A GEOLOGIC SECTION
FROM THE SIERRA NEVADA TO DEATH VALLEY,
CALIFORNIA

A thesis submitted in partial fulfillment of the
requirements for the degree Doctor of Philosophy
in Geology

by

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1939

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ABSTRACT

This paper describes the geology of an area six miles wide and 67 miles long, extending from the crest of the Sierra Nevada to the floor of Death Valley approximately along the 36°16' parallel of latitude. Structural geology is emphasized. Correlations are suggested between events in the geologic histories of this area and of other areas in southeastern California.

The area mapped is in one of the most rugged parts of the Great Basin, and has a relief of more than 10,000 feet. It extends across the three westernmost ranges of the Great Basin in this latitude, the Coso, Argus, and Panamint Ranges. The topographic features of these ranges strongly suggest that each of them owes most of its present relief to uplift by faulting. In the western half of the area the displacements of an extensive sheet of late Pliocene or early Pleistocene basalt support the topographic evidence of faulting. On the summit portions of the ranges are areas of low relief, believed to be remnants of a single old-age erosion surface which extended across the area before the beginning of the range-forming fault movements. The period of undisturbed erosion which produced this surface ended shortly before the deposition of the fossiliferous late Pliocene or early Pleistocene Coso formation; therefore this surface is correlated with the Ricardo erosion surface of the Mohave Desert region, which bevels tilted early Pliocene strata and which is also dislocated by range-forming faults.

The ranges are composed dominantly of pre-Tertiary rocks. Pre-Cambrian metasediments exposed in the Panamint Range attain a thickness of 15,000 feet; they are chiefly mica schists and dolomites. The Paleozoic rocks are more than 30,000 feet thick, and the fossils collected indicate the probable presence of all the Paleozoic systems. Limestones, dolomites, shales, and quartzites are the principal rock types. Cambrian and Carboniferous strata make up about three-fourths of the total Paleozoic section. During the late Jurassic Nevadian orogeny the pre-Mesozoic rocks were folded, faulted, and intruded by plutonic bodies ranging in composition from granite to gabbro. The post-Mesozoic rocks are almost entirely of late Cenozoic age, and include a wide variety of volcanic and sedimentary types.

Movements of large magnitude took place on the fault zone on the east edge of Panamint Valley in late Tertiary time, and activity on this zone has continued into the Recent epoch. Most of the faulting to which the region owes its present relief, however, occurred in the early or middle part of the Pleistocene epoch, probably after the first (McGee) glacial stage in the Sierra Nevada. All the range-forming faults whose attitudes could be determined were found to be normal faults.

INTRODUCTION

PURPOSE AND NATURE OF THE STUDY

The work on which this thesis is based was undertaken as a study of the structural development of a typical portion of the western Great Basin. In particular, it was desired to investigate the histories of some of the large range-bounding faults of this region. Because it is one of the most rugged and least alluviated parts of the Great Basin, the country between the Sierra Nevada and Death Valley was considered especially favorable for this project. Time did not permit a detailed study of this large and little-known region in its entirety, so it was decided to map an elongate area transverse to the major structural trends in order that an accurate geologic section could be drawn. The following report is a discussion of the geology of the strip mapped, with some comments on the adjoining territory.

The geologic mapping was done by the writer during the summer, fall, and winter of 1937, 157 days being spent in actual field work. The geology was plotted on a base map consisting of portions of the Olancha, Ballarat, and Furnace Creek quadrangles enlarged to a scale of one mile to the inch. The geologic map of Plate 1 (in pocket on back cover) is a copy of the field map re-drawn to a reduced scale.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his gratitude to Messrs. L. F. Noble and R. P. Bryson, of the U. S. Geological Survey, and H. D. Curry, of the U. S. National Park Service, for valuable suggestions regarding certain

phases of the work, particularly in the Panamint Range. Thanks are also due to Messrs. G. H. Girty, Edwin Kirk, L. G. Henbest, and Josiah Bridge, of the U. S. Geological Survey, for their identification of the fossils collected. Finally, the writer wishes to express his indebtedness to Professor J. P. Buwalda, of the California Institute of Technology, for general guidance and for helpful advice and criticism.

DEVELOPMENT OF IDEAS REGARDING BASIN-RANGE STRUCTURE

The Great Basin of the southwestern United States contains numerous north-trending mountain ranges separated by alluviated basins. Because of their position in the Great Basin these ranges have come to be known as "basin ranges", and the general structure of the region is referred to as "basin-range structure". This type of structure has been studied intermittently for nearly 80 years, and in the following paragraphs the course of this study is briefly traced and the conclusions resulting from it are summarized.

While serving as geologist with Simpson's U. S. Army expedition in 1859, Henry Engelmann made observations which led him to report that the relief of the Great Basin "has been shaped by numerous parallel fissures and corresponding mountainous upheavals, running nearly north and south" (in Simpson, 1876, pp. 301-302). As early as 1859, therefore, Engelmann apparently conceived of the basin ranges as fault-blocks. The report containing his brief statement was not published, however, until 1876, because of the oncoming of the Civil War shortly after the completion of his field work.

In 1870 Clarence King advanced the view that the basin ranges are eroded anticlines and that the intermont basins are alluviated synclines. He believed the folding to be of late Mesozoic age (King, 1870, pp. 2, 451).

G. K. Gilbert, in the progress report of the Wheeler Survey (1874, p. 50) first clearly explained the basin ranges as eroded fault-blocks. In his final report (1875, pp. 24, 41-42) he amplified his earlier statement, and announced his belief that the folding and faulting of the strata in the basin ranges were both of late Jurassic age.

J. W. Powell (1876, pp. 32-33) and C. E. Dutton (1880, p. 47) recognized that previous to the faulting which created the present basin ranges there had been a long period of erosion, reducing the region to a condition of low relief. Dutton, in particular, stated that this period of erosion intervened between the older period of folding and the younger period of faulting, and that the mountains created by the late Mesozoic folding were completely worn away before the advent of the faulting to which the region owes its present relief.

This idea of basin-range history --- a history of late Mesozoic folding, followed by long erosion, followed by Cenozoic block-faulting --- came to be generally accepted by these and other western geologists. It was, however, based almost entirely upon hasty reconnaissance work and upon physiographic considerations. Ranges with steep scarps on one or both sides and with internal structural axes oblique to the range margins were considered, without supporting evidence, to be bounded by faults. Although small scarps, definitely known to be of Quaternary age because they displace the beds of Pleistocene Lakes Bonneville and Lahontan, had been reported at the bases of several ranges (Gilbert, 1882, pp. 199-200; Russell, 1885, pp. 274-283), the literature recorded no observations of faults whose movements could actually be proved, on the basis of stratigraphic displacements, to have uplifted the existing mountain ranges to their full heights. This lack of observed range-bounding faults, and the occurrence of many faults not marked by scarps within the ranges, led J. E. Spurr to challenge the theory that the basin ranges owe their present relief to faulting, and to suggest that many of them are merely erosional features. He wrote that "only the more recent faults or folds find direct expression in the topography; the older ones are mastered by erosion" (1901, p. 265).

Spurr's challenge was soon answered. W. M. Davis (1901, 1903) analyzed the physiographic development of fault-block mountains far more carefully than had been done before, and cited examples of various stages in this development. Davis showed the impossibility of the development of typical basin ranges, with internal structural axes oblique to the range margins, by long-continued erosion, for he maintained that, by the more rapid removal of the weaker beds, mountains remaining as erosion residuals would have margins determined by the outcrops of the more resistant strata. Further, G. D. Louderback, from a study in western Nevada, found lava-capped ranges in which the total present relief could be proved to be the result of normal faulting along the range margins (1904, especially pp. 306-309). These later investigations therefore tended to confirm the fault theory and to discredit Spurr's idea of the basin ranges as erosional remnants.

A more recent development has been the eolation hypothesis of C. R. Keyes, advocated since 1909 in a number of papers. Keyes has summarized his views as follows: "The origin of the Basin ranges and of the desert ranges generally is, therefore, regarded as due in the main to extensive and vigorous deflation on a region that had been previously flexed and profoundly faulted and then planed off, bringing narrow belts of resistant rocks into juxtaposition with broad belts of weak rocks, the former now forming the desert highlands and the latter the desert lowlands, or intermont plains"

(1910, p. 598). Wind erosion on an uplifted peneplain, in other words, is supposed to have scoured out the belts of soft rock and to have left the belts of more resistant rock as the basin ranges. Louderback (1923) has shown that this hypothesis cannot apply in the western part of the Great Basin, because there is no reason to believe that the present valleys were once filled with soft rocks and because there is ample evidence of Recent movement on many of the range-bounding faults.

Thus the general idea of the structure of the basin ranges developed before 1880 has prevailed up to the present time. Cenozoic faulting is still thought to have formed the present ranges; late Mesozoic folding and intrusion, and later erosion, are still considered to be the major events in the history of the region previous to the range-forming faulting. Some modifications and additions to this structural history, however, have become necessary as geologic study in the region has progressed. In the southwestern part of the Great Basin and Sierra Nevada, for instance, at least two periods of Tertiary erosion, resulting in the production of land surfaces of low relief, are recognized, separated by crustal movements involving folding and normal and thrust faulting (Baker, 1911, pp. 380-381 and 1912, p. 142; Hewett, 1928; Matthes, 1933, pp. 34-36; Hulin, 1934, pp. 419-422).

PREVIOUS GEOLOGIC WORK IN THE REGION OF THIS INVESTIGATION

Southeastern California has received relatively little attention from geologists. One reason for the general lack of interest in this region is that few economically important mineral deposits have been found in it. Another is the small scale of the U. S. Geological Survey topographic maps;

these as yet cover only a portion of this part of the state. The scarcity of roads and settlements and the excessive heat and dryness of the summers have also discouraged geologic work to some extent. As a consequence of these conditions, the geology of the region between the Sierra Nevada and Death Valley, and extending from the Mohave Desert on the south to the Inyo Mountains on the north, has remained almost unknown.

Nearly all the accounts of the geology of this region are short and have been based on hasty reconnaissances. In Volume I of the Geological Survey of California (Whitney, 1865, pp. 473-474) a brief description of the topography is given, stating that the bottom of Death Valley is believed to be about 175 feet below sea-level. The Panamint Range is reported as consisting of crystalline and metamorphic rocks and the Coso Range of granitic and gneissoidal rocks. The Argus Range is not mentioned.

Of the Federal surveys which operated in the West prior to the creation of the U. S. Geological Survey, only the U. S. Geographical Surveys West of the 100th Meridian, with G. M. Wheeler in charge, penetrated the region under consideration. G. K. Gilbert was a geological assistant in this organization and accompanied one of its topographic parties on a trip through eastern California in 1871. He described the Amargosa Range, east of Death Valley, as consisting of limestone, schist, and quartzite, with later rhyolite on the flanks, and added that "the Panamint Range, on the opposite side of Death Valley, appeared from the distant view to be similarly constituted" (Gilbert, 1875, p. 34). Later in the account (p. 124) it is noted that the west base of the Coso Range consists of lavas. There is no mention of the Argus Range.

W. A. Goodyear studied the geology of Inyo County in 1870-1872 as a member of the Geological Survey of California, but because of the disbanding of this organization his work remained unpublished. Later, as a geologist for the State Mining Bureau, Goodyear resumed his work in Inyo County, and the results of his studies were published in 1888. His investigations were confined almost entirely to the Sierra Nevada and the Inyo Range, but he traveled as far east as the Darwin mining district, reporting that the Darwin Hills consist of limestone, quartzite, and granite (Goodyear, 1888, pp. 225-226). He also noted the occurrence of light and dark volcanic rocks on the west side of the Coso Range (p. 240).

In 1891 the California State Mining Bureau issued a preliminary geologic map of California on which almost all of the southeastern part of the state appears as unexplored territory. However, a large area including the Coso Range, Coso Valley, and the north half of the Argus Range is colored to indicate the outcrop of volcanic rocks.

H. W. Fairbanks spent four months of 1894 in a reconnaissance of east central California for the State Mining Bureau. In his report he stated that the southern Argus Range is composed of granite which passes to the northwest into the Coso Range, and that the northern Argus Range, between Darwin and the Modoc Mine, consists chiefly of limestone and quartzite; he further observed that the mica schist, slate, quartzite and limestone form the main bulk of the Panamint Range, but that some granite is present (Fairbanks, 1894, p. 473). In a later paper the same author mentioned the stratified gravels of the west slope of the Panamint Range, briefly described the granite of the east side of the northern Argus Range, and noted the occurrence of andesite and younger basalt in the western part of the Coso Range (Fairbanks, 1896, pp. 71-73).

During a reconnaissance of the borax deposits of eastern California for the U. S. Geological Survey in 1900, M. R. Campbell gathered considerable information about the general geology of this region, and included it in his report (Campbell, 1902, pp. 19-20). He briefly described the Panamint Mountains in the vicinity of Towne's Pass and Wildrose Canyon, noting the occurrence of a great thickness of stratified gravels with interbedded lava. Observing that these gravels and the underlying Paleozoic beds dip east, Campbell expressed the opinion that the Panamint block may have turned on a horizontal fulcrum, the eastern edge sinking to form Death Valley and the western edge rising to form the Panamint Range. He also mentioned briefly the lake beds of Coso Valley. Slightly later, speaking before the Geological Society of America, Campbell (1903, p. 552) reiterated his view that the present topography of this region is largely the result of the tilting of crustal blocks.

In 1903 J. E. Spurr compiled for the U. S. Geological Survey all existing knowledge of the geology of southern Nevada and east central California. This compilation was based on the literature already cited, and also on reconnaissances made by Spurr, R. B. Rowe, and F. B. Weeks. Spurr added little new information regarding the area of the present study. He considered the pre-Tertiary sedimentary rocks of the Panamint Range within this area to be Cambrian, and believed that the strata of the northern Argus Range were of the same age (Spurr, 1903, Plate I and p. 212). The Cenozoic lake beds near the present Haiwee Reservoir were thought to be pre-Pliocene (1903, p. 210). Spurr's rough geologic map, with a scale of 15 miles to the inch, was the first attempt to indicate the rock types exposed in all parts of the region between the Sierra Nevada and Death Valley.

In 1905 the U. S. Geological Survey began a program of topographic mapping in the region. S. H. Ball accompanied one of the topographic parties as a geologist, and his report on the geology of an area in southwestern

Nevada and eastern California was subsequently published by the Geological Survey (Ball, 1907). Though of a reconnaissance nature, Ball's geologic map was a great improvement over the small-scale map of Spurr. The part of California mapped by Ball includes only the northeast quarter of the Ballarat quadrangle, northeast of the area of the present study.

Shortly after the publication of Ball's report a brief note on the geology of the Coso Range appeared (Reid, 1908). Reid wrote that this range is composed of granitic rock with basalt flows on the north and east flanks. He further stated that the range possesses a subdued summit topography, and that it is bordered on the east by a fault.

C. L. Baker's studies in the Mohave Desert and the El Paso Range (1911 and 1912) were of particular value in proving that late Tertiary folding and faulting had occurred in these areas, followed by an interval of erosion which reduced parts of them to a condition of low relief.

In 1914 the U. S. Geological Survey published a short description of the Darwin mining district by Adolph Knopf. Fossils collected during this investigation established the age of the stratified rocks of the Darwin Hills as Pennsylvanian (Knopf, 1914, p. 5). The rocks of the district were described in some detail in this report, but no geologic map was made.

The results of H. S. Gale's studies of the late Quaternary lake system in this region appeared in 1915. Gale showed that the waters of Owens Lake had formerly overflowed into Searles and Panamint Valleys and probably also into Death Valley, and that the evaporation of the ancient lakes, as the climate became more arid, caused the precipitation of the saline minerals now found in their dry basins.

A brief descriptive paper on Death Valley by G. D. Hubbard also appeared in 1915. It states that the valley owes its origin to block-faulting and the erosion of the resulting forms, but the locations of the faults and the mechanics of their movements are not discussed.

In 1916 the State Mining Bureau issued a geologic map of California on which the geology of Inyo County was the work of C. A. Waring. A more detailed geologic map of this county, with a description of the geology by Waring, was published the following year (Waring, 1917). This highly generalized county map shows the east slope of the Sierra Nevada as consisting of plutonic rocks, with a fault at its base. Almost the entire surface of the Coso Mountains is mapped as Tertiary volcanics, with some plutonic rocks indicated on the east flank of this range. Waring was apparently unaware of the discovery of Pennsylvanian fossils by Knopf in the strata of the Darwin Hills; following Spurr, he mapped the rocks of the Darwin Hills and northern Argus Range as Cambrian meta-sediments, and showed that they were intruded in a few places by plutonic rocks. The summit and east slope of the Panamint Range, where crossed by the area of the present study, are also represented as Cambrian on Waring's map, and the west slope is shown as consisting of Ordovician and Silurian limestone and quartzite. A fault is shown at the west edge of the Panamint Range, but its characteristics are not discussed.

The results of the reconnaissances of the Inyo Range and the east slope of the Sierra Nevada by Adolph Knopf and his associates were published in 1918. The Inyo Range had previously received considerable attention from geologists and paleontologists, and at present it has been more completely studied than any of the California ranges in the Great Basin. The geologic map accompanying Knopf's report covers the northwest corner of the Ballarat quadrangle and the portion of the Olancha quadrangle included in the area of the present investigation.

Descriptions of the fault zones on the east sides of Panamint and Death Valleys south of the area of this study appeared in 1926 in a contribution by L. F. Noble. Evidence brought forth by Noble showed that movements have taken place along these fault zones very recently.

W. M. Davis briefly discussed the Argus Range from a physiographic standpoint in two recent papers (1930, pp. 299-300; 1932, pp. 243-244), showing how the sloping lava flows mark the range as a tilted fault-block.

In 1932 the California State Division of Mines published the results of F. M. Murphy's investigation of a portion of the Panamint Range south of the area of the present study. This report deals principally with stratigraphy and petrography, little attention being devoted to the younger structural features. Murphy believed that the oldest rocks of this part of the range are pre-Cambrian and that the younger metasediments are of early Paleozoic age, but he found no fossils to substantiate these beliefs.

On the geologic map of the United States published by the U.S. Geological Survey in 1932 the geology of the area mapped in the present investigation is represented in much the same way as on the 1916 geologic map of California, but the rocks shown as Cambrian on the California map are indicated as undifferentiated Ordovician and Silurian strata, and a narrow band of pre-Cambrian rock is added along the west edge of the Panamint Range.

In a recent article, Eliot Blackwelder (1933) described evidence of the presence of a late Pleistocene lake in Death Valley.

For several years C. D. Hulin has been studying the geology of the Searles Lake quadrangle, adjoining the Ballarat quadrangle on the south, and a brief report on some phases of his work appeared in 1934.

In the same year a short description of the rocks of Death Valley appeared (Noble, 1934). This paper is a preliminary report on a study of the geology of Death Valley by the U. S. Geological Survey, an investigation which is still going on. In it Noble described very briefly the rocks of the part of Death Valley south and east of the area of the present study.

J.R.Schultz recently (1937) described a vertebrate fauna of late Tertiary or early Quaternary age from the beds on the west flank of the Coso Mountains. An account of the geology of the fossil localities, all north of the area mapped in the present investigation, is included in his paper, but no geologic map is presented.

The results of a detailed study of the ore deposits of the Darwin mining district, accompanied by a geologic map of the Darwin Hills, recently appeared in an article by V. C. Kelley (1937).

Thus reports on the geology of this part of eastern California, though quite numerous, have mostly been based on short reconnaissance studies covering large areas. An indication of the lack of adequate knowledge of the geology of this region is furnished in a recent report by O. P. Jenkins, chief geologist of the California State Division of Mines, giving the sources of information used in compiling the geologic map of the state recently issued[1]. Jenkins' report includes a map of the state showing the areas for which satisfactory geological information is available. No published reports are indicated for the area mapped in the present investigation, or a large area surrounding it, except Knopf's reconnaissance report (1918) on the east slope

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[1] O. P. Jenkins: Source data of the geologic map of California, January, 1937. Calif. Journal of Mines and Geology, vol. 33 (1937), pp. 9-37.

of the Sierra Nevada; Kelley's description of the Darwin district, more recent than Jenkins' paper, should now be added.

GENERAL GEOGRAPHY

LOCATION

The area mapped in the present investigation is a strip six miles wide and 67 miles long, extending from the crest of the Sierra Nevada to the floor of Death Valley approximately along the 36°16' parallel of latitude. The position of this strip with respect to the surrounding territory is shown in Plate 9a. This area was chosen for study because the later events in its structural history are unusually well recorded in the displacements of a thin lava sheet which covers much of its surface. The strip extends across the southern part of the Ballarat quadrangle and has its western and eastern extremities in the adjoining Olancha and Furnace Creek quadrangles, respectively. On the index map of Plate 1 is shown the topography of the portions of these quadrangles considered in this paper.

Mining is the only industry in the area mapped. Darwin, with a population of about 50, is the only town, and is supported by the silver-lead mines of the Darwin Hills. A few men are living at the Minnietta and Harrisburg camps, where limited mining operations are being carried on. The only other inhabitants are itinerant prospectors and Indians who enter the area from time to time.

CLIMATE AND VEGETATION

The great differences in altitude within the area result in widely differing climates. The Sierra crest receives an average annual precipitation of about 20 inches (Lee, 1912, plate VII), but the yearly precipitation lessens rapidly to the east because the winds from the Pacific lose most of their moisture upon being intercepted by the Sierra. At Keeler, on Owens Lake, the average annual rainfall is about 3 inches, and in Death Valley it is approximately 1.5 inches.

East of the Sierra front the climate is typical of the southern Great Basin. Summer shade temperatures often exceed 110°F. in the valleys, and the world's highest officially recorded natural shade temperature, 134°F., was reached at the U. S. Weather Breau station at Furnace Creek Ranch in Death Valley in July, 1913. At elevations above 5000 feet, however, the summer heat is never oppressive. During the spring and fall the maximum daily temperatures may be almost as high as those reached in summer, but the nights are much cooler. In these seasons it is not uncommon for the temperature to approach 100°F. in the middle of the day and to fall below 40°F. at night at altitudes of 5000 feet or more. The winters are mild in the valleys, but rather severe in the mountains.

The great diversity in elevation and climate is reflected in the vegetation of the area. The lower parts support sparse growths of creosote bush, greasewood, and various kinds of cactus. Somewhat higher is a zone in which common sagebrush is the most abundant plant. Above 4500 feet the Joshua tree is common, particularly in the Coso Range, where specimens of this type of yucca are sometimes as much as two feet in diameter at the base of the trunk and twenty feet high. At about 6000 feet the junipers and pinon pines appear, and in the high parts of the Panamint Range, above 7500 feet, mountain mahongany occurs with these plants. Only in the Sierra, however, are the conifers abundant and large.

ROCK EXPOSURES

The sparseness of vegetation and soil and the ruggedness of the country combine to give excellent exposures of the rocks, although in a few localities portions of the steep slopes are masked by talus slides and some of the hilly areas of low relief are largely covered with the products of rock disintegration. In general, however, the distinctness of the lithologic units and the nearly complete continuity of outcrops made possible fairly rapid geologic mapping.

TOPOGRAPHY AND GEOMORPHOGENY

GENERAL STATEMENT

The area mapped lies within one of the most rugged portions of the Great Basin. The highest point is the summit of Round Mountain, on the Sierra Nevada crest 9944 feet above sea-level; the lowest point is the floor of Death Valley, approximately 250 feet below sea-level. These points are respectively at the western and eastern ends of the strip mapped. All three of the intervening ranges reach elevations greater than 8000 feet, but the culminating peaks of these ranges --- Coso Peak (elevation 8156 feet) in the Coso Range, Maturango Peak (elevation 8850 feet) in the Argus Range, and Telescope Peak (elevation 11,045 feet) in the Panamint Range --- are all a few miles to the south of the area mapped. In contrast to most of the Great Basin, the alluviated valleys between the ranges are narrower than the ranges themselves.

In the following paragraphs of this section the topographic features of the area will be described and their significance discussed, proceeding from west to east.

SIERRA NEVADA

It is well known that the broader topographic features of the Sierra Nevada in this latitude result from the tilted fault-block structure of the range. The crest trends in a northerly direction and is very much nearer to the eastern margin of the range than to the western. The steep eastern scarp is three to five miles wide and drops from the crest to the piedmont alluvial slope five to eight thousand feet below. The broad western slope, with an average width of about 50 miles, is characterized by old-age topography developed when the range stood at a lower elevation than at present. A few deep canyons have been cut in this old topography by rejuvenated westward-flowing streams, the rejuvenation having been caused by repeated uplifts of the range by faulting along its eastern edge. Thus the range is still in a decidedly youthful stage of the erosion cycle which was begun by the most recent major uplift. Glaciation has modified the topography in the higher parts of the range.

Evidences of recent movement along the base of the Sierra Nevada scarp are lacking within the mapped area. Here the scarp is deeply eroded and indented by canyons. No minor scarps are present in the alluvium east of the margin of the range. No steepening of the east-trending spurs as they approach the alluvial apron is noticeable, though such steepening is quite pronounced a few miles to the north, west of the town of Olancha.

The area mapped includes a small portion of the plateau-like western slope of the Sierra south and west of Round Mountain. No evidence of glaciation was observed in the high parts of the Sierra in this vicinity; Knopf (1918, p. 100) noticed no topographic features suggesting glaciation south of Olancha Peak, 3.5 miles north of the strip mapped.

COSO RANGE AND COSO VALLEY

East of the Sierra front the area extends across Haiwee Pass, in which the Haiwee Reservoir of the Los Angeles aqueduct system is located. This pass separates Owens Valley to the north from Rose Valley to the south.

East of Haiwee Pass the area includes the northern part of the Coso Range. In plan view the outline of the range, though roughly elliptical with the longer axis trending north-northwest, has its width and length so nearly equal that it is almost circular; this is in marked contrast to the narrow elongate north-trending outlines of the more typical basin ranges. Northeast of the large embayment in the western margin of the range known as Cactus Flat, the western slope rises to the crest of the range in a series of four huge steps, each capped by a sheet of black olivine basalt. These steps are readily visible from the highway south of Olancha and are obviously the result of step-faulting which caused the dislocation of a once-continuous basalt sheet. The "risers" of these steps slope steeply to the west, but the "treads" slope gently east, so that small playa lakes, about 200 feet long and 100 feet wide, have developed high on the side of the range at the bottoms of the two center "risers". Views of the west side of the Coso Range, showing the displacement of the lava by step-faulting, are shown as Figures 1, 2, and 3.

Plate 2.

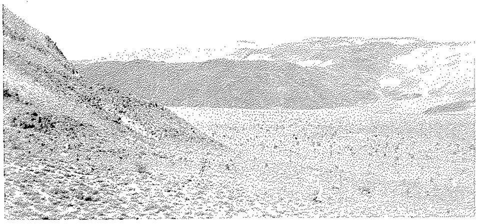

Figure 1. A view of the northern part of Cactus Flat. In the background, resting upon granitic rock, is the step-faulted basalt of the western Coso Range. The hill in the left foreground consists of Tertiary andesite.

Figure 2. Looking north along the "riser" of the uppermost step in the zone of step-faulting on the west slope of the Coso Range, showing the displacement of the once-continuous basalt sheet, remnants of which are seen at the left and right edges of the photograph. The amount of the vertical displacement is about 600 feet.

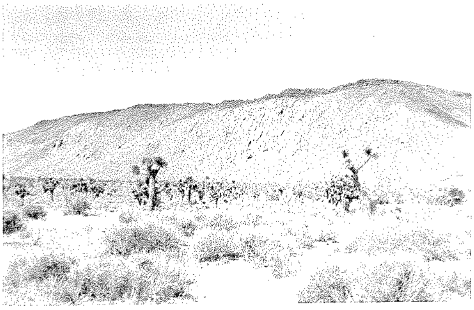

Figure 3. The steep 600-foot scarp which constitutes the "riser" of the uppermost step in the zone of step-faulting on the west flank of the Coso Range. The rock below the basalt cap is brown granite.

The high central part of the Coso Range is characterized by low relief. It is manifestly a surface of old-age topography which was developed at a lower elevation and has been uplifted in the recent geologic past. The most conspicuous high area of subdued relief is Centennial Flat, which is within the area of this study. Situated at an elevation of about 6900 feet, Centennial Flat has less than 300 feet of relief over its nearly circular tract of about four square miles, the area of which is continually being reduced by headward erosion of the steep canyons on the sides of the range. The southern part of Centennial Flat is lava-covered, the lava being the eastern extension of the basalt cap that covers the highest step on the west side of the range. The low central part of the flat contains a thin deposit of Quaternary alluvium which covers a small part of the old-age erosion surface preserved in the surrounding bedrock. Figure 4 is a view of a portion of Centennial Flat.

Directly east of Centennial Flat the steep and rugged eastern slope of the Coso Range descends 1500 feet to the alluviated floor of Coso Valley. The entire east flank of the range, like that of the Sierra Nevada, is an abrupt drop from the old-age topography of the summit to the lowland to the east.[2] For this reason it is believed to be a deeply eroded scarp produced by movement along a buried northwest-trending fault. Reid (1908, pp. 64-66) came to the same conclusion.

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[2] Where the geologic section of Plate 1 is drawn across the east flank of the Coso Range the slope is actually to the north rather than to the east or northeast, and therefore, unless reference is made to the topographic map, the section may give the incorrect impression that the east slope is quite gentle.

Plate 3.

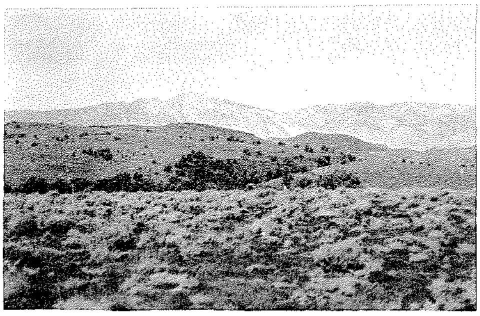

Figure 4. A view of the southern, lava-covered part of Centennial Flat. The east face of the Sierra Nevada appears in the background, with Olancha Peak (elevation 12,135 feet) the highest point on the skyline.

Figure 5. A view looking west at the Darwin Hills across lower Darwin Wash. In the foreground are the white Darwin Wash lake beds, overlain by old alluvium and dissected by the drainage system of the present Wash.

Figure 6. Darwin Falls, the 70-foot perennial waterfall which represents the drainage from the Darwin Wash area.

HILLS WEST OF DARWIN

Coso Valley is bounded on the east by a straight and abrupt north-northwest-trending scarp, about 400 feet high, which appears to be a southerly prolongation of the west scarp of the Inyo Mountains. Extending east from this scarp for a distance of three miles toward the town of Darwin is a hilly tract of relatively low relief in which steep-sided low knobs of granitic rock project above areas of granitic waste and alluvium. The summits of the knobs have elevations of 5600 to 6100 feet, and the relief within this entire tract is not more than 700 feet. Some of the higher parts are capped by a sheet of basaltic lava which is undoubtedly correlative with the similar sheet capping the uplifted surface of low relief in the Coso Range, and in these portions the same old-age land surface represented by Centennial Flat is preserved; in much of the area, however, dissection has destroyed the old erosion surface.

DARWIN HILLS AND DARWIN WASH

East of this hilly area is a lower alluviated tract approximately two miles wide which trends north-northwest and is a northwesterly arm of Darwin Wash. Near its eastern edge is the town of Darwin, at an elevation of 4750 feet, and directly to the east are the Darwin Hills. These hills are six miles long and two miles or less wide, and are entirely within the area of this study. They trend north-northwest and are bordered on the west, south, and east by alluviated areas which are portions of Darwin Wash. To the north, however, they grade into groups of lower hills, and their northern termination is thus poorly defined.

The Darwin Hills rise from 500 to 1000 feet above their alluvial border.

Their two highest points are both slightly over 6000 feet in elevation, the more southerly being known as Ophir Mountain. The broader topographic features of these hills suggest late maturity, but there has been a small amount of recent dissection in some of the gullies on their sides; because of these characteristics the Darwin Hills are believed to be a slightly rejuvenated feature of the surface of low relief preserved in the hills west of Darwin and in Centennial Flat. The rejuvenation of the Darwin Hills has been caused by faulting along their west edge resulting in their uplift, and, as will be explained in the following paragraph, by a lowering of the baselevel of the intermittent streams draining them. That the hills have been slightly uplifted by faulting along their west edge is clearly shown by a displaced lava flow northwest of Ophir Mountain.

Lower Darwin Wash east of the Darwin Hills is an alluviated area two miles wide, with dissected white lake beds in its lowest part attesting the presence of a former lake (Figure 5). The Wash drains to the north into Darwin Canyon, a narrow gorge which empties into Panamint Valley. The upper part of Darwin Canyon is shown in Figure 31. Headward erosion in Darwin Canyon has recently cut through the bedrock dam behind which was formed the lake in lower Darwin Wash into which all the intermittent streams draining the Darwin Hills once flowed, so that the baselevel of these streams has been lowered from the level of this lake to that of the playa lake in Panamint Valley, a decrease in elevation of 2000 feet. This lowering of baselevel has occurred so recently, however, that there has as yet been little rejuvenation in the area affected.

The catchment basin of Darwin Canyon is an area of 190 square miles lying to the south and west and including the highest parts of the Coso and

Argus Ranges. Sufficient precipitation falls in this basin to support three springs in the canyon. The lowest of these springs is Darwin Falls, a 70-foot waterfall which flows throughout both wet and dry years. A photograph of this unusual desert waterfall appears as Figure 6. The water from the falls flows about a half mile before disappearing into the alluvium; this is the only perennial stream in the mapped area east of the Sierra Nevada.

ARGUS RANGE

The steep rugged western slope of the northern Argus Range lies directly east of Darwin Wash and Darwin Canyon. The Argus Range is 50 miles long, has an average width of about six miles, and trends in a northerly direction. The strip mapped in this study crosses the northern six miles of the range, and within this area the elevation of the highest point is slightly over 7000 feet. Throughout the northern half of its length the crest of the Argus Range is much closer to the western margin of the range than to the eastern, and the western slope is steeper than the slope to the east into Panamint Valley. These facts strongly suggest that the steep western slope is an eroded fault-scarp. In the southern part of the area mapped the west slope rises to the crest in a series of four lava-capped steps, which, because of the displacement of the lava sheets, are obviously the result of step-faulting. Photographs showing these lava-capped steps appear as Figures 7, 8, and 9. W. M. Davis (1930, pp. 299-300) sketched this part of the Argus Range and prepared a cross-section showing how the displaced lava caps can be used in elucidating its later history.

On the summit and east slope of the northern part of the range are preserved conspicuous remnants of an old land surface of low relief which has been partially covered by a thin sheet of basaltic lava and uplifted and

Figure 7. The lava-capped steps on the west side of the Argus Range as seen from the Darwin Hills. The flat lava-covered old erosion surface is shown at the summit of the range. Basaltic talus covers the "risers" of the three lowermost steps. A cinder cone appears to the left of the steps.

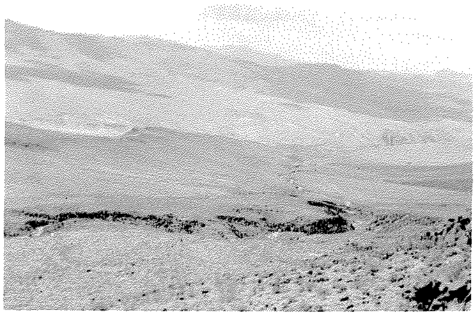

Figure 8. A view looking north along the "tread" of the lowermost of the steps in the zone of step-faulting on the west slope of the Argus Range. The flat "tread" surface is a lava-covered portion of the old erosion surface now faulted and tilted east. In the background are the cloud-shadowed Darwin Hills.

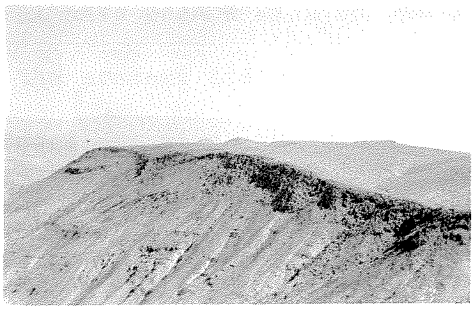

Figure 9. The lava-covered old erosion surface of low relief preserved at the summit of the Argus Range. A view of the western edge of the southernmost basalt outcrop in the portion of the range mapped.

tilted to the east. This lava sheet is similar in every respect to the lava sheets already described and is clearly to be correlated with them. Between the lava-capped remnants of this old surface the east slope of the range is dissected by numerous steep-sided canyons cut into the bedrock of Paleozoic sedimentary and Mesozoic igneous rocks; thus the thin lava sheet has served as a protective capping for the old land surface and has tended to preserve it from destruction by erosion. This old surface in the Argus Range had attained a very advanced stage in the erosion cycle before the lava was extruded upon it, for the base of the lava very closely approximates a plane. The thickness of the lava is nearly constant over any small area, though it gradually increases toward the east. No alluvium or gravel was observed between the bedrock and the lava. The most impressive remnants of this old land surface coincide with the two large lava-covered areas shown on the geologic map high in the range; a portion of one of them appears in Figure 9. Just to the east of the more southerly of these two lava-covered areas is the highest part of the Argus Range within the strip mapped, an area of conspicuously subdued topography which very probably represents a portion of the old land surface which was not covered by lava, but which has not yet been destroyed by headward erosion of the surrounding intermittent streams because of its height. This high area may well have been a hill on the old land surface around which the lava flowed; the present distribution of the lava-covered areas in a crude semicircle around the high area tends to corroborate this idea (see Plate I and Figure 10). For at least ten miles south of the area mapped for this study there are no other lava outcrops in the Argus Range, but farther south, near Shepherd Canyon, is another east-sloping lava sheet which caps the range.

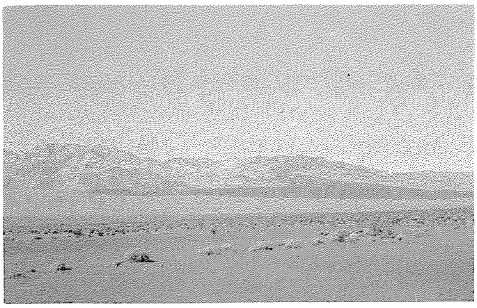

Figure 10. The eastern slope of the Argus Range, where crossed by the strip mapped, as seen from Panamint Valley. The black rock is basalt, the white is Mississippian limestone, and the gray is chiefly upper Carboniferous limestone and shale. The high part of the range to the left has a summit area of subdued relief, and is thought to be a hilly part of the old erosion surface which the lava flowed around but did not cover.

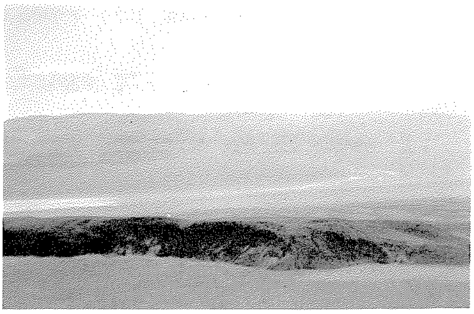

Figure 11. A view looking east from the northern Argus Range. In the foreground is the alluviated strip which separates the range proper from the ridge which parallels its eastern edge. Beyond this is the black basalt-covered ridge itself. In the background is Panamint Valley, with the southern part of the playa lake at the left.

Figure 12. The west front of the Panamint Range just north of the mouth of Wildrose Canyon, showing the badland topography produced in the soft Tertiary fanglomerate. Also shown is a series of triangular-faceted spur ends at the edge of the range.

The lava cap of the Argus Range slopes to the east and dips under the alluvium at the edge of the range. Paralleling and just east of the northern Argus Range proper, and separated from it by a narrow low alluviated strip, is a long narrow north-trending ridge shown on the topographic sheet of the Ballarat Quadrangle just east of the Modoc Mine. This ridge is twelve miles long and one to two miles wide, and its northern and highest part, which rises 400 feet above the valley alluvium, is within the area of this study. This part of the ridge is capped by an east-dipping basaltic sheet undoubtedly correlative with the lava caps just to the west, so that it is obvious that the ridge owes its existence to uplift along a fault separating it from the Argus Range proper (see geologic section, Plate I). A photograph of part of the ridge appears as Figure 11.

PANAMINT VALLEY AND PANAMINT RANGE

Panamint Valley is a basin lying between the Argus and Panamint Ranges in its northern part and between the Slate and Panamint Ranges in its southern part. The valley trends north-northwest, is about 65 miles long, and has a maximum width, measured between the bedrock margins of the bordering ranges, of 10 miles. It is a completely closed basin, containing two playa lakes separated by a broad low ridge of alluvium which extends transversely across the valley opposite Wildrose Canyon in the Panamint Range. The greater part of the surface of the valley consists of alluvial fans, but in addition to the playa lakes there is a small area of sand dunes at the extreme north end. The prevailing wind is from the south, and, in removing sand from the valley floor and carrying it to the north to form the dunes, it has created broad pebble-covered areas of desert pavement at various places. The strip mapped in the course of the present study crosses Panamint Valley near its northern end, where the valley is six miles wide, and contains the southern end of the more northerly of the two playa lakes, the surface of which has an elevation of 1614 feet.

The Panamint Range is approximately 100 miles long, extending in a north-northwesterly direction from Brown Mountain to a northerly gradation into the Last Chance Range. Where crossed in its central portion by the area of this study the range is 23 miles wide, and, though its average width is three or four miles less, it is still one of the widest ranges of the Great Basin. Throughout the greater part of its length the Panamint Range is bordered on the west by Panamint Valley, but Saline Valley lies directly west of the northern part of the range and separates it from the Inyo Mountains.

The west slope of the Panamint Range rising from Panamint Valley is unusually steep and high. From the Valley floor near Indian Ranch at an elevation of 1100 feet it rises vertically 9945 feet to the summit of Telescope Peak in a horizontal distance of slightly more than seven miles; this is its highest, but not its steepest, part. The steepest substained slope along the scarp is just east of the northern end of Panamint Valley, where a rise of 4000 feet is accomplished in a horizontal distance of two miles. The two steep parts of the scarp mentioned above are respectively south and north of a broad convex salient in the western front of the range north of the mouth of Wildrose Canyon. Here the slope is considerably less steep. Resistant Paleozoic and pre-Cambrian sedimentary and metamorphic rocks form the steep parts of the slope south and north of the salient, but in the salient itself Tertiary fanglomerate and volcanic rocks, intricately dissected into a badland area, form the front of the range.

Striking topographic evidences of recent faulting are present along the west base of the Panamint Range. This is particularly true south of Wildrose Canyon (Noble, 1926, pp. 425-428). Here the range front is steep and high, as noted above, but the alluvial fans at its base are so insignificantly small in comparison with those extending from the Argus Range that the lowest part of Panamint Valley is close to the foot of this scarp instead of in the center of the valley. The volume of these fans along the west base of the Panamint Range represents only a very small fraction of the volume of rock removed in the cutting of the canyons which extend up into the range from their apexes. Thus the late movements on the zone of faulting along the east edge of Panamint Valley must have involved not only a raising of the mountain block to the east but also a lowering of the valley block west of the fault zone so that the pre-existing piedmont alluvial slope along the west margin of the Panamint Range could be lowered and covered by fans spreading eastwardly from the Argus Range. In some of the most recent movements on this fault zone, however, small apical portions of fans at the west base of the Panamint Range have been uplifted with the range and minor west-facing scarps have been produced in the alluvium, as exemplified in a re-entrant in the range east and south of Ballarat. The main bedrock scarp itself is oversteepened at its base, but the major portion of the scarp, as Noble (1926, p. 425) has pointed out, slopes west at about 35°. In some places, notably a few miles south of Ballarat, this 35° slope forms a nearly plane surface of very considerable area, two or three thousand feet high, which is dissected only by narrow acutely V-shaped gullies running directly down the slope (Figure 13). Viewed from a distance, the range front here appears to be a fault footwall so recently exposed to erosion that the huge

Figure 13. The west face of the Panamint Range a few miles south of Ballarat. The face of the range, cut in resistant pre-Tertiary rocks, is nearly a plane surface, dissected only by shallow and narrow gullies. The summit portion of the range here is a remnant of an old erosion surface of low relief.

Figure 14. A view looking south along the outcrop of the strike-slip fault on the west edge of the Panamint Range just south of the Towne's Pass road. Stream courses running down the slope of the range, to the left in the photograph, are deflected to the north by the ridges in the center of the picture before resuming their westwardly course into Panamint Valley.

facets remain as nearly continuous remnants of the fault surface itself. The rock in which the facets are cut is greatly crushed, sheared, and discolored, which strengthens the impression that the facet surfaces actually represent a fault plane (Noble, 1926, pp. 426-427).

One of the most conspicuous evidences of recent faulting along the west edge of the Panamint Range is a large north-trending graben in the alluvium just south of the mouth of Wildrose Canyon. This structural feature is expressed topographically as a depression over three miles long, nearly a mile wide, and 400 feet deep in its deepest part.

Large fans spread out from the mouths of Wildrose Canyon and the canyons north of Wildrose into Panamint Valley, so that opposite and north of Wildrose Canyon the lowest part of the valley is in the valley's center. The west-facing scarps on the east side of the valley here, however, show unmistakable evidences of very recent movement on the faults which lie at their bases, as will be explained in a following paragraph. The presence of large alluvial fans at the west base of the Panamint Range opposite and north of Wildrose Canyon, and their absence farther south, is probably the result of the difference in bedrock types on the west slope of the range; as the latest uplift of the range by faulting progressed, the pre-Cambrian metamorphic rocks of the range front south of Wildrose Canyon resisted erosion to such an extent that very small fans are present at their base, whereas the softer material of the salient of Tertiary rocks yielded enough detritus for the building of large fans.

At the mouth of Wildrose Canyon there is a pronounced change in the direction of trend of the west margin of the Panamint Range which coincides with the south end of the badland salient of Tertiary rocks. South of this point the margin of the range trends almost due north, but north of Wildrose Canyon, in the area to which particular attention was devoted in this study, the range margin trends about N 40° W. North of the canyon the west slope is considerably gentler than to the south, but the range front is rectilinear and is not embayed by heads of alluvial fans. This suggests that the uplift of this part of the range by faulting has been as recent as it was farther south, but that the slope is less steep here for one or more of three reasons: because of a lesser amount of uplift here than farther south, or because the total uplift is accomplished here by step-faulting rather than by faulting along a single break, or because the rate of erosion of the soft Tertiary rocks in this salient is more rapid than that of the old metamorphics to the south.

The suggestion of recent fault uplift of this part of the range conveyed by its general form is convincingly supported by an examination of the smaller topographic features along the west edge of the salient. Just north of the mouth of Wildrose Canyon, as is shown in Figure 12, is a series of aligned, triangular-faceted spur ends at the edge of the range; and within the range itself, near its western edge, are two prominent west-facing scarps, each a few hundred feet high, unquestionably the result of faulting. The locations of these scarps are indicated by the positions of the faults shown on the geologic map. The most impressive topographic feature indicating recent tectonic activity in this zone, however, is a rectilinear fault trace, along which stream courses have been displaced, at the west edge of the range just south of the Towne's Pass road. This fault trace, shown in Figures 14 and 15, extends two miles in a northwesterly direction and is crossed by 19 stream gullies which have been offset by strike-slip movement on the fault in such

Figure 15. Another view of the aligned ridges along the strike-slip fault shown in Figure 14. To the right are the sand dunes at the north end of Panamint Valley.

Figure 16. A view of the uplifted surface of moderate relief which forms the highest part of the Panamint Range where crossed by the strip mapped. In the center is the playa in White Sage Flat; to the right is a small portion of Harrisburg Flat. In the distance are the Argus and Sierra Nevada Ranges.

Figure 17. A view from the summit of the Panamint Range looking east down Trail Canyon into Death Valley. Cambrian and Ordovician strata are exposed on the sides of Trail Canyon. The most conspicuous white bed is the Zabriskie quartzite member of the Wood Canyon formation.

a way as to show the southwest side of the fault moved relatively northwest. The recent movement on this fault also included a dip-slip component, the southwest side of the fault having been raised relative to the northeast side by about 40 feet in the central part of the linear trace of the fault where its movement was greatest. This dip-slip movement thus raised the valley block with respect to the mountain block, creating a range-facing scarp and a narrow discontinuous trench along the edge of the range. The offset stream courses originate on the west slope of the range and run westwardly to this trench, where they turn and follow the trench northwestwardly for a short distance, then turn to the west, resuming their former courses, and run out upon the alluvial fans. During the considerable time which has elapsed since the fault movement displaced the gullies, infrequent torrents have rounded off the sharp angles of the stream courses at the fault trace, and two of the larger courses have been completely straightened by this process. This rounding of the angles in the stream courses lessened to some extent the accuracy of the measurement of horizontal dislocation along the fault. Offsets of the different streams range from 80 to 200 feet, with the larger offsets in the central part of the fault trace.[3] Similar recent strike-slip faults, with the same direction of relative movement, have been recently reported in Death Valley (Curry, 1938).

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[3] This strike-slip fault along the west edge of the Panamint Range is very similar in direction of trend, direction of relative movement of the two sides, and in topographic expression to certain portions of the San Andreas fault, particularly along the west side of the Temblor Range. An aerial photograph of the San Andreas fault in this region is given as Plate IV in R. D. Reed: Structural evolution of Southern California. American Association of Petroleum Geologists, Tulsa, Okla. (1936).

Within the area mapped for this study the west flank of the Panamint Range slopes upward from the fault zone along its west edge at a relatively low angle (approximately 15° from the horizontal) until it encounters a steep west-facing scarp high on the side of the range. This scarp trends in a northerly direction, and its prolongation north from the strip mapped forms the east side of Towne's Pass, through which runs one of the roads into Death Valley from the west. The position of the scarp is not well shown on the topographic map of the Ballarat quadrangle, but it coincides with the contact between the older Quaternary alluvium and the Paleozoic rocks shown on the geologic map of Plate I. The average slope of the scarp is about 35°. It is three to four hundred feet high in the northern part of the area mapped, but its height decreases southward until it ceases to exist at the south end of the wedge of Paleozoic rock.

Extending for eight to ten miles east of the scarp just described is a broad area of subdued topography which is the highest part of the Panamint Range in the strip mapped. This surface of low to moderate relief bevels the upturned edges of beds of both the Tertiary fanglomerate and of the pre-Cambrian and lower Cambrian metasediments to the east. The area of subdued topography in the center of the Panamint Range stands at elevations of 5000 to 7000 feet and contrasts very strongly with the rugged, highly dissected east and west slopes of the range; clearly it is a remnant of a once more extensive old-age surface which has been uplifted relatively recently and is being reduced in size by headward erosion of the canyons on both sides of the range. Included within this area of moderate relief are White Sage Flat and Harrisburg Flat. The lower portions of these flats, however, are filled with Quaternary alluvium and their surfaces are therefore not parts of the old erosion surface. This is particularly evident in White Sage Flat, where an east-spreading fan has recently dammed Nemo Canyon and a small playa lake has formed behind the dam. This playa, and parts of the area of subdued topography surrounding it, are shown in Figure 16.

The presence of an uplifted old erosion surface in the Panamint Range north of Wildrose Canyon was noted by Campbell, who wrote that it "looks like an ordinary stretch of desert transplanted to the summit of a rugged mountain" and that its nature "certainly leads to the belief that it was very recently elevated to its present position" (1902, p. 19). Ball (1907, p. 202) noted remnants of an older topography along the crest of the Panamint Range north of Towne's Pass, and Murphy, in his report on a portion of the range south of Wildrose Canyon (1932, p. 335), described uplifted remnants of an old erosion surface east of Ballarat which had been previously mentioned by Noble (1926, p. 426).

The area of moderate relief high in the Panamint Range within the strip mapped is very probably to be correlated with the similar areas to the west already described, although no part of it is covered by a sheet of basaltic lava. The small isolated patch of basalt just south of White Sage Flat, forming a cap for a low hill of pre-Cambrian rock, is believed to be an outlier of the Tertiary Nova formation and thus older than the period of erosion which developed the surface of subdued relief. North of Towne's Pass, however, an east-dipping basalt sheet of considerable size caps the flat higher portions of the Panamint Range, and is similar in all respects to the basalt sheets on the summits of the Coso and Argus Ranges.

On the east, the upland belt of subdued topography in the Panamint Range within the area studied is bounded approximately by a line connecting

Aguerreberry Point with the head of Nemo Canyon. East of this line is the steep eastern flank of the Panamint Range. From the crest of the range at elevations of 5000 to 7500 feet the eastern slope descends to the line of contact between the bedrock of the Panamint Range and the alluvium of Death Valley, which contact ranges in elevation from 0 to 1500 feet above sea-level. This slope is much dissected by deep, steep-sided canyons which extend up into the range from the heads of the large alluvial fans on the west side of Death Valley; the largest of these canyons within the area of the present study is Trail Canyon, shown in Figure 17. Steeply dipping stratified rocks of variable resistance to weathering make the intercanyon areas exceedingly rugged.

Evidences of recent faulting, clear and unmistakable along the west edge of the Panamint Range, are absent on the eastern margin of the range where it is crossed by the strip mapped. On the west side of the range the contact between bedrock and alluvium is nearly straight, but on the east side it is sinuous; the heads of the large alluvial fans extend far up the canyons into the range, and spur-end facets are lacking. The topography of the east slope of the Panamint Range is, in fact, very similar to that of the east slope of the Sierra Nevada in the area mapped, and, as in the case of the Sierra Nevada, the general form of the Panamint Range strongly suggests that its steep and high eastern front is a deeply eroded fault scarp. This is indicated because summit upland of subdued relief, though manifestly uplifted by recent faulting along the west edge of the range, does not slope to the east and disappear under the alluvium of Death Valley; instead, it appears to have been raised without perceptible tilting, and is terminated abruptly on the east by the youthful topography of the steep eastern slope.

In summary, then, the topographic features of this portion of the Panamint Range indicate that a land surface of moderate relief, developed in an older erosion cycle, was uplifted along fault zones bounding the range on the west and east, and that the movements along this zone on the west have continued into the Recent epoch.

DEATH VALLEY

Immediately east of the Panamint Range is Death Valley, a region of such unusual natural and historical interest that in 1933 it was made a national monument. This desolate and forbidding valley received its name from the Manly emigrant party, some of whose members died there in 1849 in their attempt to reach the California gold fields.

Death Valley is a long and narrow basin which extends in a general north-northwesterly direction for approximately 165 miles and has an average width of 8 to 10 miles. The large portion of the valley floor below sea-level includes the lowest point on the North American continent not covered by water, 279.5 feet below sea-level. Directly west of the valley is a mountain belt including, from north to south, the LastChance Range, the Panamint Range, and the Owlshead Mountains. East of the valley are Gold Mountain and, farther south, the Amargosa Range, which includes, from north to south, the Grapevine Mountains, the Funeral Mountains, and the Black Mountains.

The small portion of Death Valley included within the area of this study is on the western edge of the deepest part of the valley, between the high central portions of the Panamint and Black Mountains. The lowest point in Death Valley is on the eastern edge of the valley; just east of this point the very steep west-facing scarp of the Black Mountains rises 5000 feet in a horizontal distance of two miles. On a large part of this scarp triangular facets are so well developed that the entire lower half of the scarp is virtually a plane surface, dissected only by narrow slot-like canyons with very small alluvial cones at their mouths. The similarity of this scarp on the west side of the Black Mountains to the scarp on the west side of the Panamint Range south of Wildrose Canyon has been stressed by Noble, who described both features and showed that they are the result of faulting along zones at the eastern edges of Death and Panamint Valleys. In discussing these two fault zones Noble stated his belief that "parts of their huge scarps are fresher than any other scarps of similar magnitude in the West" (1926, p. 425). He considered it probable that the date of the faulting represented by the two great scarps is early Quaternary (1926, p. 427). The evidence is plain that the deepest part of Death Valley attained its present position by being lowered along the fault zone at the west base of the Black Mountains just as the deepest portion of Panamint Valley was lowered along the fault zone at the west edge of the Panamint Range.

DISCUSSION OF GEOMORPHIC FEATURES

The area of this study can be divided into three geomorphic elements: alluviated valleys, which have no outlets to the sea and which drain into basins in or near the area mapped; steep, rugged mountain slopes, which form the sides of the ranges crossed; and surfaces of relatively low relief, which occupy the highest parts of the area. The latter appear to be remnants of a single erosion surface of low to moderate relief which once extended across the entire region.

Certain features of the geology of the Coso Range afford a means of dating this old erosion surface. At low elevations around the west, north, and east margins of the range are exposures of gently dipping, poorly consolidated sediments of the Coso formation. At the base of this formation is a coarse fanglomerate consisting of fragments of plutonic rocks similar to the material composing the granitic core of the range. The composition of this fanglomerate, and its distribution around the edges of the range, indicate that its deposition was induced by an uplift[4] of the range after the long-continued degradation which resulted in the old-age erosion surface now represented on the summit by Centennial Flat. Since the Coso formation is definitely dated as late Pliocene or early Pleistocene on the basis of fossil vertebrates found in its basal fanglomerate (Schultz, 1937), it follows that at least the latter part of this degradation took place in the middle or latter part of the Pliocene epoch.

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[4] This uplift of the Coso Range immediately preceding the deposition of the Coso formation was presumably accomplished by faulting near the margins of the present range. On its east margin the range was raised along the fault zone now buried by the Coso formation, basaltic lava, and Quaternary alluvium. On its west edge the range may likewise have been raised by movement along faults now buried, or the uplift may have occurred along the large fault extending north from the east border of Cactus Flat, upon which later movement has taken place. Only a part of the present relief was caused by the uplift prior to the deposition of the Coso formation; much of the height of the range is the result of a later elevation which occurred after the deposition of the Coso formation and the extrusion of the overlying basalt, and which took place chiefly along the step-faults on the west border of the range.

A study of the orogenic history and geomorphology of neighboring regions yields additional information regarding this old erosion surface. In both the Sierra Nevada (Matthes, 1933, pp. 34-36) and in the region south of the area of the present study (Hulin, 1934, pp. 419-422), a period of virtually undisturbed erosion had produced, by the middle part of the

Miocene, an old-age land surface of low relief. The Sierra Nevada area and the area immediately to the east drained into the Pacific Ocean. In middle or upper Miocene the entire region was affected by faulting; the eastern escarpment of the Sierra Nevada come into existence, and east of this escarpment mountains and basins were created by block-faulting. The material eroded from the newly-uplifted mountains east of the Sierra Nevada, instead of escaping into the Pacific, accumulated in local basins as the fossiliferous Rosamond and Ricardo series, of upper Miocene and lower Pliocene ages. Faulting and folding followed the final Ricardo sedimentation, and then ensued a long period of relatively undisturbed erosion which resulted in the development of an erosion surface of low relief named the "Ricardo erosion surface" by Baker (1911, p. 138).

The type locality of the Ricardo erosion surface is 40 miles south of the Coso Range. At various places the Ricardo surface has been covered by thin flows of black olivine basalt and has later been deformed by folding and faulting (Baker, 1911, pp. 366-367 and Plate 42; 1912, pp. 126-128, 131-132). If this basalt is correlative with the similar flows capping the postmature erosion surfaces of the Coso and Argus Ranges, as seems highly probable, the Ricardo surface and the old erosion surface preserved in the summit portions of the Coso and Argus Ranges were both in existence, and were both partially covered by olivine basalt flows, just before the faulting to which this general region owes most of its present relief. The old erosion surface in the Coso Range was formed shortly before the deposition of the fossiliferous late Pliocene or early Pleistocene Coso formation. The suggestion is very strong, therefore, that the Ricardo surface and the surface preserved on the summits of the Basin Ranges of the present area are of the same age, and that they were developed by erosion during a period at least approximately corresponding to the Pliocene epoch.

In much of the surrounding territory the Pliocene is known to have been an epoch of erosion with little or no crustal movement. In the Sierra Nevada, the canyons produced by the late Miocene uplift of the range had widened to mature valleys by the latter part of the Pliocene (Matthes, 1933, p. 36). Baker (1911, pp. 361-365; 1912, p. 138) has pointed out that the Ricardo surface is developed over much of the Mohave Desert, and he believes that it may be represented along the summit of the San Bernardino Mountains. Old-age erosion surfaces, many of them of known or suspected late Pliocene age, have been reported in the high parts of many ranges in southern and western Nevada, among them the Amargosa, Belted, and Kawich Ranges (Ball, 1907, pp. 161, 99-100, 119), Cedar Mountain (Buwalda, 1914, p. 362), the Toyabe Range (Meinzer, 1915, p. 90), the Toquima Range (Ferguson, 1924, pp. 61-62), and the Spring Mountains (Hewett, 1931, pp. 4-5). Similar subdued topography is present in the summit portions of the central Inyo Range. It is therefore quite well established that during the Pliocene epoch of crustal stability in the Sierra Nevada and the southwestern Great Basin the rugged topography created by the earlier diastrophism was reduced by erosion to a condition of low to moderate relief. The lack of known middle or early upper Pliocene land-laid deposits in the California desert region south and east of the Sierra Nevada suggests that the rock which was removed during the development of the late Pliocene surface of low relief was carried to the Pacific; Reed (1933, p. 251) has already inferred that the exceedingly thick clastic Pliocene marine sediments of the Los Angeles and Ventura Basins were derived from the Mohave Desert region.

This extensive Pliocene surface of low relief began to be broken by block-faulting late in the Pliocene or early in the Pleistocene. The elevated blocks, or portions of blocks, form the present mountain ranges, and the depressed blocks, or portions of blocks, form the present basins. Considerable erosion in the mountains and deposition in the valleys has occurred since the faulting commenced, but the area is still in a decidedly youthful stage in the erosion cycle begun by the dislocation of the Pliocene surface. Within the area mapped for this study major faulting has taken place along the western margins of the Coso, Argus, and Panamint Ranges, and on the eastern margins of the Sierra Nevada and the Coso and Panamint Ranges. Similar faulting, of lesser magnitude, has occurred along the west edges of the groups of hills west and east of Darwin and on the east edge of the Argus Range. Topographic features of the fault zone at the west margin of the Panamint Range indicate that movement along it has continued in the Recent epoch.

STRATIGRAPHY AND PETROGRAPHY

GENERAL STATEMENT

The rocks exposed in the area mapped range in age from pre-Cambrian to Quaternary. Outcrops of pre-Cambrian rocks are confined to the Panamint Range, where the exposed pre-Cambrian metasedimentary rocks have a thickness of approximately 15,000 feet. Paleozoic rocks are widely distributed, outcropping in the Darwin Hills and in the Argus and Panamint Ranges; they consist almost entirely of limestones, dolomites, quartzites, and shales.

Fossiliferous horizons are numerous enough to indicate that all the Paleozoic systems, with the possible exception of the Permian, are represented. The thickness of the Paleozoic rocks is slightly over 30,000 feet, about three-quarters of which is made up of Cambrian and Carboniferous beds. No Mesozoic sediments were found, but the widespread granitic intrusive rocks are throught to be of late Jurassic age. Tertiary rocks, sedimentary and volcanic, are exposed in the Coso and Panamint Ranges. The basalt cappings of the Coso and Argus Ranges are probably early Quaternary; various lacustrine and alluvial deposits are known to be of Quaternary age.

PRE-CAMBRIAN ROCKS

In the central portion of the Panamint Range, between Tertiary fanglomerate on the west and lower Paleozoic strata on the east, is the only part of the area mapped where pre-Cambrian rocks are exposed. Nearly all of these rocks are metasedimentary, and schist is the most abundant type. The metasediments have a general easterly dip and are overlain unconformably by lower Cambrian strata.

The pre-Cambrian rocks were less studied than any of the other units mapped, and their stratigraphy was not investigated thoroughly. Approximately the lowest third of their exposed thickness, outcropping in lower Wildrose Canyon, consists of strongly metamorphosed schists and limestones intruded by a few small bodies of diabase. Schist types included quartz-biotite schist, quartz-biotite-muscovite schist, and biotite-actinolite schist. The limestones are crystalline, light buff or gray, and often contain sericite and tremolite. Diabase is present as dikes, sills, and irregular intrusive masses. Murphy, in his study of a part of the Panamint Range south of Wildrose Canyon (1932), named this group of rocks the Panamint metamorphic complex.

Above these rocks is a group of approximately equal thickness which consists predominantly of quartz-biotite schist, slate, and phyllite. This group is well exposed just east of the road connecting Wildrose Canyon with Harrisburg Flat. Most of these rocks weather to a dark brown color, but a few dolomitic limestone and quartzite beds, more resistant than the other rock types, are lighter brown. The limestones commonly are conglomeratic, consisting of limestone fragments cemented by limestone. Most of the limestones contain sparsely scattered flakes of sericite. Closely spaced stratification lines are visible in many of the slate and phyllite layers. High in the section is a bed of coarse metamorphosed conglomerate.

On the basis of stratigraphic position and lithologic similarity this second group of pre-Cambrian rocks is correlated with the Surprise formation of Murphy (1932, pp. 344-348). The Marvel dolomitic limestone, described by Murphy as lying between the Panamint metamorphic complex and the Surprise formation in the district which he studied, is evidently not present in the area of this investigation. Murphy suggested that an unconformity separates the Panamint metamorphic complex from the overlying rocks, because the Panamint metamorphic complex is more coarsely crystalline and more highly folded than the rocks above it. There is similar evidence of a depositional break in the area north of Wildrose Canyon, but no actual outcrop of an unconformity was seen.

The uppermost third of the exposed thickness of the pre-Cambrian rocks is composed chiefly of buff and darker brown thin-bedded dolomitic limestones. These rocks contain both small and large folds (Figures 18 and 19), but in

Figure 18. Thin-bedded dolomite in the upper part of the pre-Cambrian, near the head of Trail Canyon.

Figure 19. The base of the Cambrian near the head of Trail Canyon. On the left is highly folded pre-Cambrian dolomite; on the right are dark shales and slates of the Johnnie formation.

Figure 20. Part of a bed of cross-laminated quartzite in the Wood Canyon formation just west of Aguerreberry Point.

common with the other pre-Cambrian units they have a general easterly dip. A few schist members are present in the dominantly dolomitic series. This highest unit of the pre-Cambrian is at least in part correlative with the Telescope group of Murphy (1932, pp. 348-350). It overlies the schist-slate-phyllite group of the middle pre-Cambrian without apparent angular discordance.

Murphy found no fossils in the part of the Panamint Range which he studied, but on lithologic grounds he tentatively assigned the Telescope group to the lower Paleozoic. Noble (1934, p. 174) suggested that Murphy's Panamint metamorphic complex may be Archean and the Telescope group Algonkian. This suggestion is supported by the discovery, during the present investigation, of lower Cambrian fossils in beds which overlie the Telescope group unconformably.

At various other places in southeastern California are exposures of rocks of known or suspected pre-Cambrian age; among these localities are the Inyo Range (Knopf and Kirk, 1918, pp. 23-25), the Randsburg district (Hulin, 1925, pp. 29-31), the region east of Death Valley (Noble, 1934, p. 174), and the San Gabriel and San Bernardino Mountains (Miller, 1934, pp. 63-64; 1938, p. 438). No correlation of the pre-Cambrian rocks of the Panamint Range with those of these other localities was attempted in the present study.

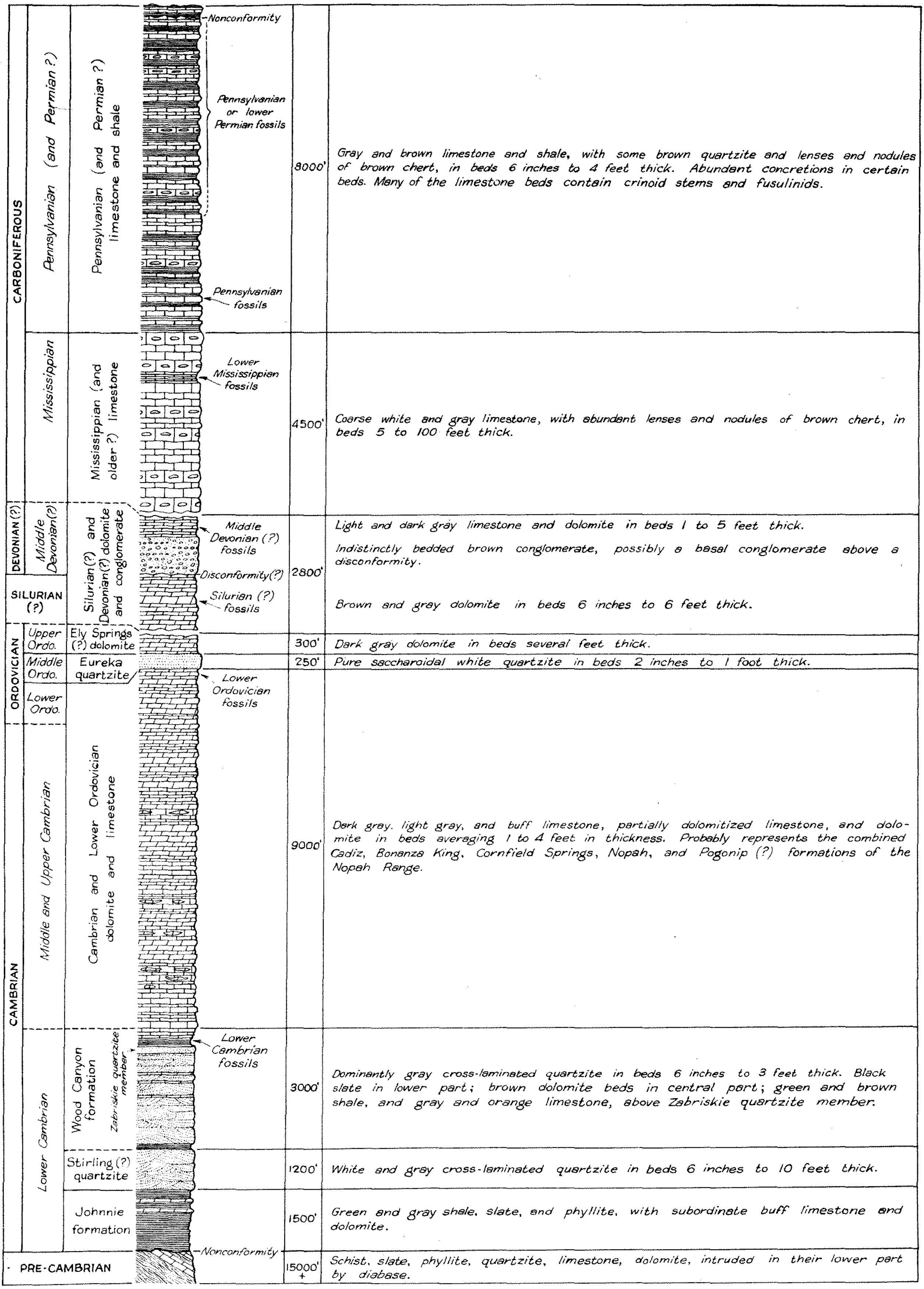
CAMBRIAN AND ORDOVICIAN ROCKS

Resting upon the pre-Cambrian rocks of the Panamint Range with a pronounced angular unconformity is a thick group of apparently conformable strata in which Cambrian and Ordovician fossils were found. The lowest beds within these strata in which determinable lower Cambrian fossils were found are about 5000 feet stratigraphically above the base of the group. Although the age of the beds making up the lowest 5000 feet of this group is thus not known from paleontologic evidence, these beds are believed to be lower Cambrian, and the nonconformity at their base is considered to be the base of the Cambrian rocks in the area. The Cambrian and Ordovician rocks lie on the east slope of the Panamint Range and are excellently exposed in Trail Canyon (Figure 17). Their total exposed thickness is about 15,000 feet. Though fossils are scarce, the presence of distinctive lithologic units in the Cambrian and Ordovician section makes possible correlations with formations previously named and desdribed in the region east of Death Valley. Definite correlations are not possible for the post-Ordovician rocks. A columnar section of the Paleozoic rocks exposed in the area is given as Plate 9. Plate 9a shows the area of this report in its relation to neighboring areas where the Paleozoic rocks have been studied.

Johnnie Formation (lower Cambrian)

The basal Cambrian beds are gray and green shales, slates, and phyllites, with subordinate interbedded gray and buff limestones and dolomites. The shales, slates, and phyllites are gray or greenish gray on fresh surfaces, very fine grained, highly fissile, and frequently contain small cubes of hematite which are pseudomorphic after pyrite. The cleavage is usually, but not always, parallel to the bedding planes. Thin gray dolomite beds and thicker pinkish buff dolomitic limestone members are particularly abundant in the northern part of the area, but nowhere make up more than one-fifth of the total section. Quartz veins, presumably of late Mesozoic age, are common throughout the section.

This lowermost Cambrian unit, about 1500 feet thick, is correlated with



CARBONIFEROUS	Pennsylvanian (and Permian ?)	Pennsylvanian (and Permian ?) limestone and shale	8000'	Gray and brown limestone and shale, with some brown quartzite and lenses and nodules of brown chert, in beds 6 inches to 4 feet thick. Abundant concretions in certain beds. Many of the limestone beds contain crinoid stems and fusulinids.
	Mississippian	Mississippian (and older ?) limestone	4500'	Coarse white and gray limestone, with abundant lenses and nodules of brown chert, in beds 5 to 100 feet thick.
DEVONIAN (?)	Middle Devonian (?)	Silurian (?) and Devonian (?) dolomite and conglomerate	2800'	Light and dark gray limestone and dolomite in beds 1 to 5 feet thick. Indistinctly bedded brown conglomerate, possibly a basal conglomerate above a disconformity.
SILURIAN (?)				Brown and gray dolomite in beds 6 inches to 6 feet thick.
ORDOVICIAN	Upper Ordo.	Ely Springs (?) dolomite	300'	Dark gray dolomite in beds several feet thick.
	Middle Ordo.	Eureka quartzite	250'	Pure saccharoidal white quartzite in beds 2 inches to 1 foot thick.
	Lower Ordo.	Cambrian and Lower Ordovician dolomite and limestone	9000'	Dark gray, light gray, and buff limestone, partially dolomitized limestone, and dolomite in beds averaging 1 to 4 feet in thickness. Probably represents the combined Cadiz, Bonanza King, Cornfield Springs, Nopah, and Pogonip (?) formations of the Nopah Range.
CAMBRIAN	Middle and Upper Cambrian			
	Lower Cambrian	Wood Canyon formation Zabriskie quartzite member	3000'	Dominantly gray cross-laminated quartzite in beds 6 inches to 3 feet thick. Black slate in lower part; brown dolomite beds in central part; green and brown shale, and gray and orange limestone, above Zabriskie quartzite member.
		Stirling (?) quartzite	1200'	White and gray cross-laminated quartzite in beds 6 inches to 10 feet thick.
		Johnnie formation	1500'	Green and gray shale, slate, and phyllite, with subordinate buff limestone and dolomite.
PRE-CAMBRIAN			15000' +	Schist, slate, phyllite, quartzite, limestone, dolomite, intruded in their lower part by diabase.

Plate 9. Columnar section of the Paleozoic rocks. Breaks in the section indicate that the sequence is interrupted by faulting.

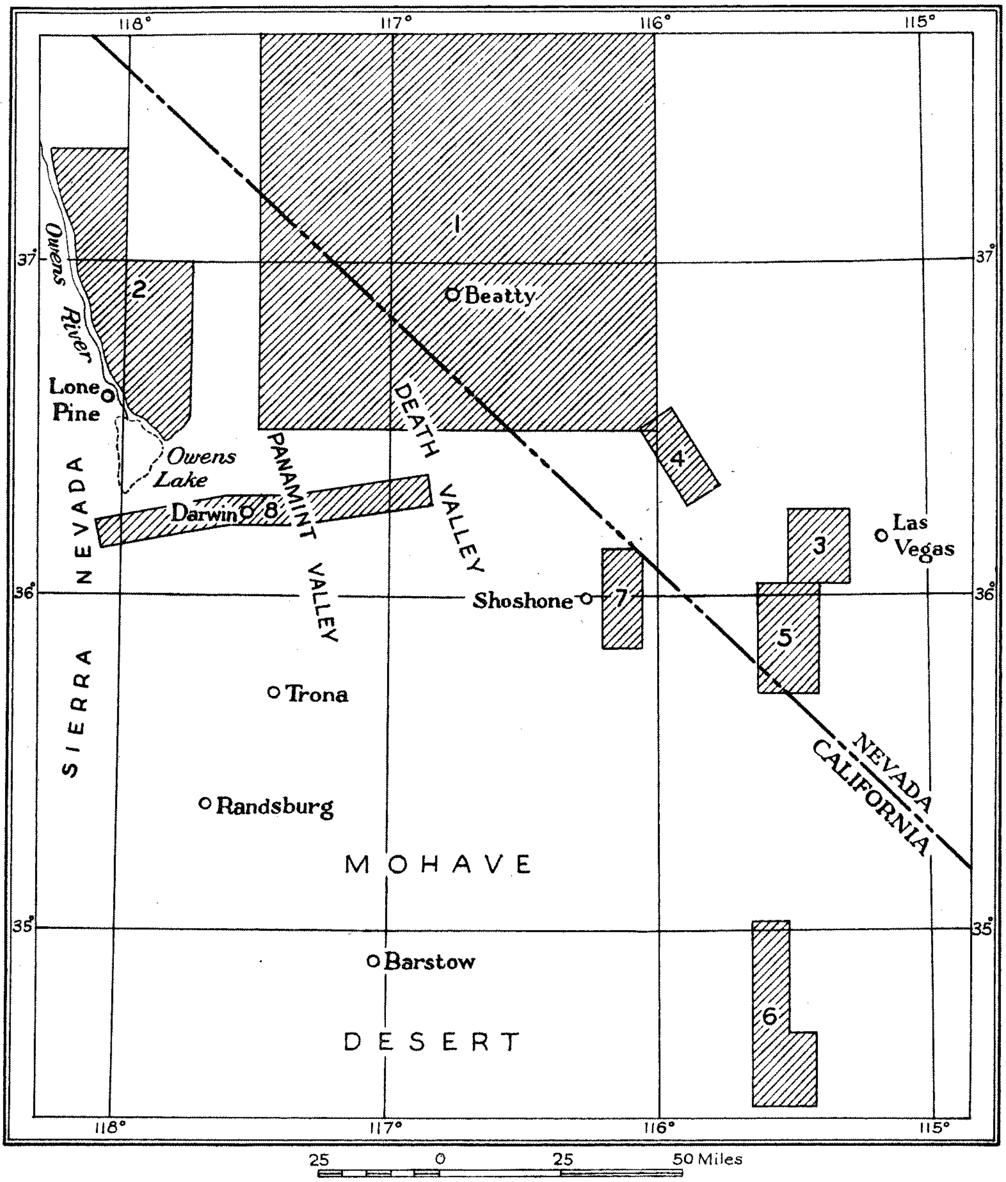


Plate 9a. Index map of a part of southeastern California and southwestern Nevada, showing areas where the Paleozoic rocks have been studied.

(1) Southwestern Nevada and an adjacent part of eastern California (Ball, 1907). Reconnaissance geologic map. Only slight attention devoted to Paleozoic stratigraphy.
(2) Southern and central portion of the Inyo Range (Knopf and Kirk, 1918). Reconnaissance geologic map.
(3) East-central part of Spring Mountain Range (Glock, 1929). Geologic map.
(4) Northwest part of Spring Mountain Range (Nolan, 1929). Geologic map.
(5) Goodsprings quadrangle (Hewett, 1931). Geologic map.
(6) Providence and Marble Mountains (Hazzard, 1933 and 1938). Geologic map; particular attention to Cambrian rocks.
(7) Nopah and Resting Springs Ranges (Hazzard, 1937). Columnar section.
(8) Area of the present report.

the lower Cambrian Johnnie formation of the region east of Death Valley, but it is believed that probably only the upper part of the Johnnie is represented in the area mapped. Nolan (1929, pp. 462-463) has described very similar greenish slaty shales and dolomites from the upper part of the type Johnnie formation in the Spring Mountains of southern Nevada, where the formation attains a total thickness of more than 4500 feet. Brown and greenish shales and thin dolomites are likewise the dominant rocks of the upper part of the Johnnie (?) formation in the Nopah Range, 35 miles east of Death Valley (Hazzard, 1937, p. 279), though some sandstones are interbedded with these strata. In this latter locality the Johnnie (?) is 2550 feet thick, and is underlain conformably by the thick basal Cambrian Noonday dolomite.

Low-angle thrust faults of large displacement and of post-Paleozoic age have been discovered in the region directly east of Death Valley (Glock, 1929, pp. 335-337; Nolan, 1929, pp. 465-471; Hewett, 1931, pp. 43-55; Noble, 1938). On many of these thrusts the amount and direction of horizontal movement is unknown. It is, therefore, hazardous to speculate about Paleozoic paleogeography on the basis of the present meager data. However, the overlap indicated by the absence of the Noonday dolomite and of the lower part of the Johnnie formation from the portion of the Panamint Range mapped in the present study suggests a transgression of the lower Cambrian sea across the Death Valley region from east to west.

Stirling (?) quartzite and Wood Canyon formation (lower Cambrian)

Above the Johnnie formation is a quartzite unit, with a maximum thickness of about 1200 feet, believed to represent the Stirling quartzite, which overlies the Johnnie formation in the Spring Mountains (Nolan, 1929, p. 463) and in the Nopah Range (Hazzard, 1937,pp. 278-279). This quartzite, in beds several inches to several feet thick, is white and gray, weathering to a light pinkish brown, and is fine to medium-grained. To the south the unit thickens and contains several thin black slate members. Many of the quartzite beds are cross-laminated or ripple-marked, and pebbly lenses are not uncommon. Small quartz veins are present throughout the section. The correct position for the top of the Stirling (?) quartzite is not known, for the lower part of the overlying Wood Canyon formation is largely composed of similar quartzite. The thickness of the combined Stirling (?) quartzite and Wood Canyon formation is considerably less here than in the Nopah Range, and it is possible that the Wood Canyon formation rests directly on the Johnnie and that the Stirling quartzite is not represented in this area. For this reason the Stirling (?) quartzite and Wood Canyon formation has been mapped together as a single unit.

Overlying the Stirling (?) quartzite are about 3000 feet of lower Cambrian strata referred to the Wood Canyon formation, orginally described by Nolan (1929, pp. 463-464) from the Spring Mountains and recently recognized by Hazzard (1937, p. 278) in the Nopah Range. The Wood Canyon formation consists largely of quartzite, but shale and limestone are present in its upper part. The base of the formation is tentatively placed at the bottom of a 50-foot bed of dark gray spotted slate, for a shale member is at its base in the Nopah Range. Above the slate are roughly 2600 feet of cross-laminated brown and gray quartzite in beds averaging one to four feet in thickness. The typical appearance of these beds is shown in Figure 20. Ripple marks are common in the quartzites, and pebbly lenses are distributed through the section. The beds contain a few small quartz veins. In its upper half the quartzite unit is micaceous and somewhat shaly, and contains a few beds of gray, brown-weathering, sandy dolomite.

Near the top of this quartzite unit is a very conspicuous member, about 70 feet thick, consisting of light pink cross-laminated saccharoidal quartzite. This is identified as the Zabriskie quartzite member, named by Hazzard from the upper part of the Wood Canyon formation in the Nopah Range. Aguerreberry Point, popular with Death Valley visitors because it affords an excellent view of the valley, is located on the outcrop of the Zabriskie quartzite. The Zabriskie member is traceable across most of the area mapped and is known at many other localities in this general region. The gray quartzite just below the base of the Zabriskie contain tube-like structures, several inches long, oriented perpendicular to the bedding planes. These appear to be sand-filled borings of worms of the Scolithus type. Similar tubes are present at the base of the Zabriskie in the Nopah Range.

The uppermost 300 feet of the Wood Canyon formation, above the Zabriskie quartzite, consist of shale and limestone with a little interbedded sandstone. Immediately above the Zabriskie quartzite is a green shale member about 100 feet thick which weathers into small thin platy chips. Interbedded with it are thin layers of brown calcareous sandstone, not more than two inches thick, which contain trilobite remains. Locally, these fossils are very abundant in the brown layers. A collecting locality in this zone which is better than any discovered in the mapped area lies just east of Mosaic Canyon on the north edge of Tucki Mountain, 15 miles north of Harrisburg. The trilobite fragments of this zone were identified by Dr. Josiah Bridge as representing a single species, probably Olenellus gilberti Meek, indicative of lower Cambrian age. Lower Cambrian fossils have been found in similar green shale directly above the Zabriskie quartzite in the

Nopah Range (Hazzard, 1937, p. 278).

Above this green shale are about 200 feet of dark gray and reddish limestones and greenish shales. These beds extend upward without any break into the overlying thick Cambrian and Ordovician limestones and dolomites, so that here, as in the Nopah Range, the upper limit of the Wood Canyon formation is not well defined.

On the geologic map (Plate 1) the outcrop of the combined Stirling (?) quartzite and Wood Canyon formation widens greatly at its north end because much of the Wood Canyon is exposed on a dip slope.

The Stirling (?) quartzite and the lower part of the Wood Canyon formation are similar to, and may be correlatives of, the lower Cambrian Prospect Mountain quartzite of southern Nevada (Ball, 1907, p. 28; Westgate and Knopf, 1932, pp. 6-8) and the lower Cambrian Campito sandstone of the Inyo Range (Knopf and Kirk, 1918, pp. 27-28). The part of the Wood Canyon formation above the Zabriskie quartzite is similar lithologically to the lower Cambrian Pioche shale, which lies just above the Prospect Mountain quartzite at Pioche, Nevada, and also contains _Olenellus gilberti_ (Westgate and Knopf, 1932, p. 10).

Cambrian and lower Ordovician dolomite and limestone

Overlying the Wood Canyon formation conformably is a series of limestones, dolomitic limestones, and dolomites approximately 9000 feet thick. These rocks are crystalline and thin-bedded, and consist of alternating light and dark gray layers (Figure 21). In the lower part of the series the dark gray dolomitic limestones are in places mottled with light gray stringers of dolomite. In the entire series there are no conspicuous marker beds. No fossils were found in the lower part of the dolomitic series, but near its

Figure 21. Cambrian and lower Ordovician limestone and dolomite on the east slope of the Panamint Range. Death Valley is in the background.

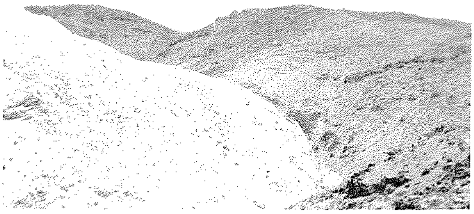


Figure 22. The contact between Mississippian limestone (white) and Pennsylvanian limestone and shale (gray) in the northern Argus Range.

Figure 23. Unconformity in the Pennsylvanian or Permian strata in Darwin Canyon.

top, just below the Eureka quartzite, is a zone in which a large gastropod and a sponge are quite abundant. Dr. Edwin Kirk identified specimens of these forms, from fossil locality 8, as Mitrospira longwelli Kirk and Receptaculites sp. respectively; the gastropod is a typical upper Pogonip (lower Ordovician) fossil.

A similar series of limestones, dolomitic limestones, and dolomites, about 8000 feet thick, occupies the same stratigraphic position, between the Wood Canyon formation and the Eureka quartzite, in the Nopah Range (Hazzard, 1937, pp. 276-278). In this series Hazzard has found small middle and upper Cambrian, as well as lower Ordovician, faunas, and he has subdivided the series into the following formations: Cadiz, Bonanza King, and Cornfield Springs formations (middle Cambrian), Nopah formation (upper Cambrian), and Pogonip (?) dolomite (lower Ordovician). His Pogonip (?) dolomite is known to be represented in the uppermost part of the dolomitic series in the Panamint Range, and it seems virtually certain that middle and upper Cambrian beds are present in this series, though no fossils of these ages were found.

Eureka quartzite (middle Ordovician)

Resting conformably on the dolomitic limestone described above is a quartzite unit, 250 feet thick, composed of white pure saccharoidal quartzite, in beds several inches to one foot thick, which weathers pinkish- or yellowish-brown. From its lithologic character and its stratigraphic position above beds carrying upper Pogonip fossils this unit is identified as the Eureka quartzite, a middle Ordovician formation known from many parts of Nevada and from the Nopah Range in California (Hazzard, 1937, p. 276).

Ely Springs (?) dolomite (upper Ordovician)

Dark gray dolomite, in beds averaging three to four feet in thickness, conformably overlies the Eureka quartzite, and is conformably overlain by Tertiary volcanic rocks and Quaternary alluvium so that its top is not exposed. This dolomite, about 300 feet thick, is not very definitely dated from paleontologic evidence, for the only fossils found in it were sponges of the genus Receptaculites. It is tentatively correlated with the upper Ordovician Ely Springs dolomite, which conformably overlies the Eureka quartzite in the Pioche district (Westgate and Knopf, 1932, pp. 15-16) and is believed to overlie the Eureka quartzite in the Nopah Range (Hazzard, 1937, p. 276).

SILURIAN (?) AND DEVONIAN (?) DOLOMITE AND CONGLOMERATE

On the west slope of the Panamint Range is a patch of Paleozoic dolomite and conglomerate which stands out above the surrounding Tertiary and Quaternary sediments because of its greater resistance to erosion. The area of outcrop of the Paleozoic rocks is a southward-tapering wedge, the southerly extension of the west flank of Pinto Peak. North of the area mapped, just east of Towne's Pass, the Eureka quartzite is present in the lower part of the beds in this wedge, but within the area mapped the rocks in this wedge consist of about 2800 feet of strata well above the Eureka quartzite. The lowest 1500 feet of this unit consists dominantly of beds of brown and gray crystalline dolomitic limestone, many of them conglomeratic and consisting of angular dolomite fragments cemented by dolomite and limestone. Fossils are uncommon in these beds, but the following forms were collected at fossil locality 9 and were identified by Dr. Kirk, who reports their age as doubtfully Silurian:

Amplexus? sp.
Cladopora sp.
Stromatopora sp.

Lying above these dolomitic limestones without angular discordance is a brown conglomerate about 1000 feet thick. This is a very firmly consolidated rock composed of limestone and quartzite fragments, averaging one to two inches in diameter, cemented in a fine-grained brown matrix. In the upper part of the conglomerate these fragments are fairly well rounded, but lower in the section they are angular.

Resting on the conglomerate, apparently conformably, is a series of thin-bedded light and dark gray limestones and dolomites, roughly 300 feet thick, which is overlain unconformably by Tertiary fanglomerate. Some of the limestones are oolitic. Crinoid stems are not uncommon in these beds, but other fossils are rare and poorly preserved. The following forms, identified by Dr. Kirk, were collected at fossil locality 5 from a bed rich in silicified brachiopod fragments about 200 feet above the top of the conglomerate:

Schuchertella sp.
Spirifer sp.
Zaphrentis-like coral

Dr. Kirk reports that such silicified brachiopods are known in the West in the lower half of the Nevada limestone (middle and upper Devonian) only, and he believes that a middle Devonian age is indicated for this lot.

These dolomite, limestone, and conglomerate beds, on the basis of their stratigraphic position above the Eureka quartzite and from the evidence of their fossils, are mapped together as a Silurian (?) and Devonian (?) unit. In the Nopah Range Hazzard (1937, p. 276) recognized an unconformity at the base of middle (?) Devonian dolomite and limestone with clastic beds in their lower part. In the Goodsprings district, and in the Providence Mountains, Devonian strata rest unconformably upon middle Cambrian beds (Hazzard and Mason, 1935, p. 378; Hazzard, 1938, p. 241). In the Inyo Range middle (?) Devonian limestones, with sandstone at their base, rest without angular discordance on Ordovician beds (Knopf and Kirk, 1918, pp. 34 and 37). By analogy, the conglomerate below the upper limestones and dolomites in the unit just described may be a basal conglomerate of middle Devonian age lying above a disconformity.

CARBONIFEROUS ROCKS

Strata of Carboniferous age are widespread and thick in the northern Argus Range and in the Darwin Hills, and are the only Paleozoic rocks known in these districts. They appear to be a southeasterly continuation of the belt of upper Paleozoic rocks in the southern Inyo Range. No Carboniferous strata are present in the part of the Panamint Range crossed by the strip mapped, although sediments of this age were found farther north in the range by Ball (1907, pp. 203-204).

In the Argus Range and Darwin Hills the Mississippian beds are limestones, and the Pennsylvanian strata are chiefly limestones and shales, with some quartzites. The Mississippian strata of the Nopah Range are likewise limestones, and the Pennsylvanian rocks also are dominantly limestones and apparently contain less clastic material than the Pennsylvanian in the area of the present study (Hazzard, 1937, p. 275). In the Inyo Range, on the other hand, the Mississippian strata consist chiefly of shale and sandstone, and more than half of the Pennsylvanian section is made up of shale, quartzite, and conglomerate, the remainder consisting of limestone (Knopf and Kirk, 1918, pp. 38-43). It thus appears that in a west-northwesterly direction from the Nopah district to the Inyo Range the proportion of clastic material in the Mississippian and Pennsylvanian sediments progressively increases. The landmass which was eroded to yield this clastic material, then, probably lay to the north or west of the Inyo Range. Nolan has demonstrated that in late Paleozoic time a south-southwest-trending geanticlinal positive area occupied the central part of Nevada, and he believed that the southerly extension of the axis of this geanticline should pass to the northwest of the Inyo Range (1928, pp. 154 and 160). The foregoing data, therefore, tend to confirm this belief.

Mississippian (and older?) limestone

A belt of limestones which are at least in part of Mississippian age extends diagonally across the northern Argus Range from northwest to southeast, reaching its greatest width in its southwestern part, west of the Modoc and Minnietta mines. The base of these limestones is not exposed, but they are at least 4500 feet thick. Pennsylvanian strata flank them on both sides of their belt of outcrop, for these Mississippian (and older?) limestones are the oldest exposed rocks along the axis of the truncated anticline which is the major structure of the northern Argus Range. The Pennsylvanian sediments overlie the Mississippian limestones without angular discordance.

The limestones mapped as Mississippian (and older?) are in general thick-bedded and are predominantly white or light brown, but dark gray fetid beds are also present in the section. Brown-weathering chert lenses and nodules are quite abundant. The limestones are crystalline throughout, and near the contacts of the Mesozoic intrusives they are coarsely crystalline, with grains as large as one-quarter inch in diameter. Tremolite, wollastonite, garnet, and idocrase are developed in the limestones in these exomorphic zones.

Fragments of crinoid stems are common in the dark gray fetid beds, but other fossils are rare. The only good fossiliferous zone discovered is about 600 feet below the top of the unit, in rather thin-bedded dark gray limestones. The most abundant fossils in this zone are corals, especially Syringopora and Lophophyllum. The following forms were collected from this zone at fossil localities 2 and 3, and were identified by Dr. G. H. Girty:

Locality 2

Amplexus? sp.
Caninia? sp.
Cyathaxonia aff. arcuata Weller
Lithiostrotionella girtyi Hayasaka?
Lophophyllum n. sp.
Syringopora aff. aculeata Girty
Crinoid stems
Camarotoechia metallica White?
Cleiothyridina aff. hirsuta Hall
Cleiothyridina aff. obmaxina McChesney
Composita humilis Girty
Cranaena? sp.
Delthyris nova-mexicana Miller
Hustedia aff. circularis Miller
Productus (Linoproductus?) aff. sampsoni Weller?
Productus (Pustula) n. sp. aff. Productella? lachrymosa Conrad
Rhipidomella aff. diminutiva Rowley
Schizophoria aff. chouteauensis Weller
Spirifer, apparently related to S. grimesi Hall
Spiriferella? sp.
Platyceras sp.
Pleurotomaria sp.

Locality 3

Amplexus? sp.
Lophophyllum n. sp.
Syringopora aff. aculeata Girty
Cleiothyridina aff. hirsuta Hall
Rhipidomella aff. diminutiva Rowley
Loxonema? sp.

Dr. Girty refers this fauna to the lower Mississippian. The lower and middle Mississippian Monte Cristo limestone, 700 feet thick, of the Goodsprings district, Nevada, contains some of the same fossils and is similar lithologically to the beds carrying the above fauna (Hewett, 1931, pp. 17-21), so these beds may well be equivalent to some part of the Monte Cristo. In the Nopah Range, Hazzard (1937, p. 275) has described about 2200 feet of Mississippian limestones, subdivided into the Monte Cristo (?) limestone at the top and the similar Stewart Valley limestone below. It is quite possible that this latter formation is also represented in the Argus Range. Because the limestone unit of the Argus Range extends several thousand feet below the fossiliferous horizon, its lower parts may be older than Mississippian. It is not certain whether there are beds of middle and upper Mississippian age in the area, but such beds may be present in the apparently conformable sequence of strata between the lower Mississippian and Pennsylvanian fossiliferous horizons.

Pennsylvanian (and Permian?) limestone and shale

Resting upon the Mississippian limestone with apparent conformity is a series of strata in which two fossil zones were found: a lower zone containing Pennsylvanian fossils and a thick upper zone carrying fossils which are either Pennsylvanian or Permian. Outcrops of these strata make up the greater part of the surface of the Darwin Hills and of the portion of the northern Argus Range crossed by the area studied. These strata are intruded by Mesozoic plutonic rocks and are overlain unconformably by Cenozoic lavas and sediments.

The Pennsylvanian (and Permian?) strata are at least 8000 feet thick and consist chiefly of dark gray thin-bedded partly silicified limestones and brown and gray calcareous shales. Thin beds of fine-grained brown quartzite and lenses of chert are intercalated with the shales and limestones, making up a subordinate part of the section. A few of the shale beds are magenta-colored. Concretions are abundant in some of the beds. The section as a whole is a rather monotonous assemblage of brown and gray strata lacking prominent marker beds. Typical exposures of these rocks are shown in Figures 31 and 33. The contact between the Mississippian and Pennsylvanian rocks is extremely sharp lithologically, for the Mississippian limestone just below the contact is white, whereas the overlying Pennsylvanian limestones and shales are darkgray (Figure 22). The Mississippian (and older?) limestones of the Argus Range are in general thicker bedded, lighter colored, richer in chert nodules, and more coarsely crystalline than the younger Carboniferous rocks which overlie them.

The dark gray Pennsylvanian (and Permian?) limestone beds very commonly contain crinoid stems, fusulinids, and poorly preserved corals, but other fossils are rare. Fusulinids and crinoids appear in the gray limestones immediately overlying the white Mississippian limestone, but the lowest zone found which contains other fossils is 600 feet above the top of the Mississippian, at fossil locality 10. At this locality the following forms, identified by Dr. Girty, were collected:

Fusulinids
Campophyllum? sp.
Lophophyllum? sp.
Crinoid stems
Derbya sp.
Hustedia mormoni Marcou
Productus sp.
Bellerophon? sp.
Naticopsis aff. wortheni Hall

These forms are referred by Dr. Girty to the Pennsylvanian.

Because fossil localities 1 and 11, in the next higher fossil zone, are separated from the zone of locality 10 by the fault which extends along the west side of the Argus Range, the exact thickness of beds between these two zones cannot be ascertained. From the amount of displacement of the northernmost lava sheets in the Argus Range by this fault, however, it can be determined that fossil localities 1 and 11 are at least 2000 feet higher stratigraphically than fossil locality 10. The fossils collected from localities 1 and 11 are listed below; the megafossils were identified by Dr. Girty and the fusulinids by Mr. L. G. Henbest.

Locality 1

Schwagerina sp.
Triticites? sp.
Acervularia adjunctiva White?
Chonophyllum? sp.
Lithostrotionella sp.
Lithostrotionella? sp.
Crinoid stems
Composita mexicana Hall?
Spirifer (Neospirifer) triplicatus Hall?

Locality 11

Pseudoschwagerina sp.
Schwagerina sp.
Triticites? sp.
Acervularia adjunctiva White?
Chonophyllum? sp.

Dr. Girty, in reporting on this fauna, states that the opinions of paleontolgists differ regarding its age. He considers beds carrying this fauna Pennsylvanian, whereas Mr. Henbest refers them to the lower Permian. In view of this difference of opinion it has seemed best to map the post-Mississippian Carboniferous rocks as a Pennsylvanian (and Permian?) unit. It is believed that all of the Carboniferous rocks west of the fault belong in the upper part of this unit, and thus may be Permian. Dr. Girty (in Knopf. 1914, p. 5) had previously designated the Carboniferous strata of the Darwin Hills as

Pennsylvanian on the basis of a small fauna found in the south end of the hills.

The Pennsylvanian (and Permian?) of the Darwin Hills and Argus Range is doubtless at least in part correlative with the "later Pennsylvanian limestone and shale" of the Inyo Range (Knopf and Kirk, 1918, pp. 41-42). The Bird Spring formation of southern Nevada, originally described as Pennsylvanian in the Goodsprings district (hewett, 1931, pp. 21-30), is similar in lithology and stratigraphic position to these two units in California, and is very probably to be correlated with them; Longwell and Dunbar (1935) have recently shown that it contains beds of Permian, as well as Pennsylvanian, age.

Just south of the Darwin tear fault, between the anticline and syncline in upper Darwin Canyon, is a small exposure of an angular unconformity high in the Pennsylvanian (and Permian?) section (Figure 23). The surface of the unconformity dips northeast against the Darwin tear fault. Nowhere except in this restricted locality was this unconformity seen, but it is probably the same unconformity that was noted by Kirk in the "later Pennsylvanian limestone and shale" of the Inyo Range (Knopf and Kirk, 1918, p. 41).

LATE JURASSIC PLUTONIC ROCKS

All the ranges crossed by the strip mapped contain bodies of plutonic intrusive rocks probably of the same age as the late Jurassic batholith of the Sierra Nevada. The Coso Range and the hills west of Darwin are composed almost entirely of granitic rocks which are doubtless an eastward extension of the similar rocks of the Sierra Nevada across the Sierra Nevada fault zone. East of Darwin in the area mapped the plutonic rocks outcrop only as small stocks cutting through the Paleozoic and pre-Cambrian sedimentary and metamorphic rocks. However, the eastern border of the main granitic mass in the western third of the area mapped trends in a southeasterly direction, so that the southern parts of both the Coso and Argus Ranges consist almost wholly of plutonic rocks. Though the plutonic rocks vary in composition from granite to gabbro, they are represented on the map by a single symbol. In the following paragraphs of this section the plutonic rocks of the ranges in the area mapped are briefly described.

Sierra Nevada

The portion of the Sierra Nevada in the area studied had been previously investigated by Knopf, who mapped its rocks as a "plutonic complex" (Knopf and Kirk, 1918, pp. 70-72). As Knopf has stated, these rocks form a very complicated assemblage of many plutonic types, including granite, aplite, quartz monzonite, quartz diorite, and gabbro. The sequence of intrusion appears to have been one of successively increasing acidity. Partly assimilated schist masses, probably representing both inclusions and portions of roof pendants, are common in the plutonic complex. Nowhere east of the Sierra Nevada in the area mapped were plutonic bodies of such complexity encountered.

Coso Range and hills west of Darwin

Except for scattered lava patches, the part of the west slope of the Coso Range crossed by the area mapped is composed of medium- to coarse-grained light-colored granite almost completely devoid of ferromagnesian minerals. Weathered surfaces of the granite are light orange-brown, and some parts of the mass show excellent examples of spheroidal weathering (Figure 24). A typical specimen of the granite, studied under the microscope, was found to consist almost wholly of quartz and potash feldspar, with a little sodic plagioclase. Magnetite and biotite form a very small portion of the rock. This granite is very similar to granite described by Knopf from parts of the Sierra Nevada and Inyo Range (Knopf and Kirk, 1918, pp. 67-69).

The granitic rock of the summit portion (Centennial Flat and vicinity) and eastern slope of the Coso Range and of the hills west of Darwin forms a large rather homogeneous mass sharply separated from the granite to the west. It is made up of gray medium-grained rock which probably varies in composition from quartz monzonite to quartz diorite. A study of two thin-sections showed that granodiorite and quartz diorite are among the types represented. Biotite and hornblende are present in approximately equal amounts, and together form about one-quarter of the volume of the typical rock. Magnetite is a minor accessory. Schist inclusions, though not abundant throughout the mass as a whole, locally are numerous and closely spaced (Figure 25). A few veins of coarsely crystalline quartz and epidote cut the rock, and aplite dikes are quite common.

Darwin Hills

In the central part of the Darwin Hills is a narrow elongate stock of medium-grained gray and greenish gray plutonic rock with which the silver-lead metallization of the district is associated. The rocks of this stock were studied in considerable detail by Kelley (1937, pp. 991-993), who states that they range in composition from quartz monzonite to gabbro.

Figure 24. Spheroidal weathering in the brown granite on the west slope of the Coso Range. The average diameter of the spheroids shown is about eight feet.

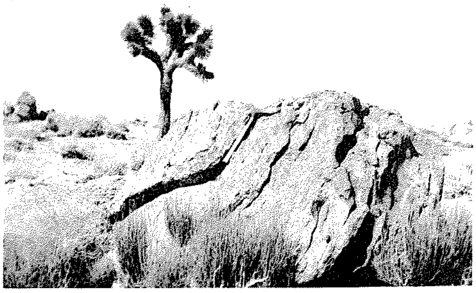


Figure 25. Granitic rock of the eastern part of the Coso Range, mottled by numerous small schist inclusions.

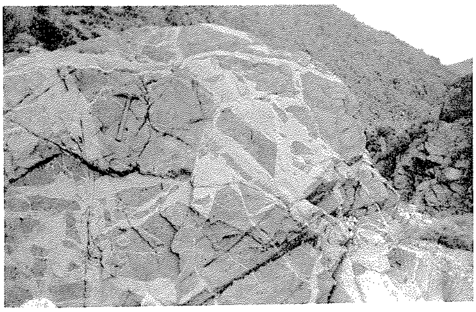


Figure 26. Inclusions of greenish-gray epidotized quartz diorite in fine-grained light pink granite west of the Minnietta Mine.

Biotite is the commonest ferromagnesian mineral in the acidic phases, but in the more basic types hornblende and augite predominate. The more basic phases are concentrated at the north and south ends of the stock; from this relation Kelley advanced the hypothesis that the material first intruded was basic, and that later surges, more acidic in composition, forced the basic material out toward the ends of the stock. Dikes, more acidic than the intrusive, cut both the intrusive and the country rock. The silver-lead deposits are along intrusive contacts, on bedding planes, and in fissure veins in and near the stock.

Argus Range

A belt of intrusive bodies extends across the northern Argus Range from Darwin Falls to the vicinity of the Minnietta mine. This belt is not continuous on the surface, but consists of a series of truncated stocks whose outcrops fall within a narrow southeast-trending zone. At least three types of plutonic rock are present in these intrusives: gabbro in the stock at Darwin Falls, granite in the stocks between Darwin Falls and the Modoc mine, and quartz diorite in the intrusives near the Minnietta mine.

The gabbro at Darwin Falls is a medium-grained greenish-gray rock consisting largely of labradorite and augite, with accessory magnetite. The green color is imparted by epidote, which is present in considerable amounts in veins and as a product of the saussuritization of the labradorite. Several large dikes of the gabbro, somewhat finer-grained and highly saussuritized and chloritized, are present in the northern part of the Argus Range; two of them in the limestone just north of Darwin Falls have widths as great as 50 feet.

Coarse pink granite is exposed in the central part of the zone of intrusives in three separate areas. Pink orthoclase makes up about half of the volume of this rock, and the remainder consists mainly of quartz, albite, biotite, and magnetite. The orthoclase is extensively altered to kaolin and sericite, and the biotite to chlorite. The granite weathers more readily than the gabbro and quartz diorite, and forms pinkish brown rounded slopes.

The plutonic rocks west and south of the Minnietta mine are less homogeneous than those of the stocks to the northwest. In the two most southerly areas of plutonic rock mapped in the Argus Range the chief type is a medium-grained gray rock resembling the quartz diorite of the Coso Range. Under the microscope a representative section of this rock proved to be quartz diorite, with biotite and hornblende, in approximately equal proportions, making up about one-fourth of its volume. In the gray rock are greenish patches which owe their color to epidote. Dikes of fine-grained pink granite are abundant in certain localities, cutting the gray and greenish rock in many directions. In some places these dikes appear to have filled closely spaced intersecting joints in the gray and green rock, so that numerous angular green and gray inclusions are set in a matrix of pink granite (Figure 30). Thus in the Argus Range, as well as in the Darwin Hills and the Sierra Nevada, there is evidence that the intrusion of the basic rocks preceded the intrusion of the more silicic types.

Since the stocks at both ends of the belt of intrusives in the Argus Range are more basic than the stocks in the central part of this belt, it is possible that these stocks are merely cupolas of a larger elongate stock at depth, which, like the Darwin Hills stock, has its earlier basic phases at its extremities.

Panamint Range

A belt of ligh-colored, medium- to coarse-grained granite extends from a point about four miles south of Harrisburg north to the vicinity of Skidoo. Microcline and quartz make up the major part of the granite; biotite, the only ferromagnesian mineral, is a minor constituent. The gold-bearing quartz veins of the Harrisburg and Skidoo districts may be genetically related to this granite.

TERTIARY ROCKS

Eocene (?) dikes and sills

Lamprophyric dikes and sills are present in the Carboniferous and Jurassic rocks of the northern Argus Range and in the granitic rocks of the hills west of Darwin, but were not encountered elsewhere in the area. These small intrusives, generally not more than two feet wide, are composed of porphyritic rock in which brown hornblende laths are embedded in a fine-grained groundmass of calcic plagioclase, and are thus lamprophyres of the camptonite type. The age of these rocks is not known, but they are tentatively correlated with similar post-Jurassic and pre-middle Miocene dikes described by Hulin (1934, pp. 418-419) from the Searles Lake quadrangle just to the south. Hulin has provisionally dated these dikes as early Eocene.

Andesite of the Panamint Range

Lava flows and tuffs are exposed on the eastern ends of the two east-trending spurs of the Panamint Range north of Trail Canyon. These volcanic rocks, with an exposed thickness of about 3000 feet, rest unconformably upon Ordovician dolomite and quartzite, and dip to the east under the alluvium of

Death Valley. The base of the volcanic section is irregular, showing that the topography was rather uneven at the time the rocks were deposited.

In the lower part of the volcanic section black obsidian and vitrophyre are abundant. Above these glassy rocks is a zone of light brown and pink tuff and agglomerate. The highest part of the section, constituting two-thirds or more of its total thickness, is made up of dark purplish brown porphyritic dacite and biotite-andesite, with small amounts of interbedded pink and green rhyolitic flows and tuffs. In the biotite-andesite, the commonest rock type, andesine phenocrysts that average one-eighth of an inch in length make up about one-fifth of the volume of the rock. Biotite and magnetite phenocrysts are smaller and less abundant. The groundmass, constituting about 70 percent of the rock, is a fine-grained intergrowth of feldspar, biotite, and magnetite. Alteration of the magnetite to hematite has given the rock its purplish brown color. Figure 27 is a view of the volcanic rocks on the second ridge north of Trail Canyon.

Identical lavas and tuffs are present below the Tertiary lake beds of Furnace Creek, on the east side of Death Valley, and there is little doubt that these volcanic rocks on opposite sides of the valley are correlative. The Furnace Creek lake beds, considered Miocene by Ball, overlie the volcanic rocks unconformably (Ball, 1907, p. 32). The volcanic rocks along the east edge of the Panamint Range in the area mapped probably correspond to Ball's earlier rhyolite of the Amargosa Range, of probable early Miocene age (1907, pp. 168-170).

Andesite of the Coso Range

The ridge west of Cactus Flat is the northern end of a belt of lava along the west flank of the Coso Range which extends southward for about

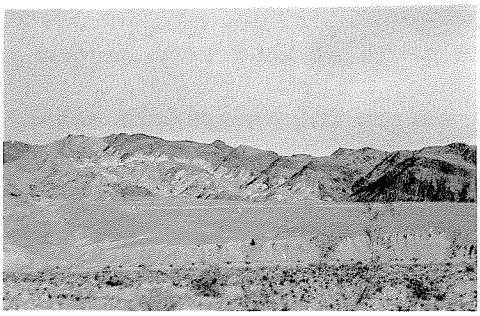


Figure 27. The eastern part of the second ridge north of Trail Canyon, showing dark purplish brown Tertiary andesite and dacite, with light-colored tuff at their base, overlying Ordovician dolomite.

Figure 28. Lake beds of the Coso formation, on the west flank of the Coso Range, overlain by basalt. In the background is the dry bed of Owens Lake.

Figure 29. Late Pliocene or early Pleistocene basalt, with crudely developed columnar jointing, above beds of basaltic cinders in the eastern part of the Coso Range.

seven miles. Within the area mapped this rock is brown and gray andesite, with well developed flowage planes dipping at low angles to the west and northwest. The lava is porphyritic throughout; in the typical rock andesine phenocrysts, about a quarter of an inch in diameter, and biotite phenocrysts, not more than half as large, are set in a gray groundmass composed largely of glass but also containing minute crystals of plagioclase. The andesite weathers to dark brown rather pitted surfaces, frequently blackened by desert varnish.

Overlying the andesite unconformably are the tuffs and lake beds of the Pliocene or Pleistocene Coso formation. Nowhere within the area mapped is the andesite in contact with the granitic rock of the Coso Range, but farther south it rests on an erosion surface cut in the granite. The andesite is therefore post-Jurassic and pre-Pleistocene. It may be upper Miocene, for andesites of that age are reported by Hulin (1934, p. 420) to be widely distributed in the region to the south.

Nova formation (late Miocene?)

On the west flank of the Panamint Range, between Wildrose Canyon and Towne's Pass, are beds of Tertiary fanglomerate with subordinate intercalated layers of volcanic material. These beds have been briefly mentioned by Fairbanks (1896, p. 71) and Campbell (1902, p. 19). At least 3000 feet thick, they lie unconformably upon pre-Cambrian and Paleozoic rocks. Their contact with these older rocks is poorly exposed along much of its extent, but in lower Nemo Canyon the fanglomerate can be observed lying with depositional contact upon pre-Cambrian rock. Near the large faults on the west slope of the Panamint Range this contact is complicated by faulting. The fanglomerate and lava dip to the east and southeast. These same rocks are undoubtedly present under the alluvium of the eastern part of Panamint Valley.

This sedimentary and volcanic unit, important because it makes possible the recognition of large Tertiary movements on the fault zone east of Panamint Valley, is well exposed in Nova Canyon, and for it the name Nova formation is therefore proposed.

Within the area mapped this formation is composed almost wholly of fanglomerate consisting of angular to sub-rounded cobbles and boulders, most of them with diameters between three and six inches, set in a matrix of rather soft light brown mudstone or sandstone. It is certain that the fanglomerate was derived from the east, for its boulders and cobbles consist exclusively of rock types of the central and eastern Panamint Range --- pre-Cambrian and Cambrian metamorphic rocks and Jurassic granite. Sorting and stratification are poorly developed, but bedding planes can be recognized in many exposures. The deposit is somewhat better cemented than the material of the present alluvial fans, but is similar to it in all other respects. On the steep lower part of the west slope of the Panamint Range the Nova formation has been eroded to form a badland, but south and east of Pinto Peak the tilted fanglomerate is truncated by the old erosion surface of moderate relief which occupies the central part of the range. The fanglomerate appears to be entirely barren of fossils.

Interbedded in the fanglomerate at various horizons are layers of vesicular basaltic lava and agglomerate, evidently the products of intermittent volcanic outbreaks during the deposition of the alluvial fan material.

Movement on the major fault that lies buried under the eastern part of the fanglomerate has brought Silurian (?) and Devonian (?) strata on the west against pre-Cambrian rocks on the east in such a way that fully 20,000 feet of pre-Cambrian, Cambrian, and Ordovician rocks are cut out. The activity along this fault must once have produced a large west-facing scarp. The thick fanglomerate is believed to be the consolidated alluvial fan material which accumulated rapidly at the base of this scarp and buried the fault as the scarp was worn down.

The date of movement on the buried fault is not accurately known from direct field evidence. This movement must have occurred some time before the development of the late Pliocene erosion surface of low relief, however, for the tilted fanglomerate which buries the fault is truncated by this surface. To the south, in the Searles Lake quadrangle, post-Jurassic erosion, accomplished by an external drainage system, had by middle Miocene time produced an old-age erosion surface; then, in middle or late Miocene, faulting and warping uplifted mountain ranges and depressed intermont basins, thus developing an interior drainage system and causing the deposition of alluvial gravels and other terrestrial sediments in the lower areas (Hulin, 1934, p. 419). These terrestrial deposits, the Rosamond and Ricardo series, contain upper Miocene and lower Pliocene vertebrate fossils in their middle and upper parts. It is believed probable that the movement on the fault buried by the Nova formation of the Panamint Range occurred during this same Miocene period of diastrophism, and that this formation may consequently be of upper Miocene or lower Pliocene age.

TERTIARY OR QUATERNARY ROCKS

Coso formation (late Pliocene or early Pleistocene)

On the west, north, and east flanks of the Coso Range are alluvial gravels and overlying tuffs and lake beds, mentioned by Knopf as the "lake beds south of Keeler" (Knopf and Kirk, 1918, pp. 51-52), to which the name Coso formation has recently been applied (Schultz, 1937, p. 79). This sedimentary and volcanic unit has an exposed thickness of about 500 feet in the area mapped. It rests upon an erosion surface cut in the granitic rocks of the range, and is overlain without angular discordance by flows of basaltic lava. Figure 28 shows the general appearance of the lake beds of the Coso formation.

The alluvial material at the base of the formation is not as well exposed in the area mapped as it is two miles farther north, where Schultz (1937, p. 80) estimated that its thickness is at least 300 feet. This basal material consists of reddish arkose and buff-colored gravel, sandstone, and shale. Above it are about 200 feet of well stratified thin-bedded white and light buff lake beds, with interbedded white rhyolitic tuffs. The lake beds are well sorted silts and sands which locally contain fish bones. In general the tuffs are well sorted and stratified, and many of them were probably laid down in a lake. In the southern part of the area mapped, however, some of the tuffs are poorly stratified and contain angular fragments of silky rhyolite pumice one to five inches in diameter, so that their origin as water-laid deposits is more doubtful. The alluvial materials quite clearly were derived from the granitic rocks of the Coso Range. The material which forms the tuffs may have come from vents near the center of Quaternary rhyolitic activity at Coso Hot Springs, about 10 miles farther south in the range.

In general, the beds of the Coso formation dip away from the range at low angles. On the west flank of the range the formation dips toward the Sierra Nevada even in its westernmost exposures on the banks of Haiwee Reservoir. These westerly dips average about 10°, but in places are as steep as 20°. Though some fraction of these dips may be original, they are believed to be largely the result of Quaternary deformation. The Coso formation on the western flank of the range probably never extended much farther east than it does now, for just east of its present eastern limit the basalt flows, which are not much younger than the Coso formation, rest directly upon granite. The formation extends to the west under recent alluvium for an unknown distance, and may abut against the Sierra Nevada fault zone.

Vertebrate fossils have been found in the alluvial fan material just below the tuffs. On the basis of this fauna the Coso formation was dated as late Pliocene or early Pleistocene by Schultz, who was inclined to favor the view that the formation is of early Pleistocene, possibly Nebraskan, age (1937, pp. 86-98). Just before the deposition of the Coso formation, the old-age erosion surface now represented by Centennial Flat was deformed, at least in part by faulting, to create a high area where the present Coso Range now stands. This uplift caused the deposition, around the edges of the uplifted area, of the coarse basal fanglomerate of the lower part of the formation; slightly later a lake came into existence directly west, north, and east of the uplifted area, and in and near this lake the upper part of the formation was deposited. As has been pointed out in the discussion of geomorphology (pp. 34-35), these relations demonstrate that the latter part of the period of erosion during which the old-age topography was produced must have been coincident with the middle or latter part of the Pliocene epoch. The faulting to which the Coso Range owes most of its present relief occurred after the deposition of the Coso formation and the extrusion of the overlying basalt.

Late Pliocene or early Pleistocene basalt

Much of the surface in the part of the area west of Panamint Valley is covered by thin flows of olivine basalt. These flows form a conspicuous feature of the landscape because of their black color and because they occur as thin sheets capping the summits of hills and mountains. In the Coso and Argus Ranges, and in the intervening Darwin district, the widespread flows cover remnants of the old erosion surface of low relief. In the Panamint Range within the area mapped there are no exposures of late Pliocene or early Pleistocene basalt, but basalt believed to be of this same age has been reported farther north in the range (Ball, 1907, p. 210). Correlative basalts are widespread in the Inyo Range (the "late Tertiary basalts" of Knopf and Kirk, 1918, p. 74).

The basalt sheets are 15 to 150 feet thick except just north of Cactus Flat, where their thickness exceeds 400 feet; here, however, the conditions are somewhat special and will be further described in the section on Cenozoic faulting. In many places the basalt exhibits crude columnar jointing, and just below the basalt flows, in some localities, are beds of basaltic cinders totaling 10 feet or less in thickness (Figure 29). Along the eastern edge of the Argus Range the basalt is directly underlain by light pinkish brown rhyolitic agglomerate and white rhyolitic tuff of unknown age.

The flow basalt is very similar petrographically over the entire area. In hand specimens it appears as a very dark gray volcanic rock with medium-grained olivine phenocrysts and plagioclase laths set in an aphanitic groundmass. Vesicles are common, and are often elongated in the direction parallel to the flow layers. In thin sections it is evident that by far the greater part of the rock is composed of laths of rather calcic labradorite, usually arranged with a pronounced parallelism. The olivine phenocrysts are rounded, and are extensively altered to iddingsite and magnetite. Between the labradorite laths are very small grains of labradorite, magnetite, and augite, giving a typical intersertal texture. The three thin sections examined, from the Coso Range, the hills west of Darwin, and the Argus Range, are similar in all respects.

The evenness of the base of the basalt indicates that the lava flowed out upon a surface of low to moderate relief. The portions of the Coso and Argus Ranges crossed by the line of the geologic section of Plate I were very flat at the time of the basalt extrusions, but in the eastern parts of the Coso and Argus Ranges within the area mapped there is evidence that the old erosion surface included hills several hundred feet high which were partly surrounded by lava. Along the east edge of the Argus Range vertical basalt dikes in Paleozoic strata can be traced up into the flows, indicating that the flows, at least in part, were fed through fissures. At many places on the upper surface of the basalt are broad low mounds of red basaltic cinders and bombs, apparently cinder cones considerably flattened by erosion. Very probably much of the basalt was extruded through the pipes over which the cinder cones were built.

In the Coso Range the basalt flows overlie the Coso formation without angular discordance. The basalt, therefore, cannot be older than late Pliocene. The lake beds of lower Darwin Wash were deposited in a basin created by post-basalt faulting, and yet these lake beds are older than the deposits of the latest Pleistocene lakes. It can therefore be stated with certainty that the basalt was extruded between late Pliocene and the latter part of the Pleistocene; its most probable age is considered to be early Pleistocene, in view of the severe diastrophism and extensive erosion which have occurred since its extrusion.

QUATERNARY ROCKS

Lake deposits

In the low parts of Darwin Wash and Panamint Valley are exposures of white and light buff sediments which undoubtedly were deposited in Pleistocene lakes, either playa or perennial. These strata are soft, fine-grained, and thin-bedded, with bedding planes very nearly horizontal. In both Darwin Wash and Panamint Valley the deposits are about 30 feet thick, and their base is not exposed. In both places, also, the beds are overlain conformably by old alluvium and are intricately dissected by small gullies. The pattern of outcrops of the lake beds consists of very irregular and sinuous thin bands which are too narrow to be represented on the geologic map of Plate 1; instead, the lake beds and older alluvium are mapped under a single symbol in the two localities where they occur together.

In Panamint Valley the lake beds are buff-colored silts similar in appearance to the silts of the present desert playas, and in their upper part they are interfingered with the old alluvium. In Darwin Wash, however, the lake beds are much whiter, and appear to consist largely of water-deposited rhyolitic ash. The ash may have been derived from the centers of Quaternary rhyolitic explosive activity known to exist in the Coso Range. The lake beds of Darwin Wash are shown in Figures 5 and 30.

Just east of the lake beds of Darwin Wash are the step-faulted lava sheets on the west slope of the Argus Range, and it is quite evident that the lake beds were deposited in a basin formed by post-basalt faulting and warping. Thus, although these lake beds resemble the upper beds of the Coso formation, it is certain that they are younger than the Coso lacustrine deposits. The history of the region after the deposition of the Darwin Wash lake beds includes the deposition of the old alluvium, the capture of the Darwin Wash basin by headward erosion of Darwin Canyon, and the dissection of the lake beds and old alluvium, so it seems improbable that the lake beds can be younger than middle Pleistocene. At the mouth of Waucoba Canyon in the Inyo Range are lake beds, containing rhyolitic particles, which are overlain by old alluvium and dissected to a badland. Knopf (1918, p. 52) believed these lake beds (which he referred to as the "lake beds east of Zurich") to be younger than the Coso formation, for he considered that Waucoba Canyon was cut, and the lake beds deposited in it, after the main uplift of the Inyo Range, which occurred later than the extrusion of the basalt overlying the Coso formation. At both Waucoba Canyon and Darwin Wash, therefore, the lake beds appear to have been deposited in basins created by the major deformation which closely followed the extrusion of the late Pliocene or early Pleistocene basalt, and for this reason it is believed very probable that the lake beds of these two localities are of contemporaneous origin. The dissected lake beds of Panamint Valley may be of the same age, but it is possible that they are

Figure 30. An exposure of white lake beds, and overlying darker old alluvium, in Darwin Wash.

Figure 31. A view looking south along upper Darwin Canyon just south of the Darwin tear fault. The tilted upper Carboniferous strata are on the west limb of the syncline shown in Figure 32.

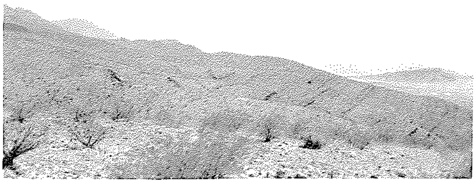


Figure 32. Looking south along the axis of the syncline just east of upper Darwin Canyon.

younger deposits formed in the lake which occupied Panamint Valley during the latest glacial stage of the Sierra Nevada.

Older alluvium

At several places in the central and eastern parts of the area are patches of elevated and dissected alluvial gravels obviously older than the alluvium of the present canyons and valleys. This old alluvium is typical fanglomerate, composed of angular to sub-rounded cobbles and boulders loosely cemented by light brown mudstone and sandstone. Sorting and stratification are poorly developed. In both Darwin Wash and Panamint Valley the old alluvium rests upon lake beds without angular discordance, and in Panamint Valley its lower part is interfingered with the lake beds. These old alluvial deposits in the area mapped are believed to be correlative with the older alluvium of the western flank of the Inyo Range (Knopf and Kirk, 1918, p. 54) and are considered to be of middle or late Pleistocene age.

Younger alluvium and lake deposits

In the intermont basins of the area are deposits of alluvial detritus, and, in Death Valley, of chemical precipitates. By far the greater part of this material is coarse fanglomerate making up the alluvial fans on the sides of the basins and in the lower parts of the mountain canyons, although large playas are present in both Panamint and Death Valleys. Panamint Valley contains two playas, of which the more northerly, a smooth hard surface of sun-baked brown silt, is crossed by the strip mapped. The Death Valley playa is notably different, for on its surface is a salt deposit representing the residue from the evaporation of a lake. Though in a broad way the surface of this salt flat is level, in detail it is made extremely rough by very numerous closely spaced hummocks and pinnacles of salt one to two feet high. This salt field has been named the Devil's Golfcourse.

Both Panamint and Death Valleys contain evidences of the recent presence in them of large lakes. In the part of Panamint Valley crossed by the area studied no old shorelines or shore deposits were found, but farther south, where these features are present near Ballarat, they indicate that the former lake extended north across the area mapped and had a maximum depth there of about 350 feet (Gale, 1915, plate 7 and pp. 312-317). The former presence of a lake in Death Valley is demonstrated by the saline residue in the bottom of the valley and by evidences of ancient shorelines on the sides of the bordering ranges (Blackwelder, 1933, pp. 465-468). Gale (1915, pp. 251-252, 320) has shown that these lakes owed their existence to the overflow of the waters of Owens Lake into Indian Wells Valley, and thence into Searles Basin, Panamint Valley, and Death Valley, and he believes that the melting of the ice which accumulated in the Sierra Nevada during the latest glacial stage made possible the development of this extensive lake system. He has estimated (1915, p. 264) that about 4000 years have elapsed since Owens Lake ceased to overflow through Haiwee Pass into Indian Wells Valley. In the last 4000 years, therefore, the lakes in Panamint and Death Valleys have evaporated, and the recent alluvial fans spreading out into the valleys have to a large degree covered the former floors of these lakes.

STRUCTURE

In the area of this report, as in other parts of the Great Basin, it is convenient to discuss the pre-Cenozoic structures separately from those of Cenozoic age. The older rocks within the basin ranges contain folds, normal and reverse faults, and intrusive structures which originated in pre-Tertiary time. The Cenozoic structures of the region involve both old and young rocks, and prominent among them are the basin-range faults along which relatively recent movements have uplifted mountain ranges and depressed intermont basins.

PRE-CENOZOIC STRUCTURES

Folds

The most important pre-Cenozoic flexures in the area are folds in the Carboniferous strata of the Darwin Hills and Argus Range, although other old folds are present in the pre-Cambrian and early Paleozoic rocks of the Panamint Range. In all cases these folds are transected by stocks of plutonic rock, and from this it is known that the folding preceded the late Jurassic intrusions.

An anticlinal axis extends along the greater part of the east flank of the Darwin Hills. The strata on the west limb of this anticline dip about 50° to the west and are intruded by the stock in the center of the hills. On the east limb the beds are closely folded into a series of small, nearly isoclinal, anticlines and synclines which trend north-northwest, parallel to the major fold. The number of these small folds east of the major anticline and west of the edge of the alluvium in lower Darwin Wash varies from two or three to ten or more, but most of them are too small to be represented on the map.

Several north-trending folds of moderate size are exposed in the Carboniferous strata of upper Darwin Canyon. Where the road from Darwin to Panamint Valley enters these rocks it runs along the strike of the east-dipping beds of the common limb of an anticline and syncline (Figures 31 and 32). Minor drag folds are exceptionally well developed in the incompetent shales and thin-bedded limestones involved in these flexures (Figure 33). These drag folds evidently resulted from slippage between the more competent beds, and their axial planes are essentially parallel to those of the major folds.

The largest fold in the area is a northwest-plunging anticline in the Argus Range. Mississippian, Pennsylvanian, and possibly Permian strata are involved in this anticline and in the associated structures. The northwestward plunge of the anticline causes a large mass of Mississippian (and older?) limestone to be brought to the surface in the southeast part of the strip across the Argus Range, in the vicinity of the Modoc and Minnietta mines. The younger Carboniferous rocks lie to the west, north, and east of the main Mississippian outcrops in accordance with the plunging anticlinal structure, but their contact with the Mississippian is not the simple curved line of the ideal case. Instead, this contact has many irregularities caused by minor folding, faulting, and the intrusion of granite stocks across it. In its northern part the anticline is cut by two transverse faults in such a way that its core of Mississippian limestone is offset to the west north of these faults. The northernmost area of Mississippian rocks mapped owes its exposure to uplift by faulting, both of the faults which bound it, and

Figure 33. Drag folding in the thin-bedded incompetent shales on the east limb of the anticline just west of upper Darwin Canyon.

Figure 34. The west slope of the Panamint Range within the area mapped, as seen from the Argus Range.

particularly the Darwin tear fault on its south, having helped to raise it to its present position. The small patch of Mississippian limestone just south of the granite stock east of Darwin Falls is partly surrounded by Pennsylvanian rocks which dip away from it, and has apparently been pushed up by minor folding associated with the intrusion of the granite.

The beds on the east limb of the northern part of the major anticline of the Argus Range are overturned, dipping steeply west, as shown in the geologic section of Plate I, and are cut by a few minor thrust faults which dip west at angles of 5° to 30°. These thrusts are of small displacement (100 feet or less) and appear to be dislocations caused by the same forces which produced the overturning of the strata. They are not represented on the map. Farther south along the east limb of the anticline the beds become less and less overturned, finally passing through the vertical position and assuming a normal easterly dip. A syncline whose axial plane dips 40° to 45° west lies to the east of the overturned beds, but it extends no farther south than the point where the overturning disappears.

Flexures in the pre-Cambrian and Paleozoic rocks of the Panamint Range are relatively unimportant. The structures in the rocks directly beneath the unconformity at the base of the Johnnie formation, however, prove at least that deformation in this area in pre-Cambrian time included folding. Also, the steep homocline of lower Paleozoic rocks on the east flank of the range indicates post-Ordovician pre-Cenozoic folding, for its dip is too great to have been caused by any of the known Cenozoic crustal movements.

Faults

Faults are numerous within the ranges of this study, but only the more important of them are mapped. The only faults which can be proved to be of pre-Cenozoic age are in the Argus Range and Darwin Hills, and are dated by their relationships to the Jurassic intrusive bodies. In some cases the stocks have been intruded across these fractures, indicating clearly that faulting preceded intrusion. In other instances faulting closely followed intrusion, for, although the intrusive bodies are offset by the faults, ore minerals genetically related to the intrusives have been deposited on the fault surfaces. Most of these pre-Cenozoic faults strike in an east-southeast direction, though some strike east-northeast, and their general dip is to the south at angles not much less than 90°. In all cases the north sides are offset to the west.

The most important of the pre-Tertiary fractures is the Darwin tear fault, recognized and named by Kelley (1937, p. 995) during his work in the Darwin Hills. It is at least seven miles long and extends in an east-southeasterly direction across the north ends of the Darwin Hills and Argus Range. The trace is expressed in the topography as a series of aligned gullies and saddles. The dip of the fault surface, wherever observed, is to the south at about 80°. Drag folds and displaced beds indicate that the north side of the fault has moved westwardly and upward with respect to the south side. As the fault is traced to the east it passes beneath the largest basalt sheet of the Argus Range, and does not reappear east of it. Where the fault would be found if it continued east of this basalt sheet the Carboniferous strata on the east flank of the large anticline of the Argus Range are vertical; directly to the north these beds are overturned, dipping steeply west, and directly to the south the beds are not overturned, but dip to the east. This fact makes it seem virtually certain that the Darwin tear fault is causally related to the overturning of the beds, for the fault appears to die out eastwardly into the fold by which the overturned beds are righted. The north-trending folds on both sides of upper Darwin canyon terminate abruptly at the Darwin tear fault, and are absent north of the fault.

The offsetting of the Mississippian limestone core of the major anticline of the Argus Range indicates large movement on the Darwin tear fault, but complications introduced here by intrusion, partial burial by lava flows, and later faulting make it impossible to measure the components of this movement very accurately. Drag folding along the fault, and the overturned folding of the northeast part of the Argus Range anticline, clearly indicate dip slip, and from the overturned folding it is estimated that the north side of the eastern part of the fault has been raised relative to the south side by roughly 2000 feet (Plate 15, stages 1 and 2). If this estimate of dip slip is approximately correct, the offset of the Mississippian-Pennsylvanian contact as reconstructed in stage 2 of Plate 15 means that the strike slip is roughly 5000 feet.

The largest of the other pre-Tertiary faults is in the Argus Range about a mile south of, and parallel to, the Darwin tear fault. It dips south at about 80° and is reflected in the topography as a long straight canyon emptying into Panamint Valley. The north side of this fault has moved west with respect to the south side, but whether the north side was raised with respect to the south cannot be determined from the displacement of the Mississippian-Pennsylvanian contact because of the intrusion of a granite stock across the eastern part of this contact. However, because this fault is near and parallel to the Darwin tear fault, and is of the same age, it seems probable that its movement also included dip slip, and this has been assumed in Plate 15. The total displacement on this fault, whether or not it included dip slip, must have been at least 1500 feet.

The stocks of the Argus Range were intruded after the movement on the Darwin tear fault and on the parallel fault to the south, for these faults abut against the contacts of the stocks without offsetting them. However, several minor strike-slip faults with a general easterly trend cut the stock in the Darwin Hills in such a way that on their north sides the edge of the stock is offset to the west. Silver and lead ore minerals, which Kelley (1937, p. 1004) found to be genetically related to the stock, have been deposited on some of these faults, so the faults must be only slightly younger than the stock.

In the Cambrian and Ordovician strata on the east slope of the Panamint Range within the strip studied are several rather unimportant faults, of which the four largest are mapped. These faults cannot be accurately dated, but since they are within the range and have no relation to the present topography they may be pre-Cenozoic. Three of the faults mapped strike northeast and dip northwest at moderate to steep angles. Drag folds and slickensides indicate that the southeast sides of these faults have moved up and to the northeast with respect to the northwest sides. The most northerly fault has a displacement of approximately 1000 feet at the eastern end of its outcrop, but displacement along it diminishes westwardly so that the base of the Cambrian is not offset. The southernmost fault is a strike fault of undetermined attitude; its west side has moved relatively upward, however, so that a small part of the upper Wood Canyon formation, including the prominent Zabriskie quartzite, is omitted.

Intrusions

No structural data were obtained regarding the large intrusive masses of the Sierra Nevada and Coso Range. Concerning the stocks to the east, however, two generalizations can be made: first, the stocks tend to be elongate in a northerly or northwesterly direction, parallel to the strike of the intruded strata; and second, the stocks have intruded along or near the axial planes of pre-existing anticlines.

Discussion of Pre-Cenozoic Structures

On the basis of the present study little can be said about the structural development of the area during the pre-Cambrian and Paleozoic. In pre-Cambrian time a thick group of sediments was deposited, folded, metamorphosed, and eroded. During the Paleozoic the area was a part of the Cordilleran geosyncline and was receiving sediments almost continuously, but there was probably a break in this deposition between the Silurian and middle Devonian, and the deposition was certainly interrupted during the latter part of the Carboniferous, as shown by the angular unconformity within the Pennsylvanian or Permian strata in Darwin Canyon. The type of crustal movements which gave rise to these unconformities cannot be determined from the present study because of the narrowness of the area mapped; however, the deformation just preceding the development of the Carboniferous unconformity must have been rather intense, for the angle between the bedding planes above and below the unconformity is approximately 20° in the place where it was observed. In the Inyo Range, Kirk (in Knopf and Kirk, 1918, p. 41) described what is believed to be the same unconformity as "an erosional unconformity of considerable magnitude, the significance of which could not be determined".

From all that can be learned in the strip mapped, and from a comparison with neighboring regions, it appears that the first important post-Proterozoic orogeny which affected the area was the Nevadian orogeny, occurring late in the Mesozoic era and involving the intrusion of the late Jurassic plutonic rocks. Relations of faulting to folding and intrusion in the Argus Range and Darwin Hills make possible the following statements regarding the post-Carboniferous and pre-Cenozoic, and hence presumably Nevadian, deformation in this district:

(1) The offsetting of the major plunging anticline of the Argus Range along the Darwin tear fault and the parallel fault to the south, which are oblique to its axial plane, indicates that this fold was in existence before the inception of movement on these faults.

(2) As already explained, the relation of the overturned folds in the northeast part of the Argus Range to the Darwin tear fault shows that the formation of these folds occurred at the same time as movement on the fault.

(3) The termination of the folds directly east and west of upper Darwin Canyon at the Darwin tear fault, and the absence of counterparts of these folds farther to the west on the north side of the fault, indicates that these folds were formed during or after, but not before, movement along the fault.

(4) The transection of folds and major faults by the stocks proves that intrusion followed the principal part of the deformation; however, minor faulting along breaks parallel to the major faults, and with the same direction of movement, occurred shortly after the intrusion of the stock in the Darwin Hills.

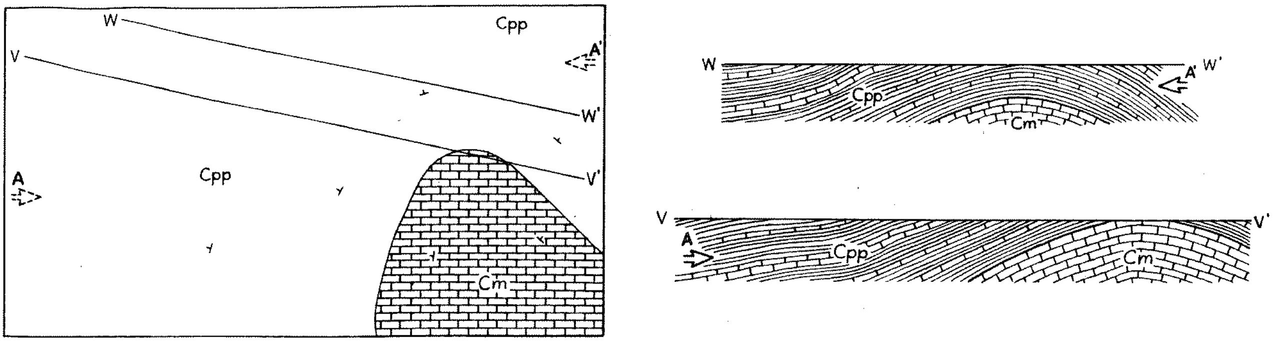
From these relations the stages in the Nevadian orogeny pictured in Plate 15 are inferred. In brief, the large plunging anticline of the Argus Range was first formed, probably by compressional stress in an approximate east-west direction. The application of horizontal shearing stress then caused the development of the strike-slip faults and smaller folds. This shearing stress may merely represent a later inequality in yielding to regional compression which formed the original anticline of stage 1. The close folds at X and Y (stage 2) apparently represent the result of compression of the relatively incompetent thin-bedded upper Carboniferous strata against the core of the more competent Mississippian limestone by the stresses A and A' of the shearing couple (refer to geologic sections of stages 1 and 2). The stocks were intruded after the major faults and folds had formed, and apparently the magma was able to rise most easily into the cores of the anticlines. Following the intrusion of the Darwin Hills stock there was minor strike-slip faulting across it, and slightly later the silver-lead ores of the district were deposited.

CENOZOIC STRUCTURES

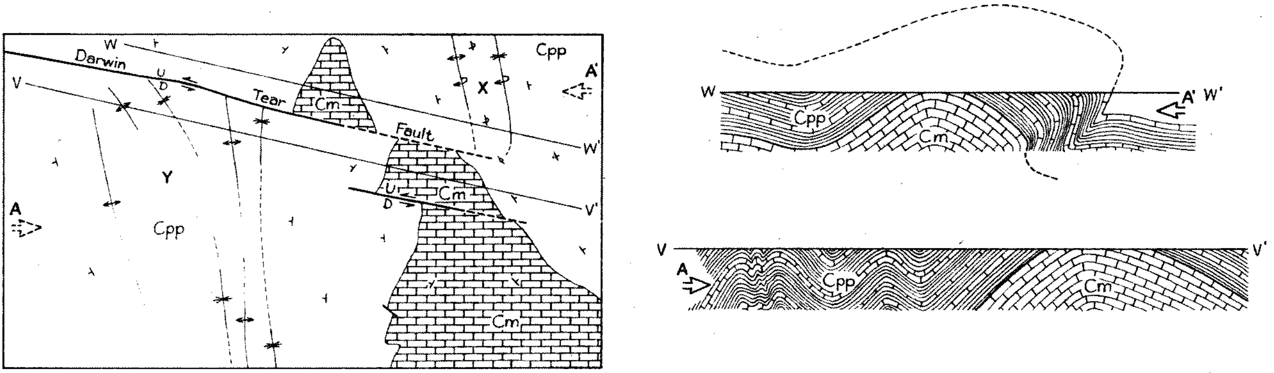
Folds

The late Tertiary fanglomerate of the Panamint Range contains a few broad flexures, apparently the result of gentle folding accompanying the tilting of the beds. In the Coso formation there is a low north-trending anticline just west of Cactus Flat which may be the result of drag along the fault paralleling it to the east. The dips of this formation on opposite sides of the Coso Range in the geologic section of Plate 1 suggest a broad

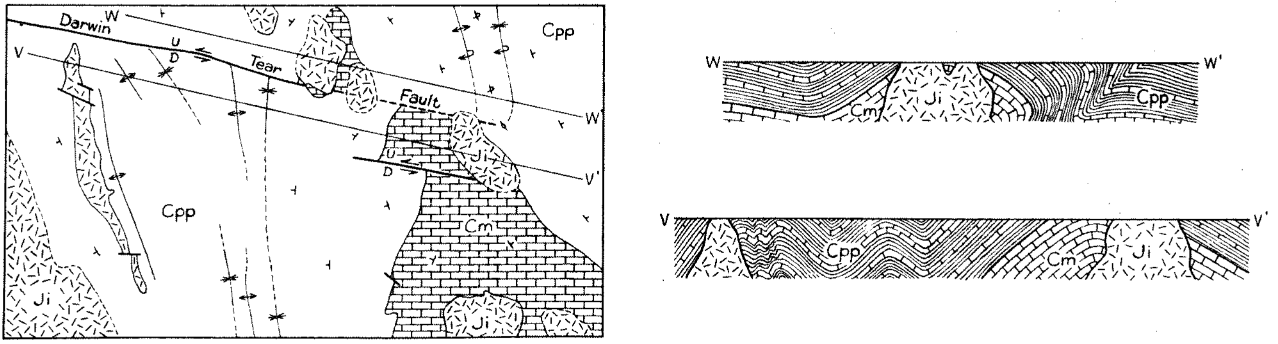
Plate 15.



Stage 1. Application of horizontal shearing stress, indicated approximately by arrows A and A', across a large northwest-plunging anticline with a core of competent Mississippian limestone overlain by relatively incompetent Pennsylvanian (and Permian ?) limestone and shale.



Stage 2. Development of the Darwin tear fault and related faults, and of close folds in the incompetent beds near X and Y, in response to this shearing stress.



Stage 3. Intrusion of stocks ranging in composition from gabbro to granite, the more basic being earlier. Minor post-intrusive faulting in the Darwin Hills. Slightly later, deposition of silver-lead ores.

Plate 15. Inferred stages in the late Jurassic Nevadian orogeny in the Argus Range and Darwin Hills. The above diagrams are geologic maps and sections drawn with the reference plane approximately the present erosion surface, which of course was several thousand feet below the earth's surface at the time of the orogeny.

anticlinal structure, but this apparent fold may have resulted from the tilting of fault-blocks rather than from flexing. The surfaces of the thin basalt sheets of the Coso and Argus Ranges are nearly flat, but broad low undulations are characteristic of them. These may in part be original irregularities of the flow surfaces, but they indicate that a small amount of warping accompanied the displacement of the lava by faulting.

Folding is thus unimportant in the Cenozoic rocks of the area mapped. This is not the case, however, in the region to the east and south, for on the east side of Death Valley the Furnace Creek lake beds, of supposed Miocene age, have been folded and even overthrust (Ball, 1907, pp. 198-199; Noble, 1938), and the Miocene strata in parts of the Mohave Desert have been similarly deformed (Baker, 1911, p. 346 and pp. 352-353; Hewett, 1928).

Faults

In the area mapped, faults of Cenozoic age are numerous and important. The majority of them lie in basin-range fault zones along which blocks of the earth's crust have been raised to form mountain ranges or lowered to form desert basins. In the strip studied each of the three ranges within the Great Basin is bordered on its western edge by a zone of late Cenozoic faulting along which the range has been uplifted and tilted to the east. In all determinable cases the faults of these zones are high-angle normal faults, but there is some evidence that strike-slip movement has accompanied the dip slip along them.

Sierra Nevada fault zone

Although the general form of the Sierra Nevada in this latitude suggests that the range is a west-tilted block, there is no evidence of recent faulting along its eastern base. However, the separation of the slightly tilted old-age topography of the summit from the alluviated valley to the east by a steep scarp is in itself a strong indication that the east edge of the range is determined by a zone of faulting. The Sierra Nevada fault zone is completely buried by alluvial fans in the area mapped; consequently, nothing is known about its nature here. It is represented on the geologic section of Plate 1 simply as a single normal fault.

Faults in the Coso Range

Seven post-basalt faults of mappable magnitude outcrop on the west flank of the Coso Range. These faults may be readily located by the displacement of the basalt sheets, which form resistant cappings for scarps in the granite bedrock. The coarse-grained granite disintegrates rapidly, however, so that scarps in the granite unprotected by basalt cappings have been nearly or completely destroyed by erosion. For this reason the faults of relatively small displacement cannot usually be traced into the areas of granitic rock adjoining the basalt-covered areas.

The three largest faults trend in northerly directions. The westernmost fault, with its upthrown side on the west, extends along the west edge of Cactus Flat. In its northern part it offsets the lava sheet approximately 200 feet, with the displacement apparently increasing to and beyond the south border of the area mapped. This is presumably a normal fault, but nowhere could its attitude be observed. The next fault to the east, a normal fault dipping steeply west, bounds Cactus Flat on the east, so that Cactus Flat is an alluviated graben. Movement along this fault produced a west-facing scarp along the east edge of the Cactus Flat graben, and in the central part of the area mapped a basalt sheet was displaced 700 feet by this movement. Just to the south, slightly younger basalt then flowed westwardly over the scarp thus produced, and filled the northern part of the Cactus Flat depression to a depth of at least 400 feet. This basalt is exposed as the steep hillside, over 400 feet high, which now bounds Cactus Flat on the north (Figure 1). It is believed that this slope is far too high and steep to be the edge of a basalt flow; therefore, a fault which created this scarp is assumed to be the northern structural boundary of Cactus Flat. In the Cactus Flat district, then, two lava flows of nearly the same age are thus separated in time by faulting and are followed by later faulting. Nowhere else in the area is there evidence of faulting during extrusion.

East of the fault bounding Cactus Flat on the east are the step-faults of the Coso Range. All these faults have their upthrown sides on the east, but none of their attitudes could be determined. The lava sheets are displaced about 200 feet on the smaller faults and 600 feet on the easternmost fault in the zone.

The post-basalt faults of the east part of the Coso Range are small and unimportant. The west side of the north-trending fault immediately east of Centennial Flat is upthrown about 200 feet. A minor fault in upper Coso Valley has uplifted a small patch of lava and tilted it to the east.

Post-basalt movement has thus occurred on all but one of the faults mapped in the Coso Range, and to this movement the range owes much of its present relief. The effect of this faulting was to raise the range as a tilted horst, uplifted more on its west side than on its east.

The one mapped fault along which post-basalt movement has not occurred is the buried fault extending along the east edge of the range. As has been previously mentioned, the erosion surface of low relief represented by Centennial Flat was uplifted toward the close of the Pliocene to form, where the Coso Range now stands, a topographically high area which shed the coarse basal gravels of the Coso formation. This older uplift took place along the buried fault bordering the range on the east, and possibly along faults on the west side of the range also. As a result of this uplift, parts of the Coso Range had considerable relief at the time the basalt was extruded, as is well shown east of Centennial Flat by the granitic hills which rise above the lava flows but are almost completely surrounded by them.

Faults between the Coso and Argus Ranges

The mapped faults of Cenozoic age between the Coso and Argus Ranges displace lava sheets; no pre-lava Cenozoic faults were recognized. A buried fault zone extends along the steep western scarp of the hills west of Darwin, and the area immediately to the east of this zone has been raised with respect to Coso Valley. The amount of movement along this fault zone is impossible to determine accurately, but it is at least 500 feet and probably not more than 1000 feet. The presence of the faults along the northwest edge of the Darwin Hills is clearly shown by the displacement of a lava sheet, the more westerly fault having a vertical displacement of about 200 feet and the fault to the east a vertical displacement of approximately 75 feet. The distance these faults extend to the south under the alluvium is uncertain. These are the only faults by which the Darwin Hills are known to have been uplifted in late Cenozoic time, and consequently these hills are considered to be essentially a feature of the late Pliocene erosion surface.

Faults in the Argus Range

The northern Argus Range is an east-tilted block which has been raised to its present position by post-basalt normal faulting along its western edge. The fault zone on the west margin of the range consists of a single main fault and two subsidiary step-faults father west. The main fault, extending completely across the area mapped, is well exposed along much of its trace. It is marked by a band of gouge five to ten feet wide which dips west at 75° to 80°. In the northern part of the area mapped the displacement of the lava sheet indicates that the east side of this fault has been raised about 1700 feet with respect to the west side, but the amount of the displacement diminishes southwardly, so that at the south edge of the area mapped the Carboniferous beds have been displaced vertically only 300 feet. Alluvium covers the intersection of the Darwin tear fault with this later fault, but the apparent slight offset of the Darwin tear fault indicates only a small strike-slip component for the younger fracture.

The two step-faults west of the main fault displace a lava sheet, and are thus readily located even though the faults themselves are covered by basaltic talus (Figure 7). The maximum vertical displacements on the faults, respectively from west to east, are about 400 and 200 feet. These step-faults cannot be traced beyond the area of displaced lava. There is no indication as to whether movement occurred along the fault zone on the west edge of the Argus Range prior to the development of the late Pliocene erosion surface of low relief, but there is evidence that such movement did occur along the Panamint Valley fault zone. Within the Argus Range itself are a few small faults which offset the basalt sheets 50 to 100 feet.

The north-trending fault on the east edge of the Argus Range displaces older alluvium as well as basalt, and is therefore younger than the faults on the west flank of the range. This fault is buried by younger alluvium along its entire course so that its attitude cannot be determined, but its maximum vertical displacement, at its northern end, is approximately 400 feet.

Panamint Valley fault zone

Noble (1926, p. 425) named the fault along the east edge of Panamint Valley south of Wildrose Canyon the Panamint Valley fault. The term Panamint Valley fault zone would therefore seem to be appropriate for the zone of faults along the entire eastern edge of Panamint Valley, north as well as south of Wildrose Canyon. This is the widest and most complex fault zone mapped within the strip studied, and the movements along it have been very large. Figure 34 is a photograph showing the country traversed by the Panamint Valley fault zone within the area mapped.

The westernmost fault in this zone extends completely across the area along the west edge of the Panamint Range. For most of its length this fault is buried under the thin eastern edge of the most recent Panamint Valley alluvium, but its presence is clearly indicated by the straightness of the range front, by triangular facets on the west ends of the west-trending spurs in the Nova conglomerate (Figure 12), and, in its northern part, by the actual outcrop of the fault. The topographic features associated with this northern portion of the fault indicate strike-slip movement, as has already been explained. Though the vertical displacement accompanying this recent strike-slip movement raised the west side of the fault approximately 40 feet with respect to the east side, the major dip-slip movement has been in the opposite direction, resulting in the uplift of the Panamint Range with respect to Panamint Valley.

East of this westernmost fracture are two faults in the Nova fanglomerate marked by west-facing scarps about 400 feet high. The more westerly one dips west at approximately 65°, but the attitude of the other could not be determined.

Farther east, high on the west slope of the Panamint Range, is a fourth fault in the Panamint Valley fault zone. This fault separates fanglomerate of the Nova formation on the west from Paleozoic dolomite and conglomerate on the east, and is marked by a prominent west-facing scarp of Paleozoic rock which extends north of the area mapped to form the east side of Towne's Pass. The trace of the fault is largely covered by elevated and dissected alluvium, but in its southern part the fault is exposed, dipping steeply to the west. Its dip slip is about 5000 feet in the northern part of the area mapped, for the Nova formation, at least 3000 feet thick, has been raised on the east side of the fault so that its base is 2000 feet higher than the top of the same formation on the west side (as shown in the geologic section of Plate 1). To the south, however, the displacement diminishes so that Nova fanglomerate is exposed on both sides of the fault. The southerly portion of the fault, where both sides consist of the relatively easily eroded fanglomerate, is not marked by a scarp.

The four faults in the Panamint Valley fault zone thus far described all have the same general north-northwesterly strike, and on all of them the east sides have been raised relative to the west sides. These faults therefore constitute a zone of step-faults. Uplift of the Panamint Range to its present position accompanied the movement along this zone, for the scarps resulting from this movement are all younger than the erosion surface of subdued relief which makes up the highest portion of the range. The easternmost fault in this zone ---- the one at the base of the scarp of Paleozoic rock ---- is evidently the oldest, for much of its length is covered by old alluvium, now uplifted and dissected, and the part of it in the Nova fanglomerate is not marked by a scarp. The old alluvium here is a layer capping the "tread" of a step in the zone of step-faults. The three faults to the west, all marked by scarps in the Nova fanglomerate, must be considerably younger than the fault partially buried by old alluvium.

A fault buried by the Nova formation east of the band of Paleozoic rocks on the west flank of the Panamint Range has already been mentioned in the discussion of this fanglomerate. Such a fault is indicated by the proximity of the east-dipping Silurian (?) and Devonian (?) strata, on the west, to the east-dipping pre-Cambrian rocks on the east. The thickness of pre-Cambrian, Cambrian, and Ordovician rocks cut out by this buried fault is fully 20,000 feet, and it is believed that the dip slip is probably of this order of magnitude. Since the coarse and thick Nova fanglomerate was derived from the east, it is inferred that the movement along this fault created a west-facing scarp which was eroded to yield the fanglomerate.

The location of the fault buried beneath the Nova fanglomerate is not known from any direct field observations in the area mapped. There is good reason to believe, however, that this buried fault is a northerly continuation of the long straight north-trending marginal fault on the west edge of the Panamint Range south of the mouth of Wildrose Canyon, for a north-trending zone of crushed and discolored pre-Cambrian rock on the west edge of the range in and south of Wildrose Canyon disappears under the Nova fanglomerate as it is traced to the north. This zone of crushed rock dips about 35° west; for a short distance south of Wildrose Canyon it constitutes the front of the range, which is similar to the faceted part of the mountain front south of Ballarat described by Noble (1926, pp. 425-427) and illustrated in Figure 13. If this straight marginal fault is extended to the north into the area mapped it passes between the Paleozoic and pre-Cambrian outcrops on the west side of the Panamint Range, as the buried fault must, and emerges in Emigrant Wash. The presence of a fault beneath the gravel of Emigrant Wash was suggested by Ball (1907, p. 210; this fault is also inferable between the Pennsylvanian and Cambrian of Ball's section LL', p. 198). In the map and section of Plate 1 the buried fault is therefore indicated as a single normal fault, a direct prolongation of the north-trending fault marginal to the present range south of the mouth of Wildrose Canyon.

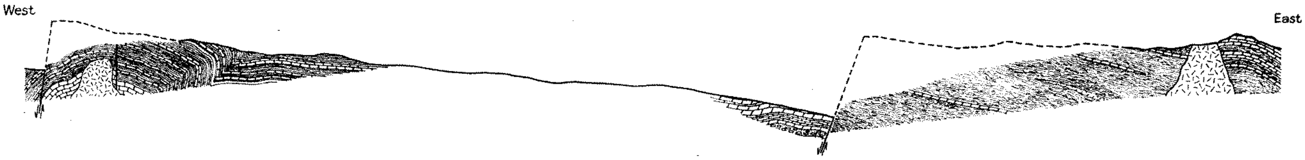
As interpreted from the foregoing data, the earliest activity on this part of the Panamint Valley fault zone was movement on the buried fault which separates the Paleozoic rocks from the pre-Cambrian. The large displacement on this fault leads to the belief that its movement may have created a high west-facing scarp. The Nova fanglomerate, known to have been derived from the east, is considered to be the product of the degradation of this scarp. Shortly after their deposition the fanglomerate and the interbedded basalt were tilted slightly to the east, probably by faulting along the Panamint Valley fault zone. Then ensued the long period of erosion, ending toward the close of the Pliocene epoch, which reduced the relief of the region to an old-age condition. Later faulting, blocking out the present west front of the Panamint Range, followed the strike of the old north-trending fault south of the mouth of Wildrose Canyon, but north of the mouth of Wildrose Canyon it took place along north-northwest-trending fractures, the step-faults of the Panamint Valley fault zone in the area mapped. Thus the part of the north-trending fault north of Wildrose Canyon, buried by the Nova formation, did not become active again; the later movement followed a north-northwesterly course.

Plate 16 illustrates the history of the portion of Panamint Valley crossed by the strip mapped, as thus interpreted.

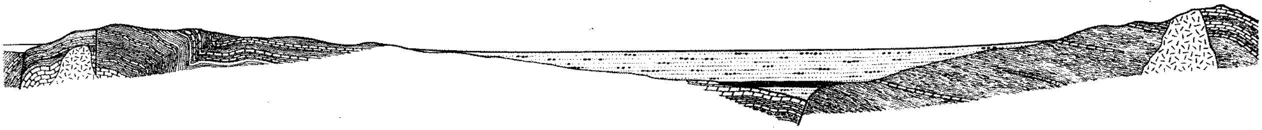
Faulting on the east edge of the Panamint Range

As has been already stated (p. 31), the evidence for major faulting along the east margin of the Panamint Range within the area mapped is entirely geomorphic. The old-age surface of subdued relief on the summit has been uplifted, without appreciable tilting, several thousand feet above the floors of Panamint and Death Valleys, and is bounded on both west and east by steep and rugged slopes. The slope to the west is the result of the step-faulting just described. The slope to the east, though considerably steeper, is much more deeply dissected. There is no evidence of recent movement along faults within it or at its base. In all its geomorphic aspects, including height and steepness, it is comparable to the east front of the Sierra Nevada within the area studied. For these reasons it is considered to be a deeply eroded fault scarp, and on the geologic map and section of Plate 1 a buried fault of unknown attitude is indicated just east of the present margin of the Panamint Range. From a consideration of the deeply eroded character of the scarp, the major movement along this buried fault or

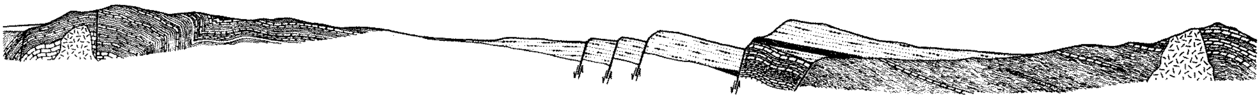
Plate 16.



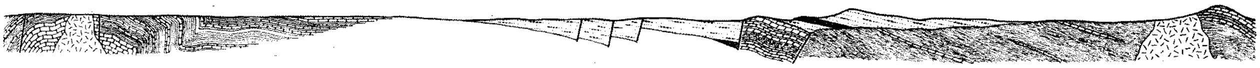
Late Miocene? Initial blocking out of the Argus and Panamint Ranges.



Late Miocene to early Pliocene? Deposition of the Nova formation (alluvial fan material, derived from the degradation of the west-facing scarp, and interbedded basalt).

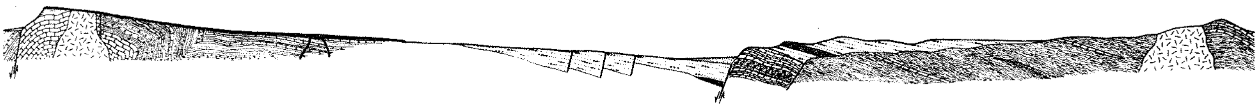


Early Pliocene? Tilting to the east on the Panamint Valley fault zone.

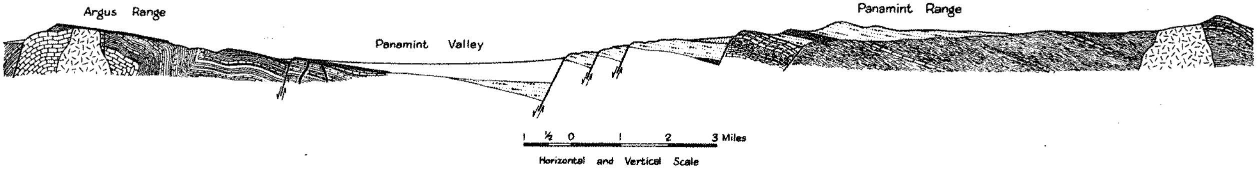


Middle and late Pliocene. Undisturbed erosion, and the development of an erosion surface of low relief.

Late Pliocene or early Pleistocene. Extrusion of basalt.



Early Pleistocene. Initial Quaternary movement on the Panamint Valley fault zone.



Pleistocene and Recent. Faulting along the east and west edges of Panamint Valley, bringing the structure section to its present condition.

Plate 16. Inferred events in the later Cenozoic history of Panamint Valley. Formational symbols as in the geologic section of Plate 1.

fault zone is believed to have occurred early in the Pleistocene, at which time the range was uplifted as a horst (next to last stage in Plate 16).

Later uplifts of the range seem to have been accomplished wholly by normal faulting along its western edge. The large scale of these movements on the Panamint Valley fault zone, the equally large scale of the late movements along the fault zone on the east edge of Death Valley, and the lack of known contemporaneous deformation between these two zones, suggest that during this later faulting the Panamint Range and Death Valley behaved essentially as a rigid crustal block, and that the west edge of the block was uplifted, elevating the Panamint Range, while the east edge was lowered, depressing Death Valley. This suggestion implies that the Panamint Range has been tilted to the east by these latest movements, yet the old erosion surface on the summit does not appear to be tilted. The width of the crustal block between the two fault zones, however, is so great that a considerable uplift of the Panamint Range could be brought about by a rather small rotation. The two zones are about 29 miles apart, which would mean, for example, that a 4° rotation of the block about a north-trending horizontal axis near the earth's surface midway between the two zones would elevate the west part of the Panamint Range 5300 feet and would depress the east edge of Death Valley an equal amount. This factor may explain the failure to notice evidence of tilting of the summit upland.

Nowhere is the east edge of the central part of the Panamint Range marked by the evidences of recent major uplift by faulting, such as triangular-faceted spur-ends and straightness of bedrock-alluvium contact, which are so prominent on the west margin of the range. At a few places, however, there are small east-facing fault scarps in the alluvium of the large fans which spread to the east into Death Valley. An especially large scarp of this kind lies east of Telescope Peak. These scarps suggest that fault movements are being resumed along the east edge of the range, and that the uplift now in progress is again of the horst, rather than of the tilted block, type.

Discussion of Cenozoic Structures

From the foregoing description of the Cenozoic structural features it is evident that deformation has occurred frequently during the latter half of the Cenozoic era. A summary of the age, location, and nature of the known Cenozoic crustal movements is given below, in chronologic order:

(1) Faulting, older than the Nova formation, on the west flank of the Panamint Range

(2) Eastward tilting of the Nova formation of the Panamint Range before the development of the late Pliocene land surface of subdued relief

(3) Uplift of the Coso Range, at least partly by faulting, after the development of the late Pliocene surface of low relief but before the deposition of the late Pliocene or early Pleistocene Coso formation

(4) Extensive normal faulting throughout the entire area after the extrusion of the late Pliocene or early Pleistocene basalt but before the deposition of the older Quaternary alluvium

(5) Faulting, younger than the older Quaternary alluvium, on both sides of Panamint Valley.

Virtually all of the Cenozoic crustal movements, therefore, have resulted in faulting. The faults whose attitudes could be observed are normal faults, and it seems probable that all the Cenozoic faults are of the normal variety. There is no evidence of Tertiary thrusting such as occurred in the region to the south and east (Hewett, 1928; Longwell, 1928; Glock, 1929; Nolan, 1929;

Noble, 1938).

During the deformation to which the area owes most of its present relief ((4) in the list above), the crustal blocks between Cactus Flat, and the Panamint Range, bounded by Quaternary faults, were tilted to the east, and those west of Cactus Flat were tilted west. East of Cactus Flat, faulting and tilting both occurred in the relatively short period after the outflow of basaltic lava but before the deposition of the Quaternary lake beds and older alluvium; this strongly suggests that faulting and tilting were contemporaneous. If so, the movement was a rotation of the fault-blocks to the east, so that the fault surfaces were tilted as well as the lava sheets. The Argus Range and Panamint Valley, for example, constituted a crustal block bounded on the east and west by fault zones, and movement along these zones tilted the block so that its west edge was uplifted to form the Argus Range and its east edge was depressed to form Panamint Valley. During the post-basalt deformation of the area the upper part of the earth's crust must have been lengthened in an east-west direction, but the magnitude of this lengthening cannot be calculated because of the unknown dips and dip slips of some of the major faults, and also because of the unknown strike slips along the faults, whose traces are not parallel.

No close folds were created by the Cenozoic crustal movements, but the deformation did include the forming of gentle flexures. Warping seems to have accompanied the earlier tilting of the Nova formation ((2) in the above list; early Pliocene? stage of Plate 16), for the eastward dips of this formation are in general somewhat larger in the west part of the Panamint Range than in the central part. The importance of warping in the later Cenozoic deformation is difficult to evaluate because the observed effects which may have been produced by major warping may equally well be the result of the rotation of rigid fault-blocks. The dips of the Coso formation in the geologic section of Plate 1, for example, suggest that the latest uplift of the Coso Range ((4) in the list above) may have involved broad anticlinal flexing, but it is equally possible that these dips resulted from the tilting of rigid blocks by faulting. Referring again to this geologic section, it might even be postulated that, just prior to the faulting by which the present topography is so largely determined, the late Pliocene erosion surface of low relief was flexed into a great north-trending upwarp whose axis was near the site of the present Coso Range and which included as its west and east flanks the Sierra Nevada and the Argus Range, respectively. The faulting between the summits of the Sierra Nevada and the Argus Range could then be regarded as the result of the later collapse of the crest of this great anticline. LeConte's similar hypothesis for the creation of the entire Great Basin by the breakdown of an upwarp extending from the Sierra Nevada to the Wasatch Range is well known (Le Conte, 1889, p. 262).

There are objections, however, to the idea that any such upwarp existed for an appreciable length of early Pleistocene time. The height of its central part would have been so great that evidences of glaciation should now be found on the summit of the Coso Range. Furthermore, deep gorges, counterparts of those formed early in the Pleistocene on the west slope of the Sierra Nevada, would have been cut on the east limb of the anticline also, and should now be represented as canyons extending from the west edge of Panamint Valley completely up to the crest of the Argus Range, with evidence that their heads originally lay even farther west. The absence of such canyons is reason for belief that the eastward tilt of this range could not have existed for a very long time before the faulting which created its western scarp. This supports the suggestion, made in a previous paragraph, that tilting and faulting occurred at the same time as parts of the same process.

During the Quaternary deformation in the area the outer portion of the crust was extended and most parts of it were elevated. It is quite possible that this deformation was caused by regional anticlinal warping, with east-west tension in the upper part of the crust accompanying a tendency for broad uplift; if this was the case, however, the flexing in the deeper part of the crust must have resulted almost immediately in normal faulting at the surface. The recent strike-slip faulting in Death and Panamint Valleys, where the southwest sides of the faults have moved relatively northwest, demonstrates that horizontal shearing stresses were active in at least the latter part of the deformation.

GEOLOGIC HISTORY

PRE-CENOZOIC GEOLOGIC HISTORY

The oldest rocks of the area indicate that during pre-Cambrian time a thick group of sediments was deposited here, folded, metamorphosed, intruded by small basic igneous bodies, and eroded. There is very probably at least one unconformity within the pre-Cambrian metasediments.

Paleozoic sedimentation in this part of the Cordilleran geosyncline was nearly continuous, but two breaks in deposition are indicated: one by the apparent disconformity between the Silurian and Devonian, and one by the angular unconformity within the upper Carboniferous. The types of crustal movements which caused these unconformities are unknown. Other breaks in the Paleozoic section may be discovered when more intensive stratigraphic work is done.

Nothing is known of the early Mesozoic history of the area mapped. Marine Triassic sediments are present in the Inyo Range to the northwest (Knopf and Kirk, 1918, pp. 47-48) and in the Spring Mountains to the east (Hewett, 1931, pp. 32-33), so it is quite possible that a Triassic sea covered the area of the present study. Later in the Mesozoic the Nevadian orogeny affected the area, and during this disturbance the Paleozoic and pre-Cambrian strata were folded, faulted, and intruded by late Jurassic plutonic rocks.

CENOZOIC GEOLOGIC HISTORY

At no time since the Nevadian orogeny has the region between the Sierra Nevada and Death Valley received deposits of marine sediments. During Cretaceous and early Tertiary time the mountains created by this orogeny are supposed to have undergone virtually undisturbed erosion, so that by middle Miocene the region was worn down to a condition of low relief. An external drainage system to the Pacific probably was in effect during most or all of this period of erosion, for nearly all the eroded material was carried away from the region. The only sediments known to have been deposited in eastern California while this erosion was in progress are those of the land-laid lower Oligocene Titus Canyon formation, just east of Death Valley (Stock and Bode, 1935).

At some time between the Nevadian orogeny and the middle Miocene, presumably early in the Tertiary, the extrusive and explosive volcanic activity represented by the flows and tuffs of the eastern Panamint Range took place, and, probably in the same interval of time, the lamprophyre dikes and sills of the Coso and Argus Ranges were intruded. The andesite of the western Coso Range is tentatively referred to the upper Miocene because of the occurrence farther south of andesite known to be of that age.

The events in the later Cenozoic history of the area investigated have already been referred to, in a disconnected way. They are systematically summarized in the first three columns of Plate 17. For comparison, a fourth column is added, listing and tentatively correlating the corresponding events in the history of the Inyo Range, Owens Valley, and the east slope of the southern Sierra Nevada as interpreted by Gale (1915), Knopf (1918), Blackwelder (1931), and Matthes (1933). Perhaps the most interesting feature of this comparison is the correlation offered between the glacial and interglacial stages in the Sierra Nevada and events to the east. The following paragraphs are in explanation of these correlations.

Blackwelder (1931, p. 918) has recognized evidences of four glacial stages on the east slope of the Sierra Nevada, and has tentatively correlated them with the standard North American Pleistocene section as follows:

Standard section	Sierra Nevada
Wisconsin	Tioga
Iowan	Tahoe
Kansan	Sherwin
Nebraskan	McGee

On the basis of its vertebrate fossils the Coso formation was dated as late Pliocene or early Pleistocene by Schultz, who believed that it was deposited

PLATE 17.

	COSO RANGE	ARGUS RANGE AND DARWIN HILLS	PANAMINT RANGE AND PANAMINT VALLEY	INYO RANGE, OWENS VALLEY, AND EAST SLOPE OF SIERRA NEVADA
RECENT	Erosion and alluviation.		Evaporation of lake in Panamint Valley. Faulting on Panamint Valley fault zone. Erosion and alluviation.	Development of existing arid climate. Disappearance of late Pleistocene lake system. Faulting in Owens Valley. Erosion and alluviation.
PLEISTOCENE			Formation of a lake in Panamint Valley.	Tioga glacial stage in Sierra Nevada. Development of Owens Valley - Indian Wells Valley - Searles Basin - Panamint Valley - Death Valley lake system.
				Recurrence of arid conditions during a short interglacial period.
		Tapping of Darwin Wash by headward erosion of Darwin Canyon. Dissection of old alluvium and lake beds.	Faulting on west and east sides of Panamint Valley. Dissection of old alluvium and lake beds.	Renewed faulting. Tahoe glacial stage, with increased humidity. Dissection of older alluvium and lake beds.
		Interglacial stage of increased aridity. Disappearance of lakes, and deposition of older alluvium.		
		Deposition of lake beds in Darwin Wash (and Panamint Valley?)		Sherwin glacial stage in Sierra Nevada, a stage of high humidity. Deposition of Waucoba Canyon lake beds.
	Normal faulting, uplifting the ranges and tilting the Coso and Argus Ranges to the east. Horst-uplift of the Panamint Range.			Normal faulting, uplifting the Inyo Range. Major uplift of Sierra Nevada by movement on Sierra Nevada fault zone.
LATE PLIOCENE OR EARLY PLEISTOCENE	Extrusion of basaltic lava.			Extrusion of basaltic lava in the Inyo Range.
LATE PLIOCENE OR EARLY PLEISTOCENE	Faulting, elevating the Coso Range and causing it to shed the coarse basal detritus of the Coso formation. Later, deposition of the lake beds of the Coso formation.			McGee glacial stage in Sierra Nevada.
MIDDLE AND LATE PLIOCENE	Undisturbed erosion, and development of a land surface of low to moderate relief.			
EARLY PLIOCENE (?)			Probable activity on Panamint Valley fault zone, tilting the Nova formation to the east.	
LATE MIOCENE (?) TO EARLY PLIOCENE (?)			Deposition of the Nova formation on the west side of the Panamint Range.	
LATE MIOCENE (?)			Faulting on Panamint Valley fault zone, creating the Panamint Range and Panamint Valley.	Initial movement on Sierra Nevada fault zone, creating the eastern escarpment and tilting the range to the west.

during a time of cool and humid climate and favored the view that it is of early Pleistocene, probably Nebraskan, age (1937, pp. 86-98). The Coso formation may thus correlate approximately with the McGee till of the Sierra.

Flows of olivine basalt were spread over much of the mapped area just after the deposition of the Coso formation. Basalt flows believed to be of this age are widely distributed throughout this part of California, usually as caps on uplifted remnants of old-age erosion surfaces. In the region discussed in this report these flows certainly include Knopf's "late Tertiary basalts" of the Inyo Range (1918, p.74), and they very probably include the flows of olivine basalt which rest upon the Ricardo erosion surface (Baker, 1911, pp. 366-367; 1912, pp. 126-128, 131-132). Shortly after the extrusion of the basalt, the Inyo, Coso, Argus, and Panamint Ranges were uplifted by normal faulting approximately to their present heights. Matthes (1933, p. 38) has pointed out that there is reason for believing that the major uplift of the Sierra Nevada along the fault zone at its eastern edge did not occur until after the McGee glaciation, for the McGee moraines are now situated high on the eastern slope of the range, whereas the younger moraines lie at the mouths of the present canyons. From a comparison of the amount of dissection of the Sierra scarp with the amount of dissection of the scarps of the Inyo, Coso, and Argus Ranges it appears quite probable that the major uplifts of these ranges by faulting occurred at substantially the same time. Thus the greater part of the relief of this portion of the Great Basin is believed to have been created by normal faulting during the early or middle part of the Pleistocene epoch.

Knopf (1918, pp. 104-105) recognized evidences for the two latest glacial stages in the Sierra Nevada, and inferred from the history of the alluvial fans of the Inyo Range that there had been two corresponding periods of increased humidity in the region (1918, p. 57). He recognized a third and earlier period of relatively high humidity represented by the lake beds of Waucoba Canyon (1918, p. 57), but, having noted only two glacial stages, could not correlate the Waucoba lake beds with a Sierran glacial stage. It is evident, as Knopf stated (1918, p. 52), that the Waucoba lake beds are younger than the Coso formation, for the Waucoba beds were deposited in the lower part of a canyon cut into the Inyo Range after its uplift by the major faulting. Therefore, if the Waucoba beds actually indicate increased humidity associated with a Sierran glacial stage, it would appear that they should be correlated with the second, or Sherwin, glaciation. This correlation would imply that the major uplift of the Inyo Range occurred during the interval between the McGee and Sherwin glacial stages. Also, if the correlation of the lake beds of Darwin Wash with the Waucoba beds is correct, the post-basalt uplift of the Argus Range must have taken place in this same interval. From these relations it is suggested in Plate 17 that the normal faulting to which the region owes most of its present relief occurred in the McGee-Sherwin interglacial stage.

Old alluvium, now dissected, overlies the lake beds in Waucoba Canyon and Darwin Wash. Knopf (1918, p. 57) considered that it was deposited in a rather long period of increased aridity during which alluvial fans spread over the former lake bottoms. This period may therefore represent the interglacial stage between Blackwelder's Sherwin and Tahoe glacial stages.

Faulting next occurred on the edges of the Inyo Range, uplifting the old alluvium and allowing it to be dissected (Knopf, 1918, pp. 56-57). Similarly, faulting along both edges of Panamint Valley followed closely the deposition of the older alluvium. Knopf believed that renewed humidity associated with his first (Blackwelder's Tahoe) glacial stage aided in accomplishing the dissection of the old alluvium. Presumably during this time of higher humidity and increased stream competence Darwin Wash was tapped by headward erosion in Darwin Canyon, and the lake beds and old alluvium which had accumulated in the Darwin Wash basin were soon dissected by the new drainage system thus developed.

On the basis of a terrace about 50 feet above the present canyon bottoms Knopf (1918, p. 57) recognized a short arid period between his first and second glacial stages. No similar terrace was found in the area of the present investigation. Blackwelder (1931, p. 881) has estimated that this post-Tahoe interglacial stage lasted only about one-tenth as long as the post-Sherwin interglacial stage during which the old alluvium was deposited.

During the last glacial stage in the Sierra Nevada the great lake system described by Gale (1915) came into existence. The waters of Owens Lake, fed by Sierran glacial streams, overflowed successively into Indian Wells Valley, Searles Basin, Panamint Valley, and Death Valley. With increasing aridity and the disappearance of most of the glaciers, present-day conditions began; Owens Lake ceased to overflow, the lakes to the south and east evaporated, and recent alluvial fans spread over the edges of their basins. Faulting has continued in some parts of the region up to the present time, as witnessed by the recent scarps of the Panamint Valley fault zone and by the well-known Owens Valley earthquake of 1872.

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