100	75	98

and pinches out a few hundred feet to the north. Nearby there are two other agglomerate bodies with an extent greater vertically than laterally. The flow around one of them dips somewhat erratically away from the agglomerate body. These agglomerate bodies probably are plugs that intruded some flows and were the source of other flows; perhaps they even were the source of the same flow through which they later intruded.

Tuff-breccia is the dominant rock intercalated with the flow units in the vitrophyre member. It forms the upper and lower parts of the interflow units and grades downward into gray vitrophyre or very pale orange devitrified glass or finely porous scoria of the upper zone of the underlying flow. Tuffaceous and pumiceous sandstone, grit, and conglomerate a few feet to a few tens of feet thick lie roughly in the middle of the interflow units. Bedding parallels the flow surfaces; in some places it is very regular, but locally it is crossbedded. Tuff and pumice fragments are the most abundant constituents of the tuff-breccia, but scattered gray vitrophyre blocks are common near the underlying flow, and dark-gray vitrophyre blocks are common near the overlying flow. One 4-inch block of garnet-muscovite schist appeared in float derived from the basal tuff-breccia at the southern end of the northern volcanic pile.

Most rocks of the vitrophyre member contain less than 30 percent phenocrysts as well as 10 percent microlites and crystallites in a uniformly flow banded, unaltered or little altered, clear to pale-brown glass. A few rocks contain as much as 55 percent phenocrysts, and the felsic virtophyres contain more abundant microlites in a glass or cryptocrystalline groundmass, which is obscured by clay mineral and hematite alteration. Phenocrysts consist chiefly of plagioclase, biotite, and amphibole and of smaller amounts of various combinations of orthopyroxene and clinopyroxene phenocrysts and quartz xenocrysts. The estimated abundance of phenocrysts, microlites, and secondary minerals is summarized in table 8.

Porphyritic and flow textures are ubiquitous. Phenocrysts, microlites, devitrified pods, as much as a few centimeters long, and varicolored gray and brown glass lenses or layers with various amounts of microlites are alined parallel to small cavities. Cavities and devitrified pods are more abundant in the middle and top parts of a flow than in the lower part. The layers and lenses of glass are most common in the basal zone, and some of them truncate others. In one place a perlitic vitrophyre is truncated by a penecontemporaneous nonperlitic one. Very likely the local cooling history of the basal part of a flow has still other complications of chilling, rupturing, separation of fragments, and remixing of fluids with slightly different amount of oxidation or microlite content than those mentioned above. Perlitic fractures occur in about 15 percent of the rock but are less well developed in the vitrophyre member of the Greenwater volcanics than in some of the vitrophyres of the older volcanics. The index of refraction and specific gravity of some vitrophyres are listed in table 9.

The plagioclase forms clean euhedral or subhedral, stubby or lath-shaped crystals and less commonly is vermicular, rounded, embayed, or fragmental. Broad zones of dusty inclusions or vermicular zones, and normal and oscillatory composition zones are common. Most of the plagioclase is andesine; some is labradorite, and a little is bytownite or oligoclase.

Amphibole and biotite also are euhedral or subhedral. A few biotite flakes are bent in most of the rocks. The biotite in about 55 percent of the rocks is pleochroic in green or yellow brown, and reddish brown; in others oxybiotite is pleochroic in light and dark reddish brown or is black. One rock contains both types of biotite. About half the amphibole is common

TABLE 9.—*Some physical characteristics of vitrophyres of the Greenwater volcanics*

Specimen No.	Field No.	Specific gravity [1]		Index of refraction of glass	Part of flow	Color
		Vitrophyre	Glass			
12	56D93	2.32	2.30	1.496	Middle or top	Light gray.
13	56D165	2.50	2.48	1.508	Base	Grayish black.
15	56D159	2.52	2.50	1.496	Base	Medium gray.
32	56D157	2.30	2.28	1.496	Top	Light gray.
39	56D169	2.49	2.47	1.496	Top	Medium gray.
40	57D300	2.39	2.33	1.500	Vent(?) agglomerate.	Medium light gray.
41	57D302	2.40	2.37	1.502	Base	Dark gray and reddish gray.
42	57D309	2.40	2.35	1.500	Base of agglomerate flow.	Medium light gray.
43	57D310	2.51	2.48	1.508	Base	Grayish black.

[1] Specific gravity was obtained by averaging that of five selected chips that were mostly free of phenocrysts and vesicles weighed on a Berman balance.

hornblende that is pleochroic in greens and browns and has $Z \wedge c$=15–24°, and half is oxyhornblende that is pleochroic in reddish browns and has $Z \wedge c$=0–15°. Some amphiboles with the pleochroism of common hornblende but an extinction angle of 9–15° of oxyhornblende are transitional. Oxyhornblende always occurs in rocks containing oxybiotite, but a few rocks contain only oxybiotite.

Hypersthene and clinopyroxene, probably augite but possibly diopside, generally occur together as euhedral crystals. In the northern volcanic pile they occur only in the second prominent and widespread flow beneath peaks 5107 and 5148. In the south volcanic pile, which has been sampled less than the northern one, the lowest flow and the vitrophyre agglomerate at peak 4507 contain these minerals. The clinopyroxene is clear or very pale brown and has a very large extinction angle. The clinopyroxene in the agglomerate at peak 4507 has rims of common hornblende.

Various types of spherulitic structure and pods with cryptocrystalline texture are abundant in the middle and upper parts of flows. The very pale orange rock associated with the upper gray vitrophyre is largely cryptocrystalline and spherulitic and contains 10–20 percent of minute cavities lined with tridymite or cristobalite. Layers of abundant alined microlites are not disrupted or deflected by the spherulites. Cryptocrystalline material lies in lenses near and around cavities in the felsitic vitrophyre, and locally occurs around phenocrysts and along perlitic fractures in the gray vitrophyre.

Vitrophyre was apparently remelted by younger basalt in two places. About 5.3 miles from the east edge and 0.1 mile from the north edge of the quadrangle, a basalt dike a few feet thick has changed about 3 feet of the adjacent vitrophyre to a darker and more vesicular rock that outwardly resembles the basalt. The rock nearest the basalt is a brown glass that contains 40 percent subspherical to elongate vesicles. Microlites and phenocrysts are crudely alined between these vesicles and along their longer sides, but the ends of the vesicles cut across the microlite trains. All the normally unaltered biotite and hornblende are oxidized and clouded with dark opaque material in the altered zone. These minerals are surrounded by halos of clear glass that contain microlites of apparently a later generation arranged radially about the phenocrysts.

At the second locality, about half a mile northwest of the first one, pebbles and cobbles of vitrophyre of the Greenwater volcanics in a tuffaceous conglomerate are locally changed near an overlying thin olivine basalt flow. The fragments are elongate to several times their normal length and contain at least 10 percent small vesicles. The biotite and hornblende in the small fragments and in the rims of the larger ones are oxidized. The matrix of the fragments is reddish brown only near the basalt flow.

PETROLOGY

Little has been learned about the rhyolite and rhyodacite magma prior to its extrusion because most of it chilled at the surface to form glass. The quartz xenocrysts probably were picked up from the monzonitic or metamorphic host rocks, for quartz is scarce in the older volcanics. Plagioclase xenocrysts are not abundant and could readily come from the older volcanics.

The fact that some hornblende and biotite were oxidized and some were not raises questions on what the temperature, pressure, and availability of oxygen to the magma were when the oxidation occurred. Perhaps the temperature of the magma was only locally sufficiently high to change the extinction angle of hornblende and the color of hornblende and biotite. This temperature may have been near 800°C, for Day and Allen (1925, p. 49–53) report that biotite oxidizes at 900°C, and Kōzu, Yoshiki, and Kani (1927, p. 107–117) report that hornblende oxidizes at 750°C. Alternatively, the oxidation occurred in an oxygen-poor environment, such as might more readily be expected before atmospheric oxygen was available to the magma.

The distribution of submicroscopic inclusions and possibly of submicroscopic vesicles may explain the different colors of vitrophyre. In one specimen finely divided dark material appears in dark glass, but in most dark glass inclusions are invisible. However, the association of newly grown microlites in halos of microscopically clear glass around phenocrysts with surrounding brown glass close to basalt dikes suggest that the material from which the new microlites were made was obtained from previously submicrospic microlites in the surrounding glass. The greater abundance of devitrified rock and of secondary silica material toward the top of the flows suggests that the upper vitrophyre is more porous than the rest of the flow. Since the microscopic porosity is not noticeably greater, submicroscopic vesicules are suspected. This would also account for the generally slightly lower specific gravity of vitrophyre from tops of flows than from bottoms.

Very likely, then, the basal glass solidified first after extrusion and entrapped minute crystallites. Flow tops also solidified early but were more porous. Siliceous fluids migrated upward from the flow centers and were slightly concentrated near the solidified top of the flow. These fluids devitrified some of the glass adjacent to the cavities within the upper chill zone and devitrified much of the glass of the top of the flows.

TUFF-BRECCIA MEMBER

The tuff-breccia member underlies lowland area and forms a small-scale canyon-and-mesa topography with relatively resistant massive or thick-bedded units alternating with less resistant thin-bedded units. It is very pale orange to grayish pink and in most places weathers the same color but immediately below the vitrophyre member it weathers grayish brown and has a case-hardened surface. Some of the thick-bedded units weather to conspicuous overhanging ledges and large cavities beneath the case-hardened surface. Some of the cavities contain charcoal and stone flakes and were temporary occupation sites for Indians. Narrow canyons cut in the thick-bedded tuff-breccia contain scoured plunge-pool basins, in some of which water collects. These basins, or tanks, attracted the Indians, for the large cavities above them are the only ones decorated with numerous petroglyphs.

Within the tuff-breccia member in the Greenwater area there are several distinctive units. The lowest unit, 5–10 feet thick, is a pumiceous sandstone, grit, and fine conglomerate that is slightly limy and well sorted in beds 2–12 inches thick. It contains a very few fragments of grayish-red felsite or of basalt, and they are draped around the irregularities and gullies beneath the basal unconformity. The middle unit, 75–200 feet thick, laps eastward over the lower unit and thins westward. It is a pumiceous sandstone, conglomerate and tuff-breccia that is poorly bedded and sorted. Adjacent to older rocks the unit consists of sedimentary breccia with abundant coarse angular blocks that are locally derived. Most of the fragments of this unit are subangular tuffaceous and pumiceous rhyolite, but small amounts of vitrophyre and felsite are also present. In one locality on the east side of Greenwater Canyon, 2.1 miles from the northern edge and 3.2 miles from the eastern edge of the quadrangle, pumiceous sandstone and fine conglomerate, probably of the middle unit, is overlain by a poorly sorted boulder pumicite, tuff-breccia, and agglomerate that probably is associated with one of the lowest flows west of the canyon. It contains less than 1 percent vitrophyre and felsite, and scattered fragments of muscovite schist, biotite schist, and biotite augen gneiss that are 2–5 inches in diameter, the same size as the adjacent pumice blocks. The upper unit, 75-150 feet thick, is a massive tuff-breccia that laps over the middle unit to the west and northeast. It is the most extensive of the three units in the Greenwater Canyon area and probably the only unit present south and east of the canyon. It contains about 30 percent angular to subangular fragments of light-gray vitrophyre, pumice, pumiceous tuff, dark-gray vitrophyre, and moderate-red felsite in a sandy and gritty tuffaceous matrix. The uppermost beds, a few tens of feet thick, are bedded tuffaceous sediments that locally are sorted and massively crossbedded, suggesting dune deposits.

AGE AND CORRELATION

The Greenwater volcanics are tentatively dated as Pliocene(?). They unconformably overlie the older volcanics of middle(?) Tertiary age and are largely or wholly younger than the Furnace Creek formation of Miocene or Pliocene age. They are unconformably overlain by the Funeral formation of Pliocene and Pleistocene(?) age.

ORIGIN AND ENVIRONMENT

The Greenwater volcanics were erupted from several vents or vent clusters alined on a northwest-trending axis and lying a few miles southwest of exposures of the Furnace Creek formation. The surface underlying the flows in the vicinity of Greenwater Canyon had about half the present relief.

The first eruptions from the two vent groups within the quadrangle were explosive. The initial explosions of the vents northwest of Greenwater Canyon produced abundant coarse pumice and scattered fragments of the underlying metamorphic rocks. This material was deposited in a shallow basin and was slightly reworked by running water before it was buried by more pumiceous tuff that was only locally reworked. Thick rhyolite and rhyodacite vitrophyre flows spread to the pumice-filled and tuff-filled basin and to areas northward and westward of the northern volcanic center. Similar agglomerate and vitrophyre flows spread eastward from the southern centers. Minor explosive eruptions preceded and followed most of the large flows and, during the short interval between a final outburst following one flow and the initial outburst preceding the next flow, the tuffaceous rocks were slightly reworked by small streams and slope wash. The flows built domes about 1,500 feet high with a radius of 1–2 miles about the vent centers. After the extrusion of as many as six large flows, the activity from these vents ceased.

TERTIARY ANDESITE AND BASALT

GENERAL DESCRIPTION

Small amounts of porphyritic andesite and basalt lie conformably within or intruded into all the Tertiary formations younger than the monzonitic rocks. The andesite and basalt form a single suite of rocks that fall close to, and on both sides of, the rock classification boundary, as explained in the section of this report introducing the Tertiary rocks. Andesite was not separated from basalt because field criteria were unreliable. The mineralogical difference between these andesites and basalts is small; basalts contain more than 15 percent and andesites less than 7 percent modal olivine. Chemical distinctions are unreliable because many rocks contain xenocrysts of quartz and sodic plagioclase. Hence "andesite and basalt" are used as one unit unless otherwise specified.

Two large areas and many small areas underlain by andesite and basalt lie at or near the base of the Copper Canyon formation. The small areas underlain by andesite and basalt, associated with the older volcanics and the Furnace Creek formation probably lie at or near their tops. The andesite and basalt associated with the Greenwater volcanics are at the base of the formation or possibly underlie it. Some of the small bodies mapped with the andesite and basalt member of the Funeral formation could also be interpreted as belonging to the andesite and basalt of Tertiary age. The andesite and basalt are described as one unit because of their similar lithology and origin and the suggestion that they were emplaced during a time interval that was short relative to that during which the other Tertiary rocks were deposited.

Practically all the andesite and basalt occur in scattered small areas in the northern half of the quadrangle, which total less than 3 square miles. Many of these areas are alined between Dantes View and the hill south of Greenwater townsite. Two other large areas underlain by andesite and basalt lie in Copper Canyon, and another is in the northeastern corner of the area. Most of these areas are irregular, but some are elongate or lenticular.

The andesite and basalt are extremely weak rocks that usually underlie small basins and valleys and, from a distance, are purplish or greenish gray. Only in Copper Canyon do the andesite and basalt locally cap ridges. The rocks generally form few outcrops, and most of the mineralogic data is obtained from unaltered residual blocks.

Many andesite and basalt bodies are flows, for their tops are scoriaceous. Furthermore, they are capped by tuffaceous sedimentary rocks containing abundant fragments of andesite and basalt only near these bodies, and wedges of tuffaceous sedimentary rocks with abundant fragments of basalt and andesite lie adjacent to some flows and thin away from them over a few tens to hundreds of feet. Some of the basalt bodies are unusual because they form sheets or lenses either conformably within or intrusive into the surrounding rock. A few basalt bodies, such as the one on the hill south of Greenwater townsite, are largely parallel to the adjacent beds but locally cut across them. The attitude of the beds adjacent to and overlying a few of them is peculiar; for instance, rocks dip steeply away from the basalt near Kunze townsite and in lower Greenwater Canyon, just north of the quadrangle, near the place where the road leaves the canyon for the Lila C mine. One mile west of Furnace townsite the tuffaceous sediments adjacent to an andesite or basalt body dip very steeply and locally are overturned.

The thickness of the andesite and basalt lenses or sheets generally is less than 200 feet; only the large lenses in Copper Canyon are 300–500 feet thick.

PETROGRAPHY

Fresh andesite and basalt are dark gray to olive black; they usually weather pale purple, light olive gray, or dusky yellow, and less commonly weather moderate reddish brown. The rocks are thoroughly broken and much altered, so that most fragments are small and irregular. Subrounded blocks of fresh rock are scarce. Polygonal joints cut the massive flow in lower Coffin Canyon. Six massive zones alternating with more rubbly zones in the body that crosses Copper Canyon suggest that it contains five sheets, perhaps separate flows.

Vesicular, scoriaceous, amygdaloidal, and solid aphanitic basalt are equally abundant. Reddish-brown cinders and volcanic bombs are the only andesite and basalt types in a small circular patch about 2 miles south 55° west of the northeastern corner of the quadrangle. Calcite and zeolites commonly fill amygdules and scattered veins and pockets. Most of the andesite and basalt are slightly porphyritic; they commonly contain large olivine and feldspar crystals and, less commonly, large clinopyroxene crystals. Large quartz xenocrysts are conspicuous in the andesite and basalt from the hill south of Greenwater townsite.

The dominant minerals are, in decreasing order of abundance, labradorite, clinopyroxene, and olivine; the accessory minerals are orthopyroxene, magnetite, and apatite. Xenocrysts of quartz, andesine and, more rarely, of biotite are present in about 20 percent of the rocks. Secondary sericite, clay minerals, chlorite, uralite, calcite, zeolites, hematite, iddingsite or bowlingite, and serpentine are generally abundant. Some rocks contain a little fresh or altered glass. The modes of six relatively unaltered rocks are presented in table 10.

TABLE 10.—*Modes of andesite and basalt of Tertiary age*

Specimen No.	17	19	44	18	20	45
Field No.	56D2	56D12	56D78	56D96	56D144	56D103
Associated formation	Copper Canyon formation			Older volcanics		
Mode points	1,000	1,042	1,000	1,112	1,104	1,256
Plagioclase composition	An_{50-65}	An_{50-60}	An_{35-60}	An_{50-65}	An_{45-65}	An_{50-75}
Plagioclase xenocryst composition.	--------	--------	--------	--------	An_{30-45}	--------
Plagioclase:						
Xenocrysts	0	1.5	0	0	10.0	0
Other	49.3	55.3	46.6	47.0	45.1	47.0
Augite	24.8	20.1	27.1	27.1	33.6	34.7
Olivine	6.8	5.9	21.3	16.8	1.8	11.0
Magnetite	12.3	4.9	4.0	7.0	3.4	5.4
Apatite	4.6	3.2	1.0	0.1	1.0	.6
Altered glass	2.2	9.1	--------	--------	.4	1.4
Quartz xenocryst	--------	1.5	--------	--------	2.7	--------
Zeolites	--------	--------	--------	1.0	--------	--------

The large plagioclase crystals of most rocks are alined in flow texture or have a felty texture, and the ferromagnesian minerals are either intergranular or ophitic. Some plagioclase is also ophitic, and other plagioclase and glass are intersertal. Phenocrysts of dominant minerals and of magnetite are ubiquitous but rarely exceed 10 percent, although in two rocks they constitute 30 percent. The groundmass laths are 0.1–0.3 mm long, the intergranular crystals are about 0.01–0.03 mm long, and phenocrysts are 1–6 mm long.

Most mineralogic features are common to all andesites and basalts of this formation. Plagioclase crystals commonly form laths and less commonly form stubs, angular fragments or partly resorbed crystals. Normal and oscillatory composition zoning are inconspicuous. Composition ranges of zones are as large as 23 percent anorthite. The composition of the ophitic plagioclase is undetermined, for cleavage and twin planes are indistinct or undeveloped. Plagioclase xenocrysts are more sodic than the groundmass plagioclase. They have vermicular zones and, in one specimen, pyroxene reaction rims. Many feldspars alter to clay minerals. Augite occurs in pale-brown anhedral to euhedral grains with $Z \wedge c = 40° - 45°$, and a very large $(+)2V$. It alters to uralite but is less altered than the olivine in the same rock. Olivine is euhedral and is partly or wholly altered to serpentine or to a reddish-brown mineral resembling bowlingite, iddingsite, or hematite. It is more abundant in basalt than in olivine. Some rocks contain acicular apatite crystals. A few rocks contain a trace of an orthopyroxene, probably hypersthene, and a trace of biotite that may be xenocrystic. Xenocrystic quartz occurs in more than 10 percent of the specimens as embayed anhedra, which are rimmed by thin shells of glass and clinopyroxene. Unaltered light-brown or light-gray glass occurs in most of the fresh rocks and presumably is hidden in the severely altered rocks. Glass alters to minerals with a yellowish or greenish color, a crude radial fibrous structure, and low birefringence. Zeolites, calcite, and opal(?) fill the cavities of some andesite and basalt.

Table 11 shows some detailed optical properties of olivine and augite in specimen 18 of the basalt of Tertiary age and compares them with similar properties of two specimens of the basalt of the Funeral formation. Indices were determined by comparison with index oils, using sodium light and temperature controls on the spindle stage (Wilcox, 1959). Optic angles were obtained from plots of extinction positions on a Wulff net using a method described by Wilcox (1960) for the spindle stage. The sensitivity of these methods of obtaining indices and optic angles is much finer than the range of composition obtained from

TABLE 11.—*Some optical properties of olivine and augite of three specimens of andesite and basalt*

Specimen No.	Field No.	Olivine [1]							Augite [2]							
		Grain No.	$2V_x$	n_x	n_y	n_z	Percent		Grain No.	$2V_z$	n_x	n_y	n_z	Percent		
							Fo	Fa						Wo	En	Fs
18	56D96	1	--------	--------	1.699	--------	78	22	--------	--------	--------	--------	--------	--------	--------	--------
		2	--------	--------	1.692	1.699	86–81	14–19	--------	--------	--------	--------	--------	--------	--------	--------
		3	--------	--------	1.687	1.700	85–83	15–17	--------	--------	--------	--------	--------	--------	--------	--------
		4	--------	1.668	1.684	--------	84–83	16–17	--------	--------	--------	--------	--------	--------	--------	--------
		5	--------	1.664	1.687	1.700	86–83	14–17	--------	--------	--------	--------	--------	--------	--------	--------
21	56D257	1	--------	--------	1.696	--------	79	21	5	52°	--------	1.691	--------	43	41	16
		2	87°	--------	--------	--------	81	19	6	65°	--------	1.699	--------	52	29	19
		3	--------	--------	1.694	--------	80	20	7	54°	1.696	[3] 1.70	1.720	44	33	23
		4	--------	--------	1.696	--------	79	21	--------	--------	--------	--------	--------	--------	--------	--------
22	56D210	1	--------	1.668	1.687	--------	83	17	6	58°	--------	--------	--------	--------	--------	--------
		2	--------	--------	1.695	--------	79	21	7	58°	--------	--------	--------	--------	--------	--------
		3	86°	1.670	1.698	--------	82–78	18–22	8	61°	--------	1.691	--------	51	36	13
		4	86°	--------	--------	--------	79	21	9	42°	--------	1.692	--------	36	44	20
		5	85°	--------	--------	--------	78	22	10	56°	1.670	1.685	--------	47	42	11
									11	56°	1.686	1.699	--------	47	32	21
									12	60°	--------	--------	--------	--------	--------	--------

[1] Fo–Fa content obtained from table by Tröger (1956, p. 37) after Kennedy. [2] Wo–En–Fs content obtained from table by Tröger (1956, p. 62) after Hess. [3] n_y obtained from n_x and n_z.

different grains of olivine and augite from one specimen. These data suggest that the rock is poorly mixed on a grain-to-grain scale; the variation in chemical analyses and modes (tables 4, 10, 12) show that they are poorly mixed on a specimen-to-specimen scale. There is more variation within the two mapped units of andesite and basalt than there is between them; so they cannot be distinguished mineralogically or chemically.

AGE AND CORRELATION

The andesite and basalt cannot be dated closer than late Tertiary, for the ages of the associated rocks are poorly defined, and their relations to the andesite and basalt are not everywhere clear. Because the age of the fossils in the Copper Canyon formation is accepted as Pliocene, the associated basalt flows have a similar age.

Scattered small andesite(?) and basalt bodies with similar habits occur in the Furnace Creek formation about 10 miles northwest of the quadrangle, and also occur in the rhyolites near Rhyolite, Nev., about 50 miles northward.

ORIGIN AND ENVIRONMENT

The Tertiary andesite and basalt represent numerous small extrusions and near-surface intrusions that occurred during a relatively short time interval in a relatively long-lived rhyolite and rhyodacite volcanic field. Conceivably the andesite and basalt extrusions and intrusions occurred with, or at about the time of, late Tertiary block faulting as is discussed in the structure section of this paper. It was followed by a renewed, but more limited, outburst of rhyolite volcanism.

Most andesite and basalt bodies appear to be small flows, for the immediately adjacent or overlying sediments contain basalt rubble. They are mostly conformable to the enclosing rocks, and sediments are admixed with the scoriaceous tops of some basalt bodies.

Near-surface intrusion into unconsolidated sediments, playa silts, and clays of the Furnace Creek formation, tuffaceous sediments of the older volcanics, and possibly others, is suggested by the andesite and basalt, which has both intrusive and extrusive characteristics. Perhaps sills injected near the surface and at the base of an unconsolidated tuffaceous sheet, or injected in moist and plastic playa clays and silts, locally broke through to the surface and bowed up the adjacent sediments.

The small amount of andesite and basalt is interesting in that it occurs with the extrusion of a large sequence of rhyolite and rhyodacite, for most of these rocks lie near the top of the older volcanics and at the base of the overlying Greenwater volcanics. Two simultaneously active source chambers with different locations and different tectonic environments would most easily have provided a large amount of rhyolite and rhyodacite magma and a small amount of andesite and basalt magma. Judging from the gross picture of the earth's crust, the andesite and basalt magma has the deeper and more distant source and was injected during some brief change in the tectonic picture from one during which relatively shallow magma chambers were tapped to one during which deeper chambers were tapped. Perhaps andesite and basalt magma was injected to the surface from its relatively deep chamber when the stresses in the crust were abnormally great, a time during which faulting within the Black Mountains block was more severe than it ordinarily was. The faulting that immediately followed, or even put an end to the extrusion of the older volcanics, probably was more severe than most younger faulting, for the older volcanics are tilted more than 40° and presumably are much broken to repeat their stratigraphy, whereas the younger rocks are much less deformed.

TERTIARY AND QUATERNARY ROCKS

FUNERAL FORMATION

GENERAL DESCRIPTION

Conglomerate that commonly contains andesite and basalt fragments, is interbedded with andesite flows and basalt flows and that is only slightly faulted and tilted unconformably overlies the rhyolite and rhyodacite volcanic rocks and the Furnace Creek formation. Noble (1941), following Thayer, named the rocks the Funeral fanglomerate (p. 981). Its type locality is "* * * north of Ryan," a few miles north of the Funeral Peak quadrangle. He correlated it with conglomerate and basalt in ranges adjacent to Greenwater Valley and believed the rocks to be "* * * mainly later Pliocene but possibly in part early Pleistocene."

Because the lithology of the rocks is so variable, it is desirable to use the nongenetic name, Funeral formation. The formation has poorly defined stratigraphic limits that probably vary widely in age from place to place. The type area has never been adequately mapped, but correlation of rocks along Greenwater Valley with those in the type area is plausible because the rocks are almost continuous. Correlations over longer distances are much less certain.

The Funeral formation underlies 15 square miles of the quadrangle. About half of the outcrop area is in the northeast corner near Greenwater Canyon. Smaller areas are at Funeral Peak, in the southeastern corner of the quadrangle, in Copper Canyon, and at Mormon Point. Within the quadrangle scattered areas of still smaller size that are underlain by the formation and residual, unmapped blocks far from present andesite-capped or basalt-capped areas suggest that the formation once formed a fairly continuous and far more extensive sheet than it does today.

Along Greenwater Valley the formation contains andesite and basalt flows that form resistant dark caps in most areas. Slopes beneath the caps are veneered with almost continuous sheets of blocky talus commonly 3–10 feet thick. The flows and their talus are a brownish black that contrasts strongly with the color of most of the other rocks in the area. The andesite and basalt blocks are blacker and more angular, and the flows are thinner than the thick vitrophyre flows of the Greenwater volcanics. In three places the andesite and basalt fail to make a prominent dark cap: it forms a large pile of gray platy-weathered fragments rather than a cap near peak 4906 east of Greenwater Canyon; fragmental andesite and basalt underlie the deeper part of upper Greenwater Canyon; and much of the andesite and basalt in the southeastern corner of the quadrangle forms weak caps of gray, platy debris.

Most of the conglomerate is a somber-gray or pale-brown moderately well indurated rock that underlies gentle slopes. These rather general criteria of color and induration, as well as degree of deformation, are used to identify this conglomerate only where the absence of included fragments of andesite and basalt could be explained by the great distance of the conglomerate from the source of these fragments. The conglomerate of the Funeral formation along the east side of Death Valley is identified in this manner. The conglomerate in Copper Canyon is distinctly grayer, slightly less indurated, and slightly unconformable over the Copper Canyon formation. The conglomerate near Mormon Point is gray, moderately well indurated, and more deformed than the adjacent gravels.

The formation overlies older rocks with an unconformity that in most places has a relief slightly less than the present one. Locally, as in the Funeral Peak area and east of Gold Valley in the southeast corner of the quadrangle, the unconformity is generally flat but is incised by channels about one-third to two-thirds as deep as the present relief in these areas. In most of the northeast part of the quadrangle, the unconformity lies flat, as along the northern border of the quadrangle, but in a few places the surface contains mountains possibly as high as the present ones in this area; for example, the andesite and basalt lapped around the flanks of the rhyolite and rhyodacite volcanic dome northwest of Greenwater Canyon. In the upper end of Greenwater Canyon and in the area to the northeast, the unconformity has a relief greater than the present one, for the exposed thickness of the andesite and basalt exceeds the present relief along a northeast-trending belt less than a mile wide.

In one place near the lower end of Greenwater Canyon five stratigraphic units are present: conglomerate, basalt, conglomerate, basalt, and conglomerate, but generally only one basalt unit and one conglomerate body are present. The five stratigraphic units of the lower end of Greenwater Canyon overlie another andesite and basalt that is mapped with the andesite and basalt of Tertiary age because it is as thoroughly altered as the older unit and because fragments of it are abundant in the immediately adjacent and overlying beds of the Furnace Creek formation along Greenwater Canyon just north of the quadrangle. Megabreccia occurs in conglomerate in the Copper Canyon area, and similar units occur in other young conglomerates of nearby areas. The andesite and basalt units and the megabreccia body are mapped as separate, unnamed members.

The formation is unconformably capped by younger gravels.

CONGLOMERATE MEMBER

The conglomerate member of the Funeral formation is a heterogeneous unit that commonly contains some andesite and basalt pebbles and that consists of three assemblages of fragments. The two most abundant assemblages are a conglomerate with fragments of felsite, quartzite, and limestone and a conglomerate with fragments of felsite but lacking quartzite and limestone. The least abundant assemblage is a conglomerate with some fragments of felsite and much pumice. Siltstone is subordinate to conglomerate except east of Greenwater Canyon.

The conglomerate with quartzite and limestone fragments is restricted to the northeast corner of the quadrangle and to the vicinity of Virgin Spring Wash near the southern border of the quadrangle. It forms unbroken sheets, as thick as 200 feet. It is a pale-yellow-brown poorly indurated rock that commonly contains subrounded to subangular cobbles, pebbles, and a few boulders, chiefly of local rock types such as pumiceous tuff, olivine andesite and basalt, red porphyritic felsite, and rhyolite and rhyodacite vitrophyre, along with quartzite, limestone, and dolomite of Paleozoic age. The quartzite includes very light gray to pinkish-gray fine-grained quartzite, pale red-purple quartzite, quartzitic granule-conglomerate, pale red-purple micaceous shaly quartzite, and greenish-gray micaceous shaly quartzite. The limestone includes mottled light-gray and dark-gray fine-grained limestone, medium-gray algal(?) limestone, and medium-gray limestone with a few crinoid(?) stems. Most dolomite is medium to dark gray similar to Paleozoic dolomites in general, but some is pale yellow brown and resembles the Noonday dolomite. The fragments lie poorly sorted in beds 1–3 feet thick with a matrix of abundant moderately well indurated to poorly indurated pale yellow-brown sand and silt. Locally, the conglomerate contains sandstone and siltstone lenses with channel scars and fluviatile cross-bedding.

The conglomerate without quartzite and limestone fragments occurs adjacent to Greenwater Valley and on the west flank of the Black Mountains. It forms extensive thin lenses and restricted thicker lenses that resemble channels. The conglomerate weathers to gentle slopes veneered with fragments, but locally it forms gray cliffs. The rock comprises subangular to subrounded cobbles, boulders, and pebbles of andesite and basalt, monzonitic rocks, metamorphic rocks, and assorted rhyolitic volcanic rocks, all of local types, set in a coarse sandy matrix. Locally there are sandstone lenses in the conglomerate, and elsewhere the conglomerate is so rich in andesite and basalt that it resembles an agglomerate. In Copper Canyon the gray conglomerate contains a 6-foot-thick white tuff bed that weathers pale yellow gray and contains scattered biotite. The index of the glass in the tuff is $n=1.496$, which is about the index of the rhyolitic glasses of the area. The fragments in the conglomerate on the west flank of the Black Mountains are angular and toward its eastern limits it grades into a sedimentary breccia.

About 100 feet of white to yellowish-gray pumice conglomerate overlies the andesite and basalt member with probable conformity in a small basin immediately southeast of upper Greenwater Canyon. Pumice and pumiceous tuff constitute more than 99 percent of the fragments; the rest is basalt and red porphyritic felsite. This conglomerate is conspicuously stratified; beds a few inches to a foot thick are common. Well-sorted beds alternate with poorly sorted ones.

The sandstone and siltstone, other than local lenses, are restricted to the northeast corner of the quadrangle from peak 4276 northward along the edge of the Amargosa Valley. The rock is poorly indurated, is pale yellow brown, and generally contains lenses of conglomeratic sandstone bearing quartzite and limestone fragments of Paleozoic age. A little limy siltstone and limestone occurs with the thickest sandstone and siltstone. Beds are 1–5 inches thick, and commonly the material is well sorted but locally contains scattered pebbles and cobbles. The beds resemble very closely the mudflow beds along the intertonguing contact of the conglomerate member and siltstone and saline member of the Copper Canyon formation. Cross-bedding and channel fills are scarce.

ANDESITE AND BASALT MEMBER

In most places there are only one or two flow units, but locally, as east of upper Greenwater Canyon, one unit contains many flows. They are mostly conformable over the basal conglomerate, and the few minor irregularities in the base of the andesite and basalt differ little from local channel fills within the conglomerate. The widespread, distinct flows are uniformly 20–40 feet thick; the other flows are associated with piles of andesite and basalt and of agglomeratic rubble as thick as several hundred feet. Lenses of reddish-brown lapillae and scattered bombs occur in six places in sufficient abundance to suggest remnants of cinder cones. The largest of them, which lies on the north wall of the canyon just east of Funeral Peak, has a central plug of agglutinated basalt. Larger cinder cones that still form conical knobs, although probably much reduced from their initial form, are abundant just north and east of the Funeral Peak quadrangle. Dikes of similar basalt are numerous; one, about 5 miles S. 30° W. of the northeast corner of the quadrangle, is clearly a feeder dike, and others are probably similar vents. Some of these dikes are difficult to distinguish from small bodies of basalt of Tertiary age. Others are distinguished by their little alteration and habit of weathering into large blocks.

Most fresh andesite or basalt is medium bluish gray to dark gray and weathers brownish black. It breaks into blocks and plates many feet across which, when weathered, break into small platy debris a few inches across. Other andesite or basalt is light or medium gray and weathers directly into small platy debris. Highly scoriaceous andesite or basalt is reddish or yellowish brown. The more massive and platy rock has a few irregularly shaped vugs, which are crudely alined parallel to the flow. Other andesite and basalt is scoriaceous or amygdular.

The dominant minerals are, in decreasing order of abundance, labradorite, augite, and olivine; and the accessory minerals are commonly magnetite and apatite and, less commonly, are orthopyroxene and biotite. Andesine and quartz xenocrysts occur in about half the specimens studied, and biotite xenocrysts appear

TABLE 12.—*Modes of the andesite and basalt member of the Funeral formation*

Specimen No.	21	22	23	24	46	47
Field No.	56D257	56D210	56D153	56D150	56D148	57D364
Mode points	1,100	2,236	1,009	1,133	1,032	1,565
Plagioclase:						
Xenocryst:						
Amount	-------	-------	4.0	7.0	2.7	-------
An content	-------	-------	35–50	35–50	30–40	-------
Plagioclase:						
Phenocryst and groundmass:						
Amount	-------	-------	51.5	49.7	47.0	-------
An content	55–75	-------	45–70	45–70	45–60	60–75
Total plagioclase	46.0	63.9	55.5	56.7	49.7	51.0
Augite	28.6	16.3	23.3	31.2	35.9	21.0
Olivine	18.7	14.5	3.3	2.5	2.8	6.8
Magnetite	6.0	3.9	5.1	4.0	4.0	4.3
Apatite	.3	1.2	1.1	1.3	1.0	2.2
Biotite	-------	.1	-------	-------	-------	.2
Glass	.3	<.1	11.3	2.8	3.4	-------
Cristobalite	.1	-------	-------	1.1	.7	-------
Quartz xenocryst	-------	-------	.5	.4	2.5	-------
Zeolite (analcite?)	-------	-------	-------	-------	-------	14.7

in a few of them. Secondary minerals are relatively scarce and comprise clay minerals, hematite, iddingsite or bowlingite, uralite, chlorite, and zeolites. Most rocks contain a few percent of unaltered glass, but one contains about 60 percent glass with $n=1.512$. The modes of six rocks are presented in table 12.

Textures are chiefly determined by the felty to flow-alined plagioclase laths. Ferromagnesian minerals, additional plagioclase, and glass are either intergranular or ophitic between the network of plagioclase laths. Plagioclase, olivine, and, less commonly, augite, orthopyroxene, quartz, magnetite, and biotite constitute the phenocrysts or xenocrysts. The groundmass laths are about 0.1 mm long, the intergranular material 0.02–0.05 mm; some ophitic clinopyroxene that encloses many plagioclase laths is about 2 mm across; and phenocrysts average about 0.5 mm but are as large as 4 mm. Reaction rims of clinopyroxene and rims of glass surround quartz xenocrysts.

Plagioclase groundmass crystals and phenocrysts commonly are labradorite and rarely are andesine or sodic bytownite; one rock contains some anorthite grains. The plagioclase crystals are euhedral to subhedral, long laths, or stubby laths that form clusters in a few rocks. Ophitic plagioclase is anhedral and does not have the sharp twinning and cleavage common to most larger laths. Plagioclase xenocrysts are cores of andesine or oligoclase rimmed by labradorite similar in compositions to the groundmass plagioclase. They are anhedral to subhedral, commonly are embayed, and have vermicular cores or vermicular zones between the more sodic centers and more calcic rims. The sodic cores of many xenocrysts have strong oscillatory composition zones, and the outermost rims of xenocrysts commonly are like those of the phenocrysts.

Pyroxene and olivine phenocrysts are invariably euhedral, but in the groundmass these minerals are subhedral or anhedral. The iddingsite or bowlingite alteration along edges and fractures of olivine is slight. Augite is light gray to pale brown, has an extinction angle of 40°–45°, and is altered in a few rocks to pale-green uralite or chlorite. Orthopyroxene is faintly pleochroic or nonpleochroic and forms long prisms. Quartz xenocrysts are commonly intricately embayed. The pyroxene crystals in the rims around quartz are crudely radial. The rare biotite forms small subhedral plates in the groundmass, or large subhedral xenocrysts surrounded by a rim of black opaque material. The biotite xenocrysts are most common in rocks that contain oligoclase xenocrysts, orthopyroxene, and a groundmass rich in glass.

The andesite and basalt member of the Funeral formation is petrographically and chemically difficult to distinguish from the Tertiary andesite and basalt. In most places the former is fresher and contains more glass. Large bodies of andesite and basalt that characteristically weather to coarse blocks and bodies associated with conglomerate of the Funeral formation are probably part of the andesite and basalt member of that formation. But some dikes of the two units are especially difficult to distinguish. The proximity to andesite and basalt of known age is used as guide to place a few small bodies of uncertain age.

MEGABRECCIA MEMBER

The megabreccia member is a relatively homogeneous now largely coherent lens of shattered and brecciated metadiorite, monzonite, and porphyritic felsite. It underlies slightly less than 1 square mile of the Copper Canyon area and is more than 1,000 feet thick in the middle of its outcrop area, but it tapers to a thickness of a few tens of feet along its strike.

The lateral northern and southern parts of the mass lie conformably on the conglomerate member of the Funeral formation, but for about half a mile near the center of its belt of outcrop, the mass rests on a greatly disturbed zone about 20 feet thick at the top of the siltstone and evaporite member and the conglomerate member of the Copper Canyon formation, as shown in figure 7. In an earlier report (Drewes, 1959, p. 1, fig. 2), a distance view of this contact appears on a photograph, which shows the contact between the symbols QTf and Ts, and almost beneath p€m. Southwest of hill 2410 the basal contact of the megabreccia lens dips about 55° E., parallel to the relatively undeformed siltstone and limestone beds underlying the disturbed zone. The disturbed zone consists of severely broken and warped siltstone beds. The basal 70 feet of the overlying megabreccia consists of a bluish-gray gouge

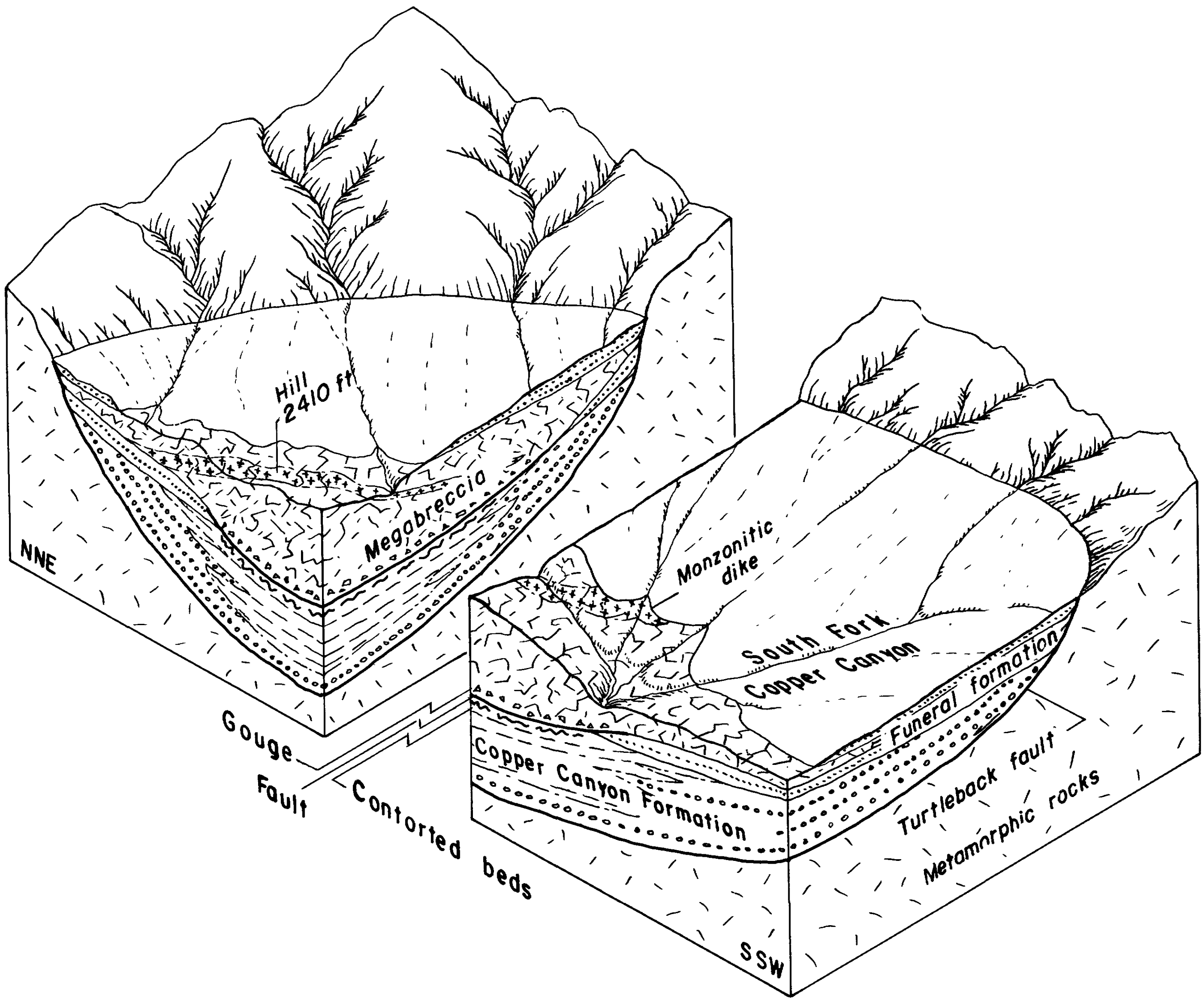


FIGURE 7.—Schematic block diagram of part of the Copper Canyon area showing relations between the megabreccia member of the Funeral formation and other rocks.

of clayey and granular metadiorite. The megabreccia is crudely zoned; above the middle of the megabreccia body, there is a lens of monzonite rock, and near the top there is some reddish-gray porphyritic felsite. Unmapped monzonite and feldspathic dikes, most of which resemble the small feldspathic dikes of Precambrian age, cut the metadiorite. These lenses and dikes are thoroughly shattered and locally, particularly near the top, are brecciated. The breccia fragments are a few inches to many feet across, but fragments of the shattered rock commonly are many inches to many feet across. The shattered and brecciated rock contains no weathered gravel, and the shattered rock no gouge. The dikes cutting the metadiorite are scarcely interrupted by the shattering over distances of 500 to 1,000 feet. Most of the shattered and brecciated rocks are firmly healed, so that they are more resistant than the adjacent rocks. The megabreccia is conformably overlain by more conglomerate of the Funeral formation.

The megabreccia member resembles breccias found in many Tertiary rocks from western Arizona to southern California. It resembles, except for the size of the mass, the breccia in the siltstone and evaporite member of the Copper Canyon formation and is somewhat similar to the sheets of sedimentary breccia in the conglomerate member of that formation. I was shown similar breccias by C. R. Longwell a few miles southeast of Hoover Dam in Arizona, and by D. F. Hewett along Star Wash in the Ivanpah quadrangle.

These are described by Longwell (1936, p. 1426–1428; 1951; 1963) and by Hewett (1956, p. 86–91). They also resemble closely others described in Emigrant Wash of the Panamint Range, Calif. (Wright and Troxel, 1954, p. 27–29), in the Jubilee Pass area just south of the Funeral Peak quadrangle (Noble, 1941, p. 982–983), and in the Avawatz Mountains, Calif. (Jahns and Engel, 1949, 1950).

Megabreccia deposits differ from the chaotic mixture of blocks lying on the Amargosa thrust fault, which have already been described. The chaotic blocks are essentially unshattered but rotated blocks set in a gouge matrix, whereas the megabreccia deposits are shattered or partly brecciated but little rotated blocks.

Most of these megabreccia deposits are recognized as landslides, or more properly, as rockslides. The deposit in Star Wash, which is interpreted as a thrust mass, also looks like a megabreccia deposit. But megabreccia deposits differ a little from some typical rockslides, such as the 1925 Gros Ventre slide, Wyoming, and the 1959 Madison Canyon slide, Montana. The rock of these typical rockslides was thoroughly broken and much mixed (J. B. Hadley, oral communication), whereas the rock of the megabreccia deposits was largely shattered and only partly brecciated and was mixed very little. Apparently the rockslides that deposited the megabreccia were less fluid and had less energy, and very likely moved a little slower than these rockslides of historic times.

The megabreccia member of the Funeral formation is pictured as having slid from a steep mountain front across the adjacent fan, and onto and partly into the playa beds beyond the fan at a rate somewhat less than is common for some typical rockslides.

AGE AND CORRELATION

The age of the Funeral formation is Pliocene and Pleistocene(?) (Noble, 1941, p. 957). No fossils have been recovered from the Funeral formation. It overlies the Pliocene(?) Copper Canyon formation with minor unconformity that suggests a change in tectonic environments rather than a long time lapse. It is overlain by several gravel bodies at Mormon Point, described in the next section; and beach scarps of late(?) Pleistocene age are cut into one of the youngest of these gravels. Noble also mentions that in Amargosa Valley, beds with Pleistocene fossils lie unconformably over the Funeral formation. Noble's age determination is corroborated by G. E. Lewis (written communications, 1956), who identified fossils of *Equus* sp., *Camelops*? sp., and an antilocaprid cf. *Tetrameryx* (*Stockoceros*) sp. or *Antilocapra* sp. The formation may be partly Pliocene and partly Pleistocene; very likely the ages of the deposits included with this formation differ considerably within these limits.

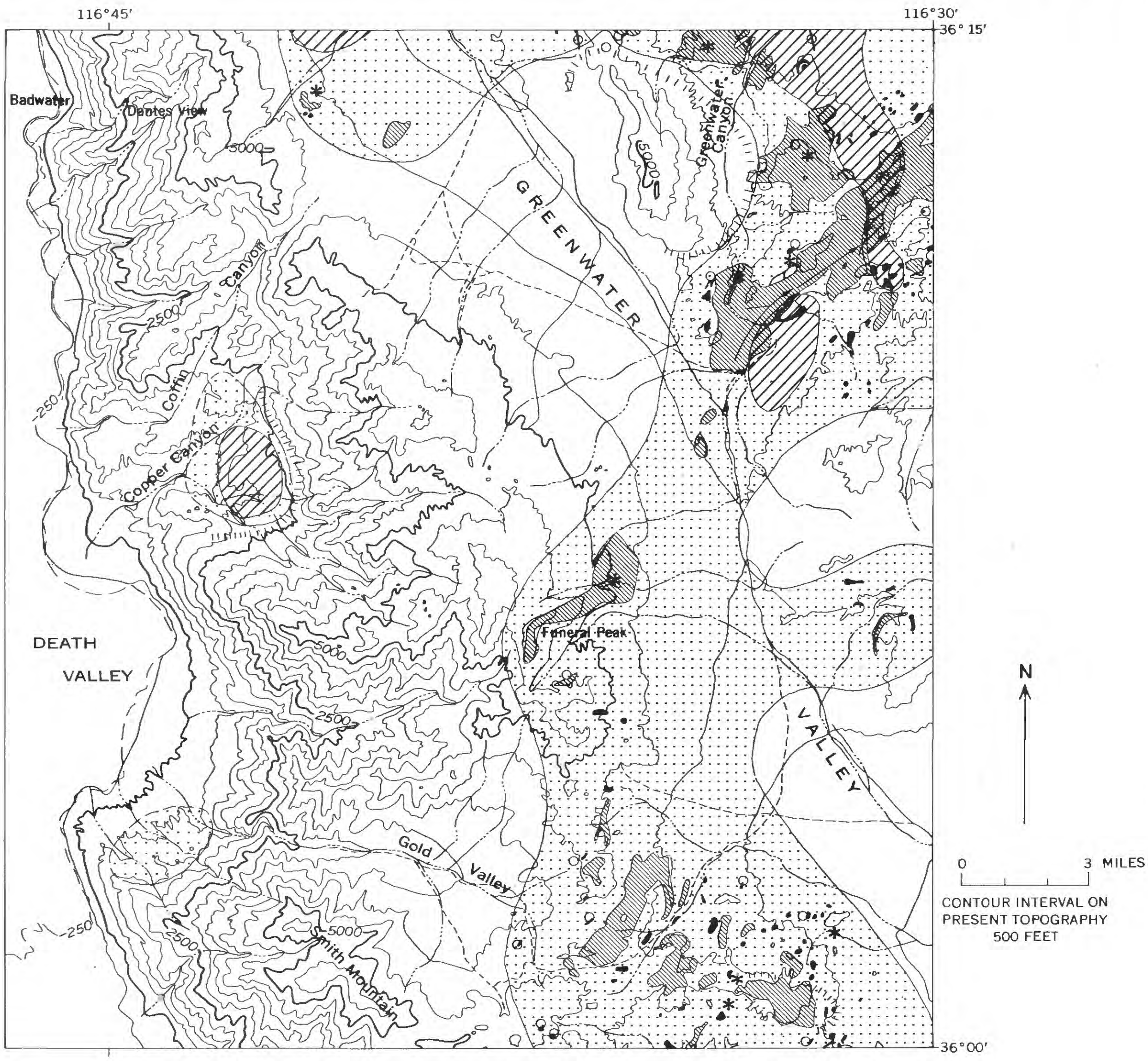
The Funeral formation at the type locality, Ryan, is lithologically similar to other conglomerates scattered around Death Valley and adjacent valleys. However, all these rocks are unfossiliferous, and reliable time-stratigraphic correlations are not possible.

ORIGIN AND ENVIRONMENT

By the end of Greenwater time the relief of the west half of the quadrangle had been greatly increased, and the drainage of Greenwater Canyon was fixed in its present course (fig. 8). The climate was drier than it had been in Furnace Creek and Copper Canyon times, for a fresh-water lake had been filled with playa deposits. The environmental changes during Funeral time are described for the Greenwater Canyon area, the Copper Canyon area, and the southeastern corner of the quadrangle. The changes in these areas are not integrated because the andesite and basalt flows need not be contemporaneous and because they are absent in some places.

In the Greenwater Canyon area silty gravel was deposited in a narrow playa that extended from hill 4276, about 1 mile west and 4 miles south of the northeastern corner of the quadrangle, to beyond the northern border of the quadrangle before the andesite and basalt unit was extruded. The playa is now marked (fig. 8) by the conglomeratic siltstone with the cobbles of Paleozoic rocks that forms a lens about 100 feet thick. The cobbles of Paleozoic rocks are more likely derived from a local source, now buried, than from the Funeral Mountains, which contain abundant Paleozoic rocks but lie 6 miles north of and across the playa from this area. The thinner and less continuous deposits of gravel surrounding the thick lens of conglomeratic siltstone were deposited on the flanks of the playa. These deposits are absent from the rhyolite and rhyodacite dome northwest of Greenwater Canyon, which probably was a hill then, as now. The andesite and basalt flows lapped around the hill from the north, east, and south. They also filled an old canyon running from the southern end of the present Greenwater Canyon northeastward to the playa. Some of the cinder cones built around vents were buried by later lava flows; others, as those just north and east of this part of the quadrangle, were never buried and rise above the surfaces of the youngest lava flows. The lava-filled canyon was probably the ancestral Greenwater Canyon. The water that had flowed down it was temporarily ponded in another playa that lay just southeast of the southern end of Greenwater Canyon.

Pumiceous tuff, derived from an unknown source, collected in this playa. The pumiceous tuff may have been reworked from the tuff-breccia member of the Greenwater volcanics, if that member had been more extensively distributed in the past than it is now or, it may have been reworked at least partly from deposits of a late eruption of rhyolitic rocks. Airborne deposits of a similar pumiceous tuff are interbedded in conglomerate of the Funeral formation elsewhere, as in Copper Canyon. When this playa was filled the drainage found a new outlet north of the old one, and the present course of Greenwater Canyon was initiated. A third playa, about which little is known, probably occupied a small area largely north of the quadrangle



EXPLANATION

Outcrops of andesite and basalt of the Funeral formation

Playa deposits of the Funeral formation

Large areas without outcrops of the Funeral formation
The formation may be buried beneath Death Valley or may never have been deposited in hilly areas

Cinder cones of Funeral time

Area underlain by small scattered patches of conglomerate of the Funeral formation

Hill during Funeral time

Fissure vents of Funeral time

Ancestral Greenwater Canyon

Dike

FIGURE 8.—Geologic and paleogeographic features during Funeral time.

in Greenwater Valley, but one edge probably lapped into the quadrangle.

In the Copper Canyon area the fresh-water lake of late Copper Canyon time was partly filled by fans derived from the adjacent mountains, for the fans of gray gravel overlying the fresh-water limestone and siltstone deposits of the Copper Canyon formation almost merged with each other from opposite sides of the basin. The change from red conglomerate of Copper Canyon time to gray conglomerate in Funeral time reflects completion of the removal of the red volcanic rocks and exposure of the grayer metamorphic rocks. The deposition of gray gravel was interrupted by the sliding of a part of the adjacent mountains, down across the fans and into the lake left over from Copper Canyon time; the slide severely churned up the underlying clays and silts. The landslide mass came down as one unit, which remained largely intact; for although the rock is shattered, most of the blocks are not rotated. The transgression of the gray fans over the older lake deposits and the large landslide were probably caused by a geologically rapid increase in the relief along Death Valley. Large fans rich in sedimentary breccia were also deposited near Mormon Point. Death Valley was probably a major tectonic depression at this time, for fanglomerates with similar characteristics and presumably similar age are common in many places along the flanks of Death Valley.

In the southeast corner of the quadrangle, the conglomerate, deposited before the extrusion of the andesite and basalt, becomes thicker southward along the headwaters of the present Virgin Spring Wash, 3 miles east of the southeast corner of the map area. Very likely the ancestral Virgin Spring Wash follows much the same course as the present Virgin Spring Wash. A hill lay about 1½ miles east of the ancestral Virgin Spring Wash in the vicinity of the present hill 4456. Andesite extruded from high on this hill flowed down its north and east sides in gullies which are now partly exhumed. Cinder cones in this area were small.

QUATERNARY ROCKS

Several bodies of gravel and one of silt and evaporites of Quaternary age underlie basins and small areas in the adjacent mountains. In Death Valley five units are separated based on differences in the grain size or rounding of their individual particles, on induration of the deposits, or on the character of the desert pavement developed on them. The five units constitute an older gravel of Pleistocene age with subangular fragments that are moderately well indurated; a gravel of Pleistocene age with subrounded fragments that are poorly indurated; a younger gravel of Pleistocene and Recent age with subangular fragments that are poorly indurated; and surficial deposits of Pleistocene and Recent age that include gravel and sand, and silt and evaporites. In Greenwater Valley only two units are separated: gravel of Pleistocene age with poorly to moderately well indurated fragments, and surficial deposits.

SUBANGULAR AND MODERATELY WELL INDURATED GRAVEL

About 2 square miles between Mormon Point and the mouth of Sheep Canyon are underlain by moderately well indurated gravel with subangular fragments. The gravel is faulted against older rocks, but most likely it is unconformable over the Funeral formation, from which it is distinguished by less deformation and poorer induration. This unit consists of several gravel bodies that locally can be distinguished from each other by color or degree of induration. The rock is gently folded, the dips rarely exceeding 10°. The thickness of the gravel is on the order of hundreds of feet. It is unconformably overlain by the subrounded poorly indurated gravels.

The gravel is light gray to pale red and forms steep slopes or small cliffs with vertical fluting. It is deeply dissected by widely spaced gullies and canyons, between which the surface of the gravel is a well-developed pavement of stones whose exposed surfaces are strongly varnished. Many fragments of the pavement are split or shattered. The gravel consists chiefly of subangular pebbles and cobbles of metamorphic rocks, monzonitic rocks, rhyolitic volcanic rocks, and a little dolomite in a loosely packed sandy and limy matrix. The proportion of the reddish-gray volcanic rocks to the others controls the color of the gravel. This proportion is less than in adjacent conglomerate of the Funeral formation and greater than in adjacent younger gravel. The gravel is moderately well sorted to poorly sorted and is massive or thick bedded. Near Mormon Point the gravel contains tongues of silt and evaporites and a few beds of tuff that possibly is an airborne deposit little reworked before burial. It also contains conglomeratic siltstone beds that are probably mudflow deposits.

The gravel is a fan deposit off the mouths of Willow Creek and Sheep Canyon. Toward Death Valley it grades into silt and salines of a playa environment. The mudflow beds probably mark the transition between fan and playa environments. Similar gravel was probably deposited all along the foot of the mountains, but elsewhere it was faulted down and buried.

The gravel is dated as Pleistocene, for the overlying subrounded gravel was deposited in late Pleistocene Lake Manly, and the next older rocks in this area, which are considerably more deformed, are Pliocene and Pleistocene. The gravel is equivalent to Hunt's No. 2 gravel (C. B. Hunt, written communication).

SUBROUNDED AND POORLY INDURATED GRAVEL

Small areas east of Mormon Point and south of the mouth of Copper Canyon are underlain by poorly indurated subrounded gravel that lies unconformably on the older gravel. In most places it forms lenses 10–50 feet thick that lie on benches cut into older gravel but in two places just south of Mormon Point the gravel is much thicker.

The gravel has the color and composition of the older gravel but forms slopes distinctly gentler than those cut on the older gravel. The gravel contains moderately well-rounded and moderately well sorted pebbles and cobbles, with scattered boulders and some interstitial and interbedded sand. Beds are thin in the thin lenses; in the thick lenses there is deltaic cross-bedding. The sand and gravel are poorly indurated or unindurated, except for a local capping caliche layer; the upper surface of the gravel has a coat of desert varnish.

The terraces on which many of the gravel lenses lie are as wide as several hundred feet; they slope gently toward Death Valley and away from low erosional scarps. There are five particularly prominent and persistent terrace levels between the mouth of Sheep Canyon and Mormon Point. The upper edge of the highest terrace is 260 feet above sea level, and that of the lowest terrace is about 100 feet lower.

The thinner deposits on the terraces are beach deposits, and the thicker ones are probably delta deposits. The terraces and scarps above them are wavecut features. Similar shoreline features are reported from several other places at about the same altitudes around Death Valley and are ascribed to erosional and depositional processes along the margins of Lake Manly (Blackwelder, 1933, 1954, p. 37; C. B. Hunt, written communication).

Lake Manly is one of the many lakes formed in the valleys of the Basin and Range area during pluvial intervals in Pleistocene time. Blackwelder (1935) mentioned bones of elephants and other mammals of Pleistocene age found in deposits of Lake Tecopa, about 30 miles east of Death Valley, and Hay (1927, p. 85) described a Pleistocene camel from these deposits. Blackwelder suggested that Lake Manly was younger than Lake Tecopa on physiographic evidence, so that probably Lake Manly is a late Pleistocene lake. The gravels, then, probably are late Pleistocene.

SUBANGULAR AND POORLY INDURATED GRAVEL

The lower slopes near Mormon Point and small areas along the foot of the mountains are underlain by poorly indurated subangular gravel. Many of the small patches of gravel along the foot of the mountains are alined at about 200 feet above sea level. The gravel lies unconformably on older gravel or rock and is faulted but is nowhere tilted or folded. The thickness of the gravel probably does not exceed 200 feet.

The gravel is light gray and underlies moderately steep slopes and moderately well paved surfaces that have no split or shattered cobbles. It is only slightly dissected near Mormon Point. The fragments consist of subangular cobbles, boulders, and pebbles of the underlying rocks or of the rocks lying east of the gravel. They are poorly sorted and poorly indurated.

The gravel was deposited in fans along the foot of the mountains. The horizontal alinement of the mountain side of many of these fans suggests that they were still very young when they were dissected. Even the youngest fans in this area show a greater diversity of altitude along the foot of the mountains than the roots of these slightly older fans. The fault movement that truncated the fans and left their roots hanging displaced the gravel the same amount everywhere.

The gravel is of Pleistocene or Recent age and younger than Lake Manly, for it contains no beach scars in areas where such scars are common.

SUBANGULAR AND POORLY TO MODERATELY WELL INDURATED GRAVEL

Poorly indurated to moderately well indurated gravel underlies many square miles of Greenwater Valley and a corner of Amargosa Valley. The gravel unconformably overlies the Funeral formation of Pliocene and Pleistocene(?) age and probably consists of several unmapped units similar in appearance and difficult to separate consistently. It is undeformed, and along the west side of Greenwater Valley it covers a narrow pediment. Recent and Pleistocene gravel of the youngest washes unconformably overlies this older gravel.

The gravel consists of subangular fragments of locally derived rocks that are as large as boulders, but in much of Greenwater Valley it contains abundant coarse sand and pebbles. The color of the gravel varies with the dominant lithology of the fragments, and the weathering habits of the slopes underlain by the gravel are paved and varnished. Most pavements are underlain by a vesicular limy silt layer a few inches thick, and many pavements contain split and shattered cobbles.

The gravel is probably largely or wholly of Pleistocene age.

SURFICIAL DEPOSITS

Clastic sediments and evaporites form surficial lenses in many parts of the area. Sand and gravel are common in all the valleys, and silt and evaporites are restricted to the floor of Death Valley.

Sand and gravel lie in the youngest washes and on the youngest fans. The distribution of the sand and gravel deposits on plate 1 is necessarily generalized, because many are too small to be mapped. Some older gravels are very thinly or locally veneered with sand and gravel deposits that are not mapped because they are too small or because to show them would needlessly conceal the underlying rocks that are the primary object of this study. The sand and gravel are alluvial material that grades into colluvium and talus toward the mountains and into the silt and evaporites toward Death Valley.

Silt and evaporites of this map unit are restricted to Death Valley. The young silt and evaporites at the surface may conceivably be conformable with unexposed deposits beneath them that are facies of many of or all the gravel and conglomerate bodies flanking Death Valley. Of all the surficial deposits, those in Death Valley are unique in that they may lie conformably on similar underlying deposits and are probably thicker than other surficial deposits. The deposits of Death Valley are described in detail by C. B. Hunt (written communication).

STRUCTURE

GENERAL DESCRIPTION

High-angle faults are the most prominent and abundant structures in the Funeral Peak quadrangle, but there are also a few folds and remnants of the Amargosa thrust fault. The intrusion of the various igneous rocks deformed the host rocks either very little or, if severaly, then only very locally. All these structural features are of two general ages, Precambrian and Cenozoic.

Most of the structural features in the quadrangle are interpreted as having formed by movements within the Black Mountains fault block (fig. 2) in response to stresses set up by major movements along large strike-slip faults bounding the block. The Black Mountains fault block is visualized as a very large horse in a very large strike-slip fault zone. This fault block has had more freedom to move vertically than other major blocks along the strike-slip fault zone. The block has moved up as well as down, and apparently has been much more faulted along nearly flat-lying faults than most of the surrounding blocks.

The structural features of Precambrian age are much older than the earliest inferred movement on the master faults. A few low-angle normal faults and the fault under part of the megabreccia landslides are interpreted as caused by the stress of gravity and only indirectly related to the tectonic stresses that helped to give the block its large relief.

The structural synthesis outlined above and detailed below follows many of the previously accepted regional interpretations. However, a few interpretations suggested in this report depart from previously held ideas or stress other aspects. Among the new interpretations and reoriented emphases offered here are: (a) the importance of the role played by the master faults, or strike-slip faults, during Cenozoic time; (b) the rootless, yet tectonic origin of the Amargosa thrust fault and the chaotic structure on the fault plane; (c) the normal fault origin of the turtleback faults; and (d) the distinction between the megabreccia and the chaotic blocks.

The structural features are described in the following section in a chronologic order, beginning with the oldest ones. In general this order is the same as one in which large faults or faults active over a long time are described first and the smaller ones or less active ones are described later. The few Precambrian structural features are described in the first section. The several following sections on the Cenozoic structural features are introduced by a brief description of the master faults and are followed by sections on the Black Mountains fault system, the Amargosa thrust fault, other high-angle normal faults, the low-angle normal faults or turtleback faults already described at greater length (Drewes, 1959), and the small folds.

PRECAMBRIAN STRUCTURAL FEATURES

Precambrian structural features consist of several folds, a fault, and the intrusive body of metadiorite, along with the unmapped feldspathic dikes and andesitic dikes. The folds and faults are described here, and the structure of the igneous body has already been briefly described in connection with the metamorphic rocks.

The older Precambrian rocks along the western flank of the Black Mountains are folded into three anticlines and a syncline that plunge gently north-northwestward. The anticlines are open folds with an amplitude of several thousand feet, but the syncline is tight. The crest of each of the anticlines forms a ridge that descends north-northwestward roughly parallel to the plunge of the fold axis. The rocks were folded in Precambrian time, probably before the intrusion of the metadiorite of Precambrian age.

The northern anticline lies northeast of Badwater and extends to Natural Bridge Canyon about 3 miles north of Badwater and outside the map area. Bedding and foliation of the schist and gneiss of Precambrian age are broadly folded. The fold is conspicuous to the north but is more obscure to the south, where bedding and foliation are fainter. However, the folded rocks appear to extend into the south wall of the canyon east of Badwater. Little of the northeast limb of the anticline is exposed, for younger rocks truncate or cover it, but the southwest limb descends to the floor of Death Valley. The axis of the fold appears to be doubly plunging; the longer, northern part of the axis clearly plunges gently north-northwestward, and the shorter, southern part appears to plunge southward. The relations between the fold in the metasediments and the metadiorite south of the fold are not as clear as elsewhere; however, the metadiorite may cap or enclose the folded rocks, and the transition between the foliated and massive rock is possibly an intrusive contact.

The central anticline lies south of Copper Canyon and is more than 3 miles long and 2 miles wide. Bedding and foliation in the older schist, gneiss, and marble of Precambrian age are broadly folded (Drewes, 1959, fig. 3). The fold is gradually more difficult to trace southeastward and is lost before it reaches Sheep Canyon (fig. 3). The axis of the fold plunges 15°–25° north-northwestward. The southwest limb dips as steeply as 60° southwestward, but the northeast limb does not dip more than 20° northeastward.

The southern anticline and adjacent syncline lie southeast of Mormon Point; their axes are 1–2 miles long, and together the fold axes are half a mile apart. Bedding and foliation in the marble, gneiss, and schist of Precambrian age can be traced southeastward into a cliff where the metasediments are capped or truncated by metadiorite. The metasedimentary rocks of the east limb of the syncline grade over a few tens of feet into metadiorite. The contact is probably intrusive. The limbs of the main folds contain many smaller parallel ones. The axes of the folds plunge about 15° north-northwestward. The east limb of the anticline and the limb common to the anticline and syncline dip as steeply as 45°, but the east limb of the syncline dips steeper than 60°.

The age of the folding of the older Precambrian foliated rocks is probably also Precambrian, but the evidence is not conclusive. A Precambrian age of the folds is suggested by, first, the relations between the foliated rock and the metadiorite and, second, a comparison of the deformation in this area with that in adjacent areas. The metadiorite of older Precambrian age, which appears to intrude the folded schists and gneisses, is itself not deformed and suggests that folding preceded intrusion, if one assumes that the massive and foliated rocks respond in the same manner to the stresses. In nearby areas the Pahrump series of younger Precambrian age and the Paleozoic rocks do not show large plunging folds similar to those in the older rocks and suggest that such folds are older than the Pahrump series.

The trend of the Precambrian folds is paralleled by some younger structural features. Some segments of the master faults, many normal faults, and the alinement of volcanic vents also trend northwestward. Perhaps the younger structural features were localized by the folds in the Precambrian rocks, or perhaps they had a common deep-seated structural origin.

MASTER FAULTS

The master faults of the Death Valley region consist of several large strike-slip faults illustrated in figure 2. These faults include the exposed Garlock, Confidence Hills, and Furnace Creek fault zones and the inferred Death Valley and Shoshone fault zones.

The largest of the exposed master faults is the left-lateral Garlock fault zone; it lies in the southern part of the region, and its eastern end swings southward around the Avawatz Mountains and continues southward beyond the area of figure 2 as the Soda-Avawatz right lateral fault zone of Grose (1959, p. 1541–1544), or is cut by it. The Confidence Hills fault zone branches from the Garlock fault zone and extends northwestward through the Confidence Hills, west and southwest of Virgin Spring. The Furnace Creek fault zone trends northwestward parallel to the Confidence Hills fault zone and along the southwest flank of the Funeral Mountains; it probably extends at least as far southeastward as Eagle Mountain, which is tilted like the rocks in the southern end of the Funeral Mountains rather than like those in the Resting Spring Range.

The master faults are probably strike-slip faults. They are many tens of miles long; their traces are linear or gently curved, and the local topography is strongly controlled by them. The fault zones consist of many subparallel vertical individual faults that range in size from the large one shown along the Garlock fault zone in figure 2 to unmapped small ones commonly a few hundred feet long, such as those along the east side of the East Coleman Hills, 2 miles northeast of the Furnace Creek Ranch. Some of these small fault blocks contain rocks older than those in the adjacent parts of both walls of the fault zone. The distribution of the northernmost exposures of the Pahrump series on opposite sides of Death Valley suggests as much as 15–30 miles of right-lateral displacement. The northernmost exposures of the Pahrump series west of Death Valley lie opposite Mormon Point. In the Black Mountains block they are exposed in klippen in the Virgin Spring area, about 15 miles to the southeast, and in autochthonous blocks only in the southern end of the Black Mountains block, about 30 miles southeast of the northernmost exposures in the Panamint Mountains. These estimates of maximum permissible displacement, of course, must be modified an unknown amount to account for vertical displacement and possible irregularities of the initial distribution of the Pahrump series.

The master faults separate regions of distinctly different topography. In a large triangular region north of the Garlock fault zone, east of the faults in Owens Valley, and southwest of approximately the Furnace Creek fault zone, or perhaps of the California-Nevada State line, the relief is greatest, and the area underlain by mountains is more extensive than that underlain by valleys. To the northeast of this triangular region, that is, throughout most of the Great Basin, the relief is less and in general the basin areas are as extensive as the mountain areas. In strongest contrast to the triangular region, the Mohave region, as well as the Basin and Range Province in Arizona and Sonora, has a comparatively modest relief, and the valley areas are much more extensive than the mountain areas. The topographic contrast between the triangular region largely north and west of Death Valley and the regions to the south and east suggests that tectonic uplift was greatest there in relatively recent time, and the general coincidence of strike-slip faults with the borders of the strongly uplifted region indicates a close genetic relation between these faults and regional vertical movements.

Two north-trending fault zones, the Death Valley and the Shoshone fault zones, are inferred to connect the Furnace Creek and the Confidence Hills fault zones because the large structural block between them, the Black Mountains block, is markedly different from the adjacent structural blocks. It contains only small klippen of the Paleozoic rocks, although the Paleozoic section is about 4 miles thick in most of the adjacent blocks. The erosion of most of such a great thickness of Paleozoic rocks requires that the Black Mountains block moved independently from the adjacent blocks in which the Paleozoic rocks are more intact; hence, large faults along the Death Valley and Amargosa Valley sides of the Black Mountains block are inferred. These are probably also strike-slip faults because, if they are physically and temporally related to the exposed strike-slip faults, they are probably genetically related to them.

The Death Valley fault zone may consist of a series of en echelon northwest-striking faults, of which the set of longer faults along the west foot of the Black Mountains are the southeast ends. However, it is easier to give the Black Mountains block the freedom of movement that its history requires by inferring that the Death Valley fault zone is similar to the other fault zones in the region and that the longer faults along the foot of the Black Mountains splay out from the Death Valley fault zone. The Black Mountains block, is then seen as a large horse between two strike-slip master faults.

Some cumulative rotational movement can also be inferred on the master faults between the Funeral Mountains to the northeast and the Owlshead Mountains to the southwest of the Black Mountains. The Funeral Mountains are raised about a mile above the late Tertiary and the Quaternary deposits, which are about 2 miles thick on the adjacent part of the Black Mountains block, or a total displacement of about 3 miles, east side up. The Owlshead Mountains are raised a little less than a mile, and the Paleozoic rocks, normally about 4 miles thick, plus an additional but unknown amount of rocks of the Pahrump series, have been eroded away, indicating total displacement probably in excess of 3 miles, west side up. The inferred cumulative rotational movement, then, is at least 6 miles in about 40. However, at an earlier time the Funeral Mountains were low and received conglomerate derived from the Black Mountains, so that movement on the fault at the foot of the Funeral Mountains was reversed.

Furthermore, a general eastward tilting of the structural blocks adjacent to the master faults is recorded by physiographic evidence and general inclination of rocks, as described in the section on displacements along faults.

Movement on the master faults, then, was complex. The total displacement is a combination of (a) probable right-lateral movement, (b) rotational movement with the north end of the block to the east of the Black Mountains block and the south end of the block to the west of the Black Mountains block both up, and (c) vertical movement to tilt the blocks eastward. Not only was the movement complex, but as will be shown, the movement was recurrent.

AMARGOSA THRUST FAULT

GENERAL DESCRIPTION

Paleozoic rocks occur in the Funeral Peak area only as large chaotic blocks that are either bordered by faults or are intruded or covered by the older volcanics of Tertiary age. Many of the blocks are separated from the underlying rocks by flat-lying or gently inclined faults. These faults are probably remnants of an extension of the Amargosa thrust fault, mapped south of the area by Noble (1941). The Amargosa thrust fault is not connected with another probable thrust fault of the same name in the Beatty area, Nevada, 60 miles farther north that is described by Ransome, Emmons, and Garrey (1910). In the Funeral Peak area most of the upper plate of the Amargosa thrust fault has been removed by erosion or has been engulfed by intrusive bodies of the older volcanics. The existing remnants of upper plate are broken into large chaotic blocks. The direction and distance of movement of the upper plate are not known from data available within the quadrangle, but to the south there is some evidence that the upper plate moved westward a long distance (Noble, 1941, p. 980). The time of movement along this thrust fault is early or middle Tertiary.

The Amargosa thrust fault is exposed south of Gold Valley, northeast of Gold Valley, and in the southeastern corner of the quadrangle (pl. 1). South of Gold Valley the thrust fault follows the bases of two large, unbroken blocks of dolomite. The southern block and the fault beneath extend for miles beyond the southern border of the quadrangle; the northern fault block, about a mile long, is truncated by a normal fault to the east and by a dike and fault to the west. The thrust fault is exposed for short distances in many places northeast of Gold Valley. The thrust fault underlies the large dark dolomite block about 1 mile north of the northeast corner of Gold Valley. Several normal faults separate this segment of the thrust fault from adjacent segments to the south, which lie mostly near an altitude of 4,500 feet but rise gently eastward near the southern end of these segments. Several segments of the thrust fault are exposed at an altitude of 4,800 feet in a horst 1 mile east of the segments lying at 4,500 feet (pl. 2). Several other small segments of the Amargosa thrust fault are exposed in the southeastern corner of the quadrangle. The two isolated blocks of Paleozoic rocks between Gold Valley and the southeastern corner of the quadrangle may also be underlain by segments of thrust fault.

The rocks of the lower plate of the thrust fault are gneiss and metadiorite of Precambrian age and early or middle Tertiary monzonitic rocks. These rocks are only slightly sheared near the fault, and they appear to be unaltered in most places. The monzonitic rocks near the thrust fault are as coarse grained as those farther away.

The rocks of the upper plate of the thrust fault are largely chaotic blocks of dolomite, limestone, quartzite, and shale of Paleozoic age. Several blocks of monzonite among the Paleozoic blocks northeast of Gold Valley either may be part of the upper plate or may be blocks of the lower plate faulted into the upper plate after thrust faulting. Some of the blocks of dark-brown dolomite may be Pahrump series of Precambrian age rather than Paleozoic rocks. A few blocks of the older volcanics of Tertiary age also appear to be included in the upper plate, but they may be material intruded into the chaotic blocks and later broken by normal faulting. The abundant bodies of older volcanics that intrude and truncate the chaotic blocks, the unshattered and unaltered state of some pods of older volcanics among the chaotic blocks, and the unbroken or nonchaotic structure of the older volcanics near the thrust fault support the idea that most of or all the older volcanics are younger than the thrust faulting. The faults that do separate masses of the older volcanics from the surrounding weak tuffaceous bodies are local and probably result from the intrusion of these felsite bodies and later adjustments to regional tilting, rather than from thrust faulting. Thus, it is unlikely that any of the felsite blocks are related to the thrust faulting, just as it is unlikely that some of the felsite blocks are pre-Tertiary.

The chaotic blocks of the upper plate are large and disordered, but are internally coherent. Within the quadrangle they are as long as a mile, and south of the area some are even longer. Only the largest blocks are shown on plate 1, but many more can be mapped at a scale of 1:12,000, as shown on plate 2. Adjacent blocks may be of rock from two widely separated formations. Bedding attitudes also vary widely from block to block. Most of the blocks are internally unshattered, but some blocks of quartzite and dolomite are shattered and healed to their original strength. The blocks commonly are stronger than the gouge between them.

A sheet of breccia and gouge as thick as 7 feet lies along the thrust fault, and similar but thinner sheets separate the blocks from each other. The gouge sheet commonly consists of small angular fragments of the adjacent rocks set in a fine-grained groundmass of limy clayey material. Locally the gouge sheet contains a possible thrust conglomerate which is in the following section.

POSSIBLE THRUST CONGLOMERATE

A gouge sheet separating a flat-lying allochthonous block of Noonday dolomite from underlying schist and gneiss of Precambrian age is well exposed on knob 5172 south of Gold Valley (fig. 4). The sheet commonly is 2–6 feet thick and is grayish red and contains pebbles and cobbles as well as angular fragments. In several places on the east side of the klippe it contains 10–15 percent subangular to subrounded pebbles and cobbles of dolomite, schist, quartzite, quartzite conglomerate resembling the Stirling quartzite of Early Cambrian age, granite gneiss, and altered greenish-gray felsite porphyry, which give the sheet the appearance of an unbedded clastic rock.

The rounded fragments may have been derived from a conglomerate resting unconformably on schist and gneiss at the base of the Noonday dolomite, which later moved slightly over the underlying rock, or the fragments might also have been rounded by movement along the thrust fault. The conglomeratic gouge resembles the "thrust conglomerate" at Sunrise Flat, Nev. (Ferguson and Muller, 1949, p. 27), and abundant other indications of thrust faulting along this horizon suggest that the conglomeratic gouge may have had a similar origin.

DIRECTION AND MAGNITUDE OF MOVEMENT

In the Funeral Peak quadrangle there is no evidence bearing on the direction and magnitude of movement along the thrust fault, but south of the area the relative movement of the upper plate is interpreted to be westward, and the distance of movement, large (Noble, 1941, p. 980). The direction of movement is indicated by an eastern source required by some of the chaotic blocks and by an eastward shingling of some of the blocks near Virgin Spring. The large magnitude of movement, originally inferred by Noble, was based on the widespread distribution (at least 75 miles by 11 miles) of the chaotic blocks. However, there need be no necessary connection between the size of the area of outcrop of the thrust fault and the magnitude of movement along the fault. Furthermore, Noble and Wright (1954, p. 152) reduce the maximum extent of the thrust fault to about 25 miles, and Wright (1955) holds that it is even smaller, for the chaotic blocks east of the Amargosa Valley are not associated with the Amargosa thrust fault. I believe that the chaotic rocks at the mouth of Copper Canyon can also be explained as horses along normal faults; thus, the distance of movement along the thrust fault remains unknown.

AGE OF THRUST FAULTING

The Amargosa thrust fault was active during early to middle Tertiary time. Thrusting followed the intrusion of the monzonitic rocks, for unaltered blocks of Paleozoic rocks are thrust over coarsely crystalline monzonitic rocks. Thrusting preceded the formation of the older volcanics because, locally, older volcanics intrude the thrust fault and upper plate and because in other places they are unconformably overlain by extrusive rocks of the older volcanics.

A few blocks of felsite, resembling the older volcanics, are mixed with the chaotic blocks and appear to contradict the age relations just mentioned. But in most places the included blocks of porphyritic felsite are fresh and little fractured and lie along high-angle faults in the upper plate. Such faults are especially common between the extrusive and intrusive rocks of the older volcanics near remnants of the upper plate of the thrust fault; therefore, most of the felsite blocks included among the chaotic blocks were probably intruded after thrusting and were later displaced along high-angle faults. Other such blocks may be fine-grained apophyses of the monzonitic rocks that intruded the Paleozoic rocks before thrusting or may even be blocks of volcanic rocks older than the bulk of the older volcanics. Regardless of the uncertainties of the relations between a few felsite blocks and the thrusting, the thrusting took place before most of, if not all, the older volcanics were formed. Tertiary volcanic rocks, however, are thrust over older rocks near Beatty, Nev., (Cornwall and Kleinhampl, 1959; Ransome and others, 1910).

ORIGIN OF THE THRUST FAULT

Three basic hypotheses of the origin of the Amargosa thrust fault are presented and illustrated in figure 9. Under the first hypothesis the thrust fault is a strongly bifurcated near-surface feature directed from an area with a thick cover of Paleozoic rocks toward an area from which they had been eroded. Under the second hypothesis this structural feature is a surface thrust or raised block, from the front of which large blocks slid. Under the third hypothesis, slightly favored by me, the thrust fault has a locally derived upper plate that was formed by repeated adjustments of the Black Mountains fault block between two major strike-slip faults. The first two hypotheses require only one phase of regional thrusting; the third requires many phases of local thrusting. Under the first two hypotheses the upper plate may have had roots; under the third the upper plate was rootless and yet was not a gravity thrust plate. Several variations to the

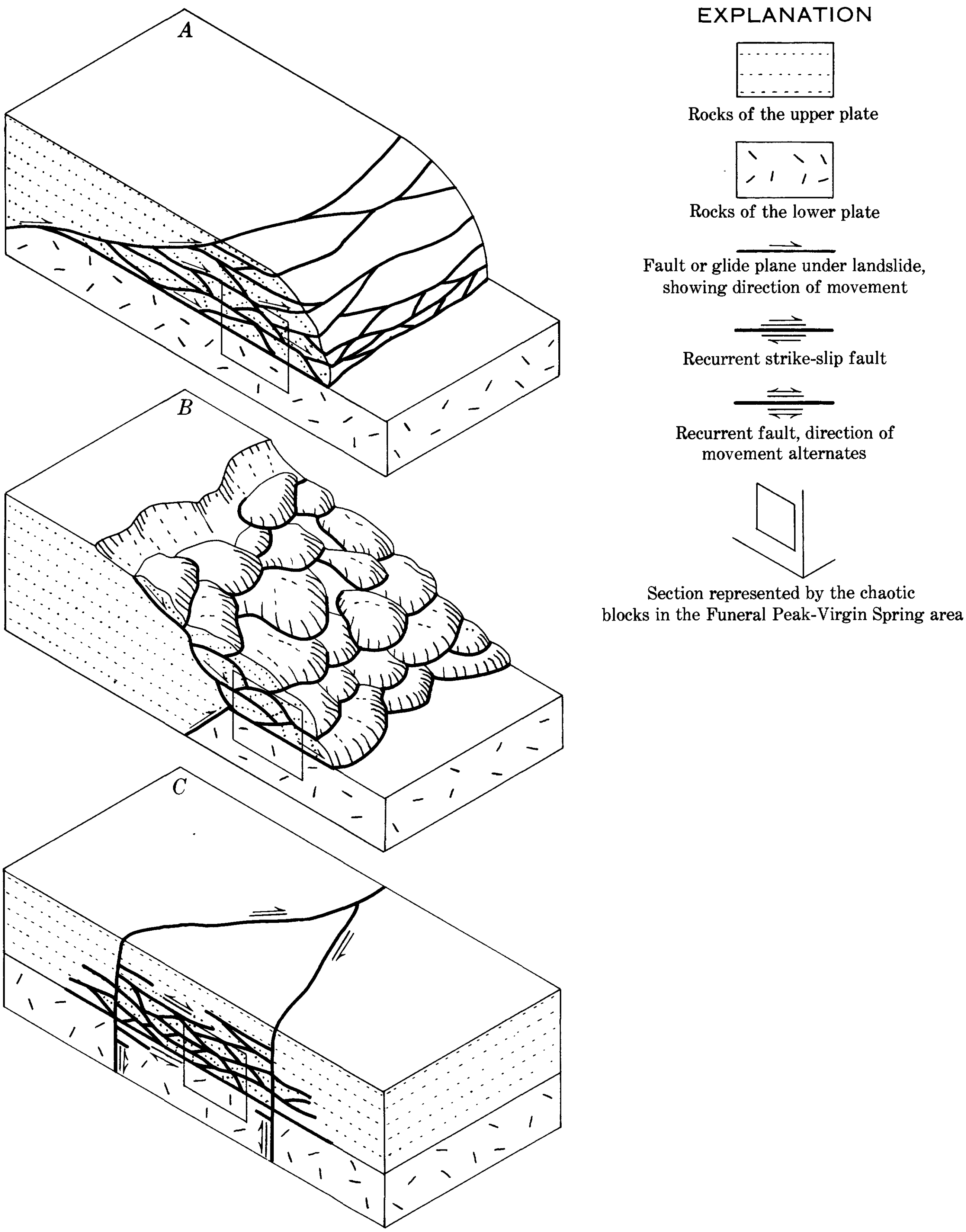


FIGURE 9.—Schematic block diagram showing an early stage of development of the Amargosa thrust fault and the overlying chaotic blocks as explained by three hypotheses: *A*, a near-surface strongly bifurcating thrust fault; *B*, landslide blocks shingled in front of a raised structural block, and *C*, the slightly favored hypothesis of recurrent movement on many thrust planes in a horse lying between major strike-slip faults.

above hypotheses are readily pictured, but none of them explain as many of the field observations, and they all present more questions than these three hypotheses.

The following are important field relations found in the Funeral Peak quadrangle and in the Virgin Spring area to the south (Noble, 1941) that need to be explained: (a) The rocks of the upper plate are broken into chaotic blocks, only a few of which are internally shattered; (b) such blocks are restricted to the Black Mountains fault block, with one exception, mentioned below; (c) the chaotic blocks consist mostly of Ordovician or older rocks; (d) where the blocks form shingled plates, they are in proper stratigraphic sequence, although much of the stratigraphy between them may be missing and the attitudes of beds in adjacent blocks may differ; (e) locally the gouge along the thrust fault contains pebbly material that suggests a thrust conglomerate; (f) adjacent areas contain no roots of thrust faults, and most areas contain a thick sequence of Paleozoic rocks.

Under the first hypothesis (fig. 9*A*) the Paleozoic rocks were eroded from the area of the Black Mountains fault block after the early or middle Tertiary intrusion of the monzonitic rocks but before the thrust faulting. Thrust faulting from an unknown direction outside the Black Mountains area reached the surface in that area. Near the surface the fault broke into many slices between which the Lower Paleozoic rocks were imbricated, and younger rocks remained over older ones in many places, and large parts of many formations were ground away. The Death Valley, Confidence Hills, Furnace Creek, and Shoshone fault zones (fig. 2) appeared later, localized perhaps by the area of thin Paleozoic rocks, and perhaps dropped the root area, so that it may be buried beneath some valley. The formation and the age of the blocks, their stratification, and the possible thrust conglomerate are explained, but the absence of a root area and the restricted areal distribution of the chaotic blocks are accounted for only by later erosion and burial. This hypothesis requires uplift and erosion of the normal stratigraphic column before thrusting, as well as uplift and erosion of part of the upper plate after thrusting.

Under the second hypothesis (fig. 9–*B*) the blocks slid from a high area, perhaps bounded by faults and containing no middle or younger Paleozoic rocks, onto an area underlain by the older Precambrian rocks. The breaking of the blocks, perhaps the imbrication of some of them, and the possible thrust conglomerate are explained, and the problem of a root area disappears. However, undoubted landslides, such as the megabreccia masses of Pliocene and Pleistocene age, consist of shattered unrotated blocks without gouge zones between the blocks, rather than unshattered rotated blocks with gouge zones between the blocks. Furthermore, the source area would probably have to be restricted to the Black Mountains block or Death Valley, because most adjacent areas still contain relatively complete sections of Paleozoic rocks.

Under the third hypothesis (fig. 9–*C*) the thrust fault is a rootless fault that originated through repeated adjustments of the Black Mountains fault block to many movements on the fault zones bordering the block. This rootless thrust fault differs from gravity thrust faults in that the trace of the fault never reached the surface at the time of movement. During movement between the major structural blocks adjacent to it, the Black Mountains fault block shifted up and down as a horse in a fault zone and ended in a structural position considerably above that of the adjacent blocks. Internal adjustments in the Black Mountains block included shearing between flat-lying Paleozoic units of greatly different competence. After repeated shifting, some of these sheets broke into blocks and were partly ground into gouge. The displacement of the blocks from their original position need not have been large, but the total movement back and forth may have been considerable. The Black Mountains block was raised before the formation of the older volcanics and the upper and middle Paleozoic rocks were eroded. This hypothesis may explain the breaking of the rocks into large blocks, and their stratigraphic imbrication in the Virgin Spring area. It explains the restriction of the chaotic blocks to the Black Mountains fault block, and it eliminates the root problem; however, it does not explain the possible thrust conglomerate. It also does not explain how the gouge was removed, but neither of the other basic hypotheses adequately explains how the missing rocks were removed.

Noble and Wright (1954, p. 152) attribute the origin the Amargosa thrust fault to squeezing and arching of the Black Mountains block, or wedge; this action probably produced landslides off the crests of the arches or possibly produced bedding-plane rupture along the limbs of the arches. This explanation is relatively unsatisfactory in the Funeral Peak quadrangle because the thrust fault is flat-lying or only gently arched. Furthermore, the arching of the Precambrian rocks is probably of Precambrian age, and the younger folds are few and small. Finally, thrusting produced by arching either involves movement along bedding planes that probably was too little to remove so much of the stratigraphic section or involves larger movements along surface faults that should bring older rocks from the crests over younger rocks on the flanks of the folds.

Sears (1953, p. 183–186) suggested a variation of the landsliding hypothesis. He pictured the rising monzonitic magma as forcing up a large dome off which the sedimentary rocks slid to form the chaotic structures. However, field evidence shows that the injection of the monzonite was passive rather than forceful and that it occurred before the development of the chaotic structure, for monzonite blocks occur within the chaotic structure. Furthermore, the chaotic blocks are not restricted to the flanks of a monzonite-cored dome, but in places lie on coarse-grained monzonite.

Bucher (1956, p. 1310–1311) presented another variation of the landsliding hypothesis. He suggested that the plates of sedimentary rocks slid down a slope lubricated by the eruption of hot fluids pent up at their base. But he did not propose an origin for the slope or a means of building up the local pressure of the fluids, or an explanation for the lack of direct signs of such fluids; and yet the idea has a certain appeal.

Kupfer (1960, p. 210–213) described a chaotic structure in the Silurian Hills about 20 miles southeast of the southern end of the Black Mountains block and near the Soda-Avawatz strike-slip fault zone; this chaotic structure resembles closely that which is farther north. He showed that the chaotic structure in the Silurian Hills cannot be of landslide origin because it underlies the main thrust fault.

The brief review of some of the ideas presented by Sears and Bucher and some of the observations by Kupfer leave me with two thoughts. First, proof for the landslide hypothesis is more remote than ever. Second, the idea of a connection between igneous activity and local tectonism is very provocative; Pakiser (1960, p. 153–159) illustrated how tension between strike-slip faults may localize volcanism in Owens Valley, Calif. The more abundant volcanism in the Black Mountains block than in most adjacent areas is also compatible with the regional setting of recurrently and complexly moving strike-slip faults. But rather than accepting that volcanism caused the chaotic structures, I would suggest that movement along strike-slip faults localized both the volcanism and the local chaotic structures.

BLACK MOUNTAINS FAULT SYSTEM

GENERAL DESCRIPTION

The Black Mountains fault system lies at the foot of the west flank of the Black Mountains for 40–65 miles and comprises many longer faults that trend north-northwest and that are connected by shorter faults that trend northeast. The faults dip moderately to steeply westward and have large normal displacement. Quaternary movement on the fault system is much larger than on most range-front faults in the Basin and Range area. The fault system is also better exposed than most range-front faults; about 10 percent of the fault system in the quadrangle is exposed, and the remainder is only thinly veneered by gravel or is marked by young fault scarps.

Three or four north-northwest-trending faults lie at the bases of the steeper scarps in the quadrangle. The southern fault, west of Smith Mountain, is about 10 miles long and probably extends many miles beneath the surficial deposits in Death Valley north of Mormon Point, for it shows no signs of dying out at Mormon Point, and it would be a rare fault that makes an abrupt turn with far greater displacement along one limb of the turn than along the other. The central fault is exposed for about 10 miles between the mouth of Sheep Canyon and the Badwater area and also probably extends beneath the surficial deposits in Death Valley. This fault consists of two parts that are separated by a narrow wedge of chaotic blocks near the mouth of Coffin Canyon. The northern fault is exposed for about 4 miles, less than half of it within the quadrangle. Other faults, such as the Artists Drive fault to the north and the fault at Ashford Mill to the south (Noble and Wright, 1954, pl. 7), probably also belong to the north-northwest-trending faults of this system. Two northeast-trending faults link the other faults. The southern of the connecting faults is 2–3 miles long and lies northeast of Mormon Point. The northern connecting fault is scarcely a mile long and lies a few hundred feet southeast of Badwater.

The faults of both sets commonly consist of a gouge zone, or of one or two discrete fault planes. The gouge zones, best exemplified between the fans north of the mouth of Copper Canyon, are at least 50 feet wide. Rocks of the footwall are sheared for hundreds of feet near the fault (fig. 10). The intensity of the shearing increases gradually toward the fault and increases abruptly near the gouge zone. Most of the gouge consists of finely granular fragments of rock similar to that in the footwall. The matrix of these fragments is too fine to be identified, but probably most of it also is crushed from the footwall. Near the floor of Death Valley and in some places as high as a few hundred feet above the floor, the matrix contains calcium carbonate and some sodium chloride. Rocks of the hanging wall are exposed only along branch faults, generally faults with comparatively little displacement, and there they are similar to the rocks of

FIGURE 10.—Rocks along the Black Mountains fault system. Pleistocene gravels, Qgi(?), are faulted (dotted line) against intrusive rhyolite and rhyodacite Ti, and tuffs, Tv, of the older volcanics. These volcanic rocks intrude and are faulted against metasedimentary rocks, pЄs, in the center of the picture. View northwestward from an altitude of 2,160 feet on the south wall of Natural Bridge Canyon, 2 miles north of the quadrangle. Summit to the right of the symbol Tv is knob, altitude 3,735 feet, Furnace Creek quadrangle.

the footwall. Two separate fault planes follow the foot of the mountain south of Mormon Point. Thinner gouge zones are present here, but otherwise the fault resembles those marked by a broad gouge zone. The southern ends of these north-northwest-trending faults have many branches. The northeast-trending fault at Mormon Point also consists of several separate fault planes.

Abundant faults branching from the central fault break a large wedge of rock near the mouth of Coffin Canyon into steeply inclined blocks a few hundred feet to a few thousand feet long. The wedge parallels the Black Mountains fault system for about 2 miles; it is one-third of a mile wide and its apex points northward. Most of the blocks consist of metadiorite similar to the rocks east of the wedge, but a few blocks consist of monzonite, porphyritic andesite or basalt, brown dolomite, and smaller unmapped blocks of the older volcanics. The brown dolomite possibly is of the Pahrump series of younger Precambrian age, or is of Paleozoic age. The andesite or basalt, which is badly altered, resembles the basalt at Mushroom Rock, about 11 miles north of Badwater, or some of the dark-red porphyritic felsite of the older volcanics east of Gold Valley. The monzonite resembles that exposed 3 miles to the northeast.

The blocks in the wedge were correlated by Noble and Wright (1954, pl. 7) with the chaotic blocks overlying the Amargosa thrust fault. However, the blocks are here considered as part of the fault zone of the Black Mountains fault system because they roughly parallel the local faults of that system and because within the wedge there are no flat-lying faults similar to that underlying other chaotic blocks.

Dips on the faults of the Black Mountains fault system are moderate to steep and westward. Dips on the more conspicuous shear planes in the gouge zones and on the discrete faults of the north-northwest-trending set are commonly 40°–55°, but they increase to as much as 75° southwest of Badwater, near Mormon Point, and at the wedge of chaotic blocks. Isolated planes 500–1,000 feet above the traces of the faults also commonly dip moderately to steeply westward (fig. 10). Dips of the northeast-trending faults at Mormon Point are obscured by slumping on the scarp.

FAULT SCARPS AND FACETS

The alinement and abruptness of the west flank of the Black Mountains and the triangular facets are typical of a large fault scarp. In fact, the facets suggest a compound fault scarp (fig. 11) with two groups of facets: a lower, steeper less dissected group of facets, and an upper, less steep and more dissected group of facets. Straight segments of some ridge crests above the facets illustrated by the topographic map may be remnants of additional extremely dissected facets.

The lower group of facets, in plane bcmn on figure 11*A*, lies along the lowest 200 feet of the fault scarp. These facets have an average slope of 40°–45° toward the valley and are trapezoidal. They are cut in metamorphic rocks, gouge, chaotic blocks at the mouth of Coffin Canyon, and gravels. The patches of gravel hanging above the floor of Death Valley lie at the top of this group of facets; this gravel is younger than any rocks cut by the upper facets.

The upper group of facets, in plane abno on figure 11*A*, rise from the tops of the lower group to altitudes of 1,400–2,200 feet (fig. 12). They are conspicuously triangular. The upper facets are cut on metamorphic rocks, conglomerate, and chaotic blocks at the mouth of Coffin Canyon. The local relief on the triangular facets is greater than on the trapezoidal facets. The upper facets slope 35°–40°, or about 15° less than the general dips of the faults and about 30° less than the steep dips on them. Similar values of the angular difference between slopes of frontal faults and slopes of associated triangular facets are reported elsewhere in the Basin and Range area by Gilluly (1928, p. 1113–1116).

The profiles of several spurs (fig. 12) have straight segments in plane aepo on figure 11*A*, sloping 20°–30° for 1,000–2,000 feet above the triangular facets. Above the straight segments the ridge crests flatten out and are more serate. These straight ridge segments may reflect a higher facet, much as alined horizontal ridge crests suggest, but do not prove, remnants of a peneplane. Such ridge segments are reasonable transition features between partly dissected facets and completely dissected hills.

The fault scarp, having two groups of facets and with possible remnants of another group, was probably formed by a combination of erosion from the same fault surface along which movement was recurrent and tilting of the block and the older facets. Eastward tilting of the Black Mountains fault block since deposition of the Funeral formation may be as much as 5°. The development of these facets by erosion alone is illustrated in figure 11*B–F* in which the initial ideal slope, a–b decreases to a_1–b. A renewed uplift of vertical displacement, h, produces the initial ideal slope bc, on which b is a point on the line separating the upper and lower facets. In addition to a decrease in the slope of the facet with time, the transition line between facets retreats from the upward projection of the fault plane, abc, toward the center of the uplifted block b_1. The facet transition line rises slightly with time, so that the height of the lower facet grows, h, h_1, h_2, at the expense of the upper one, because the rate of erosion of the lower, steeper facet is greater than that of the upper, gentler facet. Through time the migrating line describes a sloping plane surface, or perhaps a gently warped surface, convex upward on which b–b_1–b_2 lie.

DISPLACEMENT ALONG FAULT

The hanging wall of the Black Mountains fault system moved downward probably several times, with a total displacement in the order of many thousands of feet to a few miles. The interpretations of the fault movement are based solely on topographic evidence along the west flank of the Black Mountains, for nowhere in the area is the main part of the hanging wall exposed, and where it is exposed outside the area, stratigraphic control is poor. Topographic evidence for fault movement is not completely satisfactory and provides only estimates of the throw.

A large total vertical displacement is indicated along the Black Mountains fault system by the high relief along the west flank of the mountains. The prominent triangular facets are about 2,000 feet high, and the higher ridges only 2 miles from the valley lie about 5,000 feet above Death Valley. A probable minimum vertical displacement is in the order of 4,000 feet. The depth of surficial deposits burying the hanging wall of the fault system is the chief unknown factor needed to estimate the maximum vertical displacement. Gravity studies by Mabey (1959, and written communication) indicate a depth of fill of Cenozoic rock, in the center of Death Valley, of several thousand

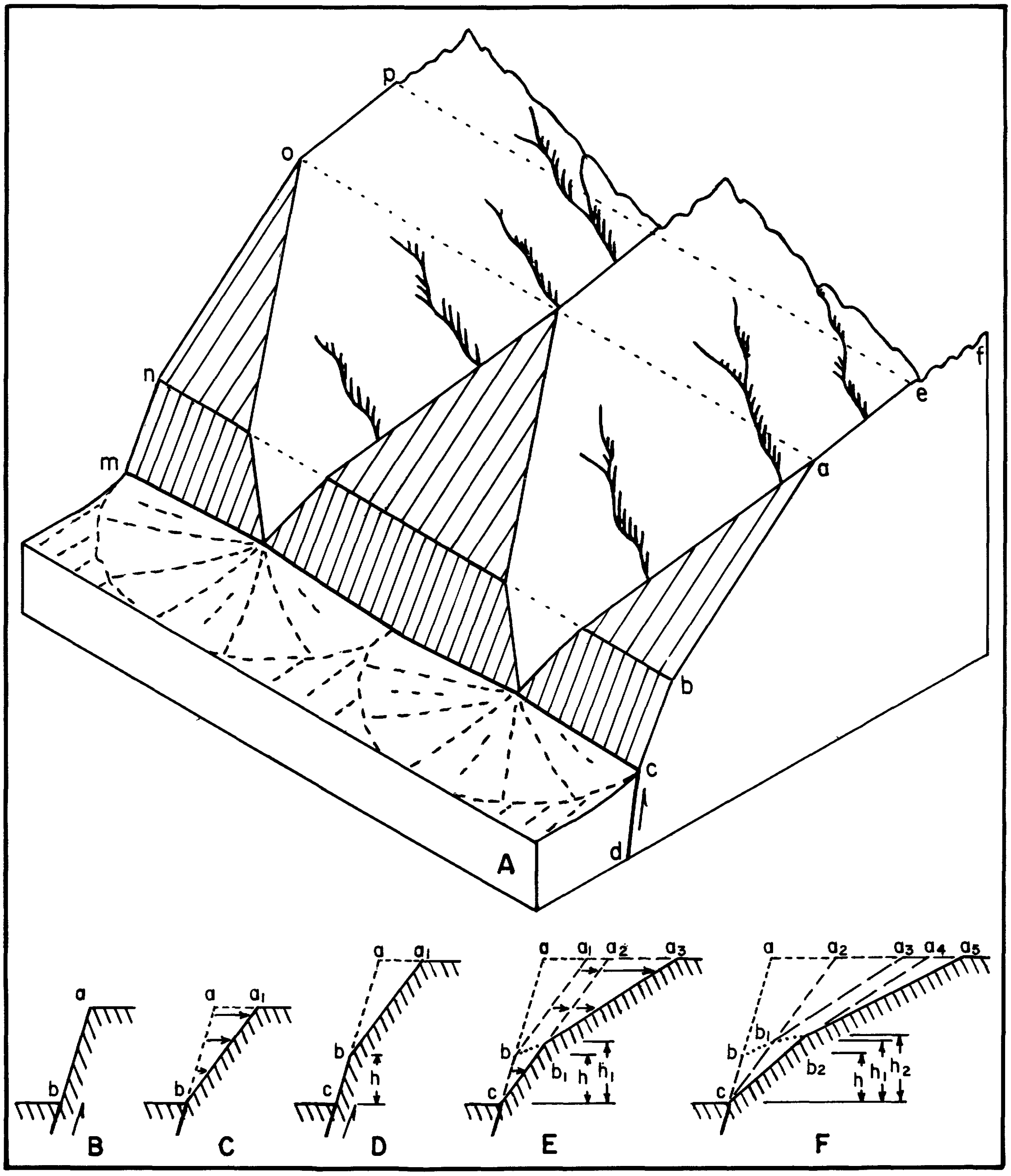


FIGURE 11.—Facets along the west flank of the Black Mountains. *A*, Block diagram schematically showing fault dcm and two sets of facets, lying on planes bcmn and on abno, and possible remaining straight ridge-crest elements of a third set lying on plane aepo. *B–F*, Profiles showing the development of two sets of facets.

FIGURE 12.—Fault scarp on the east side of Death Valley. View is northward from near the top of the prominent triangular facet north of Coffin Canyon, altitude 1,400 feet. Tops of similar facets are at *A*, altitude 1,600 feet, and at *B*, 1 mile south of Badwater, altitude 2,200 feet.

feet, perhaps even 5,000–7,000 feet. However, the thickness of surficial deposits along the east side of Death Valley in this area is unknown. It seems likely that the thickest fill lies near the east side of this part of the valley because the salt pan is tilted eastward and, in places, abuts directly against the foot of the Black Mountains. The thickness of the deposits in the Copper Canyon basin (about 12,000 feet) gives an idea of the thickness of the fill in one small structural basin in this area. The fill in Death Valley adjacent to this part of the Black Mountains may reasonably be 10,000–15,000 feet thick. Even if only half this thickness is accepted and added to the 4,000 feet of relief of the adjacent mountains that probably is due to faulting and even neglecting the loss in scarp height by erosion of the top of the scarp, the maximum total vertical displacement would be 2 miles.

The en echelon arrangement of the faults of the Black Mountains fault system suggests some strike-slip displacements in this area. The occurrence of wide gouge zones along the north-northwest faults implies northeast compression, and the northeast-trending swarm of Tertiary dikes implies northwest tension. Together these features suggest that the Black Mountains block moved south with respect to the next block west. The amount of this displacement is unknown.

The minimum displacement of 4,000 feet is a cumulative displacement value of at least six movements. The fault scarp within the quadrangle has different heights in the various crystalline rock, fanglomerate, and gravels of the footwall, which are probably reliable indicators of the vertical displacements between the times these rocks were deposited. Differential weathering of the surfaces of the rocks is small compared to the scarp heights. For example, beach terraces cut on gravels just above the scarp in late(?) Pleistocene time are well preserved; so it is unlikely that the height of the scarps below the terraces was decreased much by erosion. The scarp in the crystalline rocks is about 4,000 feet high; that cutting the fanglomerate member of the Copper Canyon formation is about 1,500 feet high; that cutting the older Pleistocene gravel near Mormon Point is about 200 feet high; that cutting the younger Pleistocene or Recent gravel is about 50 feet high; and those cutting all but the youngest gravel are less than 5 feet high. The minimum throw along the fault system was, successively, 2,500, 1,300, 150, 45, and about 5 feet. The oldest of these displacements has three stages, some of which may involve faults other

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than the Black Mountains fault system. The first stage raised the blocks from which the turtleback surfaces were eroded, if the hypothesis proposed for the origin of the surfaces and described in the next section is accepted. The second stage raised the block from which the gravels of the Copper Canyon formation were shed. The third stage raised the blocks from which the gravels and landslide mass of the Funeral formation were shed.

Major movement of the fault system probably was accompanied by minor eastward tilting of the Black Mountains fault block. Eastward tilting is suggested by the asymmetrical profile across the block and by the attitudes of the rocks within the block. The profile across the block has a long eastern segment of mature topography, on the whole sloping gently eastward, and a short western segment of young topography sloping more steeply westward. The southeastward tilting of many of the small blocks of older volcanics is a local tilting, but the gentle eastward tilting of large patches of the relatively unfaulted andesite and basalt member of the Funeral conglomerate is more regional.

AGES AND RATES OF FAULTING

The movements along the Black Mountains fault system are middle or late Tertiary to Recent; in part they postdate the older volcanics but possibly some of the earliest movements are as old as the unconformity beneath these volcanic rocks. The oldest movement, that with the three stages that have a combined minimum throw of 2,500 feet, is Miocene(?) to early Pliocene; it postdates the older volcanics and predates the Copper Canyon formation. Possibly the other two stages of the oldest movement also involved Black Mountains fault system; these movements are Pliocene(?) and Pleistocene. The second movement is early(?) or middle Pleistocene, for it postdates conglomerate of the Funeral formation and predates the gravels of Lake Manly. The third movement is middle(?) Pleistocene; it postdates the second movement and predates the gravels of Lake Manly. The fourth movement is late(?) Pleistocene; it postdates the gravels of Lake Manly and predates the adjacent poorly indurated gravels. The fifth movement is late Pleistocene or Recent, for it postdates the poorly indurated gravels and predates the Recent gravels. The sixth and youngest movement is Recent, and offsets all but the youngest of the gravel included with the surficial deposits.

The rate of vertical displacement along the Black Mountains fault system has been increasing since middle Miocene(?) time. Crude minimum average rates of throw can be estimated from the minimum displacements of the crudely dated rocks. These rates, expressed in feet per million years, are:

100 since middle Miocene
250 since middle Pliocene
400 since middle Pleistocene
750 since latest Pleistocene

Although these average rates are too crude to be very significant in themselves, the change in the rates is uniform. Not only has the Black Mountains fault block been active during much of Cenozoic time, but its activity has been increasing since middle Miocene(?) time. This conclusion is not particularly startling, for the fault scarps in the region are among the largest and youngest in the Basin and Range province; but it supports the observation made in the section as master faults, that this region has had much uplift in comparatively recent times.

TURTLEBACK FAULTS

Turtleback faults are flat-lying faults that separate Tertiary and Quaternary rocks from Precambrian rocks along the west flank of the Black Mountains. The Copper Canyon and Mormon Point turtleback faults fall within the area, but the Badwater turtleback fault lies just north of the area. The faults are described only briefly here, for they have already been described elsewhere. They have been variously interpreted as one thrust fault (Curry, 1938b, p. 1875; 1954, p. 53–59) or as separate normal faults (Drewes, 1957, p. 1823; 1959, p. 1497–1508) in connection with the turtleback problem.

The faults are broadly arched surfaces whose axes plunge 20°–30° northwestward, generally over a footwall of Precambrian rocks. A gouge sheet a few inches to a few feet thick, containing fragments of the adjacent walls, follows the faults. The footwalls commonly consist of folded metasedimentary rocks and massive metadiorite, but probable northward extensions of the Copper Canyon turtleback fault have a footwall of monzonitic rock. Possibly the red felsite body in the northern part of the Copper Canyon area is also in the footwall of the turtleback fault.

The rocks of the hanging wall consist of Copper Canyon formation, Funeral formation, and the older Pleistocene gravels at Mormon Point. They are truncated by the Black Mountains fault system to the west and north and by a northeast-trending fault along lower Coffin Canyon. The rocks of the hanging wall are broken by many small unmapped faults and a few moderately large mapped ones. The rocks of the hanging wall of the Copper Canyon turtleback fault are also folded into a syncline that plunges southeastward into a northwest-plunging trough in the fault surface (Drewes, 1959, fig. 2).

The rocks of the hanging walls moved northwestward toward Death Valley and down possibly in the order of a few thousand feet during late Pliocene or Pleistocene time. Movement was mostly down the crests of the arches and troughs of the fault surfaces, although some movement may have been more westerly. The Copper Canyon turtleback fault was active after the deposition of the Funeral conglomerate and before the time of the 1,200-foot displacement on the Black Mountains fault system. The Mormon Point turtleback fault was active after the older Pleistocene gravels were deposited and before the gravels of Lake Manly were deposited.

OTHER FAULTS

Normal faults of Tertiary and younger age that are not part of the Black Mountains fault system or the turtleback faults are most abundant near Dantes View, south and east of Greenwater Canyon, and northeast of Gold Valley. Elsewhere many faults probably were overlooked because in areas other than these three, fewer stratigraphic horizons are mapped. The displacement of most of the faults is small and the movement simple.

The chief faults near Dantes View are four long northeast-trending ones that abut into the Black Mountains fault system toward the southwest and feather out toward the northeast. Other faults, trending west to west-northwest, connect the four long ones and join the northern branch of the Copper Canyon turtleback fault. The faults are vertical or very steep, and the southern blocks generally are dropped. The stratigraphic displacement on the fault south of Dantes View is about 1,800 feet and that on the fault along lower Coffin Canyon is about 1,000 feet. Movement on all these faults is probably associated with major movement along the Black Mountains fault system, but evidence of recurrent movement and of movement synchronous with a particular phase of movement along the Black Mountains fault system is lacking. The movement on the lower Coffin Canyon fault postdates the movement along the turtleback fault, and movement on several of the faults postdates the Greenwater volcanics.

The faults south and east of Greenwater Canyon trend eastward or northeastward. The faults to the south separate large blocks of older volcanics tilted in various directions, and offset rocks as young as the Funeral formation. The faults to the east offset rocks as young as the andesite and basalt member of the Funeral formation and have throws of 40–200 feet, southeast side down. The fault between the four small patches of basalt near knob 4507 was active before and after the extrusion of the basalt, for the Greenwater volcanics are offset more than the overlying basalt.

The group of faults northeast of Gold Valley have little systematic pattern, and most of them can be followed only a short distance. Many of the faults separate felsite intrusive bodies from extrusive rocks. The rocks in the narrow fault wedge west of Funeral Peak are thoroughly shattered, suggesting that the adjacent faults are more extensive than recognized. The chaotic blocks of Paleozoic rocks 2 miles east of Gold Valley lie in a northeast-trending horst (pl. 2). Rocks as young as Funeral formation are faulted down against the south side of the horst. A large, isolated fault south of Gold Valley truncates a block of Cambrian Noonday dolomite and has a throw of at least 400 feet.

QUATERNARY(?) FOLDS

Gentle flexures deform rocks as young as the Funeral formation southeast of the Gold Valley, east of Greenwater Canyon, and in the Copper Canyon area. The andesite and basalt member of the Funeral formation southeast of Gold Valley is warped into three parallel synclines and two intervening anticlines. The axes of these folds trend generally northeastward and are gently concave to the northwest. Other very gentle flexures lie southeast of these folds, but the steep dips on the base of the basalt north of knob 4465 are largely initial dips on the lava flows. East of Greenwater Canyon there are three small flexures, and more warps on the base of the basalt, which probably are abrupt changes in direction of initial dip of the flows. The rocks of the hanging wall of the Copper Canyon turtleback fault are folded into a southeastward-plunging syncline whose axis dips more steeply than its limbs (pl. 1).

Folding of rocks as young as the Funeral formation is more intense elsewhere on the Black Mountains block. At the canyon a few miles north of the quadrangle, through which the road between Dantes View and Furnace Creek Ranch runs, the andesite and basalt member of the Funeral formation is folded into a tight syncline with a nearly vertical southwest limb. The Furnace Creek formation is also tightly folded in this area. Clearly, some of the rocks of the Black Mountains block were much compressed in comparatively recent times.

ECONOMIC DEPOSITS

Rock and mineral deposits of potential economic value are few, and at present they are not attracting many prospectors. No deposits were mined in the quadrangle during 1956–58, but assessment work was done on several prospects. During 1906 and 1907, however, about 1,500 people were working in the copper prospects at Greenwater and Furnace and at Kunze, located about halfway between the other two. Besides copper, claims were also made for gold, lead, and silver. Barite and gypsum occur in small quantities, and pumicite and perlite are plentiful.

COPPER AND BARITE

The boom for copper prospecting and speculating in the Greenwater mining district was as colorful as it was brief. Production was "slight" (Graton, 1908, p. 601), and apparently limited to the one shipment of ore made in 1907 (Aubury, 1908, p. 320). The deposits were not assayed then, and since the shafts were inaccessible in 1956, the scanty modern information comes from dumps and small prospects.

The copper and barite mineralization occurs in a zone trending from the east side of Greenwater Valley 3 miles northeast of the southeast corner of the quadrangle, northwestward about 20 miles to the vicinity of Dantes View (fig. 13). A smaller, parallel zone lies northeast of Gold Valley, and scattered traces of copper minerals are found west and south of Gold Valley.

Copper minerals are chiefly an unidentified group of blue-green copper silicates and carbonates. Copper sulfides are rare, much rarer in the prospects than in the optimistic accounts of the locally published news-

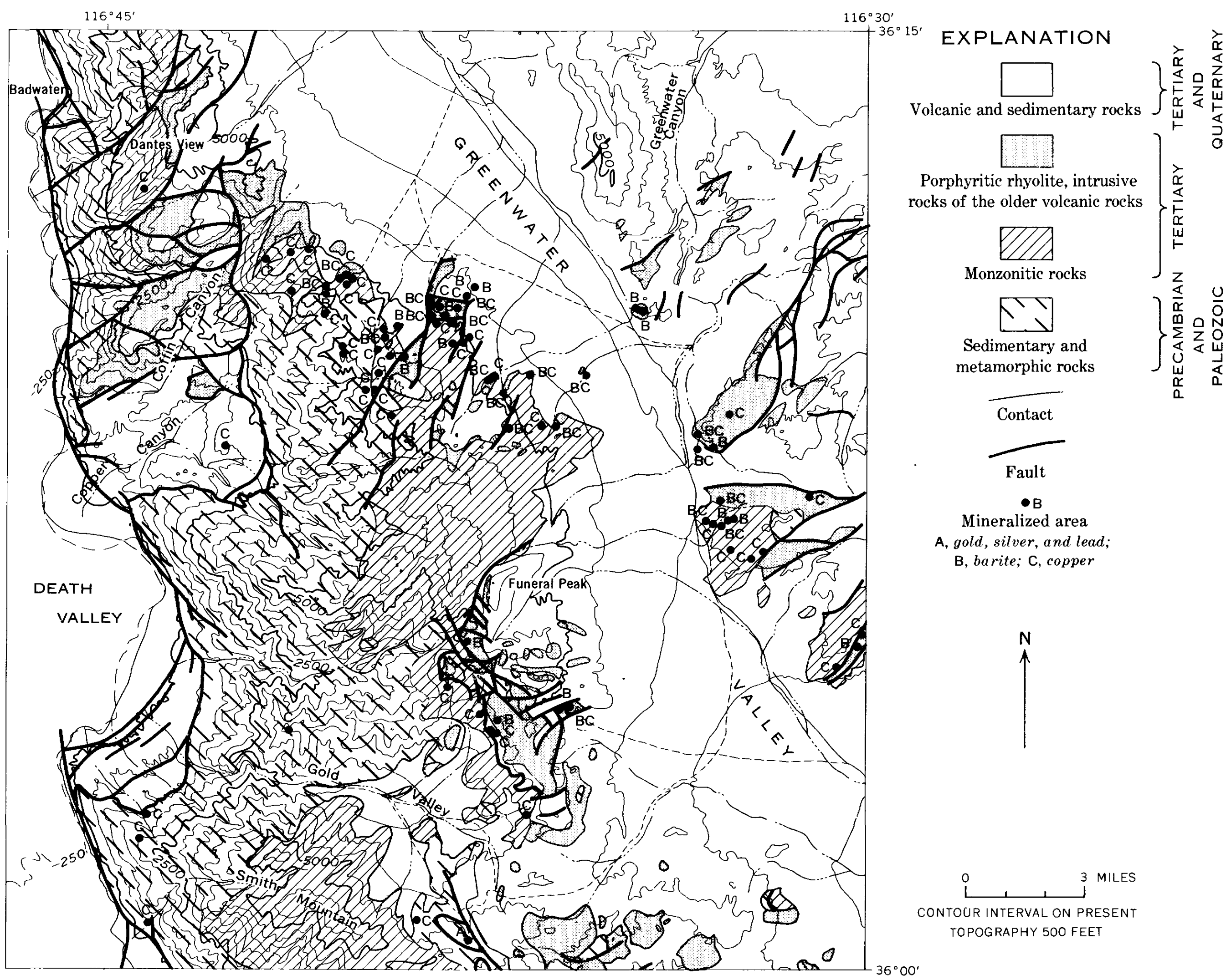


FIGURE 13.—Mineralized areas with copper, barite, gold, silver, and lead, and their relations to porphyritic rhyolitic intrusive rocks, monzonitic rocks, and faults.

paper, the long defunct Greenwater Chuckwalla. Chalcopyrite occurs in one prospect in Gold Valley, and covellite occurs in another 1 mile southwest of Furnace. Secondary copper minerals commonly appear with barite and quartz, and in some places also with hematite, other iron oxides, and calcite. Copper minerals are later than quartz in the few rocks that give any relation between minerals.

The minerals fill small open veins and tight fractures, and in a few places they are part of the matrix of fault breccia. The longest vein or system of viens is about half a mile long. Two-thirds of the richer veins of the Furnace and Greenwater area trend N. 30°–65° E. and dip steeply; the other veins trend N. 30°–70° W. and also dip steeply. The veins that strike northeast parallel the largest fault system in the area; a poorly developed group of faults also trends northwestward. Many of the deposits lie on or near these faults.

The main mineralized zone lies on the northeast flank of the largest high anomaly in the Black Mountains shown on an uncompensated gravity map by D. R. Mabey (written communication). The crest of this gravity anomaly trends southwest through a point 1 mile south of Badwater. Gravity data extend only about 6 miles from this point, so that further gravity mapping is needed to confirm the correlation.

It is possible that a larger, unexposed mineralized body might be located by further geophysical studies or geochemical prospecting. Three relations seem significant: (a) most mineralized rocks are rhyolitic intrusive rocks near their contact with monzonitic rocks, or are in the monzonitic rocks near the volcanic rocks. (b) all the copper minerals in the volcanic rocks, and probably including those from the shafts that reach depths of 300–500 feet, are secondary; (c) the only copper sufides occur in monzonite or in older rocks near monzonite. The best explanation of these relations is that the primary copper is disseminated in the monzonite. After this mineralization copper was moved upward and deposited as silicates and carbonates in the rhyolitic rocks during or after their intrusion. Faults, which may also have localized the rhyolitic intrusive bodies and volcanic vents, broke the earlier intrusive bodies and were channels for relatively early silica-bearing fluids and relatively late copper-bearing and barium-bearing fluids. Local faults, breccia zones, and fracture zones are the immediate controls of mineralization. According to this explanation the primary mineralization is associated with the monzonitic rocks of early to middle Tertiary age, and the secondary mineralization is younger than these rocks, perhaps with particularly abundant movement during Miocene or earlier Tertiary time when the rhyolitic rocks intruded the monzonitic rocks.

Two alternate explanations may be visualized from the available evidence: first, in the situation just described primary mineralization emplaced copper sulfides in the top of the monzonite stock, that part largely eroded away during early Tertiary time. During this erosion the copper minerals were altered and, in part, transported downward, always remaining a step ahead of complete removal by erosion. Second, the mineralization may be entirely contemporaneous with, or slightly older than the intrusion of the other volcanics. Some of the host rocks were mineralized near the intrusions, and sulfide deposition and preservation were favored by the composition or greater depth of the monzonite and metadiorite.

The potential economic implications of the first explanation are great, for they suggest a porphyry copper deposit. They may be sufficiently great to justify the cost of a further preliminary geochemical investigation to determine the extent of the association of copper with the monzonite or with the rhyolitic intrusive rocks, and geophysical prospecting to extend the gravity anomaly and to determine the depth of fill over monzonitic rocks in Greenwater Valley.

GOLD, SILVER, AND LEAD

Aubury (1908, p. 316) reports the occurrence of gold, silver, and lead from the Gold Valley area "6 miles west of Willow Creek." Presumably this is the prospect in the large block of Noonday dolomite of Early Cambrian age, and possibly some Johnnie formation just south of Gold Valley. According to Aubury the ore contains cerussite, galena, free gold, and some copper minerals. Two shipments of presumably handpicked, high-graded ore were made. In spite of the glowing account of the values shown by these shipments, no other production is recorded from this deposit.

The material on the dumps at these prospects is largely or wholly iron oxides, probable manganese oxides, and much-brecciated, altered dolomite and shaly dolomite. No assays were made. It is highly probable that the continuity of the deposit is interrupted by the abundant small faults within the carbonate block and by the major thrust fault probably 150–200 feet below the prospect.

OTHER DEPOSITS

Prospects for borates in the northeastern corner of the quadrangle near the Lila C mine apparently did not find any. The zone of rocks of the Furnace Creek formation that contains borates does not extend laterally into the Funeral Peak quadrangle, and most likely it ends because of stratigraphic changes rather than structural reasons. A little cottonball ulexite occurs in the clay and silt sheets veneering the siltstone and evaporite member of the Copper Canyon formation, but no borates were found in the unweathered rocks.

Thin gypsum beds and veinlets occur in the siltstone and shale of both the Copper Canyon formation and the Furnace Creek formation.

Pumicite may be sufficiently pure and abundant to have potential economic value. Tuffaceous pumicite and pumiceous tuffs are abundant in parts of the Greenwater volcanics and the Funeral formation. The purest pumicite is part of the tuff-breccia member of the Greenwater volcanics and lies on both sides of Greenwater Canyon east of peak 5107 and 2 miles from the northern edge of the quadrangle. A pumicite bed or tongue 2,000 feet east of the canyon is about 40 feet thick. About 99 percent of the rock is pumice in fragments ranging in size from sand to cobbles 18 inches in diameter. Most foreign fragments are tuff and rhyolite vitrophyre pebbles and cobbles, and a few are metamorphic rocks. The extent of this pumicite bed is unknown; however, rapid changes in lithology of beds may be expected. Another group of fairly pure pumicite beds lies about 1,500 feet west of Greenwater Canyon opposite the first pumicite deposit. The best exposures are at an altitude of 3,400 feet on the south side of a small canyon tributary to Greenwater Canyon. These exposures are of massive to coarsely cross-bedded well-sorted pumicite about 50 feet thick and appear to be dune deposits. Again, the extent of the beds is unknown, but probably is not large, for dune deposits are scarce in this formation.

Some of the glassy rhyolitic rocks may contain sufficient water to make commercial perlite that is suitable for light-weight concrete aggregate. The vitrophyric rocks of the Greenwater volcanics along lower Greenwater Canyon and along the eastern edge of the quadrangle may be the most abundant and accessible of the glassy rocks likely to be suitable.

GEOLOGIC HISTORY

The geologic history of the Funeral Peak quadrangle and that part of the geologic history of the Black Mountains fault block clarified by events within the quadrangle are summarized in this section and in figure 14. The well-supported conclusions are not separated from the very tentative ones, and where alternate hypotheses have been presented before, only the favored one is included here. The observations, inferences, and qualifications supporting the geologic history presented in this dogmatic manner appear in the preceding sections.

The geologic history of the area begins with the metamorphism of sedimentary rocks to schist, gneiss, and marble in early Precambrian time, about 1,700 million years ago. The rocks were recrystallized to the greenschist metamorphic facies after they were metamorphosed under slightly higher temperature and pressure than required to reach that state. The metasedimentary rocks were arched into broad, gently northwestward-plunging folds in Precambrian time and before or during their intrusion by a large body of diabase or similar rock. Most of the intrusive body was altered to the present metadiorite, and the rocks were uplifted and deeply eroded.

Sediments of the Pahrump series were deposited during late Precambrian time in a deep basin. Most of the rocks of this series are preserved in an area elongated northwestward and lying chiefly south of the Funeral Peak quadrangle. These rocks were only very slightly metamorphosed, and they were also uplifted and eroded. The sea invaded this part of the Basin and Range province in very late Precambrian time or very early Paleozoic time. A sequence of clastic and carbonate rocks about 4 miles thick was deposited almost without interruption from pre-Ollenelus time to Permian time throughout much of the province. Details of this episode are obtained only from outside the Black Mountains fault block. Late during the Paleozoic era and during the Mesozoic era, the rocks of many of the surrounding areas were severely disturbed by orogenic forces that produced numerous thrust faults and injected stocks and batholiths of granitic rocks. Most likely the Black Mountains block was also affected by some of these orogenic forces, but the record is blank until early Tertiary time.

In early Tertiary time (fig. 14*A*) about 30–45 million years ago, monzonitic magma gently invaded a large part of the Black Mountains block. The magma chambers were elongated northwestward, probably reflecting control by Precambrian structural features. Late magmatic fluids altered the monzonitic rocks a little and may have disseminated copper sulfides in part of one stock.

Either during or shortly after this time, major northwest-trending, strike-slip faults of the region shifted, and the Black Mountains fault block, caught between two such faults with right lateral displacement, was compressed, internally jostled, and uplifted (fig. 14*B*). The Amargosa thrust fault was formed as a result of these internal adjustments within the recurrently shifting horse and was localized by the major stratigraphic break at the base of the thick section of Paleozoic rocks. The rocks were severely ground along rootless bedding-thrust planes. Some thrust plates were entirely ground up, the gouge was largely removed, and the lower Paleozoic stratigraphic sequence was telescoped. In extreme cases the mixing of the blocks is truly chaotic, but there are always discrete little-shattered blocks separated by gouge zones.

By about Oligocene or Miocene time most of the Paleozoic rocks were eroded from the Black Mountains block (fig. 14*C*) and rhyolite and rhyodacite volcanic rocks, perhaps localized on the Black Mountains block by tension between two strike-slip faults, covered it and lapped onto small areas of some of the adjacent blocks (fig. 15*D*). The tuffaceous rocks near the base of these volcanic rocks were intruded by numerous plugs, sills, dikes, and laccoliths, and locally were severely deformed by them. A little andesite and basalt intruded into and extruded onto the youngest of these rhyolitic rocks. At this time, too, the copper sulfides were remobilized, and henceforth secondary copper minerals continued to be moved toward their present sites along fractures in the rhyolitic intrusive rocks and adjacent monzonitic rocks.

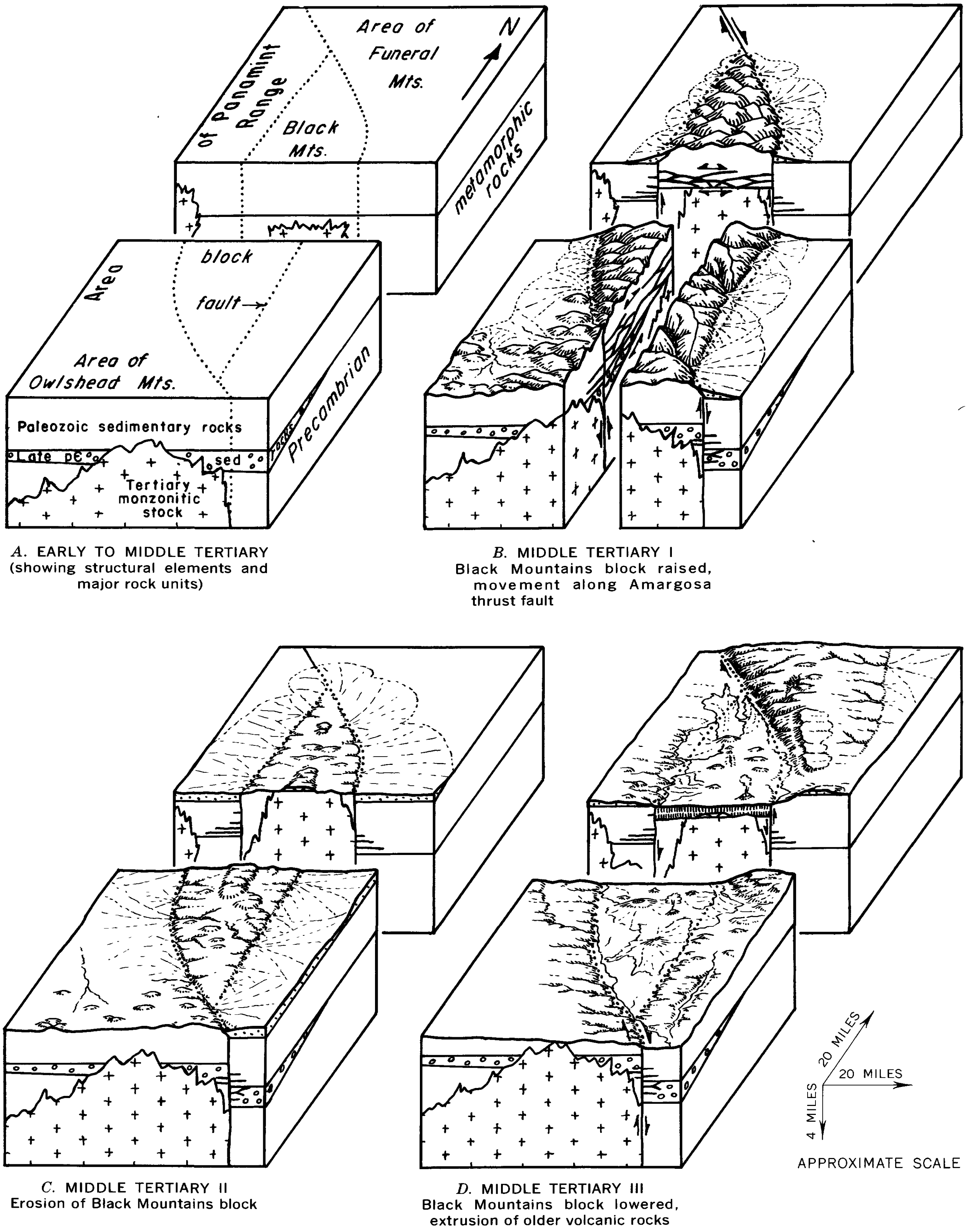
The Black Mountains fault block continued to shift between the bordering strike-slip faults (fig. 14*E*). As a result of these movements the older volcanics were broken by normal faults, tilted southeastward, and eroded from part of the block. Some of the eroded debris was deposited in large fans northeast of the block from source areas in the northeast corner of, and north of, the quadrangle. This part of the block was dropped at least a mile in Miocene or Pliocene time, and a trough was filled with many thousands of feet of fan and playa sediments of the Furnace Creek formation. Sufficiently unusual conditions existed to allow large deposits of borates to accumulate in these sediments. Judging solely from the general history of the Black Mountains fault block, the borates probably originated through some combination of the early volcanism plus the extremely active and reversible local tectonic movements in the area that made a succession of small, internally drained basins in which high concentration ratios were reached. These rocks were warped into a moderately tight syncline, and since then borates have been eroded from them and carried to Death Valley.

During Pliocene(?) time (fig. 14*F*) fan and playa sediments, almost 2 miles thick, of the Copper Canyon formation were accumulated in a small trough along the west side of the Black Mountain block. This trough is similar to the one containing the Furnace Creek formation but is probably not continuous or synchronous with it. The older sediments of the playa in the Copper Canyon area contain evaporites other than borates, and the younger ones contain fresh-water limestone with abundant tracks of birds and mammals. A few small andesite and basalt bodies were also intruded into and extruded onto the sediments of both these playas.

Late in Pliocene time, either just before, during, or after the accumulation of the Furnace Creek formation, the Greenwater volcanics of rhyolite and rhyodacite were extruded as a row of domes approximately along the northwest-trending axis of the Black Mountains block.

During Pliocene and Pleistocene (fig. 14*G*) time, fanglomerate of the Funeral formation with abundant interbedded andesite and basalt flows and a few intertonguing playa deposits accumulated over much of the central part of the Black Mountains block and lapped around the flanks of the high rhyolitic dome northwest of Greenwater Canyon. Small cinder cones were built in many places in the quadrangle and large ones were built north and east of it. Locally the andesite and basalt ponded and diverted the streams. A large mass of metamorphic and monzonitic rock slid from the high mountains across the adjacent fan and into the remnants of the playa in the Copper Canyon area, leaving the megabreccia body with its thoroughly shattered structure and little-rotated blocks not separated by gouge zones. A little rhyolite tuff, ejected from a nearby vent, is also interbedded with the fanglomerate. The Black Mountains block was again uplifted and broken by normal faults.

Large movements recurred along the Black Mountains fault system along the east side of Death Valley. Several large blocks of Tertiary sediments slid across the structurally controlled stripped surfaces on which they had been deposited, as the supporting blocks on the Death Valley side of the fault system were dropped. The reexposed and further exhumed surfaces are the turtleback surfaces. The rocks that slid over these surfaces are little ruptured but broadly folded. Late in Pleistocene time Lake Manly occupied Death Valley and was fringed by narrow beaches and wave-cut terraces. Recent movements along the Black Mountains fault system have dropped Death Valley several times and truncate all but the most modern stream gravels. The rate of displacement along this fault system has been increasing since late Tertiary time, leaving an extremely youthful fault scarp with two levels of facets eroded back only slightly from the same fault surface.



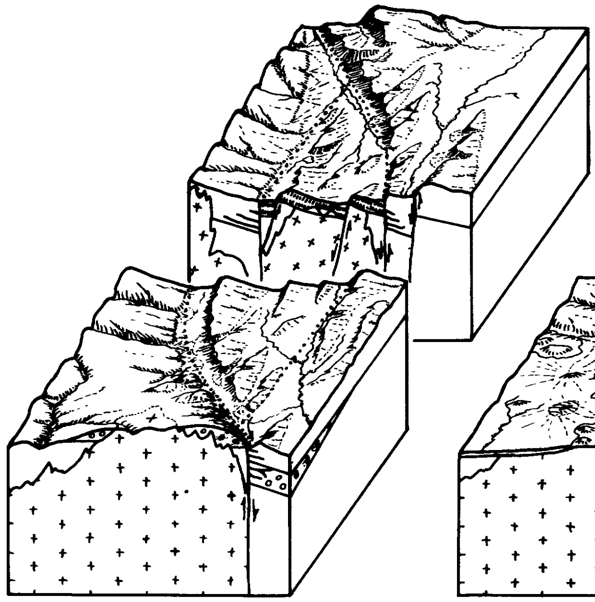
A. EARLY TO MIDDLE TERTIARY (showing structural elements and major rock units)

B. MIDDLE TERTIARY I Black Mountains block raised, movement along Amargosa thrust fault

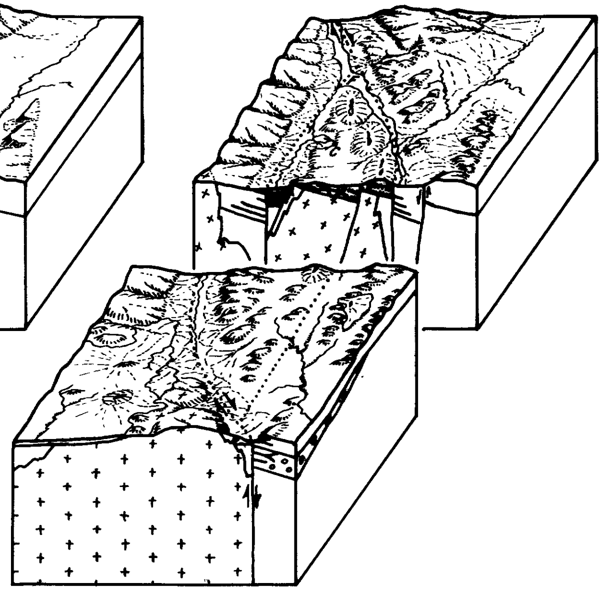
C. MIDDLE TERTIARY II Erosion of Black Mountains block

D. MIDDLE TERTIARY III Black Mountains block lowered, extrusion of older volcanic rocks

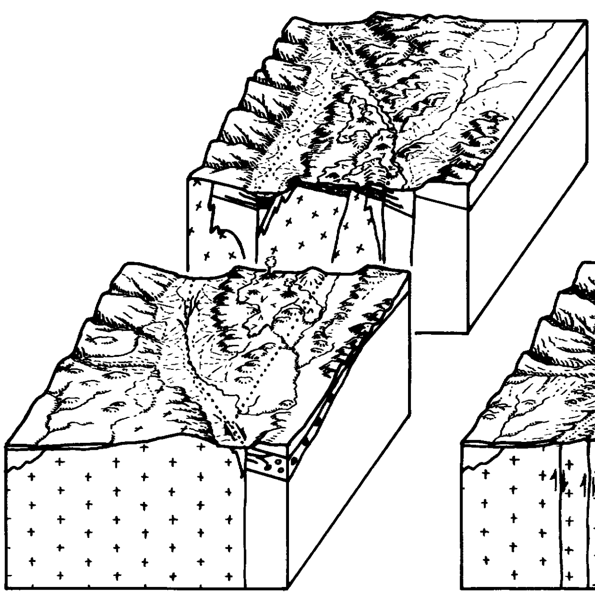
FIGURE 14.—Schematic block diagram showing development of structure and topography of the Black Mountains block during Tertiary and Quaternary time. Large blank areas completely unknown topography. Relations outside of Funeral Peak quadrangle adapted from Noble and Wright (1954, pl. 7).



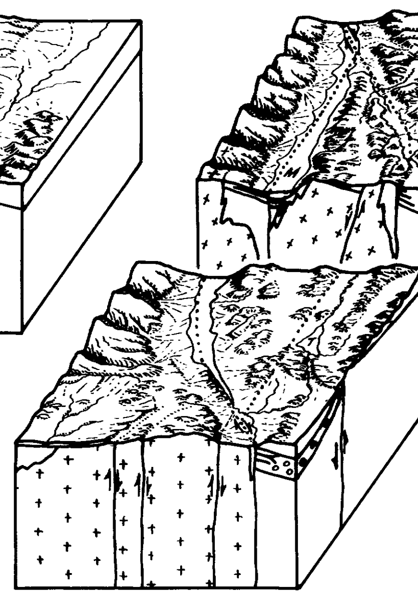
E. LATE TERTIARY I
Block faulting; local basins formed



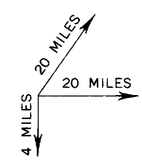
F. LATE TERTIARY II
Extrusion of Greenwater volcanics and other younger volcanic rocks; Furnace Creek Lake, F, and Copper Canyon Lake, C



G. EARLY PLEISTOCENE
Extrusion of the andesite and basalt of the Funeral formation



H. LATE PLEISTOCENE
Ranges uplifted; M, Lake Manly and, T, Lake Tecopa (slightly earlier than Lake Manly)



APPROXIMATE SCALE

FIGURE 14

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