

2. GEOLOGY OF THE SOUTHEASTERN MARGIN OF THE SAN JOAQUIN VALLEY CALIFORNIA

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ABSTRACT

The southern Sierra Nevada and Tehachapi Mountains are made up of a pre-Cretaceous crystalline complex composed of Jurassic (?) plutonic rocks with hornblende-biotite quartz diorite predominating, and linear inclusions of Paleozoic (?) schists, quartzite, and marble. The crystalline complex is overlain by a Tertiary-Quaternary marine and continental sedimentary series cropping out along the foothill areas and underlying the San Joaquin Valley where the series thickens southwestward to an estimated total of about 25,000 feet just north of Wheeler Ridge. The Tertiary series dips under San Joaquin Valley with the crystalline-rock contact sloping southwest at an average angle of about 6°, steepening to about 20° immediately northwest of the White Wolf fault.

The White Wolf fault, nearly parallel to the Garlock fault and about 18 miles northwest of it, is a major fault traceable from Tehachapi Canyon southwest along the base of the steep northwest slope of Bear Mountain for 17 miles, and probably extends under San Joaquin Valley toward Wheeler Ridge. The southeastern block has been elevated on this fault to a maximum displacement of at least 10,000 feet as indicated by surface and subsurface data, with the maximum displacement near the mouth of Sycamore Canyon.

Surface effects along the White Wolf fault zone produced on July 21, 1952, including overthrusting in the mole-track scarplets formed, shortening of fences and the railroad tracks crossing the fault, and dips of the more continuous fault-trace ruptures, strongly suggest thrusting. Seismographic evidence favors a high-angle reverse fault at depth. Ground cracks and small pressure ridges oblique to the fault trace, and small ground offsets indicate some left lateral movement.

The White Wolf fault is essentially a reverse fault, locally a thrust, elevated in the southeast block, with a small left lateral component of movement. It is more closely related to the Garlock and Pleito faults than to faults in the northern part of the area mapped.

INTRODUCTION

The southeastern margin of the San Joaquin Valley and the adjacent mountain area was the scene of the violent earthquake of July 21, 1952, which severely damaged the small towns of Arvin and Tehachapi in Kern County. The cause of this major earthquake was found to be a movement on the White Wolf fault at the base of the steep northwest slope of Bear Mountain as indicated by ground ruptures formed along the supposed course of this fault.

The topographic base map which most adequately covers the area which the White Wolf fault traverses is the 30-minute Caliente quadrangle, scale 1 inch = 2 miles, issued by the U. S. Geological Survey in 1914.

The geology of the northeastern quarter of the Caliente quadrangle was taken from previous detailed mapping done by the writer in 1950 (Dibblee, 1953). The geology of the northwestern quarter of the quadrangle is based on mapping by the writer during several week-ends in 1950, accompanied several days by A. H. Warne. The geology of the southern portion of the quadrangle and northernmost portion of the adjoining Tejon quadrangle is based on published maps and reports by Hoots (1930), Marks (1938), and Wiese (1949), although a week was spent in remapping critical portions of these areas. Two weeks of the present investigation were spent in the southeastern quarter of the Caliente quadrangle in the vicinity of Bear Mountain and southwest into the

Tejon Hills; as time was limited, the mapping is largely of reconnaissance nature.

Acknowledgments are due the geological staff of Richfield Oil Corporation for access to well logs used to determine the subsurface structure of the top of the basement complex buried under the San Joaquin Valley.

STRATIGRAPHY

Basement Complex

The pre-Cretaceous basement complex exposed throughout the southern Sierra Nevada, Tehachapi and San Emigidio Mountains, and buried under Tertiary strata in the San Joaquin Valley, is composed of granitic igneous rocks that form the Sierra Nevada granitic batholith. They range from granite to gabbro; quartz diorite predominates. The metamorphic rocks occur within the granitic batholith as roof-pendants or linear remnants of a once tremendous thickness of gneiss, schist, quartzite and limestone. The age of the metamorphic and igneous rocks is not definitely known, although the former are believed to range from pre-Cambrian to early Mesozoic, and the latter are directly traceable into the granitic rocks of late Jurassic age in the north central Sierra Nevada where they intrude the Upper Jurassic Mariposa slate and are unconformably overlain by Cretaceous sandstones and shales. Brief descriptions of the principal mapped units of the basement complex follow.

Pelona Schist. The pre-Cambrian (?) Pelona schist, as mapped by Wiese (1950, pp. 12-13), occurs only between the two branches of the Garlock fault in the Tehachapi Range where about 5,000 feet is exposed. The formation is highly foliated, with prominent cleavage, and is composed predominantly of dark greenish-gray mica-chlorite-albite-quartz schist which was probably metamorphosed from tuffaceous shale.

Biotite Gneiss. A large mass of gneiss of unknown but probable pre-Cambrian age is exposed on the north flank of the Tehachapi Mountains in the vicinity of El Paso Canyon. This formation is a complex of well banded biotite-hornblende-quartz-feldspar gneiss, and numerous injections of massive quartz diorite.

Pampa Schist. In the Cottonwood Canyon area of the western slope of the Sierra Nevada are several lenticular and linear pendants of mica schist within quartz diorite. The schist, of unknown age, mapped as the Pampa schist (Dibblee, 1953) and named after Pampa Peak, is dark gray and prominently foliated parallel to bedding. It is a biotite-quartz-feldspar schist similar to that of the Kernville series. The most southwesterly exposures of the schist in Cottonwood Canyon contain numerous large crystals of andalusite (chiastolite) elongated parallel to foliation planes. The Pampa schist is of sedimentary origin, having been metamorphosed from clay shale.

Kernville Series. The linear inclusions of metasediments exposed in the Sierra Nevada from Walker Basin southward to Keene and again on Bear Mountain ridge and Brite Valley were mapped as the Kernville series, because they are similar to the Kernville series mapped

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FIGURE 1. Mole-track scarp extending northeastward, close to trace of White Wolf fault. View northeast toward Bear Mountain. Photo by Lauren A. Wright.

by Miller and Webb (1940, pp. 349-353, map) in the Kernville quadrangle. The Kernville series is a sequence of metamorphosed marine sediments composed predominantly of biotite-feldspar schist with prominent platy foliation parallel to bedding. Interbedded with the schist are layers of gray-white quartzite and fine textured gray to white limestone. The maximum exposed thickness of the Kernville series within the mapped area is about 6000 feet, but the original thickness was no doubt many times that amount. The age of the Kernville series is unknown, as no diagnostic fossils have been found in it.

Limestone of Tehachapi Range. On the southeast slope of the Tehachapi range are several isolated exposures, within and south of the Garlock fault zone, of metamorphic blue-gray to white limestone containing minor interbeds of gray-white quartzite, lime-silicate hornfels and black schistose biotite hornfels. This formation is probably the same as the Bean Canyon schist-limestone series described by Simpson (1934, pp. 381-383) exposed 8 miles beyond the east border of the mapped area, and may be also the equivalent of the Kernville series north of the Garlock fault.

Schist of the San Joaquin Valley. Schist underlies the Tertiary sediments under a large portion of the east side of San Joaquin Valley, being encountered in wells throughout the Arvin-Mountain View-Edison oil field area, northward to the Ant Hill field, and southward nearly to the White Wolf fault. This buried schist is probably continuous with the outcrops of the Pampa schist exposed in Cottonwood Canyon to the northeast.

The schist immediately underlying the Tertiary sediments was shattered or rendered porous by weathering

prior to deposition of the sediments; and in portions of the Edison and Mountain View-Arvin oil fields, it is a reservoir rock for oil derived from the Tertiary strata where they buttress against the schist up dip. Basement cores from many wells in and near these fields have been examined by May and Hewitt (1948, pp. 129-158), who have determined the character and distribution of the schist under this part of the valley.

Diorite-Gabbro. In the western Sierra Nevada foothills there are three small exposures of a dark intrusive rock ranging from diorite-gabbro to gabbro. One of these occurs in Kern Gorge, another in Rattlesnake Canyon and one in the foothills east of the Rockpile. A large exposure of gabbro crops out east of Pastoria Canyon in the Tehachapi Mountains. These exposures are composed of dark-gray to nearly black medium-textured, equigranular rock composed almost entirely of calcic plagioclase feldspar and hornblende.

Quartz Diorite. The granitic rock so extensively exposed throughout the southern Sierra Nevada within Caliente quadrangle has been determined petrographically as quartz diorite (C. W. Chesterman, in Dibblee 1953). This rock, predominant in the vicinity of the White Wolf fault, is composed of quartz and white orthoclase and plagioclase feldspars with plagioclase predominating, and biotite mica and hornblende in varying amounts, but the dark minerals seldom exceed 30 percent of the total rock mass. The rock is light to medium-gray, depending on the amount of dark minerals present, is medium-textured, equigranular. Two facies of quartz diorite are developed in the southern Sierra Nevada and appear to have intruded the pre-existing rocks at different times or in different modes.

In the San Joaquin Valley the basement complex underlying the Tertiary sediments is made up largely of quartz diorite. From the foothill area between Caliente Canyon and the White Wolf Ranch the quartz diorite extends westward under the adjacent portion of the valley where it has been found below the Tertiary in all well cores. Well logs indicate the quartz diorite-schist contact exposed 2 miles north of Bena extends southwestward 6 miles to the Edison oil field, through which it curves southward passing just east of Arvin probably to the White Wolf fault. In the vicinity of the Kern River and Bakersfield most wells that penetrated to the basement complex cored quartz diorite.

Granite. A nearly white massive plutonic rock mapped as true granite by Wiese (1950, pp. 24-25) crops out on the south side of the Tehachapi Range south of the Garlock fault. Numerous dikes of pegmatite and aplite cut the foliated quartz diorite, especially at or near the borders of the massive facies from which the dikes may have originated. The pegmatite is composed of very coarse textured quartz and white feldspar, with gradations to fine textured aplite of the same minerals. The dikes range from less than an inch to 10 feet thick, and are especially numerous east of Caliente and in Rattlesnake Canyon where they trend northeast parallel to the contacts of the massive quartz diorite and dip steeply toward it.

Hypabyssal Intrusives. Fine textured intrusive igneous rocks have been cored in the basement complex by many wells that have reached it in the Bakersfield, Edison, and Mountain View areas, as reported by May and Hewitt (1948, pp. 141-3). These rocks are hard, massive to slightly schistose, light to dark gray or greenish gray, and are composed of aplite, malchite (microdiorite), andesite, diorite-aplite, diorite porphyry, and lamprophyre.

Intrusive rhyolite of probable Cenozoic age crops out 1 mile east of Keene as several small dikes up to 12 feet thick cutting quartz diorite. The rhyolite is a dense cream-white rock weathering tan, with small phenocrysts of quartz and feldspar. Associated with one of the rhyolite dikes is a small deposit of cinnabar at the Walibu mine.



FIGURE 2. Detail of mole-track scarp (pressure ridge) about 4 miles due east of Arvin. Bear Mountain in background. Photo by Lauren A. Wright.

Tertiary-Quaternary Series

The basement complex of the Sierra Nevada and Tehachapi-San Emigdio Mountains is unconformably overlain by the Tertiary and Quaternary sequence of sediments ranging in age from Eocene to Recent. Where the series is buried under the San Joaquin Valley the stratigraphy has been determined from numerous well logs. The series crops out as a strip along the Sierra Nevada foothills as far southeast as Caliente Canyon where the outcrop section is terminated by the Edison fault. Between this fault and the White Wolf fault to the southeast the Tertiary is not exposed. South of the latter fault the series again crops out in the Tejon Hills and along the foothills around the southeast end of the valley into the San Emigdio Mountains.

The Tertiary series within the mapped area is a continuous succession characterized by numerous and rapid changes of facies and thicknesses. In general the series thickens from east to west, absent along the foothills between the Edison and White Wolf faults and as thick as 25,000 feet just north of Wheeler Ridge. This westerly thickening is accompanied by gradation from coarse detrital material along the eastern margin to fine-grained argillaceous, thin-bedded sediments as the series thickens toward the deeper portion of the San Joaquin depositional basin. The general stratigraphic succession is as summarized below.

Marine sediments of Eocene age, the Tejon formation, overlie the basement complex and crop out only at the southern end of the San Joaquin Valley. This formation, which lies deeply buried under the westerly portion of the valley and does not extend as far east as the overlying strata, was deposited in a sea which transgressed from the west.

The Tejon formation and the basement complex are overlain by the nonmarine Tecuya formation of the San Emigdio-Tehachapi foothills, and the Walker formation and Bealville fanglomerate of the Sierra Nevada foothills, all of Oligocene (?) - lower Miocene age. These are made up of coarse, land-laid sediments containing some volcanic lavas and tuffs, deposited after regression of the Eocene sea. These sediments eventually grade westward into marine strata of the Pleito formation and its equivalents.



FIGURE 3. Broken fence, suggesting compression, across White Wolf fault east of Highway 466, at base of Bear Mountain east of Arvin. Photo by Lauren A. Wright.

The Tecuya and Walker formations are overlain by marine sandstones and clay shales of the Temblor (or Vaqueros) formation, lower Miocene age, deposited as the Miocene sea transgressed eastward to the present site of the Tehachapi and Sierra Nevada foothills. The Temblor formation crops out in the San Emigdio Mountains, and on the east margin of the San Joaquin Valley where it is represented by the Pyramid Hill, Vedder, and Jewett sands, Freeman silt, and Oleese sand. The Temblor formation is followed by the Maricopa (or Monterey) shale, a series of organic shales of middle and upper Miocene age deposited in the Miocene sea when it reached its maximum extent and depth. This formation extends eastward under the valley to the Tejon Hills and Sierra Nevada foothills where it is represented by the Round Mountain silt, Fruitvale shale, and marginal sand lenses. Overlying the Maricopa shale and its equivalents is the Santa Margarita sand, which is fairly persistent throughout the mapped area and represents the final stage of marine deposition as the Miocene sea regressed.

All of the above Miocene marine formations grade eastward into terrestrial facies mapped as the Bena gravels, which crop out in the Sierra Nevada foothills, Tejon Hills and Tehachapi foothills. There coarse detrital sediments were deposited as piedmont alluvial fans on the coastal plain bordering the Miocene sea whose strandline persisted along the present site of the southeastern margin of the San Joaquin Valley.

The Miocene strata are overlain by terrestrial sediments of the Chanac and Kern River formations, of Pliocene age, the latter ranging into Pleistocene. These coarse alluvial sediments crop out in the lowest portions of the Sierra Nevada foothills, Tejon Hills, Tehachapi foothills and Wheeler Ridge, and underlie San Joaquin Valley where the series attains a maximum thickness of 14,000 feet just north of Wheeler Ridge. The Chanac, and perhaps the lower part of the Kern River formation, eventually grade westward into the brackish-marine Etchegoin formation; the first definite marine beds appear in the outcrop section about 8 miles west of Wheeler Ridge, beyond the mapped area.

Summary of Geologic History

Pre-Cambrian (?). Accumulation of muds, volcanic ash, and minor amounts of sand and lime, probably in an open sea, now the gneiss and Pelona schist in the Tehachapi Mountains.

Paleozoic (?) to Jurassic (?). Accumulation of muds, sands, limestones and some lavas of the Kernville and Pampa series under an open sea to a tremendous thickness, resulting in a very deep burial of the lower strata and of the underlying strata.

Late (?) Jurassic Nevadan Orogeny. Strata deposited during pre-Cambrian (?) to Jurassic (?) time subsided to such great depth (10 miles or deeper) that they became subject to regional thermodynamic metamorphism. Pre-Cambrian (?) formations altered to gneiss and the Pelona schist, and Paleozoic (?) or early Mesozoic (?) strata to schist, quartzite, marble and meta-igneous rocks of the Pampa and Kernville series. At this great depth metamorphosed rocks were intruded by molten magmas which crystallized into granitic rocks, chiefly quartz diorite.

Cretaceous. Long interval of erosion; mountainous terrain built up during Nevadan orogeny deeply eroded to surface of low relief; westward tilt initiated, causing continued or renewed uplift of Sierra Nevada-Great Basin region and downward tilt of area to west under Pacific ocean.

Eocene. Continuation of last event; Sierra Nevada probably blocked out during this time by faulting; down-tilted area to west submerged under waters of ocean that transgressed from west;

deposition of sands and clays of Tejon and equivalent formations on deeply eroded and peneplaned surface of metamorphic and granitic basement complex.

Oligocene (?). Continued westward tilting; Sierra Nevada underwent renewed uplift and erosion; eroded debris deposited along western base as alluvial fans of the Bealville, Walker and Tecuya formations, causing partial regression of Eocene sea; local volcanic eruptions of pumiceous ash and some basaltic lavas.

Miocene. Continued westward tilt with some renewed uplift and erosion of ancestral Sierra Nevada; eroded debris deposited along western base as alluvial fans of the Bena gravel; down-tilted area continued to submerge under a great open sea transgressing from the west, with ancestral shoreline along base of Sierra Nevada uplift from site of mouth of Kern Gorge southward through Edison-Mountain View-Arvin oil fields, Tejon Hills, and across Tehachapi Mountains; sands deposited in shallow waters near shore, clays and siliceous muds in deeper waters farther to west. Sea transgressed from west in early Miocene time, regressed at end of Miocene; Edison fault developed during Miocene deposition, with uplift of south block.

Pliocene. Continued westward tilt; renewed uplift and erosion of Sierra Nevada; Tehachapi and San Emigdio ranges formed by compressive uplift against Garlock and San Andreas faults respectively; San Joaquin embayment thus formed with deposition of Etchegoin formation at southeast extremity of this lingering embayment; debris eroded from mountains deposited as alluvial sediments of Chanac and Kern River series, thus filling embayment to form San Joaquin Valley; major and some minor faults in area may have been initiated.

Pleistocene-Recent. Recurrent uplift of Sierra Nevada, involving adjacent foothill area, causing partial uplift and erosion of Tertiary sediments deposited along western base; development of Kern River fault and numerous other faults in foothill area and eastern San Joaquin Valley; Kern Canyon fault; uplift of Breckenridge Mountain block on Breckenridge fault and consequent filling of upper Walker Basin Canyon to form Walker Basin; development of Garlock and White Wolf faults with uplift of Bear Mountain, Bear-Brite-Cummings-Tehachapi Valley and Tejon Hills area as a single block between them; recurrent compressive uplift of Tehachapi-San Emigdio Range against Garlock and San Andreas faults; compressive northward movement and elevation of San Emigdio uplift on Pleito thrust fault and rise of Wheeler Ridge anticline and foothills in front of San Emigdio overthrust; material derived from erosion of all elevated areas deposited as alluvial fill in San Joaquin Valley.

GEOLOGIC STRUCTURE

Structural Setting of the Southeastern San Joaquin Valley Region. The southern Sierra-Great Valley province of California constitutes a regional structural block about 120 miles wide and roughly 600 miles long, made up of a complex of crystalline metamorphic and intrusive granitic rocks stabilized to a comparatively rigid mass during the great Nevadan orogeny at the end of Jurassic time. During Cretaceous and Cenozoic time this huge structural block was tilted westward almost continuously, with the eastern portion elevated to form the Sierra Nevada, and the western portion tipped downward to form the Great Valley. As this block was tilted, material eroded from the rising Sierra Nevada was carried westward and deposited to form an enormous thickness of Cretaceous-Cenozoic sediments in the sinking Great Valley area which was submerged under marine waters until late Tertiary time when it became filled with sediments. Westerly tilting caused progressively more rapid subsidence of the west side of the Great Valley so that the basement complex is progressively more deeply buried from east to west, being buried many miles deep on the western margin.

The Sierra Nevada has been uplifted as a huge west-tilted block on the north-trending Sierra Nevada fault zone along its eastern base. In this zone faulting is of the normal type with fault planes dipping steeply east-

ward. The northern and central portions are made up of several en echelon north-trending faults, while the southern portion is a single fault along which the mountain block was elevated to great heights to form the imposing front of the high Sierra. The southern Sierra Nevada fault is paralleled about 15 miles west by the Kern Canyon-Breckenridge fault along which the western portion of the southern Sierra Nevada was elevated.

The pivotal area of the continuously westward tilted Sierra Nevada-Great Valley block follows the present margin between the Sierra Nevada and the Great Valley, as topographic and stratigraphic evidence indicates this marginal area to have been neither elevated nor depressed to any great extent during Cretaceous or Cenozoic time. During that long interval of time this 600-mile long pivotal area has been remarkably stable and free from tectonic movements. Only in the extreme southeastern portion in the vicinity of Bakersfield have tectonic disturbances occurred and these have been in the form of faulting. The largest of these faults is the White Wolf fault trending northeast directly across the pivotal margin between the Sierra Nevada and the San Joaquin Valley. The area southeast of this fault was elevated as a block to form the great westward protrusion of the Sierra Nevada or the Bear Mountain uplift. Geologic and seismic evidence indicate this fault to be a southeast-dipping reverse fault with lesser left lateral movement.

The Sierra Nevada-Great Valley province is terminated on the southeast by the northeast-trending Tehachapi Range and uplift, traversed along its crestal portion by the Garlock fault. This is a master fault extending 150 miles north of east from its juncture at Lebec with the San Andreas fault, and separates the Sierra Nevada and Basin-Range provinces on the north from the Mojave Desert province on the south. This fault is a great active shear zone of a type similar to the San Andreas, although movement on the Garlock has been left lateral, with the north block having moved westward relative to the south block.

The Tehachapi Range merges westward with the San Emigdio Range which trends north of west and forms the southernmost of the inner Coast Ranges bordering the San Joaquin Valley on the southwest. These ranges have been formed by compressive uplifts recurring during Cenozoic time along or near the northwest trending San Andreas fault, largest and most vigorously active crustal break in California. Movement on this 600-mile-long vertical shear zone has been largely horizontal, right lateral, with the southwestern block having moved northwest relative to the northeastern block. This fault has been recurrently, if not continuously, active throughout Cenozoic time, and cumulative right lateral displacement has amounted to many tens of miles. The horizontal shear movement has been accompanied by crustal shortening, which in the San Emigdio Range on the northeast side of this great shear zone has been so severe that the once deeply buried rigid basement complex has been shattered and squeezed up to form the high crest of the mountains. The overlying thick Tertiary series has been folded and thrust northward toward the San Joaquin Valley on the Pleito fault along the foothills to form the San Emigdio overthrust.

It is noteworthy that the San Emigdio overthrust lies north of the intersection of the San Andreas and Garlock faults, two master shear zones with opposite horizontal movement. There is suggestive evidence that the White Wolf fault may extend at depth southwest to the San Andreas, and that it may have some left lateral component of movement like the Garlock fault. The White Wolf and Pleito faults are probably genetically related to the Garlock and San Andreas shear faults and not to any of the faults to the north.

The White Wolf Fault

Geologic Evidence. The steep northwest slope of the high westward protrusion of the Sierra Nevada between Tehachapi Canyon and the Tejon Hills has long been recognized as the scarp of a major fault. Such a fault was first recognized by Lawson (1906), and was mapped by Hoots (1930, p. 314), as the White Wolf fault, named after the White Wolf Ranch through which it passes.

The White Wolf fault trends from lower Tehachapi Canyon S 50° W for 17 miles along the base of the steep northwest slope of Bear Mountain to Comanche Point, and probably extends at least an equal distance across the San Joaquin Valley toward Wheeler Ridge. This fault is nowhere clearly exposed and is thereby difficult to trace as the northeastern portion is within quartz diorite, the central portion is covered by numerous landslides from the elevated block, and the southwestern portion is concealed by alluvium. Prior to July 21, 1952, practically nothing was known about this fault. Knowledge of its existence was based entirely on topography and was later substantiated by deep drilling in the valley area north of the fault and at Comanche Point. The steep, abrupt slope of Bear Mountain indicates the fault to have been active in very late Pleistocene and Recent time. Its generally straight base line might lead to the interpretation that the White Wolf fault is a normal fault, but the presence of numerous landslides and earth flows from the elevated mountain block suggests the fault to be of the reverse or thrust type. Left lateral movement on this fault might be inferred from its parallel trend with the left lateral Garlock fault, but this is not conclusively indicated by topographic or stratigraphic evidence.

Surface Ruptures Developed on July 21, 1952. The surface ruptures developed in the ground along the course of the White Wolf fault during the earthquake of July 21, 1952, if these represent the actual movement on the fault, serve to determine its exact location at the surface and indicate its probable direction of dip and nature of movement. Surface cracks formed along almost the entire 17-mile known course of the White Wolf fault, and most of these occurred on or very near its trace. The fracturing occurred mainly along the northeastern, central and southwestern portions of the fault, with gaps in between. The type of rupturing in each portion varies greatly and there is some doubt as to whether these all represent actual tectonic fault movements which caused earthquakes or gravitational earth settling movements which resulted from the earthquakes. For reasons stated in the following paragraphs, these large cracks along the White Wolf fault are believed to be primary features of fault movement on July 21, 1952, as expressed at the surface.



FIGURE 4. Northwestern slope of Bear Mountain, showing landslide topography. Two earthquake cracks, roughly at right angles, are near center of photo. The more prominent crack trends northeast and is close to the trace of White Wolf fault. *Official photograph, U. S. Air Forces, Edwards Air Force Base, Edwards, California.*

In areas upslope from the White Wolf fault there are many small ruptures on the steep slopes of Bear Mountain and on both sides of Sycamore Canyon up to the 4,000 foot contour. These ruptures are 10 to about 200 feet long and either follow a contour or in most cases are concave down slope. They are always gaping and dip steeply downhill with the hanging block having always slid downhill one or several feet. One of these on the south slope of Bear Mountain slid down as much as 30 feet. These are small shallow landslide features which developed only in the soil or in weathered or shattered quartz diorite on steep slopes, and were produced by gravitational settling of this material by lurching resulting from the main shock; they are therefore not faults.

The ruptures developed along the trace of the White Wolf fault are the largest and most extensive, and are believed to be true faults. The greatest and most continuous zone of fracturing exists along the central 5 miles of the White Wolf fault or that portion following the base of the steep 5,000-foot-high granitic scarp of Bear Mountain beginning at a point 4 miles east of Arvin and extending continuously for 3 miles northeastward, then intermittently for another 2 miles to the canyon south of the White Wolf ranch house. The entire mountain block on the southeast side of this zone of fracture was elevated 1 or 2 feet, and thrust toward the northwest. The fracturing along this 5-mile portion of

the White Wolf fault is consequently characterized by thrust fault scarplets usually facing northwest, and associated pressure ridges or mole tracks. In most places the upthrust block formed a single scarplet a foot or two high and traceable for several hundred feet. All the scarplets along this portion of the fault were miniature overthrusts with the plane of movement dipping southeast at low angles and with displacements toward the northwest or west of north. There was no evidence of oblique movement except where the scarplet deviated from the usual northeast trend, in which case the movement was always toward the northwest. In places where a scarplet was not developed, the same amount of shortening was taken up by a series of parallel pressure ridges or mole tracks. The hard dry soil was always broken up into small irregular blocks along the scarplets and ridges. However, in some places where they trend obliquely to the normal northeast trend, oblique tension fissures trending northwestward were developed along each scarplet. The scarplets and bucklings pass around spurs and extend up gullies or small canyons where they indicate an attitude of the plane of movement of about 5° to 20° southeastward toward the mountain mass with a probable average dip of about 15° . Throughout most of its extent, the zone of scarplets and bucklings follows the exact base of the steep mountain front along the contact between quartz diorite above and alluvium below. Only at the west end do the scarplets appear to

die out into alluvium, but mapping indicates that here also the elevated southeastern block is underlain either on the surface or at shallow depths by quartz diorite.

It seems clear that a thrust fault is indicated by the 5-mile-long zone of scarplets and pressure ridges at the base of the granitic scarp of Bear Mountain. Crustal shortening is definitely indicated, not only by the pressure ridges and miniature overthrusts, but in one instance by a fence crossing this zone of buckling in which several posts were pushed several inches toward each other, leaving the wires sagging. There is some doubt as to whether this zone of surface thrusting is an actual thrust movement on the White Wolf fault, or whether it is the result of landslide or earthflow movement of shattered material from the steep slope of Bear Mountain, as it was interpreted by Buwalda (1952, p. 5). Support for the latter interpretation is found in the generally shattered condition of the quartz diorite and resulting landslide topography of the steep northwest slope of Bear Mountain, and by the occurrence of this zone of thrusting only at the base of this high, steep slope. However, the following evidence seems to indicate thrust rather than landslide movement:

- (1) Not all of the lower northwest slope of Bear Mountain is characterized by landslide topography, but much of this slope rises abruptly from the base and is intact.
- (2) There is no large scale rupturing or separation of material upslope on Bear Mountain from the zone of buckling as would be expected if the buckling at the base of the steep slope resulted from downward movement of material from upslope.
- (3) The quartz diorite is shattered only on the lower slopes of Bear Mountain and is generally intact elsewhere.
- (4) The plane of movement is not horizontal nor does it dip downslope, but dips into the mountain throughout its course at an average angle of about 15°.
- (5) The White Wolf fault at the base of Bear Mountain has all the characteristics of a reverse or thrust fault, similar to the Pleito thrust, and not of a normal fault, as its course is irregular—the bedrock immediately above it is highly shattered and the scarp is characterized by numerous landslides as is always true of thrust fault scarps.
- (6) The July 21 earthquake failed to move any of the large landslides on the steep northwest slope of Bear Mountain, a fact indicating that even large landslides are superficial features developed only during or following periods of heavy rainfall.

It is concluded that the zone of surface thrusting at the base of Bear Mountain is most likely the result of actual thrust movement on this portion of the White Wolf fault along which the mountain block was thrust upward and toward the San Joaquin Valley about 3 feet on July 21, 1952.

The zone of rupturing along the northeastern 6 miles of the White Wolf fault between the White Wolf ranch house and the railroad tunnels east of Bealville is characterized by ruptures quite different from those of the central portion. The fractures of the northeast portion did not follow the exact trace of the fault, but occurred as vertical ruptures en echelon along and oblique to it with a more northerly trend. Between the White Wolf ranch house and the Bealville road there are two or three series of north-trending vertical fractures 1 mile to 3 miles long. These fractures developed as small pressure ridges or ruptures in the soil indicating left lateral movement (west block moved south relative to east block) in every case, with fences and highways offset a foot or two. These fractures did not form scarplets except in irregular topography, in which the scarplets

faced either direction, depending on the direction of slope, and always indicated left lateral displacement. The consistent left lateral offsets on these ruptures show them to be true fault cracks formed by tectonic movements rather than landslide cracks formed by earth settling movements.

Between the Bealville road-U. S. Highway 466 intersection and Tehachapi Creek, the White Wolf fault is within quartz diorite and the steep northwest-facing scarp gradually disappears rendering this portion of the fault difficult to locate. Its position is believed determined by an alignment of saddles and small canyons extending north of east from the road intersection, and also by the highly sheared, crushed and shattered condition of the quartz diorite on the north side of this alignment. In the July 21 earthquake fractures developed in the shattered quartz diorite immediately north of this supposed fault trace. The fractures between the road intersection and Southern Pacific Railroad Tunnel 5 trended generally northeast and showed evidence of left-lateral displacement and strong compressive movement indicated by contortion of the rails into S-shaped curves and shortening at tunnel 3 east of Bealville. On the south slope and crestal portion of the large hill through which tunnel 5 passes there were four parallel fractures trending west of north for half a mile and dipping steeply north (see photographs, Part III, Contribution 6). On each of these fractures the northern or uphill side slipped down so that movement on each one formed a gaping fissure up to 6 inches wide and a scarplet up to 2 feet high facing northward upslope. There was no evidence of lateral slip. These are probably minor tensional cross faults to the main course of the White Wolf fault, or might be the result of gravitational settling or lurching of shattered quartz diorite northward toward Tehachapi Canyon.

There is no topographic or structural evidence that the White Wolf fault extends beyond Tehachapi Creek although one small northeast-trending crack formed on the lower northeast slope of the canyon. One large north-trending crack extending about 1000 feet developed across the Tehachapi-Caliente divide, along the contact between quartz diorite and the Bealville conglomerate. This crack dips steeply west and formed a 3-foot scarp facing west.

In Caliente Canyon many very small north-trending cracks formed across the road in shattered quartz diorite for about a mile east of Harper Canyon. These appear to be fractures along jointing in the quartz diorite with no movement indicated.

On the southwestern portion of the White Wolf fault fractures developed along the northwestern base of the hills at Comanche Point and again at the mouth of Little Sycamore Canyon. Others developed about a mile south of the White Wolf fault near the mouth of Comanche Creek and in the foothills to the east. All these fractures were vertical or steep and produced northwest-facing scarplets up to a foot high.

At Comanche Point the alignment of scarplets followed the northwest base of the hills for a mile and the scarplets were vertical and up to 8 inches high. Some showed a small lateral component of movement of several inches.



FIGURE 5. Severe cracking in water-saturated low terrace in lower Comanche Creek; apparently east of White Wolf fault. Photo by Gordon B. Oakeshott.

The scarplets at the mouth of Comanche Canyon and in the foothills to the east were vertical and up to 8 inches high with no lateral motion indicated. These cracks did not seem to follow any definite alignment, but tended to be parallel to the northeast strike of the Chanac formation here. They may have been secondary effects produced by settling movements. At the springs near the mouth of Comanche Canyon, the alluvium was broken by numerous cracks, some of which produced small mud volcanoes of fine sand. These cracks could not be traced into the hills on either side of the canyon; they were obviously produced by lurching of the water soaked alluvium.

At the mouth of Little Sycamore Canyon a continuous zone of rupturing up to 70 feet wide was strongly developed on the White Wolf fault for a mile and a half along the base of the foothills. On the side-hill to the southwest a series of pressure ridges formed in the soil. From the mouth of the canyon northeastward the fracture zone followed the edge of the valley alluvium and was developed as a series of northwest-facing scarplets up to a foot high indicating an overall uplift of the southeastern block of $1\frac{1}{2}$ or 2 feet. The fractures were vertical or dipped steeply southeast, and nearly all showed left-lateral offsets up to 8 inches. In places where no defined scarplets were formed, especially where the fracture zone was dying out northeastward, the hard dry soil was broken by a series of en echelon north-trending gaping ruptures. These were tension ruptures

produced by left lateral motion (southeast block moved northeastward) along this portion of the White Wolf fault.

The fracturing of both Comanche Point and at the mouth of Little Sycamore Canyon was no doubt developed along the trace of the White Wolf fault, and indicated oblique movement on this portion along which the southeastern block was elevated up to 2 feet and displaced northeastward about half a foot. There is some doubt as to whether these fractures represent actual movement on the fault or gravitational settling of the thick valley alluvium, but the generally consistent left lateral displacement on so many of these fractures is difficult to explain by movements other than tectonic or fault movements.

The ruptures along the course of the White Wolf fault indicate a displacement of as much as 3 feet on July 21, on which the southeastern block was elevated and shoved laterally to the northeast. However the displacement at depth at and near the focus was probably much greater than that at the surface, as indicated by the fractures, as the displacement probably decreased upward and in many places failed to reach the surface. In the valley area southwest of Comanche Point past which the fault is believed to extend, the displacement may have been completely absorbed by the thick sedimentary fill; this could account for the total absence of fractures there.

Total Displacement. The amount of total vertical displacement on the White Wolf fault is indicated by the height of the Bear Mountain scarp on the elevated block plus the depth to the basement complex of the relatively depressed block, or the difference of the depth to the basement complex of each block where covered by Tertiary sediments. Depth to the basement complex under the alluviated valley floor is indicated by subsurface contours on the geologic map, based on points on the top of the basement complex as encountered in all wells that reached it. From a study of the geologic map, it may be seen that the total upward displacement of the southeast block of the White Wolf fault increases rapidly from none at Tehachapi Canyon to 5,000 feet or more at the base of Bear Mountain, and 10,000 feet between the mouth of Little Sycamore Canyon and Comanche Point. Southwest of Comanche Point the displacement is unknown, but it probably decreases.

Some left lateral displacement on the White Wolf fault is indicated by movement on the fault fractures as mentioned. However, the total overall lateral displacement must be small, probably not over 2000 feet. The easterly pinchout of the Santa Margarita sand is in about the same position on either side of the fault and therefore is not appreciably offset. There are no definitely offset streams along the course of the fault.

Dip of Fault Plane. The dip of the White Wolf fault plane is to the southeast as indicated by both the surface ruptures and by the physiographic expression of the landslide-covered Bear Mountain escarpment. The amount, as indicated by the ruptures, ranges from 10° to 90° . The ruptures indicate a low dip for the central portion and a high dip for the southwestern and northeastern portions. Perhaps the overall dip may best be indicated by the location of the epicenter—if accu-



FIGURE 6. Mud volcanoes along cracks in water-saturated low terrace in lower Comanche Creek; apparently east of White Wolf fault. Photo by Gordon B. Oakeshott.

rately determined. According to St. Amand (oral communication, November 1952), one important epicenter was located almost directly under Bear Mountain at about 12 miles below sea level. Projecting this position up to the nearest surface trace would determine a dip of about 70° southeast.

From the foregoing it appears that the only surface fractures that represent the true dip of the White Wolf fault are those at and near the mouth of Little Sycamore Canyon. The low angle thrust feature at the base of Bear Mountain must then be a local flattening of the fault at the surface where the elevated mountain block partially overrode the San Joaquin Valley area. The north-trending left lateral fault cracks along the northeastern portion of the White Wolf fault probably branch off from the main fault below the surface and were produced by upward and northeastward movement of the southeastern block.

Type of Fault and Movement. The foregoing data indicate the White Wolf fault to be a high angle reverse fault dipping southeast along which the southeastern block was elevated to a maximum displacement of some 10,000 feet and displaced a much lesser distance to the northeast—relative to the stationary northwestern block. The low-dipping thrust fault rupture along the central portion of the fault indicates that the northwestern or footwall block is stationary and that the southeastern block was actively elevated and thrust northwestward. This is further suggested by the intensity of the earthquake of July 21, 1952, which was more violent in the area southeast of the White Wolf fault than in the area to the northwest.

Possible Northeastward Extension. There is neither physiographic nor geologic evidence that the White Wolf fault extends northeast of Tehachapi Canyon and there is no evidence that the White Wolf fault ties to the Breckenridge Mountain fault. However, between the Tehachapi and Caliente Canyons several isolated ruptures trending nearly northward did develop in shattered quartz diorite. These may have formed along one

or several north-trending branches of the White Wolf fault that might extend at depth as far northward as Caliente Canyon.

Possible Southwest Extension. The extent of the White Wolf fault southwesterly from Comanche Point is unknown as there is no direct surface indication of this fault beyond that point, and no surface ruptures were formed during the earthquake of July 21, 1952. The White Wolf fault apparently does not reach the surface anywhere southwest of Comanche Point. However, stratigraphic, structural, subsurface, geophysical and seismic evidence indicate or suggest that the White Wolf fault does extend southwestward across the San Joaquin Valley and at depth under Wheeler Ridge and the San Emigdio foothills, possibly to the San Andreas fault. The exact location of this buried portion of the White Wolf fault is as yet unknown, but available evidence indicates it to maintain the same $S 50^{\circ} W$ trend as does the exposed portion between Tehachapi Canyon and Comanche Point.

Evidence that the White Wolf fault extends southwest from Comanche Point across the southeastern San Joaquin Valley to Wheeler Ridge is—(1) the 10,000 foot displacement at Comanche Point, indicating the fault to extend far beyond that point; (2) the abrupt change of the water table at the supposed trace of the fault across the valley; (3) differences in depth of geophysical reflections on either side of this buried fault; and, (4) the much greater depth to the base of the Plio-Pleistocene continental sediments in the valley area on the northwest side of the buried fault as encountered in deep wells in which the maximum drilled depth to this horizon is 14,000 feet on the northwest side of the fault and 4,000 feet on the southeast side. Although no well has reached the basement complex in the deeper portion of the valley area on either side of the fault, the marine formations underlying the continental Pliocene strata are consequently much more deeply buried under the valley area on the northwest side of the supposed extension of the White Wolf fault than on the southeast side. The great difference in thickness of the

Plio-Pleistocene continental series on opposite sides of this fault indicates it to have been active during deposition of those sediments.

Evidence that the White Wolf fault extends under Wheeler Ridge is as follows: (1) seismic—the occurrence of the main epicenter (St. Amand and Buwalda, 1953) of the July 21 earthquake, under the southwestern portion of the Wheeler Ridge anticline (latitude $35^{\circ} 00'$, longitude $119^{\circ} 02'$), at a depth of about 10 miles indicates that the White Wolf fault plane must pass through that point; (2) stratigraphic—the White Wolf fault probably passes under the northwestern portion of the Wheeler Ridge anticlinal uplift as the thickness of the Plio-Pleistocene series is about 4,000 feet on this structure, or about the same as in the adjacent valley area to the east, while it is over 12,000 feet thick in the valley area to the north; also a well drilled at the west portion of the Wheeler Ridge anticline reached the basement complex at a depth of about 12,000 feet while the basement complex is probably more than twice as deep in the valley area to the north; (3) structural—faulting under the north flank of the Wheeler Ridge anticline is suggested by its steep dip, and also by the occurrence of southward-dipping minor reverse faults under this asymmetric fold as encountered in deep drilling; faulting under the southward-plunging portion of this anticline is suggested by the northeast-trending alignment of small sharp east-trending subsidiary folds, which appear to be the result of left lateral movement on the White Wolf fault, or one aligned with it, at depth in the basement complex.

Evidence that the White Wolf fault may extend from Wheeler Ridge southwestward under the San Emigdio foothills at depth is suggested by the sharp upturning and intense folding of the Cenozoic sediments along these foothills. This disturbed zone is joined by the Pleito fault from the southeast, which here curves south of west to follow this zone of disturbance for some 12 miles nearly to the San Andreas fault, as mapped by Hoots (1930, map). Along this trend the Pleito fault steepens to over 50° as indicated by a well drilled in Pleito Canyon, and the basement complex is brought to the surface on the elevated southern block west of San Emigdio Canyon. This portion of the Pleito fault and the adjacent zone of sharp folding on the footwall block are aligned with the White Wolf fault, suggesting this zone of disturbance to have formed along or over the deeply buried White Wolf fault zone in the basement complex below.

While detailed mapping indicates that the Pleito fault zone does not extend to the San Andreas fault, nevertheless a distinct bend or curve concave northeast is developed in the San Andreas where the Pleito fault, or the underlying White Wolf fault zone, would intersect it if projected to it. Northwest from that point the San Andreas fault trends consistently $N 45^{\circ} W$, and to the southeast it trends $N 60^{\circ} W$. Although this bend is not sharp it is noteworthy in being the greatest deviation of trend in the San Andreas and suggests that this rift zone is intersected by the White Wolf fault at depth, that the bend may have resulted from left lateral movement on the buried White Wolf fault, and that the Pleito



FIGURE 7. Cracks and scarplets in White Wolf fault zone, Tejon Hills, just northeast of Comanche Creek. Photo by Gordon B. Oakeshott.

fault zone developed partly from uplift of the southeastern block on the White Wolf fault below.

Age of the White Wolf Fault. The White Wolf fault appears to have been most active during Pleistocene and Recent times. It may have been active during most, if not all, of Pliocene time as indicated by the much greater thickness of the Pliocene sediments of the San Joaquin Valley throughout the northwest block as compared to the southeast block as encountered in deep drilling. The fault may have been initiated in Miocene time, although there is as yet no definite evidence.

Regional Tectonics

The tectonic movements active in this area are the result of constant regional strain in this part of the earth's crust. The mapped area lies at the juncture of three great physiographic provinces—the Sierra Nevada, Great Valley, and Coast Ranges provinces. Adjacent ones are the Basin Ranges province to the east, Mojave Desert province to the southeast, and Transverse Ranges province to the south. Each one of these physiographic provinces is also a tectonic province, characterized by a well defined strain pattern, so that within the mapped area several related strain patterns exist.

Sierra Nevada-Great Valley Provinces. The Sierra Nevada-Great Valley province is made up of crystalline rocks stabilized during the Jurassic Nevadan orog-

eny to a comparatively rigid, compact mass and is overlain by a generally little disturbed Cretaceous-Cenozoic sedimentary series under the Great Valley. This large, rigid segment of the earth's crust has resisted tectonic movements; only in the extreme southern portion, where tectonic movements have been more severe, has it yielded by faulting.

The southern Sierra Nevada, bounded on the east by the Sierra Nevada normal fault zone, is partly broken into two major north-trending blocks by the normal Kern Canyon-Breckenridge fault zone.

Southeastern San Joaquin Valley. The mountainous areas surrounding the southeastern San Joaquin Valley are undergoing active uplift. These are rising portions of the earth's crust caused by constant, deep seated compressive and shear movements active throughout Quaternary time on the San Andreas, Garlock, and related faults. Earthquake-producing displacements have occurred on these faults several times in a century, and an earthquake produced by slippage on one may set off movement on another. This apparently happened during the recent earthquake in which the movement on the White Wolf fault that produced the shock of July 21, 1952, may have set off movement on a minor buried fault southeast of Bakersfield that caused the Bakersfield earthquake of August 22, 1952. It is also possible that many of the aftershocks of the first earthquake may have been caused by movements on minor faults in the vicinity of the White Wolf fault.

The southern Sierra Nevada foothills and eastern San Joaquin Valley northward from the White Wolf fault are cut by many parallel faults trending northwest to north. In the area south of the Kern River the faults trend generally northwest, and north of the river, tend to swing north. They trend due north in the Kern Front oil field area north of Bakersfield. This makes a broadly arcuate pattern. The great majority of these faults are of normal type although some are probably vertical or even steep reverse. Many of the northeast-dipping normal faults bound southwest-tilted blocks as indicated by the steepened southwesterly dip of the Tertiary sediments involved. These faults are of the same type as the major faults of the Sierra Nevada and displacements are probably mostly if not entirely vertical, although there are evidences of some lateral movements.

The southern Sierra Nevada is broken by only two widely spaced major normal faults—the Sierra Nevada and Kern Canyon-Breckenridge; while the adjoining foothill area is broken by moderately spaced normal faults of moderate displacement, the largest being the Kern River and Edison faults. The eastern margin of the adjacent San Joaquin Valley is broken by faults more closely spaced and with very small vertical displacements. From northeast to southwest the faults become progressively more closely spaced and their vertical displacements appear to decrease outward into the San Joaquin Valley.

The extreme southeastern portion of the Sierra Nevada-San Joaquin Valley provinces was elevated as a block on the northeast-trending White Wolf fault to form the Bear Mountain-Tejon Hills uplift. The Tehachapi Mountains are in part a compressive uplift formed against the northeast-trending Garlock fault, a

master shear zone separating the Sierra Nevada from the Mojave Desert province to the southeast. Nearly all of the movement on the Garlock fault has been left lateral, along which the Mojave Desert block has moved relatively northeastward. This would indicate a great north-east-southwest counterclockwise torsional stress. The Garlock fault took up nearly all this stress between these two provinces of crystalline rocks. However, a small part of this stress was taken up on the White Wolf fault as indicated by the small left lateral component of movement on it.

The area between the White Wolf and Garlock faults has undergone some northwest-southeast crustal shortening, as indicated by the northerly or northwesterly movement of the Bear Mountain uplift on the southeastward-dipping White Wolf fault, by east-west folding in the Tejon Hills, and by the compressive uplift of the Tehachapi Mountains against the Garlock shear zone. This would suggest a north-south compressive stress.

The pattern of slightly to moderately tilted north-northwest-trending fault blocks is similar to that of the Basin Ranges province so that both areas are apparently under the same stress. However, too little is known to determine what stress formed this pattern. The normal faults indicate, at least near the surface, an east-west tensional stress yet the mountain blocks seem to be actually rising as if heaved up from below while some of the valleys (such as Death Valley) are apparently sinking. The most plausible hypothesis that can be offered is that the entire combined Sierra Nevada-Basin Ranges province constitutes a thick segment of the earth's crust which was arched upward probably by a very deep-seated east-west compressive stress; and that the upper portion of this thick segment became broken into north-south trending blocks, some of which failed to rise, or even sank. During this arching process, the western margin became compressed downward to form the Great Valley. In the eastern San Joaquin Valley, the arcuate pattern of faults with the trends gradually swinging from south to southeastward suggests that southward the subterranean stress was directed progressively more from an east-west to a northeast-southwest direction.

The extreme southeastern portion of the Sierra Nevada-Great Valley province is thus affected by three stresses: (1), a deep subterranean east-west and/or northeast-southwest compressive (?) stress; (2), a north-east-southwest counterclockwise torsional stress; and (3), a relatively shallow north-south compressive stress.

Coast and Transverse Ranges Provinces. In the San Emigdio Mountains, the strain pattern is one of extensive north-south crustal shortening as indicated by northward movement of the San Emigdio uplift on the southward-dipping Pleito thrust fault and by the strongly compressed folds in Cenozoic strata with axes trending slightly north of west. The crustal shortening developed in the Tehachapi Mountains progressively increases westward into the San Emigdio Range as indicated by the increasing amount of movement on the Pleito fault and increasing deformation of the Cenozoic strata westward. This pattern is obviously the result of a severe compressive stress directed from the south or slightly west of south, and is progressively more intense west of that active in the Tehachapi Mountains.



FIGURE 8. View west toward Jones ranch house, showing cracks in alluvium. These cracks are not parallel to the fault trace but are in an area of extensive lurch cracking on the valley floor. At Edison Road about 4 miles southwest of Arvin. *Photo by Lawrence W. Chasteen.*

The San Emigdio Range, the southeasternmost member of the Coast Ranges province, is a compressive uplift built up against the San Andreas fault, as are all of the Coast Ranges adjacent to this great right lateral shear zone. The strain pattern of the San Emigdio Range is thus typical of that throughout the Coast Ranges province.

In marked contrast to the rigid Sierra Nevada-Great Valley province, the Coast and Transverse Ranges provinces together are a great zone of weakness in the earth's crust. It is an unstable zone of intense crustal shortening and shearing in which the San Andreas fault is the greatest single rupture.

In the Coast Ranges province the strain pattern is composed of several faults of the San Andreas type, that is, northwest-trending vertical or high angle shear faults with right lateral displacements of which the San Andreas is the largest and most active, and a series of tightly squeezed folds trending slightly west of north-west and some reverse or thrust faults with a similar trend. The San Andreas type faults are deep-seated ruptures originating many miles deep in the basement complex. Several of these faults were active throughout Cenozoic time with cumulative right lateral movements amounting to many tens of miles (Hill and

Dibblee, 1953, pp. 443-458). These great shear faults must be the result of a northwest-southeast clockwise torsional stress. The compressive folds and lesser reverse or thrust faults are comparatively shallow structures affecting the Cretaceous-Cenozoic strata and are most intense and numerous adjacent to or near the great shear faults and decrease outward away from them—as in the San Joaquin Valley. These compressive structures must therefore be subsidiary to the master shear type faults and were formed by an east-northeast west-southwest compressive force resulting in part from right lateral horizontal drag on the shear faults and in part from pressure and counterpressure of the opposing fault blocks.

In the Transverse Ranges province, the strain pattern is basically the same as that of the Coast Ranges province except that the folds and reverse or thrust faults trend more nearly east and in addition there are several major shear type of oblique slip faults trending slightly south of west with left lateral movements similar to the Garlock and White Wolf faults. This would indicate, in addition to the stresses active in the Coast Ranges province, that the northeast-southwest counter-clockwise torsional stress active along the Garlock shear zone across the San Andreas fault affected the Transverse Ranges province also.

Tectonic Implications of the Strain Patterns. Tectonic implications and relationships of the San Andreas, Garlock and other major strike-slip faults and related structures are discussed by Hill and Dibblee (1953), who suggest that they are genetically related and resulted from an overall single regional north-south stress.

It is concluded that the White Wolf fault is genetically related to the Pleito and Garlock faults and possibly in part to the San Andreas fault, but not to any of the faults to the north. Both the White Wolf and Pleito faults are in part the result of compressive stresses developed along both the Garlock and San Andreas shear zones. This is indicated by the southward dip of both faults toward the great shear zones and squeezing of the area between these faults and the shear zones. The White Wolf fault is believed to be closely related to the Garlock fault as indicated by its northeast trend parallel to it, southeast dip toward it, and by evidence of left lateral movements on both. The bending of the great San Andreas shear zone at both points where it is, or may be, intersected by the Garlock and White Wolf faults implies that both these northeast-trending faults are deep seated zones of weakness along which the rigid Sierra Nevada-Great Valley block is being pushed southwestward relative to the Mojave Desert block.

3. KERN CANYON LINEAMENT

BY ROBERT W. WEBB *

Introduction. The recent earthquakes in the Tehachapi area of the southern Sierra Nevada have refocused attention of geologists on this critical area of California structure. The recent summary of the Arvin-Tehachapi earthquake (California Division of Mines, 1952), calls attention to what may be a structural pattern in a series of faults (Jenkins, 1938; Nugent, 1942) whose geological relationships have never been established. The faults in question are known as the White Wolf, Breckenridge Mountain, Havilah Valley, Hot Springs, and Kern Canyon faults. The regional topographic pattern of these faults and the inter-segments between them will be referred to as the "Kern Canyon lineament." It seems pertinent to examine what is known currently about the structural pattern and to suggest a possible interpretation for the apparent pattern.

Geography of the Faults in the Lineament. The disconnected fault zones and inter-segments that appear to compose a structural lineament extend from the Tejon Hills in the southern San Joaquin Valley, northeastward and northward for more than 100 miles, beyond the headwaters of the Kern River. The faults have been studied, and evidence (Hoots, 1930, pp. 301-319; Lawson, 1906; 1904, pp. 291-376; Webb, 1936) for them presented. Between these are apparently unfaulted segments, none of which has been mapped in sufficient detail to prove positive connection, at least in the present-day structural pattern; other inter-segments are unmapped.

Historical Background. The first recognition of an important fault in the Kern River Canyon was by Lawson (1904), in the first of a series of three papers, discussing faulting in the upper Kern Basin. In a second paper (1906) he presents his observations made in the middle Kern Basin, the Havilah Valley, and Walker Basin, which suggested to him the apparent importance of faulting. A connection between the northern (Kern Canyon) faults and those in the Havilah and Walker regions was tentatively postulated. In his third paper on the Tehachapi Range (Lawson, 1906a) he recognized the important Tehachapi (White Wolf) fault, and raised the possibility of a connection between the earlier described faults and the White Wolf, although no connection between any of these faults was seriously implied, since he did not undertake geologic mapping. In 1922, the publication of a structural map of California (Seismological Society of America, 1922) showed the White Wolf fault, and that part of the Kern Canyon fault from the mouth of Golden Trout Creek nearly to Fairview, as "dead fault, well located;" the Breckenridge fault is symbolized as "probable fault, character and location uncertain." Additional geologic studies were not published until 1928, when faulting was mentioned incidental to other geologic problems (Hake, 1928; Miller, 1931). The White Wolf fault was mapped in 1930 (Hoots, 1930), and the Kern Canyon fault studied in 1936 (Webb, 1936). Interest in damsites along the Kern

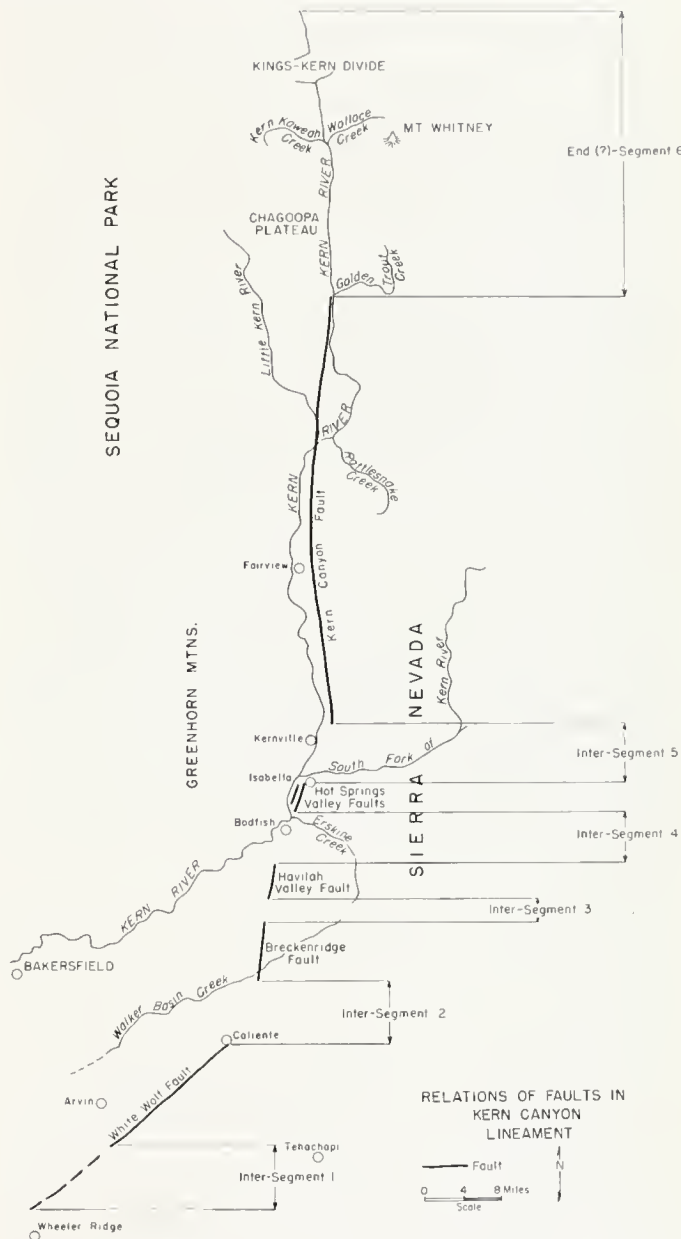


FIGURE 1.

River was revived, and several reports appeared ¹ (Marliave, 1938; Treasher, 1949, 1949a). Significant information on faulting in Hot Springs Valley, at the site of the new Isabella Dam near the junction of Kern, and South Fork of Kern River will appear with the full publication of these studies. A geologic map of the Kernville quadrangle was published in 1940 (Miller and

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¹ Holdredge, Clair, Personal communications, July 19, 1949, and Oct. 7, 1949.

Webb), and included the southern part of the Kern Canyon fault and some observations on the Hot Springs fault; the influence of faulting in the mines in the vicinity of Kernville was discussed in a paper on the Big Blue mine (Prout, 1940); and the northern section of the Kern Canyon fault was mapped in 1946 (Webb, 1946). It is evident that no published work to date justifies the assertion of a single fault; nor of the connection of the separate faults into a master structure.

The map of California accompanying the text on the Arvin-Tehachapi earthquake (California Division of Mines, 1952, p. 2) is the first known to the writer since the 1922 map cited above that clearly shows the White Wolf fault as a separate and distinct structure, based on geologic mapping by Dibblee (Dibblee and Chesterman, 1953) in one of the critical inter-segments.

Interpretation of the Lineament. Although the relationship between the White Wolf, Breckenridge, Havilah Valley, Hot Springs Valley, and Kern Canyon faults is imperfectly known, the topographic patterns suggest a regional plan of the faults. The relation to the curving southern end of the Sierra, where the Sierra Nevada fault system and the Garlock fault system merge, seems significant. Also, if such superficial evidence as slickensides and epidotized joints is accepted, faulting can be demonstrated in segments between recognized faults. Reconnaissance in intersegments shows that the rocks involved are almost exclusively of the massive plutonic type, whereas faults are reflected in areas where the basement complex includes many penchants and residual areas of metamorphic rocks.

Faults arranged in a lineament, with evidence of ancient or recent movements on some faults and little or

no evidence of faulting in rocks of inter-segments might be explained by a geologically ancient continuity of the faults, with no necessary current relation of faults of a former continuous structure. An explanation of an apparent regional pattern might be found if the nature of fault decline with depth were understood.

The roots of a major fault of regional proportions originally continuous in a rock cover now stripped from an uplifted land mass, might be evidenced by residual segments, parts only of the original fault. The structural effects of fault movement, such as measurable displacement and drag, slickensides, gouge, and brecciation, effective to differing depths and in differing degrees as the original fault descended into changing rock types of the block would thus be discontinuous.

The Sierra Nevada might be such a block, thus faulted and denuded.

The assumption so often repeated in map and text of a major continuous fault, extending from the headwaters of the Kern River on the north to the San Joaquin Valley on the south through more than 100 miles will not easily be dispelled. Though the possibility of a direct present relationship between separate faults known in this regional lineament must be admitted, the concept of a single structure important in today's geology should be abandoned. The suggestion that the faults known today may be remnants of an ancient, and originally continuous, fault, developed in the cover rocks of the ancient Sierra Nevada, is advanced as a plausible explanation of the topographic lineament. Understanding of this lineament, like so many of the faults of regional geologic maps, rests, like all other geologic problems, on completion of detailed geologic mapping.