3. GEOLOGY OF THE PENINSULAR RANGE PROVINCE, SOUTHERN CALIFORNIA AND BAJA CALIFORNIA*

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GENERAL FEATURES

The Peninsular Range province is a well-defined geologic and physiographic unit that occupies the southwestern corner of California and extends southeastward to include the Baja California peninsula (fig. 1). It is characterized by elongate ranges and valleys whose general northwesterly trend is terminated abruptly on the north by the east-west grain of the Transverse Ranges. The part of the province that lies above sea level is approximately 900 miles long, 140 miles in maximum width, and 55 miles in average width. An additional large part is mainly submerged beneath the Pacific Ocean, and is represented by Santa Catalina, Santa Barbara, San Nicolas, and San Clemente Islands.

The higher parts of the province, which are underlain chiefly by igneous and metamorphic rocks of pre-Cenozoic age, include the Santa Ana, San Jacinto, Santa Rosa, Agua Tibia, and Laguna Mountains in California, and the Sierra Juarez, Sierra San Pedro Mártir, and other ranges that form the ''backbone'' of Baja California (fig. 1). San Jacinto Peak, near the north end of the province, rises to an altitude of 10,805 feet, and La Providencia Mountain, in northern Baja California, reaches an altitude of 10,126 feet. These and other high mountain masses occupy the northeastern and eastern parts of the region, and are bounded from the adjoining Colorado Desert region and the Gulf of California on the east by spectacular scarps, 6,000 feet to more than 9,000 feet high, that bear a striking resemblance to the east face of the Sierra Nevada. Most of these scarps are disposed en echelon, and mark the subparallel traces of major zones of faulting.

The general topography of the region becomes less rugged toward the west and southwest, where it is characterized by remarkable combinations of subdued upland surfaces (figs. 4, 11), prominent ridges and peaks (figs. 4, 8), longitudinal valleys that are in part fault-controlled (fig. 11), numerous basins and broad, mature valleys (fig. 8), and some tortuous, very steep-walled canyons (fig. 6). Farther west is an irregular coastal plain, a few hundred feet to as much as 30 miles wide, on which marine and fluviatile terraces are prominently displayed (fig. 2). This plain is underlain chiefly by sedimentary and volcanic rocks of late Mesozoic and Cenozoic age, and its surface is interrupted here and there by ridges and other projections of older, more resistant rocks.

The region as a whole presents an asymmetric transverse profile whose relatively long and gentle westerly slope is considerably broken in detail (fig. 3). Some of the major topographic irregularities are ascribable to erosion along or adjacent to fault zones, and similar fault-controlled irregularities evidently are present beneath the sea floor on the continental borderland (Shepard and Emery, 1941). The Los Angeles basin, at the northwestern end of the province, marks a broad area of Cenozoic marine sedimentation. In many respects it resembles basins that lie farther north, in the western part of the Transverse Range province (see Bailey and Jahns, Contribution No. 6, this chapter), but its principal structural features have the characteristic northwesterly trend of the Peninsular Ranges. The Desierto de Santa Clara marks a somewhat similar basin in central Baja California (fig. 1).

The province is one of great climatic contrasts. Annual precipitation ranges from only a few inches in the arid valleys and adjacent slopes along its eastern margin to as much as 50 inches on some of the highest mountain ranges. The southern California coastal area receives 11 to 18 inches of rainfall per year, but the amount decreases southward to less than 5 inches along parts of the Baja California coast. The climate ordinarily is mild in the northern coastal areas, but elsewhere the ranges of temperature are greater, and locally are extreme.

The pattern of vegetation in the region is highly varied, and representatives of nearly all the major life zones are present (see Bailey, Contribution No. 2, Chapter I). Typical desert forms occur in the lower interior areas, and are widespread in Baja California. In contrast, the highest mountain ranges are timbered, and park-like stands of pine and cedar are present as far south as the crest of the Sierra San Pedro Mártir. Dense growths of brush cover many of the mountain slopes (figs. 4, 7), and over large areas form such a serious obstacle to travel on the ground that one frustrated investigator was moved to write, ''Where the steepness does not forbid the way, the chaparral everywhere disputes it.''

Except for the northern coastal areas, the region is sparsely populated, and large parts of Baja California are essentially uninhabited. The geology of the province as a whole has been investigated only in reconnaissance, and detailed studies of moderately large areas have been restricted to the portion that lies north of the international boundary. The most general reports on large parts of the region are those of Beal (1948), Darton (1921), Ellis and Lee (1919), Fair-

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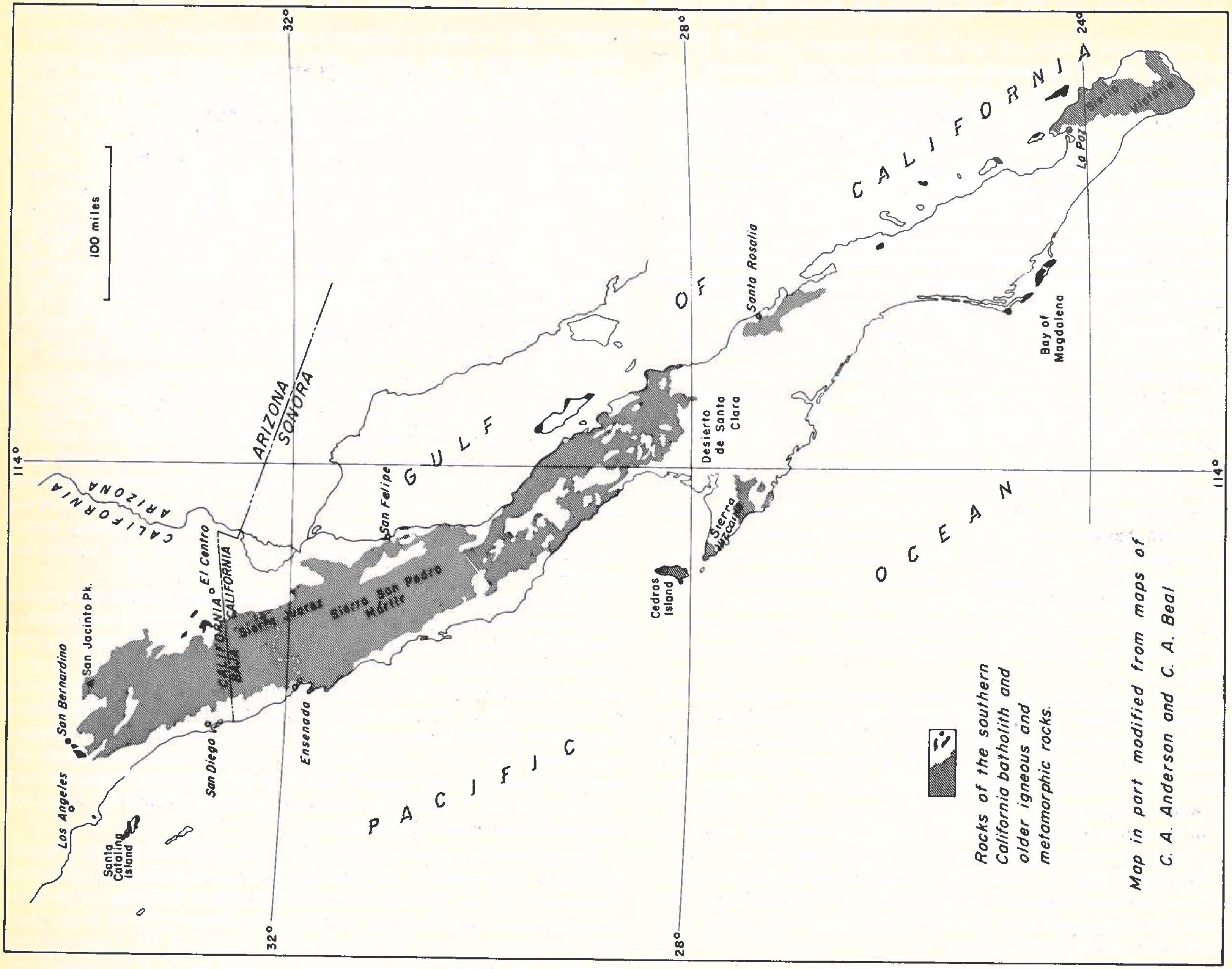

FIGURE 1. Map of the Peninsular Range province, southern California and Baja California, showing the distribution of rocks that lie beneath the great Mesozoic unconformity.

banks (1893), Larsen (1948), Merrill (1914), Nelson (1922), Reed (1933), Sauer (1929), Waring (1919), and Wisser (1954). The published record includes numerous other contributions that deal with specific areas, problems, or mineral deposits, and a sampling of these is provided in the list of references at the end of this paper.

Despite the present incompleteness of geologic data for the region as a whole, it is possible to summarize the general nature and occurrence of rock types and major structural features within it, and to outline the principal episodes of its geologic history. Many of the features that bear critically upon this history are known only from Baja California, and it is mainly for this reason that a brief treatment of this large peninsula is included in the following pages.

THE GEOLOGIC SECTION

General Relations

The rocks of the Peninsular Range province, like those in many other parts of southern California, can be readily grouped into two major divisions that are everywhere separated by a profound unconformity. Moderate to very great differences in lithology, structure, and degree of metamorphism distinguish the rocks beneath this break from those that lie above it, even though in some areas the respective rocks represent closely adjacent parts of the general geologic column. The oldest rocks above the unconformity are marine strata of Upper Cretaceous age, and the youngest rocks beneath it are plutonic types that are demonstrably intrusive into marine strata of Lower Cretaceous and earliest Upper Cretaceous age at several localities in western Baja California.

The exposed rocks in the eastern and other mountainous parts of the province are dominantly igneous, metasedimentary, and metavolcanic types of Paleozoic and Mesozoic age (plate 3). Most abundant among these members of the older sequence are gabbroic to granitic plutonic rocks that constitute the great southern California batholith. The metamorphic rocks and some other igneous rocks antedate this batholith, and form a widespread but generally subordinate part of the crystalline terrane.

The younger sequence comprises marine and nonmarine strata of Upper Cretaceous, Tertiary, and Quaternary age, as well as volcanic rocks of Tertiary and Quaternary age. Nearly all of the marine strata are in the coastal parts of the province, where they are dominantly clastic and form a fairly continuous apron, a few hundred feet to a few thousand feet thick, that slopes gently in a seaward direction. Despite its gross simplicity, however, the section shows numerous complications of stratigraphy and structure. It thickens enormously in the Los Angeles basin, where it amounts to 40,000 feet or more, as well as in at least two other large basins in Baja California. These thick sequences are broken by major unconformities, and paleontologic evidence suggests some markedly contrasting environments of deposition. In several areas the strata have been considerably warped and folded.

Marine incursion along the northeastern margin of the province is represented mainly by remnants of Upper Tertiary clastic strata in the Imperial Valley area and adjacent parts of Baja California. Other marine sections appear farther south, along the Gulf of California.

Nonmarine strata, chiefly fluviatile in origin, are scattered through the interior parts of the province, where they commonly are preserved as the upper parts of structurally low fault blocks. Typical of these occurrences are interbedded clastic sediments, clay, and lignite of Paleocene age in the Corona-Elsinore area and nearby parts of the Santa Ana Mountains, and clastic sediments of late Tertiary and Quaternary age in the Redlands-San Jacinto area farther northeast (plate 3). A very thick section of dominantly clastic nonmarine strata is widely exposed along the western margin of the Coachella and Imperial Valleys, where it apparently represents intermittent deposition since mid-Miocene time. Nonmarine sedimentation in the coastal areas is recorded mainly by strata of Paleocene to Miocene age, some of which are interbedded with marine sediments.

Volcanic rocks of Miocene age are exposed in many parts of the coastal area and along the western margin of the Imperial Valley, and are widespread in central and southern Baja California. They are mainly shallow intrusives, flows, and pyroclastic accumulations of andesitic and basaltic composition. Younger basaltic rocks, of late Tertiary and Quaternary age, form typical mesa cappings in the Santa Ana and Santa Margarita Mountains, and are extensively exposed in parts of Baja California.

Rocks Beneath the Great Unconformity

Older Sedimentary and Volcanic Rocks. The oldest exposed rocks in the region are sedimentary strata and subordinate interlayered volcanic rocks that have been mildly to severely metamorphosed. In general they appear as small to very large inclusions, pendants, and screens within or around masses of younger plutonic rocks, and plainly are remnants of a very thick and once-extensive terrane that was broken up and locally much deformed by widespread igneous invasion.

This old terrane is exposed over large areas in the San Jacinto, Santa Rosa, and Coyote Mountains, where quartzite, crystalline limestone, phyllite, hornblende and mica schists, and quartz-feldspar schists and gneisses may reach an aggregate thickness as great as

Figure 2. Aerial view east-northeastward from the coastline immediately south of San Onofre, showing prominent low marine terrace. Note the numerous bench-like remnants of several higher terraces that were cut into the foreground ridge of Tertiary sedimentary rocks. Santa Margarita Mountains are at extreme left, and San Marcos Mountains are in center distance. *Photo by J. S. Shelton and R. C. Frampton.*

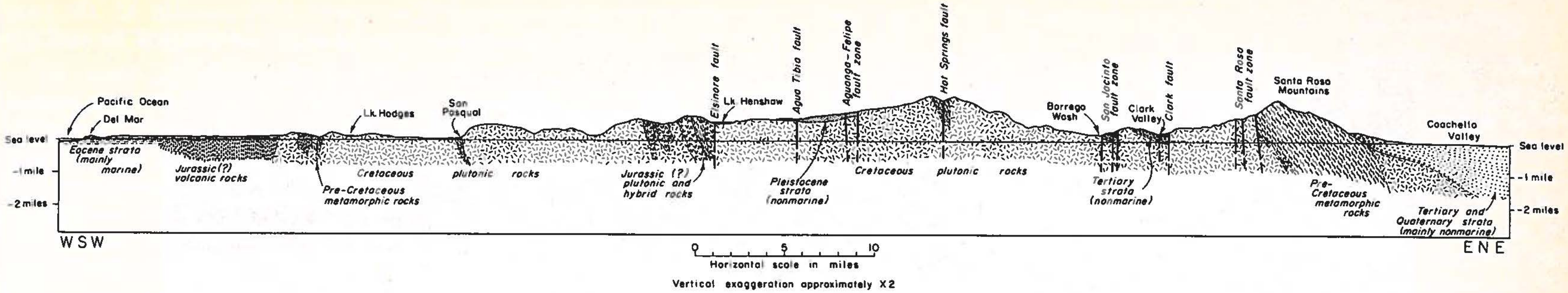

FIGURE 3. Cross section of the Peninsular Range province from Del Mar to the north end of the Salton Sea.

22,000 feet. These rocks may be in part correlative with Paleozoic strata of similar lithology that are exposed in the northern part of the San Bernardino Mountains, and possible fossil material that further suggests a Paleozoic age was obtaned by Miller (1944, pp. 21-25) from localities a few miles southeast of Palm Springs. Similar metamorphic rocks are widely distributed in areas to the west and northwest (pl. 3), and "reasonably well-preserved" fossils of apparent Mississippian age have been found in at least one locality a short distance south of Winchester (Webb, 1939).

Farther west, in the Santa Ana, Elsinore, and Santa Margarita Mountains, is a section of mildly metamorphosed strata, perhaps as much as 20,000 feet thick, that is composed mainly of gray to brownish argillite and slate, with subordinate feldspathic quartzite and a few lenses of limestone and conglomerate. These rocks, termed the Bedford Canyon formation by Larsen (1948, pp. 18-22), are sparsely fossiliferous and are generally regarded as Triassic in age. They are overlain unconformably by slightly metamorphosed agglomerates, breccias, tuffs, and flows that range in composition from andesite to latite and quartz latite. These volcanic rocks, together with some fine-grained argillaceous sedimentary rocks that are interlayered with them, are known as the Santiago Peak volcanics (Larsen, 1948, pp. 22-27), and also have been termed the Black Mountain volcanics in areas to the south (M. A. Hanna, 1926, pp. 199-204). They appear to be many thousands of feet thick, and have been tentatively assigned to the Jurassic by most investigators. They are gray, greenish gray, and reddish to purplish brown, and characteristically form rough slopes with many ragged, irregular, dark-appearing cliffs.

The boundary between the Bedford Canyon formation and the older rocks to the east has not been established precisely, as the metamorphism of the younger rocks increases progressively in an easterly direction from the type area in the Santa Ana Mountains, and no pronounced lithologic break has been recognized. Larsen (1948, pp. 17-18) postulates a fault between these major units in the area south of Winchester (plate 3), but points out that rocks of Paleozoic age probably are present in areas southwest of this contact.

Metasedimentary rocks also are widespread farther south in the province, especially in the Agua Tibia and Laguna Mountains. Here they are known mainly as the Julian schist (Merrill, 1914, pp. 638-642; Hudson, 1922, pp. 182-190; Donnelly, 1935, pp. 337-340), and consist of quartz-mica schist and feldspathic to vitreous quartzite, with minor amphibolite, quartz-mica-amphibole schist, metaconglomerate, and recrystallized limestone. The different rock types commonly intergrade along and across the strike, and appear to represent an original series of shallow-water sediments. Most of the amphibole-bearing rocks evidently were derived from flows and tuffs of intermediate to basic composition. It has been suggested by Fairbanks (1893, pp. 82, 87), Hudson (1922, pp. 188-190), and others that the Julian schist may correspond, at least in part, to the Triassic section of the Santa Ana Mountains, but this correlation should be regarded as tentative. Some of the schist sequence may well be of Paleozoic age.

Similar metamorphic rocks are widespread in the northern half of Baja California, where fine-grained schists are dominant. These rocks, like the Julian schist, may well represent both Paleozoic and lower Mesozoic sedimentation.

A distinctly different assemblage of mildly metamorphosed schists, chert, limestone, and associated igneous rocks underlies much of the western part of the province, where it is largely concealed beneath the waters of the Pacific Ocean. These rocks are best exposed in the Palos Verdes Hills, at the western margin of the Los Angeles basin, and on several of the banks and islands offshore; in Baja California (fig. 1) they have been noted from the Sierra Vizcaino (Beal, 1948,

FIGURE 4. Aerial view west-northwestward over a part of the Agua Tibia Mountains, showing typically irregular, brush-covered terrain. Barker Valley is in foreground at right, and Palomar Observatory is in middle distance at left. Note the alignment of benches, gulches, light-colored grassy areas, and clusters of trees that mark the trace of the Agua Tibia fault extending away from the observer in center of view. *Photo by J. S. Shelton and R. C. Frampton.*

pp. 36-37), Cedros Island and several smaller islands to the northwest (G. D. Hanna, 1925, 1927), and from the western margin of the Bay of Magdalena (Hirschi and De Quervain, 1933).

The most abundant rock types are fine-grained chlorite-bearing schists that commonly contain epidote, actinolite, muscovite, and albite, and that are particularly distinguished by the presence of glaucophane and lawsonite. Bodies of metavolcanic rocks and altered and metamorphosed intrusive rocks, chiefly serpentine and dioritic to gabbroic types, are widespread. The rocks of this terrane may be older than the metamorphic assemblage farther east, but it seems more likely that they represent a southern extension of the Mesozoic Franciscan group of California, as suggested by Beal (1948, pp. 107-108) and others.

Older Intrusive and Migmatitic Rocks. Hypabyssal intrusive rocks that probably are related to the Santiago Peak volcanics (Larsen, 1948, pp. 27-32) transect the Bedford Canyon formation in the Santa Ana Mountains, in the area north of Elsinore Lake, and in areas farther south. They are older than the more widespread plutonic rocks of the southern California batholith, which are described farther on. Together with the Santiago Peak volcanics, these older intrusives occupy a north-northwestward trending belt more than 80 miles long and 2 to 12 miles wide (plate 3). They are fine to medium grained, and include such rock types as gabbro, gabbro porphyry, diabase, tonalite, granodiorite, and dacite, latite, and quartz latite porphyries. Most of them resemble the Santiago Peak volcanics in general composition and degree of metamorphism.

In the eastern parts of the province are numerous irregular plutonic masses, some of them very large, of tonalite and granodiorite that also antedate the rocks of the southern California batholith. Most of these rocks have a well-defined gneissoid structure, and many of them are extensively granulated and otherwise deformed on a small scale. The Stonewall granodiorite (Hudson, 1922, pp. 191-193; Merriam, 1946, pp. 230-231; Everhart, 1951, pp. 61-64) is a widespread representative of this group in the Laguna Mountains and adjacent areas, and the highly sheared and foliated granodiorite that is prominently exposed on the west side of Palm Canyon, in the San Jacinto Mountains, is another characteristic type. Similar rocks appear in many parts of the higher ranges in Baja California.

The larger plutons commonly are in part bordered by broad zones of injection gneiss, contact breccias, and other migmatitic rock types. These mixed rocks plainly were derived from the older metamorphic rocks already described, and they underlie large areas in the eastern ranges, both in California (Donnelly, 1934, pp. 337-340; Merriam, 1946, pp. 231-232; Everhart, 1951, pp. 64-65) and northern Baja California (Woodford and Harriss, 1938, pp. 1310-1313).

Younger Sedimentary and Volcanic Rocks. Fossiliferous stratified rocks of Lower Cretaceous and early Upper Cretaceous age are known from several areas in western and northwestern Baja California, where they are separated from younger Upper Cretaceous strata by a marked angular unconformity. They have been referred to as the San Fernando formation (Beal, 1948, pp. 38-40) and the Alistos formation (Santillán and Barrera, 1930), and consist of shale, sandstone, conglomerate, and limestone with interlayered tuff and other volcanic rocks of basic to intermediate composition. In places they have been mildly metamorphosed, and the section has been considerably folded.

These upper Mesozoic strata have been intruded by plutonic rocks that may well be parts of the southern California batholith, and hence they bear critically upon the problem of dating this great igneous mass. Farther east, in the Sierra San Pedro Mártir, rocks of the batholith are intrusive into the San Telmo formation, a thick sequence of slate, phyllite, quartzite, metaconglomerate, and volcanic rocks from which some fossils that ''have a Mesozoic aspect'' are reported (Woodford and Harriss, 1938, pp. 1306-1310). This sequence may be in part a metamorphosed equivalent of the San Fernando formation (Beal, 1948, p. 39), or it may be entirely older.

Rocks of the Southern California Batholith. A series of fine- to coarse-grained intrusive rocks constitutes the very large and complex batholith, termed the southern California batholith by Larsen (1941), that underlies much of the Peninsular Range province. It extends from the Jurupa Mountains, northwest of Riverside, to the southern tip of Baja California and points beyond, and hence it probably is more than 1,000 miles long. It is in part concealed by younger rocks, especially in Baja California, but appears to be at least 50 miles in average breadth. It thus is even larger than the Sierra Nevada batholith, and has the gross form of a gigantic, steeply dipping dike. The northern part of this great mass has become well known through the classic investigations of Larsen (1948; see also the summary in Contribution No. 3, Chapter VII, this volume).

The batholith is internally complex, and comprises many separate intrusive units, or plutons, that range in maximum outcrop dimension from a few hundred feet to several miles. Some of these are separated by straight or curved septa and screens of older metamorphic rocks, whereas others are directly juxtaposed along contacts that can be recognized only through detailed examination or can be inferred from differences in composition or internal structure of the plutons involved (fig. 5).

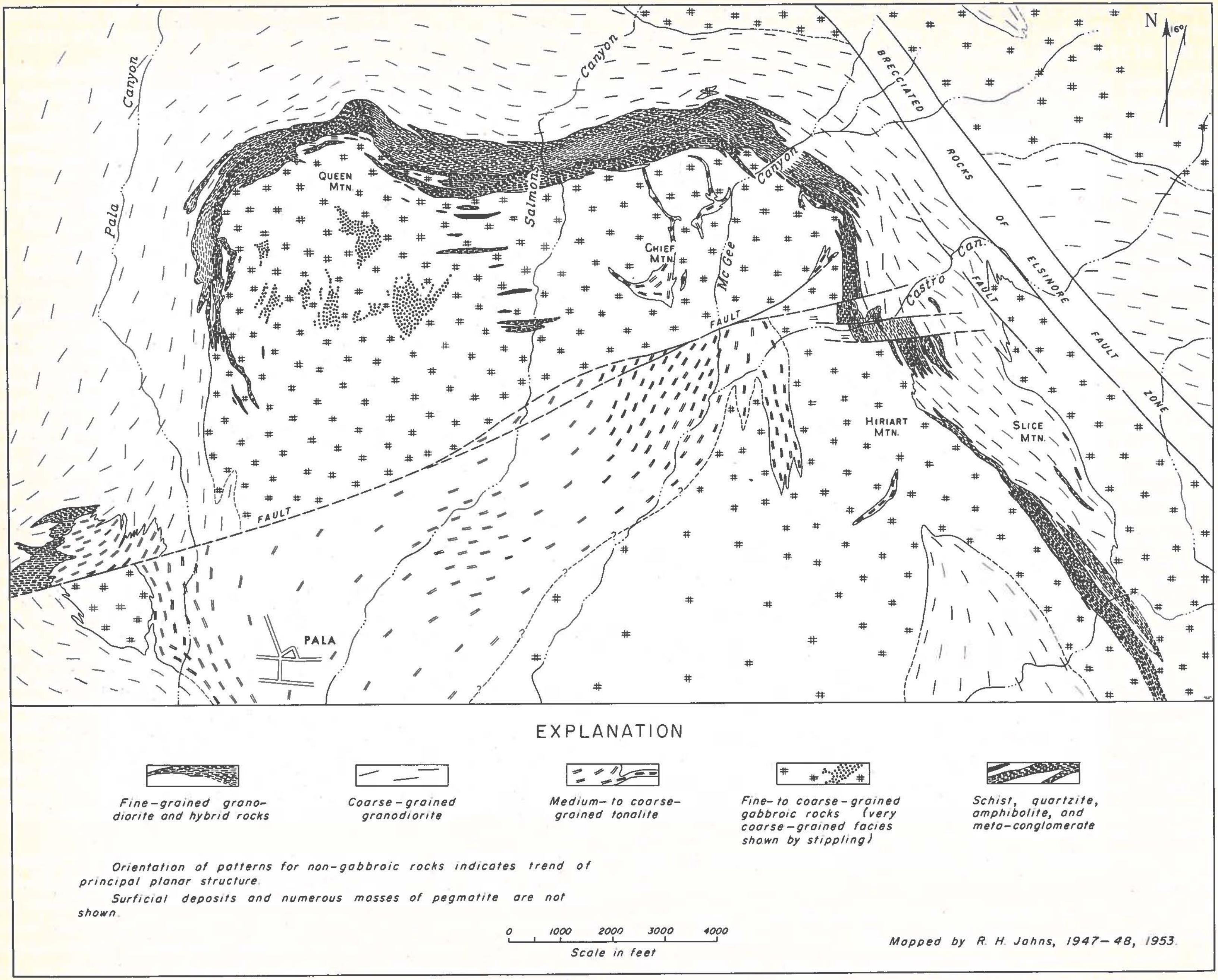

FIGURE 5. Geologic map of a part of the Pala district, showing typical relations between plutons of the southern California batholith.

The average composition of the entire batholith is in the tonalite range, and tonalite is by far the most abundant single rock type. From one pluton to another, however, the composition ranges from gabbro to granite, and the succession of intrusions appears to have been, with remarkably few exceptions, gabbro → basic tonalite → tonalite → granodiorite → quartz monzonite → granite. As pointed out by Larsen (Contribution No. 3, Chapter VII), five major rock types in the gabbro-to-granodiorite range constitute more than 90 percent of the exposed parts of the batholith in southern California, and also form nearly all of the large intrusive units. Individual rock types vary in composition and texture from place to place, but in a broad way they are so uniform that they can be readily identified in widely separated areas. The gabbroic rocks are relatively abundant in the western parts of the province, but are rare farther east, where leucocratic tonalites and granodiorites are predominant.

Tabular inclusions are present in many of the tonalites and granodiorites, and in places are so abundant that the rocks resemble flow-layered breccias. Some of the plutons are bordered by hybrid gneisses formed through invasion of the older metamorphic rocks by igneous material. In general these gneisses are much less extensive than the hybrid rocks that are related to the plutonic rocks of pre-batholith age.

Dike rocks associated with the batholith are widespread, and include leucogranite, pegmatite, aplite, diorite, microtonalite, and porphyries of intermediate composition. Represented among the pegmatitic intrusives are the famous gem-bearing dikes of Riverside and San Diego Counties (Schaller, 1925; Jahns and Wright, 1951; Hanley, 1951; see also Contribution No. 5, Chapter VII).

The batholith probably is of early Upper Cretaceous age. It is believed by Larsen (1948, pp. 134-172; Contribution No. 3, Chapter VII) to have been formed from a slowly differentiating parent magma of gabbroic composition. Successive injections of this magma and its differentiates probably accompanied episodes of local to regional diastrophism, and yielded many large and relatively uniform bodies of gabbroic to granodioritic rock, as well as smaller bodies of rocks that represent a wider range of composition.

Metamorphism. Most of the pre-batholith rocks in the western part of the province have been only mildly metamorphosed, and they represent the greenschist facies of Eskola. This metamorphism is uniform over very large areas, and does not appear to be related to masses of igneous rocks; it probably antedates the emplacement of the southern California batholith. To the west, the low-rank metamorphic rocks give way abruptly to wholly different Franciscan-like schists and associated rocks that represent the glaucophane schist facies. To the east there is no such fundamental lithologic change, and instead the degree of metamorphism gradually increases; the slaty and phyllitic rocks, for example, grade into muscovite- and biotite-bearing schists.

The Paleozoic rocks in the eastern part of the province have been moderately metamorphosed in a regional sense, and correspond to the greenschist facies and the albite-epidote amphibolite facies. Among the more widespread minerals are biotite, muscovite, hornblende, garnet, and epidote. These rocks may have been metamorphosed prior to deposition of the Mesozoic rocks that later were themselves metamorphosed, but no compelling evidence for this has been recognized as yet.

Many of the rocks have been locally affected by contact metamorphism, especially where they occur as relatively thin inclusions and screens in rocks of the southern California batholith. The commonest products include feldspathic gneisses, hornfelses, tactite and other varieties of reconstituted limestone, and foliated rocks that contain garnet, amphibole, pyroxene, and sillimanite, either singly or in some combination. Contact metamorphism of calcareous rocks is especially well shown around intrusive masses of gabbro and serpentine in the Winchester area (Larsen, 1948, pp. 35-36), and around masses of tonalite or other plutonic rocks at the famous mineral occurrences of the Crestmore area near Riverside (see Burnham, Contribution No. 7, Chapter VII) and at numerous other localities in areas farther south (for example, Larsen, 1948, pp. 34-36; Fries and Schmitter, 1945).

Rocks Above the Great Unconformity

Upper Cretaceous Rocks. Clastic strata of Upper Cretaceous age rest unconformably upon the Bedford Canyon formation and the Santiago Peak volcanics in the Santa Ana Mountains. The section is nearly 6,000 feet in maximum thickness, and at its base is 300 to 400 feet of coarse, prevailingly reddish nonmarine conglomerate, the Trabuco formation of Packard (1916, p. 140). The remainder is marine, consists of interbedded conglomerate, arkosic sandstone, siltstone, and dark-colored shale, and in places is highly fossiliferous (Popenoe, 1941, 1942). In the Santa Monica Mountains to the west-northwest, Upper Cretaceous strata of similar lithology are about 7,000 feet thick, and commonly have been referred to the Chico formation.

Strata that apparently correspond to the upper part of the Santa Ana Mountains section are discontinuously exposed farther south along the coast, where they are only a few hundred feet thick. They are mainly sandstone, sandy limestone, and shale that is in part carbonaceous, and locally are underlain by redbeds that may be correlative with the Trabuco formation (see Hertlein and Grant, Contribution No. 4, this chapter). Still farther south, in coastal Baja

FIGURE 6. Vertical view of the area immediately south of Temecula, showing typical contrasts in weathering of different rocks. Jointed granodiorite forms rough slopes in south part of area, metamorphic rocks of Triassic age underlie the smoother slopes west of Murrieta Creek and north of the steep-walled Temecula Canyon, and arkose of Pleistocene age underlies the remainder of the area. Note the possible offset of Temecula Creek along the trace of one break (dashed line) in the Elsinore fault zone. *U. S. Department of Agriculture photo.*

California, Upper Cretaceous conglomerates, sandstones, shales, and coaly beds, known as the Rosario formation, rest with marked angular unconformity upon older Cretaceous strata (Beal, 1948, pp. 40-44). They are at least 2,500 feet in maximum thickness, and are almost wholly marine. Paleontologic evidence suggests that the exposed beds become younger toward the south, but, according to Beal (1948, p. 44), no complete section has been observed at any one locality.

Paleocene and Eocene Rocks. Sedimentary rocks of Paleocene and Eocene age rest upon a widespread erosional surface of low relief that was developed at the close of the Cretaceous period. Paleocene strata crop out in the Santa Ana Mountains, where they are about 1,400 feet in maximum thickness. They have been correlated by English (1926, p. 19) with the Martinez formation of areas far to the northwest, and have been termed the Silverado formation by Woodring and Popenoe (1945). They also appear in the Santa Monica Mountains, and probably underlie a considerable area in the eastern part of the Los Angeles basin (see Woodford, et al., Contribution No. 5, this chapter).

The Silverado formation rests unconformably upon Upper Cretaceous strata, and consists of nonmarine basal conglomerate, an overlying section of arkosic sandstone, clay, and lignite, and an upper section of marine sandstone. To the east and northeast, in the structurally complex area between Corona and Elsinore, Silverado strata of similar lithology may be as much as 4,000 feet thick. Here they rest mainly upon rocks of pre-Cretaceous age, and their base is marked by a buff to reddish clay that in a few places appears to have been derived *in situ* from the weathering of underlying igneous rocks.

Overlying the Silverado formation with apparent conformity are Eocene strata that have been correlated with the Tejon formation of areas farther northwest (English, 1926, p. 21). Known as the Santiago formation (Woodring and Popenoe, 1945), this sequence is about 2,700 feet in maximum thickness and consists mainly of thin- to massive-bedded sandstone with numerous lenses of siltstone and conglomerate.

Marine beds of middle and late Eocene age extend southward in the coastal part of the province as far as San Diego, where they are known as the La Jolla formation (M. A. Hanna, 1926). They are about 600 feet in maximum thickness, and are mostly sandstone and sandy shale whose lithology and contained fossils suggest deposition in warm waters under lagoonal and near-shore conditions. Above this formation is the Poway conglomerate (Ellis and Lee, 1919, pp. 67-68), which is chiefly nonmarine pebble to boulder conglomerate with irregularly interstratified marine sandstone. Vertebrate and invertebrate fossils obtained from this rather complex section indicate that it is largely of early upper Eocene age (see discussions in Hertlein and Grant, Contribution No. 4, this chapter, and in Durham, et al., Contribution No. 7, Chapter III).

As much as 7,000 feet of Paleocene and Eocene strata, termed the Tepetate formation, appears in three general areas on the Pacific slope of Baja California (Beal, 1948, pp. 44-51). The section is dominantly marine and almost wholly clastic. Sandstones, siltstones, and shales are most abundant, and commonly are variegated. Much of the formation appears to have been deposited under deltaic or other near-shore conditions, and at least some of the remainder probably is terrestrial. Scattered invertebrate fossils show relations to both Pacific Coast and Caribbean faunas (Beal, 1948, pp. 49-51), and indicate an age range from Paleocene to late Eocene.

Oligocene (?) and Lower Miocene Rocks. The Oligocene appears to have been an epoch of emergence in the Peninsular Range region, and strata of this age are essentially restricted to the Santa Ana Mountains and San Joaquin Hills. They are nonmarine, consist mainly of variegated sandstone, siltstone, and conglomerate, and appear to be correlative with the Sespe formation of the western Transverse Range province. They have yielded no fossils, but probably range in age from late Eocene to earliest Miocene (Woodford, et al., Contribution No. 5, this chapter).

These nonmarine beds lie upon the Santiago formation with apparent conformity, and are in part overlain by, in part intertongued with, gray to greenish gray and buff marine sandstone, conglomerate, and siltstone of the Vaqueros formation. The Vaqueros strata have yielded lower Miocene invertebrate fossils that suggest a shallow-water environment (Loel and Corey, 1932, pp. 51-60). The maximum combined thickness of the marine and underlying nonmarine units is slightly more than 3,000 feet.

A redbed section about 300 feet thick has been reported from the eastern, or gulf-coast, side of the Baja California peninsula by Beal (1948, pp. 51-53), who regards the strata as probably Oligocene in age. They lie beneath marine strata that may be equivalent to the Vaqueros formation (Loel and Corey, 1932, p. 160).

Middle and Upper Miocene Rocks. Rocks of middle and upper Miocene age are broadly distributed in the region, and represent sequences of volcanism and widespread marine and terrestrial sedimentation that are too complex to be detailed in this paper. In the coastal part of southern California the section is dominantly marine, and is best represented in the Los Angeles basin and adjacent areas (see Woodford, et al., Contribution No. 5, this chapter). It includes the coarsely clastic, shallow-water deposits of the Topanga formation, which are 2,000 to 7,500 feet thick; the organic to cherty siltstones and mudstones of the Monterey shale, which are about 4,200 feet in maximum thickness and represent deposition in both shallow and deep waters; the sandstones and partly organic shales of the Modelo formation, which are about 5,000 feet in maximum thickness; and the dominantly clastic deposits of the Puente formation, about 11,000 feet in maximum thickness.

The Topanga formation has been dated as middle Miocene, the Monterey shale as mostly middle Miocene and partly upper Miocene, and the Modelo and Puente formations as upper Miocene. Some of these units are in part equivalent, and Modelo and Puente are names applied to upper Miocene rocks of similar lithology in different areas.

Unusual conditions of sedimentation south of the Los Angeles basin are reflected by the San Onofre breccia (Woodford, 1925), which consists mainly of fragments, many of them slabs 5 feet or more long, of glaucophane schist and other rocks that are characteristic of the metamorphic terrane along the southwestern side of the province. This unit is about 2,500 feet in maximum thickness, and is thought to have been derived from a source that lay to the west, beyond the present coastline.

Volcanic flows, tuffs, and breccias, mainly of andesitic composition, are abundant in the middle Miocene section, and locally reach thicknesses of more than 3,000 feet. Most of these are described elsewhere in this volume by Shelton (Contribution No. 4, Chapter VII). Widely scattered dikes and plugs of similar composition probably are related to these rocks.

Miocene strata are absent from the coastal part of southern California south of the Santa Ana Mountains, but they reappear farther south in Baja California, where they have been divided into three formations, the San Gregorio, Ysidro, and Commondú (Beal, 1948, pp. 53-77). These units have an aggregate maximum thickness of more than 6,500 feet. The San Gregorio and Ysidro formations are marine, and consist mainly of diatomaceous, siliceous, and clay shales, as well as sandstones, tuffs, and impure limestones. The Commondú formation, which crops out over much of the southern half of the peninsula, is a thick sequence of lavas, agglomerates, and tuffs with interlayered clastic sediments of terrestrial origin.

Nonmarine strata of Miocene age are widely exposed along the western margins of the Coachella and Imperial Valleys, where they are about 2,800 feet in maximum thickness (see Dibblee, Contribution No. 2, this chapter). They comprise arkosic sandstone, conglomerate, and breccia, and as much as 100 feet of bedded gypsum is present at the top of the section in the northwestern part of the Fish Creek Mountains. Volcanic breccias, tuffs, and flow rocks of andesitic composition are exposed in several areas along the southwestern margin of the Imperial Valley.

FIGURE 7. Bouldery exposures of granodiorite near the west end of the Agua Tibia Mountains. The rock is broken by two sets of steeply dipping joints, and by a third set of joints that dip gently from right to left.

Clastic nonmarine strata of probable Miocene age are exposed locally in the area north of San Jacinto, and also appear beneath andesitic volcanic rocks in the vicinity of Jacumba, near the international boundary.

Pliocene Rocks. Marine sedimentary rocks of Pliocene age are largely confined to the coastal area. As exposed in the marginal parts of the Los Angeles basin, they comprise siltstones, sandstones, and conglomerates of the Repetto and Pico formations (Woodford, et al., Contribution No. 5, this chapter), which are slightly more than 6,000 feet in maximum aggregate thickness. These rocks become somewhat finer grained toward the central part of the basin, where they are more than 10,000 feet thick; foraminiferal faunas indicate that much of this section was deposited in deep water (see Natland and Rothwell, Contribution No. 5, Chapter III).

Pliocene strata are widely exposed in the coastal areas to the south, including both sides of the Baja California peninsula. They are 800 to about 3,500 feet thick, and consist chiefly of fine- to coarse-grained clastic sediments that were deposited in shallow marine embayments. In places they include bentonite, tuff, and agglomerate. This section is known as the San Diego formation in southwestern California and mainly as the Salada formation in Baja California.

Nonmarine strata of Pliocene age are widely distributed in the interior parts of the province. Fluviatile and lacustrine conglomerate, arkosic sandstone, siltstone, and clay reach a maximum thickness of at least 10,000 feet along and near the western margin of the Coachella and Imperial Valleys (fig. 8), and in parts of this area they overlie a section of marine sandstones and siltstones as much as 4,000 feet thick (Dibblee, Contribution No. 2, this chapter). The marine strata, known as the Imperial formation, were deposited in a shallow embayment that extended northward from the Gulf of California during lower Pliocene time. They contain abundant marine fossils of tropical affinities (Durham, Contribution No. 4, Chapter III).

Locally preserved in the area west of the San Jacinto Mountains is as much as 7,000 feet of continental sandstones, siltstones, and conglomerates, some of which form typical redbed sequences. Known as the Mount Eden and San Timoteo formations (Frick, 1921, 1933; Fraser, 1931, pp. 511-514; Axelrod, 1937, 1950), these rocks have been dated as middle Pliocene and upper Pliocene, respectively, on the basis of plant and vertebrate fossils.

Quaternary Rocks. Marine sedimentation in many of the coastal areas appears to have been essentially continuous from late Pliocene into early Pleistocene time. The lower Pleistocene deposits, mainly sands, silts, and marls, generally grade inland into continental accumulations that correspond in age to fluviatile sediments laid down in isolated basins still farther inland.

Submergence and intermittent emergence of the coastal areas during later Pleistocene time led to development of extensive marine terraces (fig. 2), most of which are thinly veneered with marine sediments that in turn are largely concealed by terrestrial deposits. The well-known mid-Pleistocene orogeny of the southern California region is attested by marked unconformities between the marine cappings on some of the terraces and the underlying deformed strata of earlier Pleistocene age. These and other relations within the Pleistocene marine section have been studied with particular care in the San Pedro area (Arnold, 1903; Woodring, Bramlette, and Kew, 1946).

Fluviatile and lacustrine sedimentation during the Pleistocene epoch is recorded in many interior parts of the province by masses of coarse- to very fine-grained sediments, some of which have yielded vertebrate and plant fossils. These deposits include the Ocotillo conglomerate and Brawley formation of the Coachella and Imperial Valleys (Dibblee, Contribution No. 2, this chapter), the Bautista beds of the San Jacinto River Valley and nearby areas (Frick, 1921, pp. 283-288; Fraser, 1931, pp. 504-516, 536-537), the Temecula arkose of the Elsinore-Temecula Valley (Mann, 1951), and similar sediments in many parts of Baja California. Gravels and sands that are in part contemporaneous with these deposits, and also with some of the coastal marine terrace deposits, form many of the largest alluvial fans in the region (fig. 9). Some of these fossil fans have been partly buried by younger alluvial material, whereas others have been deeply trenched since Pleistocene time.

Widespread sediments of Recent age include marine and lagoonal deposits in the coastal areas, alluvial-fan and flood-plain sands and gravels in many of the valleys, lacustrine silts in the Imperial Valley area, swamp and pond deposits in cienegas of the mountain areas, and aeolian deposits that include prominent belts of dunes along the coast and along the western margins of the Imperial and Coachella Valleys.

Volcanic rocks of probable Quaternary age appear as remnants of flows in the Santa Ana and Santa Margarita Mountains, and are widespread in parts of Baja California (Beal, 1948, pp. 84-85; Anderson, 1950, pp. 46-47). Most are andesitic or basaltic in composition, and they occur typically as mesa cappings and as broad aprons of lava in some valleys. Volcanic cones are present along the east coast of Baja California, and some of them show evidence of Recent activity.

STRUCTURE

General Relations

In the broadest structural sense, the Peninsular Range province can be regarded as an uplifted and westward tilted plateau that has been broken into several large, subparallel blocks by major faults (fig. 3). Some of these blocks consist of rocks that lie both above and below the great Mesozoic unconformity, but most of them consist almost wholly of rocks that represent the older sequence. The major faults trend northwest, and many of the elongate blocks that they define are segmented by cross faults. Some of the blocks have undulatory profiles that may be in part ascribable to transverse warping.

Most of the major faults appear to have been intermittently active during large parts of Cenozoic time, and plainly have had a profound influence on the distribution, thickness, and lithology of the younger sedimentary rocks, as well as on the development of the various landforms. Adjacent fault blocks commonly have had distinctly different histories, which has complicated the problems of stratigraphic correlation and geomorphic interpretation in both onshore and offshore parts of the province.

Structural Features in the Older Rocks

The metamorphic rocks that antedate the southern California batholith, although much deformed in detail, have a remarkably consistent regional grain. In nearly all large areas of exposure they

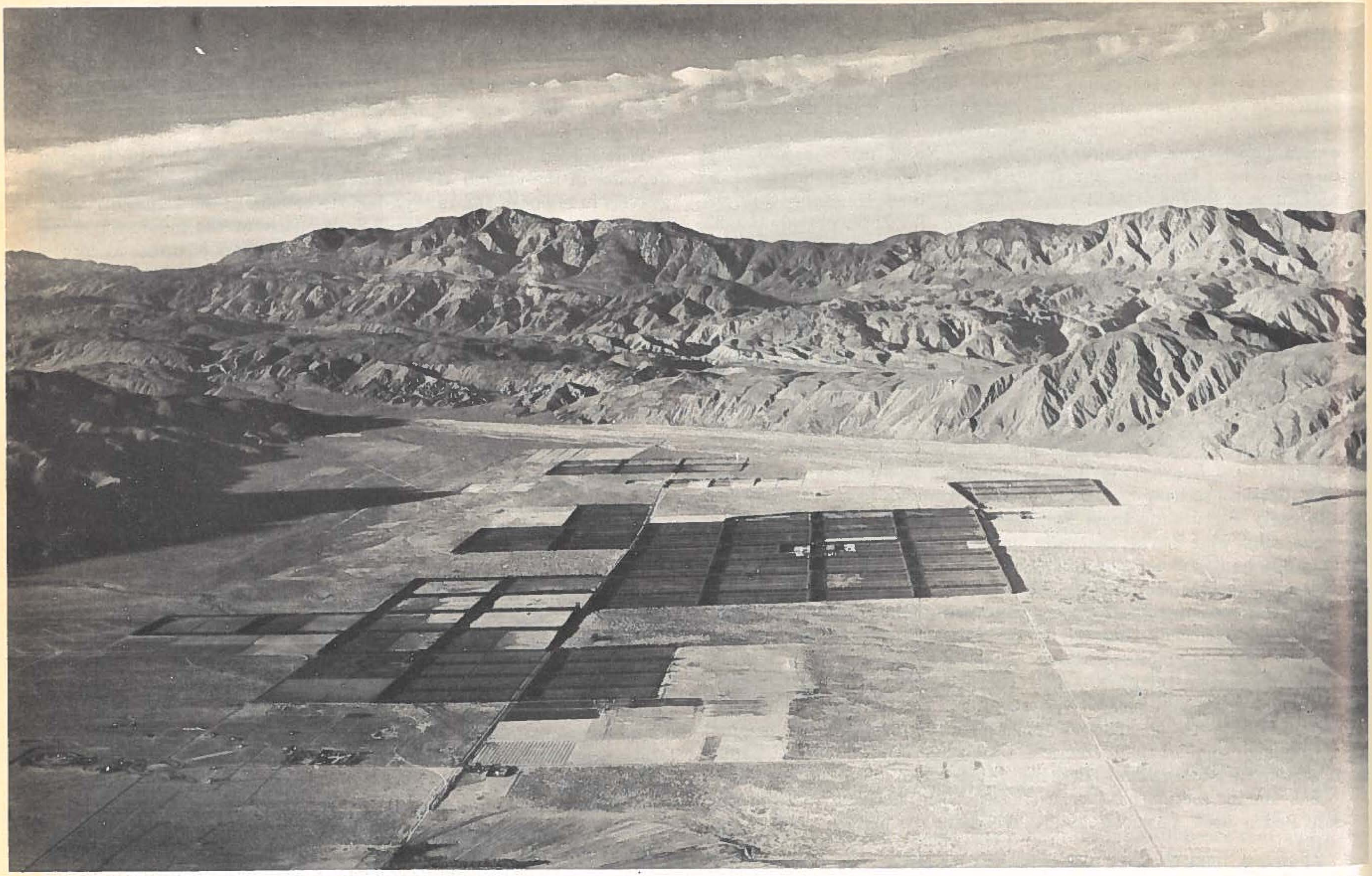

FIGURE 8. Aerial view north-northeastward across Borrego Valley toward the Santa Rosa Mountains, showing scarp of the San Jacinto fault at far edge of valley flat. Beyond this, at successively higher levels, are scarps associated with the Clark and Santa Rosa faults. The badlands at the northern corner of Borrego Valley, immediately beyond the shadow area, have been carved in terrestrial sedimentary rocks of Tertiary age. *Pacific Air Industries photo.*

trend northwest to north-northwest and dip steeply southwest or moderately to steeply northeast. Other trends, however, are common along or near many masses of plutonic rocks. The metamorphic terrane has been so extensively interrupted by igneous intrusives and so much divided into separate structural units by major faults that large-scale folds, if present, are difficult to recognize, and the section in most areas is best regarded as homoclinal. Large folds in the older rocks thus far have been traced only in parts of the Mesozoic section in northwestern Baja California.

Bedding commonly is recognizable in the rocks of sedimentary origin, and original flow structure is preserved in many of the metavolcanic rocks. Foliation and schistosity are broadly conformable with these primary features, but transect them in the axial parts of numerous small folds. Ptygmatic folds are locally abundant in the injection gneisses and other hybrid rocks.

Primary structural features of the plutonic rocks include mineralogic and textural layering, planar orientation of tabular minerals and inclusions, linear alignment of elongate minerals and mineral streaks or clots, and well-defined sets of joints. Most of these features are related systematically to the form—generally steep-walled and stock-like—of the individual intrusive masses in which they occur. The patterns of intersecting joints in some plutons of the southern California batholith are very distinct, especially as viewed from the air (fig. 6), and the exposed joint blocks commonly weather to boulders of distintegration (Larsen, 1948, pp. 114-117) that are prominent even on the more densely brush-covered slopes (fig. 7).

Younger joints, some more regional in their distribution and others apparently related to nearby major faults, also are present in the batholith rocks. Pervasive shearing along fault zones has converted both the igneous and metamorphic rocks into flaser gneisses and large, tabular masses of mylonite in several areas.

Major Faults

The fundamental elements of Cenozoic structure in the province are the steeply dipping major faults that slice the older rocks into northwest-trending blocks. Many of these breaks have remained active to the present time, and hence transect the younger rocks as well. The principal faults and fault zones in the northern part of the province are shown in plate 3, and include the Newport-Inglewood, Norwalk, Whittier, Chino, Elsinore, Agua Tibia-Earthquake Valley, Aguanga-Felipe, San Jacinto, Clark, and Santa Rosa. Similar fault zones are present in the offshore area, and the province is bounded on the north by the San Andreas fault and by east-trending faults that form parts of the Transverse Range pattern. To the south, in Baja California, the bold east faces of the Sierra Juarez and Sierra San Pedro Mártir are the scarps of a major fault zone, and other large faults lie beneath the waters of the Gulf of California.

Some of the faults are well-defined single breaks, especially where they cut rocks of Tertiary or Quaternary age. Most, however, are zones of subparallel to broadly anastomosing breaks that separate lenses and slices of profoundly shattered to almost undeformed rocks (fig. 10). These fault-bounded masses range from slivers a few feet thick to gigantic pinching-and-swelling slabs that are thousands of feet in maximum thickness (fig. 11). Several of the major fault zones show a ramifying pattern on a still larger scale, as in the area southwest of the San Jacinto and Santa Rosa Mountains.

The individual breaks commonly are difficult to recognize where they cut the younger sedimentary rocks, as on the floors of the Los Angeles basin and the valley between Elsinore and Temecula. Others, in contrast, are locally well exposed, and elsewhere are plainly marked by scarplets, sag ponds, offset drainage lines, or other features resulting from recent movement. Also observable along many of the faults are unusual trends in the distribution of vegetation, numerous springs disposed in a linear pattern, sharp differences in ground-water levels, and trenches, elongate ridges, anomalous scarps and benches, and other features characteristic of fault-controlled topography (figs. 4, 8, 9, 11).

Evidences of recent movement are especially well preserved along parts of the San Jacinto, Clark, and Earthquake Valley faults, but in general the most distinctive topographic evidences of faulting appear to have resulted wholly from erosion along the fault zones. Some segments of the major faults are concealed beneath very recent accumulations of alluvium and other debris; much of the trace of the Elsinore fault along the southwestern side of the Agua Tibia Mountains, for example, has been buried by large masses of slope wash and landslide material.

That displacements along several of the faults have been very large is demonstrated by the juxtaposition of dissimilar masses of older rocks and by measurable offsets in sections of the younger rocks, and is further suggested by the occurrence of large scarps, many of them parts of the present topography and others buried beneath thick sections of Cenozoic rocks in some of the basins. The Newport-Inglewood fault zone separates rocks that were wholly unlike when they were formed, and that have undergone dissimilar types of metamorphism (Woodford, et al., Contribution No. 5, this chapter). Although discontinuities of this fundamental type have not been demonstrated along the Elsinore, San Jacinto, and other fault zones to the east and southeast, individual plutons and other masses of crystalline rocks cannot be correlated across these breaks within specific small areas.

FIGURE 9. View northwestward over valley of the San Luis Rey River east of Pala, showing large alluvial fans of Pleistocene age. These consist of material derived from the Agua Tibia Mountains, which are off the view at right. Hills at left and in distance are underlain chiefly by gabbro; note the rib-like projections of pegmatite dikes on several of these hills. The broad bench at the upper right-hand corner of view marks the position of the Elsinore fault zone. *Pacific Air Industries photo.*

The direction of net slip along most of the major faults probably has been oblique, but not enough evidence is yet available precisely to determine this direction, the amount of the slip, or the degree to which reorientation of movement may have taken place during the history of a given fault. Large dip-slip displacements are suggested by vertical differences in the positions of corresponding rocks on opposite sides of some faults, but many of these relations might be as well explained in terms of dominantly strike-slip, or lateral, movements. Scarps in alluvium and other Quaternary deposits testify to a distinct vertical component of recent movements along the San Jacinto fault zone, and the graben-like structure of the Elsinore-Temecula Valley (fig. 10) seems best explained in terms of a large dip-slip component of movement along some faults in the Elsinore system. A somewhat similar narrow graben appears to be present on the floor of the Gulf of California between San Felipe and Santa Rosalia (fig. 1).

Topographic evidence of recent strike-slip (right-lateral) movement of the San Andreas type is widespread in the San Jacinto fault system, and is present locally in the Elsinore system, as well. Additional evidence appears in the form of offset fold axes, as well as drag folding and wrinkling, in adjacent sedimentary rocks of Cenozoic age, especially in areas along the western margin of the Imperial Valley. As pointed out by Dibblee (Contribution No. 2, this chapter), the series of east-trending drag folds and the numerous northeast-trending faults that are present in some of the major blocks between the Elsinore and San Jacinto fault zones may well be subsidiary features in a strain pattern resulting from a general northwest-southeast clockwise torsional stress. Large-scale strike-slip movements are suggested by the relative positions of several apparently related masses of older rocks on opposite sides of the major fault zones, but the evidence thus far obtained must be regarded as presumptive.

Some of the faults, like the Whittier, appear to have been active mainly during late Cenozoic time, but most of them evidently are parts of an extensive, deep-rooted system that probably was developed as long ago as late Mesozoic time. Where they cut strata of Cenozoic age, as in the Los Angeles basin, they displace these rocks less and less in progressively higher parts of the section, and locally they die out upward into zones of folding.

Structural Features in the Younger Rocks

The thick sections of sedimentary rocks in the major basins have been folded along axes that trend west-northwest to north-northwest. Most of the large folds are open, but their flanks are complicated in places by unconformities or by minor wrinkling. Their crests and troughs are undulatory, and several well-defined elongate domes along two major lines of anticlinal folding in the Los Angeles basin have been of particular significance in the accumulation of oil. Many of the folds in this basin have cores of older crystalline rocks that evidently were deformed along with the overlying sedimentary strata; some of these cores also may have been hills at the time when deposition of the younger sediments began.

Most of the folding in the Los Angeles basin appears to be genetically related to nearby faults, and some of it plainly has resulted from fault displacements at greater depths. As suggested by Ferguson and Willis (1924, pp. 579-581), the folds may be products of right-lateral movements between buried blocks of "basement" rocks; parts of these blocks, however, must also have been warped during the folding, as they are present as deformed cores in many anticlines. The Tertiary rocks along the margins of the Imperial and Coachella Valleys have been sharply folded where they lie adjacent to major faults, and "basement" rocks also have participated in much of this folding. Some of the largest folds in this area, however, are less directly related to faults. A typical example is the southeastward plunging anticline at the south end of the Santa Rosa Mountains, where the sedimentary strata are wrapped around a broad nose of much older crystalline rocks.

The Cenozoic rocks in the western part of Baja California occupy a broad and very gentle syncline whose axis trends northwest and in part lies offshore (Beal, 1948, pp. 91-92). A broad anticlinal uplift is present along the Gulf of California in the southeastern third of the peninsula. Both of these folds are complicated by many open to very tight folds of much smaller size, but no well-defined anticlines and domes like those that are associated with faults in the Los Angeles basin have been reported.

Episodes of deformation are recorded by numerous unconformities in the Cenozoic section, particularly in and near the Los Angeles basin. Paleocene deposits rest upon a surface that truncates tilted and locally folded strata of Upper Cretaceous age in the Santa Ana Mountains, and in areas farther south Eocene deposits lie upon what may be the same surface of low relief. Widespread erosion and local deposition characterized much of Oligocene and early Miocene time, and were interrupted in mid-Miocene time by large-scale faulting and uplift. Marked changes were made in the pattern of drainage and in the sizes and shapes of sedimentary basins, and the diastrophism is reflected by major unconformities that are especially prominent along the margins of the sedimentary basins. Smaller breaks in the section represent additional deformation in late Miocene and Pliocene time.

The mid-Pleistocene orogeny is demonstrated by major unconformities in the coastal areas, and in some of the nonmarine interior

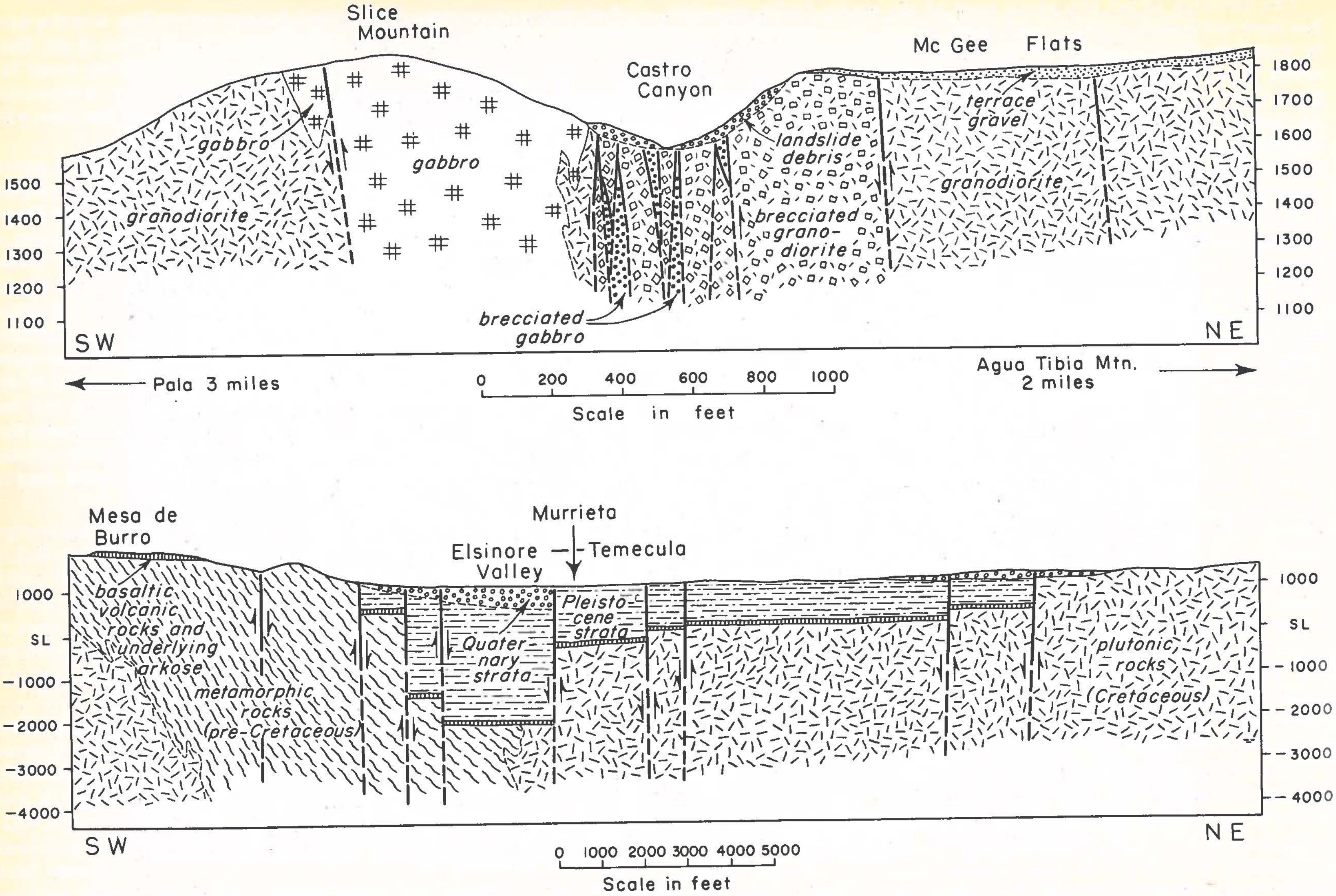

FIGURE 10. Sections across the Elsinore fault zone.

basins, as well. This episode of deformation evidently has continued to the present time, as suggested in many areas by recent warping and by recent displacements along faults. Continuing development of numerous anticlinal folds in the Los Angeles basin has led to remarkably faithful surface expression of their structure, and very young alluvium is involved in some of this folding.

GEOMORPHOLOGY

General Features of the Block Units

Many features of the present landscape in the Peninsular Range region were initially defined during the widespread mid-Pleistocene orogeny, and have been subsequently modified only in detail. Others, in contrast, may have been exhumed from beneath a protective cover of younger sedimentary rocks, and hence may be much older. Regardless of the details of their respective histories, all of these features are related in a fundamental way to the histories of fault-bounded blocks.

The form of the uplifted blocks has been developed in its present detail mainly by erosion, the effects of which have been controlled in many places by the lithology and structure of the rocks involved. In addition, transverse warping may have been responsible for broad differences of present topography within some blocks, as in the San Jacinto, Santa Rosa, and Agua Tibia Mountains. Deposition on the uplifted blocks during Quaternary time has been essentially restricted to local basins, some of which have been downwarped or downfaulted; to the larger canyons and valleys, where erosional terraces have been veneered with coarse sediments; and to the margins of the blocks, where aprons of alluvial material have accumulated.

The relatively depressed blocks are largely mantled by alluvial fill and local lacustrine deposits. Some also contain sections of older nonmarine deposits, and hence must have been lowland blocks in pre-Quaternary time. Others, like those that form the floor of the Los Angeles basin, were low enough to be covered by considerable thicknesses of marine strata whose lithology and structure reflect numerous episodes of deformation. Similar complications in the histories of blocks that now are high are suggested by local remnants of pre-Quaternary sedimentary strata that have been preserved on their surfaces.

Erosion Surfaces

Broad surfaces of low relief, interrupted here and there by hills and ridges, are present in many of the highland areas (fig. 11), and appear at altitudes ranging from 1,200 feet near the coast to 6,000 feet or more in the San Jacinto Mountains, Laguna Mountains, and parts of northern Baja California. They have been developed mainly on the pre-Cenozoic terrane of crystalline rocks, and are characterized by discontinuous but locally thick mantles of soil and weathered rock.

These surfaces have been interpreted as remnants of a single, once-extensive peneplain, commonly known as the southern California peneplain, by Fairbanks (1903), Dickerson (1914, pp. 259-260), Ellis and Lee (1919, pp. 37, 48-49), English (1926, p. 64), Miller (1935), Gale (1932, p. 2), and others. The positions of the surfaces at various levels have been attributed to dislocation of the peneplain by block faulting during Quaternary time. Sauer (1929), in contrast, has concluded that the typical surfaces of low relief were formed independently at different levels, and that each specifically reflects the history of the block on which it appears.

Some of the surfaces may be exhumed features that were originally formed in pre-Quaternary time, as suggested by Dudley (1936) and others, and hence they may be older than some nearby surfaces that lie at higher altitudes. Larsen (1948, pp. 12-13), however, has presented evidence against this argument in at least one large area. If truly exhumed, at least some of these older surfaces might be correlative with the surface exposed beneath Paleocene and Eocene rocks in areas nearer the coast.

Several of the surfaces may have been warped during Quaternary time. That many of them have been offset along faults seems probable, particularly in areas where the implied vertical displacements are compatible with displacements of nearby upper Tertiary and Quaternary rocks. On the other hand, it seems unwise to postulate faults solely on the basis of geomorphic evidence, in order to account for the discordance of presumedly correlative surfaces. Miller (1935), for example, has inferred an impressive mosaic of such faults for a large part of the province, but detailed mapping of the bedrock in several areas has convinced the writer that most of these faults do not exist. Everhart (1951, p. 97) has reached a similar conclusion on the basis of mapping in the Cuyamaca Peak quadrangle. It seems clear that the origin of the erosion surfaces cannot be established in advance of careful geologic mapping, structural analysis, and consideration of all factors that affect the erosion of the rock types involved. The work of Larsen (1948, pp. 5-15) constitutes a realistic approach to the problem.

Terraces

Terraces are present along many of the streams, and their number, extent, and elevations above present stream level vary from one block to another. They are younger than the erosion surfaces described above, but appear to be in part contemporaneous with some of the marine terraces along the coast.

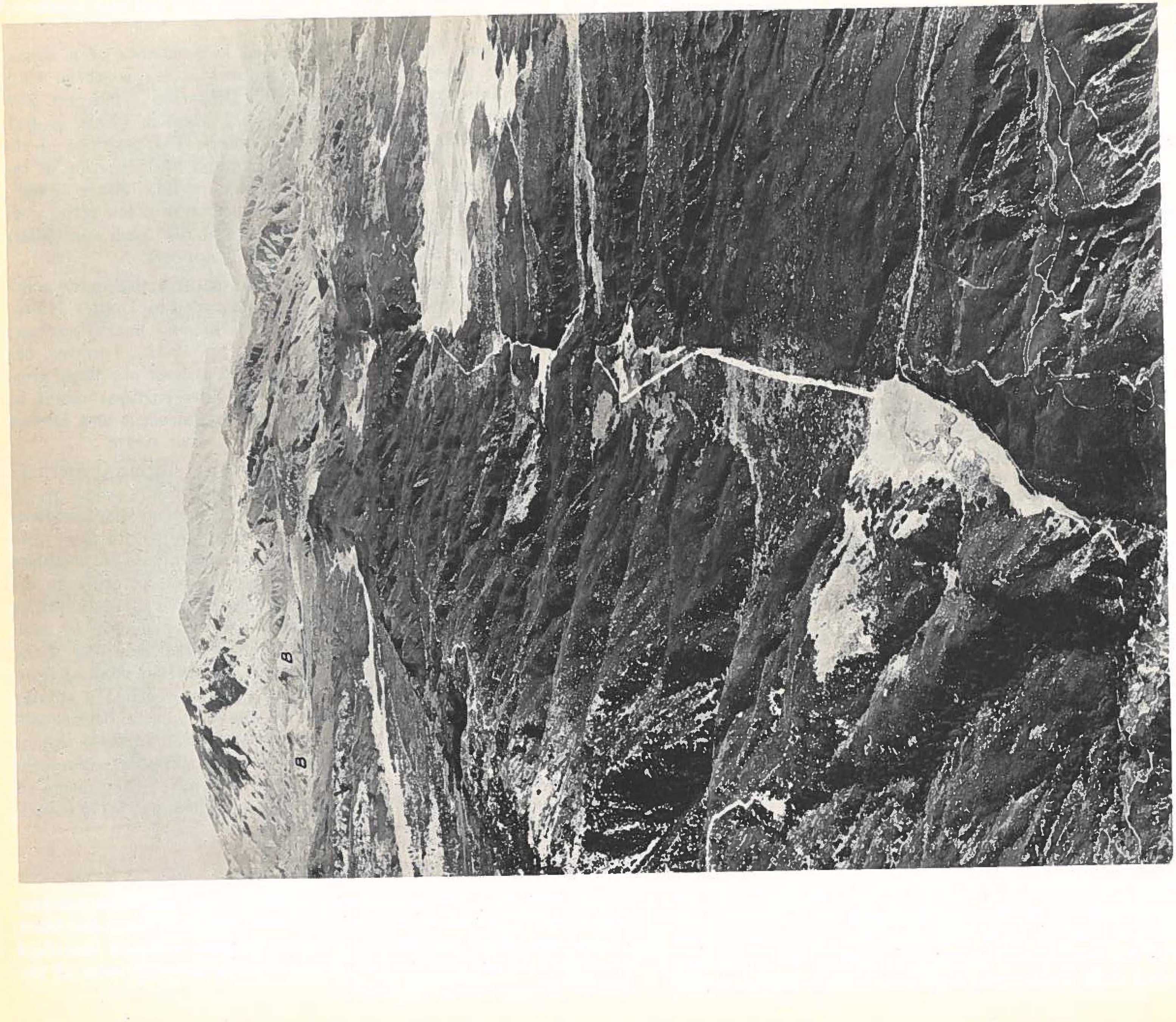

FIGURE 11. View southwestward along the San Jacinto fault zone toward the Santa Rosa Mountains. Note the broad trench and offset streams along the main break in central part of view, as well as the difference in altitude between Hemet Valley at left and the broad Anza surface at right. Recent alluvium and Pleistocene Bautista beds (B) appear in Hemet Valley; the remainder of the area is underlain by igneous and metamorphic rocks. Thomas Mountain is in foreground at left-hand edge of view, Toro Peak is in left distance, and Borrego Valley is in far distance at right. *Photo by J. S. Shelton and R. C. Frampton.*

As many as 13 to 22 marine terraces, some of them warped or otherwise deformed, are present along parts of the coast, and the highest ones are about 1,300 feet above sea level in southern California and nearly 2,000 feet above sea level in Baja California. They have been described by Ellis and Lee (1919, pp. 25-30), M. A. Hanna (1926, pp. 192-198), Woodring, Bramlette, and Kew (1946, pp. 113-118), Beal (1948, pp. 28-33), and many other investigators. They demonstrate considerable submergence of the coastal areas during late Pleistocene time, but present many problems of origin and correlation that remain to be solved.

Drainage Anomalies

Among the anomalous features of drainage in the region are convex stream profiles and abrupt changes in gradient that are not related to differences in the rocks traversed, unusual drainage patterns that feature numerous right-angle bends (fig. 6), hillside swamps and ponds, sag ponds and graben lakes, and offset streams (fig. 11). These are related mainly to the distribution and history of faulting, and have been discussed by Sauer (1929), Larsen (1948, pp. 5-15), and others. Evidence of stream capture is widespread, and capture of numerous other streams seems to be imminent.

Several streams that flow across the Los Angeles basin have cut downward through structural blocks that have risen during Quaternary time (see Woodford, et al., Contribution No. 5, this chapter). The Santa Ana River may well be similarly antecedent to the uplift of the Santa Ana Mountains, and San Felipe Creek probably is antecedent to two large uplifted ridges that are bounded by the Earthquake Valley and Felipe faults south of Borrego Valley. Many other streams whose courses lie athwart the trend of the major fault zones may also have cut downward through rising blocks, but in most instances this cannot be proved. Some anticlines in the Los Angeles basin evidently have risen so rapidly during late Quaternary time that none of the preexisting streams could breach them. On a much larger scale, rapid uplift of the Santa Ana Mountains along the Elsinore fault system evidently blocked the San Jacinto River from a former westerly course across the range, and diverted the drainage to northwest and southeast lines.

NATURAL RESOURCES

Soil, water, and petroleum are by far the most important natural resources in the California portion of the Peninsular Range province. The soil-water combination of course sustains the extensive agricultural development of the region, and irrigation in many areas imposes heavy demands on both surface-water and ground-water supplies. Domestic and industrial requirements also are very large, especially in the area centering about Los Angeles and in coastal areas to the south. The occurrence of water reflects, both directly and indirectly, the structural history of the region, particularly as it has governed the formation of ground-water basins. Many of the faults control the distribution of ground-water in detail, and numerous springs are present along some of these breaks.

Solar evaporation of sea water yields commercial salt and calcium chloride in the San Diego area, and iodine is recovered from oil-well brines in the Los Angeles area.

The Los Angeles basin contains enormous quantities of petroleum, chiefly in strata of Miocene and Pliocene age, and it is one of the major oil-producing areas of the United States. The occurrences of oil and gas in this basin are discussed in Chapter IX of this volume. Despite considerable search, areas elsewhere in the province have yielded no significant production of petroleum as yet, but there may well be hope for new discoveries in some areas (see, for example, Beal, 1948, pp. 120-133).

Rocks of Cenozoic age are of considerable economic importance in this region. Impressive quantities of sand and gravel, used mainly for construction purposes, are obtained from Quaternary deposits in the vicinity of Los Angeles, San Bernardino, San Diego, and other centers of population. Beds of late Tertiary and Quaternary age yield lesser amounts of brick clays, foundry sands, and non-swelling bentonite in several of these areas, and beach and dune deposits yield various sands for specialty uses. Commercial quantities of grinding pebbles, mainly metamorphosed volcanic rocks, have been obtained from several beaches between Oceanside and San Diego.

In the Corona-Elsinore area, strata of Paleocene age are worked for glass sand and high-grade fire clay (Sutherland, 1935), and once were worked sporadically for lignite and sub-bituminous coal of low grade. Similar strata yield china clay in the northern part of the Santa Ana Mountains.

Diatomite is mined on a large scale from upper Miocene marine beds in the Palos Verdes Hills (Woodring, Bramlette, and Kew, 1946, pp. 33-35, 119-120). The largest gypsum mine in the State has been developed in a bedded deposit of probable late Miocene age in the Fish Creek Mountains southeast of Borrego Valley (see Ver Planck, Contribution No. 1, Chapter VIII), and small amounts of gypsite have been mined near Corona. Celestite also has been obtained commercially from a deposit in the Fish Creek Mountains. Deposits of sulfur are present along the eastern margin of the province, especially in Baja California, where they commonly are associated with gypsum and appear to have been developed in part through fumarolic and solfataric action. Calcite of optical grade occurs as pockets and fissure fillings in Tertiary sandstone at several localities near the south end of the Santa Rosa Mountains.

Granitic and gabbroic rocks of the southern California batholith have been quarried for dimension stone, aggregate, or riprap in many places (Larsen, 1948, p. 129; Hoppin and Norman, 1950; MacKevett, 1951). Numerous bodies of pegmatite have yielded commercial quantities of feldspar, quartz, and gem minerals, and a few have been worked for lithium minerals, mica, radio-grade quartz, or other materials (see Jahns, Contribution No. 5, Chapter VII). Bodies of altered ultrabasic rocks have yielded small quantities of amphibole asbestos in the San Jacinto Mountains, and magnesite in an area south of Winchester (Hess, 1908; Gale, 1914).

Recrystallized limestone of pre-batholith age is quarried on a large scale in the Jurupa Mountains, northwest of Riverside, where it serves a major part of the Portland cement industry of southern California. Large reserves of limestone occur elsewhere in the region, especially in the Santa Rosa Mountains and along the northern margin of the San Jacinto Mountains. Metamorphosed volcanic and intrusive rocks are quarried for roofing granules near Corona, and altered volcanic rocks yield pyrophyllite in the costal area southwest of Escondido (Jahns and Lance, 1950).

Among the metals, gold has been economically the most important in the California portion of the province. A substantial aggregate production has been obtained, chiefly prior to 1910, from many small to moderately large vein deposits in the Julian district (Donnelly, 1935), the Perris area (Sampson, 1935), the Santa Ana Mountains (Fairbanks, 1893, pp. 114-117; Larsen, 1948, pp. 131-132), and other areas where crystalline rocks of pre-Cenozoic age are exposed. Some placer gold also has been won from Recent stream gravels and from patches of reddish, coarse, well-cemented gravels of probable Eocene age.

Associated with bodies of gabbroic rocks in the Julian district are massive sulfides that are moderately nickeliferous (Creasey, 1946), and smaller deposits of this type are present in the Santa Ana Mountains. Much mining has been done in scattered vein deposits of lead, zinc, and some copper that occur in the metamorphic rocks of the Santa Ana Mountains, and one lead-zinc deposit on Santa Catalina Island also has been worked commercially. Several tungsten deposits of contact-metamorphic origin have been worked in the Laguna Mountains and other areas in San Diego County. Of periodic interest but much less economic significance are the cassiterite-bearing quartz-tourmaline veins in the Temescal district southwest of Riverside (Sampson, 1935, pp. 515-518), molybdenite-bearing aplite dikes at several localities in Riverside and San Diego Counties, and numerous bodies of pegmatite that contain traces of uranium-, thorium-, and rare-earth-bearing minerals.

A summary description of ore deposits in Baja California recently has been provided by Wisser (1954), and need not be repeated here. The occurrences of principal interest are numerous gold-quartz veins of late Mesozoic age, and some placer accumulations derived from them; base-metal vein deposits of probable Tertiary age in the Sierra Victoria; manganese and copper deposits in sedimentary and volcanic rocks of Tertiary age along the Gulf of California (Touwaide, 1930; Wilson, 1948; Wilson and Veytia, 1949; Noble, 1950); and tungsten deposits of contact-metamorphic origin in the Sierra Juarez (Fries and Schmitter, 1945).

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