9. GEOLOGY OF THE TEHACHAPI MOUNTAINS, CALIFORNIA*

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INTRODUCTION

The San Joaquin-Sacramento Valley, also known as the Great Valley of California, separates the Coast Ranges on the west from the Sierra Nevada on the east. The southern part of this major physiographic and structural province is about 50 miles in average width, and is terminated abruptly at its southeastern end by the Tehachapi Mountains, a range that trends roughly northeast. Uplifted principally by faulting, this mountain mass rises boldly (fig. 2) from the floor of the San Joaquin Valley—a floor so smooth and so extensive that in early days it was referred to as the San Joaquin Plains. The range also presents a rather straight and imposing, though somewhat less formidable, front toward the Mojave Desert to the southeast.

The alluviated surface of the San Joaquin Valley lies only a few hundred feet above sea level, whereas the surfaces of the extensive coalescing alluvial fans built out into the Mojave Desert by the intermittent streams that drain the southeast slopes of the Tehachapi Mountains stand at elevations of 2,500 to 3,000 feet above sea level. The general altitude of most of the mountain mass is 4,000 to 5,000 feet, but several ridges rise above 6,000 feet and the dominating peak of the range, Double Mountain, reaches nearly 8,000 feet about 7 miles south of Tehachapi.

For many years the Tehachapi Mountains were regarded simply as the southern end of the great rigid, westward tilted Sierra Nevada block, but their structure, geological history, and origin are entirely different from those of the Sierra Nevada. Topographically the Tehachapi Mountains are continuous with the Sierra Nevada to the northeast, and form a connecting link between that range and the Transverse Range province to the southwest. They did not originate as an unbroken fault block tilted toward the San Joaquin Valley, but instead resemble a broad horst with complicated internal structure and with complex fault structure along its margins.

The northwest and southeast sides of the Tehachapi Mountains are rather sharply set off from adjacent provinces, mainly by fault scarps, but the end boundaries are topographically rather indefinite. The San Andreas fault southeast of Tejon Pass, and Grapevine Canyon north of the pass, form an irregular but convenient southwest limit of the range. The northeast limit on some maps is taken at Tehachapi Valley and Tehachapi Creek, the general route of the Southern Pacific Railroad and the Bakersfield-Mojave highway, but commonly included in the range is the mountainous country as far north as the south ends of Breckenridge Mountain, Walker Basin, and Kelso Valley. The northeast-southwest dimension of the range hence is roughly 50 miles, and its width increases from about 11 miles at the southwest end to about 30 miles at the indefinite northeast end.

Most of the range is in a semi-arid climatic belt that receives 10 to 20 inches of rainfall per year. The lower slopes and adjacent parts of the San Joaquin Valley and Mojave Desert are arid, and receive only a few inches of rainfall per year. The highest ridges and peaks, which constitute only a small fraction of the range, receive as much as 30 inches.

AREAL GEOLOGY

General Features

Upturned Tertiary formations crop out along both the northwest or San Joaquin Valley margin and the southeast or Mojave Desert margin of the Tehachapi Mountains, but more than 90 percent of the area of the range is underlain by pre-Cretaceous crystalline rocks (fig. 1). Some of these older rocks are metamorphic, but most are coarse-grained intrusive types. One area of Tertiary strata and associated volcanic rocks, several tens of square miles in extent, lies within the mountains northeast of Tehachapi Valley. These Tertiary strata, together with those exposed along the flanks of the range, shed much light on the later geologic history of the region and on the origin of the range. Unfortunately only a small fraction of the area has been mapped in detail, and hence no discussion of the geology can be made in more than general terms.

Pre-Cretaceous Sedimentary Rocks

Numerous patches of pre-Cretaceous metasedimentary rocks are scattered within the Tehachapi Mountains, but their aggregate outcrop area is only a small fraction of the total area of the range. They are well exposed on both the north and south sides of Tehachapi Valley, on the south side of the mountains about 9 miles west of Mojave and in areas farther west, and east of Tejon Pass, between Gorman and Lebec. They consist mainly of marbles, quartzites, slates, phyllites, and schists derived from both sedimentary and igneous rocks. The carbonate rocks have been burned for lime in the vicinity of Tehachapi during past decades, and are now being quarried for cement at Monolith.

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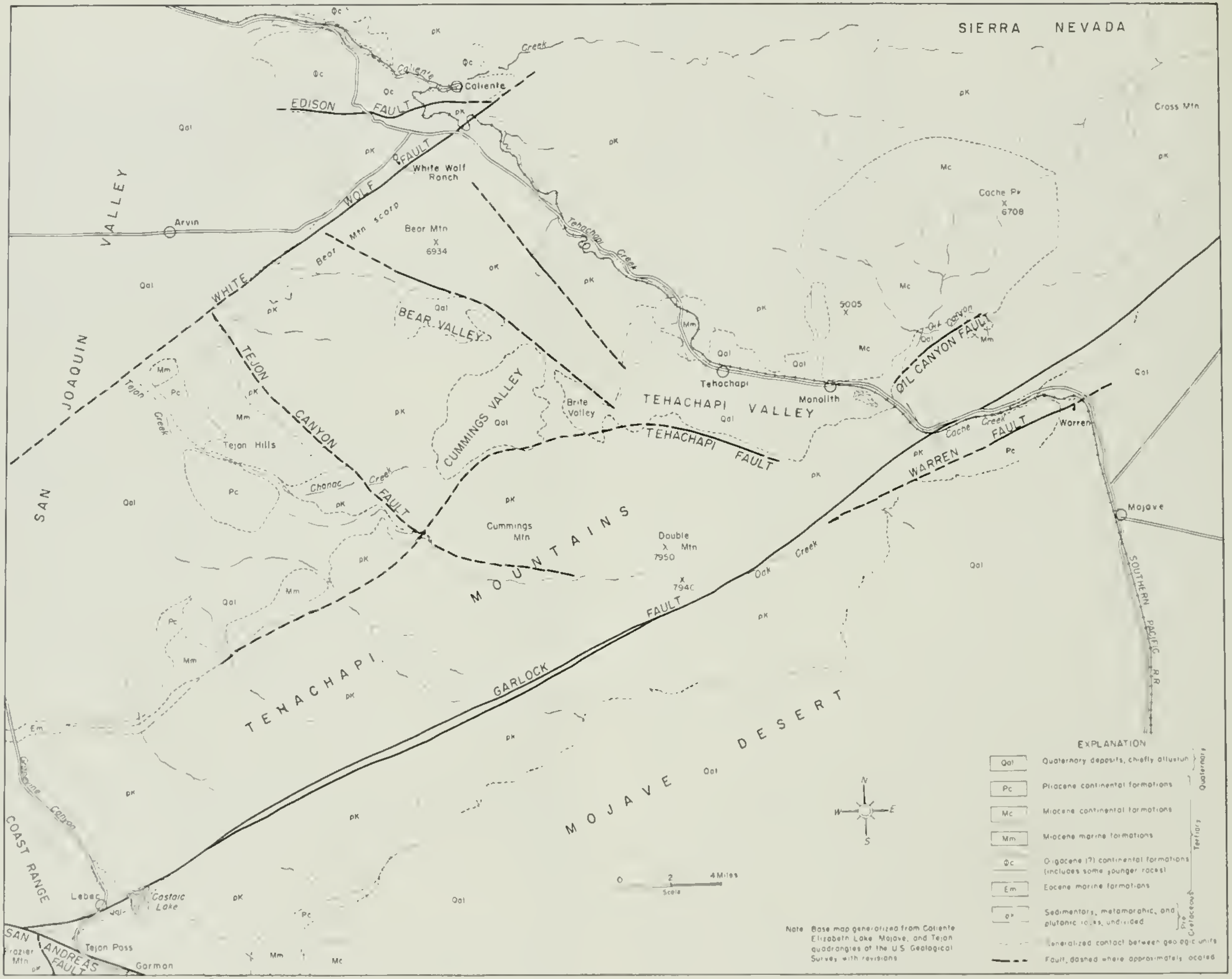

FIGURE 1. Geologic map of the Tehachapi Mountains.

The foliation in these metasedimentary and included igneous rocks ordinarily is parallel or nearly parallel to the bedding. The sedimentary section presumably corresponds to the Bean Canyon series of Simpson (1934) and to the Kernville series of Miller (1931) in the country farther north. On the basis of lithologic similarity, it has been considered as probably equivalent to the Calaveras formation of the middle Sierra Nevada, which usually is regarded as Carboniferous in age. Direct evidence of age of these beds in the Tehachapi Mountains consists only of supposed crinoid stems found by Goodyear (1888) on the south side of Brite Valley; they would indicate a Paleozoic or Mesozoic age.

The metamorphosed sediments occur in elongate patches as much as several miles in length, and with widths that generally do not exceed a mile or two. They commonly trend north to northwest. The strata themselves ordinarily strike roughly parallel to the long dimensions of the patches and dip at steep angles, but they are strongly deformed and commonly show small-scale folding, crumpling, and minor faulting. Thicknesses of several thousand feet can be measured, and the bodies clearly are remnants of a once-thick and important series of sedimentary formations that underlay the whole region; the remnants probably are mostly roof pendants.

Also present are scattered patches of still older metasedimentary rocks, mainly schists commonly associated with quartzites. One of the largest masses of these rocks is the strip of Pelona schist that lies between two branches of the Garlock fault and extends from a point near Lebec northeastward for a distance of more than 20 miles (Wiese, 1950). Its width is about 1 mile. These metasedimentary rocks are presumably pre-Cambrian in age.

Pre-Cretaceous Intrusive Rocks

By far the most extensive rocks in the Tehachapi Mountains are plutonic types of pre-Cretaceous age. They have not been studied exhaustively in any one district, but some general statements about them have been published by Goodyear (1888), Lawson (1904), Hoots (1930), Miller (1931, 1946), Simpson (1934), Miller and Webb (1940), Dibblee (1952, 1953), and others. For many years these intrusive rocks were thought to be a part of the great Sierra Nevada batholith, and to connect the old rocks of the Sierras with those of the Coast Ranges, but it now seems clear that, as in the Sierra Nevada farther north, the history of intrusion is far more complex than the emplacement of a single great molten body. The Tehachapi Mountains consist of numerous coarse-grained plutons of somewhat diverse mineralogical composition, of very irregular shapes and sizes, and of different ages.

Two general categories of older intrusive rocks can be recognized in the range. The younger of these includes the great bulk of the intrusives—rocks that range in composition from granite through monzonite, granodiorite, and quartz diorite to gabbro. The average composition is in the granodiorite range. These rocks are probably Jurassic in age, and correspond in general to the granodiorites of the Sierra Nevada. They are foliated in only a few areas, and are intrusive into metasedimentary rocks believed to be late Paleozoic in age.

Figure 2. View eastward at northwest face of Bear Mountain, with floor of San Joaquin Valley in foreground. The entire face consists of pre-Cretaceous crystalline rocks. The violent earthquake of July 21, 1952, originated on a reverse fault along base of this scarp; the fault displacement created numerous ground ruptures along the trace, involving offsets of as much as a few feet.

An older group of scattered intrusive bodies is cut by the Jurassic (?) intrusives just described. In general they are more basic and commonly are gabbroic or dioritic. They also are more foliated. These rocks are intrusive into the late Paleozoic (?) strata, but their intrusion may have been in part contemporaneous with the deformation of that terrane. They probably are late Paleozoic or early Mesozoic in age. Some local masses of coarse-grained, commonly highly foliated intrusive rocks apparently are still older, and may be pre-Cambrian.

Tertiary Rocks within the Mountains

So far as is known, no Cretaceous formations of either sedimentary or igneous origin are present within or along the flanks of the Tehachapi Mountains.

Tertiary sedimentary strata, with associated lavas and pyroclastic rocks, occur within the mountains northeast of Tehachapi and north

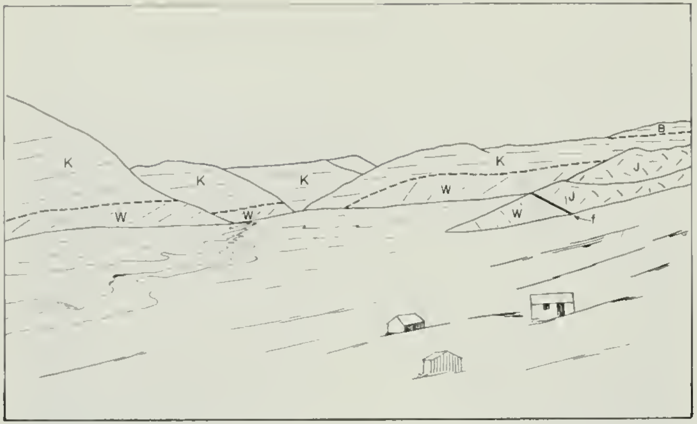

FIGURE 3. View northward up Cache Creek from a point about 1.5 miles east of Monolith. Beds of upper Miocene Bopesta formation (B) rest upon volcanic rocks of upper or middle Miocene Kinnick formation (K), which in turn rest with strong angular unconformity upon continental strata of lower Tertiary Witnet formation (W). Pre-Cretaceous crystalline rocks (J) have been thrust over overturned Witnet strata along a fault (f) of pre-Kinnick age. *Sketched from a photograph.*

of Monolith, where they underlie an area of perhaps 50 square miles. Three nonmarine formations, all at least moderately deformed, constitute this body of younger rocks; in order of decreasing age, these are the Witnet, Kinnick, and Bopesta formations.

Witnet Formation. The oldest of the three Tertiary formations, the Witnet, is the least widely exposed; it underlies an area of only a few square miles along Cache Creek and lower Oil Canyon about 5 miles northeast of Monolith. It consists mainly of beds, each generally a few feet thick, of coarse gray arkose alternating with thinner beds of dark sandy shale or siltstone. The arkose contains both angular fragments of volcanic rocks and locally numerous well-rounded pebbles and small boulders of quartz and quartzite. In general the materials are rather poorly sorted and the bedding is rude. The strata stand at steep angles, and are in part overturned. Their exposed thickness is not less than 4,000 feet, but neither the top nor the base of the formation is exposed.

In spite of repeated search, no fossil material of any kind has been found in the Witnet beds. Miocene strata lie with strong angular unconformity across their upturned edges (fig. 3), as is beautifully shown at the confluence of Oil Canyon and Cache Creek, and in turn they overlie the granitic rocks of the region. They appear to be much less lithified than the Cretaceous formations of the California Coast Ranges. Although they are distant from the nearest exposures of Sespe strata, they resemble some parts of this Oligocene Coast Range formation more closely than any other sedimentary unit. The Witnet formation is therefore of almost certain early Tertiary age, and may be Oligocene. Its arkosic character, the poor sorting of its materials, its rude bedding, the lack of fossils in it, and the angular form of its larger clasts indicate a continental, probably largely terrestrial, mode of deposition under arid or semi-arid climatic conditions. The numerous well-rounded quartz pebbles and cobbles, incongruous among arkosic and angular materials, presumably were derived in already-worn form from some older conglomeratic formation.

Kinnick Formation. In contrast to the underlying Witnet formation and the overlying Bopesta formation, the Kinnick formation consists largely of volcanic debris. It underlies an area of about 25 square miles north of Monolith, between Cache and Whiterock Creeks and along Sand Canyon. The beds that appear rather conspicuously in the hills immediately north of the cement plant at Monolith, and that are utlized to some extent in cement making, mark the southern end of this outcrop area of the Kinnick formation. A small isolated patch of sedimentary strata 1 mile to 3 miles northwest of Tehachapi probably was originally continuous with the upper part of the Kinnick section. Presumably the Kinnick beds extend southward and underlie the alluvium of at least part of Tehachapi Valley.

The formation consists mainly of green and other highly colored basic volcanic tuffs and some coarse agglomerates. Basic lavas constitute only a small part of the section. The upper few hundred feet of the formation consists of gray sandy clays that locally are interbedded with white fresh-water diatomite and gray and yellow cherts. The total thickness of the Kinnick is not less than 1,500 feet.

No fossils have been found in the pyroclastic lower and middle parts of the formation, but the sandy clay beds in the upper part have yielded the Phillips Ranch mammalian fauna. This fauna comprises several forms, including the genus *Merychippus* (Buwalda, 1916), and is presumably of middle or late Miocene age.

The Kinnick formation lies with strong angular unconformity upon the Witnet formation. It appears to be conformable with the overlying Bopesta formation, and is distinguished from it by a marked upward coarsening of the strata.

Some parts of the Kinnick section contain fossil leaves of deciduous trees, and also palm fronds. Much of the formation is well sorted and sharply stratified, and the sedimentary upper part is fine grained and water-laid. Some of these beds closely resemble playa deposits, and fossils representing several species of herbivorous mammals are found in them. It appears that the formation was deposited in a region of active volcanism and not very great relief, and under climatic conditions that probably were semi-arid rather than arid.

Bopesta Formation. The youngest of the three Tertiary formations, the Bopesta, is widely exposed in spectacular badlands (fig. 4) east of upper Cache Creek and 6 to 7 miles northeast of Monolith. It consists mainly of white to tan-colored, fine- to coarse-grained quartzose sandstone containing some ash and larger fragments of volcanic rock. Some beds are conglomeratic, and some gray sandy shale also is present. The formation extends northward under Cache Peak. It is moderately deformed (fig. 5), with dips up to about 30 degrees, and its thickness is not less than 3,500 feet.

Vertebrate fossil material has been found in some abundance in the lower and middle thirds of the section. Known as the Cache Peak fauna (Buwalda, 1916), it contains several mammalian species and is clearly of late Miocene age. It was previously thought that the Bopesta formation might be unconformable upon the Kinnick formation, because the dominant species of *Merychippus* in the Phillips Ranch fauna of the Kinnick formation is a small and apparently primitive form formerly thought to be of early Miocene age. This would mean that rocks of middle Miocene age are missing between the Kinnick and the Bopesta sections. More recent study of the Phillips Ranch fauna, however, seems to indicate that it is little older than the Cache Peak fauna, a conclusion that is compatible with the apparent structural conformity between the two formations.

Most of the constituent materials in the Bopesta beds are well rounded, and sorting in much of the formation is fairly good. Distinctness of bedding ranges from vague to sharp, the coarser material being in general the least definitely stratified. Cementation is highly variable; most of the strata are rather incoherent, but others are cliff-makers and aid in producing the very bold and picturesque badlands. The nature of the lithology and the vertebrate remains suggest deposition under semi-arid to humid conditions. Some of the materials apparently were lacustrine, whereas others probably were deposited by streams building up alluvial fans. The bouldery character of some of the coarse sandstone beds suggests considerable relief in the area that supplied the debris, and the generally rounded character of the debris and the paucity of arkosic material suggest a humid climate for those surrounding uplands.

Lavas and pyroclastic rocks, mainly of andesitic composition, overlie the Bopesta formation at Cache Peak and in some of the adjacent areas. Still younger are thin flows of olivine basalt 1 mile to 3 miles northeast of Monolith. They lie across the edges of the Kinnick formation, and probably are of Quaternary age.

FIGURE 4. View northeastward at gently tilted continental upper Miocene strata of mammal-bearing Bopesta formation east of upper Cache Creek, south of Cache Peak.

Tehachapi Formation. On the north side of the west end of Tehachapi Valley, 1 mile to 3 miles west of Tehachapi, several hundred feet of a coarse fanglomeratic unit of probable late Pliocene or early Quaternary age, termed by Lawson (1906) the Techachapi formation, overlies gray tuffaceous shale, sandstone, and chert that probably are the equivalent of the upper part of the Kinnick formation. The Tehachapi beds dip toward the valley at about 10°; they are probably unconformable on the Kinnick(?) beds, which here dip somewhat more steeply. These fanglomeratic strata indicate that at least part of the development of Tehachapi Valley took place in later Pliocene or early Quaternary time.

Tertiary Geology along San Joaquin Valley Border

The Tehachapi Mountains present a bold northwest front toward the San Joaquin Valley from Grapevine Canyon on the southwest to Caliente Creek and the Southern Pacific Railway tracks on the northeast. This front consists of three segments. The two end segments, each about a third of the total length, trend northeast, and the somewhat shorter middle segment, east of the Tejon Hills, trends northwest. The entire front consists dominantly of pre-Cretaceous crystalline rocks, but Tertiary strata are exposed in strips a few miles in maximum width along the base. These sedimentary formations, commonly several thousands of feet thick, dip away from the mountains at moderate to steep angles, and the upper parts of the sections are concealed in many places beneath overlapping valley alluvium.

In the southwestern part of this bordering apron of stratified rocks, near Grapevine Canyon and the Coast Ranges, the Tertiary formations are mainly marine; northeastward along the mountain front, however, nonmarine beds and volcanic rocks become progressively more abundant. Near Grapevine Canyon the Tertiary section consists of several thousand feet of gray marine sandstone and siltstone (type section of the upper Eocene Tejon formation), above which are some hundreds of feet of Oligocene(?) land-laid beds (Tecuya formation). Resting upon these are several thousand feet of lower Miocene Vaqueros marine beds and a similar thickness of middle Miocene Maricopa marine diatomaceous shale. The Tecuya formation is unconformable on the Tejon, but in general the Tertiary section shows little angular discordance. The beds are steeply tilted and partly overturned at Grapevine Canyon, but farther northeast, toward Tejon Ranch, the northwesterly dips gradually decrease to moderate angles (Hoots, 1930).

In the Tejon Hills, about 15 miles northeast of the mouth of Grapevine Canyon, several hundred feet of middle Miocene marine strata rests unconformably on the pre-Cretaceous rocks at the base of the scarp. The strata dip moderately toward the valley, and thicken rapidly in that direction. Resting unconformably upon them are some hundreds of feet of upper Miocene marine Santa Margarita beds, which in turn are overlain without visible unconformity by Pliocene nonmarine strata of the Chanac formation, all dipping gently away from the mountains (fig. 6).

For about 8 miles north of the Tejon Hills no Tertiary formations crop out along the west base of the Tehachapi Mountains, but at Caliente Creek a strip of Tertiary strata several miles wide extends back into the range for a distance of nearly 10 miles to points beyond the town of Caliente (Dibblee, 1953). These strata, about 3,000 feet in thickness, have been dropped into the crystalline basement terrane by movement on the Edison fault, which bounds them on the south. The section consists of the Oligocene (?) Walker formation, the lower Miocene Ilmon basalt, the lower Miocene Freeman-Jewett shale, the Miocene Bena gravels, and the Pliocene Kern River gravels. Only the Freeman-Jewett shale, about 500 feet thick, is of marine origin. The bulk of the section is coarse grained, and some of it is dominantly volcanic in origin. The Pliocene Kern River gravels lie unconformably on the older Tertiary formations, and the Miocene strata have moderate to steep dips. Clearly this foothill belt experienced vigorous deformation in both Tertiary and post-Tertiary time.

Tertiary Geology on Mojave Desert Margin

Tertiary formations are exposed along a part of the southeast base of the Tehachapi Mountains. They are in part marine in the

FIGURE 5. View northward toward upper Miocene continental strata of Bopesta formation south of Cache Peak, showing folding along northeast-trending axes.

southwestern portion of the outcrop area, and wholly nonmarine farther northeast. In places they dip off the older rocks of the range and under the alluvium of the Mojave Desert, and in places they have been faulted down against the basement rocks.

Near Quail Lake, in the southwestern portion of the Mojave Desert front of the range Crowell (1952) and Wiese (1950) have mapped several thousands of feet of upper Miocene Santa Margarita formation, consisting of marine sandstone, conglomerate, and shale, and extending for about 4 miles northeastward from the San Andreas fault. Miocene continental deposits, presumably 5,000 to 8,000 feet thick, overlie the Santa Margarita and extend about 10 miles northeastward from the fault. These beds may be in part little different in age from the Santa Margarita section. Pliocene fresh-water lake beds, mainly siltstone, clay, and marl, also crop out along the southeast foothills of the range for about 8 miles. They may be in part equivalent to the upper part of the Miocene continental deposits, and have a maximum thickness of approximately 5,000 feet. Pleistocene terrace deposits and alluvium as much as several hundred feet thick lie unconformably upon all the older formations. Dipping from a few degrees to as much as 25 degrees, they record Quaternary tilting and faulting along the southeast flank of the range.

No Tertiary formations are known along the desert margin of the Tehachapi Mountains for a distance of about 20 miles northeast of the Tertiary exposures just mentioned, but a few miles northwest of the town of Mojave a strip of land-laid sediments appears along the south side of the east-west ridge that lies south of the railroad

FIGURE 6. Typical badland exposure of continental lower Pliocene Chanac formation in Tejon Hills. The beds dip gently toward the San Joaquin Valley.

and lower Cache Creek. These strata often have been referred to as the Warren beds or Warren formation. They have been dropped down against a ridge of crystalline rocks along an apparently normal fault; the Garlock fault lies north of the ridge. The beds consist mainly of arkosic sandstone with one or more thin layers of volcanic ash. The total thickness exposed is several hundred feet. Vertebrate fossil remains indicate that the strata are approximately early Pliocene in age, and hence the equivalent of the Ricardo beds. They are gently to moderately folded.

No Tertiary strata occur along the southeast base of the range for 20 miles beyond the patch of Warren beds northwest of Mojave. At Jawbone and Redrock Canyons, still farther northeast, are extensive exposures of the Ricardo formation, consisting of about 7,000 feet of lower Pliocene terrestrial sandstone, conglomerate, and siltstone, with volcanic rocks. This section has been faulted down along the base of the eastern part of the Tehachapi Mountains and along the El Paso Mountains, and has been tilted northwestward at angles of about 30° by the uplift of the latter range (Dibblee, 1952).

STRUCTURE

Pre-Cretaceous Structural Features

The structure in the patches of pre-Cretaceous stratified rocks that are scattered through the Tehachapi Mountains is diverse, but is not yet well known. Elongate strips of Paleozoic (?) limestone and quartzite north of Tehachapi Valley commonly trend north to northwest, and the strata stand at steep angles; many exceptions are known, however, especially in the smaller patches. In the El Paso Mountains immediately to the east, Dibblee (1952) has described Permian strata with an apparent thickness of 23,000 feet that likewise trend north to northwest. Farther north, in the Kern River area, are inliers of old sediments with similar trend.

These formations, which have been intruded by the Mesozoic granitic rocks, probably were folded during Nevadan or Jurassic time, along with the pre-Cretaceous sedimentary formations of the Sierra Nevada farther north. Thus the area of the Tehachapi Mountains may well have been a part of the original Sierra Nevada. On the other hand, along the Garlock fault north of Mojave and at certain other localities, elongate strips of old rocks trend east to northeast, or roughly parallel to the Garlock fault. These features suggest that the east-west structural trend exhibited in the Transverse Range province to the south and southwest may have been initiated long before Tertiary time.

Tertiary Structural Features

The present Tehachapi Mountains are a product of Cenozoic deformation. The range is bounded on both sides by complex fault zones and by strips of sharply upturned Cenozoic formations. It is not merely an anticlinal arch, but is a complex horst, with both faulting and warping at its margins.

Structure along San Joaquin Valley Margin. As already noted, the northwest margin of the Tehachapi Mountains comprises two end segments that trend about N. 50° E., or roughly parallel to the Garlock fault on the opposite side of the range, and a third or intermediate segment that trends at right angles to the other two. These three divisions of the San Joaquin Valley front are determined by separate structural features of somewhat different type.

The northeast segment, extending for about 15 miles northeastward from the Tejon Hills to points beyond Caliente Creek and the Southern Pacific Railroad, is determined by the active White Wolf fault. It was on this break that the Arvin-Tehachapi earthquake of July 21, 1952, occurred; this was one of the strongest shocks in southern California since 1857, and the strongest in the entire State since the San Francisco earthquake of 1906. The fault lies along the base of the spectacular northwest-facing Bear Mountain scarp, which is about 5,000 feet in height. Extensive geological, seismological, and geodetic studies in connection with the 1952 earthquake indicate that the fault is of reverse character, dipping southeastward under the mountains at a probable angle near the surface of 45° ± 15°. Northeast of the Tejon Hills the fault is bounded on both sides by pre-Cretaceous crystalline rocks, except at Caliente Creek, where small masses of Bealville conglomerate, considered by Dibblee (1953) to be of Oligocene age, have been dropped down against the older rocks along the fault. At the Tejon Hills the folds in the Tertiary formations, the youngest of which is the Pliocene Chanac, are apparently cut off by the fault, which continues southwestward beneath the Quaternary alluvium of the San Joaquin Valley for about 15 miles to Wheeler Ridge or beyond.

The epicenter of the 1952 earthquake was on the south side of Wheeler Ridge. Northeastward from this ridge, geophysical exploration by the Richfield Oil Corporation demonstrates that the total offset of the basement surface along the White Wolf fault is about 10,000 feet. Geodetic work by the U. S. Coast and Geodetic Survey indicates that northeast of the Tejon Hills the upper side of the fault moved northward 2 to 3 feet horizontally and rose about 2 feet, while the northwest side sank about the same amount in connection with the recent earthquake, but the points of both maximum uplift and subsidence were several miles from the fault, with apparently no sharp vertical offset at the fault. The recent fault movement was therefore presumably oblique slip, but mainly dip slip. West of the Tejon Hills the horizontal displacements of triangulation points were comparable in magnitude but entirely different in direction, being mainly westward on both sides of the fault; unfortunately, only one point was located on the lower block. The vertical change here was also about 2 feet on each side, with the maximum subsidence again occurring several miles northwest, and the maximum uplift several miles southeast, of the fault.

The White Wolf fault developed no fresh traces of displacement on the San Joaquin Valley alluvium during the recent earthquake. Northeast of the Tejon Hills tremendous landsliding on the Bear Mountain scarp during past centuries has produced a topography and a macerated rock mass across the approximate trace of the fault such that only numerous disconnected soil ruptures of very diverse trends and amounts and directions of offset were formed. However, several huge new cuts, developed during revisions of four Southern Pacific Railroad tunnels that were damaged by the earthquake, revealed at least three fractures in the bedrock. Taken to be branches of the fault, these breaks dip 30° to 45° southeastward and under Bear Mountain.

The middle segment of the San Joaquin Valley front of the Tehachapi Mountains trends northwest. The great scarp rising from the White Wolf fault turns a right angle at the Tejon Hills, and continues southeastward, with a height of about 2,000 feet, along the northeast side of Tejon Creek canyon practically to the summit of the range. The presumed fault responsible for this scarp was termed the Tejon Canyon fault by Hoots (1930). There is little structural evidence for this fault except near its northwest end, where at one locality Santa Margarita beds butt against older granitic rocks. The Tertiary formations of the Tejon Hills in general lie with depositional contact on these granitic rocks, but dip away from the mountains at angles of 10° to 50°. The boldness of the scarp, and the sharp topographic boundaries between it and the Cummings Valley upland above and the Tejon Valley below, indicate either a northwest-trending fault or a very sharp warp, or a combination of the two, developed in post-Chanac time.

The third or southwest segment, closing in the extreme southeast end of the San Joaquin Valley, extends from Tejon Creek to Grapevine Canyon. At the mouth of this latter canyon, upper Eocene Tejon strata stand at very steep angles or are overturned toward the valley. Hoots (1930) showed probable fault relations here, and, considering the prevalence of reverse and overthrust faulting west of Grapevine Canyon, the boldness of the scarp of old rocks that rises above the Tertiary formations, and the overturned structure of the Tertiary beds, it is almost certain that strong reverse or overthrust faulting has occurred here and for some distance to the east.

East of Grapevine Canyon, the Miocene strata, finally lying in depositional contact on the older rocks, dip less and less steeply as they are traced toward the Tejon Ranch headquarters. But as far as Tejon Creek the steep bedrock front, meeting the Tehachapi Mountains upland with a rather definite angle, must indicate either faulting near the base of the scarp (but topographically above the basal contact line of the sediments) or a sharp warp in the bedrock. And it is probably not a coincidence that a rather bold scarp in the older rocks lies nearly in line with it on the opposite side of Tejon Creek, along the southeast side of Cummings Valley, on the block uplifted by movement along the Tejon Canyon fault. The Cummings Valley scarp is more or less continuous with the impressive escarpment along the south side of Tehachapi Valley, and the structural break along its base may be continuous with the Cache Creek reverse fault or overthrust, as will be mentioned farther on.

Structure along Mojave Desert Side of Range. It has often been held that the Tehachapi Mountains were uplifted and differentiated from the Mojave Desert block by movement on the Garlock fault, but this is true only for about the northeastern third of the range from the San Andreas fault to Jawbone Canyon. From a point near Warren, northwest of Mojave, northeastward to Jawbone Canyon, the range front is a straight, bold fault scarp 2,000 to 2,500 feet high, with the Garlock fault at its base. This break is mainly a strike-slip fault, with left-lateral displacement that has been estimated to be at least several miles.

Southwestward from Warren, the Garlock fault lies within the mountains, at average distances from their southeastern base that increase irregularly from a mile or two near Warren to 6 or 7 miles near the San Andreas fault. For nearly all of the distance from Warren to Oak Creek, the apparently normal Warren fault, subparallel to and probably a branch of the Garlock fault, defines the southeast base of the mountains, the slice between the two faults having been elevated along with the mountain mass. Southwestward from Oak Creek to the point where Tertiary strata appear along the base of the range, the physiography suggests that the front of the range is determined in part by local faults that make large angles with the Garlock fault, and in part by warping. The Garlock fault, which here lies well within the range, gives little indication of dip-slip movement, and seems to have had little or no part in uplifting the Tehachapi Mountains. In the most southwesterly 10 miles of the range front, the Tertiary and older Quaternary sediments dip in general toward the desert region, and a number of faults have been mapped by Crowell (1952) and by Fine (1947). Most of them have trends that differ considerably from that of the Garlock, and are not connected with this major break. The faults presumably had some relation to the uplift of the range, but this section of the range front apparently was determined mainly by warping.

Structure within the Range. In contrast to the rigid Sierra Nevada block, which was little deformed during Tertiary time, the Tehachapi Mountains were both strongly folded and faulted internally, and probably at several times during the Tertiary period. The Witnet formation, early Miocene or pre-Miocene in age, dips very steeply northward along Oil Canyon and gently southward along Cache Creek half a mile north of its junction with Oil Canyon, and hence apparently forms an acute syncline that trends northeast. The overlying middle or upper Miocene Kinnick and Bopesta formations likewise have been folded synclinally but less acutely so, and the broad northeast-trending fold includes several lesser folds (fig. 5) and is cut by numerous minor faults. Basic lavas, probably of Pliocene age, apparently lie unconformably on the Miocene strata. There are evidences of still other Tertiary episodes of deformation, as in the Coast Ranges to the west.

Along the southeast sides of Cache Creek and Oil Canyon, east of Monolith, the pre-Cretaceous crystalline rocks have been thrust northwestward over the pre-middle Miocene Witnet formation, which has been acutely upturned and overturned (fig. 3). This thrust, the Oil Canyon fault, dips 30° to 45° southeast. It apparently is mainly or entirely of pre-middle Miocene age, for Kinnick strata have not been found to be cut by it and patches of Kinnick, but little deformed, rest on the older rocks southeast of the fault. The surface trace of the fault is terminated northeastward by a cross fault that drops Kinnick strata down on the east side, but its alignment suggests that it may well continue in the older rocks and be responsible for Lone Tree Canyon, in which case it continues to, and is cut off by, the Garlock fault. Southwestward the Oil Canyon fault passes beneath the alluvium of Tehachapi Valley. It may terminate against an east-west fault that Lawson (1906) predicated along the south margin of Tehachapi Valley, but it appears equally probable that the Oil Canyon thrust turns somewhat westward, becomes the Tehachapi Valley fault, and is responsible for both Tehachapi and Cummings Valleys. Continuing southwestward, it would be offset by the Tejon Canyon fault, but it may well be a continuation of the zone of sharp deformation that bounds the northwest side of the Tehachapi Mountains from Tejon Canyon to Grapevine Canyon.

A second set of faults within the Tehachapi Mountains trends roughly northwest, and includes the Tejon Canyon fault, previously referred to, and the two faults that bound Bear Mountain on the northeast and southwest sides, and between which the mountain was hoisted to its present height of nearly 7,000 feet. It is not known whether these faults continue northwestward on the floor of the San Joaquin Valley beyond the White Wolf fault, or whether they terminate against it, but it is known that similar northwest-trending faults extend discontinuously northwestward beneath the valley toward structures of similar trend that plunge southeastward beneath the valley alluvium from the eastern margin of the Coast Ranges in the Coalinga area. Similar northwest-trending faults drop Tertiary formations down against the basement rocks along the eastern margin of the San Joaquin Valley east and north of Bakersfield; the great fault-line scarp at the mouth of the Kern River Gorge, 12 miles northeast of Bakersfield, is one of these. These faults are taken to be Central Coast Range structures that traverse obliquely the southern San Joaquin Valley floor and reach into the Tehachapi Mountains.

ORIGIN OF THE TEHACHAPI MOUNTAINS

The Tehachapi Mountains bear little structural or genetic relation to the Sierra Nevada, with which they merge on the northeast. They do not trend north, they do not constitute a tilted block, and the great north-trending fault zone that bounds the Sierra Nevada on the east does not reach into the Tehachapi country and has no relation to the Garlock fault, which lies along or within the south margin of the Tehachapi Mountains. On the other hand, the range trends more nearly parallel to the Transverse Ranges to the south and southwest, and it lies east of and on the projection of the structural lines of the Transverse Ranges. Instead of being a tilted block, it is a plateau or complex horst elevated between faults or sharp flexures along its San Joaquin Valley and Mojave Desert margins. It has internal structures that in nature and trend seem to be extensions of both the east-trending structures of the Transverse Ranges to the west and of the northwest-trending structures of the Central Coast Ranges projected obliquely southeastward across the San Joaquin Valley. Like the Coast Ranges, the Tehachapi Mountains experienced several mountain-making disturbances during the Tertiary period.

It is not known whether the Tehachapi Mountains ever were largely covered by Tertiary sedimentary formations similar to those in the Coast Ranges, and it is clear that some interior parts, such as that north of Monolith, were not. These parts are still underlain by some Tertiary deposits that are different from deposits of similar ages in the Coast Ranges. Typical Coast-Range Tertiary formations thousands of feet thick now dip off the margins of the Tehachapi Mountains, and plainly extended for considerable distances into the interior of the present range. In general the range apparently stood higher than the Coast Range country west of it during at least a large part of the Tertiary period, so that it was covered only in part by marine sediments and received land-laid deposits in other parts. It apparently rose much higher in late Cenozoic time, so that it is now mainly old crystalline rocks at the surface, whereas the Coast Ranges west of it still carry great thicknesses of Tertiary formations.

ORIGIN OF THE TEHACHAPI VALLEY SYSTEM

One of the remarkable features of the upland surface of the complex horst that makes the Tehachapi Mountains is the existence on it of several broad, flat-floored valleys. Lawson (1904) described the general geologic nature of these striking depressions picturesquely and accurately nearly 50 years ago. They lie at an altitude of about 4,000 feet, and hence are high above both the Mojave Desert and the San Joaquin Valley. Streams are now heading back into them from the San Joaquin Valley side, and will eventually destroy them.

The largest of these upland depressions is Tehachapi Valley, about 10 miles long and 3 miles wide, which trends east athwart the range and affords the pass for the railroad line and one of the main highways between southern and central California. To the west of it lie Brite Valley, Cummings Valley, and Bear Valley, which are smaller but otherwise similar depressions. All these valleys contain Quaternary alluvium as much as several hundred feet deep. Each of the valleys is bounded on one or more sides by a bold scarp that rises abruptly from its alluvial floor and that has been developed on old crystalline rocks. Apparently in large part because of these striking scarps, Lawson (1904) concluded that the Tehachapi valleys were formed chiefly by Quaternary faulting. The gentle southerly tilt of the upper Pliocene or Quaternary Tehachapi formation tends to support this view, although the tilt may be related to a synclinal downwarping of that formation and the underlying Cable, Tank, and Atlas formations as a separate episode, as Lawson suggested. Moreover, it is clear that Tehachapi Valley was in part eroded out of the Tehachapi formation and the Kinnick formation, as the considerable thickness of the latter unit exposed at and north of Monolith originally must have extended southward into the area now occupied by the valley and must have been removed by erosion before the thick body of alluvium was deposited on the valley floor.

The writer knows of no Tertiary strata on the south side of Tehachapi Valley or in Brite, Cummings, or Bear Valleys, and hence has no clue as to their original distribution in these valleys. The apparently necessary inference that Tehachapi Valley was at least in part formed by erosional removal of these less resistant beds, and the physiographic similarity of these other three valleys to the larger valley, leads to the supposition that they also are at least in part excavational rather than entirely tectonic in origin. No evidence of faulting so recent as to cut the alluvium has been found along any of the scarps. The northwest-trending scarps on the two sides of Bear Mountain appear to be bolder and younger than the east-trending scarps along the south side of Tehachapi, Brite, and Cummings Valleys, and it is entirely possible that the former are true fault scarps and that the latter are in part fault-line scarps resulting from the erosional excavation of Tertiary beds to form the three valleys. The excavation presumably would have occurred during or after uplift of the horst.

GEOLOGIC HISTORY OF THE TEHACHAPI MOUNTAINS

The geologic history of the Tehachapi Mountains is at best a very incomplete record of the episodes of uplift, erosion, deposition of sediments, volcanism, folding, faulting, and metamorphism, and is further limited by the small fraction of the range that has been mapped or studied in detail. Probably the earliest known event in the evolution of the range is recorded in patches of metamorphosed sediments believed to be of pre-Cambrian age. These now are mainly schist (the Pelona schist), and are present between Tehachapi and Mojave, as well as in larger areas in the southwest part of the range, where they have been described by Wiese (1950). These rocks are believed to represent mainly the fine-grained sediments laid down in one or more invasions of a pre-Cambrian sea.

Another epoch of pre-Cambrian marine deposition probably is represented by a body of rocks, termed by Wiese (1950) the "gneiss complex," in the southwestern part of the range. Partly old sediments and partly intrusive rocks, this complex indicates another long chapter of pre-Cambrian history, but whether this was earlier or later than the deposition of the Pelona schist is not certain.

What occurred in this region during the early and middle parts of the Paleozoic era is not known, but probably in Carboniferous time another marine transgression resulted in deposition of a thick section of limestones, sandstones, and other sedimentary strata. Diastrophism followed in later Paleozoic or early Mesozoic time, and during or after the deformation intrusive rocks invaded the sediments. These igneous bodies were more basic in composition than the widespread granodioritic intrusives of later Mesozoic age, and commonly are now more gneissic.

There is no known record of Mesozoic sedimentation in the entire Tehachapi Mountains, but presumably during the Jurassic period widespread intrusion of batholithic rocks occurred, ranging in composition from gabbro to granite but dominantly of granodioritic type. The exact date of this igneous activity has not been determined in this region, but the similarity of the rock types to those in the Sierra Nevada farther north has led to the assumption that these intrusive formations are "part of the granites of the Sierra Nevada."

Presumably just preceding and during the intrusion of the granodioritic rocks in Jurassic time, vigorous mountain making affected this region as it did the northern Sierra Nevada and large parts of western Nevada and southeastern California. Although the history of the Tehachapi Mountains in post-Mesozoic time seems to have been rather independent of that of the Sierra Nevada, the tectonic affinity of these regions in Jurassic time seems to be strongly indicated by the similarity in trends of the remaining patches of Paleozoic sedimentary strata, and by the structural trends in the magnificant section of Permian strata so excellently mapped in great detail by Dibblee (1952) in the El Paso Range, the mountain mass that is adjacent to the Tehachapi Mountains on the east. Deep and presumably long-continued erosion, embracing later Jurassic, Cretaceous, and perhaps early Tertiary time, stripped away the roof rocks of these Jurassic intrusive bodies in the Tehachapi Mountains and much of the surrounding region, except for scattered patches of Paleozoic and pre-Cambrian sediments and gneissic intrusives.

What episodes of mountain making, deposition, and erosion occurred on the granitic platform of what is now the Tehachapi Mountains during Cretaceous and early Tertiary time is not known. At some date previous to middle Miocene time, and presumably during the Oligocene epoch, deformation within the range was sufficiently intense to result in deposition of angular arkosic sediments and interstratified dark shales nearly a mile thick. Well-rounded and polished cobbles among these angular, presumably land-laid sediments (Witnet formation) imply the erosional destruction of some older coarse-grained sedimentary formation in the region, as well as earlier mountain making leading to the deposition of that unknown sedimentary unit.

Presumably in later Oligocene or in early Miocene time vigorous deformation again occurred. The Witnet formation was strongly folded, and granitic rocks were thrust over it from the south along the Oil Canyon fault. Then, as far as can be determined from the limited remaining areas, erosion again reduced much of the relief that resulted from the mountain making.

In middle and upper Miocene time volcanism led to accumulation of many hundreds of feet of basic lavas and associated highly colored tuffs (Kinnick formation). This activity must have been accompanied by further crustal deformation, for resting on the volcanic rocks are some thousands of feet of land-laid, largely non-volcanic sediments (Bopesta formation) clearly derived from highlands surrounding the basin of deposition. They resulted from weathering, transportation, and deposition under semi-arid conditions. Both the Kinnick and Bopesta beds contain vertebrate fossils that demonstrate their middle or late Miocene age.

On the San Joaquin Valley side of the Tehachapi Mountains is recorded a Tertiary history of repeated uplift and depression of the mountain mass relative to sealevel or to baselevel. Near Grapevine Canyon the sea must have covered neighboring parts of the range during upper Eocene time, when the Tejon formation was deposited to a thickness of thousands of feet at its type section. Emergence was followed by the deposition of the Oligocene (?) Tecuya formation, and at about this same time the thick section of the land-laid Walker formation, with its Bealville conglomerate, was deposited farther northeast, in the Caliente Creek region (Dibblee, 1953). It is not known whether these formations were laid down earlier than, contemporaneously with, or later than the Witnet formation within the range.

Little is known about the Eocene and Oligocene history of the southeast margin of the range, as no rocks of these ages have been recognized there. However, the type section of the Rosamond formation, mainly volcanic rocks and continental beds of probable Miocene age, accumulated in the neighboring part of what is now the Mojave Desert. In upper Miocene time the sea invaded the western end of the Mojave Desert and deposited Santa Margarita beds on the southeast flanks of the western part of the Tehachapi Mountains, and this was followed by accumulation of a considerable thickness of continental beds. This is the only known record of post-Paleozoic marine deposition in the Tehachapi Mountains or adjacent parts of the Mojave Desert.

In Pliocene time a fresh-water lake received some thousands of feet of sediments along the Antelope Valley margin of the range, presumably as the result of uplift of the range and relative depression of the adjoining margin of the Mojave Desert. Farther northeast, in an area northwest of Mojave and between that area and Redrock Canyon still farther northeast, terrestrial strata (Ricardo formation) accumulated to similar thicknesses, and entombed vertebrate fossils that provide a good view of the nature of mammalian life roaming the semi-arid plains and hill country of that time.

The deposition of the continental Ricardo formation on the southeast margin of the range, and of the Chanac formation and the Kern River gravels along the northwest base of the range, doubtless resulted from further uplift and deformation within the Tehachapi Mountains in post-Miocene time. No Pliocene strata were laid down within the range, so far as is known, but the Bopesta formation was moderately folded along east-west axes, and was cut by faults. Probably, but not certainly, both it and the older formations on which it rests were bevelled off, and in later Pliocene time andesitic flows and agglomerates, of which only patches now remain, probably buried a large part of these Tertiary sediments. One remnant of the flows now caps Cache Peak, north of Tehachapi Valley, at an altitude of 6,700 feet.

In late Pliocene and Quaternary time deformation apparently continued within the range, as the Pliocene or Quaternary Tehachapi formation of the northwest corner of Tehachapi Valley was folded and tilted so that it now extends beneath the valley alluvium. If the Tehachapi valley system developed mainly by late faulting, it must have been at this time, as the marginal scarps are in part still bold. Certainly faulting within the range occurred during Quaternary time, as shown by the northeast and southwest faces of Bear Mountain. If the origin of the Tehachapi valleys was mainly erosional, they must have been excavated during Quaternary time. But the larger-scale deformation during Quaternary time was by faulting and warping along both margins of the range, and by elevation of the complex Tehachapi Mountains horst between the two fault systems. The mountain mass rose 2,000 to 3,000 feet with reference to the Mojave Desert block southeast of it, which itself may well have been elevated somewhat at this time, and the mass was lifted 5,000 feet or more with reference to the San Joaquin Valley. To judge by the seismic activity, the locally offset alluvial surfaces, and the freshness of the scarps, this marginal faulting, and presumably the marginal warping and the uplift, are still continuing. In addition, the last episode in the recent history includes the vigorous dissection and degradation initiated by the last uplift of the range.

In summary, the Tertiary history of the Tehachapi Mountains, like that of the Transverse Ranges west and southwest of them, is one of repeated deformation, subsidence, and uplift, with resultant deposition of marine or land-laid sediments and volcanic rocks in constantly shifting areas and their equally irregular erosional removal, giving rise to numerous unconformities and complex areal distribution and structural relationships. It appears that the range was in existence during most of Tertiary time, as suggested by the structural relations of the sediments along its flanks, but in general it probably stood much lower than at present. The thick Tertiary sediments, now truncated along its margins, must have covered much larger parts of the range during a considerable part of the time, and the continental sediments within the range clearly extended at times over much larger areas. Late in the Cenozoic era—so late that dissection has not yet reached into the interior of its wider parts—the range was uplifted vigorously. This resulted in rapid stripping of sediments both in the interior and along the margins, and produced a complex horst in which old pre-Cretaceous intrusive rocks are widely displayed at the surface.

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