

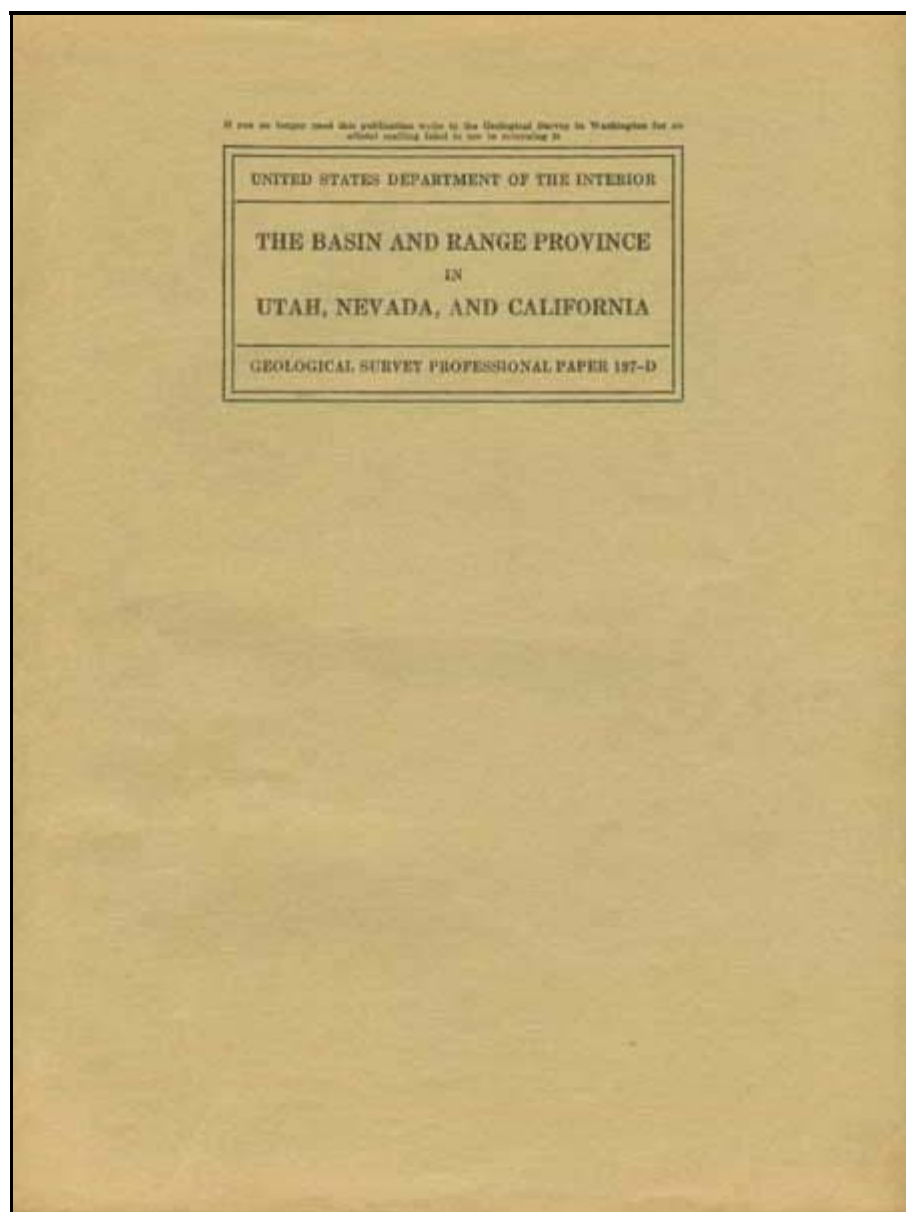


Geological Survey Professional Paper 197—D

The Basin and Range Province in Utah,
Nevada, and California

THE BASIN AND RANGE PROVINCE IN UTAH, NEVADA, AND CALIFORNIA

By
Thomas B. Nolan



**Shorter contributions in general geology, 1941-42
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ABSTRACT

THE BASIN AND RANGE PROVINCE IN. UTAH, NEVADA, AND CALIFORNIA¹

By THOMAS B. NOLAN

¹This account of Great Basin geology was prepared as a contribution to "Geology of North America," to be published by Gebruder Borntraeger under the editorship of Robert Balk. The inability of the German publishers to issue the second and third volumes of this work has led to the publication of this paper by the Geological Survey. Unfortunately, there has been neither time nor opportunity to bring up to date the original account, which was transmitted in December 1938.

In this report an attempt has been made to summarize and in places to interpret the published information that was available through 1938 on the geology of those parts of Nevada, California, and Utah that are included in the geologic province known as the Basin and Range province. This region includes most of the Great Basin, from which no water flows to the sea, as well as part of the drainage basin of the lower Colorado River. It is characterized by numerous parallel, linear mountain ranges that are separated from one another by wide valleys or topographic basins.

All the major divisions of geologic time are represented by the rocks exposed in this region. The oldest are of pre-Cambrian age and crop out chiefly along the eastern and southern borders. They have been carefully studied at only a few localities, and the correlation and extent of the subdivision so far recognized is uncertain. There appear to be at least three series of pre-Cambrian rocks which are probably separated from one another by profound unconformities. Large masses of intrusive igneous rocks have been recognized only in the oldest series.

During the Paleozoic era the region was a part of the Cordilleran geosyncline, and sediments were deposited during all of the major and most of the minor subdivisions of the era. There are thick and widespread accumulations of Cambrian and Ordovician strata, the maximum aggregate thickness possibly exceeding 23,000 feet. The eastern and western boundaries of the province were approximately those of the area of rapid subsidence within the geosyncline, though the axes of maximum subsidence oscillated back and forth during the two periods. The Silurian and Devonian seas, on the other hand, extended beyond the province and, possibly as a consequence, are represented by much thinner sections—of the order of 6,000 feet. At the end of the Devonian period the geosyncline was split by the emergence of a geanticline in western Nevada, and Mississippian and Pennsylvanian sedimentary rocks are known only in the central and eastern part of the province. They locally attain considerable thicknesses, however, as the combined thickness of the two series in western Utah approaches 24,000 feet. The geanticline appears to have been eroded by Permian time, as Permian strata have been recognized in most parts of the province except the southern, where

another geanticline, which persisted into the Mesozoic era, began to rise coincidentally with the disappearance of the older one. Igneous activity was at a minimum throughout the Paleozoic era. Some volcanism appears to have occurred locally in the Carboniferous period, but the lavas and sills cannot yet be accurately dated and may be somewhat younger.

The second geanticline, which began to form in Permian time, was greatly extended during the Mesozoic era and eventually caused the disappearance of the geosynclinal seas that had persisted throughout most of Paleozoic time. Its axis lay east of the earlier geanticline, and its gradual emergence resulted in the development of two depositional troughs within the province. The western trough was filled with more than 30,000 feet of sediments and interbedded volcanic deposits, which range in age from basal Lower Triassic through the Lower Jurassic. Deposition in this trough was terminated by a period of intense orogeny near the end of Lower Jurassic time. The deposits of the eastern trough are found only along the eastern border of the province; they consist largely of nonmarine sedimentary beds ranging in age from Triassic to Upper Cretaceous. Marine Lower Triassic, possible Middle Triassic, and Upper Jurassic sedimentary rocks have been found in a few places, and some pyroclastic rocks occur in Lower Triassic and Upper Cretaceous beds. The eastern seaway appears to have been closed to the south, for lagoonal deposits, such as salines, characterize the southern and southeastern extensions of the marine formations. In addition to the surficial volcanic rocks, there are numerous extensive bodies of coarse-grained intrusive rocks. Some of these are clearly extensions of the late Jurassic or early Cretaceous intrusions of California, but some of those in Utah are best dated as early Tertiary. Most of the intrusive masses cannot be accurately dated, but practically all of them were emplaced after the intense local orogeny that affected individual areas at various times from the Lower Jurassic well into the Tertiary.

Cenozoic rocks underlie more than half of the province. Most of them, however, are either igneous rocks or nonmarine sedimentary rocks that are sparsely or not at all fossiliferous. As a result, definite age assignments for many of the rock units cannot be made, and correlations between the relatively few well-studied sequences are hazardous. The few marine sedimentary rocks are restricted to the southwestern border of the province. The province appears to have been a highland under going erosion throughout Eocene and Oligocene time. Continental and, in southern California, marine sedimentary deposits of Eocene age have been recognized only along the borders of the province, though volcanic rocks of this age may be represented throughout the area. Oligocene sedimentary rocks have been recognized in only one area, but here they appear to have been formed in a basin not unlike those existing at present. Several bodies of granular intrusive rocks in the eastern part of the province have been referred to either the Eocene or the Oligocene. By far the greater number of the known fossiliferous sedimentary rocks are assigned to the Miocene and Pliocene and are almost exclusively of continental origin, being composed of fanglomerates, silts, and saline beds that are in many respects like the beds now being deposited in the intermontane valleys. Volcanic debris commonly forms a large proportion of the sedimentary sequence and thick accumulations of lava flows and pyroclastic rocks and local intrusive masses are generally associated and interbedded with them. The widespread Quaternary sedimentary deposits in the province consist chiefly of lake beds and fanglomerates, but locally glacial deposits and river gravel and silt are well developed. Basalt flows and in places rhyolite flows are also found at several localities.

The Basin and Range province has been orogenically active throughout a large part of its history. The pre-Cambrian structural history is little known at present, though it appears that were in pre-Cambrian time at least three epochs of deformation.

Beginning with Cambrian time the record is much more complete. The geosynclinal sea which in the early part of the Paleozoic era covered most of the province and in which many

thousands of feet of sediments were deposited was divided in late Devonian time by a rising arch or geanticline in western Nevada. Locally there was moderate deformation during the uplift, but by Permian time elevation had ceased and most of the positive area had been covered by marine sediments. Coincidentally with the degradation of this geanticline during the Permian epoch similar uplift began in eastern Nevada, and a land mass between two seas persisted there until early Jurassic time, when, instead of subsiding as the earlier one did, it became the site of intense diastrophism, marked particularly by large overthrust faults. To judge from the relatively meager evidence available, recurrent epochs of similar deformation continued into early Tertiary time, affecting an area that considerably exceeded that of the Basin and Range province. No regular pattern in space or time can yet be discerned for these epochs; in one area there may be evidence of only one episode of deformation, but in another area nearby there may have been several. The Mesozoic and early Tertiary folding and overthrusting were succeeded closely by the initiation of the block faulting that has been the chief cause, directly or indirectly, of the present relief of the province. The faulting appears to have started at least by early Oligocene time and to have continued up to the present day. For several reasons the block faulting is regarded as an end stage of the more intense deformation that preceded it.

The Paleozoic and later structural history of the province leads to the suggestion that these events have been integral parts of a single orogenic cycle, during which the initial geosynclinal downwarping was successively followed by one or more broad geanticlinal uplifts, the last of which culminated in an epoch of folding and overthrusting, and a final stage of block faulting.

The province contains many mining districts, from which large quantities of the nonferrous metals and of nonmetallic materials have been obtained.

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INTRODUCTION

The Basin and Range province in Utah, Nevada, and California includes as its major subdivision the semiarid to arid region that has long been known as the Great Basin; it also includes, in southeastern California, parts of the locally poorly defined subdivision called by Fenneman (61)^{1a} the Sonoran Desert and the Salton Trough. The boundaries of this region are in large part those established by Fenneman (62), but some departures have been made along the northern and southern boundaries, both of which are much less well defined than the western boundary, formed by the eastern front of the Sierra Nevada, and the eastern boundary, made up by western borders of the Wasatch Range and the Colorado Plateau. On the north a purely arbitrary line has been selected, which runs from Susanville, Calif., to McDermitt, Nev., and thence eastward along the northern boundaries of Nevada and Utah to the Wasatch Range. The southeastern boundary of the Colorado River is equally arbitrary, but the use of the San Andreas fault as the boundary on the southwest is perhaps as defensible as the irregular boundary heretofore used. The region thus bounded is shown on figure 10; throughout this text it is called, for the sake of brevity, the "Great Basin" or, simply, the "province."

^{1a}Numbers in parentheses refer to the bibliography at the end of this report.





These boundaries differ from the hydrographic limits set by Frémont (71) in the original definition of the Great Basin as the region from which no water flowed to the sea. A boundary drawn solely on the basis of drainage, however, would exclude a considerable area drained by the Colorado River that is geologically and topographically closely related to the undrained regions and would include part of southern Oregon that is geologically similar to the adjoining Columbia River Plateau.

According to Fenneman (61, pp. 342-343), the distinctive features of the Basin and Range province are "isolated, nearly parallel mountain ranges (commonly fault blocks) and intervening plains made in the main by subaerial deposits of waste from the mountains. These deposits, although locally absent, are often very deep and are generally unconsolidated. The consolidated older strata and lavas which make the mountains are locally horizontal. In general they are deformed and at places very much so." Although some may object to the implications of origin included in this statement, there can be little dissent to the distinctiveness, as compared with adjoining provinces, of the numerous individual mountain

ranges which have been graphically characterized by Dutton as an "army of caterpillars crawling toward Mexico" and which are in general sharply separated from the intervening valleys.

Any summary of the geology of this great region is necessarily a statement of progress in the accumulation of knowledge and is based on rather inadequate data rather than on a selection of comprehensive observations and confident conclusions. The sources of information for a large proportion of the area are the hasty reconnaissance surveys made many years ago, and some large areas are still unexplored. Most of our present conceptions of Great Basin geology are therefore based on a few detailed studies of widely separated areas combined with the uncertain interpretation of older reconnaissance reports, and it is not surprising that the conclusions reached by different workers show considerable variance.

The present text emphasizes the more recent work in the region, but this more detailed work has, on the whole, far higher standards of accuracy. The recent publications cited, however, commonly include references to the older work.

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HISTORY OF EXPLORATION²

²Prepared by D. F. Hewett.

The fact that there was a large area in the western part of the present United States from which no water flowed into the sea was first determined by Frémont in 1844, and the name "Great Basin" was given to it. Parts of this region had been entered as early as 1776 by Escalante, and it was crossed in 1826 by Jedediah Smith, and in 1833-34 by Bonneville and Walker. After the territory was acquired by the United States there were numerous explorations by United States Army engineers to determine the available railroad routes to the Pacific coast. The most thorough of these explorations were those made across the northern and central part of the Basin by Stansbury (1849), Beckwith (1854), Steptoe (1855), and Simpson (1858-9) and those made across the southern part by Whipple (1853) and Williamson (1854). These explorations yielded considerable geographic information but only meager data concerning the geologic features. The study of the geologic features practically began with the survey of the 40th parallel under the leadership of Clarence King from 1867 to 1873, the surveys of the Rocky Mountain region under J. W. Powell and the surveys west of the 100th meridian by the geologists under Lieutenant Wheeler (G. K. Gilbert, A. R. Marvine, and E. E. Howell) from 1869 to 1874. After these surveys were completed the principal geologic work in the Great Basin before about 1900 included detailed studies of two mining districts—Comstock by G. F. Becker (1882) and Eureka by Arnold Hague and J. S. Curtis (1880)—and the studies of the two great Pleistocene lakes of the basin—Lake Lahontan by I. C. Russell (1885) and Lake Bonneville by G. K. Gilbert (1890).

The explorations by J. E. Spurr in 1899 yielded a reconnaissance geologic map of Nevada south of the 40th parallel and, beginning with the discovery of Tonopah in 1900, numerous mining districts were studied, notably Tonopah (1903), Silver Peak (1899-1900), Goldfield (1905), Bingham (1900-1902) and Tintic (1896, 1916). Other than studies of local mining districts, however, the only large areal studies before 1919 were those of S. H. Ball (1905) and Adolph Knopf (1912). During the period 1900 to 1919 the geologic staff of the University of California made numerous local studies bearing on problems of Tertiary stratigraphy, structure, and physiography. Beginning in 1919, several extensive areal surveys have been undertaken in the province and numerous smaller areas around mining camps have been studied in detail.

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ACKNOWLEDGMENTS

In many respects these pages are a joint contribution from the several members of the Geological Survey whose recent studies, both published and unpublished, in the Great Basin region have provided much of the basic information here presented. I am greatly indebted to them for many enlightening discussions, as well as for the use of numerous unpublished data, and have refrained from designating some of them as co-authors only because some of my conclusions have not been uniformly accepted.

Among these collaborators, to whom are due my deepest appreciation, are Eugene Callaghan, for a critical reading of the section on structural history; F. C. Calkins, for unpublished data on the Cottonwood and Comstock Lode districts; H. G. Ferguson, for a critical reading of the whole paper, many stimulating discussions, and much unpublished information on many parts of Nevada; C. L. Gazin, of the National Museum, for a critical reading of the section on Cenozoic stratigraphy; James Gilluly, for data and suggestions regarding both stratigraphic and structural problems; D. F. Hewett, who provided in addition to sympathetic supervision, the draft of a summary of Great Basin geology and much unpublished information on the Ivanpah quadrangle; W. D. Johnston, Jr., for unpublished information on the Comstock Lode region; Edwin Kirk, Jr., for critical reading of the section on the pre-Carboniferous Paleozoic stratigraphy; G. F. Loughlin, for many helpful suggestions throughout the manuscript; S. W. Muller, for unpublished information on western Nevada, especially in regard to the Mesozoic stratigraphy; J. B. Reeside, Jr., for critical reading of the section on Mesozoic stratigraphy; W. W. Rubey, for critical reading of the section on structural history; J. S. Williams, for critical reading of the section on Carboniferous stratigraphy; and W. P. Woodring, for critical reading of the section on Cenozoic stratigraphy and assistance in its preparation.

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STRATIGRAPHIC AND IGNEOUS HISTORY

All major divisions of geologic time are represented in the Great Basin. The pre-Cambrian rocks have been but little studied as yet, but several unconformable series of metamorphic, igneous, and sedimentary rocks have been distinguished. The Paleozoic and early Mesozoic strata record the vicissitudes of a complex and persistent geosyncline, in which many thousands of feet of sediments were deposited. This sea was finally expelled from the province in mid-Mesozoic time, and the later Mesozoic and Cenozoic rocks comprise widely distributed local accumulations of nonmarine sedimentary beds and igneous intrusive and extrusive rocks.

The inadequate treatment of the igneous rocks in these pages is the result, in large part, of the absence of accurate information regarding their age, and the consequent difficulty in describing the volcanism as a feature of the geologic history of the province. Little can be added from the province to Lindgren's description and interpretation of the Cordilleran volcanism (141).

The assignment of the boundaries of the individual systems and series of the Paleozoic and Mesozoic and their major subdivisions is largely that presented in the charts accompanying Guidebook 29 of the Sixteenth International Geological Congress (200).

PRE-CAMBRIAN ROCKS

In the Great Basin pre-Cambrian rocks crop out chiefly along the eastern and southern borders, where the cover of Paleozoic or Mesozoic sediments was relatively thin. These older rocks have been carefully studied at only a few localities, and the correlation and extent of the subdivisions so far recognized are uncertain. There appear to be at least three series of pre-Cambrian rocks, which are probably separated from one another by profound unconformities. Large masses of intrusive igneous rocks have been recognized only in the oldest series.

The best known pre-Cambrian exposures along the eastern border of the province are in the Wasatch Range of Utah. Blackwelder (21) suggested that three series of pre-Cambrian rocks occur in this range—an oldest gneissic series, a series of metaquartzite and schist of intermediate age, and a young series of quartzite and slate. The relations of the intermediate series to the others, however, have not been satisfactorily determined.

The old gneissic series, which includes biotite and other schists, has been commonly assigned to earliest pre-Cambrian time. The earlier geologists included with these metamorphic rocks certain masses of granitic rocks that are now known to be much younger (24, pp. 8788). This series is possibly the most widely distributed of the three; it is locally directly overlain by the Cambrian. Little is now known of the intermediate series (21, 41) beyond the fact that its varied lithology and degree of metamorphism are notably different from those of the other

two series. Blackwelder has tentatively correlated it with rocks of similar appearance in Wyoming and the Black Hills region whose age has been determined as early pre-Cambrian.

The youngest series comprises 10,000 or 11,000 feet of quartzites and slates in Cottonwood Canyon, Utah, though 45 miles away, near Santaquin, only 500 to 1,000 feet of similar beds intervene between the Cambrian and the older gneisses (56). Blackwelder (14, p. 525) regards the series as of continental origin and was the first to describe the unconformity between it and the overlying Cambrian quartzite that had previously been regarded as a part of the series. A tillite with an overlying varved slate occurs locally between the main mass of the series and the Cambrian and has been found both in the Wasatch Range and the region to the west (112, 32, 19). It was originally considered a part of the quartzite-slate series, but recent investigations have shown it to be underlain by an unconformity, and Calkins (36) now assigns it questionably to the lower Cambrian. The series has generally been correlated with the Belt series to the north and the Grand Canyon series to the south, and all three with the rocks of Algonkian type in the Lake Superior region. Hinds (111), however, regards the series as older than the Belt rocks and places it, together with some similar rocks in Colorado and Arizona, in a new time division that he calls the Uncompahgran.

Other pre-Cambrian rocks have been reported from parts of Utah west of the Wasatch Range (32), but little is known about their correlation. The most southwesterly exposure in the Beaverdam Mountains continues southward into the Virgin Mountain pre-Cambrian area of Nevada described by Longwell (145). Here, as at most of the other occurrences in southern Nevada and in southern California near the Colorado River, the pre-Cambrian rocks consist of gneisses and schists that are considered to be earliest pre-Cambrian. In the Boulder Dam region, however, Longwell (148, pp. 1406-1409) has found two areas of sedimentary rocks that are possibly of late pre-Cambrian age.

Still farther south the pre-Cambrian rocks have been subdivided at two localities. In the Ivanpah quadrangle, Nev., Hewett (105) distinguishes an older gneissic series, which is overlain unconformably by a younger sedimentary series 4,000 feet thick. Hazzard and Dosch (96), however, recognize three units in the eastern part of San Bernardino County, Calif. Here the oldest, called by them the Essex series, consists of 7,000 feet or more of various types of gneiss and schist, with some quartzite and marble, and is regarded as largely of sedimentary origin. It is intruded by their Fenner and Kilbeck gneisses, of which the Kilbeck is in places relatively little metamorphosed.

Much of the Mojave Desert region of California and the country south of it is underlain by metamorphic rocks, part of which may be of pre-Cambrian age (28, 89, 192, 241), although some of these much-altered rocks have yielded Paleozoic fossils. Hulin (116) has made one of the few detailed studies of the older rocks in this region and has distinguished a probably older Johannesburg gneiss, including 2,500 feet, more or less, of metamorphosed sedimentary rocks, and a younger Rand schist, 1,500 to 2,000 feet thick, which was originally a series of interbedded sedimentary and volcanic rocks with some intrusives. The age relations between the two units are not certain, but the gneiss shows a considerably higher degree of metamorphism. Noble (180) has also found a gneiss and a schist series near the San Andreas rift along the southwestern border of the Mojave Desert. The schist series is known as the Pelona schist, and its identity with the Rand schist is commonly accepted. A thickness of about 7,500 feet has been found by Simpson (213, pp. 378-381). Some what different older pre-Cambrian rocks have been found by Miller (172) to the southeast.

North of the Mojave Desert there are considerable exposures of the pre-Cambrian in the Death Valley region and in the northern Inyo Mountains or White Mountains. Noble (183), in a preliminary statement, has divided the Death Valley rocks into an Archean system of partly igneous and partly sedimentary origin and a dominantly sedimentary Algonkian

system, which is 7,000 feet thick. Both groups show resemblances to the rocks of similar age assignment in the Grand Canyon region. Murphy (177) has mapped four preCambrian formations in the Panamint Range, immediately west of Death Valley, but their correlation with the Death Valley rocks is as yet uncertain.

The section in the Inyo Mountains, Calif., was first studied by Kirk (130, pp. 23-25), who distinguished three formations—a lower one composed of considerably metamorphosed sandstone and dolomite; the Reed dolomite, 2,000 feet thick; and the Deep Spring formation, from a thin edge to 1,600 feet thick, composed of sandstone, limestone, and some shale. Unconformities were believed to be present above and below the Deep Spring formation. Maxson (162) has recently published an abstract of the results obtained during a resurvey of this area. In addition to the Reed and Deep Spring formations, to which thicknesses of 2,900 and 2,100 feet were assigned, he described, beneath the Reed, the Wyman formation, 3,700 feet of schist and phyllite, and the still older Roberts formation, 2,500 feet of contorted schist and dolomite. Unconformities were believed to occur between all the formations.

Anderson (2) reports a quite different pre-Reed dolomite sequence a short distance north of the area studied by Kirk and Maxson. He found three unconformable groups composed dominantly of originally elastic rocks, in contrast to the schists and dolomites of the southern area. The lower group includes two thick flows of amygdaloidal basalt. The notable differences in the two nearby areas illustrate the difficulties met in attempts to correlate the pre-Cambrian rocks in the province. An additional complication in this particular area lies in the possibility, suggested by Hazzard (95), that the Reed dolomite and Deep Spring formation may prove to be the equivalents of his Lower Cambrian Noonday dolomite and of the Johnnie formation of the Death Valley region.

The maps and text of the 40th Parallel Survey indicate the existence of several pre-Cambrian outcrops in northern Great Basin, the largest one in the Ruby of central Nevada (88, pp. 532-537). The Ruby Range occurrence, however, has been shown by Hill (109, pp. 55-58), to be a granite intrusive into the Paleozoic, and it seems fairly certain that other supposed pre-Cambrian outcrops are also later intrusives. Turner (244) has reported Archean gneiss and schist at Silver Peak, Nev., but Spurr (226) considers it probable that the rocks thus designated are crumpled Paleozoic sedimentary strata that have been complexly injected by intrusive granitic rocks. The correlation of Turner's Algonkian sedimentary system is likewise somewhat uncertain, as the 7,500-foot sequence of dolomite, quartzite, and schist is described as being essentially conformable with the overlying Cambrian and may therefore be basal Lower Cambrian.

PALEOZOIC ROCKS

During the Paleozoic era the Great Basin region was a part of the Cordilleran geosyncline, and sedimentary beds deposited during all of the major and most of the minor subdivisions of the era are widely distributed in the province. The stratigraphic sections shown in plates 40 and 41 indicate that the geosynclinal seas had a trend somewhat east of north. They are known to have extended far north of the province, but their occurrence to the southwest has been a matter of some debate. The known outcrops of Paleozoic sedimentary rocks in the Mojave and Colorado Deserts of southeastern California are so few that the suggestion has been made that the geosyncline never extended over this region but either terminated abruptly along the northern border of the Mojave Desert or was in some way deflected around it. The trends in thickness shown in the northern part, together with the lithology of the strata in the regions immediately north of the Mojave Desert, however, seem to indicate that the geosyncline must have extended southward along its projected axis. The absence of recognizable sedimentary deposits in this southern region may then be the result either of

intense deformation or of erosion following differential movement and possible uplift along the Garlock fault (p. 186), which forms the northern boundary of this southern region.

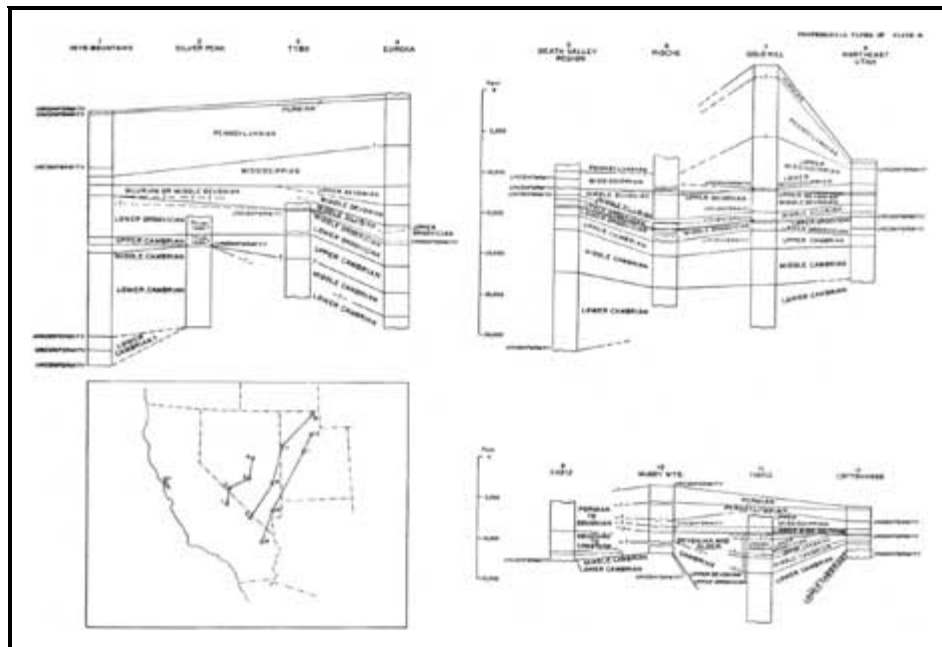
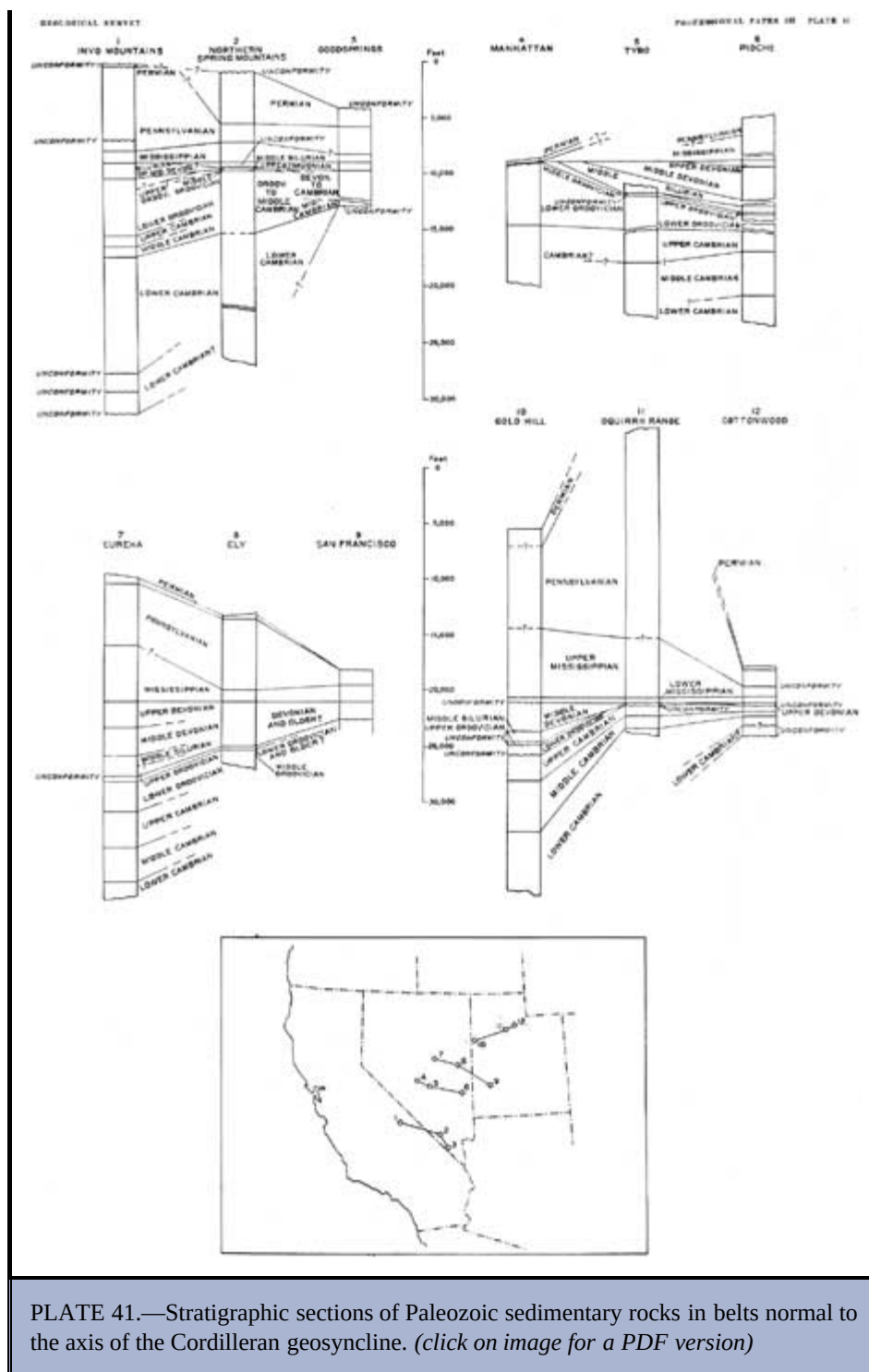


PLATE 40.—Stratigraphic sections of Paleozoic sedimentary rocks in belts parallel to the axis of the Cordilleran geosyncline. ([click on image for a PDF version](#))



Within the larger region where Paleozoic rocks are abundantly exposed there are thick and widespread accumulations of Cambrian and Ordovician strata, the maximum aggregate thickness possibly exceeding 23,000 feet. The eastern and western boundaries of the province were approximately those of the area of rapid subsidence within the geosyncline, though the axes of maximum subsidence oscillated back and forth during the two periods. The Silurian and Devonian seas, on the other hand, extended beyond the boundaries of the Great Basin and, possibly as a consequence, are represented by much thinner sections—on the order of 6,000 feet. At the end of Devonian time the geosyncline was split by the emergence of a geanticline in western Nevada, and Mississippian and Pennsylvanian sedimentary rocks are known only in the central and eastern parts of the province. They locally attain considerable thicknesses, however, as the two series in western Utah aggregate nearly 24,000 feet. The geanticline appears to have been eroded by Permian time, as Permian strata have been found

in most parts of the province except the southern, where another geanticline, which persisted into the Mesozoic era, began to rise coincidentally with the disappearance of the older one.

Although the combined maximum thickness of the Paleozoic sedimentary strata exceeds 50,000 feet, this figure has not been attained at any one locality. At the few localities where the entire Paleozoic sequence has been carefully studied the individual sections are all somewhat less than 30,000 feet. The fact that there is a fairly close correspondence in total thickness at these several widely separated localities, in spite of notable differences in the thickness of the component systems, may indicate the amount of subsidence that was possible in the simple Cordilleran geosyncline, but the data are too scanty to warrant more positive statements.

Igneous activity was at a minimum throughout the Paleozoic era. Some volcanism appears to have occurred locally in the Carboniferous period, but the lavas and sills cannot yet be accurately dated and may be somewhat younger.

The descriptions of the sedimentary rocks of the several systems and series in the following pages have been based largely on rather recent and fairly detailed studies of small areas. Considerable additional information is available in the reports of the pioneer surveys (88, 125, 78) and in the reconnaissance reports of Hague (87), Spurr (225), Ball (11), Hill (108, 109), and Butler (32). For the most part, however, it is difficult to evaluate the stratigraphic information in these reports for purposes of detailed correlation, and more recent detailed work in areas covered by these reconnaissance surveys has commonly shown numerous inaccuracies in their stratigraphic and paleontologic interpretations.

CAMBRIAN SYSTEM

Cambrian sedimentary rocks are found in many places in the Great Basin and probably were originally deposited over the whole province. The beds commonly rest with marked unconformity on various kinds of pre-Cambrian rocks, but locally, as in the central Wasatch Mountains, Utah (24, p. 84), there has been debate about the position of the break; and similar uncertainty exists concerning the basal Cambrian contact in the Inyo Mountain and Death Valley regions.

The Cambrian sedimentary rocks within the province thicken abruptly westward. The southeastern border of the region here described corresponds more or less closely with the eastern edge of the area of rapid subsidence within the geosyncline. Thus, in the Virgin Mountains of southeastern Nevada less than 1,000 feet of Cambrian sedimentary strata are present, but they thicken to over 18,000 feet about 50 miles to the west. The western edge of this deep trough has never been recognized but appears to have been somewhere in the neighborhood of the present Sierra Nevada, to judge from the thickness of fine-grained clastic deposits found in the westernmost Lower Cambrian exposures. Its position may have varied, however, as the maximum thicknesses of Middle and Upper Cambrian sedimentary beds are some distance east of those of the Lower Cambrian.

LOWER CAMBRIAN

Thick Lower Cambrian sections are exposed in the vicinity of Death Valley and in the Inyo Mountains-Silver Peak region. The Death Valley section has recently been carefully studied by Hewett (105), Noble (183), and Hazzard (95) and may be considered, for the present at least, a standard for this part of the province. The basal formation, the Noonday dolomite of Hazzard, is about 1,500 feet thick and rests with marked unconformity on preCambrian sedimentary beds. Above it are the Johnnie formation, 2,550 to 4,500 feet of slates and quartzites (186); the Stirling quartzite, 2,600 to 3,700 feet thick; and the Wood Canyon formation (3,000 feet), composed of sandstone, shale, and some limestone. The maximum

thickness at any one locality appears to be in the neighborhood of 10,000 feet.

The Lower Cambrian section of the Inyo Mountains may have a maximum thickness of over 13,000 feet, but its limits are as yet uncertain. Kirk (130) and Maxson (162) consider the Campito sandstone the lowest Cambrian formation. It is 2,000 to 3,200 feet thick and similar in lithology to the Stirling quartzite of the Death Valley region. Above it is the fossiliferous Silver Peak group, about 7,000 feet thick,³ consisting of shale, sandstone, and limestone. These beds were studied by Walcott both here and at Silver Peak many years ago (246, pp. 185-189), and the Inyo Mountains section at Waucoba Springs is the source of the series name Waucoban now commonly used for the Lower Cambrian sedimentary rocks. Hazzard (95) has recently suggested that the two formations beneath the Campito—the Deep Spring formation (2,000± feet thick) and the Reed dolomite (2,000-2,900 feet thick)—are correlative with the lithologically similar Johnnie formation and Noonday dolomite of the Death Valley section. Should this suggestion be validated by future work and the present assignment of the Johnnie and Noonday to the Cambrian be confirmed, the Inyo section would be without question the thickest Lower Cambrian unit in the province.

³Turner estimates a thickness of 10,000 feet at Silver Peak, Nev. (244).

The only other localities where a complete Lower Cambrian sequence is known lie along the eastern edge of the province, near the border of the geosyncline, where the sedimentary beds of this age are commonly only a few hundred feet thick. The most southerly of these is in the eastern Mojave Desert near Cadiz, Calif. Here Clark (39) and Hazzard (92) found 400 to 500 feet of quartzite overlain by less than 200 feet of shale and limestone containing Lower Cambrian fossils. The beds rest unconformably on the pre-Cambrian and are overlain by fossiliferous Middle Cambrian. A section of similar thickness and lithology to the northeast, in the Goodsprings district of Nevada (104), is now also considered to be Lower Cambrian (98), although a nearly identical section in the Virgin Mountains, Nev. (145), is apparently a continuation of the Middle Cambrian Grand Canyon section (179). Still farther northeast in the central and southern Wasatch Mountains, Utah (112, 36, 56), a basal quartzite (Tintic quartzite) 800 to 900 feet thick is assigned to the Lower Cambrian and the lower portion of the overlying Ophir shale, 200 to 400 feet thick, has yielded Lower Cambrian fossils and the upper portion Middle Cambrian fossils. The successively younger age of the progressively more eastern basal clastic sedimentary beds has commonly been interpreted, in accordance with Walcott's conclusion (248, p. 180), as the result of an eastward overlap of the Cambrian sea, the initial deposits at each locality, though of different ages, being composed of the reworked regolith of the invaded area.

The incomplete sections of Lower Cambrian sedimentary beds in western Utah and central and eastern Nevada consist of a thick quartzite and an overlying shale. The quartzite is commonly called the Prospect Mountain quartzite in Nevada and the Tintic quartzite in Utah. The exposed thicknesses range from a few hundred feet to over 6,000 feet (142); in western Utah, where nearly 5,000 feet is found, there are several thick shale members in the lower portion (187). The shale likewise has had different names in the two States, Pioche shale being used in Nevada and Ophir formation in Utah. It commonly has interbedded limestones that have been the hosts for valuable ore bodies. Westgate (254) assigned 1,100 feet of shale, limestone, and sandstone to the Pioche shale at the type locality and considered it all to be Lower Cambrian. Both Burling (30) and Deiss (48), however, regard the fauna of the upper few hundred feet as basal Middle Cambrian. A similar inclusion of Lower and Middle Cambrian faunas in the Ophir formation is reported from Ophir (82), Tintic (142), and the central Wasatch Range (36), Utah. At all these localities the total thickness of the formation is about 400 feet. Walcott (246) reported Walcott had tentatively assigned to the Middle Cambrian Langston limestone.

The tillite and varved slates found beneath the Tintic quartzite in the vicinity of Salt Lake City, Utah, originally assigned to the pre-Cambrian (112), have in recent years been questionably placed in the Lower Cambrian (19, 36). This assignment is in accord with Walcott's belief that a glacial epoch occurred near the end of Lower Cambrian time (248, pp. 184 and 200-201); he suggested that the barren sandstones and quartzites of the Tintic and Prospect Mountain quartzites may have been deposited during such an epoch.

Although there has been a recent revival of interest in the western Cambrian faunas, the Lower Cambrian has not yet been given as much attention as the younger parts of the system. Walcott distinguished four zones (247, p. 250) based on trilobite genera; and Resser (204) has recently listed seven or eight, though these are based on sections in the eastern United States. Mason, Longwell, and Hazzard (157), however, found only one trilobite fauna in the Lower Cambrian in the southern Great Basin, though Hazzard (94) has called attention to the rather slight stratigraphic range of the fossil organism known as *Girvanella* within the region.

MIDDLE CAMBRIAN

Over most of the Great Basin Middle Cambrian sedimentary beds appear to be exactly conformable with the Lower Cambrian—indeed, in many places the boundary between the two lies within a succession of lithologically similar rocks and is determinable only on fossil evidence. At a few places, however, there are suggestions of slight disturbances at the beginning of the epoch. These conform with Walcott's belief that disturbances are required to account for the sharp change in the fauna, although he considered that the bordering lands showed low relief throughout the remainder of the epoch (248, pp. 180, 189-190).

During this epoch the zone of maximum sedimentation in the geosyncline appears to have been shifted about 100 miles east of its position in the Lower Cambrian. The thickest section so far described is in the Death Valley region, where Hazzard (95) has described three formations—the Cadiz, Bonanza King, and Cornfield Springs—with an aggregate thickness of 5,180 feet. These three units may be recognized for a considerable distance to the east and southeast and are considered by Hazzard and Mason (99) to be equivalent to the greater part of the Goodsprings dolomite of Nevada (104). They maintain a total thickness of 2,500 to 3,000 feet even in the regions where the Lower Cambrian is less than 1,000 feet thick (98, 92). Westward there is apparently a somewhat more abrupt thinning, for only 900 feet of Middle Cambrian beds, largely sandstone, were recognized in the Inyo Mountains by Kirk (130). At Silver Peak, Nev., Turner (244) found no Middle Cambrian whatever, and the Upper Cambrian apparently rests unconformably on the Lower Cambrian. These two localities along the zone of maximum sedimentation in Lower Cambrian time provide the chief evidence for a minor disturbance at the beginning of the Middle Cambrian.

North-northeast of Death Valley there are thick Middle Cambrian sections at Pioche, Nev. (about 4,000 feet), Gold Hill, Utah (4,475 feet), and northeastern Utah (probably about 4,000 feet). At Gold Hill a quartzite is the lowest unit in the series (187), but both at Pioche (254, 48) and in northeastern Utah (246, 205) the bottom has been either in dispute or uncertain. Middle Cambrian sections of nearly comparable thickness are also reported from Eureka, Nev. (87, 249) and the House Range, Utah (246, 48), where they are slightly more than 3,000 feet thick. At all these localities except Eureka four to six formations, composed chiefly of limestone or dolomite, have been distinguished in the Middle Cambrian series, but none of these can be correlated with another.

Westward from this portion of the zone of thick sections several thousand feet of unfossiliferous Cambrian sedimentary rocks, chiefly metamorphosed sandstones and shales, have been found at Tybo, Nev. (66), and Manhattan, Nev. (63). Some of these may

eventually be referred to the Middle Cambrian, but, to judge from the evidence at Silver Peak and in the Inyo Mountains, it seems more likely that the bulk of them are either Lower or Upper Cambrian.

Several Middle Cambrian sections in central Utah, east of the thick sequences in the western part of the State, have been described. That at Tintic (142) is about 1,900 feet thick, the one at Ophir (82) about 1,100 feet, and those in the central (36) and southern (56) Wasatch Mountains about 400 feet. At the two localities in the Wasatch Range the Ophir shale is the only formation present, but at Tintic and Ophir there are, in addition, several formations composed almost entirely of limestone and dolomite.

The Middle Cambrian faunas have been extensively studied in recent years, but the results of these investigations have been only incompletely published. Resser (204), Mason, Longwell, and Hazzard (157), Deiss (49), and Howell and Mason (115) have recognized from three to nine faunal zones in the series, most of which are found in various parts of the Great Basin.

UPPER CAMBRIAN

Wherever both Middle and Upper Cambrian sedimentary beds have been recognized in the Great Basin they appear to be perfectly conformable. The unconformable relations between the Upper and Lower Cambrian at Silver Peak, Nev. (244), may, however, reflect a disturbance in early Upper Cambrian time, though an early Middle Cambrian date now seems somewhat more probable. The Upper Cambrian differs from the two lower divisions of the Cambrian both in its smaller average thickness and in the apparent absence of any well-defined belt of maximum thickness. These features may be the result either of the post-Cambrian erosion represented by the unconformity that has been recognized in several places at the base of the Ordovician or of the exceedingly low relief of the border lands during the Upper Cambrian epoch, which permitted great extensions of the sea (248, pp. 193-194).

Only two sections more than 3,000 feet thick have been described. The thicker of these is in the House Range, Utah (246, pp. 173-185; 200, pl. 1; 48), where about 4,000 feet is now assigned to the Upper Cambrian. Three formations at Eureka, Nev., are also believed to be of this age and aggregate 3,150 feet (87), but the thicknesses assigned and possibly the lower limit of the group may be revised with future work.

Most of the remaining Upper Cambrian sections in the province range between 1,000 and 3,000 feet in thickness, but there appears to be little system in the variations from place to place. Thus in northeastern Utah (205, 200, 48) there are about 1,400 feet of beds; in the Oquirrh Range, Utah (82), about 1,000 feet; at Gold Hill, Utah (187), 1,600 to 2,200 feet; at Pioche, Nev. (254), 1,900 feet; at Tybo, Nev. (66), possibly as much as 3,000 feet; in the Inyo Mountains, Calif. (130), about 1,000 feet; and in the Death Valley region (95), 1,700 feet. An Upper Cambrian section of uncertain thickness occurs at Silver Peak, Nev. (243), and beds of this age may be present at Manhattan, Nev. (63), and in the San Francisco district, Utah (31). At almost all these localities, except the western ones, limestone or dolomite forms the bulk of the section.

Erosion after Upper Cambrian time appears to have been pronounced along the eastern border of the province, for at both Tintic (142) and in the Cottonwood district, Utah (36), from 400 to 600 feet of Upper Cambrian limestones and dolomites are locally entirely missing. Possibly a similar explanation may account for the current uncertainty regarding the age of portions of the Goodsprings dolomite in southern Nevada. As originally defined (104), this formation included beds ranging in age from Upper Cambrian to Devonian (?). Recent work (99) seems to indicate that south of the type area no Upper Cambrian is present in beds correlated with the formation. As Upper Cambrian fossils were found at Goodsprings, it may

be that the beds of this age have in places been removed by pre-Ordovician or pre-Devonian erosion.

Resser (204) and Howell and Lochman (114) have recently distinguished 15 or 20 faunal zones in the Upper Cambrian of the United States. Many of these are present in the Great Basin region; Mason, Longwell, and Hazzard (157) have distinguished four in the southern part of the province.

ORDOVICIAN SYSTEM

Ordovician sedimentary rocks are not as widely distributed in the Great Basin as those of Cambrian age. They are absent in many of the more easterly localities; where present, they are commonly considerably thinner than the Cambrian beds found with them. Although Lower, Middle, and Upper Ordovician rocks are all found in many places, the two younger series are represented by relatively thin sections of fairly constant thickness. The Lower Ordovician, however, shows a notable increase in thickness westward, its belt of maximum thickness apparently coinciding with that of the Lower Cambrian. The greatest thickness of Ordovician rocks so far recorded from the province is 5,050 feet in the Inyo Mountains, Calif. (130).

The nature of the contact between Ordovician and Cambrian strata is somewhat uncertain. Fossils are not abundant in the beds, and in many places the exact location of the boundary is difficult to determine. Walcott (248) and others have considered that the two systems are generally conformable, but erosional unconformity has been reported at three localities—northeastern Utah, Gold Hill, Utah, and the Tintic district, Utah. At two of these, however, the discordance now appears to be at a different horizon than the faunal change. Thus in northeastern Utah, Deiss (48) has recently found Ordovician fossils in the St. Charles formation beneath the supposed unconformity, and at Gold Hill (187, p. 15) *Scaevogyra* sp., considered by Bridge (26) to be a typical Upper Cambrian fossil, occurs in beds assigned to the Lower Ordovician. Until more extensive collecting has been done in this part of the Great Basin Paleozoic section, and a general agreement reached by paleontologists as to the proper location of faunas that have been referred by some authors to the Ozarkian and Canadian systems as defined by Ulrich, it is probably futile to speculate about the magnitude and extent of the probable unconformity at the base of the Ordovician.

LOWER ORDOVICIAN

There are two facies of Lower Ordovician sedimentary rocks in the province—an eastern facies composed chiefly of limestone and dolomite and a western facies characterized by shales. The eastern sequence is frequently referred to as the Pogonip limestone, named from a ridge in the White Pine district, Nevada (88), though local names or subdivisions have been used at several localities. At the type locality the Pogonip is reported to be 5,200 feet thick (87, p. 191), but this figure needs checking, as only 2,700 feet is present in the nearby Eureka district. Sections at Tybo (66) and Ely (219), Nev., and in the Death Valley region (95), with thicknesses of 3,000, 1,400±, and 1,040 feet, respectively, have also been assigned to the Pogonip. At Pioche, Nev., Westgate (254) has divided the Lower Ordovician carbonate rocks into two formations with a minimum thickness of 1,120 feet. In the Tintic district, Utah, Loughlin (142) recognized three units, aggregating more than 2,000 feet; the uppermost formation, however, contains Upper Ordovician fossils near the top. Sedimentary rocks of this age are also present in the San Francisco district, Utah (31), though their total thickness is unknown; at Gold Hill, Utah (187), where the thickness reaches 1,000 feet; and in north eastern Utah (205, 48), where a lower limestone and an upper quartzite total 2,300 feet. The Ordovician rocks reported by Hintze (112) from the Cottonwood district, Utah, are now considered to be Cambrian (36). Some Lower Ordovician beds are also probably present at

Goodsprings, Nev. (104), in the Goodsprings dolomite, but beds of this age are apparently absent from the formation in nearby areas (98). The thickest Pogonip section, except for the one in the White Pine district, appears to be in the Inyo Mountains, Calif., where Kirk (130) distinguishes four unnamed formations with a total thickness of more than 5,000 feet.

The western facies of the Lower Ordovician has been studied at relatively few places. It was first recognized in the Silver Peak region, Nevada, where Turner (243, pp. 265-266) found the Palmetto formation of graptolite-bearing slates and argillites. The lavas that he believed to be interbedded are now regarded as metamorphosed sedimentary rocks (67). To the north, at Manhattan, Nev., Ferguson (63) found a similar sequence probably more than 5,000 feet thick. Argillites, slates, and limy shales that are possibly correlative are known from the Toyabe Range, south of Austin (108, pp. 115-116), and the Troy or Irwin Canyon district (109, p. 139), both in Nevada. At the Toyabe locality about 7,000 feet of beds are reported to occur, but this thickness may be excessive (128).

The eastern and western facies have each yielded two rather distinct faunas, one of early and one of late Lower Ordovician age. In the eastern facies the older fauna is compared with the Beekmantown of the eastern United States and the younger one with the Chazy. The two graptolite faunas of the western facies are commonly correlated with the Deepkill and the Normanskill of the East. The older graptolite zone has also been found in the eastern facies in northeastern Utah (40). With additional study other and more precise faunal zones may be distinguished over the province, for Kirk (127) has recognized at several places in Nevada one of the three zones that are known in the El Paso limestone, of Beekmantown age, in Texas. Possibly another faunal horizon in the Lower Ordovician may be represented by the higher Ozarkian beds of Walcott (250, p. 224), though most of these are now regarded as Upper Cambrian.

MIDDLE ORDOVICIAN

The Middle Ordovician sedimentary rocks in the Great Basin have a smaller areal extent and are notably thinner than the Lower Ordovician sequence. In part, these two features may be the result of erosion before Upper Ordovician time, but it seems probable that the chief cause of the difference between the two series was the smaller size and shorter duration of the Middle Ordovician seaway.

Beds of this age appear to be largely restricted to eastern and central Nevada but are also represented locally in southern California and western Utah. The thickness is commonly 500 feet or less. Over most of this area the Middle Ordovician is represented by the Eureka quartzite (87); Kirk (126) considers that west of 117° these siliceous beds pass into the graptolite shales of the upper part of the Palmetto formation at Silver Peak and the Toquima formation at Manhattan, both in Nevada.

In most places the Eureka appears to be conformable upon the underlying Pogonip limestone or its correlative, and locally the contact is apparently gradational. At Ely, Nev., however, according to Spencer (219), the quartzite rests on different members of the Pogonip, suggesting unconformable relations, and a similar reflation apparently exists in the Roberts Creek Range, as reported by Kirk (126, pp. 31-32).

Kirk's recent review of the Eureka quartzite (126) summarizes the known distribution and relations of the formation. Fossils have been found within it at only one locality (in central Nevada) and are of lower Middle Ordovician age (Black River of the eastern United States). These occurred in the basal member of the formation, and the upper part may be somewhat younger.

The thickness of the Eureka quartzite as reported by Kirk is commonly only a few hundred

feet. In the San Francisco district, Utah, and the region north and northeast of Death Valley, Calif., however, sections of quartzites from 1,000 to 2,500 feet thick have been correlated with the Eureka, but these assignments are rather doubtful. At the Utah locality the quartzite, as described by Butler (31), differs lithologically from the Eureka at other places in the province, and there are some grounds for considering it an overthrust plate of Lower Cambrian quartzite. The thick sections near Death Valley are also possibly erroneously correlated with the Eureka. The original correlation was made by Ball (11) on the basis of a rapid reconnaissance; recent more detailed work in the Spring Mountains, Nev. (149), and in the region southeast and east of Death Valley (95) have shown that the true Eureka quartzite is not more than 300 feet thick.

The relation between the Eureka quartzite and the somewhat similar Lower Ordovician Swan Peak quartzite of northeastern Utah (205) has never been determined. There is, however, a possibility that both these Ordovician quartzites are part of a single regressive sandstone deposit of variable age.

UPPER ORDOVICIAN

As deposits of Upper Ordovician age are found at Utah localities (Gold Hill and Tintic districts) where those of Middle Ordovician age are absent, the later seaway appears to have been shifted somewhat to the east of the earlier. Similarly, Upper Ordovician rocks have not been recognized in many of the more westerly Middle Ordovician localities. Commonly the two series are separated by an erosional unconformity: at Gold Hill, Utah (187), at least 1,000 feet of beds older than Upper Ordovician have been locally eroded.

The Upper Ordovician strata are dominantly dolomites, and in places they have not been distinguished from the similar dolomites of the Silurian above or the Lower Ordovician beneath. They have been separately mapped as the Fish Haven dolomite in northeastern Utah (205) and at Gold Hill and as the Ely Springs dolomite at Pioche, Nev. (254), and in the Death Valley region (95). At these localities the thickness ranges from 250 to 800 feet, and the thickest section is in Death Valley. Parts of the Lone Mountain limestone of the Eureka district, Nevada (87), and the Bluebell dolomite of the Tintic district, Utah (142), contain typical Upper Ordovician faunas; and other localities where similar fossils occur are cited by Kirk (126).

The position in the Upper Ordovician assigned to these beds, which contain a rather uniform coral and brachiopod fauna, has been shifted from time to time. Originally regarded as representing the Trenton of the Eastern States, they were later considered to be equivalent to the Richmond of the Cincinnati region; now, however, they are thought to be, in part at least, correlative with the Maysville of the Cincinnati region (128).

SILURIAN SYSTEM

Silurian dolomites have a moderately wide distribution in the Great Basin. Their eastern limit is approximately that of the underlying Upper Ordovician dolomite—from northeastern Utah through Gold Hill to Pioche, Nev. Westward they probably extend beyond the limits of the Upper Ordovician and in several places directly overlie Middle Ordovician or older beds. The western limit of the seaway is uncertain, as the Silurian sedimentary rocks in the western part of the province have been removed by erosion that followed up-arching in this region in Devonian and later Paleozoic time. As beds of this age have been recognized in the Taylorsville region, California, west of the province (51), the Silurian sea extended at least that far westward, marking a considerable expansion of the geosyncline beyond its limits during the Cambrian and Ordovician.

At several localities these beds rest unconformably on the Ordovician strata, though there is commonly no recognizable discordance in strike or dip. The absence of basal Silurian rocks and the occurrence of beds at different horizons in the Ordovician beneath the contact indicate a fairly long interval of erosion preceding the deposition of the Silurian formations.

In the northeastern part of the province rocks of Silurian age have been mapped as the Laketown dolomite. They have a total thickness of about 1,000 feet both in northeastern Utah (205) and at Gold Hill (187). In Nevada they constitute the upper and probably greater part of the Lone Mountain limestone of the Eureka district (87), though as mapped at Tybo (66) the Lone Mountain is wholly Silurian. Kirk (126) has recorded many occurrences of Silurian dolomites in Nevada, and they have also been found at Pioche, Nev. (254), and in the Death Valley region, California (95). The Death Valley locality is one of the few at which accurate measurements of total thickness have been made; here only 335 feet of beds are present, much less than in the Utah occurrences.

Silurian rocks may be present at other localities in the thick series of post-Cambrian and pre-Carboniferous dolomites that occur in the Great Basin. At Ely, Nev., for example, it is very probable that both Silurian and Upper Ordovician beds will eventually be recognized in the lower part of the thick and poorly fossiliferous unit mapped as Nevada limestone (219). At Goodsprings, Nev., also, a questionable Silurian fossil is reported from the Goodsprings dolomite (104), and fossils of undoubted Silurian age have been found in the region immediately to the north (144, p. 556). The Morehouse quartzite of the San Francisco district, Utah, assigned in part to the Silurian, however, is probably of Cambrian age (p. 151), like the supposed Middle Ordovician quartzite of the same region.

A fairly extensive coral and brachiopod fauna has been obtained from the Silurian dolomites of the Great Basin province. It is correlated with the Niagaran or middle portion of the Silurian sequence of the eastern United States. Strata representing the lower and upper parts of the system appear to be absent.

DEVONIAN SYSTEM

Devonian sedimentary rocks appear at one time to have covered all of the province, and they record the beginning of a notable change in the nature of the Cordilleran Paleozoic geosyncline. Throughout earlier Paleozoic time the eastern and western borders of this seaway had been approximately those of the province, and, though its axis shifted from time to time, the depression in which the earlier sediments were deposited had been relatively simple. Toward the end of the Devonian period, however, an arch or geanticline began to rise in west-central Nevada, approximately along the line of maximum sedimentation in the Cambrian and Ordovician (185). This arch divided the old simple geosyncline into two new seaways, one lying west of the province, the other occupying its eastern portion and extending still farther eastward.

The distribution of Devonian sedimentary rocks reflects these changes in two ways—by the almost complete removal of the earlier Devonian deposits along the axis of the arch, and by the eastward shift of the zone of maximum sedimentation, the thickest sections being in eastern Nevada in the vicinity of Eureka and Ely, where Devonian beds 4,000 to 5,000 feet thick are present. Limestones and dolomites comprise the greater part of the section, but shales and sandstones are commonly abundant in the Upper Devonian, presumably the product of erosion from the rising land to the west.

An unconformity at the base of the Devonian has been reported at only four localities—in the Cottonwood district (36), Oquirrh Range (82), and Gold Hill district (187), Utah, and the Death Valley region (95), California. At all four the unconformity is marked by transgression

of the underlying beds; it is most apparent in the Cottonwood district, where more than 600 feet of the underlying Cambrian sedimentary beds are locally absent, and the beds on the two sides of the contact diverge 5° in dip. It is not improbable that more detailed work will show that similar unconformities are present in other parts of the province, as both the uppermost Silurian and the basal Devonian appear to be generally absent.

LOWER DEVONIAN

It has generally been considered that no Lower Devonian sediments were deposited in the Great Basin (200, pl. 4). Recently, however, C. W. Merriam (165) has questionably correlated the basal part of the widespread Nevada limestone with the Oriskany of the eastern United States. Confirmation of this assignment and possible extensions of the correlation must await the completion of his faunal studies of the Great Basin Devonian.

MIDDLE DEVONIAN

Middle Devonian dolomites and limestones occur over most of the Great Basin. The thicker sections, which range from 1,000 to more than 3,000 feet, occur in western Utah and eastern Nevada and in the reports on Eureka (87) and Ely (219), Nev., are referred to the Nevada limestone, which also contains Upper Devonian faunas near the top and, as noted above, probable Lower Devonian faunas at the base. Recent workers have commonly assigned local formation names to the Middle Devonian sedimentary rocks; and in places they have been subdivided into two or three units. Thus at Gold Hill, Utah (187), three Middle Devonian formations have an aggregate thickness of 2,650 feet; in the San Francisco district, Utah (31), there is 1,500 feet; and at Pioche, Nev. (254), 3,000 feet or more.

Thinner sections are found along the eastern border of the province. The beds of the northeastern part are assigned to the Jefferson dolomite, which has a thickness of 1,200 feet in northeastern Utah (205), 185 feet in the Oquirrh Range (82), and 150 feet in the Cottonwood district (36). To the south the thicknesses are somewhat uncertain. At least 300 feet of Middle Devonian beds are present in the Muddy Mountain region, Nevada (145), and about 800 feet of beds of possibly equivalent age are found in the Goodsprings and Sultan formations of the Goodsprings district, Nevada (104). Hazzard (95) has measured 890 feet in the Death Valley region.

In the western part of the Great Basin Middle Devonian strata have been found at two localities, indicating that the uplift in this region did not begin until Upper Devonian time. In the Inyo Mountains, Calif., 1,400 feet of limestone, shale, and sandstone have been described by Kirk (130), though he now believes (128) that these beds may be Silurian. Muller and Ferguson (174) report several hundred feet of limestone from the San Antonio Range of west-central Nevada. Within short distances of that locality, however, Devonian sedimentary rocks are absent, and Permian beds rest directly on Ordovician beds. Confirmation of the belief that the Middle Devonian seaway continued across this region is also furnished by the almost identical faunas present in the Great Basin sections and in northwestern California (227).

Detailed paleontologic study of the Middle Devonian faunas has begun only in recent years, but preliminary results indicate that a rather complete sequence is present. Merriam (165) has distinguished four Middle Devonian faunal zones, ranging in age from the lower part of the series (Onondaga of the eastern United States) to highest Middle Devonian (*Stringocephalus burtoni* zone). Stumm (236, 237) has found two coral faunas; the lower one is correlated with the Calceola limestone of the Rhine Valley, and the upper one with the Hamilton group of New York.

UPPER DEVONIAN

Upper Devonian rocks are less widely distributed and in general are much thinner than the Middle Devonian beds, with which they are commonly associated. This difference is thought to be in large part the result of the rising geanticline in the western part of the province, but it may also reflect in part the unconformity that is generally present at the base of the Carboniferous.

The thickest sections of Upper Devonian sedimentary rocks so far studied in the province are in the Eureka district, Nevada. Here Merriam (165) has measured 2,325 feet of beds which were formerly assigned to the Nevada limestone (87) but which he suggests should have a separate designation. The thick section of Nevada limestone at Ely, Nev. (219), mostly Middle Devonian, very probably also includes similar Upper Devonian beds.

The more easterly sections are much thinner. At Pioche, Nev. (254), there is 500 feet of limestone; in the San Francisco district, Utah (31) 50 feet of shale; and in northeastern Utah (205), 200 feet of beds assigned to the widespread Three Forks limestone. The section at Tintic, Utah (142), is unusual in that the 150 feet or less of the Upper (?) Devonian Pinyon Peak limestone directly overlies dolomites assigned to the Ordovician, though it is recognized that the upper few hundred feet of these dolomites, which are unfossiliferous, may be of Middle Devonian age. At all other localities in the province Upper Devonian sedimentation appears to have followed that of the Middle Devonian without interruption and in the same seaway, which was, however, considerably less extensive.

Merriam (165, 166) has distinguished three faunal zones in the Upper Devonian of east-central Nevada, the youngest one correlated with the Chemung formation of the eastern United States. The Upper Devonian corals from this region have been studied by Stumm (238).

MISSISSIPPIAN SERIES⁴

⁴The Geological Survey classifies Mississippian, Pennsylvanian, and Permian rocks as subdivisions ("series") of the Carboniferous system. In the Great Basin, however, the sedimentary rocks assigned to each of these three series are comparable in thickness and distribution to those of the older Paleozoic systems; they have therefore been given coordinate rank in the headings, though the use of the term "series" rather than "system" indicates their subordinate position in the accepted classification of the Geological Survey.

The Mississippian sedimentary rocks of the Great Basin show clearly that the geanticline which was developed in western Nevada during late Devonian time continued throughout the Mississippian epoch also. The maximum extent of the land mass appears to have been attained in early Mississippian time, as beds of this age have not been reported in the province northwest of a line extending from Gold Hill, in western Utah, to the Death Valley region, in California. The later Mississippian sea extended considerably farther westward into Nevada, roughly as far as a line through Eureka, Nev., to the Inyo Mountains, Calif. Whether it was joined with the sea of the same age in central and northern California by a passage to the north or to the south is not yet known.

An unconformity beneath the Mississippian is reported from most of the Great Basin localities, but there is commonly little evidence of much disturbance other than the absence of uppermost Devonian or basal Mississippian beds. The Tintic district, Utah, is the only region so far studied in which there are notable erosional irregularities along the contact (142).

The Mississippian geosyncline appears to have differed from the older Paleozoic seas in that portions of it, especially during later Mississippian time, seem to have been subject to

extreme subsidence. Thus at Gold Hill (187) and in the Oquirrh Range (82), in west-central Utah, more than 6,000 feet of sediments were deposited, whereas the comparable sections at nearby localities are very much thinner. Although a part of these marked variations may have been caused by erosion at the end of the epoch, the available evidence tends to indicate that they are due chiefly to notable differences in the thickness of the sediments originally deposited.

LOWER MISSISSIPPIAN

As used by geologists working in the Great Basin, the term "lower Mississippian" designates beds equivalent to the Madison limestone of the northern Rocky Mountains, which in turn is the correlative of the Kinderhook and Osage groups in the eastern United States (200, pl. 5). The sedimentary rocks of this age are restricted to the eastern portion of the province and consist almost entirely of limestone. Commonly the thickness of individual sections is less than 1,000 feet. Similar beds extend eastward from the Great Basin for considerable distances.

The more northerly sections can be traced with relatively short gaps to the type locality of the Madison limestone and have been mapped under that name. In northeastern Utah the unit ranges from 600 to 1,600 feet in thickness (205), but in the Cottonwood district (36) and the Oquirrh Range (82) the thicknesses are 560 and 460 feet, respectively. A similar thickness is probably present in the southern part of the Wasatch Range (56), to judge from the published descriptions of the combined Madison and upper Mississippian section. Gold Hill, in western Utah (187), is probably close to the western boundary of deposition, for there Madison limestone is present in one thrust plate but lacking in another.

Farther south and southwest local names have been used for the lower Mississippian strata, and there appears to be a tendency toward minor, though rather abrupt variations in thickness. Possibly, however, this feature is due rather to paleontologic difficulties in separating the lower and upper Mississippian on the evidence supplied by the scanty fossil collections that have been obtained in this region. Thus in the Tintic district, Utah (142), the lower Mississippian may exceed 700 feet in thickness, and a comparable figure is reported from Pioche, Nev. (254). At both localities two or three local formations have been distinguished, and the boundary between the lower and upper Mississippian is not definitely located. Farther south Longwell (145) found 600 feet of lower Mississippian limestone (Rogers Spring limestone) in the Muddy Mountains, Nev., a thickness closely comparable to that of the Redwall limestone of the Grand Canyon region, to the east (179). In the Spring Mountains of southern Nevada and the adjoining Death Valley region of California, however, the thicknesses are much more variable. In the northern part the Monte Cristo limestone, which as defined by Hewett (104) appears to be largely of lower Mississippian age, is 925 feet thick (85) and in the southern part it is possibly as much as 1,000 feet thick. In the Death Valley region, however, Hazzard (95) has recognized 987 feet of beds which he questionably correlates with the Monte Cristo limestone and, in addition, 1,180 feet of lower Mississippian beds that lie unconformably beneath. This thickness of more than 2,100 feet is by far the largest thus far recorded for the lower Mississippian.

UPPER MISSISSIPPIAN

The sedimentary beds assigned to the upper Mississippian in the Great Basin are equivalent to the Brazer limestone of the northern Rocky Mountains and are correlative with the Meramec and Chester rocks of the central Mississippi Valley (200, pl. 5). Although rocks of this age are widespread over the eastern and central parts of the province, the seaway in which they were laid down appears to have been subject to local extreme subsidence and uplift, as there are marked differences in thickness of nearby sections. In the eastern part the

strata are composed chiefly of limestone with some sandstone; in the western part they are made up largely of black shales, which overlap the old land mass that existed in this part of the province in early Mississippian time. At most places the lower and upper Mississippian appear to be perfectly comfortable, but to the south there is an unconformity between the two groups. The break may prove to be more extensive than is thought at present, moreover, as Gilluly (82) has described a black phosphatic shale at the base of the upper Mississippian in the Oquirrh Range, Utah.

The upper Mississippian sections so far described may be divided into several groups, in each of which there has been a tendency to use common formation names because of similarities in thickness or lithology. The name Brazer limestone has been extended into northeastern Utah, where Richardson (205) has measured thicknesses of 800 to 1,400 feet. Although Eardley (56) has extended this name into the southern part of the Wasatch Range, the upper Mississippian rocks of most of central and west-central Utah may be more conveniently referred to the section in the Oquirrh Range (82), where four formations of this age are recognized. The oldest of these, the Deseret limestone, is 650 feet thick at the type locality, but only 200 feet is present in the Cottonwood district (36). It is probably equivalent to the 1,000-foot Pine Canyon limestone of the Tintic district (142), the lower portion of which was originally thought to be lower Mississippian. The overlying Humbug formation, first described from Tintic (142), is 650 to 750 feet thick at Cottonwood (36) and in the Oquirrh Range (82). It is composed of pink, brown, and purplish marine calcareous sandstones and shales and is probably the unit which Blackwelder (14, pp. 528-529) and Hintze (112) regarded as possibly nonmarine. The Deseret and Humbug together are possibly the equivalent of the 1,500-foot Woodman formation of west-central Utah (187). Next above the Humbug formation is the Great Blue limestone (82) or Ochre Mountain limestone (187), 3,600 to 4,500 feet thick, with a thin black shale member in the lower half. The uppermost Mississippian beds are found in the lower portion of the Manning Canyon formation, composed of 500 to 1,100 feet of black shale and sandstone. The basal part contains highest Mississippian (Chester) fossils, and the top part basal Pennsylvanian (Pottsville) fossils, and, although there may be an unconformity between the beds at these two horizons, it has not yet been identified. In the Cottonwood district (36), however, less than 25 miles east of the Oquirrh Range, the 4,000 feet of beds that make up the Great Blue and Manning Canyon formations are absent.

Correlation of the southwestern sections with the column in the Oquirrh Range is not yet possible. The Topache limestone of the San Francisco district, Utah (31), is 1,500 feet thick and apparently includes all the Mississippian beds present in the region, but the details of its lithology and faunal content are not well known. The section at Pioche, Nev. (254), also has puzzling features. Time upper part of the Peers Spring formation and the Scotty Wash quartzite, with a total thickness of about 1,000 feet, are perhaps the equivalents of the Deseret and Humbug formations, but the proper correlation of the overlying rocks mapped as the Bailey Spring limestone is in doubt, as in some places the basal beds contain upper Mississippian fossils and in others Pennsylvanian fossils. Girty's suggestion (254, p. 23) that there may be two limestone units, each underlain by quartzite, is possibly strengthened by the occurrence at Gold Hill, Utah (187), of lithologically similar quartzite-limestone sequences in both the Mississippian and Pennsylvanian.

A quite different upper Mississippian facies is found along the western edge of the seaway and is commonly referred to as the White Pine shale. Black shales with subordinate sandstone and limestone compose the unit, which has a thickness of 2,500 feet in the Eureka district, Nevada (87), and 1,400 feet in the Inyo Mountains, Calif. (130). Although originally considered to be of Devonian age, the White Pine has been assigned to the upper Mississippian. Probable upper Mississippian fossils also occur in the basal portion of the overlying Diamond Peak quartzite. The section at Ely, Nev. (219, 194), may be interpreted as

a connecting link between the White Pine type of lithology and that in the Oquirrh Range in that it consists of two black-shale units (the Pilot and Chainman shales) separated by the Joana limestone; the aggregate thickness of the three is about 1,000 feet.

Over much of southern Nevada and the adjoining parts of southern California upper Mississippian beds appear to be missing. Longwell (145) found 900 feet of limestone of this age in the Muddy Mountains of Nevada, and the basal 700 feet of the Bird Spring formation of the northern Spring Mountains is also reported to be upper Mississippian by Longwell and Dunbar (150). This unit thins southward, however, and in the southern part of the range beds in the Bird Spring formation that are assigned to the Pennsylvanian rest upon the lower Mississippian Monte Cristo limestone (104). Similar conditions prevail in the Death Valley region (95) and in the Grand Canyon, Ariz. (179). A large part of the extreme southern part of the province thus appears to have been elevated above sea level during upper Mississippian time. There are other localities in the province where Mississippian rocks are probably present, but the fossil and lithologic evidence is too poor to permit definite correlation. Thus the thick Furnace limestone of Woodford and Harriss (260) in the San Bernardino Mountains along the southwest edge of the Mojave Desert, Calif., contains a few poorly preserved fossils that have been tentatively considered to be characteristic of the Mississippian. Another scanty fauna similarly assigned is found in a limestone unit associated with a thick series of altered clastic sedimentary rocks near Mountain City, in northern Nevada.

PENNSYLVANIAN SERIES

Pennsylvanian sedimentary rocks in the Great Basin have a similar distribution to those of Mississippian age, but are somewhat more widespread and generally of greater thickness. They also show even more abrupt changes in thickness within relatively short distances than the upper Mississippian sections, and this variability, together with the higher proportion of clastic material in the beds and the presence of local unconformities, indicates considerable instability in the geosyncline during Pennsylvanian time. These features appear to be especially characteristic of the sedimentary sections near the eastern and southeastern borders of the province and suggest the presence in these regions of particularly active zones.

Over much of the province the Pennsylvanian beds rest with apparent conformity on the Mississippian, and in localities where both highest Mississippian (Chester) and basal Pennsylvanian (Pottsville) faunas have been recognized there is no pronounced stratigraphic break between them. In the Oquirrh Range (82) and the Gold Hill district (187), Utah, for example, the boundary between the two series has been placed within the Manning Canyon formation. Along the eastern and southeastern borders of the province, however, a marked unconformity is present at the base of the series. Though local studies suggest conformity in places (13), the stratigraphic evidence available indicates that unconformable relations persist throughout the Wasatch Range, Utah, and may extend southwestward as far as the Muddy Mountains, Nev. (145).

The Pennsylvanian limestones and sandstones in the Oquirrh Range, Utah (82), attain a thickness of about 18,000 feet, the thickest section of Pennsylvanian rocks known in the United States; and at several other localities more than 8,000 feet of beds are present. Little progress has yet been made in the determination of the faunal zones of these sections, aside from the recognition, in the basal portion of many of the more western sequences, of a zone correlative with the Pottsville of the east, and a satisfactory subdivision of the thick sections has been impossible.

The Pennsylvanian sections along the eastern border of the province show considerable lateral variation. In northeastern Utah the series is represented by 300 to 600 feet of the Wells

formation, which rests unconformably on the underlying upper Mississippian (205). The Cottonwood section (36) consists of the Morgan (?) formation, 200 feet thick, at the base, overlain by the Weber quartzite, about 1,000 feet thick. The Weber is in turn overlain by the Park City formation, the lower part of which is Pennsylvanian and the upper part Permian. Between these two areas, in the northern Wasatch Mountains, the basal Park City strata rest on the Weber quartzite with slight angular discordance, with the result that the Weber is absent from the more northern localities (24, p. 65). The Morgan formation changes northward from dominant limestone into red beds and also apparently disappears, for locally at least the Park City formation rests unconformably on Mississippian beds (14). South of the Cottonwood district, in the southern Wasatch Mountains, an even more striking change occurs. The 1,500 feet of beds at Cottonwood are here represented by about 10,000 feet of interbedded sandstone and limestone, which Eardley (56) has mapped as the "intercalated series."

The section in the southern part of the Wasatch Range appears to be identical in lithology with the 18,000-foot sequence in the Oquirrh Range, Utah, described by Gilluly (82) as the Oquirrh formation, though it is somewhat thinner. In the Oquirrh region the upper part of the underlying Manning Canyon shale is also of Pennsylvanian age and contains a fauna of Pottsville age. A similar sequence is present in western Utah at Gold Hill (187), where, however, the total is about 8,000 feet, and the upper part of the Oquirrh formation appears to be of Permian age. The Gold Hill section, moreover, is somewhat more varied in lithology than that in the Oquirrh Range.

West of Gold Hill, in Nevada, fairly thick Pennsylvanian sections are known at several localities, but the lateral changes in lithology appear to be too great to permit confident correlation from place to place. The section at Ely (219) bears some resemblances to the sections farther east and has been subdivided into two formations, the Ely limestone of Spencer and the Rib Hill formation of Pennybaker, with a total thickness of about 6,400 feet (194). It overlies a black shale which has been assigned to the Mississippian but which may, like the similar Manning Canyon formation, include Mississippian and Pennsylvanian strata.

The section at Eureka (87), west of Ely, has little lithologic resemblance to those farther east. The Weber conglomerate at the top, 2,000 feet thick, is underlain by 3,800 feet of Hague's Lower Coal Measures limestone; and it is possible that the upper part of the underlying Diamond Peak quartzite, 3,000 feet thick, is also of Pennsylvanian age. In the course of reconnaissance surveys (11, 108), the formation names used for the Eureka section have been extended to other localities in Nevada where thicknesses of several thousand feet of Pennsylvanian rocks have been found, but the correlations thus implied are probably not trustworthy.

The Pennsylvanian rocks of the Inyo Mountains, Calif. (130), with a total thickness of 7,750 feet, have also been in part described in terms of the Eureka section. Here there is basal limestone, 1,000 feet thick, unconformably overlain by 3,000 feet of quartzite and minor limestone, which have been assigned to the Diamond Peak quartzite, although that formation at Eureka is, at least in part, of Mississippian age. Above the quartzite is about 3,000 feet of limestone and shale, in which local unconformities and possibly some nonmarine beds occur; and at the top 250 feet of Reward conglomerate, a fresh-water deposit that may be of glacial origin.

Toward the southeastern part of the province the Pennsylvanian rocks are generally considerably thinner. The top of the section is not exposed at Pioche, Nev. (254), where part of the 2,275 feet of limestone mapped as the Bailey Spring limestone is of Pennsylvanian age. In the San Francisco district, Utah (31), a total thickness of 1,400 feet of quartzite and limestone is assigned to the series, but the upper portion may include some Permian beds.

The Callville limestone of the Muddy Mountains, Nev. (145), part of the Bird Spring formation of the Spring Mountains, Nev. (104, 85) and all of the Bird Spring in the Death Valley region, California (95), are probably closely equivalent. These formations consist of limestone, dolomite, and some shale and range in thickness from about 2,000 feet on the east and south to 5,250 feet on the northwest. The Bird Spring formation was originally considered to include only Pennsylvanian sediments, but Longwell and Dunbar (150) have recently found that the thickest section contains also at the base an upper Mississippian member and at the top two members which they assign to the Permian. The Pennsylvanian portion as thus redefined is about 1,700 feet thick.

PERMIAN SERIES

The Permian epoch in the Great Basin was marked by notable changes in the geosynclinal seas that had covered most of the province in earlier Paleozoic time. The geanticline in western Nevada that had been in existence since late Devonian time was finally worn down and covered with sediments during the epoch, but coincidentally with its disappearance a new land mass began to rise in southern California and southern Nevada, approximately in the region which had been so unstable in Mississippian and Pennsylvanian time.

As a result of this new geanticline two Permian seaways were formed. The western one was in western Nevada on the site of the older geanticline and extended over a considerable part of California; the eastern one in large part covered what is now the Plateau province, east of the Great Basin, but its western edge overlapped the eastern border of the area. During the Permian epoch the north end of the geanticline between the two seas probably reached east-central Nevada, and a connecting seaway may have existed over a broad area in northeastern Nevada and northwestern Utah, although the faunas and lithology of the sediments deposited in the two seas are so different that there may have been a narrow barrier between them. Possibly, however, the differences are due to the conformation of the eastern sea, which appears to have been closed to the south and thus more subject to changes in salinity and in sources of the sediments.

The relations between the Permian sedimentary beds and the underlying older strata are not uniform over the province. In the western Nevada localities there is commonly good evidence of a marked unconformity, notably in the Hawthorne and Tonopah region, where Permian sandstones rest on Ordovician slates with angular unconformity (68). An unconformity is also present, though not pronounced, in the northeastern part of the province. Elsewhere, however, the Permian and Pennsylvanian are described as being conformable, and in some places the contact between the two series can be located only by paleontologic evidence.

Although the Permian sediments deposited in the northern California portion of the western sea have a total thickness of more than 1,000 feet, the sedimentary sections reported from the Great Basin part of the sea are commonly only a few hundred feet thick. The Owenyo limestone of the Inyo Mountains, Calif. (130), for example, is only 125 feet thick and a fossiliferous sandstone at Candelaria, Nev. (174), is also rather thin. There are a few thin exposures of sandstone of probable Permian age at Manhattan, Nev. (63). North of these localities there appear to be volcanic rocks in the Permian sequence, but their thickness and extent are as yet unknown. Thus Ferguson (67) has found a thick series of greenstones of probable Permian age in the Toyabe Range, Nev., and Wheeler (255) has recently found Permian fossils in the dominantly volcanic Koipato formation of the Humboldt Range, Nev., a unit hitherto considered to be of Triassic age. In the Eureka district of central Nevada (87), however, the Permian is represented by 500 feet of limestone, referred to by Hague as Upper Coal Measures limestone. Hill (109) has reported other occurrences of a similar unit in central and east-central Nevada.

The western sea appears to have extended continuously across northern Utah, for the *Spiriferina pulchra* fauna characteristic of it is also present in the upper part of the Oquirrh formation and in the Gerster formation (total thickness, more than 600 feet) of the Gold Hill district, Utah (187); in the Phosphoria formation (400 feet) of northeastern Utah (205); and in the upper or Permian portion of the Park City formation of the central Wasatch Range, Utah (36). At the two last-named localities unconformities have been recognized at the base of the series, and Boutwell (24, pp. 39, 65) has found locally both angular discordances and basal conglomerates.

The sedimentary beds laid down in the eastern seaway (7) in the Great Basin have been definitely recognized only in the region from the Muddy Mountains to the southern Spring Mountains, in southeastern Nevada. Two units have been generally recognized—the Supai formation, composed of red and gray shale and sandstone and local gypsum, and the overlying Kaibab limestone, with some interbedded gypsum. The Supai, generally regarded as nonmarine because of its plant remains and fossil footprints in the region to the east, ranges in thickness from 1,000 feet in the southern part of the Spring Mountains (104) through 1,275 feet in the northern part of the range (85) to more than 1,400 feet in the Muddy Mountains (145). The Kaibab contains a large marine fauna and in most places has a thickness of 400 to 700 feet but locally (85) was entirely removed by erosion before Lower Triassic time. Longwell and Dunbar (150) have recently transferred from the Pennsylvanian to the Permian of this region a third group of beds; they report that the upper 2,800 feet of the Bird Spring formation, which underlies the Supai, contains a fusulinid fauna comparable to that found in the Leonard and Wolfcamp formations of the Permian of Texas. It is as yet uncertain whether similar Permian beds are present in the limestones that underlie the Supai in other parts of this region.

The northern extension of this sea is at present unknown. No Permian strata were recognized in the San Francisco (31) or Iron Springs (138) districts in Utah (the Carboniferous Homestake limestone of the Iron Springs locality is now considered to be Jurassic) or the Pioche district (254) in Nevada. The Arcturus limestone of the Ely region, Nevada (219), however, contains a Permian fauna characterized by lamelli branches similar to those of the Kaibab limestone. Should further work prove that the Arcturus and Kaibab limestones were deposited in the same sea, as these fossils suggest, it would mean that the eastern and western Permian seaways were very probably connected in this region, as the *Spiriferina pulchra* fauna has been found at a locality about 25 miles west of Ely (225, p. 56) as well as at Gold Hill, Utah, 80 miles northeast.

MESOZOIC ROCKS

During the Mesozoic era the seaways that had existed in the Great Basin for the greater part of Paleozoic time finally disappeared. Before their disappearance, however, two depositional troughs were developed, which were separated by a wide belt of higher land; this belt later formed the Cordilleran Intermontane geanticline of Schuchert (211, p. 187). The axis of this elevated area lay east of the somewhat similar uplift that had been formed in Nevada during later Paleozoic time, and the older axis in west-central Nevada was overlapped by the great thickness of rocks deposited in the western Mesozoic trough.

The western trough was filled with more than 30,000 feet of sediments and interbedded volcanic deposits, which have yielded a rather complete series of faunas ranging from basal Lower Triassic through Lower Jurassic in age. The sequence has been studied in recent years by Muller and Ferguson (174, 175). Deposition in the trough was accompanied by extensive volcanism in Middle Triassic and early Jurassic time and was terminated by a period of intense orogeny that occurred near the end of the Lower Jurassic.

The deposits of the eastern trough are found only locally along the eastern border of the province; the major deposition in this trough was farther to the east. Within the Great Basin these deposits consist largely of nonmarine sedimentary beds ranging in age from Triassic to Upper Cretaceous; marine Lower Triassic, possible Middle Triassic, and Upper Jurassic beds are found in a few places. This eastern seaway appears to have been closed to the south, for lagoonal deposits, such as salines, occur in the southern and southeastern extensions of the marine formations. Volcanic rocks are absent throughout most of the section, but some pyroclastic rocks occur in Lower Triassic and Upper Cretaceous beds. Volcanic rocks of unknown but probable Mesozoic age have, however, been reported from several localities in the geanticlinal area west of the eastern trough (97; 254, p. 26).

In addition to the surficial volcanic rocks interbedded with the sedimentary deposits, there are numerous extensive bodies of coarse-grained intrusive rocks that are commonly assigned to the Mesozoic. These are generally granodiorites or quartz monzonites, although in composition they range from quartz diorite to granite. Over most of the province the stocks or small batholiths composed of these rocks cannot be accurately dated. In western Nevada and in the Mojave Desert of California the intrusives are clearly extensions of the late Jurassic or early Cretaceous Sierra Nevada batholith and are therefore of that age. In Utah, however, similar bodies can, with a fair degree of assurance, be assigned to the late Eocene or early Oligocene. Lindgren (141, p. 260), in a review of the volcanism in the western United States, has suggested that the intrusions gradually moved eastward, thus implying that the as yet undated intrusive bodies of central and eastern Nevada were emplaced in the Cretaceous period. Ferguson, on the other hand, believes that the different types of ore deposits associated with granitic rocks in eastern and western Nevada indicate two epochs of intrusion, one contemporaneous with the Sierra Nevada batholith, the other Laramide (65, p. 118) in age, and that a fairly sharp line may be drawn between regions invaded by intrusives of the two ages. Until it becomes possible to date the intrusives it is difficult to choose between these two hypotheses. We can be certain, however, that intrusion on a large scale occurred in the later part of the Mesozoic era and that almost without exception it took place after the intense local orogeny that affected individual areas at various times from the Lower Jurassic well into the Tertiary.

TRIASSIC SYSTEM

The Permian-Triassic contact has been studied at several places within and adjacent to the Great Basin. It is commonly marked by a well-defined erosional unconformity (143; 84, pp. 64-65), but in the eastern localities the stratigraphic break is not profound and the angular discordance is either small or not recognizable. In the western trough a small angular unconformity is present (130, pp. 45-46; 175), but it does not appear to signify either long erosion or notable orogeny. In general, Permian and Lower Triassic sedimentary rocks have essentially the same geographic distribution and are found not only in the two troughs but also in the intervening area across northeastern Nevada and northwestern Utah. Middle and Upper Triassic formations, on the other hand, are restricted to the troughs, and the two sections differ notably in thickness and character, the western sequence being thicker and containing numerous aggregates of volcanic rocks interbedded with the marine strata and the thinner eastern sequence being made up largely of nonmarine sedimentary beds without volcanic members.

LOWER TRIASSIC

Lower Triassic beds are the most widely distributed of the Mesozoic sedimentary rocks, but at most localities only the middle part of the group, the *Meekoceras* zone, is represented. In the western trough the most southerly occurrence is in the Inyo Mountains, Calif. (130), where there is 1,500 feet of Lower and Middle Triassic calcareous strata. The thickest known

section is in the vicinity of Candelaria, in west-central Nevada; here Muller and Ferguson (175) have found over 3,000 feet of sandstone, limestone, and minor tufaceous beds (Candelaria formation) that have yielded the two lowest faunal zones of the Triassic. The contact with the Middle Triassic is not exposed here. The Koipato formation or group of the Humboldt Range, Nev., composed largely of volcanic rocks and originally regarded as Lower Triassic, was considered by Knopf (131) as probably Middle Triassic. It is, however, overlain disconformably by beds containing a basal Middle Triassic fauna (175) and, near its base, contains a Permian fauna (255). The Koipato of the Humboldt Range is therefore earlier than Middle Triassic and is, in part at least, of Permian age. The upper part may be Lower Triassic.

Lower Triassic sedimentary beds that were deposited in the eastern trough are found at several localities along the eastern edge of the Great Basin. The most southerly exposures appear to be in the Providence Range of southeastern California, where there is about 1,000 feet of limestone, sandstone, and shale (93). Similar beds; which are assigned to the Moenkopi formation, occur in the Goodsprings district (104), and the Muddy Mountains (145) of southern Nevada and in southwestern Utah (31, 201), and their thickness increases to about 2,000 feet or more at the Utah localities. Some tufaceous rock appears to be present in the upper part of the formation at Goodsprings, and gypsiferous and nonmarine beds are found in the thicker sections. Eastward, in the Plateau province, the zone of the marine beds of the Moenkopi is largely occupied by continental sedimentary beds, and the seaway must have been fairly narrow, for immediately west of the known marine sequence in southern Nevada and southern California there appears to have been a mountainous area which limited the seaway in that direction (86). This high area appears to have been the predecessor of the Jurassic Sonoran geanticline of Crickmay (42).

Northward along the eastern trough the Moenkopi is probably represented by the Woodside shale and at least the basal part of the Thaynes limestone, which occur in the Wasatch Range east and southeast of Salt Lake City, Utah (159, 56). The Woodside, consisting of 200 to 1,000 feet of red shales and sandstones, is poorly fossiliferous but is considered to represent the basal Lower Triassic. The overlying Thaynes, 500 to 1,200 feet thick, contains abundant marine limestones, which have yielded an extensive fauna. Matthews (159) has divided the Thaynes, which he considers a group, into a lower Pinecrest formation, which he places in the Lower Triassic, and an upper Emigration formation, which he places in the Middle Triassic, though others have thought all of the Thaynes to be of Lower Triassic age.

Limestones containing the *Meekoceras* fauna have been found in the Ruby Range, in east-central Nevada (217, pp. 9-10), and at Gold Hill, Utah (187, p. 42), and indicate that during this part of Lower Triassic time the sea extended across northern Nevada and Utah, joining the eastern and western troughs.

The Lower Triassic marine sedimentary beds of the Great Basin have yielded extensive cephalopod faunas, which have permitted world-wide correlations. All the five faunal zones recognized by Smith (217) have been identified in the region, one or more of the three sub-zones of the middle or *Meekoceras* zone being found at almost all the localities so far studied. The two lower zones have so far been reported only from the Candelaria formation of west-central Nevada (174), and the two upper zones from the Pinecrest or lower part of the Thaynes formation of the Wasatch Range, Utah (158).

MIDDLE TRIASSIC

The contact between the Lower and Middle Triassic is not exposed in west-central Nevada, and was not located accurately in the Inyo Mountains of California. There appears to be no break in the eastern trough, regardless of whether the boundary is placed between the two

members of the Thaynes formation or above the upper member. Marine sedimentary beds representing the lower part of the Middle Triassic are present at several places in the western trough, and commonly a very considerable thickness of volcanic rocks is associated with them. Sedimentary rocks of this age may occur in the Wasatch Range near Salt Lake City, Utah, but the beds are either unfossiliferous or contain fossils whose significance is debatable. Elsewhere in the Great Basin part of the eastern trough Middle Triassic rocks are probably lacking. No Middle Triassic sedimentary beds have been found in the region between the two troughs, a lack which suggests that the development of the positive area—the Sonoran geanticline of Crickmay (42)—was well advanced by this time.

The Inyo Mountains section of Middle Triassic (130, pp. 47-48; 215, pp. 56) consists of at least several hundred feet of limestone and calcareous shale in addition to interbedded volcanic material. Several thousand feet of andesitic tuffs and breccias overlie the fossiliferous beds, which Kirk doubtfully refers to the Upper Triassic but which, in the light of more recent work in Nevada, may more probably be Middle Triassic also.

A thick section of Middle Triassic rocks occurs in west-central Nevada. Muller and Ferguson (174, 175) have described two formations of this age—one, 12,000 to 15,000 feet thick, consisting almost exclusively of volcanic rocks and water-laid tuffs; and another, 800 feet thick, consisting of slate and limestone, which is probably equivalent to part of the volcanic rocks. These formations have yielded a rather scanty lower Middle Triassic fauna, correlated with the early Muschelkalk of Europe. Similar volcanic rocks with an aggregate thickness of at least 8,000 feet are present at Yerington, Nev. (129), and are tentatively considered by Muller and Ferguson to be probable equivalents of their section.

Middle Triassic fossils have been found at several other localities in western Nevada (215, pp. 8-11), but the stratigraphy of the beds that contain them is not well known. Collections have been made at many places in the Humboldt Range (West Humboldt Range of earlier reports) from the beds assigned to the Star Peak formation (215, p. 8). This unit is several thousand feet thick and includes a considerable amount of volcanic rock. Both Middle and Upper Triassic horizons are represented, but the contact between them has not been recognized. The Middle Triassic faunas, however, represent only the lower half of the series. Knopf (131) assigned the underlying Koipato to the Middle Triassic, but, as noted above, this assignment appears to be incorrect. The Star Peak formation, in addition to its invertebrate fauna, contains a considerable number of Middle Triassic marine vertebrates.

The only sedimentary rocks in the eastern trough that may be of Middle Triassic age are found in the Wasatch Range near Salt Lake City, Utah. Matthews (159) has thus assigned his Emigration formation (the upper member of the Thaynes formation), but this interpretation has not been generally accepted. The overlying Ankareh formation, composed largely of red shales and sandstones, has yielded few fossils, and its lower part may be of Middle Triassic age.

In addition to the great thickness of volcanic flows and pyroclastic rocks found in the western trough, Muller and Ferguson (175) report some contemporaneous basic intrusives.

UPPER TRIASSIC

There appears to have been near the end of Middle Triassic time a brief episode of minor crustal disturbance that affected the southern parts of both the eastern and western troughs, as well-marked unconformities are found beneath the Upper Triassic sedimentary beds in both regions. A similar break may be present in the northern part of the western trough, but it has not yet been recognized in the little-known sections of northwestern Nevada. The dominantly continental Triassic sedimentary rocks in the northern part of the eastern trough cannot be

dated accurately enough to determine whether or not a break also occurs in this region.

The western trough contains a very thick section of fossiliferous strata that probably represent almost all of Upper Triassic time. A few interbedded lava flows provide the only evidence of contemporaneous volcanism. The deposits in the eastern trough are considerably thinner and are also almost exclusively nonmarine. They too are essentially free from admixed volcanic material. The recent work by Muller and Ferguson (174, 175) on the Upper Triassic section in west-central Nevada seems to provide clear evidence of the continued existence of the positive area or geanticline between the two troughs. The lithology of their Luning formation is indicative of strandline conditions throughout the deposition of several thousands of feet of sediments; the nearest exposures of Upper Triassic beds deposited in the eastern trough are more than 200 miles away.

Muller and Ferguson have subdivided the approximately 10,000 feet of Upper Triassic strata in west-central Nevada into two formations. The lower, the Luning formation, includes all but 420 feet of the total thickness but represents only the Karnic stage of the upper Triassic of Europe. The formation shows marked lateral variations in lithology and includes a zone of coral reefs whose fauna (also of Karnic age) is essentially identical with that of similar reefs in both the Noric stage and in the Middle Triassic (173). The overlying Gabbs formation of shales and limestones appears to represent most of Noric and Rhaetic time.

The absence of extensive volcanic rocks in either the Luning or the Gabbs raises some doubt as to the age of the andesitic rocks in the Inyo Mountains, Calif., tentatively classed as Upper Triassic by Kirk (130). Fossiliferous beds of this age, however, have been found in Eldorado Canyon (74), the Humboldt Range (151, 216), and the Eugene Mountains (123), all three localities in Nevada in the western trough.

In the southern part of the eastern trough the widespread but thin Shinarump conglomerate unconformably overlies the Lower Triassic Moenkopi formation. It is not accurately dated but grades upward into 1,000 to 3,000 feet of nonmarine varicolored shales, sandstones, conglomerates, and salines of the Chinle formation, whose age has been established by vertebrate fossils as Upper Triassic. Both the Shinarump and the Chinle extend eastward into the Plateau province, where they are extensively exposed. Their occurrences in the Spring Mountains (104) and Muddy Mountains (145) of Nevada and in southwestern Utah (201) constitute the westernmost known limits. Longwell (145) considers that the Shinarump was deposited by slope wash and temporary streams in a wide interior region that had moderate relief and an arid or semiarid climate; and that the Chinle consists of fan or delta deposits derived from a region to the south or southeast. Baker, Dane, and Reeside (6, pp. 4950), however, regard the Chinle as definitely nondeltaic and believe that the sediments came from the west or southwest and were deposited on a "well-graded but rather arid plain across which streams meandered and on which there were perhaps scattered lakes."

Farther north the Wasatch Mountains near Salt Lake City, Utah, expose 1,100 to 1,400 feet of reddish shales and arkosic sandstone, which are assigned to the Ankareh formation (56, 159). These beds conformably overlie the Thaynes formation but are not accurately dated; they are commonly considered to be of Upper Triassic age.

JURASSIC SYSTEM

The contact between Triassic and Jurassic sedimentary beds appears to be conformable in both the eastern and the western depositional troughs, and, locally at least, there is a gradational contact that implies continuous sedimentation. This conclusion is considerably at variance with older beliefs (42, p. 18) that a marked unconformity exists between the two systems everywhere in North America. The portion of the western trough within the Great

Basin was destroyed by orogeny late in Lower Jurassic time, after 6,000 feet or more of sediments, in part marine, and interbedded volcanic deposits had been laid down. The eastern trough, however, probably continued in existence throughout the Jurassic period, but extensive marine deposits were laid down only during the Upper Jurassic.

The surficial volcanic rocks in the Lower Jurassic of the western trough were probably succeeded in late Jurassic time by plutonic intrusives, but none of the numerous stocks that are now found in the region formerly covered by that trough have been accurately dated.

LOWER JURASSIC

A thick section of Lower Jurassic rocks was deposited in the western trough in west-central Nevada and has recently been studied by Muller and Ferguson (174, 175). They have recognized two formations, an older Sunrise formation, 1,200 feet thick, which is overlain by the Dunlap formation, more than 5,000 feet thick. The Sunrise overlies the Upper Triassic with a gradational contact and consists of marine limestone and shale; its invertebrate fossil fauna spans the larger part of Lower Jurassic time. The overlying Dunlap is locally conformable with the Sunrise, but in many places the two formations are separated by a notable unconformity, developed as a result of the intense orogeny which began at a time equivalent to the Pliensbachian stage of the Lias. The Dunlap is composed largely of coarse clastic and interbedded volcanic rocks and is thought by Muller and Ferguson (175) to have been deposited both in basins formed by folding and as fans in front of advancing thrust plates. It is sparsely fossiliferous but is considered to be upper though not uppermost Lower Jurassic.

Lower Jurassic marine sedimentary beds of the western trough have also been reported from the Inyo Mountains, Calif. (42, p. 23), the Humboldt Range, Nev. (151), and Eldorado Canyon, Nev. (74), but little is known regarding their stratigraphy. Muller and Ferguson (175) have called attention to the probable conformity between the Upper Triassic and Lower Jurassic in the Humboldt Range, correcting the erroneous belief in an unconformity at this horizon, which was based on an indefinite statement by Louderback (151).

The exact age assignments of the nonmarine sedimentary rocks in the eastern trough are still uncertain. A thick eolian sandstone has been described as occurring in southwestern Utah (201) and in the Muddy Mountains (145) and Spring Mountains (104) of southern Nevada. In the Spring Mountains it is known as the Aztec sandstone. It is 2,000 feet or more thick and strikingly cross-bedded. The unit has commonly been correlated with all three members of the Glen Canyon group of the Plateau province and questionably assigned to the Jurassic. In a recent review of the Jurassic formations of the Plateau province, however, Baker, Dane, and Reeside (6) suggest that the Aztec and related sandstones of the southeastern part of the Great Basin are correlative with the Navajo sandstone, which is the upper member of the Glen Canyon group and which they regard as possibly of Middle Jurassic age. The two lower members of the Glen Canyon group, believed to be of Lower Jurassic or possibly Upper Triassic age, apparently do not extend into the Great Basin. A similar statement can be made for the Nugget sandstone of the central Wasatch Mountains, Utah (159), earlier thought to be possibly Lower Jurassic but now (6) correlated with the Navajo and tentatively assigned to the Middle Jurassic.

It would thus appear that the Lower Jurassic is not represented in the Great Basin part of the eastern trough. This conclusion cannot be unequivocally accepted, however, for two reasons. The gradational contact locally found between the Chinle and the base of the Glen Canyon group suggests continuous deposition from Triassic into Jurassic time, and the possibility remains that some of the higher Chinle strata in the unfossiliferous sections of southern Nevada may be equivalent to basal Glen Canyon strata farther east. Furthermore, the basal

beds of the Navajo, locally at least, overlies with gradational contact the middle member of the Glen Canyon group, implying that the Navajo itself is not a synchronous unit. The notably thick Nevada sections may thus be in part Lower Jurassic.

MIDDLE JURASSIC

No sedimentary rocks younger than Lower Jurassic have been found in the Great Basin part of the western trough, and it seems certain that a continuation of the folding and thrusting, whose earlier phases controlled the deposition of the Lower Jurassic Dunlap formation, caused the final retreat of the western marine seas from the Great Basin.

The probable Middle Jurassic age of the correlative Aztec, Nugget, and Navajo sandstones of the eastern trough is mentioned above. This conclusion is based largely on a single marine fossil reported by Matthews (159) from the Wasatch Mountains, Utah, and the age assignment is questionable (6). The notable westward thickening of these beds indicates that their source lay in the rising Sonoran geanticline, immediately to the west. The greater part of the Navajo and Aztec sandstones shows giant cross-bedding, and eolian origin is almost universally accepted. Near the borders of the known area in which these formations were deposited, however, water-laid sandstones are reported (6), and the marine fossil from the Wasatch Mountains suggests that to the north there may have been sporadic marine invasions of the trough, though no Middle Jurassic marine deposits have been reported elsewhere nearer than Alberta, Canada.

UPPER JURASSIC

An Upper Jurassic marine invasion of the eastern trough locally extended into the Great Basin in central and southwestern Utah, but the few known Upper Jurassic localities in these regions have not been exhaustively studied. In the Plateau province, to the east, however, the dominantly marine San Rafael group and the nonmarine Morrison formation appear to represent a large proportion of Upper Jurassic time (6). The basal formation of the San Rafael group, the Carmel formation, rests upon the underlying Navajo sandstone with a sharply defined contact, but Baker, Dane, and Reeside (6, p. 7) consider that there is little evidence of a pronounced break. Presumably similar relations hold for the known sections in the Basin and Range province.

Reeside and Bassler (201) found in southwestern Utah 460 feet of marine limestone, with some sandstone, shale, and gypsum, that yielded fossils of Carmel age (6, table 1). This unit is overlain by 140 feet of variegated shale with some limestone, which they questionably assigned to the Cretaceous (201) but which is now regarded as correlative with the upper part of the San Rafael group (6, p. 33). Wells (253) has recently found the Carmel at Bull Valley, Utah, and suggests that it may be identical with the Homestake limestone at Iron Springs, Utah, which was originally considered Carboniferous by Leith and Harder (138, p. 37) on the basis of some fragmentary fossils. To judge from the isopach maps of the four formations of the San Rafael group, prepared by Baker, Dane, and Reeside (6, figs. 11, 12, and 13), Upper Jurassic sediments were probably deposited over a considerable part of western Utah, and future more detailed field work will perhaps disclose them at additional localities.

A considerable thickness of Upper Jurassic beds is present in the southern and central Wasatch Mountains. At the southern locality there is several thousand feet of closely folded shales with some limestone, gypsum, and salt, whose detailed stratigraphy is as yet uncertain (56). Carmel fossils have been recognized, but it seems probable that correlatives of higher members of the San Rafael group are also present. In the central part of the Wasatch Range, the entire group is probably represented by the Twin Creek formation as defined by Matthews (159), which consists of about 2,000 feet of limestone, locally more or less shaly and sandy.

The Twin Creek is overlain by 1,000 feet of nonmarine sediments correlated with the Morrison formation.

The Carmel fossils indicate a correlation with the Callovian of Europe (basal Upper Jurassic), and the upper part of Matthews' Twin Creek appears to be correlative with the Argovian. The age of the nonmarine Morrison has been the subject of much debate. Baker, Dane, and Reeside (6, pp. 58-63), who have recently summarized the extensive literature, regard it as falling between the Argovian and the basal Cretaceous.

No Upper Jurassic sedimentary rocks have been recognized in the Great Basin part of the western trough, and it seems fairly certain that none were ever deposited.

Many of the granodiorite and quartz monzonite intrusive bodies in western Nevada and southern California are clearly extensions of the Sierra Nevada intrusive mass and are presumably therefore of the same age. The late Jurassic or early Cretaceous age of the Sierra Nevada batholith is still debated, but it is perhaps significant that the recent work in that region has shown that the batholith is composed of several individual intrusive masses that are petrographically distinct. Crickmay, indeed, has suggested (42, p. 63) that the intrusions occurred at more than one time during the Jurassic period, in contrast with the older view that the epoch of intrusion was relatively short.

The absence of any Mesozoic sedimentary rocks younger than Lower Jurassic in western and central Nevada prevents any direct contributions from that region to help in answering the question of the age of the numerous stocks that are so widely distributed. Some of them are doubtless of late Jurassic age, but if Lindgren's correlation for the Cordilleran region of intrusion with orogenic stress (141, p. 281) is accepted, it is possible that emplacement of the stocks occurred at different times from the late Lower Jurassic into the Tertiary period.

Hulin (116, pp. 33-42) and Simpson (213, pp. 385-389) have described the granitic rocks in and bordering the western part of the Mojave Desert, which they correlate with the Sierra Nevada intrusions; Knopf (130, pp. 60-72) has described those in the Inyo Mountains, Calif., and the adjacent Sierra; and Gianella (74, pp. 41-43) has described the quartz monzonite at Virginia City, Nev., also believed to be a part of the Sierra Nevada batholith.

CRETACEOUS SYSTEM

The greater part of the Great Basin appears to have been undergoing erosion throughout Cretaceous time. The only sedimentary rocks of this age known to occur in the province are found along the eastern border in southern Nevada and southwestern and central Utah, where Upper Cretaceous strata, chiefly nonmarine, are locally present. These beds grade eastward into marine sedimentary rocks deposited in the old eastern trough, which still farther east contained a fairly complete succession of the Upper Cretaceous beds. This trough received very little material during Lower Cretaceous time throughout the plateau country of eastern Utah. Stocks of quartz monzonite or related granitic rocks were probably emplaced during the Cretaceous period at different places in the province, but the exact dates and extent of the intrusions are not known.

The only fossiliferous Cretaceous sedimentary beds so far found in this province occur in the Muddy Mountain region of southern Nevada. Here characteristic Upper Cretaceous ferns of the genus *Tempskya* have recently been found in the basal beds of the Overton fanglomerate (107, p. 121; 198, p. 127), which had previously been assigned to the Tertiary (Miocene?). The Overton consists of as much as 3,500 feet of conglomeratic sandstone and conglomerate and is overlain with apparent gradation by the Horse Spring formation, 1,000 to 2,700 feet thick and made up of nonmarine sedimentary beds including limestone, dolomite, magnesite, clay, and sand (145). Although the fossil evidence applies only to the basal beds of the

Overton, I think it probable that both the Overton and the Horse Spring are of Upper Cretaceous age. (See p. 167.)

In the Pine Valley Mountains of southwestern Utah, Reeside and Bassler (201) found 1,000 feet or more of buff sandstone with some shale, which they questionably assigned to the Cretaceous. A short distance to the west the equivalent rocks are about 3,300 feet thick and include some conglomerates (52). The few fossils that were obtained from these beds indicate a Cretaceous age. These beds are probably correlative with the Pinto sandstone at Iron Springs (138) and similar beds at Bull Valley (253), Utah. At these localities the beds are unfossiliferous but may be traced into the coal-bearing Upper Cretaceous section of the Plateau region, to the east.

Matthews (159) has also described Upper Cretaceous sedimentary rocks in the central Wasatch Mountains, and as a result of the recent investigations by Spieker (220, 221), it is possible that much of the conglomerate previously correlated with the Eocene Wasatch formation may prove instead to be Upper Cretaceous.

Many of the intrusive granitic rocks in central or eastern Nevada have been assigned to the Cretaceous, but there is little direct evidence as to their age.

CENOZOIC ROCKS

Cenozoic rocks underlie more than half of the Great Basin. Most of them, however, are either igneous rocks or nonmarine sedimentary beds that are sparsely or not at all fossiliferous, and, as a result, definite age assignments for many of the rock units cannot be made, and correlations between the relatively few thoroughly studied sequences are hazardous. The few marine sedimentary beds are restricted to the southwestern border of the province.

At some localities deposition of sediments has apparently been more or less continuous from Tertiary into Quaternary time, though no paleontologic evidence for this belief is available. Over much of the region, however, there has been a tendency to classify as Tertiary rocks that either are dominantly of volcanic origin or are generally tilted and faulted, and as Quaternary sequences composed dominantly of sedimentary beds that are only locally deformed.

TERTIARY SYSTEM

Although all four of the commonly recognized series of the Tertiary are represented in the region, the Great Basin appears to have been a highland undergoing erosion throughout most of Eocene and Oligocene time. Continental and, in southwestern California, marine sedimentary deposits of Eocene age have been recognized only along the borders of the province, though volcanic rocks of this age may possibly be represented throughout the area. Oligocene sedimentary rocks have been found in only one area, but here they appear to have been formed in a basin not unlike those existing at present. Volcanism doubtless continued throughout the Oligocene epoch also. Several bodies of granular intrusive rocks in the eastern part of the province have been referred to either the Eocene or the Oligocene.

By far the greater number of the known fossiliferous sedimentary rocks, however, are assigned to the Miocene and Pliocene and are almost exclusively of continental origin, being composed of conglomerates, silts, and sandstones that are in many respects like the beds now being deposited in the intermontane valleys. Volcanic debris commonly forms a large proportion of the sedimentary deposits, and thick accumulations of lava flows and pyroclastic rocks and local intrusive masses are generally associated and interbedded with them. Later

Tertiary marine sedimentary beds have been recognized only in southern California.

EOCENE

Sedimentary rocks that have been assigned to the Eocene have been found only in Utah, where they are moderately abundant close to the eastern border of the Great Basin, and at two or three localities in California and Nevada adjacent to the western border. Except for the most southerly of the western occurrences, all these rocks are of continental origin. Apparently all of the central part and most of the western part of the Great Basin was being actively eroded throughout Eocene time and possessed adequate exterior drainage, by which the products of erosion were removed from the province.

Most of the Utah exposures consist of conglomerates and fresh-water limestones, some of which are algal (55). The limestone commonly overlies a thick conglomerate, but other conglomerates may be interbedded with it. Sedimentary rocks of this type have been noted at several localities in the central part of the State in and near the Wasatch Mountains by Loughlin (32) and Eardley (56), and also at one locality in the western part of the State (187). Locally invertebrate fossils have been found in the limestones, but they are not known to be diagnostic, and the beds have been correlated on lithologic grounds with the Wasatch group of the east flank of the Wasatch Mountains. According to Simpson (214), the Wasatch lies at the base of the Eocene immediately above his Paleocene series. Spieker (220, 221), however, has recently found in the Plateau province, immediately east of the Great Basin, evidence that much of the supposed Wasatch is probably of Upper Cretaceous age. When completed his investigations may notably modify many of the previous correlations of supposed Wasatch sedimentary beds.

Somewhat similar rocks in southwestern Utah have been described by Leith and Harder (138) as the Claron limestone and assigned to the Eocene, though they are not fossiliferous. Unlike the Wasatch sedimentary beds to the north, which rest with marked unconformity on older rocks, strata at Bull Valley, Utah, that are believed to be the continuation of the Claron limestone overlie Cretaceous sandstones with apparent conformity (253). Hague (88) described some calcareous and sandy shales with interbedded thin seams of coal in the Ombé Mountains, northwestern Utah, and correlated them with the middle Eocene Green River formation of Wyoming. A more probable correlation, however, is with the oil shales near Elko, Nev., now considered to be Miocene (259, footnote p. 91).

The most northerly locality in the western Great Basin from which sedimentary rocks referred to the Eocene have been reported is in the vicinity of the Comstock Lode, in Nevada. Here Gianella (74) has found a fluvial conglomerate at the base of a series of rhyolite flows that he believes to be traceable into the Sierra Nevada, to the west, and to be correlative with deposits of auriferous gravel that are in part contemporaneous with the lone formation, of middle or upper Eocene age.

Eocene plants have been reported by Fairbanks (60) from coal-bearing sedimentary rocks at the base of the lower Pliocene Ricardo section, in the northwestern part of the Mojave Desert, but the locality is no longer accessible (171), and the age assignment is questionable.

The only known marine sedimentary rocks of Eocene age in the Great Basin are found farther south, on the western border of the Mojave Desert, along the San Andreas rift (50, 213). Arkosic sandstones and shales with an aggregate thickness of about 7,500 feet appear to have been deposited close to the eastern border of the existing sea and contain a fauna indicating Martinez age (basal Eocene or Paleocene of some classifications).

Spurr (223) and Ball (11) arbitrarily assigned to the Eocene many of the older volcanic rocks of the central Great Basin, but this assignment was not based on any direct paleontologic

evidence. At many places, however, thick volcanic sections are known to underlie middle Tertiary sedimentary beds unconformably (196, 68), and it may be that the oldest lavas are of Eocene age. Both Gianella (74), in western Nevada, and Wells (253), in southwestern Utah, have found volcanic rocks associated with probable Eocene sedimentary rocks, but these two localities are the only ones where Eocene volcanism can be postulated with any degree of certainty.

At several localities in western Utah the granitic or quartz monzonitic intrusive bodies have been considered to be of Eocene age. Gilluly (81, pp. 1117-1118) has reviewed the evidence concerning the age of the intrusives and suggests that they may have been emplaced at two different times—one during the late Cretaceous or early Eocene and the other during the late Eocene or post-Eocene. Moreover, there appear to have been at least two periods of late Eocene or post-Eocene volcanism, as shown by the relations of the stocks to surficial flows at Tintic and Gold Hill, Utah. At Tintic (142) the monzonite stock is younger than the associated lavas, whereas at Gold Hill (187) the quartz monzonite stock is unconformably overlain by volcanic rocks. Both intrusions are believed to be of post-Wasatch age. Ball (11) has also assigned some intrusive monzonite porphyry in southern Nevada to the Eocene.

OLIGOCENE

Only one group of sedimentary rocks of Oligocene age is known in the province—the Titus Canyon formation in the vicinity of Death Valley, Calif., recently described by Stock and Bode (235). The beds comprise a maximum of 7,000 feet of terrestrial conglomerates, mudstones, algal limestones, and sandstones with some interbedded tuff and yield a mammalian fauna (233, 233a) of lower Oligocene age. The formation was apparently deposited along the flanks of a range formed by block faulting under topographic conditions such as exist in the region at the present time.

The apparent absence of other Oligocene deposits suggests that during this epoch of the Tertiary the present Great Basin may have been high land and at least as well drained as during the Eocene. An alternate explanation, however, may be indicated by the origin of the Titus Canyon formation of Stock and Bode—either that similar basin deposits of the Oligocene may be concealed locally beneath the extensive Miocene accumulations, or that some of the unfossiliferous beds now assigned to the Miocene may in fact be older.

The occurrence of interbedded tuff in the Titus Canyon formation proves that there was volcanic activity during Oligocene time, and it is not improbable that some of the old Tertiary volcanic rocks and intrusives now commonly assigned to the Eocene may be somewhat younger.

MIOCENE

Beds of Miocene age appear to be the most widely distributed of the Tertiary sedimentary rocks in the California and Nevada portions of the Great Basin. Most of the beds are nonmarine conglomerates, silts, and sandstones that were deposited in basins brought into existence by block faulting (68), but marine accumulations have been found in the Salton Sea region of southern California and also at two localities near the western edge of the Mojave Desert. Miocene sedimentary rocks have not been definitely recognized in the eastern or Utah portion of the basin, but it is uncertain whether this is the result of nondeposition—possibly because block faulting had not yet been initiated in this region—or whether they are concealed beneath younger deposits. Thick accumulations of surficial volcanic rocks and local small intrusive bodies are commonly associated with the sedimentary beds.

The best-known marine Miocene locality is in the Carrizo Mountain district of western

Imperial County, Calif., but a similar fauna has been found at several other places in the Salton Sea trough, as far north as San Geronio Pass, at the north end of the depression. Woodring's recent account of the deposits (261), which make up the Imperial formation, also summarizes the earlier literature. The fauna is remarkable in that its affinities are with Caribbean forms, and it shows only slight relationships with known Pacific Miocene faunas. The age of the Imperial fauna has been a matter of some debate. Woodring at first (261) considered it to be late lower Miocene (Vaqueros of Coast Range section) but has since (262) found a related fauna in the late middle Miocene of the Coast Ranges. Bramkamp (25) has also tentatively assigned to this fauna a middle Miocene age (approximately Temblor). Other scanty marine or brackish-water faunas have been found in sedimentary beds exposed along the Colorado River Valley in both California and Arizona (257). The beds may be of approximately the same age as the Imperial formation, but the faunal evidence is far from being satisfactory.

Marine Miocene beds have also been found along the San Andreas rift on the southwestern edge of the Mojave Desert (182). These beds contain a normal Pacific fauna and are of Vaqueros (lower Miocene) age. A third occurrence is on the south slope of the Tehachapi Range, at the extreme western edge of the Mojave Desert (171, footnote, p. 445). The fossiliferous strata here, however, are of upper Miocene aspect (Santa Margarita of Coast Range section), according to Woodring (263).

At present the nomenclature, correlation, and age of the widespread nonmarine Miocene sedimentary beds are far from settled. The old conception of King (125) that these beds were deposited in a single widespread Pahute Lake has long been disproved, but there is still a strong tendency to regard the beds as contemporaneous, in spite of the increasing evidence from vertebrate paleontology that there are age differences and from structural geology that the sediments were deposited in local basins.

Geologic study of the beds has been especially concentrated in five general areas—the Mojave Desert region, to the south, southwestern Nevada, west-central Nevada, northwestern Nevada, and southeastern Nevada.

The Mojave Desert rocks are often called the Rosamond series, a name originally applied to an unfossiliferous Tertiary section near Rosamond station (100). Merriam (171), however, has suggested that this name be abandoned, as two different vertebrate faunas have been found in similar beds in other parts of the Mojave Desert. The strata containing the older fauna were named by him the Barstow formation; the younger beds, which he refers to the Pliocene, were called the Ricardo formation. The name Rosamond has persisted, however, and has been used by Hulin (117) and Simpson (213) for beds apparently equivalent to Merriam's Barstow.

The Barstow, or Rosamond in its restricted sense, was deposited in basins formed by faulting or warping (116) and consists of as much as 5,000 feet of interbedded volcanic and sedimentary rocks. The sedimentary beds comprise fanglomerates, arkosic sandstones, silts, and chemical precipitates such as gypsum, boron minerals, strontianite, and magnesite (8, 107) and in places contain an extensive vertebrate fauna (171).

In addition to the exposures of the Barstow formation in the lower parts of the Mojave Desert west of Barstow (181), similar nonmarine sedimentary and intercalated volcanic rocks, which are correlated with the Barstow, are widely distributed in the surrounding regions. Woodford and Harriss (260) report Rosamond sedimentary beds from the San Bernardino Mountains, to the south, and Woodring (261) suggests that the Palm Spring formation in the Salton Sea region, still farther south, together with Vaughan's Coachella fanglomerate (245), may also be correlatives. To the west Noble (182) has recognized two upper Miocene nonmarine

sedimentary sequences separated by an angular unconformity along the San Andreas rift at Cajon Pass. The older one he correlates with the Barstow, and the younger one is succeeded without notable stratigraphic break by probable Pliocene strata. Although unconformities have been recognized within the Barstow or restricted Rosamond (116), the unconformity at Cajon Pass may represent a part of the time interval between the Barstow and Ricardo. This interval, the extent and nature of which in the Mojave Desert proper appears to be unknown, may be represented southwest of the San Andreas rift by the Mint Canyon formation (161), though Noble (180) has found near Palmdale sedimentary beds with a Mint Canyon fauna that he believes to be the equivalent of the Barstow strata at Cajon Pass. Stirton (229), on the other hand, interprets the Mint Canyon fauna as being much closer to the Ricardo than to the Barstow.

Northwest of the Mojave Desert, in the Southern Sierra Nevada, there are 4,000 to 5,000 feet of interbedded sedimentary and volcanic rocks of Miocene age. Buwalda (35) has described two faunas from this sequence. The older one, which he has called the Phillips Ranch fauna, is assigned tentatively to the early middle Miocene, and the younger one, or Cache Peak fauna, is placed approximately either at the horizon of the Barstow or somewhat lower.

The Death Valley region, where two unfossiliferous sedimentary series are known, is about halfway between the Mojave Desert and the well-studied area in southwestern Nevada, and Noble (183) believes the beds to be, in part at least, of Miocene age.

Over a considerable area in southwestern Nevada the name Esmeralda formation (242) has been applied to a thick series of interbedded volcanic rocks and nonmarine conglomerates, sandstones, silts, and marls. Salines, however, are either absent or much less abundant than in the Mojave Desert beds, but diatomites and lignites are found locally. Like the beds to the south, the sediments here were laid down in closed basins not unlike those now found in the region (34, 68). The nomenclature of these beds has had a history curiously similar to that of the Mojave Desert rocks. The original name Esmeralda has been applied widely, but it now seems probable that two faunal stages are present in the region—one Miocene and the other Pliocene (228). The older beds contain the Stewart Spring or lower Cedar Mountain fauna of Teilhard de Chardin and Stirton (240); the younger beds contain the Fish Lake Valley or upper Cedar Mountain fauna. The name Esmeralda, as commonly used, probably applies to beds that contain the younger of the two faunas and is often used in that sense, but it has also been used as a group name for both units. The nature of the contact between the beds containing the two faunas is apparently unknown; the unfossiliferous Tonopah formation in the mining district of that name (188), which may represent the lower beds, is overlain with angular unconformity by the basal member of a section that has been correlated with the Esmeralda, but as this also cannot be closely dated, the significance of the unconformity remains uncertain. There are also two unconformable series at Tybo, Nev., 70 miles to the northeast where Ferguson (66) found the Esmeralda (?) formation lying unconformably above the Gilmore Gulch formation, which is tentatively correlated with the Tonopah.

Sedimentary rocks correlated with the Esmeralda in its broad sense have also been found as far to the northwest as Yerington, Nev. (129). The Yerington locality is more than halfway between the type area of the Esmeralda and the region in west-central Nevada where the Truckee formation has been studied.

The Truckee, as originally defined, was considered a lacustrine deposit, formed in an extensive lake that covered western Nevada and much of eastern Oregon, and its age was based almost entirely on vertebrate remains found in the John Day Basin in Oregon. Later work, however, has shown that only a small proportion of the formation is made up of true lake beds and that volcanic and fluvial rocks are much more abundant. Moreover, the concept of a single large lake has been disproved, and it now seems probable that the

Truckee strata were deposited in numerous separate basins (153). In most respects the lithology of the formation is similar to that of the Esmeralda, with which it has been directly correlated by both Buwalda (34) and Louderback (153). Saline deposits, however, are apparently lacking, but pyroclastic deposits and diatomites, are fairly abundant. Vertebrate fossils are rare, but invertebrate fossils of rather doubtful significance and plant remains are fairly common. Despite the somewhat unsatisfactory dating these fossils provide, the formation probably includes beds ranging in age from Miocene to Pliocene, and locally at least these beds may be separated by an unconformity. Thus recent work in the vicinity of Virginia City, Nev. (74, 120), has disclosed an upper Miocene flora in the Sutro tuff member of the Alta andesite of Gianella and a probable lower Pliocene flora in sedimentary strata interbedded with the Kate Peak andesite, which overlies the Alta andesite with marked unconformity. The sedimentary rocks in the Kate Peak, moreover, are believed to be traceable into typical Truckee strata.

A flora related to that of the middle or upper Miocene Mascall formation of Oregon has been found in the Truckee west of Reno, Nev. (38).

Sedimentary rocks that are possibly correlative with the Truckee have been found farther east in Nevada at several places. They have been carefully studied only in a small area near Elko, where oil shales are prominent constituents (259), but vertebrate fossils of middle or upper Miocene age have also been collected about 40 miles northeast of Elko (168) in beds previously assigned to the Pliocene. Chaney (38, p. 35) reports a flora possibly related to the Mascall Miocene from the sedimentary beds near Elko.

As noted on page 164, the supposed Eocene beds in the Ombe Mountains of western Utah (88) are also probably of Miocene age. Except for them, the Miocene, so far as known, is absent from the eastern or Utah part of the Great Basin.

The fourth area of well-studied Miocene sedimentary rocks is in northwestern Nevada, where Merriam (167) and his associates have named and described the lithology and vertebrate fauna of the Virgin Valley beds. Fanglomerates and salines are rare or absent, but pyroclastic rocks, silts, sands, diatomites, lignites, and carbonaceous shales are abundant. There appear to be local unconformities within the formation. The vertebrate remains indicate a middle Miocene age. Fossiliferous Pliocene sedimentary rocks have also been found in the region, but their stratigraphic relations to the Virgin Valley beds of Merriam are not yet known.

The Virgin Valley beds are probably equivalent to the upper Cedarville sedimentary beds of Russell (210). The flora of the Cedarville has recently been studied by La Motte (132) and considered to be equivalent to that of the Oregon Mascall formation, and vertebrates from the Mascall have been considered to be closely related to those from the Virgin Valley formation. La Motte, however, considers the flora to be of upper Miocene age, although most of the vertebrate paleontologists are in agreement that the closely related Mascall and Virgin Valley mammals should be assigned to the middle Miocene.

The southeastern Nevada sedimentary beds, though rather well known, are uncertainly dated at the present time. The most complete section has been studied in the Muddy Mountain region, where Longwell (145) found a total of more than 8,000 feet of fanglomerate, silts, sands, and salines, which he assigned to the Miocene and Pliocene. The two lower formations, the Overton fanglomerate and Horse Spring formation, were considered to be Miocene on the basis of their similarity to the Barstow and Esmeralda formations, though no fossils were found in them, and a third formation, the Muddy Creek, was assigned to the Pliocene. Recently, however, Rubey and Callaghan (107, p. 121) have found characteristic Upper Cretaceous plants in the basal beds of the Overton fanglomerate, and it seems that the Overton and possibly the conformably overlying Horse Spring are Upper Cretaceous. This

belief is perhaps strengthened by Stock's suggestion (231, p. 257), based on scanty vertebrate remains, that the Muddy Creek is Miocene. Longwell's recent studies (148) of basin deposits in the Boulder Dam region, which he considers to be correlatives of the Muddy Creek formation, suggest that the Muddy Creek includes Pliocene beds, and so it is possible that here, as well as at other localities in the Great Basin, the later Tertiary sedimentary deposits comprise both Miocene and Pliocene strata.

Although paleontologists are in fair agreement as to the correlation and relative age of the Miocene nonmarine sedimentary beds from which adequate fossil collections have been made, there is some uncertainty as to their absolute dating. The table below summarizes most of the age assignments that have been proposed.

Age assignments for the Great Basin Miocene faunas

	Merriam (171)	Simpson (214)	Teilhard de Chardin and Stirton (240)		Bode (22)
Lower Pliocene.			Pontian	Ricardo.	
		Mint Canyon.		Mint canyon. Esmeralda.	
Upper Miocene.	Barstow.	Barstow and lower Cedar Mountain.	Vindobonian	Barstow.	Mint Canyon.
	Cedar Mountain.	Virgin Vally, Mascall, and Cache Peak.			Barstow.
Middle Miocene.	Mascall and Virgin Valley.	Phillips Ranch.		Mascall.	Mascall. Phillips Ranch.
				Stewart Spring. Virgin Valley. Phillips Ranch.	
Lower Miocene.					

Bode (22, p. 85) has also correlated the Great Basin vertebrate fossil-bearing beds with the marine sequence of the California Coast Ranges. His chart suggests that the marine deposits are in general assigned somewhat older ages than have been postulated by many vertebrate paleontologists for the equivalent nonmarine beds.

Surficial volcanic rocks are interbedded in all the Miocene nonmarine sequences and in many places form the greater part of the section. In addition, some thick accumulations of volcanic rocks have been assigned to the Miocene, although intercalated sedimentary beds are lacking. Both flows and pyroclastic rocks have been found. As a general rule, it appears that tuffs or volcanic breccias are more abundant in regions where sedimentary members are well developed, and flows dominate where sedimentary beds are rare. The composition of the Miocene volcanic rocks does not seem susceptible of any generalization, as rocks ranging from rhyolites to basalts have been described. Albite andesites or keratophyres of probable Miocene age have been recognized in several mining districts in Nevada and were earlier regarded as true eruption products. More recent work at both Tonopah (188) and Tuscarora (189) suggests, however, that the albite is the result of hydrothermal alteration.

Numerous dikes and small intrusive bodies are present in the regions where flows and

pyroclastic rocks of Miocene age have been found. Coarsely crystalline granular intrusives, however, have been found only at the Comstock lode, in west-central Nevada, where Gianella (74) has proved his Davidson diorite to be of Miocene age.

PLIOCENE

Pliocene sedimentary and volcanic rocks may be nearly as abundant and widely distributed in the Basin and Range province as those of Miocene age, but they have not been as thoroughly studied. Pliocene marine sedimentary beds, however, are not known to occur within the Great Basin or along its borders, although they are present at no great distance west of the Mojave Desert. The ostracode-bearing beds in Owens Valley, Calif., for which Ulrich (130, p. 51) suggested a possible marine environment, now appear to be of fresh-water lacustrine origin (212, pp. 78-79). The nonmarine sedimentary rocks appear to be essentially identical with those of the Miocene and to have been deposited in local basins, in part at least of block-fault origin. The sedimentary rocks are commonly interbedded with volcanic rocks, and in many places there are thick accumulations, of probable Pliocene age, of flows and pyroclastic rocks with little or no associated sedimentary material.

The lower Pliocene sedimentary rocks associated with the Miocene beds have been noted in the preceding section. They include the Ricardo formation of the Mojave Desert (9, 117),⁵ the beds containing the upper Cedar Mountain fauna of the Esmeralda formation of southwestern Nevada (34, 228) and the strata interbedded with the Kate Peak andesite of Gianella (74), which are believed to be traceable into the Truckee formation of west-central Nevada.

⁵Stock (232, p. 52) considers that the Ricardo possibly belongs in the upper Miocene.

A Pliocene fauna is also found in the Panaca formation of the Pioche region, Nevada (231, 254). It is questionably referred to the lower Pliocene by Simpson (214) and to the middle Pliocene by Stirton (230). Some distance south of Pioche, in the Boulder Dam region, Longwell (148) has found extensive basin deposits that include coarse fanglomerates, landslide debris, sandstones, siltstones, clays, salines, and numerous flows of basalt and andesite. The uppermost member is the widespread Hualpai limestone, which was laid down when the basins were nearly filled. Longwell places the whole assemblage in the Muddy Creek formation, which he assigns to the Pliocene, but, as noted above, there appear to be some grounds for believing that the lower part of this formation may belong in the upper Miocene.

Fossiliferous middle Pliocene sedimentary beds belonging to the Thousand Creek formation of Merriam (167) are fairly widespread in northern Nevada. They are composed largely of sand and tuff but also include some gravel. Apparently equivalent beds are known as far south as west-central Nevada (258) and may also be represented by the Alturas formation of Dorf (53), in northeastern California, although the fauna in that region appears to be too scanty to permit close correlation (132).

The only other fossiliferous Pliocene sedimentary rocks in this province occur in the Coso Mountains of California. The beds in this range were described by Reid (202) and are apparently the source of a recently discovered upper Pliocene fauna that Schultz (212) regards as transitional between Pliocene and Pleistocene, though Stirton (230) classifies it as rather low in the upper Pliocene.

Unfossiliferous sedimentary rocks assigned to the Pliocene are widely distributed throughout the province; they are composed of fanglomerates and other clastic deposits; together with

lake beds that are similar in lithology to the mammal-bearing formations. Noble (180, 182) has described two formations along the San Andreas rift, one which apparently is underlain without stratigraphic break by upper Miocene fanglomerates and another which he tentatively correlates with the Saugus formation of the Coast Ranges (late Pliocene (?) and early Pleistocene). Questionable Pliocene sedimentary beds are also present in western Utah in the Ombe Range (88) and the Deep Creek Range (187), and at many places in Nevada in association with volcanic rocks.

In some localities it seems probable that the sedimentary deposits that have accumulated in the intermontane valleys may date back into Pliocene time. Block faulting along some of the present ranges in the Great Basin appears to have begun in the Pliocene and it seems reasonable to assume that deposition of fanglomerates and playa deposits has progressed more or less continuously since the faulting was initiated. Knopf (130) regards the sedimentary beds that flank the Inyo Mountains, Calif., and those along the east front of the Sierra Nevada as representing parts of both Pliocene and Quaternary time; in the nearby Coso Mountains Schultz (212) has found transitional Pliocene-Pleistocene fossils in arkosic sedimentary beds that were deposited after the range had been uplifted by faulting. Similarly, Knopf has suggested that dissected fanglomerates near Rochester (131) and Yerington (129), Nev., may represent detritus brought down after some earlier block faulting but prior to the most recent movement. Buwalda (34) has also suggested that the older valleys may contain a continuous series of sedimentary rocks that date well back into the Tertiary.

Merriam (169, 171), Simpson (214), and Stirton (230) have discussed the sequence and correlation of the Pliocene vertebrate faunas. There is fairly general agreement as to the sequence of the faunas, but some difference of opinion as to their assignment within the Pliocene, as shown in the table below.

Age assignments of Pliocene and Miocene vertebrate faunas

	Merriam (171)	Simpson (214)	Stirton (230)
Upper Pliocene.			Coso Mountains.
Middle Pliocene.		Thousand Creek.	Thousand Creek. Panaca.
Lower Pliocene.	Thousand Creek.	Panaca (?). Upper Cedar Mountain and Fish Lake valley.	Ricardo. Mint Canyon.
	Ricardo.	Ricardo.	Esmeralda.
Upper Miocene.	Cedar Mountain.	Mint Canyon.	

Surficial volcanic rocks appear to have been found interbedded with all the Pliocene sedimentary rocks so far described, and in several localities where older Pliocene sedimentary beds are probably present they are unconformably overlain by a series of flows that are considered to be of later Pliocene age. There appears to be no characteristic chemical composition for either of these groups of volcanic rocks, as a wide range of lavas has been reported. In western Utah, however, the lavas consistently contain a rather high proportion of K₂O, latites being widely distributed in the region (32, 82). The abundance of potash in these Utah volcanic rocks appears to be characteristic not only of those considered to be of Pliocene age but of the older Tertiary lavas as well.

No Pliocene granular intrusive rocks are known to have been recognized in the Basin and Range province.

SUMMARY OF TERTIARY SEDIMENTATION AND VOLCANISM

The Tertiary sedimentary record, even though it is far from adequately studied, provides a basis for some tentative suggestions as to the Tertiary geography and climate of the Great Basin. During the Eocene epoch the province appears to have been a well-drained highland, to judge from the apparent absence of Eocene sedimentary beds throughout most of the province and their relative abundance both to the east and to the west. The climate must have been humid, as a fairly heavy rainfall would have been required to maintain streams capable of transporting the debris and to permit the existence of the fresh-water lakes whose sedimentary deposits are now found along the eastern border of the province. The western part drained to the Eocene seas that existed in California—to the north over the present site of the Sierra Nevada and to the southwest directly into the sea that bordered the province in that region.

Similar conditions possibly extended into the Oligocene epoch, as sediments of this age appear to be lacking over most of the Great Basin. However, drainage to the sea was destroyed at least locally by the formation of interior basins in which nonmarine sediments accumulated. This change was accompanied by a change in climate (234), as the earlier forest environment was replaced by open plains or meadows.

The disintegration of the drainage by block faulting, with the consequent formation of interior basins, was greatly intensified in Miocene time, and the nature of the widespread sedimentary deposits of this age shows that the climate was fairly arid. Climatic conditions over the whole province were not uniform, however, as the abundant salines in the southern basins are represented to the north by diatomites, lignites, and oil shales. Some debris was possibly carried from the Great Basin through the Miocene stream channels found in the present Sierra Nevada, but on the whole there appears to have been relatively little material removed by exterior drainage, in spite of the proximity of the sea along the southwest border of the province.

The initial rise of the Sierra Nevada at the end of the Miocene epoch (160) appears to have completed the isolation of the Great Basin, and all the known Pliocene deposits in the province are of continental origin and were laid down in interior basins—locally, indeed, almost filling the fault valleys (148). A moderately arid climate is also suggested by the sedimentary beds and their contained fauna, although, so far as the sedimentary record goes, the climate does not appear to have been any drier or any more uniform than that of the Miocene. This conclusion is in conflict with the evidence adduced by some paleontologists from the fauna and flora contained in the sedimentary rocks. Chaney (38), particularly, has advanced the hypothesis that the climate of the Great Basin has become progressively more arid from Oligocene time to the present day and has based his age determinations of the fossil floras upon this hypothesis. Ransome (196, p. 107), however, long ago called attention to the probability that the climate throughout the Tertiary period "swung back and forth between moderate humidity and pronounced aridity."

The Tertiary volcanism is difficult to outline accurately, because at relatively few places can the igneous rocks be dated with confidence. Lavas and pyroclastic rocks unquestionably were erupted from Eocene through Pliocene time, but the relative abundance of eruptions at different times is unknown. Present exposures of coarse-grained intrusive bodies of supposed Tertiary age are commonly assigned to the Eocene or Oligocene, but the late Miocene diorite found at Virginia City, Nev., suggests that the concentration at the earlier Tertiary horizons is due in large part to the longer time interval during which erosion could have operated to expose the deeper intrusives.

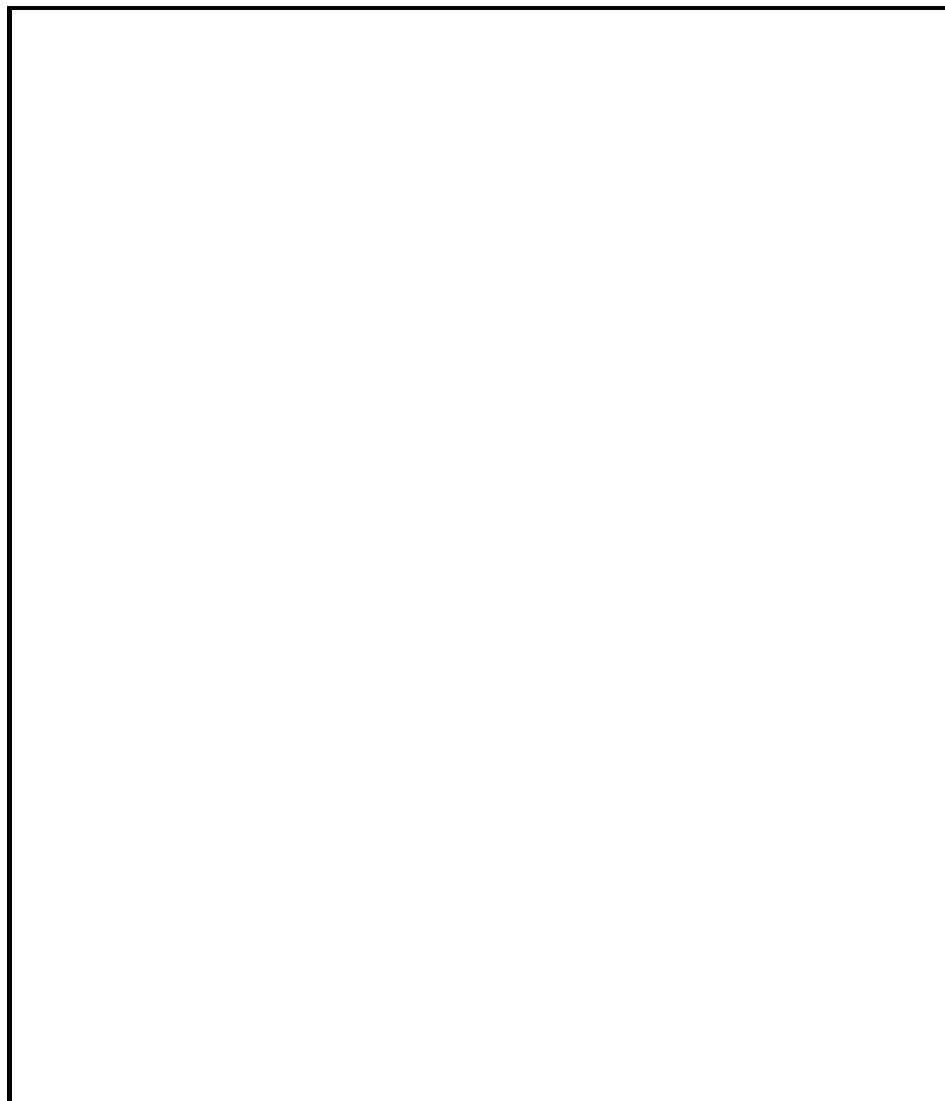
Attempts to determine a general succession of the types of lava erupted during the Tertiary

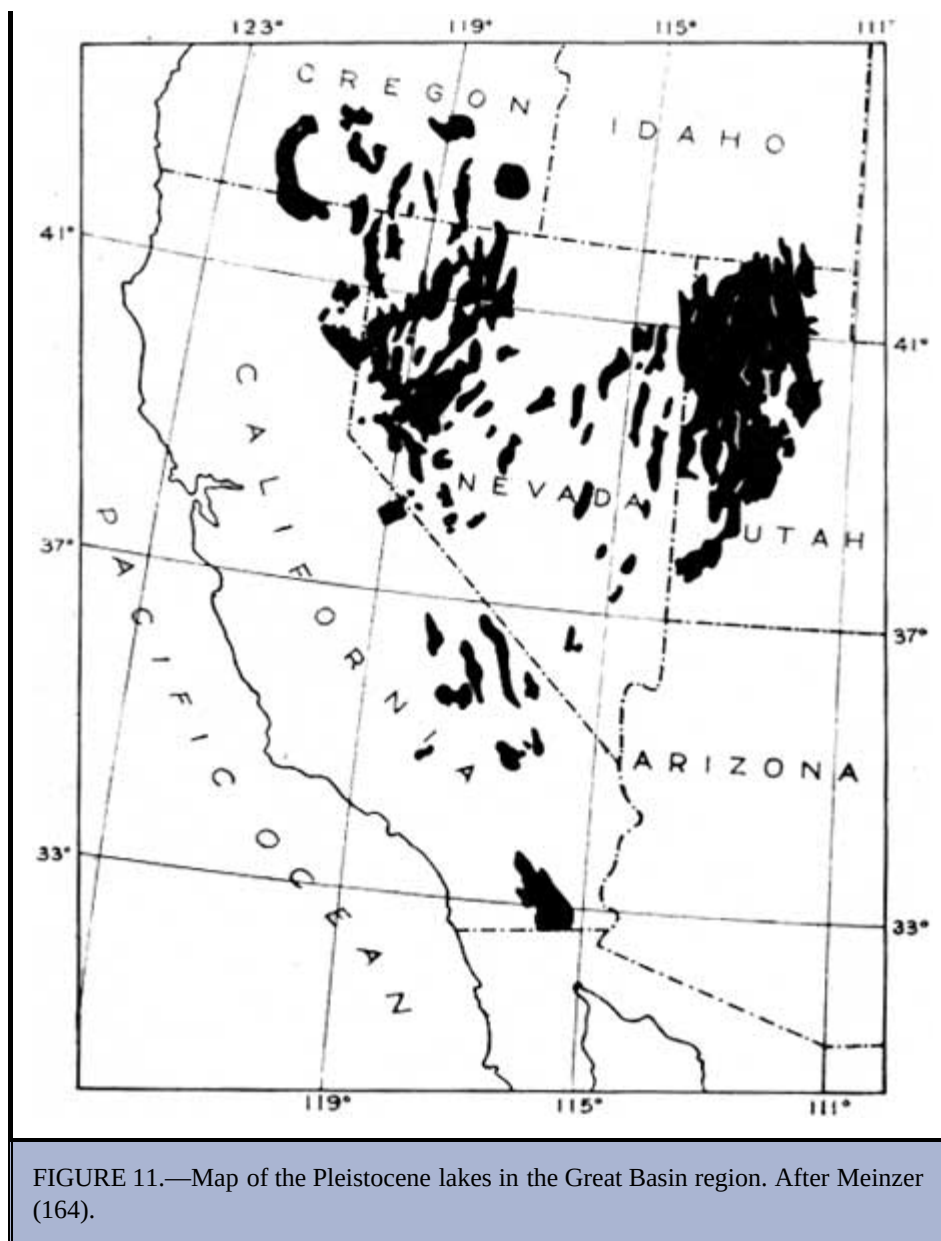
culminated in the elaborate sequence postulated by Spurr (223). The futility of such schemes was shown by Ransome (196, pp. 105-106), and more recent work has only served to confirm his statements. Thus Westgate's detailed sections of the volcanic sequences near Pioche, Nev. (254, pp. 29-31), show rapid alternations of flows and pyroclastic rocks that range from rhyolite to basalt.

QUATERNARY SYSTEM

The widespread Quaternary sedimentary deposits in the Great Basin consist chiefly of lake beds and fanglomerates, but locally glacial deposits and river gravel and silt are well developed. Basalt and in places rhyolite flows have also been found at several localities. A distinction between Pleistocene and Recent deposits is rarely made, although in general Recent geologic processes have largely resulted in the dissection of the Pleistocene deposits with concomitant transportation of the eroded material toward the local playas.

The numerous Pleistocene lakes (fig. 11) at their maximum stages covered a large proportion of the province. The two largest lakes, Bonneville and Lahontan were studied many years ago by Gilbert (79) and Russell (208), whose classic reports are still the chief sources of our knowledge of the Pleistocene history and climate of the region. Two periods of high water, separated by an interval during which the lakes dried up, were recognized; and two comparable series of lacustrine sedimentary deposits were described. From their observed relations to the local glacial deposits, the epochs of high water were correlated with the waning stages of the two periods of mountain glaciation that were then known.





Some dispute has arisen over the correlation of the lake beds with the five glacial stages found in the Mississippi Valley. Only a scant fauna has been found in the sedimentary beds, but both Merriam (170) and Hay (91) regard the vertebrate fossils as indicative of a very early stage in the Pleistocene, and Hay correlates the earlier of the two periods of lake expansion with the oldest or Nebraskan glacial stage.⁶ Jones (122), on the other hand, on the basis of his studies of the quantities of tufa deposited by Lake Lahontan, considers that the entire lake history must be compressed within the last 3,000 years and regards the fossil evidence as indicative merely that the extinct forms found in this region persisted well into very recent time. Most geologists, however, agree with Gilbert that the last period of lake expansion should be correlated with the youngest or Wisconsin glacial stage; and this belief appears to be strengthened by Antevs' discovery (3) of sediments indicative of three or possibly four stages of lake expansion in the Lahontan Basin, which by analogy appears to imply three or four glacial stages. A similar conclusion may be drawn from the results of drilling for potash-bearing brines in the Great Salt Lake desert in the Bonneville Basin (184).

⁶The placing of Hays' "Aftonian" fauna low in the Pleistocene has been questioned. A recent discussion with bibliography is given by Schultz (212. pp. 95-96).

The numerous smaller Quaternary lakes have been described by Meinzer (164). Some of these have been rather carefully studied in the course of explorations for potash (73, 107); and the lake near Manix, in southern California, has yielded a moderately extensive fauna (33, 59).

The alluvial accumulations in the intermontane valleys commonly consist largely of the coarse clastic deposits termed "fanglomerates" by Lawson (135), as they make up the great fans or alluvial cones that extend valleyward from the bordering mountains. In the valleys that were not occupied by Pleistocene lakes this material grades outward from the mountains into the fine-grained silts and clays that floor the playas or sinks of the valleys. Several valleys appear to be nearly free from these accumulations and are floored by Tertiary sedimentary or volcanic rocks, but such occurrences are believed to be the result either of capture by adjoining valleys within a lower base level or of exhumation by through drainage channels. Their study has to a considerable extent lagged behind that of the older rocks, but Spencer (219) has presented a correlation between the alluvial deposits near Ely, Nev., and the stages recognized by Gilbert in Lake Bonneville, and Knopf's study of the cones in Owens Valley, Calif. (130), has provided a basis for the unraveling of the more recent geologic history of that region. Fossils are sparse in the alluvial deposits, but some have been found in placer gravel laid down by streams that were probably contemporaneous within the Pleistocene lakes (63), in cave deposits in southwestern Nevada (90, 133), and in the alluvial accumulations at Carson, Nev. (91, pp. 149-152), where a moderately large late Pliocene or early Pleistocene fauna is present.

Glacial deposits are relatively slight in this province. Mountain glaciers were fairly extensive in the higher portions of the Wasatch Range, and their moraines locally extend down to the mountain front. Two and possibly three glacial stages have been recognized (79, 4, 190). Glaciation in the Sierra Nevada was considerably more extensive, and Matthes (160) has recognized three stages at Yosemite, on the western slope. Knopf (130) described only two stages along the eastern front of the range, but more recently Blackwelder (18) has recognized four stages.

Within the Great Basin itself glaciation was limited to a few of the highest ranges. The known mountain glaciers were small, and their deposits rather insignificant. Antevs (3, pp. 67-68) and Blackwelder (18, pp. 910-912; 20) have listed most of the localities where the results of glaciation have been recognized.

Rivers that are confined to the Great Basin, such as the Humboldt and Mojave, have been engaged chiefly in the dissection of older deposits; the gravel and silt deposited by them are confined largely to their present flood plains. A considerable series of Quaternary deposits laid down by the Colorado River, however, has been preserved within the province and has been recently described by Longwell (148). The Colorado delta also extends into the province in the Imperial Valley, and its recent history has been exhaustively studied by Sykes (239).

Basalt cones and small associated flows of Quaternary age form a striking feature of the landscape at several localities in the province. Knopf (130) has mapped those in the Owens Valley, Calif., and Ball (11) those in the vicinity of Death Valley. There are, in addition, some easily accessible occurrences in the eastern part of the Mojave Desert (92). Gilbert (79) found several craters and cones in Utah that were clearly younger than Lake Bonneville, and he considered it probable that the volcanic epoch had not yet ended.

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The Basin and Range Province in Utah,
Nevada, and California

STRUCTURAL HISTORY

PRINCIPAL FEATURES

Although the Great Basin region has been characterized (29, p. 346) as a "fracture belt of low mobility," the evidence now available indicates that on the contrary the province has been orogenically active throughout a large part of its history. Indeed, the Paleozoic and later history that can be deciphered suggests an interpretation of mountain building that is at variance with the commonly accepted belief that major diastrophic revolutions are relatively brief events marking the end of one geologic era and the beginning of the next.

The pre-Cambrian structural history is little known at present, as the scattered regions in which the pre-Cambrian rocks are exposed have been inadequately studied for purposes of correlation. It would appear, however, that the Great Basin region was active orogenically during at least three epochs in pre-Cambrian time.

The record beginning with Cambrian time is much more complete. The geosynclinal sea, which in the early part of the Paleozoic era covered most of the province and in which many thousands of feet of sediments were deposited, was divided in late Devonian time by a rising arch or geanticline in western Nevada. Locally there was moderate deformation during the uplift, but by Permian time elevation had ceased and most of the positive area had been covered by marine sediments. Coincidentally with the degradation of this geanticline during the Permian epoch a similar uplift began in eastern Nevada and a land mass between two seas persisted there until early Jurassic time. Although an unconformity is recognized between Permian and Triassic sedimentary beds in both the eastern and western parts of the province, it appears to be relatively slight except on the borders of the geanticline; over most of the province the angular discordance between the Permian and Triassic is very small, and the sedimentary beds of the two units have essentially the same geographic distribution.

This younger geanticlinal area, instead of subsiding, like the earlier one, became the site of intense diastrophism in early Jurassic time. To judge from the relatively meager evidence, similar deformation continued recurrently into the early part of the Tertiary period, affecting an area that considerably exceeded that of the Great Basin. No regular pattern in space or time can yet be discerned for these epochs of deformation within the province; in one area there may be evidence of only one episode, but in another nearby area, there may have been several. East of the province, however, there appear to be good grounds for inferring that during successively younger epochs, deformation affected regions farther and farther east. There is no evidence of a similar westward migration unless it may be provided by the early Jurassic orogeny in western Nevada and the late Jurassic folding in the Sierra Nevada. These epochs of deformation can be approximately dated at only a few localities in the province, but at none of these places, strangely enough, has it been shown that deformation took place either during late Jurassic time or during the transition from Cretaceous to Eocene time.

The Mesozoic and early Tertiary folding and thrusting were succeeded closely by the

initiation of the block faulting that is the cause, directly or indirectly, of the present relief of the province. The faulting appears to have begun at least by early Oligocene time and to have continued up to the present day. For several reasons, especially because of the apparent contemporaneity of block faulting with some late Tertiary overthrusting on each side of a major tear fault, the block faulting is here regarded as an end stage of the more intense deformation that preceded it.

This concept of an orogenic cycle in which a protracted epoch of spasmodic folding and thrusting was preceded by gentle upwarping and followed by block faulting is in many respects similar to one posthumously proposed by Woodworth (264) for the Appalachian Mountains. The Great Basin region, however, appears to provide a considerably more complete and in some respects a more readily authenticated picture than is available in the older mountain system.

PRE-CAMBRIAN OROGENY

Uncertainties regarding the pre-Cambrian structural history of the province are even greater than those concerning the correlation of the pre-Cambrian formations. The probable existence of three series of formations showing differing metamorphism both in the Wasatch Range and in the Death Valley region suggests that there were two epochs of major diastrophism during pre-Cambrian time, in addition to the orogeny that resulted in the unconformity at the base of the Cambrian. We have, however, little information regarding the nature or extent of these disturbances beyond Blackwelder's suggestion (21) that the folding trended northeastward.

The youngest of the three epochs of orogeny has some features worthy of brief comment. Perhaps the most striking is the absence of any pre-Cambrian granitic intrusive masses that are clearly younger than the sedimentary rocks involved in this deformation. Secondly, in the Inyo Mountains and possibly in the Death Valley region as well several unconformities have been recognized that separate the later pre-Cambrian formations, all of which appear to have undergone relatively little metamorphism. Finally, several observers regard at least part of these sedimentary beds as of terrestrial origin. These three features together seem to warrant the suggestion that in the part of the Great Basin where these rocks are now exposed this youngest pre-Cambrian orogeny was subsidiary and marginal to a more intense deformation in an area as yet unknown. The orogeny may thus have been similar to the younger revolution described below in having a central belt of more intense deformation and intrusion in which spasmodic activity continued over a considerable length of time.

PALEOZOIC AND EARLY MESOZOIC DISTURBANCES

During Paleozoic and early Mesozoic time the Great Basin was dominantly a region of sedimentation. In large part the structural disturbances during this time must be inferred from evidence provided by the lithology and distribution of the sedimentary deposits—data that are summarized on preceding pages. The chief events thus determined include two broad upwarps that formed geanticlines whose axes appear to be parallel to the axes of the great geosynclines in which they were developed. The deformation of the strata involved in the upwarps is negligible compared with the folds and faults that were formed in later Mesozoic and Tertiary time, and these movements may be classed as epeirogenic, but they are regarded as genetically related to and the harbingers of the revolutionary events that followed them.

The earlier geanticline (185) was formed in western Nevada and appears to have come into existence in late Devonian time. Although the involved area appears to have continued to rise

until Permian time, the aggregate uplift was not great. Marked angular unconformities reflecting more intense movement have thus far been reported only from the Hawthorne and Tonopah quadrangles, in west-central Nevada (70), where Permian sandstones rest with angular discordance on the Ordovician. There appears to be no evidence that the uplift within the Great Basin was accompanied by other than minor volcanic activity, although the final disappearance of the geanticline may have been roughly contemporaneous with the extrusion of the Permian volcanic rocks that are known in its axial region. West of the province, however, deposition of marine sediments in northern California during both Mississippian and Pennsylvanian time appears to have been accompanied by abundant volcanic activity (51). This asymmetric localization of volcanism with respect to the uplift was repeated during the later upwarp

The second geanticline first emerged as a persistent land mass in the Permian epoch, coincidentally with the disappearance of the older one, whose axis had been about 100 miles to the west. It continued in existence as a relatively narrow barrier throughout early Mesozoic time and was then greatly enlarged to form Schuchert's Cordilleran Intermontane geanticline (211, p. 187). The initial uplift in the Permian epoch appears to have been largely restricted to southern Nevada and southeastern California, approximately on the site of a region of instability in Pennsylvanian and later Mississippian time. Such stratigraphic evidence as is available suggests that the upwarping progressively extended northward, until in late Triassic time the land mass reached the northern boundary of the province.

Like the earlier geanticline, the uplift appears to have been on the whole relatively gentle, but epochs of more vigorous movement appear to have been somewhat more frequent, culminating finally in the profound folding and faulting of the later Mesozoic beds. Thus, in both eastern and western seaways the Permian-Triassic contact in areas close to the geanticline is marked by a fairly pronounced erosional unconformity; furthermore, the Upper Triassic sedimentary series, especially in western Nevada, rests with angular discordance on the older Triassic strata. The clastic and nonmarine sedimentary beds that were deposited so abundantly in the eastern seaway probably have a similar import.

This uplift also resembled the older one in that extensive contemporaneous surface volcanism was concentrated in the trough or sea that was formed west of the geanticline. The fact that the two uplifts had this feature in common is probably significant, but its interpretation is at present uncertain. A possible explanation might be that the active force causing the upwarping lay to the west.

LATER MESOZOIC AND EARLY TERTIARY OROGENY

A long period of intense diastrophism that eventually affected all of the Great Basin province began in middle Mesozoic time and continued into the early part of the Tertiary period. The folds and thrust faults that were formed during this time of crustal unrest transformed the province from a region that had been in large part a basin of sedimentation since later pre-Cambrian time into a highland area that was henceforth to be essentially free from marine invasions. It was thus revolutionary in results, although the deformation appears to have been simply an intensification of the broad uplift that began in the southeastern part of the Great Basin in Permian time.

NATURE OF THE DEFORMATION

Our knowledge of the number and relative importance of the different structural features developed during the later Mesozoic and early Tertiary diastrophism is sketchy, being based in large part upon a few detailed studies of rather widely separated areas. So far as this

information goes, it appears to indicate, first, that major folds and thrust faults of moderate to large displacement were formed over most of the province; second, that normal faults were formed only locally, although the tendency of much younger faults to follow old structural lines makes this belief somewhat uncertain; and third, that there were developed several extensive belts having nearly east-west trends, at right angles to the strike of the folding and thrusting in the rest of the province. These east-west trends, in part at least, have been developed as a result of dominantly horizontal movement along major transverse faults. Along most of the thrust faults so far described the upper plate has clearly moved eastward relative to the lower plate, and this fact, combined with the apparent westward increase in the intensity of folding, suggests that the active force causing the deformation came from the west.

FOLDS AND THRUSTS

Folding of the pre-Tertiary rocks throughout the Great Basin was recognized in the earliest geologic surveys of the province; indeed, it was so prominent that King (124) at first attributed to folding the form and location of the individual mountain ranges, comparing them with the folded Appalachians. Thrust faults, on the other hand, were not recognized until 1900, but since that time a large number have been described.

In spite of the wide extent of the folding, relatively few individual folds can be traced for any great distance, partly at least because major faults formed during a period of later block faulting commonly transect the trend of the folds. As the down-faulted portion of a fold is commonly concealed beneath younger deposits, only relatively short segments of the faulted folds are now exposed. Other ranges that apparently have monoclinical structure have been interpreted as the strike-faulted limbs of synclines or anticlines, and in several places this interpretation has been confirmed by the discovery of the fold axis where the fault has died out or where the strike of the fold diverges from that of the fault.

Two anticlines and two synclines in the Oquirrh Range, in central Utah (82), have been traced for as much as 15 miles before being terminated by faults along the range front, and if some of the monoclines, such as that found in the House Range, in western Utah, are faulted folds, even greater dimensions may be inferred. In many of the ranges, however, the continuity of the strata is interrupted either by large thrusts or normal faults or by intrusive masses, so that the province shows no such regular sequence of persistent folds as is found in the Appalachians, the middle Rocky Mountains, or even in the Coast Ranges.

King (125, p. 734) many years ago called attention to the westward increase in the intensity of folding, and more recent work, although disclosing local close folding in the east, seems on the whole to indicate that the generalization is valid. Thus the Paleozoic strata in western Utah and eastern Nevada commonly exhibit low to moderate dips, and overturned strata are exceptional, though reported at several localities, such as Goodsprings, Nev. (104), Gold Hill, Utah (187), the Oquirrh Range, Utah (82), and the southern part of the Wasatch Range, Utah (58). In contrast, Ferguson (63, 66, 70) has described the occurrence of widespread close folding, essentially isoclinal in places, at several localities in west-central Nevada, and this condition appears to be rather general throughout the western part of the State.

Although Spurr (225, p. 177) recognized a thrust fault in the southern Great Basin in 1900, Blackwelder's studies in the northern Wasatch Mountains, near Ogden, Utah, which were published in 1910 (14), were the first to establish thrust faulting as a major structural feature in the province. Most of the thrusts found in the next few years were either in the central or southern part of the Wasatch Range or close to the eastern border of the province and led to the rather commonly accepted belief that such faults were characteristic of and limited to a rather narrow zone that trends north-northeast and joins the zone that includes the Bannock

and other thrusts in southeastern Idaho and western Wyoming. In recent years, however, thrust faults have been found at several localities that are considerably west of the eastern margin of the basin, and the validity of the earlier generalization now seems somewhat questionable. The distribution of the thrusts so far discovered is shown in figure 12, but this is far from being a final record. Whether or not there are differences in character between the eastern and western thrusts, comparable to the distinction that apparently holds for the folds in the two regions, is at present uncertain. Ferguson (67) believes that at least the great majority of the thrusts mapped by him and Muller in west-central Nevada have smaller displacements and that their relations are more erratic than those of the persistent low-angle or nearly horizontal thrusts that appear to be characteristic of the eastern part of the province. Such a difference in the type of thrusts might be expected in view of the supposed differences in the folds.

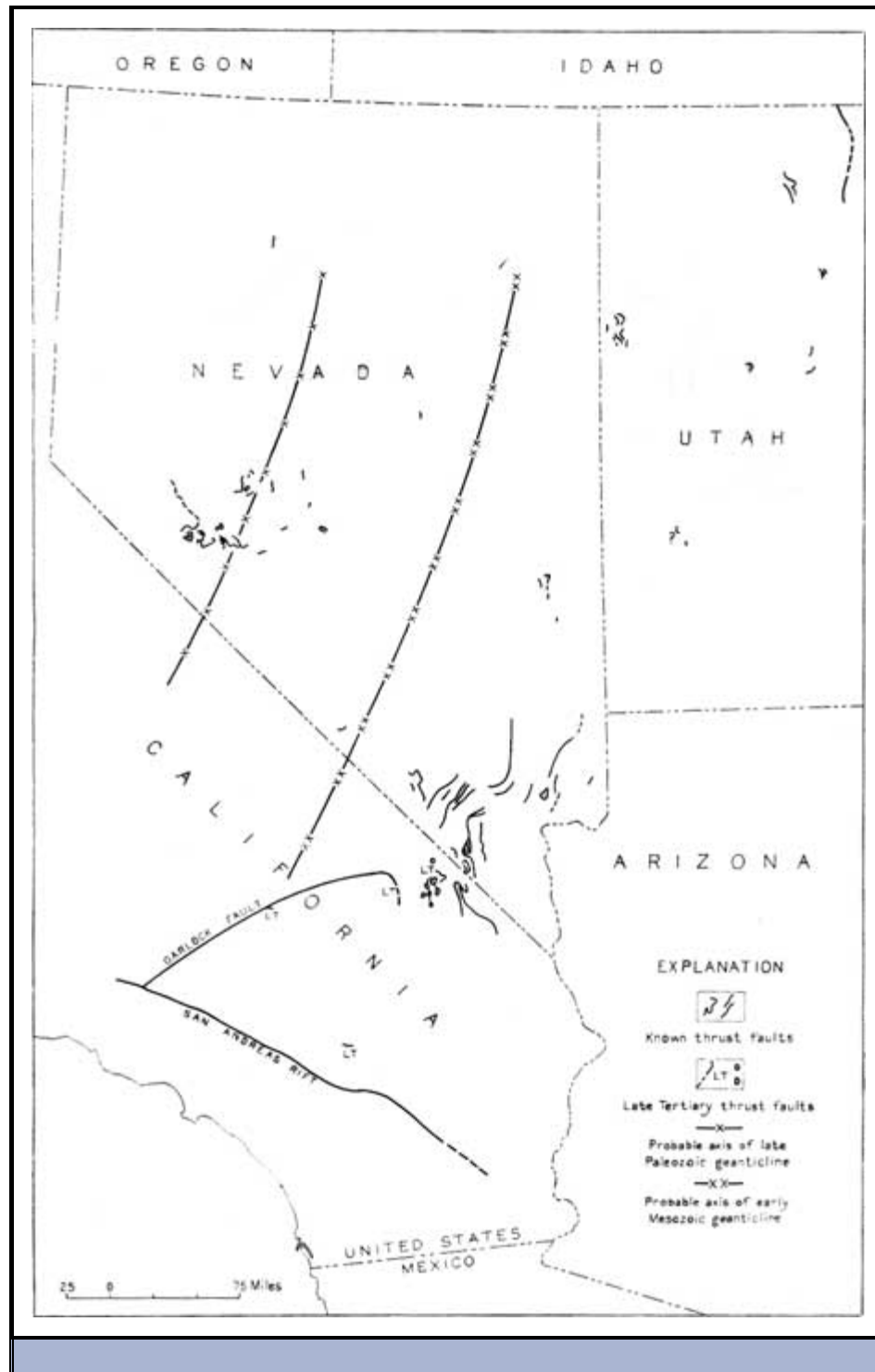


FIGURE 12.—Distribution of known thrust faults in the Great Basin region. ([click on image for a PDF version](#))

The thrusts in the northern and central parts of the Wasatch Range dip eastward, and in the earlier descriptions (14, 155, 112) the thrust plate was considered to have moved toward the west. Calkins (36), however, found that the drag folds indicated an eastward thrust, a conclusion later reached by Blackwelder (15) for the northern Wasatch and in harmony with Eardley's observations in the southern Wasatch (58, pp. 381-385), where an anticline overturned toward the east passes into a thrust. The thrust found by Loughlin (32, pp. 424-425, 438-439) in the Sheeprock Mountains, Utah, also appears to have been deformed and locally shows an easterly dip. Should the contact of the Cambrian limestone and the overlying quartzite in the Frisco district, Utah, prove to be a thrust (see p. 151), still another eastward-dipping thrust would be recorded.

The best-known series of major thrusts is in southern Nevada, near the eastern border of the province. It has been described by Longwell (144, 145) and Hewett (104) and comprises a belt of eight or more thrusts with variable but commonly low westerly dips. Some of the thrusts are regarded as having definitely moved over an old erosion surface (144, p. 570; 85). The absence of basement rocks in the overriding block, together with the observed changes in dip, suggests that the thrusts pass downward into a nearly horizontal sole (186, 147). Hewett (104, pp. 53-54) regards the thrusts in the Goodsprings area of Nevada as being successively younger westward and cites evidence indicative of an erosion interval between two of them. In this region the belt of thrust faults has been traced about 100 miles along the strike.

Of the more westerly thrusts, those at Pioche, Nev. (254, pp. 42-43), although extensive, are not well exposed. They have apparently been warped by later folding or faulting and in one place appear to be younger than some lavas of supposed early Tertiary age. The thrusts at Gold Hill, Utah, on the other hand, are exposed in a relatively small area, but seem to provide a record of prolonged orogeny, in which folding or thrust faulting occurred at several times, separated by epochs of normal faulting and erosion (187). The thrusts at Eureka, Nev., may be of minor extent but have not been adequately studied. That in the Sonoma Range, Nev., according to Muller and Barksdale (176), dips eastward.

In west-central Nevada Ferguson and Muller (69, 70) have recently found an extensive series of thrusts associated with the folded Mesozoic sedimentary rocks. This region is unique among those so far described, not only because it is possible to date the thrusting rather accurately, but because of the complexity and relationships of the fault pattern. The thrusts appear to be intimately related to marginal troughs of the late Triassic seaway, and the forces that caused the thrusting appear to have continued over a time long enough to deform some of the earlier thrusts considerably. Thrust faults had earlier been recognized in the lower Paleozoic sedimentary rocks at Manhattan, Nev. (63), a short distance to the east.

NORMAL FAULTS

Although all the areas that have been carefully studied exhibit moderate to large numbers of normal faults, it is commonly difficult to determine how many of these are genetically related to the later Mesozoic and early Tertiary epoch of diastrophism, as many of them are obviously either much younger block faults (see pp. 178-184) or are clearly the result of igneous intrusion or extrusion. In a few places, however, there is rather good evidence that normal faulting occurred on a fairly large scale during the period of folding and thrust faulting.

The best example of this relation is at Gold Hill, Utah (187) where several stages of normal faulting can be recognized. Each stage was preceded and followed by folding or thrusting, as

is shown either by the termination of the normal faults against the younger thrusts or against transverse faults associated with the thrusts, or, in the numerous examples of recurrent movement along the normal faults, by notable differences in the displacement along the normal faults above and below the thrust planes. The pre-thrust normal faults at Pioche, Nev. (254, pp. 43-44), are possibly additional examples.

TRANSVERSE STRUCTURAL FEATURES

Faults which trend normal to the strike of the folds and thrusts and along which the movement has been largely horizontal occur in many places throughout the province. They are believed to be the product of the same orogenic forces that caused the folds and thrusts. Several varieties of these faults, which have been variously termed "flaws," "tear faults," "cross faults," and "transverse faults," may be distinguished. There is also some evidence suggesting the existence of nearly province-wide east-west belts along which the structural trends are notably at variance with those throughout the rest of the Great Basin. Their trend and the fact that there has been relatively recent horizontal movement of considerable extent along at least one of them suggest that the origin of these belts is similar to that of the simple flaws.

Although these transverse faults have been definitely identified in only a few places, published geologic maps suggest that they are fairly widespread. Where such faults have been recognized, they appear, in part at least, to be rather intimately related to thrusts. Thus several of the smaller transverse faults in the Tintic (142) and Gold Hill (187) districts of Utah and in west-central Nevada (70) may be traced into minor thrusts. The steep dips with strikes normal to the structural trend of these transverse faults change rather abruptly to the low dips and concordant strikes of the thrusts. Locally, as at Goodsprings, Nev. (104), and at Gold Hill, Utah, fairly large thrusts are terminated laterally by contemporaneous transverse faults of this sort. One of the best examples of such a relation, involving a thrust of considerable displacement, is found in the southern part of the Goodsprings district, where one of the major thrust plates, the Sultan, is bounded on the south by the Tam O'Shanter transverse fault.

Another variety of transverse fault is illustrated by the Ironsides fault in the Goodsprings district. It is marked by notable horizontal shifts in the rocks above the Keystone thrust and also offsets the outcrop of the thrust itself for about half a mile. It cannot, however, be traced into the block below the thrust. Hewett (104, p. 49) considers that the Ironsides fault was developed during the epoch of thrusting. Ferguson and Muller (70) have mapped similar faults in west-central Nevada, but in some of these neither the upper nor lower plate is greatly affected, and the faults are best interpreted as steeply dipping portions of the thrust that strike nearly at right angles to the remainder of the thrust outcrops.

The Arrowhead fault, in the Muddy Mountains, Nev. (145, pp. 110-111), and an unnamed transverse fault in the Spring Mountains, to the southwest (144, pp. 572-573), are both major cross faults that differ from those so far described in that they cannot be correlated with a single thrust. Both are interpreted by Longwell as being major "flaws," along which horizontal movement during the epoch of thrusting permitted the development of notably different types of folds and thrusts on the two sides of the faults. He suggests that a still more pronounced transverse fault of this type may extend for many miles beneath the alluvium of Las Vegas Valley.

There are, of course, numerous transverse faults along which horizontal movement can be proved but which cannot be directly connected with thrust faults. It is believed, however, that for many of them this failure is the result of the vagaries of exposure.

Scattered observations suggest the possible existence of three or four transverse structural features of still greater magnitude. Their nature, extent, and relations to the provincial structure are at present uncertain, as there has been relatively little detailed mapping along any of them.

The most southerly of these east-west belts is thought to lie along the northern border of the Mojave Desert region of southern California. The Garlock fault in this region is known to have been the site of profound horizontal movement in relatively recent time (see p. 186), but Noble (180, p. 425) has suggested that it was probably also active in pre-Tertiary time. A strong argument in favor of Noble's view is provided by the differences in the exposures of Paleozoic and early Mesozoic rocks on each side of the fault. To the north there is a thick section of these rocks, considerably folded and faulted but not greatly metamorphosed; south of the fault, however, the pre-Tertiary sedimentary rocks are highly metamorphosed. Recognizable fossils have been found at only a few places, and the bulk of the schists and gneisses of sedimentary origin have been classed on rather inadequate grounds as pre-Cambrian. Regardless, however, of the age assignment of these metamorphic rocks, it seems clear that the regions on the two sides of the Garlock fault have had considerably different structural histories, and the difference is too great to be attributed to the relatively recent movement along the fault.

A second belt is suggested by the recent work of Ferguson and Muller (70) in west-central Nevada. They found a pronounced offset in the outcrops of sedimentary beds deposited along the eastern border of the early Mesozoic seaway north and south of a zone in which east-west structural trends were dominant. A possible third belt lies along the line of the Western Pacific Railroad in western Utah. This belt roughly coincides with the westerly projection of the Uinta axis and is marked by a zone of east-west strikes. A few observations near Wendover, Utah, close to the Nevada boundary, suggest that major transverse faults may also occur in this belt. The most northerly belt lies along the northern boundary of the province and extends from northwestern Utah into northern Nevada. Butler (32) called attention to the east-west strikes in the Raft River Mountains in Utah, and a similar trend in the pre-Tertiary sedimentary beds appears to extend as far west as Mountain City, Nev. The small amount of field work that has been done along this zone, however, has not yet disclosed evidence of faulting with profound horizontal movement.

DURATION AND AGE OF OROGENY

There is little direct evidence on the age of the major folds and thrusts over much of the Great Basin. In most places it is possible to determine only that they are later than the late Paleozoic or early Mesozoic and earlier than the middle or late Tertiary. A large proportion of the interested geologists have assumed that these structural features were formed during a single short orogenic epoch, which was either contemporaneous with the late Jurassic deformation of California or with the Laramide of the Rocky Mountains. Relatively recent geologic work in the province now seems to indicate that these assumptions have doubtful validity and that orogenic activity has probably persisted in one place or another over a considerable length of time, starting as early as the middle of the Lower Jurassic and continuing into the Eocene. Five areas have supplied the evidence for this belief.

In one of these areas, west-central Nevada, Ferguson and Muller (69, 70) have found that the major folding and thrusting began in early Jurassic time and reached a maximum at about the end of the early Jurassic. There must also have been some still earlier though less intense deformation, as there is a marked unconformity between lavas and tuffs assigned to the Middle Triassic and sedimentary rocks assigned to the Upper Triassic. In the second area, the Spring and Muddy Mountains farther south in Nevada, deep erosion and transverse faulting that intervened between epochs of thrust faulting have been recognized by Hewett (104, p.

53) and Glock (85); furthermore, the occurrence of a thick fanglomerate of Upper Cretaceous age (107) suggests strongly that deformation was going on at that time. In the third locality, Gold Hill in western Utah, long continued orogeny has been inferred and was marked by four or five epochs of folding or major thrusting separated by a like number of intervals of normal faulting and erosion. One of the more recent of these thrust epochs involved beds of probable Eocene age (187). The notably different trends of the Wasatch and Uinta folds also imply recurrent orogeny, although where they intersect in the Cottonwood district, Utah (36), it is not possible to assign definite times to the two epochs because of the absence of any post-Jurassic sedimentary rocks; the Uinta deformation, however, is regarded as the younger. Finally, Spieker and Schoff (222) have recently been able to date rather accurately two epochs of orogeny in central Utah a short distance east of the Great Basin, the older one post-Jurassic and earlier than Upper Cretaceous and the younger one in the early part of the Upper Cretaceous.

SIGNIFICANCE OF OROGENY

Even with the meager evidence at present available regarding the age of the folds and thrusts of the Great Basin, it no longer seems possible to regard the orogeny that produced them as simply an extension of either the late Jurassic deformation of California or the Cretaceous-Eocene (Laramide) deformation of the Rocky Mountains. On the contrary, these two better known events now appear to have been episodes in a long epoch of crustal activity that spasmodically affected the Great Basin throughout later Mesozoic and early Tertiary time.

It is possibly significant that the region for which this recurrent orogeny is suggested includes and borders upon the geanticlinal belt that persisted in the Great Basin from Permian to early Jurassic time (pp. 172-173), especially when it is considered that the beginning of marked orogeny coincided with the disappearance of the western of the two seaways that flanked the geanticline. This coincidence in place and time suggests the hypothesis that there may be a close relation between the geanticline and the orogeny; indeed, it appears possible to consider that the individual spasms of thrusting or folding may represent only local climaxes near the end of a long epoch of increasingly intense deformation that started much earlier as a broad, relatively gentle upwarping. This conception, should it be borne out by future work, should prevent such debates as have occurred in the past as to the exact position and extent of the Laramide and Sierra Nevada orogenies. These terms, together with some new ones, would simply designate subdivisions of a major Cordilleran revolution that began in the Paleozoic era and may, as noted on a succeeding page, be still in progress. The hypothesis also implies that the granitic intrusive masses, whose emplacement everywhere appears to have marked the end of major diastrophism, are of many different ages rather than essentially contemporaneous over wide areas.

LATER TERTIARY AND QUATERNARY OROGENY

The dominant process in the structural history of the Great Basin in middle and late Tertiary time was the block faulting that produced the characteristic basin and range topography of the province. The origin and age of the block faulting and at times even its existence have been the subjects of a very considerable body of controversial literature. Although there is still a lack of agreement on many features of the faulting, most geologists now working in the region seem to agree that at least the greater number of the Basin Ranges are bounded on either one or both sides by a fault or fault zone, that the faults are normal rather than reverse, and that the faulting has occurred from late Oligocene to the present time, although some of the scarps may be fault-line scarps rather than primary scarps.

The folds and overthrusts formed during this time appear to be largely restricted to a

relatively narrow east-west belt in southern California and southern Nevada. These structural features appear to have been formed at a somewhat later time than at least some of the block faults in the same region.

BLOCK FAULTING

HISTORICAL REVIEW

The origin of the individual mountain ranges in the Great Basin became a matter of speculation with the early geologic surveys in the sixties and seventies of the last century. The first theory published was that of King (124), who considered the ranges to be a series of eroded folds, similar to those of the better-known Appalachians. Shortly thereafter Gilbert (77, p. 50; 78, p. 41) presented the thesis that the mountain blocks were bordered on one or both sides by profound faults along which elevation had taken place by vertical movements. This initial statement of the block-faulting hypothesis was quickly accepted and corroborated by Powell (195); and King (125, pp. 742-743) also soon agreed to the occurrence of extensive faulting, though he emphasized his belief that the faulting had been superposed on an earlier intense folding. Dutton (54, pp. 47-48) accepted the idea of an earlier period of folding and a later one of faulting, but added the concept that the relief due to the folding had been nearly obliterated by erosion before the faulting occurred. Russell (207) and LeConte (137) also accepted the hypothesis and contributed to the speculations on the origin of the faulting.

The first notable dissent was expressed by Spurr (224) in 1901, as a result of an extended reconnaissance through the central and southern parts of the region. He reported that faults along the range fronts were exceedingly rare; that in some places unfaulted Tertiary beds in the valleys abutted against the older rocks in the mountains; and that the numerous faults within the mountain blocks were not reflected in the topography. Spurr concluded, therefore, that the present arrangement of mountains and valleys was due almost entirely to erosion.

This challenge brought forth replies from proponents of the faulting hypothesis in the succeeding few years. Davis (44, 45) presented a deductive statement of the physiographic features that should characterize a youthful fault block and found that they were present in several ranges which he examined in western Utah and northern Nevada. Louderback (151) made a detailed section of a region in western Nevada, where a basalt flow erupted on a peneplaned surface was faulted and tilted in accordance with the block-faulting hypothesis. Waring (251, 252) and Russell (209) recorded the beautifully simple fault blocks of volcanic rocks of southern Oregon, and Reid (203), on the basis of a study of the region near Lake Tahoe, in western Nevada, reached the extreme conclusion that almost every linear element of the topography was controlled by relatively recent faulting.

Baker (10) in 1913 appears to have been the first to suggest that the limiting faults of some of the ranges were reverse and therefore produced by compression; earlier writers had implied that they were all normal faults. Baker's observations were made in southern California and southern Nevada, where there was clear evidence that the fault planes were vertical or even dipped into the ranges and that the sedimentary rocks on the valley sides of the faults were closely folded and locally overturned,⁷ also raised objections to the hypothesis outlined by Gilbert; he believed that the valleys had largely been excavated by wind erosion, although he conceded that the deflation was accomplished largely by the removal of soft material that had filled depressions, which might have been formed as a result of faulting.

⁷Keyes' papers on Basin Range geology are too numerous to cite or review here; many of them are cited by Louderback (152).

Louderback, in response to the stimulus provided by Keyes' papers, reviewed the evidence of faulting present in the Sierra Nevada and adjacent ranges in western Nevada (152) and concluded that these ranges owed their present relief to relatively recent faulting. In later papers (153, 154) he proposed a late Pliocene or post-Pliocene age for the beginning of faulting and described various features of the fault scarps and of the fault blocks themselves.

Ferguson (63, 64) meanwhile found that over a large area in west-central Nevada block faulting was initiated before late Miocene time and recognized at least four stages of faulting, only the last two of which are reflected in the present topography. This was the first definite statement that the block faults were not all essentially contemporaneous. Davis (47) at about the same time implied that differences in the dates of faulting were the primary factor in the notably different physiographic stages shown by various ranges. In the same paper Davis accepted McGee's suggestion (163) that the fault planes were curved surfaces that flattened downward, and he postulated the idea that the slope (30°-40°) of the facets of the frontal scarps was approximately that of the deeper portions of fault planes that were nearly vertical where they intersected the pre-fault surface.

Since 1928 there have been several reports on detailed work in various parts of the Great Basin which have shed considerable light on different features of the block faulting. A posthumous paper by Gilbert (80) presented evidence, chiefly physiographic, indicative of normal faulting along the Wasatch and House Ranges of Utah and in the Klamath Lake region of Oregon. Russell (210) and Fuller and Waters (72) described the faulting in the Tertiary volcanic region of southern Oregon and northeastern California, both papers showing clearly that there was no basis for the conclusion reached by Smith (218) that the faults in this region were reverse. Gilluly (81), on the basis of work in central Utah, found that the dips of the faults were steeper than had been assumed by Davis and Gilbert and that they were formed at different times, not only throughout the Great Basin but in individual ranges. He considered that the faults were formed between Oligocene and late Pliocene time and that isostasy was inadequate to account for the observed displacements. Longwell (148) found that the early Pliocene (?) block faults in the Boulder Dam region probably flattened downward.

Dissent from the Gilbert hypothesis has, however, continued. Both Willis (256) and Lawson (136) have suggested that the east front of the Sierra, commonly considered the most westerly of the block faults, is rather the site of a steep thrust fault, but neither author has attempted to extend this explanation to the many other ranges in the Great Basin. Bucher (29) classifies the Great Basin region as one of his "fracture belts of low mobility" and believes that the fault pattern was developed as a result of regional tension, which preceded the uplift of individual ranges during a period of compression. Blackwelder (17) revived the Spurr concept that the intermontane valleys have been formed by erosion, but with the important modifications (16) that such eroded valleys were cut in weak rocks and that some of the boundaries between the valleys and the adjacent ranges, which are made up of more resistant rocks, may be old faults; Blackwelder terms such exhumed scarps "fault-line scarps."

The preceding review, though necessarily incomplete, reveals the three main explanations that have been advanced to account for the present topographic relief in the Great Basin. These are:

1. The ranges and valleys are limited by normal faults that are due to tensional forces.
2. They are limited by reverse faults, or by superficial normal faults caused by regional compression.
3. The valleys have been formed by erosion.

In addition some of the observers have postulated a combination of these explanations, Bucher favoring 1 and 2; Blackwelder, 1 and 3; Keyes, in part at least, 2 and 3. In the following pages the available data regarding the block faulting are summarized.

EVIDENCE INDICATIVE OF FAULTING

Four types of evidence have been advanced to prove that the individual ranges in the Great Basin are bordered by block faults—physiographic evidence, stratigraphic evidence, exposure of a fault plane, and presence of recent fault scarps along the range fronts. As the boundary between mountain and valley blocks is commonly concealed by the gravel accumulating in one or more closed basins, the second and third types of evidence are rarely found; for most places physiographic evidence has been called upon to determine the existence of a fault block.

Gilbert's original statement of the block-fault hypothesis was based almost entirely on physiographic evidence. In particular he emphasized that if the front of a mountain range is linear and straight and cuts indiscriminately across the rock structure, it must be limited by a fault. Many other physiographic features of the ranges have since been cited as evidence of faults, chiefly by Davis (44, 45) and Louderback (151). These include the abrupt rise of the ranges from waste-filled valleys; steep, narrow V-shaped ravines, which open abruptly onto the gravel fans of the valleys and flatten in grade in the central part of the range; triangular facets alined along the mountain front on inter-stream areas; absence of branches of the major valleys cutting through the ranges; mature topography or a thin capping of volcanic rocks on summits or back slopes of ranges; landslides along the range fronts; hanging valleys on range fronts (119); lowest point in adjoining valley close to scarp along the range front (130).

Blackwelder (16) has reviewed these and other proposed criteria and has pointed out that several of them are equally applicable to exhumed or "fault-line" scarps. He regards the following features as positive evidence of true fault scarps: (1) Lack of correlation between rock resistance and surface form; (2) rift features; (3) alluvial deposits on the downthrown block thickest near the fault line; (4) lake or sink close to the scarp base; (5) alluvial fans abnormally small; (6) frequent severe earthquake; (7) displacement of an older topographic surface; (8) dislocation of Recent or late Pleistocene formations; (9) basal scarplets; (10) warped terraces in the canyons; and (11) the fault plane identified as forming part of the scarp face. Some of these features are of relatively little value because of their infrequent occurrence (No. 10, for example) or because of the absence of adequate information (No. 3); and others, such as item 6, are of questionable dependability. Other observers would probably regard additional features as equally valid evidence.

Except for a few of the more carefully studied ranges in the Great Basin, one or more of the criteria above listed have been relied upon by many as indicating a fault-block origin for the Basin Ranges. When critically used (as in 45), there is little doubt that physiographic evidence alone is adequate and diagnostic. In many places, however, the use of evidence of this type has resulted in a failure to distinguish between fault scarps and fault-line scarps; and there has even been a tendency to consider that any elevated block with a more or less linear trend is necessarily a fault block.

Stratigraphic evidence of faulting along the borders of ranges has been recognized at relatively few places because valley fill commonly conceals the downthrown block. Locally, however, the downthrown blocks are exposed, either near the ends of en échelon border faults or by local stripping of the valley fill as a result of the capture of one basin by another or of cutting by such through drainage channels as the Colorado River. Eardley (57) suggests that hard-rock exposures in the valley block may also represent as yet unburied summits on a

prefaulting submature topography. Stratigraphic proof of faulting has been found in the Humboldt Lake and adjoining ranges, Nevada (151); the Lake Tahoe region, California-Nevada (203); the Oquirrh Range, Utah (81); the Warner Range, Calif. (210); the Wasatch Range, Utah (58); the Deep Creek Range, Utah (187); the Boulder Dam region, Nevada (148); and the Comstock Lode, Nev. (74). In other places faulting along the range front has been inferred from the presence of parallel step faults within the range (72).

In a few places Spurr (224) and Westgate (254) have found no evidence of faulting at the contact between the rocks that form the ridges and the Tertiary sedimentary beds that underlie the valleys. Ferguson and Cathcart (68), however, have interpreted similar occurrences in central Nevada as the result of sedimentation in the downthrown block, which overlapped the outcrop of the fault.

Several observers have described exposures of the faults bordering the ranges. These have commonly been made accessible by artificial excavations, but in a few places they have been revealed by erosion. The Wasatch fault has been located by Pack (191) and Eardley (58), several faults along the west edge of the Oquirrh Range have been located by Gilluly (81), several Pliocene faults in southern Nevada have been located by Longwell (148), and additional faults in central Nevada have been located by Ferguson (67). In the region studied by Longwell a considerable vertical extent of the fault was revealed, and here at least the dip of the fault steepened upward; at the other localities fairly steep valleyward dips prevailed, ranging from 50° to 72°.

The close correlation between small scarps formed by recent faulting—called "piedmont" scarps by Gilbert (80) or "fan" scarps by Longwell (146)—and the scarps bordering the Basin Ranges was first pointed out by Russell (207), in 1884, and since that time these recent scarps have been commonly considered to indicate the presence of persistent faults. Many of them have been recognized throughout the Great Basin—those in the Lahontan and Bonneville Basins by Russell (208) and Gilbert (79, 80), those along the Sierra Nevada by Hobbs (113), Lawson (134), and Knopf (130); those in central Nevada by Jones (121), Page (193), Gianella and Callaghan (75, 76), those in southern Nevada by Longwell (146), and those in southern Oregon and northeastern California by I. C. Russell (207) and R. J. Russell (210). In some places these scarps have clearly been developed along older border faults and extend along the contact between the hard rocks of the range and the gravel of the valley. Commonly, however, they are found in the gravel some distance from the range front, and tend to be more irregular than the front in plan. Although most of the recent scarps lie at or close to range fronts, some are also found in the intervening valleys (75, 76) and within the mountain ranges (37). Many of them are accompanied by hot springs (207) or are coincident with volcanic cones (130), and some observers therefore consider that hot springs and volcanic cones are also suggestive evidence of block faulting.

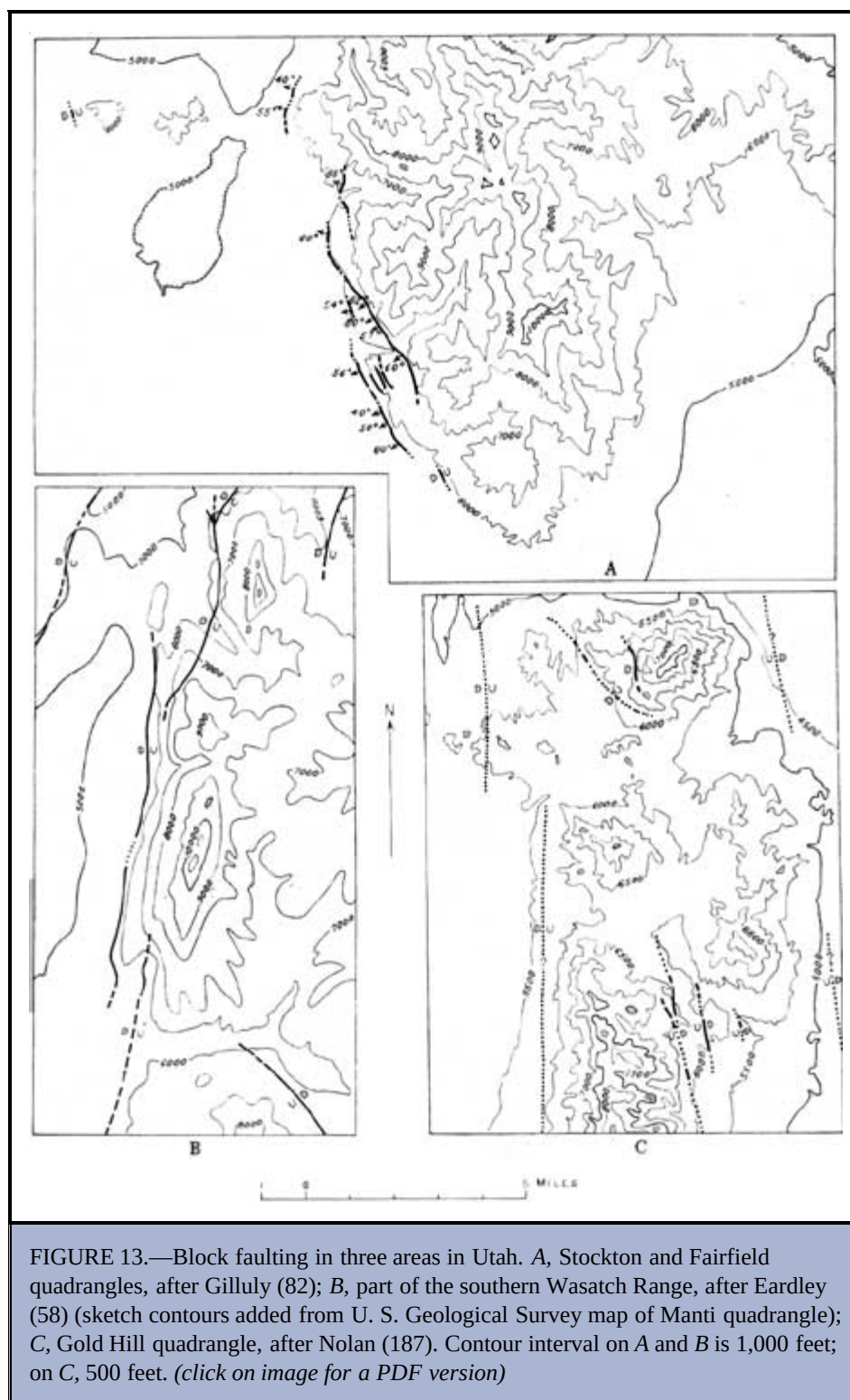
The several types of evidence presented by many geologists for such widely separated regions in the Great Basin appear to warrant the statement that most if not all of the major ranges in the province are bounded by faults on either one or both sides.

NATURE OF THE BLOCK FAULTS

Several interpretations of the character of the movement along the Basin Range faults have been offered. Some observers have considered that reverse faults are dominant, but the general opinion has favored normal faults. Adherents to the idea of normal faults differ among themselves as to the active block: some favor absolute elevation of the ranges; others postulate depression of the intermontane valleys; and still others believe that both blocks have been active. In part these differences of opinion appear to reflect differences in character of the faults, but they also arise from the scarcity of detailed studies along the

strikes of individual faults. Several discussions of the process are based largely on the assumption that a single fault found in a section normal to the range is persistent throughout the length of the range front.

The three areas illustrated in figure 13 have been mapped in detail and have yielded considerable definite information regarding the nature of the faults and the movement along them. Although this information largely confirms previous beliefs regarding the faults, in some respects it is quite different.



Some of the conclusions resulting from these detailed studies may be summarized as follows:

The range front is bordered by a fault zone in which individual faults may be relatively short, and both en échelon relations and step or distributive faults are commonly found within this zone. Although marked changes in strike may be present along individual faults, it would appear that many of the major offsets and irregularities along a range front are the result of such en échelon faulting. Movement along individual faults is normal, and the faults dip at moderate to steep angles (50° to 80°) toward the valley or relatively depressed side. The movement has not been one of simple elevation or depression, however, as both walls of the block have been active, as is shown by the tilting they have undergone. There is a suggestion that the amount or degree of tilting has reached a maximum close to the fault. Some of the faults clearly have been localized by pre-existent structural features, especially older faults; and recurrent movements along the faults appear to be fairly common. Not all the faults are of the same age, and even in a single range the maximum movement along an individual fault may have been much earlier or later than that on a neighboring fault.

It is of course questionable whether these conclusions may be applied widely. The three districts illustrated in figure 13 are representative of much of the Utah portion of the Great Basin, but observations by Geological Survey parties in several parts of Nevada indicate that many of these conclusions are valid in that region also. On the other hand, there is a region in southern California and southern Nevada (10) where they do not apply. This exceptional area, however, appears to have been subjected to deformation unlike that affecting the rest of the province. (See p. 186.)

The observed dips of the faults are uniformly greater than the dips of the facets along the range fronts. Davis (47) and Gilbert (80) interpreted these slopes as being the same as the dips of the fault planes and therefore considered that there had been relatively little erosion of the scarps. However, a considerable prism of rock must have been eroded to account for the difference in dips that is now known to exist. Pack (191) has noted this discordance along the Wasatch Range and has suggested that the observed relations indicate that movement along the fault plane was intermittent and continued over a long time and that in general erosion of the scarp facets to their slopes of 15° to 35° was concomitant with the successive uplifts.

Superficially, the dips of the faults toward the valleys and the local stratigraphic evidence that the valley blocks have moved down with respect to the mountain blocks imply that the faulting was tensional; however, the tilting of both the valley and the mountain blocks and the clear evidence in places that the mountain block has moved upward make this interpretation somewhat less attractive. If the fault blocks that make up the ridges and valleys of the province are considered independently of the surrounding regions as a group of prisms free to move in an inert medium, it may be assumed that fracturing and concomitant tilting may have occurred solely as a result of tensional forces. As the fault blocks are an integral part of the earth's crust, however, tilting such as that whose effects have been observed in the region appears impossible of accomplishment unless accompanied by either plastic flow or widespread shearing at relatively slight depths. It is difficult, therefore, to believe that either fracturing or tilting could have developed as a result of simple tension. Similarly, elevation of the mountain block cannot have been accomplished by regional tensional forces.

The assumed elongation in the crust as a result of the block faulting is likewise not necessarily indicative of tension. The data available are not adequate to prove that elongation in the crust has occurred in the region. The suggestion of Davis (47) that the fault planes are curved and flatten in depth, if borne out by future work, would indicate that the tilting could have been caused by rotation of the blocks on such curved planes, and it is possible that the shortening due to tilting may be of greater magnitude than the extension resulting from normal faulting (206a, p. 768). Simple experiments made with scissors and cards, for example, indicate that shortening of the crust may be a result of normal faulting if the radius of curvature of the fault plane is less than the width of the tilted block.

The present state of our knowledge, however, appears only to warrant the statement that simple tensional forces alone are not adequate to explain the block faults observed in the Great Basin province, although it is possible that the faults may reflect surficial tension, dependent upon and caused by a deeper and dominant tangential pressure. Further discussion of this problem may be found on pages 181-186.

AGE OF THE BLOCK FAULTING

The period during which the block faulting occurred is difficult to establish with certainty because of the scarcity of well-dated Tertiary and Quaternary formations in the province. The problem is further complicated by the failure of many authors to distinguish between the initiation of block faulting as a structural type and the activity along individual faults that have strongly affected the present topography. An additional source of confusion is the belief held by some that most, if not all, of the present scarps along range fronts are not true fault scarps but are fault-line scarps.

It seems clear, however, that the faulting cannot be assigned to a single relatively short period. Aside from the known intermittent character of the movement along many of the faults, Davis (45) long ago recognized different stages in physiographic development shown by adjacent ranges. Later he discussed this subject again (47) and implied that the major cause of the differences lay in the different dates of the faulting. Although in places there may be some question as to the reliability of physiographic criteria as an indication of the time of faulting, owing to the possibility that step or distributive faulting may have prevented the development of linear scarps (118, 130, pp. 78-79) or to the probability that rocks of greatly different resistance to erosion will produce different topographic forms, several observers agree that the present topography of the ranges shows conclusively that the block faulting has not been contemporaneous throughout the province (for example, 81, pp. 1119-1120; 68, p. 378).

Ferguson (64) and Ferguson and Cathcart (68), in addition to presenting physiographic evidence that the block faulting occurred at different times, found that similar faults, though without present topographic expression, both preceded and followed the deposition of sediments belonging to the Esmeralda formation (late Miocene and early Pliocene). The conclusion that these earlier faults were of the same character as the later block faults is based on the fact that the Esmeralda, adjacent to the pre-Esmeralda faults, is composed of material similar to that now being deposited in the fans along range-front scarps, and further, that at least some of the topographically expressed faults have followed the lines of these early faults (67). Westgate (254, p. 44) has also found evidence for block faulting of pre-Pliocene (?) age in southeastern Nevada, and Longwell (148, pp. 1456-1470) has described block faulting in the Boulder Dam region that preceded, accompanied, and followed the deposition of his Muddy Creek formation, of questionable Pliocene age. Gianella (74, pp. 85-87), similarly, has distinguished two major epochs of movement at the Comstock Lode. Finally, Stock and Bode (235, p. 578) consider that their Titus Canyon formation of the Death Valley region, which is of lower Oligocene age, accumulated under topographic conditions similar to those existing at present in the Great Basin and imply that block faulting may well have been active at that time.

At several other localities, notably in the Oquirrh Range, Utah (81, pp. 1116-1118), faults that now have topographic expression are known to have been active at an earlier time, inasmuch as they are premineral, but for at least some of these it is uncertain whether this earlier movement was part of the province-wide block faulting or was related to local igneous phenomena. The evidence provided by the Tertiary sedimentary rocks, however, appears to be conclusive that the block-faulting movements started early in the Tertiary period, probably in late Eocene or early Oligocene time, and were widespread through the later Miocene and

early Pliocene.

Louderback (153) has placed the period of topographically expressed faulting as late Pliocene or post-Pliocene and considers that the greater part of the movement was completed before late Pleistocene time. The wide range in physiographic development of the ranges makes it improbable that the bulk of the faulting throughout the province occurred at any one time, and Pack (191, pp. 406-409) believes that movement along the Wasatch fault zone has proceeded intermittently up to the present time. Gilluly (82) also considers that faulting along the Oquirrh Range has continued to recent times.

The validity of this conclusion as to relatively recent faulting has been questioned by Blackwelder (17), largely because of the fact that middle or late Tertiary sedimentary beds are exposed in many of the intermontane valleys, and little material that can be attributed to erosion following late Pliocene or Pleistocene faulting can be found. He considers that the present ranges are the result of erosion of the soft and nonresistant Tertiary beds. Longwell (148) has provided clear evidence that exhumation of old fault scarps has taken place along the Colorado River, and the process may have gone on in other parts of the province as a result of the capture of one basin by another. The determination of its extent must await more detailed topographic and geologic studies in the valleys; but the major displacements of basalt and other lavas known to be younger than the late Tertiary sedimentary rocks, together with the numerous recent scarps, prove that a fair proportion of the range-front scarps are not the result of exhumation. Blackwelder (16) has suggested either through-flowing drainage to the sea, or wholesale reduction of fluvial gravel to dust and its subsequent removal by winds, as alternative methods by which the vast amounts of debris resulting from widespread exhumation could be removed. Neither suggestion can at present be proved, though the apparent absence of Pliocene sedimentary material over much of the province (106) and the existence of considerable areas of subdued or postmature topography near the crests of many ranges (67) have been proposed as indicative of exterior drainage during Pliocene time.

The best conclusion that may be reached from present information therefore is that block faulting as a process probably began in early Oligocene time and has been more or less continuous ever since. Topographically expressed faults, however, probably date back only to late Pliocene or early Pleistocene time, though there may have been still earlier movement along such faults. There are two possible qualifications to the conclusion of intermittently continuous faulting. One of these results from the apparent widespread distribution of upper Miocene sedimentary beds, many of which were deposited in closed basins, for this suggests that block faulting with concomitant formation of such basins was especially widespread before and during late Miocene time. Increasing knowledge of the meager faunas present in these sedimentary beds and new finds in beds hitherto regarded as unfossiliferous seem, however, to weaken this suggestion. The second qualification is the apparent greater age of the faulting in the southern portion of the province, chiefly southeastern California and southwestern Arizona. Gilluly (83, p. 327) is one of the few who have mentioned this feature in print, but most workers in the province have recognized the notably more advanced physiographic stage of development shown by the southern mountains. Rock plains or pediments surrounding the ranges are widely distributed in this region, and their origin has been the subject of a considerable literature (summarized in 83).

ORIGIN OF THE BLOCK FAULTING

The ultimate cause of the block faulting in the Great Basin has been the subject of speculation for many years by numerous American geologists. Doubtless it will continue to be debated until the far distant time when detailed geologic mapping of the whole province has been completed.

Most of the theories advanced have been affected by the beliefs of their authors as to the nature of the faulting—whether it is normal or reverse. They fall into three general groups—(1) theories postulating simple tensional stress, (2) those postulating simple compressive stress, and (3) those requiring a combination of tensional and compressive forces, which either acted at different times or comprised the simultaneous action of a deep-seated regional compressive force and superficial local tension.

Leconte's name is commonly associated with the tensional theory (137), although his theory is based on the possibility of a sort of isostatic adjustment (either up or down) along more or less parallel fissures that developed as a result of an arching of the earth's crust. The arching he conceives to have been caused by "intumescence of the subcrustal liquid." Ransome (197) and Butler (32) adopted modified versions of Leconte's theory; they believed it was unnecessary to postulate a preliminary arching, but considered that the block faulting resulted from a deep foundering of the earth's crust, during which the region was depressed with reference to the adjoining provinces. Somewhat similar is Willis' suggestion (256), that the block faulting has resulted from expansion in the roof of a magma basin underlying the Great Basin; a concomitant effect would be compression in the bordering regions of the Coast Ranges and the Rocky Mountains.

There are relatively few advocates of a strictly compressional origin for the block faults throughout the province; tangential compression, presumably of the same nature as that which caused the earlier folding, is considered by Baker (10) to have been the activating stress. Other geologists, however, have postulated thrust faults bordering individual ranges and possibly would extend this interpretation over the whole province. The east front of the Sierra Nevada, for example, has been interpreted as a thrust by several geologists, most recently by Lawson (136). A modification of the compression theories is that presented by Gianella and Callaghan (76) as a result of their study of some recent rifts showing horizontal movement. They suggest that "the underlying causes of movement in at least the western part of the Great Basin may be related to those in California and * * * horizontal movements must be considered in future studies of Basin Range structure."

The oldest of the theories in which both tensional and compressive forces are assumed is that of Gilbert (78, p. 62), in which the block faulting is considered a surficial, more or less tensional expression of deep folding. This theory has still many adherents. Gilluly (82, p. 88), for example, considers it favorably, as a result of his determination that purely isostatic adjustments are not adequate to account for the observed relative elevation of individual ranges. Other explanations on this order have been proposed by Russell, Davis, and Bucher. Russell's theory (207, p. 453) is similar in some respects to those of Willis, Butler, and Ransome; it stipulates that "if the elevation of the Cordillera system as a whole is the result of tangential strain, may we not consider the force as acting on the borders of the Great Basin, while the interior region subsided and was fractured *pari passu* as the rim was elevated." Davis' suggestion (46, pp. 93-94), which was probably not very seriously considered even by himself, correlated the block faults directly with major overthrusts—each fault having been formed as a result of tension back of the thrust in the boundary region between the moving block and the part of the crust not involved in the thrusting. Bucher (29, p. 346) has given the most recent explanation of the origin of the faulting. He believes that two independent processes are involved—an earlier fracturing resulting from regional tension and a later uplift of the present ridges by "orogenic stresses" along the older tensional fractures.

Correlation of the block faulting, which in many places at least was clearly of the normal type, with at least mild compressive forces is suggested by several features brought out by this review of the Basin and Range province. One of the most persuasive is the areal restriction of the block faults to the region of folded rocks. This is most evident along the

eastern border of the province in Utah, where the eastern limit of block faulting rather closely coincides with the western limit of the Plateau region. A similar correlation exists along the eastern border of the province in Arizona and New Mexico, and similar faults have been reported by Mansfield (156, p. 170) and Rubey (206) from the folded region in southeastern Idaho and western Wyoming, northeast of the region here considered. Along most of the western border the essentially undeformed Sierra Nevada batholith forms a somewhat different but nevertheless rigid and massive boundary, the dominantly northward-trending block faults of the Basin and Range province dying out southward as they penetrate into the northwestward-trending batholith. The intrusive mass thus limits the faulted region, though it does not determine the location or trend of individual faults. South of the Sierra Nevada the San Andreas rift appears to act as a comparable surface of discontinuity.

Also significant is the apparent necessity for some sort of plastic deformation to account for the fact that both mountain and valley blocks have been active during the faulting (p. 182). Uplift of the mountain block, together with plastic flow at depth, accords ill with a purely tensional origin for the faulting.

More tangible evidence of the connection between block faulting and compressive forces appears to be provided by the regions on both sides of the Garlock fault (p. 186). North of this transverse fault typical Basin and Range topography, presumably the result of block faulting, is magnificently displayed, but south of the fault the subdued topography shows clearly that there has been essentially no recent fracturing of this kind. The block south of the Garlock fault has, however, been moved eastward in relatively recent time both along the fault itself and along the thrust into which the fault probably changes, and the implication seems strong that the ultimate force causing the horizontal shift may well have been the same as that causing the block faulting.

Finally, there appears to be a suggestive connection in time between the block faulting and the preceding folding and thrusting. Thus, block faulting is believed to have been in progress in early Oligocene time (p. 183), and thrusting seems to have continued well into the Eocene epoch (p. 177), a relation that may be interpreted as sequential and implying continuity in action of the same causative forces.

If it is granted that these features indicate a causal connection between the block faulting and compressive forces, Gilbert's theory that the faults are surficial tensional features resulting from deep-seated folding appears best to fit the known or supposed relations. Moreover, it provides a basis for a rational explanation of the block faulting as an integral part of the diastrophism that started as a broad upwarping in late Paleozoic and early Mesozoic time and reached its climax in the major thrusts, folds, and transverse faults of later Mesozoic and early Tertiary time. The block faults thus represent the final and declining stages of this revolution.

At present it is not at all clear why the deep-seated folding postulated by Gilbert should be reflected surficially by faults and not, as in the Plateau province to the east, by broad warpings and asymmetric folds or monoclines (5). It may well be, however, that the difference is directly or indirectly the result of the prior deformation undergone by the rocks of the Basin and Range province—directly, by reason of the greater fracturing in the deformed rocks and the heterogeneity of adjacent rock masses, consequent upon extensive faulting, which made them incompetent to withstand surficial tension; or indirectly, because of the restriction of large masses of igneous rocks to such deformed areas.

A connection between the block faulting and igneous activity has long been considered, especially because of the possibility that large-scale extrusion of volcanic material would be accompanied by the extensive subsidence of individual blocks along faults. This simple

explanation is probably not tenable, however, not only because volcanic rocks are absent over considerable areas that now show faulted blocks, but also because of the local evidence of uplift of individual blocks and the province-wide correlation, noted above, of faulting and compressive forces. If we may accept the numerous and extensive exposures of igneous rocks in this province and the steep geothermal gradient that has been found in all the deeper mining districts of the province as evidences of the presence of a layer containing numerous magma reservoirs a relatively short distance below the present surface, mild compression of such a mobile zone into a series of gentle folds must have resulted in extensive fracturing and relative displacement of the fragments of the brittle and thin surface layer. Surface volcanism would thus be a result and not a cause of the fracturing.

It is difficult to choose between the alternate hypotheses of a heterogeneous fractured crust or a mobile magmatic subcrustal layer as the controlling factor in the block faulting. It so happens that both east and west of the province, as well as throughout the Mojave Desert region within the province, where block faulting is relatively minor, there was scant Tertiary volcanic activity and little reason for believing that the exposed surficial igneous rocks originated within the faulted areas. There is also ample evidence of an extensive platform of relatively homogeneous rigid rocks at or near the surface. Possibly these two factors are themselves manifestations of a single major influence, but such speculation is far beyond the scope of this paper.

FOLDING AND THRUSTING

Folding and thrusting of late Tertiary or Quaternary age appears to have been confined chiefly to southeastern California but may possibly have extended into southern Nevada. Baker (8) was one of the first to recognize folds in the later Tertiary sedimentary beds in this region: He also found that the beds were cut by steep reverse faults along the bases of the mountain areas; and his theory that the Basin Ranges were formed as a result of reverse faulting (10) is founded largely on this discovery.

Subsequent exploration in the Mojave Desert region of southern California and its bordering areas has disclosed many localities where disturbance of late Tertiary or Quaternary formations by folding and reverse faulting has occurred. It appears to be significant, however, that these phenomena are in most places rather closely associated, either in location or in trend, with two major fracture zones that bound the Mojave Desert on the north and the southwest. These zones are the Garlock fault and the San Andreas rift. This localization of the compressional features, together with the much greater maturity in topographic expression of the ranges in this area than of those in the larger region to the north, seriously weakens Baker's theory of origin for the province as a whole.

GARLOCK FAULT

The Garlock fault was first recognized and named by Hess (101) north of Randsburg, in northeastern Kern County, Calif. He described the prominent scarp with its local evidence of very recent movement and stated that the fault could be traced for many miles to both the east and west. Hulin (116) studied the fault in the same region as Hess, and his description emphasizes its rift character—nearly vertical dip, branching habit, and a very large horizontal component in its displacement, which he suggests may be 5 miles, with the south side moving east. Hulin also considered that activity along the fault had been in progress for a long time, possibly dating back to the Jurassic. A nearly horizontal thrust along which Mesozoic granitic rock has overridden the later Tertiary rocks is truncated at an acute angle by the rift.

Noble (180) traced the Garlock fault from its junction with the San Andreas rift near the west

corner of the Mojave Desert for a distance of 200 miles to the Avawatz Mountains, south of Death Valley. Throughout this distance its rift character is maintained, and the fault has many features in common with the better-known San Andreas rift. Noble considered that the fracture dates back to pre-Tertiary time, and he was the first to call attention to the significance of the fault as a boundary between the youthful and linear mountain ranges in the region to the north and the irregular, shapeless ranges to the south, which exhibit a "stage of erosion nearer the hypothetical end of the arid cycle."

Not much is known about the west end of the fault. It has not been recognized west of the San Andreas rift, against which it apparently terminates. Simpson (213) has mapped the Garlock fault less than 20 miles east of the junction, where it follows the east base of the Tehachapi Range. In this region the alluvium has been folded into a dome 5 miles long and has been steeply tilted near the fault, with dips of as much as 87°. Well logs suggest a vertical component of 4,000 feet in the movement of the fault.

The Garlock fault may be traced to the east along the north side of the Avawatz Mountains, Calif. It turns to the south along the east face of the mountains, and recent work has shown that here it has the relations of a reverse fault, with metamorphic rocks of probable pre-Cambrian age faulted against Tertiary beds (106). In the Ivanpah quadrangle, a few miles farther east, Hewett (103) has found remnants of a large horizontal thrust extending over an area of 30 square miles, along which pre-Cambrian and lower Paleozoic rocks have overridden late Tertiary (Miocene?) sedimentary beds. The eastward movement of the upper plate of the thrust is estimated as at least 10 miles and may be as much as 20 or 25 miles. The relations of this thrust to the southward-trending portion of the Garlock fault are not definitely known, but it seems probable that both must be the product of the same orogenic forces and may very well be two parts of a single fracture system.

The Garlock fault thus appears to be a major fault, probably of considerable antiquity, extending eastward from the San Andreas rift for some 200 miles; the late Tertiary movement along it is dominantly horizontal, with the south side moving eastward for a distance of several miles, possibly as much as 25 miles.

SAN ANDREAS RIFT

Only a small part of the known length of the San Andreas rift (best known for its part in the San Francisco earthquake of 1906) impinges upon the Basin and Range province, although the rift coincides with the southwestern border of the province from the Tehachapi Mountains, at the south end of the Sierra Nevada, southward nearly to the Mexican border (27). Noble (180, 182) has studied a section of this portion of the rift and has described it as a "fault mosaic of sliverlike blocks whose longer axes trend parallel with the strike of the main fault," and he considers that it has possibly been active from late Mesozoic up to Recent time. The earliest datable movement in the region near San Bernardino, Calif., is believed to be of late Pliocene or Pleistocene age.

The rift is regarded as a northwestward-trending, nearly vertical shear zone, along which the movement has been predominantly horizontal. In southern California the offset of topographic features indicates that the recent movement has resulted in a relative shift of the northeast side to the southeast, and some features of the stratigraphy suggests a similar movement amounting to 24 miles. The evidence as to the direction of the major movement is not wholly satisfactory, however, and both Noble (182) and Simpson (213) consider that the net displacement may include a northwest shift of the northeast side.

Both steep reverse faults and low-angle thrusts are found along the rift zone in the San Gabriel and San Bernardino Mountains and have been described by Noble, Simpson,

Woodford and Harriss (260) and by Hill (110). The low-angle thrusts, in particular, commonly have more easterly strikes than the rift itself, but they curve into the rift and are closely related to it in their areal distribution. They appear to be somewhat older than the latest horizontal movement along the rift, but, as they involve late Tertiary sedimentary beds, they appear to be of at least approximately the same age as the more recent periods of activity.

There are no detailed geologic maps of the region where the San Andreas and Garlock faults meet, but a recent geologic map of southern California (199) shows that the Garlock fault apparently ends at its junction with the San Andreas rift, for no comparable fracture has been recognized in the block on the southwest side of the San Andreas, which is in large part underlain by Cretaceous, Tertiary, and Quaternary sedimentary rocks. The later Tertiary and Quaternary movement along the Garlock fault therefore appears to have been confined to the Great Basin province, although the termination of the fault at the San Andreas rift suggests strongly that it must at an earlier time have extended farther west. There is, however, no indication of any old east-west structure on the southwest side of the San Andreas rift, northwest of the junction point—the direction in which the westerly extension of the Garlock should have been shifted, to judge from Noble's observations of the recent topographic offsets. Southeast of the junction, though, there is a pronounced easterly trend in the transverse ranges and in the Ventura Basin of sedimentation. This feature, in connection with Simpson's observations in the San Gabriel Range (213), may be indicative of an older episode of movement along the San Andreas rift in a direction opposite to that of the recent shifts.

OTHER AREAS

Late Tertiary folds or thrusts have been recognized at a few other localities more or less remote from either the Garlock fault or the San Andreas rift. The best known are in the Mojave Desert region and are grouped in a belt parallel to and about 20 miles south of the Garlock fault. At Calico, 10 miles northeast of Barstow, Baker (10) and Lindgren (140) found folded and locally overturned Tertiary sedimentary beds on the under side of an east-west fault that appears to dip beneath the hills to the north. North of Barstow similar Tertiary sedimentary beds of late Miocene age are warped into a syncline that trends east-west. Schaller (107) found a similar synclinal warp in the borate-bearing strata north of Kramer, 30 miles west of Barstow, and steep dips in other saliniferous strata are known at Bissell, still farther west, and at Afton, nearly 40 miles east of Calico. The alinement of these localities suggests relationship in origin—possibly a control by an old east-west shear zone. Pack (192), however, considered that the folding in the region was on a small scale and discontinuous and believed that it was only a minor structural feature.

Minor folds and reverse faults that are possibly of late Tertiary age have also been recognized at two localities in southern Nevada (186, 148), northeast of the east end of the Garlock fault, but their correlation with the California structural features is uncertain.

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MINERAL RESOURCES

The Great Basin region contains a large number of mineral deposits, concerning which there is a literature much too extensive to be adequately mentioned here, especially as the Cordilleran ore deposits have so recently been reviewed elsewhere (1). Summaries, with complete bibliographies, are already available for Utah (32, 24) and Nevada (139, 65, 178) and to a lesser extent for southeastern California (107).

By far the most productive deposits are those of the nonferrous metals, which in the last 75 years have yielded gold, silver, copper, lead, and zinc valued in all at more than \$3,500,000,000. There are several hundred mining districts containing ores of these metals scattered over the whole province, but by far the greater part of the vast output has come from a small number of districts. The Bingham or West Mountain district, in Utah, with a total production of more than \$1,000,000,000, is the largest of these (23, 24). It contains, in addition to its famous disseminated or "porphyry" copper deposits, large bodies of silver-lead-zinc ore that have replaced limestone beds. Another large, low-grade copper deposit occurs in the Robinson or Ely district, in east-central Nevada (219, 194), which has produced about \$325,000,000, chiefly in copper.

All the large lead-zinc or silver-lead-zinc deposits are replacement bodies in limestone and, like the large copper deposits, appear to be genetically related to small intrusive masses that approach quartz monzonite in composition. The best-known districts that have produced these ores and the respective values of their production are the Tintic district, Utah, more than \$350,000,000 (1542, 24); Eureka, Nev. (87, 43), about \$150,000,000; Pioche, Nev. (254), and the San Francisco district, Utah (31), each about \$40,000,000; Cottonwood, Utah (36), about \$35,000,000; Goodsprings, Nev. (1504), about \$25,000,000; and Cerro Gordo, Calif. (130), about \$15,000,000.

The gold and silver produced in the province has been derived in large part from epithermal "bonanza" deposits in Tertiary volcanic rocks, which are generally considered to be younger than the granular igneous rocks associated with the base-metal deposits. The Comstock district at Virginia City, Nev. (12, 120), with a production of about \$400,000,000; Tonopah, Nev. (188), with \$150,000,000; and Goldfield, Nev. (196), with nearly \$90,000,000, are the three most famous of these bonanza camps.

Of the minor nonferrous metals, arsenic occurs in considerable amounts at Manhattan, Nev. (63), and at Gold Hill, Utah (187), and there are several small quicksilver deposits. Small quantities of antimony have been mined in the Panamint Range, Calif.

Many iron-ore deposits are known in the province (107), but, with the exception of those at Iron Springs, Utah (138), they have not been productive as sources of metallic iron. Most of them are composed of magnetite and hematite and are localized at contacts of limestone and igneous rock, but brown iron ore has been mined for smelter flux at Tintic, Utah, and Battle Mountain and Pioche, Nev. The numerous tungsten deposits (102), on the other hand, have

been sporadically active, and those at Atolia, Calif. (116) and Mill City, Nev. (123), especially have yielded considerable amounts of ore. Among the other ferro-alloy metals (107), only manganese is present in quantities that appear to warrant hope of much future production. It has been mined mainly at Pioche.

The most serious deficiencies in the mineral resources of the province lie in the mineral fuels. Oil shales (259) and impure coals have been found in some of the Tertiary sedimentary rocks, but so far they have been unable to compete economically with the petroleum of southern California or the coal of eastern Utah.

Other nonmetallic products, however, are present in large quantities (107). They include especially such salines as kernite and other borate deposits, gypsum, and the various salts, including those of potassium, which occur in both the Tertiary sedimentary beds and in the many existent playas of the province. The Tertiary beds also contain accumulations of clay, diatomite, and volcanic ash, and the older rocks have provided large quantities of limestone and dolomite, cement rock, and silica. Especially noteworthy are the deposits of dumortierite that are mined at Rochester, Nev. (131), for use in the manufacture of spark plugs.

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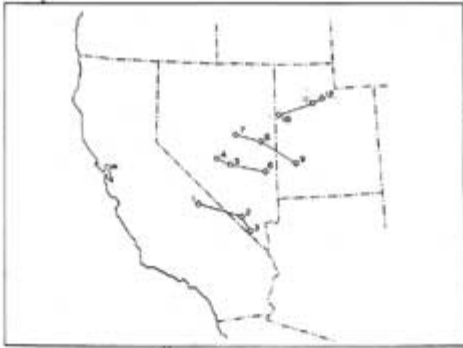
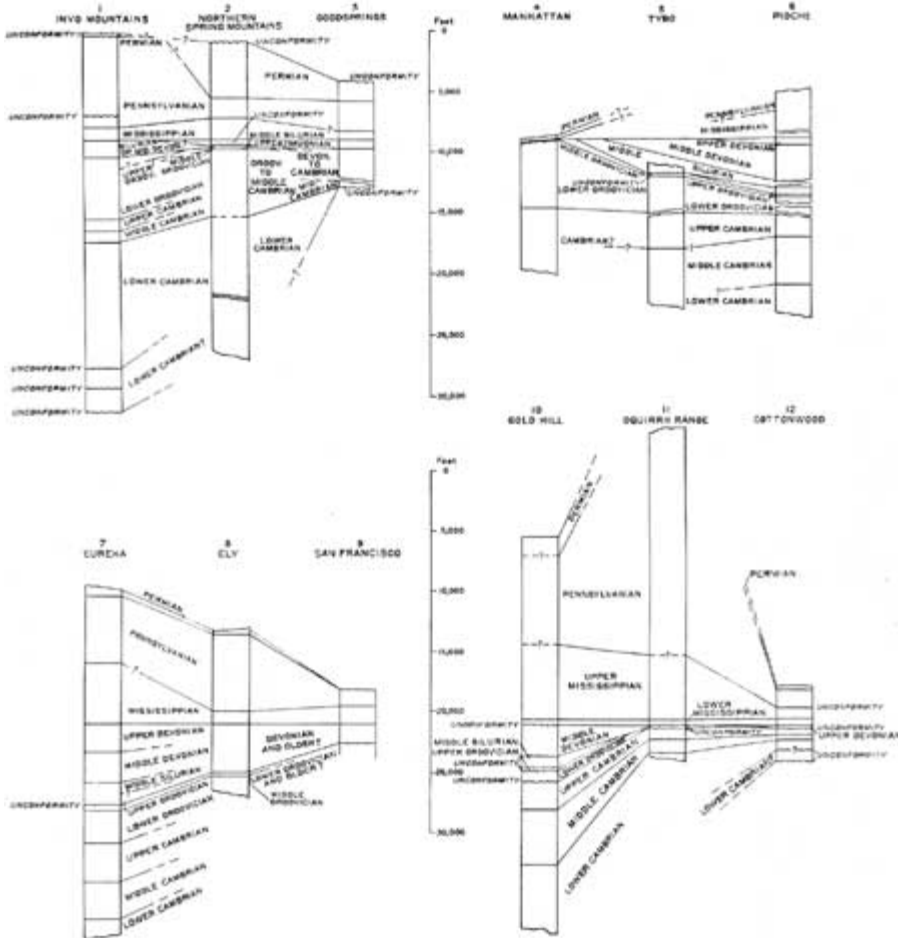
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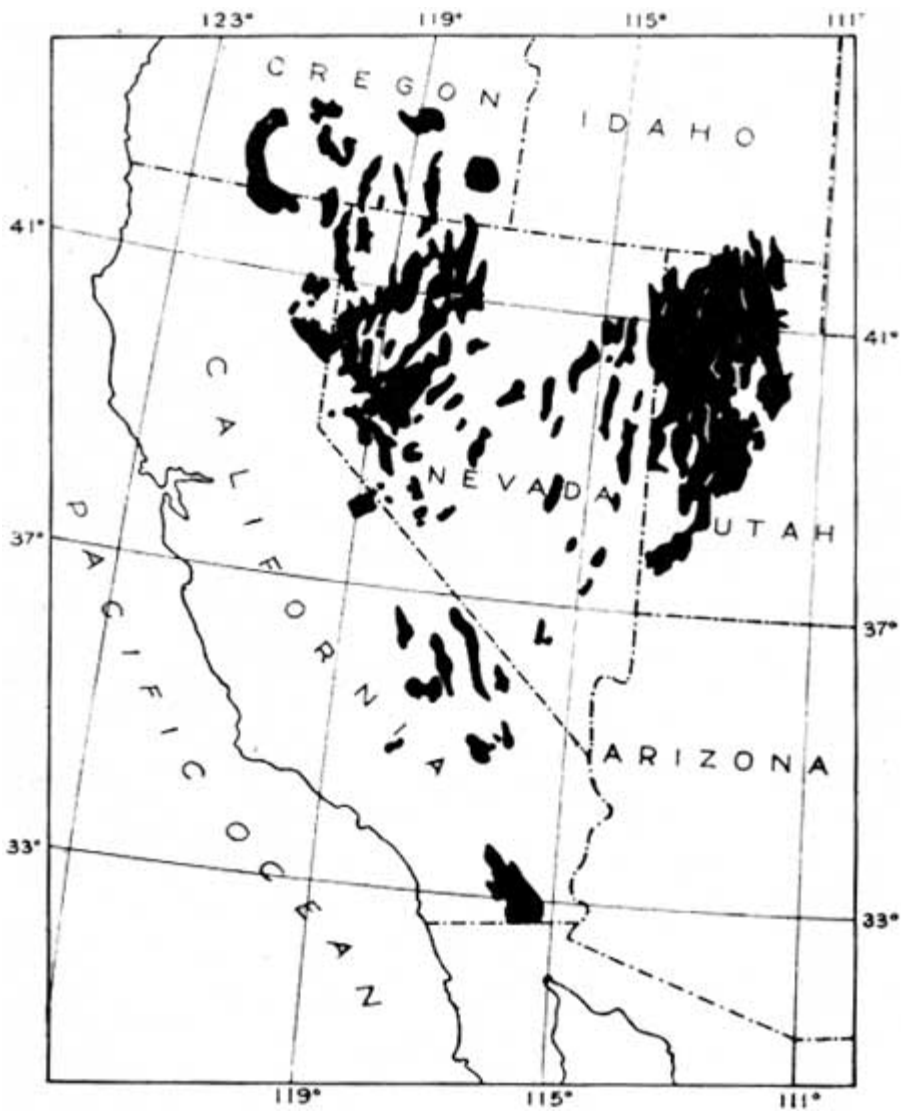
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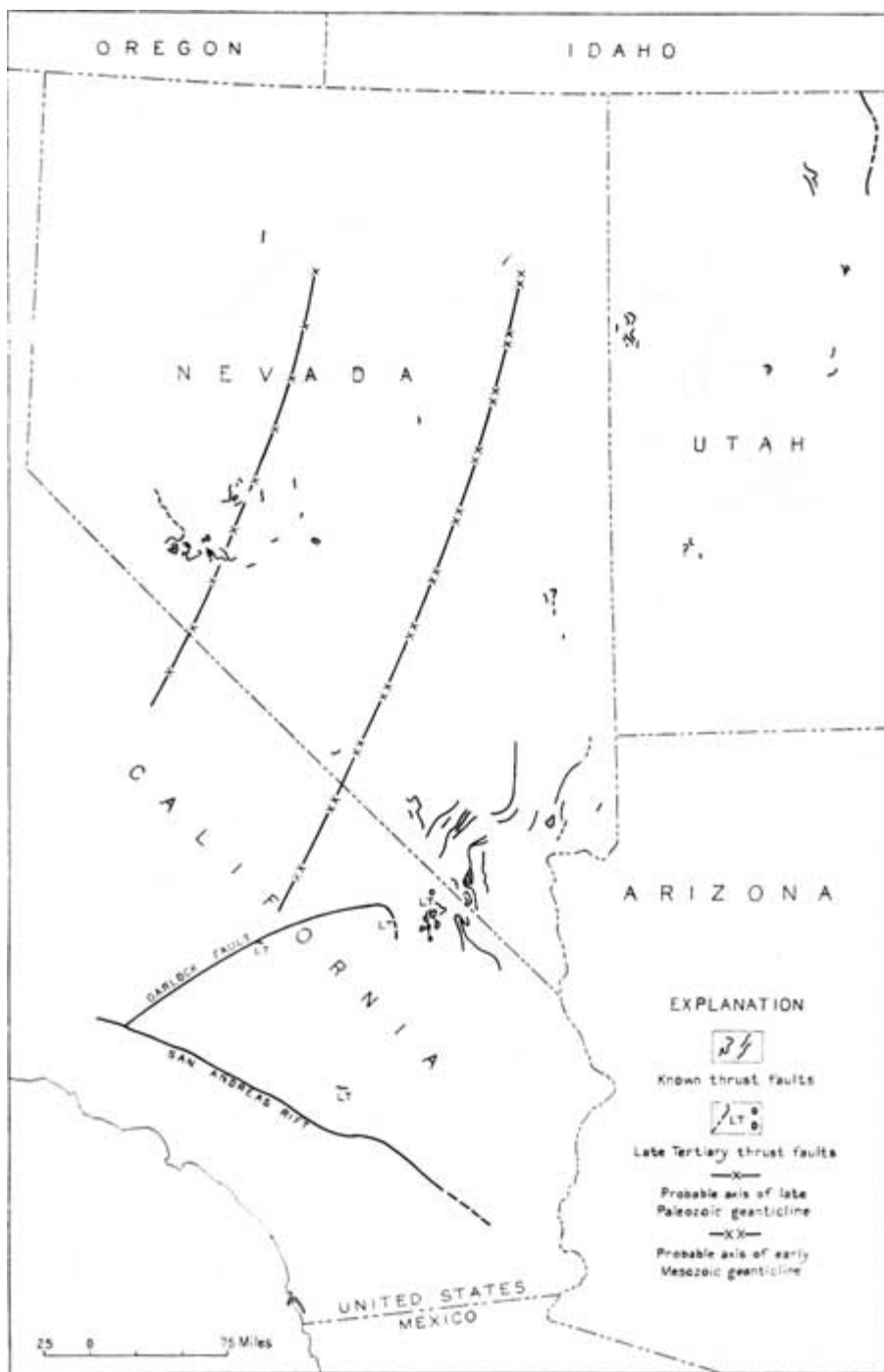
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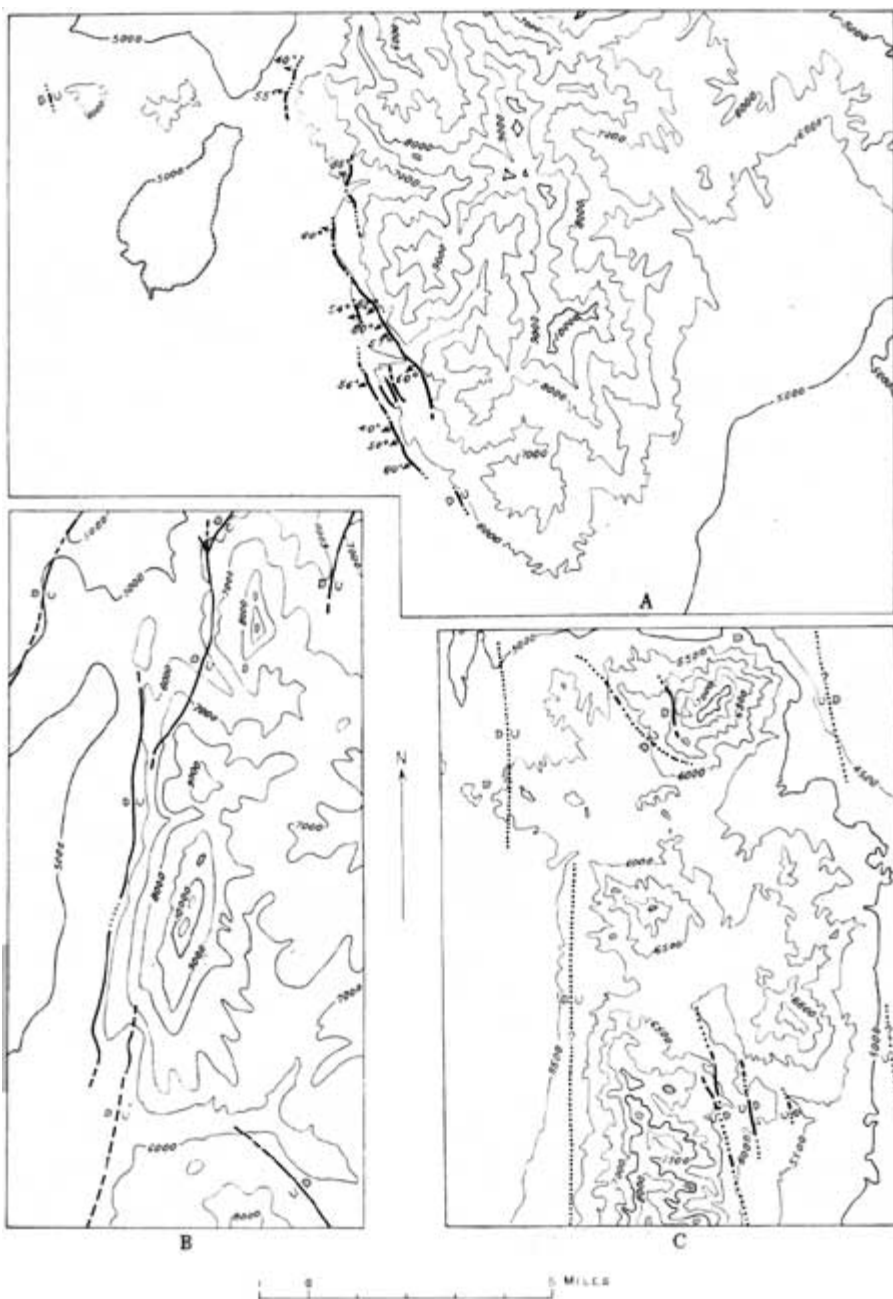
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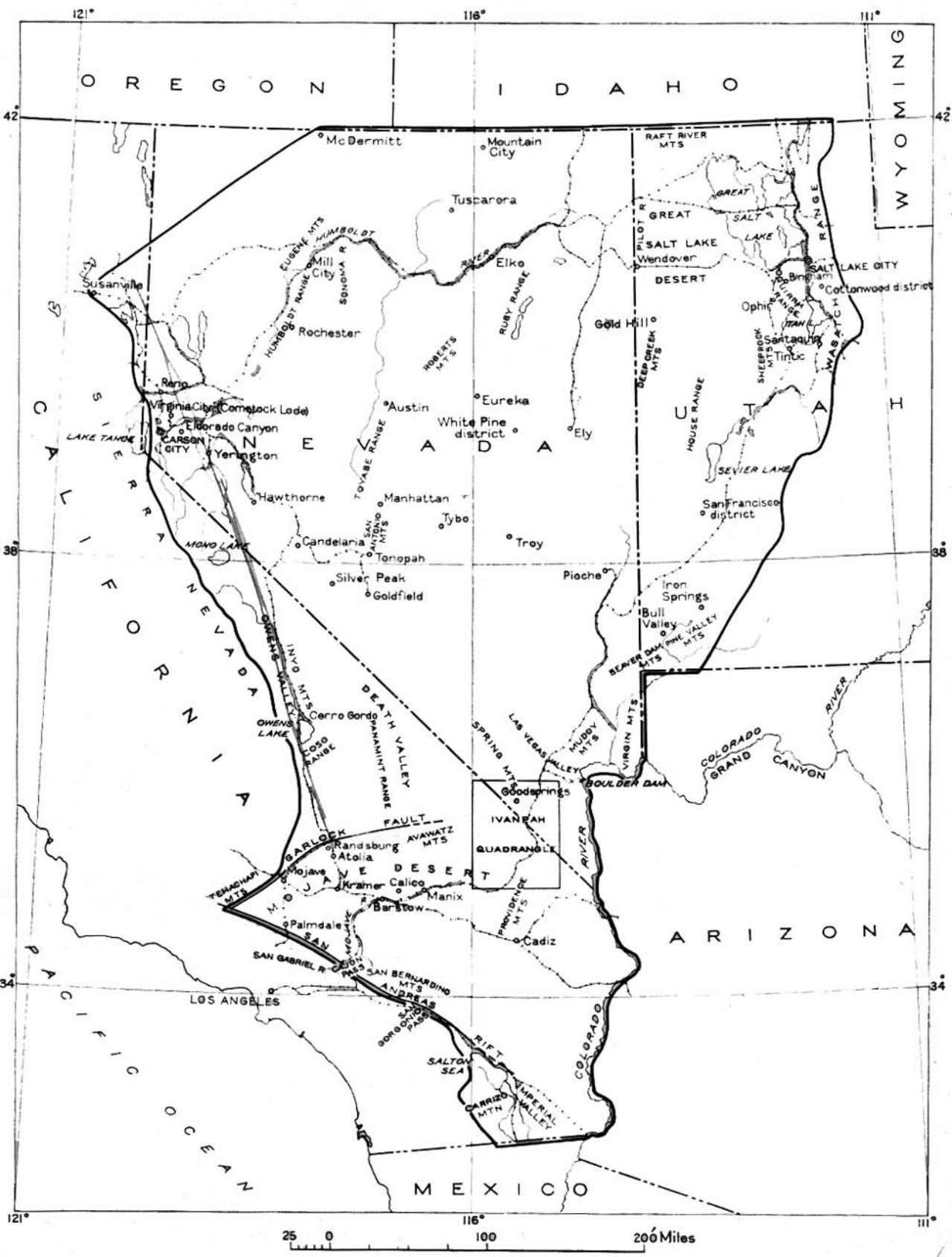


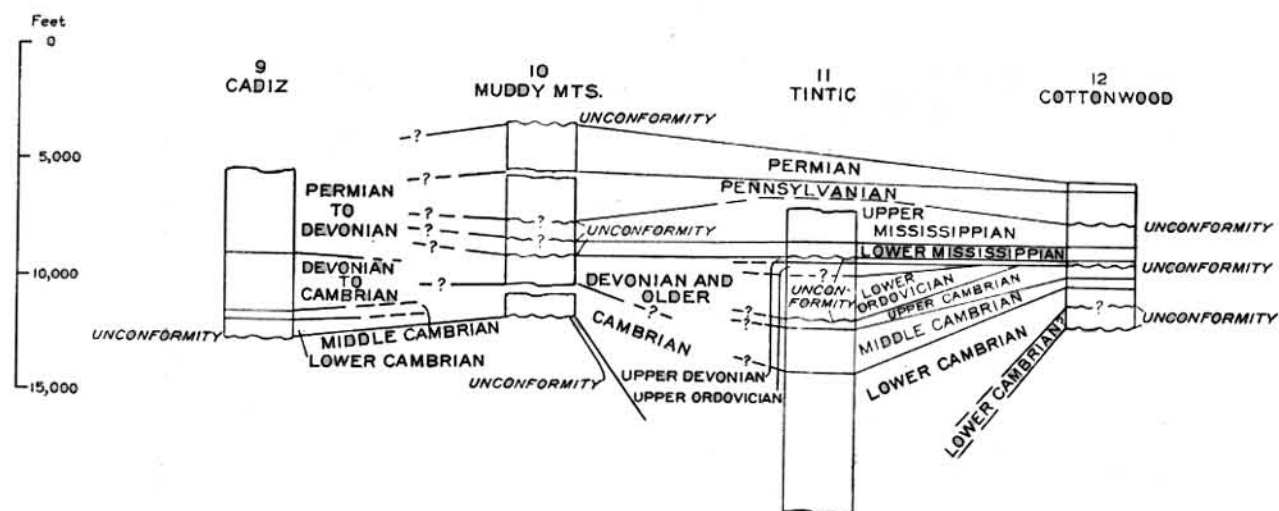
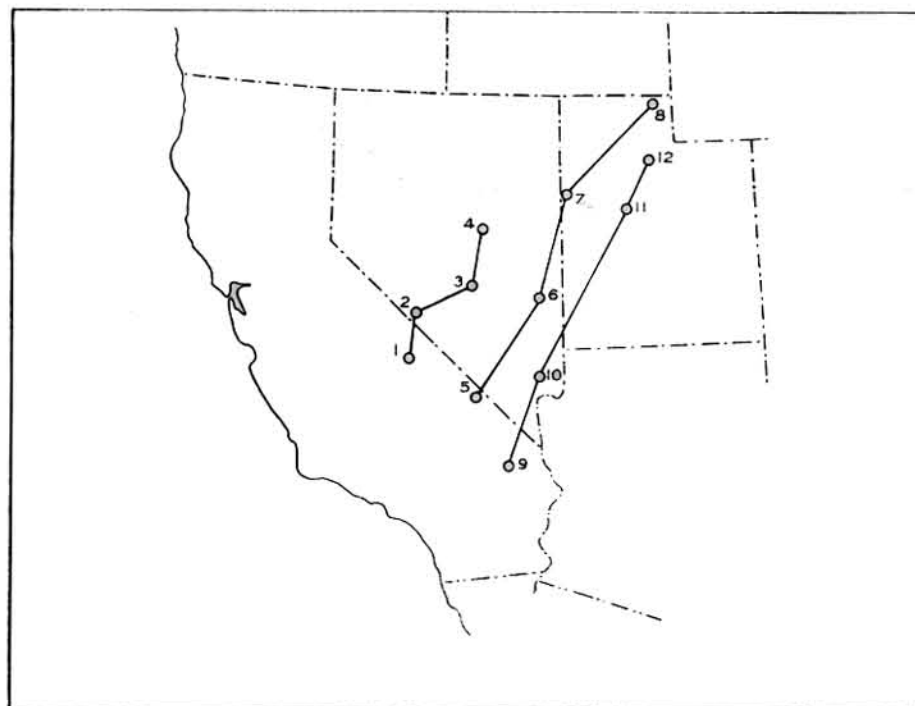
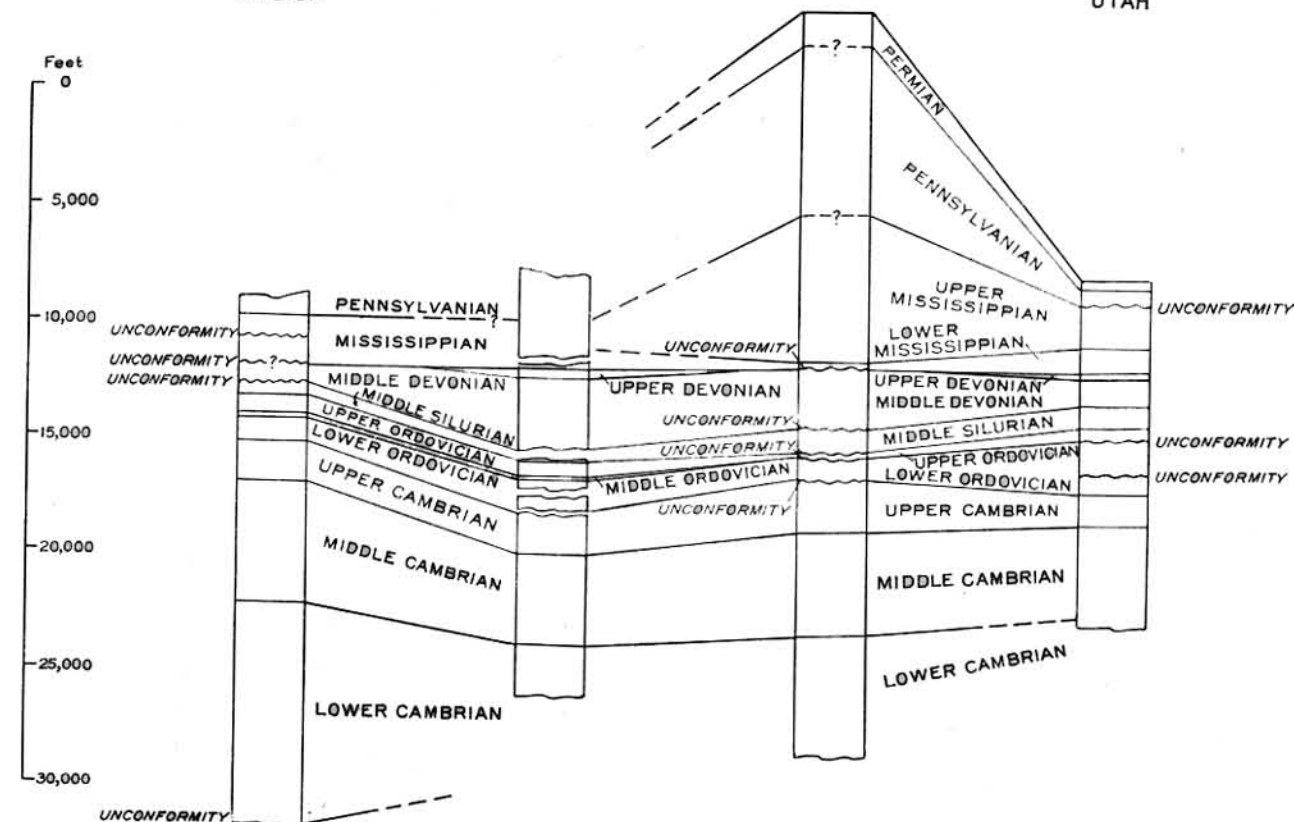
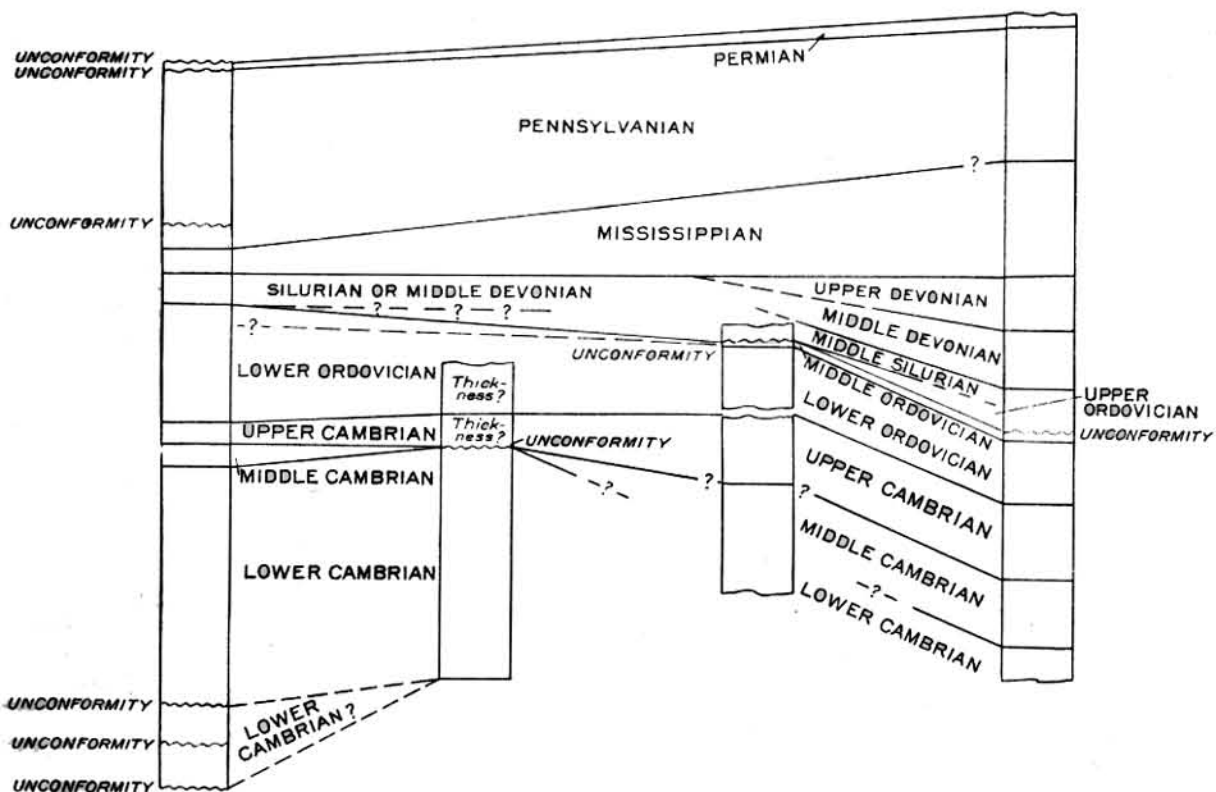


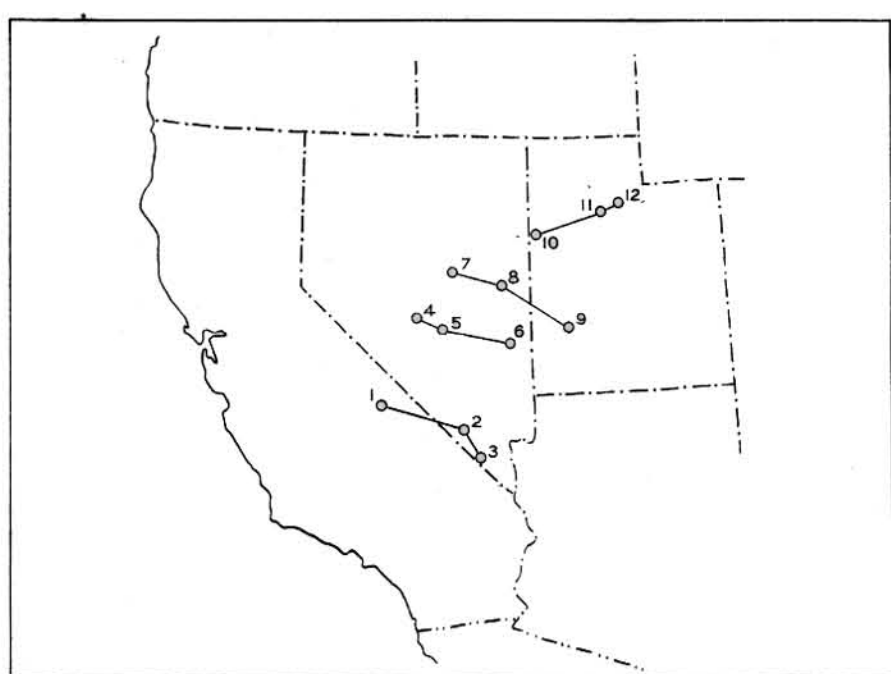
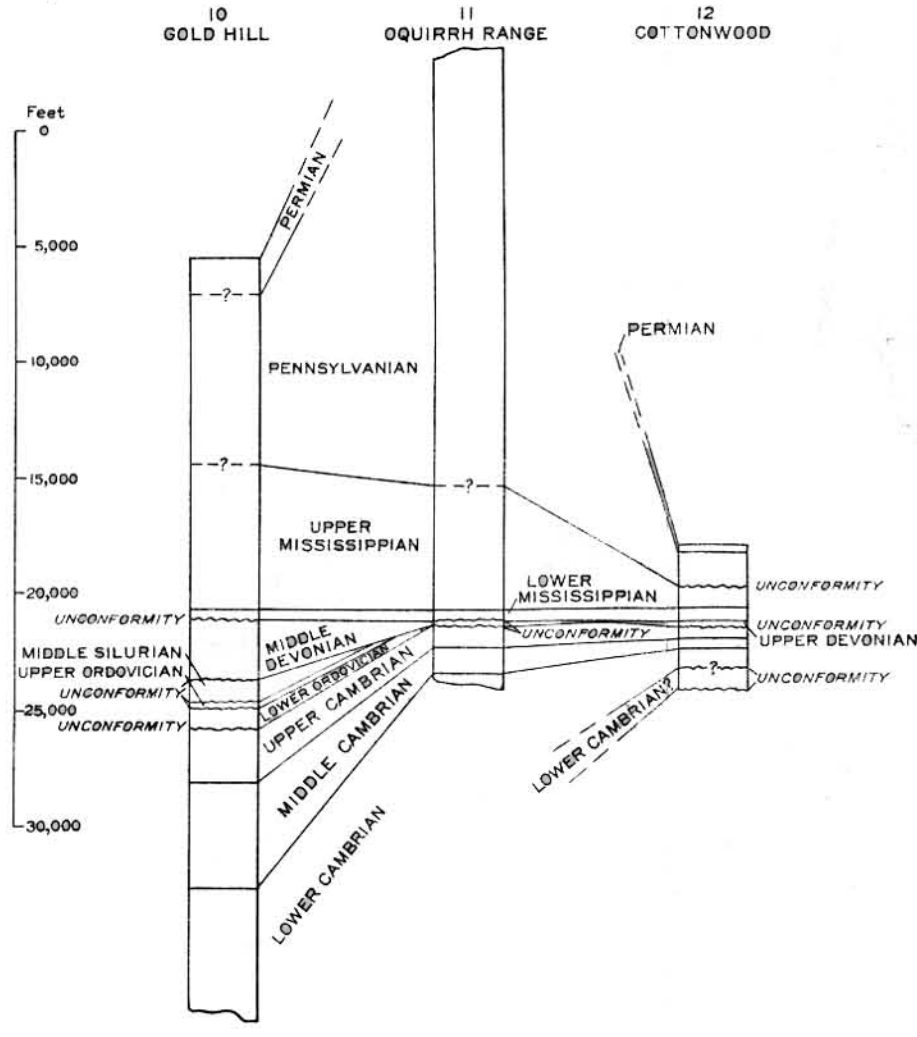
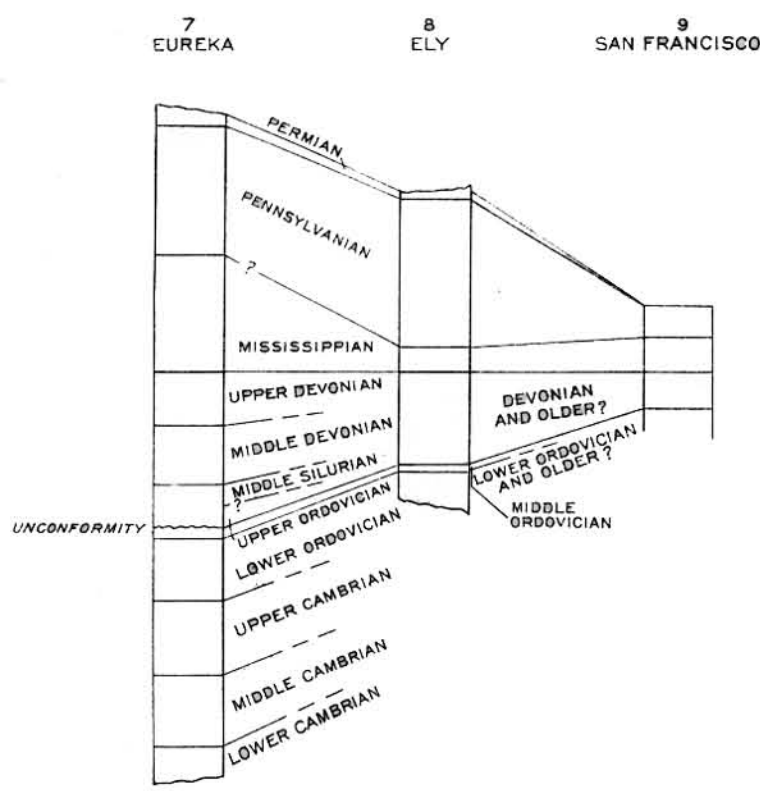
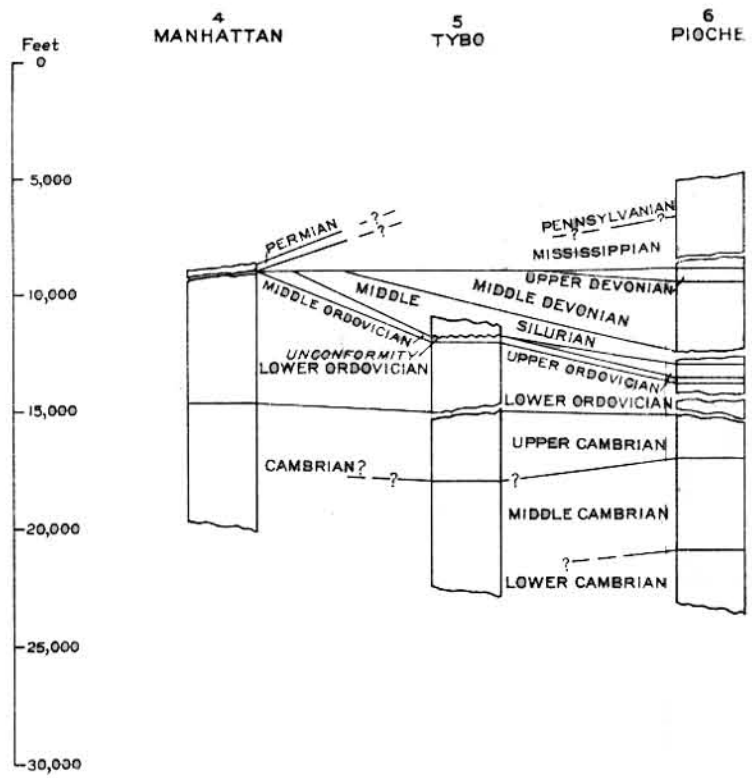
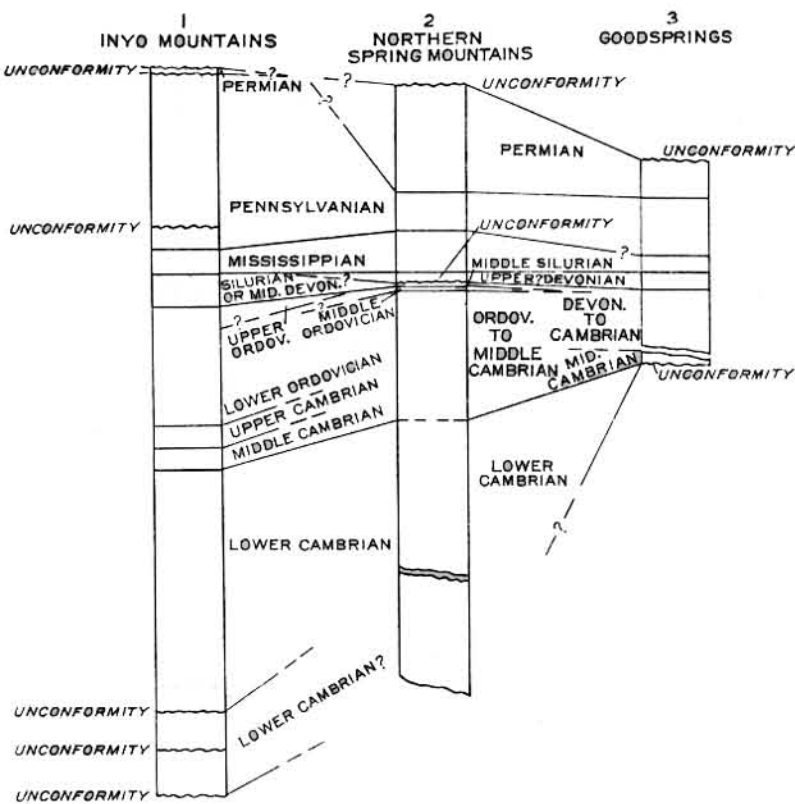












OREGON

IDAHO

NEVADA

UTAH

CALIFORNIA

ARIZONA

GARLOCK FAULT

SAN ANDREAS RIFT

UNITED STATES
MEXICO

EXPLANATION



Known thrust faults



Late Tertiary thrust faults

Probable axis of late
Paleozoic geanticlineProbable axis of early
Mesozoic geanticline

25 0 75 Miles

