6. GEOLOGY OF THE TRANSVERSE RANGE PROVINCE, SOUTHERN CALIFORNIA*

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GENERAL FEATURES

The Transverse Range province of southern California is an elongate geomorphic and structural unit that trends essentially east-west across parts of Santa Barbara, Ventura, Los Angeles, San Bernardino, and Riverside Counties (pl. 4). Its name reflects its transverse orientation with respect to the adjacent provinces, especially the Coast Ranges and Sierra Nevada to the north and the Peninsular Ranges to the south. This distinctive province is geologically very complex, and comprises chains of mountains and hills that are flanked or separated by narrow to moderately broad valleys. These features, as well as most of their structural elements, lie athwart the general northwest-southeast grain of southern California, and several of them are responsible for the anomalous east-west alignment of the coast from Point Conception to the Santa Barbara area, and along the north side of Santa Monica Bay.

The Transverse Ranges extend from the most westerly part of the southern California coast, where the Santa Ynez Mountains plunge under the Pacific Ocean at Point Arguello, to the eastern end of the Little San Bernardino Mountains, in central Riverside County, and even to points beyond. On the basis of major structural features, the inland end of the province can be placed at the eastern edge of the Eagle Mountains, or only about 50 miles from the Colorado River. Thus the total length of the Transverse Ranges exposed above sea level is about 300 miles. The province is about 50 miles wide at its western end, as measured between the Santa Ynez River and the Channel Islands southwest of Santa Barbara; as much as 55 miles farther east, as measured between Tejon Pass and Santa Monica Bay; only 15 miles in the Cajon Pass area, where the San Andreas fault zone separates the San Gabriel and San Bernardino Mountains; as much as 30 miles in the middle part of the San Bernardino Mountains; and 20 miles or less in the areas farther east (pl. 4).

The province is characterized by great topographic contrasts, and includes much of the highest ground in southern California. It is divisible into thirteen well-defined topographic and geologic units, which can be described, in a general west-to-east direction, as follows:

1. The *Santa Ynez Mountains* extend eastward from Point Arguello to the Ventura River, a distance of 80 miles. Their crest height ranges from 1,500 feet to 4,800 feet. They consist mainly of sedimentary rocks that are Cretaceous to Quaternary in age.
2. The *Topatopa Mountains* are an easterly and wider continuation of the Santa Ynez Mountains, and extend to lower Sespe Creek, north of Fillmore. Here they give way to the *Piru Mountains*, which terminate against the San Gabriel fault north of Castaic (pl. 4). The combined length of these two ranges is approximately 36 miles, and much of their crest line is 3,500 feet to 6,700 feet in altitude. They are underlain chiefly by sedimentary rocks of early and middle Tertiary age.
3. The *Channel Islands* and *Santa Monica Mountains* form a range that is at least 125 miles long and 3 to 12 miles wide. It terminates eastward at the Los Angeles River. Much of the range has altitudes of 500 feet to 3,000 feet; a large part of the remainder, in contrast, lies beneath the Pacific Ocean. It is composed mainly of Cretaceous to Miocene sedimentary and volcanic rocks. Older crystalline rocks appear in the eastern part of the Santa Monica Mountains and on Santa Cruz Island.
4. *The Pine Mountain-Frazier Mountain interior ranges* form a 12- to 25-mile wide complex group of short, high, and rugged subparallel ridges of sedimentary rocks, as well as still higher and less elongate granitic mountain masses. These lie between the San Rafael Mountains on the northwest and the Santa Ynez and Topatopa Mountains on the south, and they are terminated on the northeast by the San Andreas and associated faults. The tops of the sedimentary ridges rise to elevations of 5,000 feet to 7,400 feet above sea level, and the tops of the granitic mountains have elevations of 6,000 to 8,800 feet.
5. The *Ventura basin* lies between the Santa Ynez and Topatopa Mountains on the north and the Santa Monica Mountains and Channel Islands on the south. It contains several intra-basin chains of hills and mountains that in general are anticlinal. They rise from 400 feet above sea level to as much as 3,700 feet in the Santa Susana Mountains. Between these intra-basin highlands are broad-bottomed synclinal lowlands, the Ojai, Santa Clara, and Simi Valleys. Two of the ranges, Oak Ridge and Camarillo Hills, die out at their west ends into the flat, alluviated Oxnard Plain, which is the most extensive lowland in the Ventura basin. The western half of the basin is occupied by an epicontinental sea, the Santa Barbara Channel. The Ventura basin, including the submerged portion, is about 120 miles long and 20 to 40 miles wide. Its axial portion is marked by the valley of the Santa Clara River (fig. 4).
6. The Ventura basin is bounded on the east by the San Gabriel fault, beyond which lies the *Soledad basin*. This elongate basin is flanked on the south by the San Gabriel Mountains, and terminates eastward against the San Andreas fault zone. Both the Ventura and Soledad basins contain thick sections of marine and nonmarine strata of Cenozoic age, but the history and conditions of sedimentation appear to have been so different on opposite sides of the San Gabriel fault that the two basins are best regarded as separate units.
7. The *Ridge basin* lies north of the eastern end of the Ventura basin, and is bounded on the southwest by the San Gabriel fault, on the north by the San Andreas fault, and on the east by the Liebre Mountains and Sierra Pelona. It trends northwest, and is about 20 miles long and 2 to 8 miles wide. It is distinguished by an enormously thick section of dominantly nonmarine strata of Pliocene and late Miocene age, and its history evidently was quite different in many respects from those of the nearby Ventura and Soledad basins.
8. The *Liebre Mountains* and *Sierra Pelona* are en-echelon ranges that lie between the Mojave Desert on the north and the Soledad basin on the south. They are separated from the Topatopa Mountains by the Ridge

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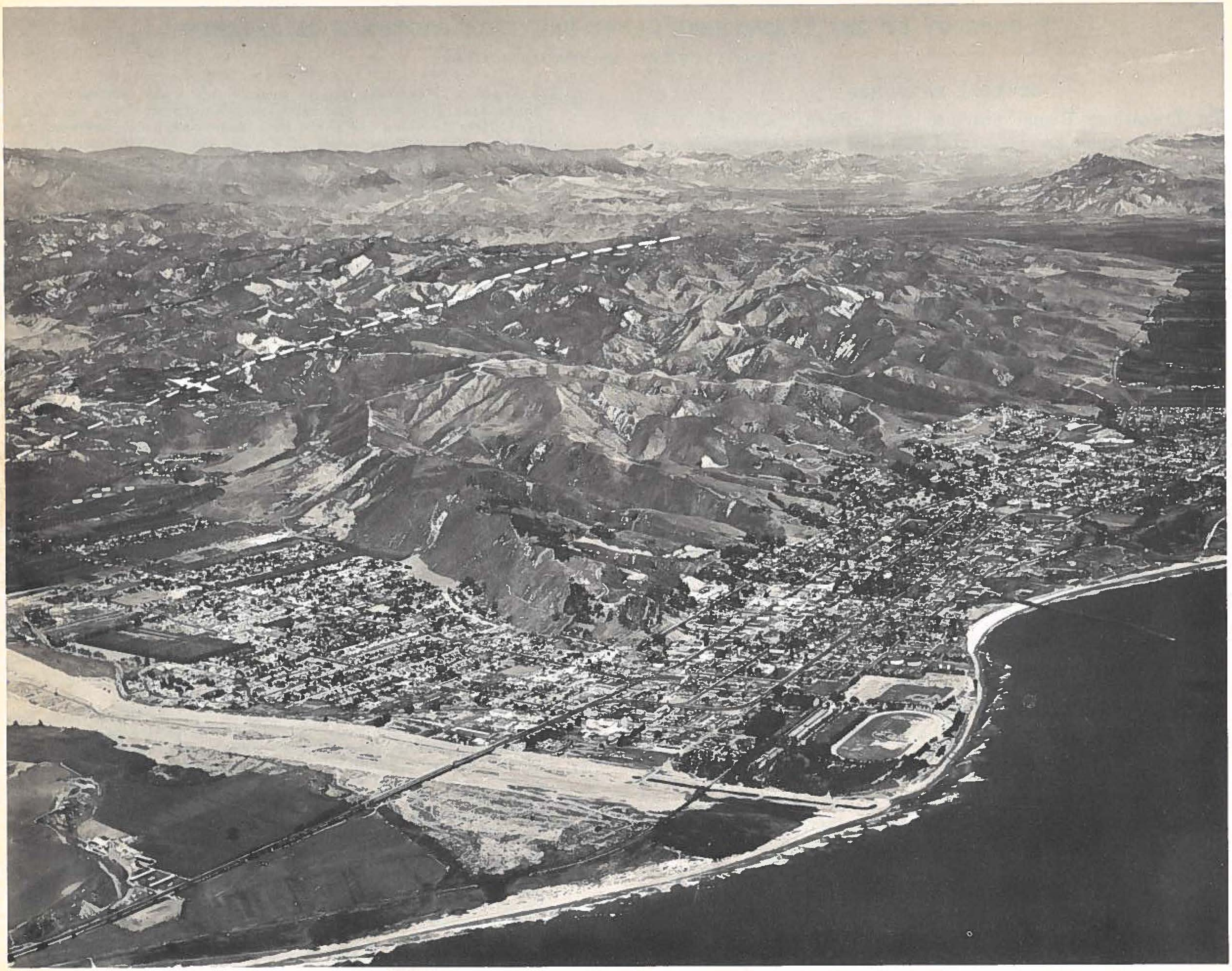


FIGURE 1. View east-northeast toward central part of Ventura basin, from Ventura (foreground). Ventura River is in middle and left foreground, and Santa Clara River valley is at right and in distance. Topatopa Mountains form the skyline at left. Hills in center of view consist of marine Pliocene and lower Pleistocene strata on the south flank of the Ventura anticline, the axial trace of which is shown approximately by the dashed line. *Pacific Air Industries photo.*

basin, and terminate eastward against the San Andreas fault zone. In most places they rise to altitudes of 3,000 feet to 5,800 feet. Unlike most of the ranges farther west, they consist almost entirely of igneous and metamorphic rocks that are pre-Cenozoic in age.

9. The *San Gabriel Mountains* form a bold, high mass that extends from the east end of the Ventura basin near Newhall to Cajon Canyon northeast of San Bernardino (fig. 3), a distance of about 60 miles. This range is lens-shaped in plan, and rises to general altitudes of 5,000 to 9,000 feet. Its highest point, the summit of San Antonio Peak, is 10,080 feet above sea level (fig. 2). The range is bounded on all sides by major faults, and is composed of plutonic igneous rocks of late Mesozoic age, together with a very complex series of older plutonic, metasedimentary, and metavolcanic rocks.

   The *Verdugo Mountains* and *San Rafael Hills* form a ridge, 15 miles long and 3 miles wide, that apparently is an upfaulted sliver of crystalline rocks along the south side of the western San Gabriel Mountains (fig. 4). This ridge forms a part of the east boundary of the San Fernando Valley, northeast of Los Angeles.

10. The *San Fernando Valley*, a broad plain about 10 miles by 20 miles in its elliptical plan, lies between the western San Gabriel Mountains and the eastern Santa Monica Mountains (fig. 4). This plain or sub-basin is an en-echelon offshoot from the southeastern part of the Ventura basin, and beneath the alluvium on its floor is a complex section of Cenozoic and upper Mesozoic sedimentary rocks.

11. The northern third of the *Los Angeles basin*, which adjoins much of the San Gabriel Mountains on the south, includes the thickly alluviated San Gabriel Valley and the intra-basin Repetto and San Jose Hills along the southern margin of this valley. Most of this area is underlain by sedimentary and volcanic rocks of middle and late Tertiary age. Although other east-trending low ranges, such as the Coyote Hills, are present farther south in the Los Angeles basin, most of the structural elements in the central and southern parts of this basin have a northwest alignment and hence represent the northern end of the Peninsular Range province.

12. The *San Bernardino Mountains* extend eastward from Cajon Pass for a distance of 55 miles, and in general rise to altitudes of 5,000 feet to 11,000 feet. They are distinguished by deep and steep-walled canyons, a subdued upland surface that is markedly discontinuous, and several prominent peaks and ridges that include San Gorgonio Peak, whose summit (altitude 11,485 feet) is the highest point in southern California (fig. 14). The east end of these mountains is marked by Morongo Valley, which separates them from the Little San Bernardino Mountains farther east.

    A zone of profound disturbance, defined mainly by the San Andreas and San Jacinto faults, separates the San Bernardino Mountains from the San Gabriel Mountains to the west (fig. 3). The geology of the two ranges is similar in many respects, but metamorphosed sedimentary rocks of Paleozoic age are more abundant in the San Bernardino Mountains. These strata rest upon a complex assemblage of older, more severely deformed rocks, and are cut by widespread plutonic rocks of Mesozoic age.

13. The *Little San Bernardino Mountains*, *Pinto Mountains*, and *Eagle Mountains* are desert ranges in a belt that extends eastward from Morongo Valley for a distance of about 70 miles. They range in altitude from 3,000 feet to 5,400 feet. They are composed mainly of Mesozoic plutonic rocks that contain numerous septa and inclusions of older metamorphic rocks, and some very large masses of these older rocks also are present.

The climate in much of the Transverse Range province is semiarid, but it ranges widely from subhumid and humid in the higher parts of the San Gabriel and San Bernardino Mountains to truly arid at the eastern end of the province. The higher peaks in the San Bernardino and San Gabriel Mountains usually are snow-capped during much of the year (fig. 2), and snow frequently lasts through the winter months in the Pine Mountain-Frazier Mountain interior ranges and in the higher parts of the Topatopa Mountains. In most of the region the annual rainfall ranges from 12 to 20 inches, and nearly all of it falls during the period from November to March, inclusive.

The topography in much of the region represents late youthful to early mature stages of the erosion cycle, and sharp, rugged ridges and narrow, steep-sided, deeply incised valleys are characteristic. Most of the streams are intermittent, and generally flow only during the winter and spring seasons. An apron of large alluvial fans is a prominent physiographic feature of the oversteepened south front of the San Gabriel Mountains (fig. 2), and many well-developed fans and pediments also are present on the north slopes of this range, as well as on the flanks of the San Bernardino Mountains and the desert ranges to the east.

The geology of large parts of the Transverse Range province has been described by several investigators, notably Dibblee (1950), Hill (1928), Kew (1924), Miller (1934), Reed (1933), Simpson (1934), and Vaughan (1922). Many descriptions and discussions of smaller areas and specific features or problems also have been published, and a sampling of these is included in the list of references at the end of this paper. The region contains numerous marine and nonmarine terraces, upland surfaces of low relief, fault-controlled valleys and canyons, and other physiographic features that raise interesting problems, but most of these are noted elsewhere in this volume (see especially Sharp, Contributions No. 1 and No. 3, and Putnam, Contribution No. 7, Chapter V), and hence are not discussed in this paper.

THE GEOLOGIC SECTION: OLDER ROCKS

General Relations. As indicated in the foregoing resumé, the Transverse Range province varies tremendously in its exposed lithologic components, which are shown in generalized form in plate 4. As in other parts of southern California, the geologic section is readily divisible into two main parts that are separated by a profound unconformity. This break, and the marked contrasts between the rocks that lie above and beneath it, reflect a major episode of Mesozoic diastrophism, igneous intrusion, and metamorphism.

The oldest rocks above the unconformity are marine strata of Upper Cretaceous age, and in some places the rocks beneath it are mildly metamorphosed strata that may well be as young as Cretaceous. In the eastern part of the Transverse Range province, the

FIGURE 2. View northeast toward scarp of San Gabriel Mountains, from Pomona (foreground). The three main peaks are, from left to right, San Antonio Peak, Ontario Peak, and Cucamongá Peak. San Bernardino Mountains form the skyline at right. The large alluvial fan in central part of view heads at the mouth of San Antonio Canyon; the course of this canyon marks the trace of a major zone of transverse faulting. *Photo courtesy Fairchild Aerial Surveys, Inc.*

exposed rocks are almost wholly igneous and metamorphic types of pre-Cambrian to Cretaceous age, and hence are members of the older sequence. Similar rocks are present in the western part of the province, but in most of the ranges and basins there they are concealed beneath thick sections of Cretaceous, Tertiary, and Quaternary clastic sedimentary rocks.

Most abundant and widespread in the sequence that lies beneath the great unconformity are plutonic rocks, mildly to severely metamorphosed sedimentary and volcanic rocks, and complex assemblages of migmatitic gneisses. These rocks, referred to collectively as "basement," "basement complex," or "crystalline basement" by many geologists, bear testimony to a highly involved series of events that probably began in pre-Cambrian time and culminated with development of batholithic masses of plutonic rocks in late middle or even late Mesozoic time.

The Western Ranges. In the Santa Ynez Mountains basement rocks are exposed only in a few small areas near the northern margin of the range. They consist of slightly metamorphosed but highly folded and faulted arkosic sandstones, slaty shales, and radiolarian cherts that have been intricately invaded by masses of serpentine and other basic intrusives. These rocks are a part of the Franciscan group, and probably are of Jurassic age.

Beneath the sedimentary strata of the Topatopa Mountains are granodiorite and related plutonic rocks of Jurassic or Cretaceous age, which enclose some roof pendants of older gneiss. These rocks are extensively exposed in areas to the north, and Frazier Mountain and Mount Pinos, for example, are underlain chiefly by quartz diorite, granodiorite, and a variety of migmatitic gneisses. The Sierra Pelona and the high northern part of the Liebre Mountains consist mainly of schists and gneisses that have been intruded by large bodies of granitic rocks. The oldest recognizable unit in this basement terrane is the Pelona schist, a thick sequence of quartz-mica schist, actinolite-mica schist, and chlorite-rich schists with minor beds of interlayered quartzite, marble, and amphibolite. Most of these rock types are fine grained, but in places they are closely associated with coarse-grained, highly deformed gneisses and migmatites. They probably are pre-Cambrian in age (Simpson, 1934, pp. 380-381). Sediments of presumably Paleozoic age are represented by hornfels, schist, and marble that occur mainly as pendants and inclusions in younger plutonic rocks.

The core of the Santa Monica Mountains and Channel Islands comprises several thousand feet of mildly metamorphosed argillaceous rocks and numerous younger intrusive masses of granitic to quartz dioritic composition. The dominant rock type in the metamorphic sequence has been variously termed argillite, phyllite, and slate, and in places it grades into mica and chlorite schists. It is lithologically similar to rocks of known Triassic age in the Santa Ana Mountains to the southeast, and is fundamentally different in composition and texture from mildly metamorphosed argillaceous rocks that crop out in the Palos Verdes Hills and on Catalina Island to the south (see Woodford, et al., Contribution No. 5, this chapter).

The Eastern Ranges. The San Gabriel Mountains are composed of a wide variety of crystalline rocks whose origin and age relations are not yet fully understood. An older sequence, of probable pre-Cambrian age, is represented in the northeastern part of the range by the Pelona schist (Noble, 1927), and elsewhere in the range by a complex and highly deformed assemblage of gneiss, schist, quartzite, marble, and numerous hybrid rocks, in part termed the San Gabriel formation by Miller (1934, pp. 49-56). Recent investigations near the western end of the range have demonstrated, by means of analyses of clean zircon concentrates, that at least two kinds of plutonic rocks there are pre-Cambrian in age (Neuerburg and Gottfried, 1954).

Of particular interest in the western third of the range is a gabbroic complex that includes anorthosite, norite, various transitional rocks, and apatite-ilmenite rocks (Miller, 1931; Higgs, Contribution No. 8, Chapter VII, this volume). The anorthosite is composed almost entirely of andesine. It has been thoroughly shattered and extensively sheared on a wide range of scales, and it contains numerous dikes and inclusions of other rock types (fig. 5). It characteristically weathers chalky and white, and commonly forms ridges and slopes that are fairly smooth in detail (fig. 11).

A younger sequence of rocks in the San Gabriel Mountains includes argillite, phyllite, quartzite, some marble, and several volcanic types. Some of the strata probably are correlative with fossiliferous upper Paleozoic rocks in the San Bernardino Mountains to the east, whereas others may well be Mesozoic in age. Still younger is a group of widespread plutonic rocks that range in composition from diorite to granite, and that probably are Jurassic or Cretaceous in age (Miller, 1934, pp. 61-65; Simpson, 1934, p. 384; Woodford, 1939, p. 257). In most parts of the range both these and the older rocks have been shattered and sheared to an impressive degree, and numerous zones of mylonite have been recognized (Alf, 1948). Many of the rocks are interlayered or otherwise intimately mixed (fig. 6), and the igneous rocks commonly contain abundant inclusions. Both the igneous and the metamorphic rocks are transected by dikes of aplite, pegmatite, lamprophyre, amphibolite, and fine-grained basaltic to rhyolitic rocks.

The San Bernardino Mountains are composed mainly of gneisses, schists, plutonic rocks, and several kinds of hybrid rocks, and also contain a sequence of marble, in which fossils of Carboniferous age can be recognized, and older quartzites and carbonate rocks of Paleozoic age (Vaughan, 1922, pp. 352-361; Woodford and Harriss, 1928, pp. 268-271; Guillou, 1953, pp. 3-13). The Paleozoic section appears mainly in the northeastern part of the range, and is about 10,000 feet thick. As in the San Gabriel Mountains, the rocks can be divided into an older sequence, characterized mainly by gneisses and schists of probable pre-Cambrian age, and a younger sequence of Paleozoic and Mesozoic rocks.

Exposed over large parts of the San Bernardino Mountains, Little San Bernardino Mountains, and other mountains to the east are plutonic rocks whose average composition appears to be in the quartz monzonite range. The most widespread type, referred to as the Cactus granite (Vaughan, 1922, pp. 363-374; Woodford and Harriss, 1928, pp. 271-274; Miller, 1946, p. 472), is mainly a light-colored quartz monzonite of Mesozoic age. The lead-uranium ratio of euxenite from a pegmatite body that cuts the Cactus granite about 11 miles southeast of Old Woman Spring, near the northern edge of the San Bernardino Mountains, indicates a middle Jurassic age (Hewett and Glass, 1953, pp. 1047-1050). Both the Cactus granite and other plutonic rocks in the eastern end of the Transverse Range province contain numerous inclusions and septa of metamorphic rocks, and some large areas are underlain by gneisses, schists, amphibolite, quartzite, conglomerate, crystalline limestone and dolomite, and other mildly to severely metamorphosed rocks (Harder, 1912, pp. 19-21) whose sequence and age relations have not been firmly established.

THE GEOLOGIC SECTION: YOUNGER ROCKS

Cretaceous Rocks. Lower Cretaceous (Knoxville) sediments are exposed within the Transverse Range province only in the western

FIGURE 3. View northwest over San Bernardino, showing the San Gabriel Mountains (left) and San Bernardino Mountains (right). San Antonio peak is on skyline at left, and Mojave Desert is in distance at right. Light-colored outcrops in upper drainage of Cajon Creek beyond the trace of the San Andreas fault are terrestrial strata of Miocene age (see fig. 7). Traces of major faults are shown by dashed lines. *Pacific Air Industries photo.*

Santa Ynez Mountains, near Lompoc and Buellton. These consist mainly of considerably sheared marine silty shales that are as much as 7,500 feet thick.

Upper Cretaceous sediments are much more widespread. They crop out extensively in the Santa Ynez Mountains, especially toward the west end of the range. To a lesser extent they appear in the northwestern Topatopa Mountains, where they consist of hard, gray, marine shale with thin beds of sandstone and a few lenses of coarse conglomerate. Similar Cretaceous rocks are widely exposed in the San Rafael Mountains north of the western Transverse Ranges. The Simi Hills and vicinity, in eastern Ventura County, are composed mainly of thick-bedded, northward dipping, marine Upper Cretaceous sandstones.

In the eastern Santa Monica Mountains the Cretaceous section consists mostly of conglomerate beds that are about 3,000 feet thick. Terrestrial redbeds form the lower several hundred feet of the section, but the remainder is marine. No rocks of definitely Cretaceous age have been found in the eastern half of the Transverse Range province, but Upper Cretaceous clastics are widely exposed in the Santa Ana Mountains, a part of the Peninsular Range province that forms the eastern rim of the Los Angeles basin.

Eocene Rocks. Paleocene and lower Eocene sandstone, shale, and conglomerate crop out extensively on the north slopes of the Simi Hills and at the east end of Simi Valley, where their aggregate thickness is 3,500 feet. A thick section of clastic Paleocene strata is exposed along the southern margin of the Liebre Mountains, north of the Santa Clara River valley. In the eastern Santa Monica Mountains about 1,000 feet of Paleocene rocks consists principally of shales with thin lenses of limestone.

Thin, elongate fault slivers of sheared and fractured Paleocene shale, sandstone, and pebbly to cobbly conglomerate are present in the western Santa Ynez Mountains and western San Gabriel Mountains. Larger fault-bounded masses of similar but less deformed rocks occupy parts of the San Andreas fault zone along the northeastern margin of the San Gabriel Mountains (Dickerson, 1914; Noble, Contribution No. 5, Chapter IV, this volume), and further attest the former wide distribution of Paleocene strata.

Sedimentary rocks of middle and late Eocene age form most of the higher parts of the Santa Ynez and Topatopa Mountains, where their thickness ranges from 3,000 feet near Point Conception to more than 13,000 feet north of Ventura. On San Miguel Island 9,000 feet of these Eocene clastics has been reported, but part of them may be Cretaceous in age. The upper and middle Eocene section consists mainly of alternating black shale and hard, gray sandstone. A few beds of conglomerate also are present. The only significant carbonate unit, an orbitoidal limestone (Sierra Blanca) that ranges in thickness from a few feet to a few hundred feet, occurs as lenses at the base of the middle Eocene section in the northern Santa Ynez and southern San Rafael Mountains, where it rests unconformably on Cretaceous rocks. Zones of red shale alternate with oyster-bearing sandstone (Coldwater sandstone) in the upper 2,500 feet of the Eocene section between Santa Barbara and Fillmore.

An upper Eocene continental redbed series (lower part of Sespe formation) crops out in the Simi Valley region, and has been penetrated in oil borings on South Mountain and Oak Ridge, south of Fillmore (fig. 8). These strata contain a large fauna of land vertebrates including early primates, rhinoceroses, titanotheres, and numerous rodents (see Durham, et al., Contribution No. 7, Chapter III). They are lithologically indistinguishable from overlying Oligocene (Sespe) redbeds with which they have been mapped, and they record the first important marine regression in the Tertiary history of this region.

The Eocene sands commonly are tight, but they produce oil commercially in several parts of the Ventura basin.

Oligocene Rocks. The Oligocene section is characterized by a generally thick succession of redbed sandstones, silty shales, and conglomerates of the Sespe formation, which extends from an area a few miles east of Point Conception eastward to the southern Liebre Mountains northeast of Saugus, and probably southeastward to Santa Ana Canyon at the east end of the Los Angeles basin. Vertebrate faunas indicate that this formation ranges in age from late Eocene through Oligocene to early Miocene. On the south flank of the Santa Ynez Mountains west of Canada Refugio (Refugio Canyon), the basal beds begin to interfinger with marine sandstones and shales. The upper half of the redbed section is overlapped to the west by marine strata of early Miocene age. This transition from continental to marine Oligocene beds continues westward progressively, so that near Point Conception and Lompoc all of the Oligocene section, here about 1,000 thick, contains numerous marine fossils.

Lower Miocene to Oligocene redbeds also occur on Santa Rosa Island and in the Santa Monica Mountains. Angular unconformities that mark local uplifts are present at the top of the Oligocene section in the western Santa Ynez Mountains and in the Simi and Las Posas Hills; elsewhere the Oligocene-Miocene contact is apparently conformable. The Oligocene (and some upper Eocene) redbeds include some of the most important oil reservoir sands in the Ventura basin.

Coarse conglomerate, breccia, and arkosic sandstone, in large part of typical redbed lithology, are widely exposed in the Soledad basin north of the western San Gabriel Mountains (fig. 11), and also appear as discontinuous erosional remnants along the San Andreas fault zone farther east. These nonmarine strata, known as the Vasquez formation, locally reach thicknesses of about 14,000 feet. They are overlain with marked unconformity by other nonmarine strata of early Miocene age, and probably are correlative with at least a part of the Sespe formation to the west. In some parts of the basin the section contains as much as 4,000 feet of andesite and basalt, chiefly in the form of flows.

Miocene Rocks. In the western Ventura basin and Santa Ynez foothills the Miocene section comprises, in upward succession, a basal unit of sandstone and conglomerate 50 feet to 400 feet thick (Vaqueros formation), 1,500 feet of mudstone, 1,000 feet to 2,500 feet of laminated, highly organic (foraminiferal or diatomaceous) shale, shaly chert, and diatomite, and 2,000 feet of silty brown organic shale at the top. Most of this Miocene shale is highly bituminous, and hence constitutes a rich source rock for petroleum. In the eastern part of the Ventura basin, between Fillmore and Saugus, the middle and upper Miocene section becomes progressively more sandy and thickens to 10,000 feet or more east of Piru, where there is a concentration of oil fields producing from these sands.

FIGURE 4. View west-southwest from the San Gabriel Mountains toward Verdugo Mountains and the San Fernando Valley beyond. Santa Monica Mountains are in the left distance, and light-colored slopes of the Santa Susana Mountains appear at the far right. *Photo courtesy Fairchild Aerial Surveys, Inc.*

The northern Los Angeles basin contains about 3,000 feet of lower and middle Miocene sandstone and conglomerate, the lower part of which includes a few redbeds. These are overlain by a maximum of 9,000 feet of upper Miocene diatomaceous shale, cherty shale, silty shale, sandstone, and conglomerate. This Miocene succession is similar to that in the eastern Ventura basin, where coarse clastics are interbedded with the organic shale.

During middle Miocene time a deep geosyncline was developed on the site of the present Santa Monica Mountains and Channel Islands. In this rapidly subsiding marine trough was deposited 3,000 to 15,000 feet of middle Miocene clay shale, sandstone, conglomerate, and schist breccia. The thickest section is in the western Santa Monica Mountains. Shortly after their deposition, these sediments were invaded by sills, dikes, and chonoliths of diabase, basalt, and some andesite. Two or three lenses of submarine volcanic flows (trachyandesites, andesites, and basalts) as much as 5,000 feet thick appear in the upper part of the middle Miocene section. Minor extrusion of acid volcanic rocks also occurred during middle Miocene time 100 miles to the northwest, in an area a few miles northwest of Point Conception.

The orogeny that raised up the Santa Monica Mountains and Channel Islands on the site of this geosyncline began in early upper Miocene time, and the upper Miocene diatomaceous shales commonly rest with an angular unconformity upon rocks that are middle Miocene and older. In the Ventura basin, only a few miles to the north, almost continuous deposition of organic shales was progressing during middle Miocene time. A post-Miocene, possibly middle Pliocene, uplift of considerable magnitude supplemented the pre-Pleistocene orogeny of the Santa Monica Mountains, and resulted in folding and faulting of the upper Miocene strata that now occupy the flanks of the mountains.

Along the northern margin of the central Transverse Ranges, from Cuyama Valley southeastward through Lockwood Valley to the northwest side of the San Gabriel Mountains, is a large area covered with continental Miocene conglomerates, sandstones, and siltstones, showing that a land area partly separated the Ventura basin from the San Joaquin basin to the north during late Miocene time. The marine and continental facies have been brought into juxtaposition for several miles by large lateral movements on the San Gabriel fault northwest of Castaic (see Crowell, Contribution No. 6, Chapter IV). Patches of similar nonmarine Miocene strata are present in the San Andreas fault zone along the north flank of the San Gabriel Mountains, and in the Cajon Pass area at least 8,000 feet of upper Miocene conglomeratic sandstone and associated finer-grained rocks is spectacularly exposed (figs. 3, 7). These strata lie unconformably upon lower Miocene marine Vaqueros beds in at least one place in this area. It is interesting to note that the presence of Vaqueros strata in the Cajon Pass area poses a problem in paleogeography and tectonic history, as the nearest other Vaqueros rocks north of the San Andreas fault lie in the San Joaquin Valley, 90 miles to the northwest, and the nearest Vaqueros rocks south of the fault lie in the Santa Ana Mountains, 40 miles to the southwest (Noble, Contribution No. 5, Chapter IV).

A few patches of terrestrial sandstone and conglomerate of doubtful Miocene age occupy fault blocks and slices in the southern part of the San Bernardino Mountains eastward from San Bernardino to points beyond San Gorgonio Pass. The widespread distribution of these and other nonmarine strata to the west and northwest, together with the dominance of plutonic and gneissic rocks as clasts within the strata, indicates that the eastern Transverse Ranges, as well as the granitic Mount Pinos, Liebre Mountains, and Frazier Mountain farther west, were being rapidly eroded during an appreciable part of Miocene time.

Pliocene Rocks. The marine Pliocene section is confined to the central part of the Ventura basin, and extends eastward from points near Goleta to the northwest corner of the San Fernando Valley near Sunland. Between Ventura and Fillmore the generally marine Pliocene soft sandstones, silty clay shales, mudstones, and fine to coarse conglomerates are 13,000 feet to 15,000 feet thick. On Oak Ridge, toward the south rim of the Pliocene basin and a few miles south of this tremendously thick section, 1,000 feet or less of upper Pliocene beds rests unconformably upon organic Miocene shales (fig. 8). In places the marine Pliocene section is not represented at all. In the Goleta-Santa Barbara area, toward the north rim of the basin, from none to possibly 700 feet of largely marine upper Pliocene strata (lower part of the Santa Barbara formation) is preserved, mostly in synclines.

Marine Pliocene clastics of similar lithology attain a thickness of 4,000 feet to 6,500 feet in the deeper parts of the Los Angeles basin beneath the Quaternary cover, but only discontinuous remnants a few thousand feet thick crop out along the northern and eastern margins of the basin northwest of Santa Monica, in the Repetto and Montebello Hills a few miles east of Los Angeles, and at the west end of the Puente and San Jose Hills between Whittier and Pomona.

In both the Ventura and Los Angeles basins the lower half of the Pliocene section contains the most prolific reservoir sands for oil and gas in this region. In the Ventura oil field a maximum of about 7,500 feet of oil-bearing Pliocene strata, excluding repetition by thrust faulting, has been penetrated by wells. This is the thickest known continuously oil-bearing section.

Continental Pliocene sediments, 2,000 feet to nearly 6,000 feet thick, are exposed in the eastern part of the Ventura basin on both sides of the Santa Clara River Valley (fig. 10), and similar beds are preserved on relatively depressed fault blocks in the southwestern part of the San Gabriel Mountains. These deposits are mostly buff gravels and arkosic sands, with interbeds and lenses of reddish and greenish silty clay.

The Ridge basin, north of the Santa Clara River Valley, contains about 29,000 feet of upper Miocene and Pliocene strata, chiefly siltstone, sandstone, conglomerate, and coarse breccia (Crowell, 1950, 1952a, b; Eaton, 1939). The lowermost 2,000 feet of the section is mainly marine, and the remainder represents fluviatile and lacustrine deposition. The enormous thickness of these beds actually is greater than the width of the depositional basin, which was outlined in large part by major faults. The Violin breccia, one formation in the group, is 27,000 feet thick but extends along the strike for a maximum distance of only 4,000 feet. Evidently it accumulated as talus or alluvial debris at the base of the San Gabriel fault scarp, and it grades abruptly into finer-grained strata on the east (Crowell, Ridge Basin Map Sheet, this volume).

The lower part of the Paso Robles formation north of the Santa Ynez River in Santa Barbara County, and the upper part of the continental sands and gravels of the Cuyama and Lockwood Valley area, between the Topatopa Mountains and the San Andreas fault, probably are Pliocene in age. Terrestrial Pliocene strata also are exposed along the northern margin of the San Gabriel Mountains and the southern margin of the San Bernardino and Little San Bernardino Mountains, where in large part they are involved in the San Andreas fault zone. Marine strata of probable Pliocene age (Imperial formation) extend northwestward as a thin tongue into the San Gorgonio Pass area from the Coachella-Imperial Valley. They contain an invertebrate fauna that is markedly different from the faunas in Pliocene strata of the coastal areas (Durham, 1950, pp. 23-33), and thus correlations between the western and eastern parts of the Transverse Range province have been difficult to establish for the marine part of the section.

During middle Pliocene time the Santa Ynez and Topatopa Mountains, as well as Oak Ridge, the Las Posas Hills, and several other low ranges in the Ventura basin, were gently folded up and eroded. Possibly the main uplift of the Santa Monica Mountains—Channel Islands range took place at this time, as well. Marked uplift of the eastern ranges during Pliocene time is attested by the sequence and lithology of the nonmarine sediments that were derived from them.

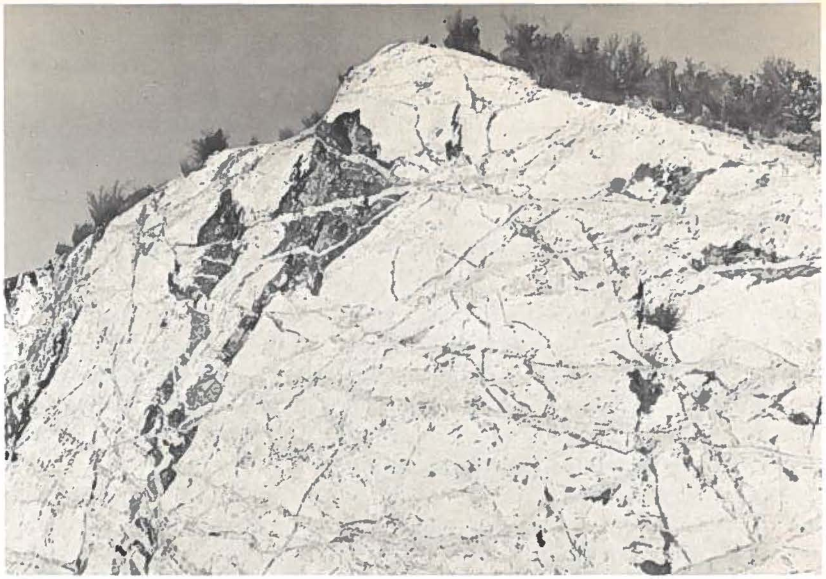


FIGURE 5. Highly sheared anorthosite with dark-colored inclusions of schist quartzite, and amphibolite. These rocks are transected by gently dipping dikes of sheared leuco-monzonite. Soledad Canyon near Ravenna, north side of San Gabriel Mountains.

Pleistocene Rocks. The most remarkable stratigraphic feature of the Transverse Range province is the existence of 4,000 to 5,000 feet of marine Pleistocene strata in the central Ventura basin. These beds have been folded along with the conformably underlying Pliocene section (fig. 1), so that they now show dips of 20 to 75 degrees. They contain both vertebrate and invertebrate fossils of Pleistocene age, and more than 90 percent of the abundant molluscan species among the marine fossils are living today. The basal Pleistocene unit (upper part of Santa Barbara formation) consists mainly of mudstone. It is overlain by an alternation of near-shore soft sands, silts, and gravels. The upper third of the section is mostly nonmarine, the marine basin having been filled by the time these beds were laid down.

At least 2,000 feet of folded lower Pleistocene beds of similar lithology is present in the Los Angeles basin. Resting with strong angular unconformity on the lower Pleistocene San Pedro formation are horizontal to slightly tilted sands, gravels, and silts that contain upper Pleistocene land vertebrates (Rancho La Brea beds and terrace deposits). This great unconformity, which shows angular discordances of 30 to 60 degrees, commonly marks the major Coast Range orogeny during which the Ventura anticline, 3 miles north of Ventura (fig. 1), was folded up far above sea level. In the Los

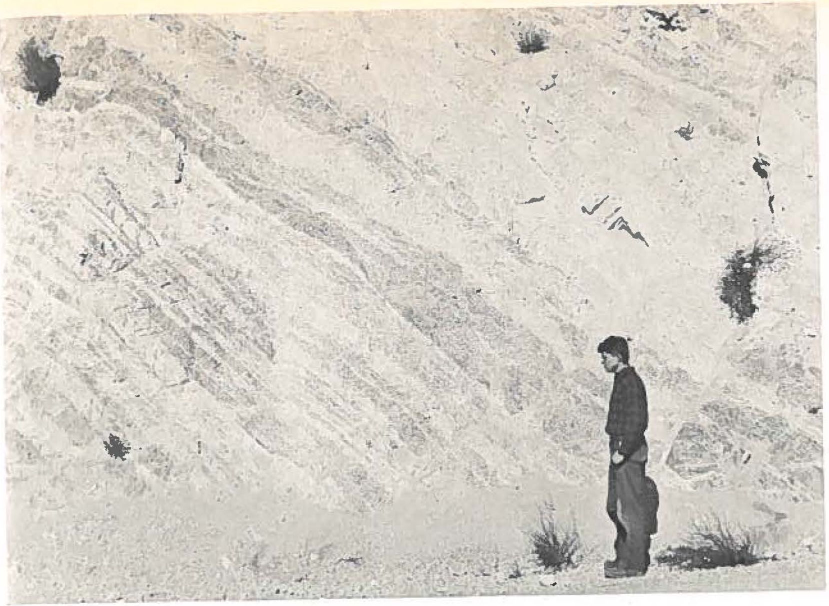


FIGURE 6. Interlayered aplite, pegmatite, and coarse-grained granodiorite. Mill Creek, western San Gabriel Mountains.

Angeles basin several important domal anticlines, on which some of the most prolific oil fields in the State have been developed, were formed or were emphasized at this time.

The effects of this mid-Pleistocene orogeny were widespread, and included intense folding and uplift in all of the older Transverse Ranges, such as the Santa Ynez, Topatopa, San Gabriel, San Bernardino, and Santa Monica Mountains, and in the intra-basin ranges, such as Red Mountain, South Mountain-Oak Ridge, Santa Susana Mountains, San Jose Hills, and Puente Hills. Great thrusts and steep reverse faults, with maximum displacements of 10,000 to more than 15,000 feet, were developed in the Ventura basin and along its margins. These include the Santa Ynez, Big Pine, Simi, Holser, and San Gabriel reverse faults, and the Red Mountain, San Cayetano, Oak Ridge, and Santa Susana thrusts (pl. 4). Faults with steep dips, northeast and northwest strikes, and large components of lateral (strike-slip) movement developed in the Santa Barbara region, and much larger lateral movements occurred along the San Gabriel fault, along the Whittier and Inglewood faults in the Los Angeles basin, and along the San Andreas and associated faults.

STRUCTURE

General Relations. Structurally the Transverse Range province consists of (1) a series of predominantly east-trending, generally steep-sided folds, many of which are broken along their axes or on one or both flanks by compressional faults or thrusts, and (2) large blocks and numerous smaller slices that are bounded mainly by reverse faults or by faults that dip very steeply and have large strike-slip components of movement. Folding either is dominant over faulting or is of equal importance in the basinal areas and in the western ranges that consist predominantly of sedimentary rocks. In contrast, the eastern ranges, in which crystalline basement rocks prevail, are characterized by marginal faults that converge downward beneath the upthrown mountain blocks. The great San Andreas fault, which generally trends northwest along its 640-mile course in California, bends to a more westerly trend in the 180-mile segment that slices obliquely across the Transverse Range province.

Santa Ynez Mountains. The relatively low and broad western part of the Santa Ynez Mountains is a considerably faulted anticlinorium that is bordered on the north by the broad syncline of the lower Santa Ynez Valley. For most of its length farther east, the range is a steeply southward dipping homocline of Cretaceous to Miocene strata that have been tilted up along the Santa Ynez fault zone. This fault generally dips steeply south, and the rocks on its south side have been upthrown from 5,000 to 10,000 feet. It lies near the base of the north side of the range and is bordered on the north for many miles by the synclinorial graben of the upper Santa Ynez Valley.

The Santa Ynez fault commonly occupies the position of the axial plane of a sharp anticline, and hence the crest of the range is on the south limb of this ruptured fold. For a distance of a few miles, the range is a rather open anticline whose north flank is cut by the Santa Ynez fault, which locally dips gently to the south. Between Santa Barbara and Carpinteria, as well as in the vicinity of Ojai, the Eocene and Oligocene strata that form the mountain mass are overturned and dip north at angles as low as 50 degrees. Where the northwest-trending San Rafael Mountains butt against the east-trending Santa Ynez Mountains, the net slip of the Santa Ynez fault has been oblique, the north side apparently having moved downward and westward. Possible transverse arching in the Santa Ynez Mountains may reflect a southward continuation of the San Rafael uplift.

Topatopa Mountains. The eastern Santa Ynez Mountains and their eastern continuation, the Topatopa Mountains, broaden into a complex faulted anticlinorium, and are separated from the higher Pine Mountain-Frazier Mountain ranges on the north by a narrow synclinal graben along upper Sespe Creek. The southern margin of the Topatopa Mountains is generally overturned between the San Cayetano thrust and the axis of a recumbent anticline or group of anticlines that is parallel to the thrust a short distance to the north.

FIGURE 7. Conglomerate, arkosic sandstone, and interbedded finer-grained rocks in the upper drainage of Cajon Creek, between the San Gabriel and San Bernardino Mountains. These nonmarine strata are of late Miocene age. *Photo courtesy of Walter H. Thrall, Jr.*

The thrust extends eastward from the area northeast of Ojai to a point a few miles beyond Piru, and lies along the base of the hills that border the Santa Clara River valley on the north. It dips 15 to 50 degrees northward, and possibly has a maximum dip-slip displacement of 20,000 feet.

As the north side of the Topatopa Mountains is bounded by the generally south-dipping Santa Ynez fault, this range is structurally a flat-topped or gently folded horst with steeply dipping to overturned margins. The Piru Mountains, the eastern continuation of the Topatopa Mountains between lower Sespe Creek and the San Gabriel fault northwest of Castaic, are a gently folded, eastward plunging anticlinorium in Miocene and Pliocene rocks that are closely folded near Hopper Mountain and Piru Creek. The San Cayetano thrust dies out a few miles east of Piru, and from Piru eastward the steeply south-dipping Holser fault is the principal exponent of crustal shortening. This fault is upthrown on the south, with displacements of 2,000 to 5,000 feet, and its sense of movement is opposite to that of the San Cayetano thrust.

The eastern boundary of the Topatopa Mountains is the essentially vertical San Gabriel fault. The north or northeast side of this break is upthrown in the western San Gabriel Mountains, but farther northwest, beyond Castaic, it is downthrown. Several lines of evidence indicate a strike-slip (right lateral) movement of at least several miles along this northwest part of the San Gabriel fault (see Crowell, Contribution No. 6, Chapter IV).

Ventura Basin. The Ventura basin is a highly folded synclinorium that contains a maximum of about 50,000 feet of Tertiary and Quaternary strata, and possibly as much as 8,000 feet of Cretaceous strata. The synclinorium is broken by a number of large thrusts or reverse faults, some of which dip south and others north. Except for its northern margin, the western half of the basin is submerged beneath the Santa Barbara Channel. Most of the larger interior valleys, such as Ojai Valley, Simi Valley, and the Santa Clara River Valley above Saticoy, are synclinal, and the intra-basin ranges of hills or mountains, such as Red Mountain, South Mountain-Oak Ridge, and the Camarillo-Las Posas Hills, are anticlinal. The most extensive lowland area, the Oxnard Plain, is gently folded but considerably faulted beneath its thick alluvial cover.

The central part of the Ventura basin has been subjected to direct north-south compression, resulting in overturning of beds and the development of thrusts or reverse faults on one or both flanks of many of the anticlinal ranges. The Santa Clara and Ojai Valleys are deep fan synclines with both limbs overturned, and the limbs are broken by thrusts that represent movements toward the valleys from both sides (fig. 8). Although Oak Ridge and the Santa Susana Mountains are parts of the same anticlinal uplift, Oak Ridge has been thrust northward along the south-dipping Oak Ridge fault, whereas the Santa Susana Mountains farther east have been thrust southward along the Santa Susana thrust, which dips northward at low angles.

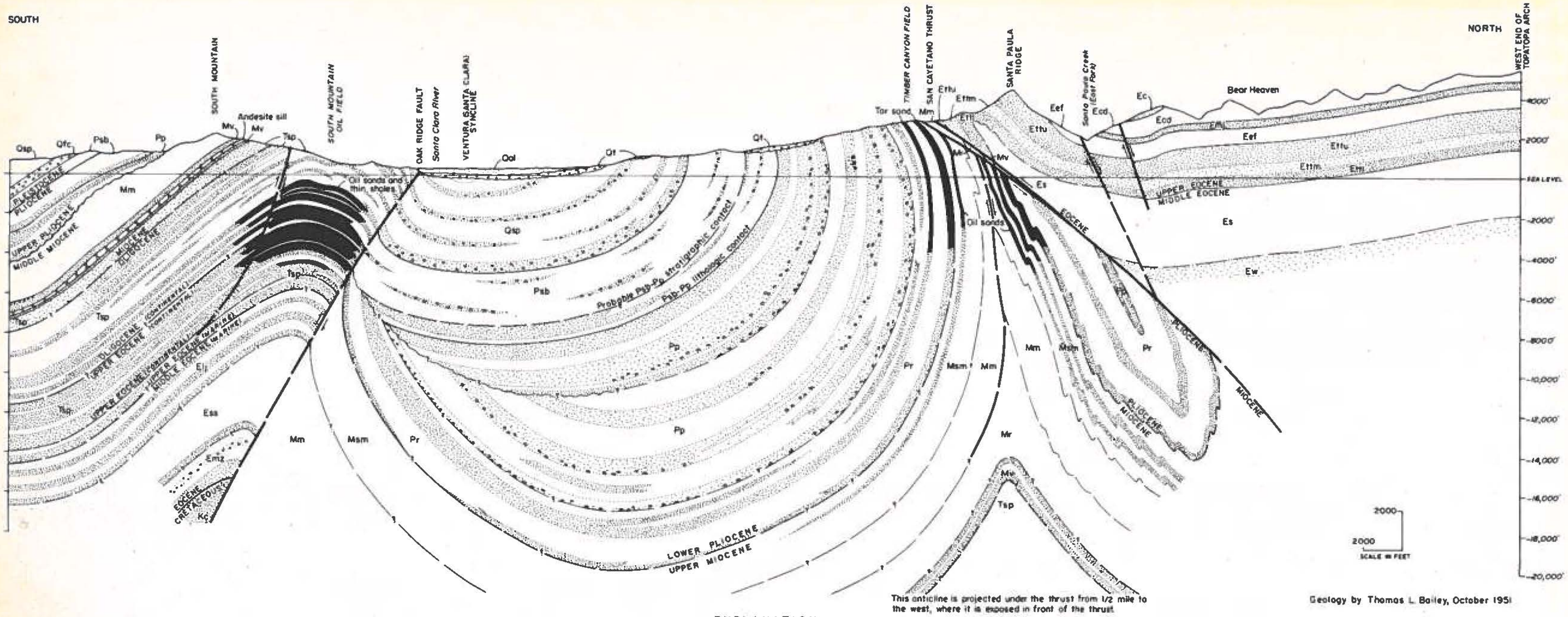
The Ventura Avenue oil field and several other good fields farther west are located on the 16-mile long Ventura anticline, the axis of which lies 3 miles north of Ventura (fig. 1). This anticline has fairly regular limbs that dip at angles of 40 to 50 degrees, but it is severely broken by thrusting, toward both the north and the south, in the subsurface Pliocene beds. These thrusts die out surfaceward into zones of steep dips.

The northwest margin of the Ventura basin includes the southern foothills of the Santa Ynez Mountains and the narrow coastal plain and hills around Santa Barbara, Goleta, and Carpinteria (fig. 9). The foothill belt is a south-dipping homocline that is interrupted by a few anticlines and synclines and is cut by many nearly vertical faults. These intersecting faults trend northeast and northwest, have had oblique-slip movements, and commonly show displacements of a few hundred to a few thousand feet. Santa Barbara and Goleta lie in alluviated valleys that are synclinal grabens, and the Carpinteria alluvial plain is structurally a syncline in Oligocene to lower Pleistocene strata that is cut by faults south of the axis.

The east end of the Ventura basin is a series of closely spaced anticlines and synclines (fig. 10) whose moderately to steeply dipping flanks are broken by the Holser reverse fault. They are cut off diagonally by the San Gabriel fault. Oil fields, surprisingly numerous for such a small area, are present in the vicinity of Piru, Newhall, Castaic, and Saugus. Most of these are on domal anticlines or faulted anticlines, but some represent stratigraphic traps on the flanks or plunging noses of anticlines.

Channel Islands and Santa Monica Mountains. The two largest Channel Islands, Santa Cruz and Santa Rosa, are essentially anticlines that are cut by large east-trending faults along or near their axes. A few smaller faults and folds also are present. The principal faults apparently are oblique-slip features, their north sides having moved downward and westward. The sedimentary and volcanic rocks on San Miguel and Anacapa Islands have generally northeast and north dips. On San Miguel Island they are cut by several nearly vertical faults that strike northwest. The entire Channel Island chain is a faulted anticlinal uplift, and represents the westerly continuation of the Santa Monica Mountains.

The Santa Monica Mountains are essentially a broad anticline that has been extensively intruded by sills, chonoliths, and dikes of diabase and basalt, and has been severely ruptured by steep



EXPLANATION

Qal, alluvium; Qt, terrace gravels; Qsp, San Pedro formation (clay, sand, gravel); Qfc, Fox Canyon formation (sandstone, conglomerate); Psb, Santa Barbara formation (mudstone); Pp, Pico formation (sandstone, shale, conglomerate); Pr, Repetto formation (sandstone, shale, conglomerate); Msm, Santa Margarita formation (shale, thin sandstone); Mm, Monterey formation (shale, chert, diatomite); Mr, Rincon formation (shale, mudstone); Mv, Vaqueros formation (sandstone, shale); Tsp, Sespe formation (mainly red beds); Elj, Llajas formation (shale, silty sandstone); Ess, Santa Susana formation (shale); Emz, Martinez formation (sandstone, conglomerate, shale); Ec, Coldwater formation (sandstone); Ecd, Cozy Dell formation (black shale, sandstone); Emj, Matilija formation (sandstone, grit); Eef, Echo Falls formation (black shale); Ett, Topatopa formation (Ettu, upper white spotted greenish sandstone; Ettm, middle white grit; Ettl, lower thin-bedded greenish sandstone); Es, Sisar formation (black shale); Ew, Wheeler formation (sandstone); Kc, Chico formation (shale, sandstone).

Figure 8. Structure section across a part of the Ventura basin, showing the remarkable thickness of Pliocene strata and the pattern of opposed reverse-fault movements on opposite sides of the Santa Clara River Valley.

oblique faults or cross faults, several of which appear to be tensional in nature. One large strike fault, the Malibu fault, trends approximately parallel to the coast for many miles west from Santa Monica. This is a steeply north-dipping reverse fault with a few thousand feet of displacement. The general plunge of the main anticline of the range is westerly, so that basement rocks are extensively exposed at the east end.

San Fernando Valley. The San Fernando Valley is a faulted synclinorium in Miocene and Pliocene sediments, and is structurally deepest toward the north side of the valley. Its northern margin is ruptured by the Santa Susana thrust zone, which dips northward at low to moderate angles. The north, or hanging-wall block has moved upward and southward 5,000 to 10,000 feet relative to the lower block. On the northwest border of the valley are the Simi Hills, which probably are anticlinal. The inferred anticline is in Cretaceous rocks, and its axial portion is overlapped by south-dipping Miocene strata.

Pine Mountain-Frazier Mountain Area. Pine Mountain is a large anticlinal ridge of Eocene sandstone between the steeply north-dipping Pine Mountain reverse fault on the south and the vertical strike-slip (left lateral) Big Pine fault on the north. Lockwood Valley is a dish-shaped syncline, filled mostly with continental sediments, that lies between the high granitic mountains, Mount Pinos and Frazier Mountain, on the north and east, and the Pine Mountain anticline on the south. The south side of Frazier Mountain is marked by a north-dipping low-angle thrust fault that is a major element in the structurally complex area of junction between the San Andreas and Garlock fault zones. The thrusting was largely Pleistocene

FIGURE 9. The Elwood oil field west of Santa Barbara, showing the narrow coastal plain that flanks the Santa Ynez Mountains. Preferential attachment of kelp to certain beds exposed on the sea floor shows evidence of offshore (westerly) closure of anticline. Goleta Point is at extreme right, and Santa Barbara lies in graben valley in right distance. *Photo by Erickson, 1929.*

FIGURE 10. Typical exposures of the Saugus formation in the eastern Ventura basin, about 7 miles west of Saugus. These nonmarine strata, of late Pliocene and early Pleistocene age, are here broadly folded. Axial traces of two folds are shown by the dashed lines. *Pacific Air Industries photo.*

in age, and the thrust plane has been sharply folded (Crowell, 1950, p. 1644).

Liebre Mountains and Sierra Pelona. The Liebre Mountains and Sierra Pelona constitute a structurally high mass of crystalline basement rocks into which a narrow wedge of lower Tertiary strata has been dropped between the Clearwater-Bouquet Canyon fault zone and the San Francisquito Canyon fault (pl. 4). These and several other breaks within the ranges are moderately to steeply dipping reverse faults that appear to reflect north-south compression. Some of them have been essentially inactive since early Miocene time, whereas others cut strata as young as Pliocene in adjacent basin areas.

The Sierra Pelona consists almost wholly of Pelona schist that has been folded into a broad anticline whose axis plunges gently west-southwest. The Tertiary strata in the fault-bounded wedge that lies immediately north of the western Sierra Pelona have been much more tightly compressed into numerous folds, several of which are overturned toward the south. The older rocks of the western Liebre Mountains have been thrust southwestward over upper Tertiary strata of the Ridge basin along the Liebre fault zone. Both the Liebre Mountains and the Sierra Pelona are cut off on the northeast by the San Andreas fault zone.

Ridge Basin and Soledad Basin. The Ridge basin is a narrow and very deep structural trough whose filling of upper Tertiary sediments has been compressed into numerous open folds. The axes of most of these folds plunge gently northwest. The lower part of the sedimentary section is cut by faults that die out upward into zones of flexure. These same faults show much larger offsets in the older rocks that appear along the margins of the basin.

Concomitant deposition and deformation in earlier Tertiary time is attested by many of the rocks and structural features of the Soledad basin, which is an open syncline with locally wrinkled flanks and a prevailingly westerly plunge. Strata of probable Oligocene age are faulted against basement rocks (fig. 11), both within the basin and along its margins, but in some places they lie with depositional contact upon these older rocks. Locally the strata have been tightly folded, and in a few areas they form thick homoclines with essentially vertical dip. The Soledad fault, which separates the older part of the basin section from the crystalline rocks of the San Gabriel Mountains to the south (fig. 11), and the Pelona fault, which bounds a part of the basin on the north, are unusual for this region in that their displacement has been chiefly dip-slip and normal, rather than reverse, in nature.

The lower Miocene and younger strata of the basin also have a broadly synclinal structure, but they have been considerably less deformed in detail. They cover many of the earlier faults, including the Soledad and Pelona, but are displaced, generally 500 feet or less, by other faults. They are truncated on the west and southwest by the San Gabriel fault.

San Gabriel Mountains. The San Gabriel Mountains can be regarded as a gigantic horst, lens-like in plan, that is transected by countless fault, shear, and shatter zones. Indeed, no other large mass of crystalline rocks in southern California has been so thoroughly fractured on such a wide variety of scales. Nearly all of the rocks attest to one or more episodes of severe deformation, including mylonitization in several areas, and some of the igneous rocks, like the gabbroic types in the western part of the range, were pervasively deformed during late stages in their crystallization.

The oldest major fault that has been recognized within the range is the Vincent thrust fault, which is marked by a southward and southwestward dipping zone of shear planes and mylonitic rocks whose sinuous trace is plainly exposed on the north side of San Antonio Peak and the high ridges to the west (pl. 4). This break appears to represent northward thrusting of plutonic rocks over the Pelona schist. It cannot be younger than Mesozoic, as it is cut by the youngest intrusive rocks of the late Mesozoic igneous complex (see Noble, Contribution No. 5, Chapter IV).

The younger San Gabriel fault zone traverses the entire range in an essentially east-west direction, and its trace lies 3 to 8 miles north of the mountain front. The steeply dipping and closely spaced breaks in this zone have strongly influenced the pattern of major drainage, and are largely responsible for the linear pattern of the West Fork and East Fork of the San Gabriel River (fig. 12). Movement on them has been dominantly strike-slip in areas northwest of the range, but little is known of the magnitude or direction of their aggregate net slip within the range. The fault zone appears to be offset along cross faults in upper San Antonio Canyon, and its eastern segment butts against the San Jacinto fault zone in the vicinity of Lytle Creek, southeast of San Antonio Peak.

The range is bounded on the north by the Soledad fault, a normal fault that appears to have been relatively inactive during late Tertiary and Quaternary time, and by the San Andreas fault, an essentially vertical strike-slip (right lateral) fault that has remained very active to the present time. The San Jacinto fault, another major break, traverses some of the high country in the northeastern part of the range. It is roughly parallel to the San Andreas fault, and these two master breaks, which are 2 to 4 miles apart in most places,

FIGURE 11. Trace of the Soledad fault on the north side of Solèdad Canyon. Light-colored anorthosite and associated rocks of the San Gabriel Mountains are in the foreground, and conglomerate and arkosic sandstone of Tertiary age appear beyond the fault in the distance.

FIGURE 12. Trace of main break of the San Gabriel fault (dashed line) along West Fork of the San Gabriel River; view west toward Mount Wilson (MW) and the Red Box divide (RB). This terrain is typical of the western San Gabriel Mountains. *Photo courtesy Fairchild Aerial Surveys, Inc.*

FIGURE 13. The western part of the San Bernardino Mountains; view north into the Mojave Desert region. Cajon Creek is at left, and Cajon Pass is immediately beneath and to left of + mark in center of view. The trace of the San Andreas fault is plainly shown by the aligned saddles, low ridges, and contrasts in vegetation across the foreground. The ridge in foreground at left is mainly Pelona schist, the mountains immediately beyond the San Andreas fault are mainly gneiss and migmatite, and the ridges farther on are Cactus granite. *Photo courtesy Fairchild Aerial Surveys, Inc.*

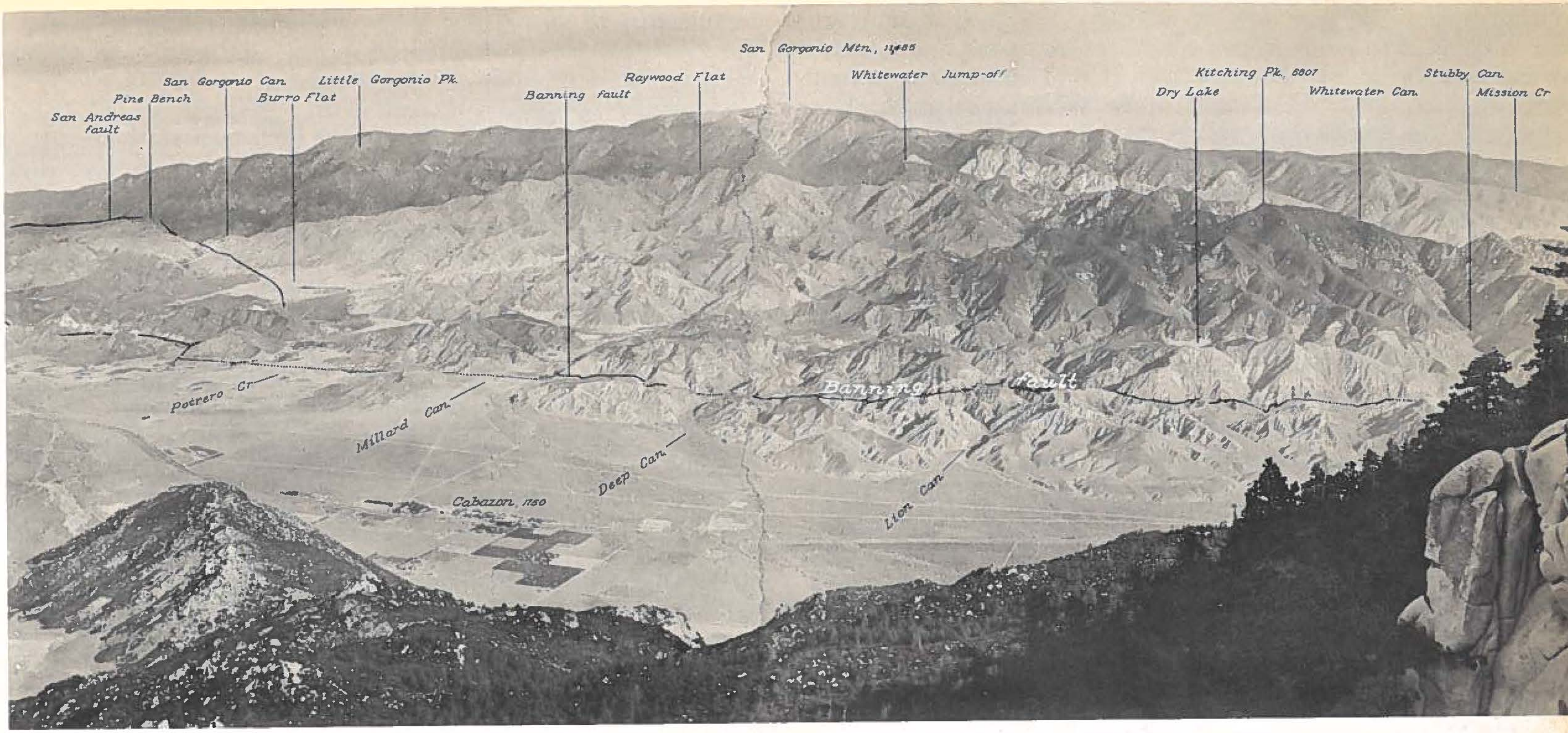


FIGURE 14. The San Bernardino Mountains; view north across San Gorgonio Pass. The traces of the San Andreas and Banning faults, where visible in this view, are shown by black lines. Many other faults are present, but are not delineated. Rocks beyond the Banning fault in center and at right are mainly gneissic types; those between the fault and the floor of the pass are mainly nonmarine strata of late Tertiary and Quaternary age. *Photo and diagramming courtesy of Clarence R. Allen.*

bound an elongate tectonic belt of extreme structural complexity (Noble, Contribution No. 5, Chapter IV).

The south face of the range, which is one of the most impressive scarps in southern California (fig. 2), is defined by the Sierra Madre fault zone, a complex group of branching and en-echelon faults whose prevailing dip is northward beneath the mountains. Individual dips range from steeply south to moderately north, and the dip direction of some of the faults, as traced along their strike, changes back and forth through the vertical. Movement on most of the breaks has been primarily dip slip in nature. The fault zone involves blocks of Miocene sedimentary and volcanic rocks north and east of Azusa, and larger blocks of Miocene and younger rocks farther west, in the area between San Fernando and Big Tujunga Creek (pl. 4).

Transverse upwarping of the range during Quaternary time is suggested by the longitudinal profiles of major elements within the San Andreas-San Jacinto tectonic belt (Noble, 1927, p. 32), and locally by the distribution and attitude of upper Tertiary and Quaternary sedimentary strata that locally veneer both margins of the range. A north-trending axis of broad upwarping may well be marked by the high country that includes Blue Ridge, San Antonio Peak, and Ontario Peak. Similar, though more local and intense, warping of crystalline rocks must have taken place in several other parts of the range, where such rocks lie immediately beneath pronounced folds in Tertiary and Quaternary strata.

San Bernardino Mountains. The San Bernardino Mountains are similar to the San Gabriel Mountains in many structural respects, although their rocks have been considerably less sheared and shattered in detail. The range has been uplifted along the San Andreas and Banning faults on the south (figs. 13, 14) and along several steeply dipping reverse faults on the north. Within the northern part of the range are several thrust faults that dip southward and southwestward at low to moderate angles (Woodford and Harriss, 1928; Guillou, 1953); some of these may be of the same general age as the Vincent thrust fault in the San Gabriel Mountains.

The western part of the range is sliced by numerous subparallel reverse faults that trend west-northwest and dip northward at moderate to very steep angles. Many of them either butt against or merge into the San Andreas fault zone. Patches of Tertiary sedimentary rocks are preserved along several of these breaks. The Arrowhead Springs and Mill Creek faults diverge northward from the San Andreas fault near San Bernardino, and both breaks are marginal to thin slices and much larger and broader blocks of Tertiary and Quaternary strata. The Mill Creek fault traverses the highest part of the range farther east, beyond which area its general trend is continued in the form of the Mission Creek fault, which extends southeastward into Coachella Valley. The two faults almost join in an area that is complicated by the Pinto Mountain fault zone, which extends eastward from the range into the desert region north of the Little San Bernardino Mountains.

The southeastern part of the San Bernardino Mountains is marked by a complex network of faults, particularly in the San Gorgonio Pass area (fig. 14). As pointed out by Allen (see San Gorgonio Pass Map Sheet, this volume), the San Andreas fault in this area is distinguished by several unusual features, among which are absence of typical rift topography along much of its presumed trace, absence of horizontal stream offsets, an abrupt major change in trend of the fault, absence of intense historic earthquake activity associated with the fault zone, and evidence of thrusting rather than strike-slip movements during Quaternary time. The relationships among the faults in the pass area are extremely complicated, particularly in terms of their respective periods of movement, and reconciling the unusual features of this zone with those of the San Andreas fault zone farther northwest constitutes one of the most provocative structural problems in southern California.

ECONOMIC FEATURES

The major current economic assets of the Transverse Range province are assuredly liquid. Impressive accumulations of petroleum have been found in many of the western ranges and basin areas, and the long-continued search for additional reserves has contributed much to the present understanding of stratigraphic and structural complexities in these areas. Many of the occurrences of oil and gas have been noted in previous paragraphs, and more detailed discussions appear in Chapter IX of this volume.

Perhaps even more important to the economy of southern California are the water resources of the province. In particular, the concentrations of ground-water in certain strata (mainly Pleistocene) of the Ventura basin and basins that lie adjacent to the San Gabriel and San Bernardino Mountains have played a vital part in the development of the region. Doubtless these resources will continue to be important in the future, even though they are far from adequate in terms of demands in the more densely populated and industrialized areas. Some of the specific problems and features of water occurrence are discussed in Chapter VI of this volume, and the occurrence of mineral deposits is discussed in Chapter VIII.

Among the nonmetallic mineral resources of the Transverse Range province, sand, gravel, diatomite, and gypsum have been most important commercially. More than half of the sand and gravel produced in the State has been obtained in this province from alluvial deposits of Quaternary age, especially along the southern margin of the San Gabriel Mountains. Placer gold has been recovered as a byproduct from deposits near Azusa. At Ventura lower Pleistocene mudstones are quarried, crushed, and fused in furnaces to form glass-like pellets that are widely used as a light-weight aggregate. Diatomite of moderate to high grade is widely distributed in Miocene and Pliocene marine strata in the western half of the province, particularly in the Santa Ynez Mountains, Purisima Hills, and Santa Rita Hills. It is most abundant in the lower part of the Sisquoc formation (Dibblee, 1950, pp. 75-79), and the largest known commercial deposit of diatomite in the world constitutes about 1,000 feet of this formation in the northern foothills of the Santa Ynez Mountains near Lompoc.

Bedded gypsum has been mined from a nonmarine section of Miocene age in the upper Cuyama River basin of northwestern Ventura County, and gypsite has been obtained from the outcrops of these strata. Gypsite also has been mined from the outcrops of Oligocene (?) gypsiferous siltstones in the eastern part of the Soledad basin. Colemanite and other borate minerals were mined years ago from Oligocene (?) lake beds in the Soledad basin, and from similar beds in the Lockwood Valley area of northeastern Ventura County.

Concentrations of graphite occur in the metamorphic rocks of the Sierra Pelona, the Verdugo Hills, and the San Gabriel Mountains (Beverly, 1934), and numerous small deposits have been mined or prospected. Stone for flagging and other decorative uses has been quarried from certain parts of the Pelona schist. Some of the other pre-Cretaceous terranes contain large reserves of limestone, especially in the San Bernardino Mountains, and both limestone and gypsum are present in some of the desert ranges to the east. A little feldspar and mica has been obtained from pegmatite deposits in the San Gabriel Mountains, San Bernardino Mountains, and the Frazier Mountain area.

Among the metals, large quantities of magnetite and hematite are being mined from extensive contact-metamorphic deposits in the Eagle Mountains, whence they are shipped to blast furnaces at Fontana, west of San Bernardino. The ore was formed by replacement of calcareous strata of Paleozoic or earlier age (Harder, 1912; Hadley, 1948). Large deposits of ilmenite and titaniferous magnetite are present in the western San Gabriel Mountains, where they are associated with anorthosite and other gabbroic rocks (Moorhouse, 1938; Oakeshott, 1948). These minerals also are concentrated in numerous Recent stream deposits, and several small placer accumulations have been worked commercially. Gold-bearing veins and placer deposits have been mined, generally on a small scale, at many localities in the San Gabriel, San Bernardino, and Little San Bernardino Mountains, as well as in parts of the basins and western ranges where basement rocks are exposed. The combined production from these operations has been surprisingly large.

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