GEOLOGIC GUIDE FOR THE NORTHERN PART OF THE PENINSULAR RANGE PROVINCE, SOUTHERN CALIFORNIA*

By Richard H. Jahns †

INTRODUCTION

Route of Travel. This geologic guide deals with parts of Los Angeles, San Bernardino, Riverside, and San Diego Counties, in southern California, and in effect is a sampling of the geology and mineral deposits in the northern part of the Peninsular Range province. The main route of travel, essentially an elongate loop (fig. 1), begins in downtown Los Angeles, extends eastward to Pomona, and from there extends southeastward to Lake Henshaw via Corona and the Elsinore-Temecula Valley. The return part of the loop trends in a general northerly direction to the San Jacinto Mountains and San Gorgonio Pass, and thence westward to Los Angeles. The entire route is approximately 320 miles long, involves travel over good roads, and can be traversed without undue haste in 2 days.

Several points of special interest can be reached by means of short side trips, about 87 miles in aggregate length, that are included in the guide. An additional trip, 82 miles long, has the form of an auxiliary loop through the Escondido-Ramona area, in San Diego County.

Both the main tour and the side trips provide excellent opportunities for observation and study of fault phenomena, geomorphic features, and a wide variety of rock types and mineral deposits. Encountered along the main route of travel are the Elsinore and San Jacinto fault zones, the Pala and Rincon pegmatite districts, and the contact metamorphic deposits at Crestmore.

Form of the Guide. This guide includes a general outline of Peninsular Range geology, annotated road logs for all routes of travel, and numerous maps, sections, and photographs that illustrate the principal geologic features. General descriptions of several areas, mining districts, and geologic units are included within the road logs. A continuous series of seven strip maps shows the geology along approximately half of the route, and three other maps provide similar coverage for selected areas along the remainder of the route.

Cumulative mileages from the starting point at the Los Angeles Civic Center are indicated for the main tour as followed in a counter-clockwise direction around the loop; the figures appear along the margins of the road log and on the maps. Mileages for the side trips and alternate loops are taken from the respective junctions with the main route of travel.

Acknowledgments. The data used in preparing this guide have been obtained from many sources, which are specifically indicated on the illustrations and in the text. In addition, special thanks are due Richard Merriam of the University of Southern California, who supplied all of the information that appears on Map 9; Clarence R. Allen and C. Wayne Burnham of the California Institute of Technology, who contributed unpublished data on the San Gorgonio Pass and Crestmore areas, respectively; and Bennie W. Troxel of the State Division of Mines, who compiled parts of the strip maps. The writer was assisted in a final field check of the route by Troxel and Lauren A. Wright.

GEOLOGY OF THE NORTHERN PENINSULAR RANGE REGION

General Features

The Peninsular Range province is a well-defined geologic and physiographic unit that extends southeastward from the latitude of Los Angeles to the southern tip of the Baja California peninsula, a distance of approximately 900 miles. It is bounded on the northeast by the Colorado Desert (Coachella and Imperial Valleys) and the Gulf of California, and it extends southwestward beneath the Pacific Ocean to form the continental borderland, parts of which appear as Santa Catalina, San Clemente, and other islands. Only the northernmost part of this extensive province is dealt with in the present geologic guide; this part includes the Los Angeles Basin and adjoining hills, the Santa Ana Mountains, the Elsinore-Temecula Valley, the Agua Tibia Mountains, the Warner Basin and adjoining ranges, the Perris and Anza Uplands, the San Jacinto Mountains, and San Gorgonio Pass (fig. 1).

The altitude and relief of this region decrease in a general way from east to west, and its coastal portion is marked by an irregular fringe of lowland country. Beneath this coastal plain and the more extensive lowland area of the Los Angeles Basin is a complex section of sedimentary rocks that range in age from Upper Cretaceous to Recent. Some volcanic rocks of Tertiary age also are present. The inland areas, in contrast, are underlain chiefly by igneous and metamorphic rocks of Mesozoic age and by some metamorphic rocks of probable Paleozoic age. Younger sedimentary rocks, chiefly nonmarine, are preserved in a few basins and valleys, and remnants of volcanic rocks appear locally. Numerous faults have been recognized, and some of them have lengths measured in tens of miles and known displacements amounting to many thousands of feet.

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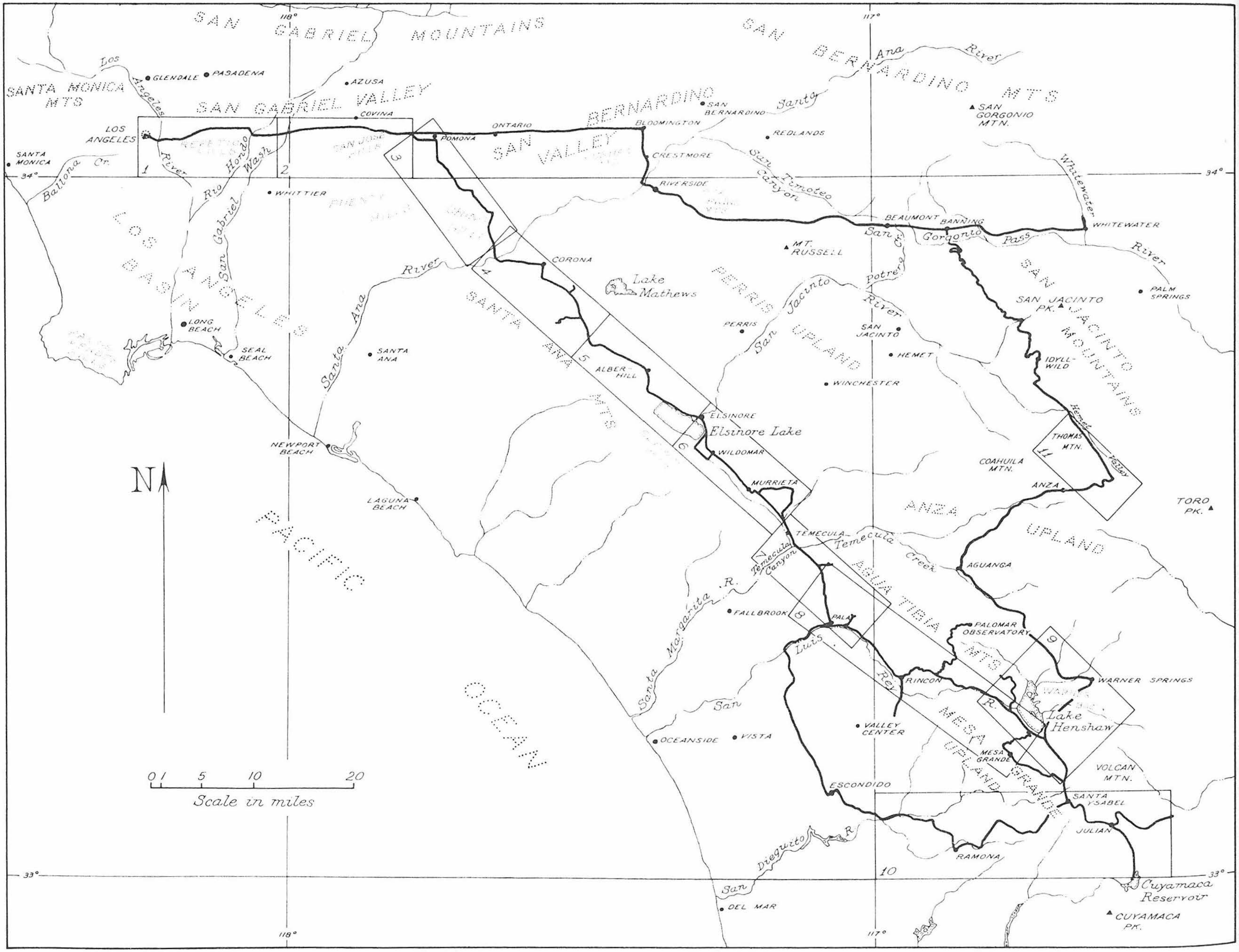


FIGURE 1. Index map of a part of southern California, showing major geographic features, routes of travel described in the road logs, and the areas for which geologic map coverage is provided.

The geology of large parts of the region has been described by Dudley (1935), Ellis and Lee (1919), Engel (1933), Fairbanks (1893), Fraser (1931), Jahns (1954), Larsen (1948), Mann (1951), Merriam (1946), Merrill (1914), Reed (1933), Sauer (1929), Waring (1919), and Woodford, et al. (1954), and specific areas and problems have been discussed by these and numerous other investigators. For more complete and detailed treatment of Peninsular Range geology than appears in this guide, the reader should consult the papers and reports that are listed at the end of the road-log descriptions.

The Geologic Section

The rocks in the northern part of the Peninsular Range province can be grouped into two fundamental age divisions on the basis of differences in lithology, structure, and degree of metamorphism. These divisions are everywhere separated by a profound unconformity, which reflects a major episode of diastrophism, igneous invasion, and metamorphism that occupied a significant part of Cretaceous time.

Older Rocks. The oldest exposed rocks in the region are schists, gneisses, quartzite, and marble that in general represent original clastic sediments and subordinate interlayered volcanic rocks. They form sections as much as 22,000 feet thick in parts of the eastern mountain ranges, but in most areas they appear as smaller masses that are surrounded or flanked by younger igneous rocks. A Paleozoic age for this ancient terrane is suggested by two possible fossil occurrences (Webb, 1939; Miller, 1944, pp. 21-25), and the rocks may correspond in part to fossiliferous Paleozoic strata that are preserved in the San Bernardino Mountains to the north.

Farther west, in the Santa Ana Mountains and adjacent areas, is a great thickness of mildly metamorphosed slaty rocks, schists, quartzite, conglomerate, and limestone that are at least in part of Triassic age. Known collectively as the Bedford Canyon formation (Larsen, 1948, pp. 18-22), these rocks appear to grade into metasedimentary and metavolcanic rocks that have been termed Julian schist (Merrill, 1914, pp. 638-642; Hudson, 1922, pp. 182-190) in areas to the southeast. The relations between these two formations and the presumably older metamorphic rocks to the east and northeast are not fully understood at the present time.

Resting unconformably upon the Bedford Canyon formation in the Santa Ana Mountains is a great thickness of slightly metamorphosed agglomerates, breccias, tuffs, and flows of andesitic to quartz latitic composition. These are the Santiago Peak volcanics (Larsen, 1948, pp. 22-27). Associated with them, and perhaps related to them, are hypabyssal intrusive masses of fine- to medium-grained, dominantly porphyritic rocks.

Plutonic masses of granodiorite and tonalite (quartz diorite), known as the Stonewall granodiorite (Hudson, 1922, pp. 191-193), are prominent in the area south of Lake Henshaw. Associated with these intrusive masses are highly irregular bodies of injection gneiss and other migmatitic rocks, which were formed by the addition of igneous material to the Julian schist.

The youngest and by far the most widespread of the rocks that lie beneath the great unconformity are plutonic types that represent the southern California batholith (Larsen, 1948, 1954), a huge composite mass that underlies much of the region. These rocks range in composition from gabbro to granite, but tonalites are most abundant. The individual intrusive bodies range from plutons of gabbro, tonalite, or granodiorite that are several miles in maximum exposed dimension (Map 10) to thin dikes of pegmatite and aplite (figs. 11, 12). In general the succession of intrusions appears to have been gabbro → basic tonalite → tonalite → granodiorite → quartz monzonite → granite; various dike rocks were emplaced during several different stages.

The batholith is thought to be of early Upper Cretaceous age, mainly on the basis of stratigraphic evidence in Baja California (e.g., Woodford and Harriss, 1938). It probably was formed from a slowly differentiating parent magma of gabbroic composition (Larsen, 1948, pp. 132-172). Successive injections of this magma 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.

Younger Rocks. The rocks that lie above the great unconformity of late Mesozoic age are mainly clastic sedimentary types. These are dominantly marine in the coastal areas and almost wholly nonmarine in the interior parts of the region. The oldest units in the sequence are exposed in and adjacent to the Santa Ana Mountains, where the basal part of the section consists of Upper Cretaceous formations that are chiefly marine (Dickerson, 1914; Packard, 1916; Popenoe, 1941, 1942; Woodring and Popenoe, 1945). These are overlain unconformably by marine and nonmarine strata of Paleocene and Eocene age (English, 1926; Woodring and Popenoe, 1945), which in turn are overlain by terrestrial beds of probable Oligocene age. This nonmarine sequence grades upward into, and is in part intertongued with, a section of marine beds that has been referred to the lower Miocene Vaqueros formation (Loel and Corey, 1932).

The younger marine strata are much more widely distributed, and appear in numerous hills that lie within and around the Los Angeles Basin (fig. 2). They form a thick section of middle Miocene to early Pleistocene age (Daviess and Woodford, 1949; Eldridge and Arnold,

FIGURE 2. Southeastward view of the San Gabriel Valley from Mt. Wilson, in the San Gabriel Mountains, 1905. The San Gabriel River traverses a broad alluvial plain in the near part of the valley, and the San Jose Hills and Puente Hills rise above the haze-shrouded valley floor in the middle distance. The Santa Ana Mountains, dominated by Santiago Peak, appear beyond the lowland area, and on the distant skyline slightly to the left are the Agua Tibia Mountains. *Courtesy of Mt. Wilson and Palomar Observatories.*

FIGURE 3. Structure section across a part of the Los Angeles basin from the Palos Verdes Hills northeastward to the Puente Hills. *Modified slightly from Schoellhamer and Woodford (1951).*

1907; Kundert, 1952; Schoellhamer, et al., 1954; Woodford, et al., 1944), and are overlain in the lowland areas by fine- to coarse-grained nonmarine deposits of Quaternary age. Volcanic rocks are present in the middle Miocene part of the section (Shelton, 1946, 1954); these are mainly pyroclastic, and are andesitic and basaltic in composition.

The geology of the younger rocks in the Los Angeles Basin and adjoining areas has been summarized by Driver (1938) and by Woodford, et al. (1954), and numerous specific features of occurrence are discussed farther on in this guide. Stratigraphic relations, thicknesses, and brief lithologic descriptions are recorded in table 1.

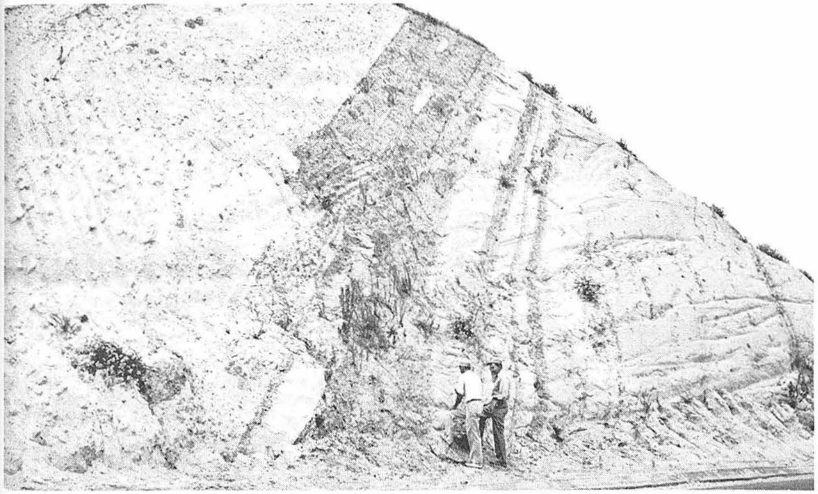


FIGURE 4. Roadcut exposure of the lower Pliocene Repetto formation at the southeast end of the Chino Hills, near Prado Dam. Intertongued siltstone (dark) and conglomerate sandstone (light) are locally disturbed in a way that suggests submarine slumping and sliding during the general period of deposition. Note the broken-off masses of siltstone in the bed of pebble conglomerate about 12 feet to left of the men.

The oldest known Cenozoic rocks of the interior areas are nonmarine Miocene strata that crop out along the margins of the Coachella and Imperial Valleys (Dibblee, 1954), as well as locally in the area north of San Jacinto. These are overlain by fluviatile and lacustrine beds of Pliocene age, which are referred to as the Mount Eden and San Timoteo formations in the area west and northwest of the San Jacinto Mountains (Axelrod, 1937, 1950; Fraser, 1931; Frick, 1921, 1933, 1937). Nonmarine deposits of Pleistocene age are more widespread, and include the Bautista beds of the San Jacinto River Valley and nearby areas (Frick, 1921; Fraser, 1931) and the Temecula arkose of the Elsinore-Temecula Valley (Mann, 1951). Like the Pliocene deposits, these consist in part of fine- to medium-grained, poorly consolidated sediments that were laid down in separate valleys and basins, and in part of very coarse-grained, moderately well-consolidated fanglomerates that represent old alluvial aprons formed along steep mountain fronts.

Sediments of late Pleistocene and Recent age are even more widespread, and include fanglomerates, stream-terrace gravels, lacustrine silts, and modern swamp, alluvial-fan, and flood-plain deposits. Late Tertiary or Quaternary volcanism in the Murrieta-Temecula area is attested by several remnants of olivine basalt flows that appear mainly as mesa cappings.

The geology of the younger rocks in the interior areas of the province has been summarized in greater detail elsewhere in this volume (Jahns, 1954), and their stratigraphic relationships in the area between Corona and Lake Henshaw are outlined in table 2.

Structure

In broad structural terms, the northern part of the Peninsular Range province is an uplifted and southwesterly tilted mass that is separated into several large, elongate, northwest-trending blocks by subparallel faults. These blocks are further sliced by lesser faults, and most are also segmented by cross faults. Both dip-slip and strike-

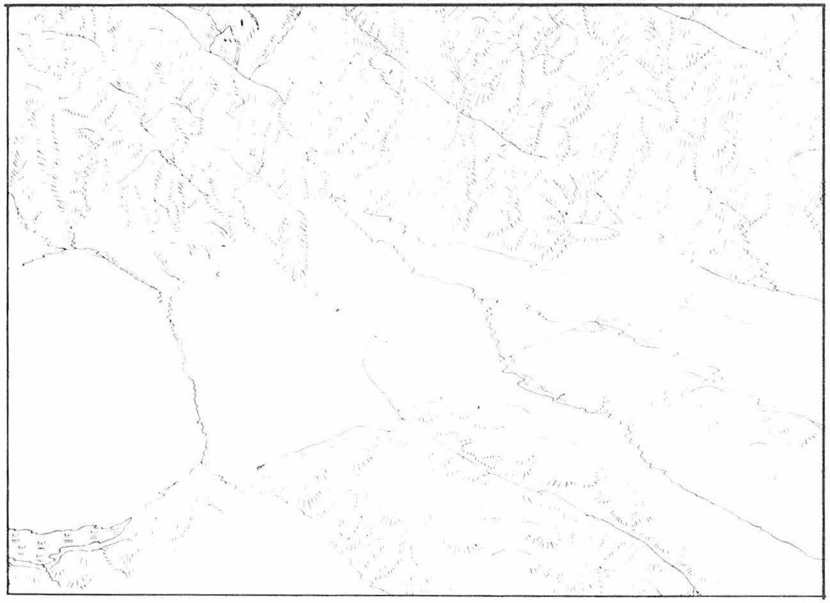


FIGURE 5. Westward view of a part of the Temescal trough, showing the steep lower slopes of the Santa Ana Mountains. The trace of the Glen Ivy South fault lies at the base of this scarp, and the trace of the Glen Ivy North fault is marked by a distinct linear scarplet that trends diagonally across the view. This scarplet, developed in Quaternary alluvial-fan deposits, faces southwestward against the general direction of drainage on the valley floor. Sketched from an air photograph.

slip (lateral) components of movement have been recognized along most of the breaks, and several of the master faults show evidence of major right-lateral displacements. Determination of the direction and amount of net slip on any of these breaks, however, remains an unsolved problem at the present time.

Most of the principal faults appear to have been intermittently active during large parts of Cenozoic time, and have had an important influence on the distribution, thickness, and lithology of the younger sedimentary rocks. Adjacent fault blocks commonly have had contrasting histories, which has complicated the problems of stratigraphic correlation, especially in the interior parts of the province. Some of the faults may well date back to late Mesozoic or earlier times, but the effects of pre-Cenozoic movements are difficult to distinguish from those of later movements.

Folding has been distinctly subordinate to faulting in most areas, and even the regional structure of the pre-Cretaceous rocks is deceptively simple. In nearly all large areas of exposure the metamorphic rocks are essentially homoclinal, with prevailingly northwest to north-northwest trends and steep southwest dips or moderate to steep

Table 1. Generalized stratigraphic column for the northern and eastern parts of the Los Angeles Basin and adjacent parts of the Santa Ana Mountains (see Maps 1-3) (in large part after Woodford et al., 1954).

AGE				MAP SYMBOL	ROCK UNIT		GENERAL THICKNESS (FEET)		LITHOLOGY
CENOZOIC	QUATERNARY	Recent		Qal	Alluvium		0-150		Gravel, sand, and silt of alluvial-fan and flood-plain origin.
		Pleistocene	Upper	Qft	Older alluvial fill and terrace deposits		0-1,700		Gravel, sand, and silt, poorly consolidated; commonly reddish and weathered.
			Lower	Qm	Fanglomerate		0-300+		Conglomerate and subordinate sandstone, locally well consolidated.
	TERTIARY	Pliocene	Upper	Tpu	Upper Pliocene deposits		1,700		Siltstone, conglomerate, and subordinate sandstone; marine.
			Lower	Tr	Repetto		600-4,500		Siltstone, with subordinate sandstone and conglomerate; marine.
		Miocene	Upper	Tpsc	Puente formation	Sycamore Canyon member	11,000 maximum	1,300	Interbedded conglomerate, micaceous siltstone, and sandstone; marine.
				Tpy		Yorba member		650	Thin-bedded gray siltstone, diatomaceous siltstone, and local sandstone and conglomerate; marine.
				Tpsq		Soquel member		1,650	Massive to well-bedded, coarse to gritty feldspathic sandstone; marine.
				Tplv		La Vida member		1,200	Gray to black, laminated siltstone, with interbedded feldspathic sandstone; marine.
			Middle	Tvol	Volcanic rocks		0-3,500		Extrusive and intrusive andesite and basalt, with abundant tuffs and breccias.
				Tt	Topanga formation		2,000		Conglomerate, sandstone, siltstone, and shale; mainly marine.
			Lower	Tvs	Vaqueros formation		3,000		Gray to buff sandstone, conglomerate, and local greenish gray sandy siltstone; marine.
		Oligocene and upper Eocene(?)			Sespe formation				Gray and variegated feldspathic sandstone, conglomerate, and siltstone; almost wholly nonmarine.
		Paleocene		Tsi	Silverado formation		1,400		Nonmarine conglomerate, sandstone, clay, and lignite, overlain by yellowish green to buff marine sandstone.
MESOZOIC	UPPER CRETACEOUS			Klh	Ladd formation*	Holz shale member	1,850		Dark gray to black shale and siltstone, with subordinate sandstone and conglomerate; marine.
				Klbc		Baker Canyon conglomerate member	1,509		Interbedded coarse conglomerate and feldspathic sandstone; marine.
	JURASSIC OR CRETACEOUS			JKp	Plutonic rocks that may represent the southern California batholith				Chiefly granodiorite and tonalite, with subordinate gneissic rocks.
	JURASSIC (?)			Jsp	Santiago Peak volcanics		8,000+		Slightly metamorphosed agglomerates, breccias, tuffs, and flows of andesitic to quartz latitic composition; includes some related hypabyssal intrusive masses.
	TRIASSIC			TRbc	Bedford Canyon formation		20,000±		Slightly metamorphosed argillite and slate, with subordinate quartzite and local lenses of limestone and conglomerate; marine.

* This unit is both overlain and underlain by other formations of Upper Cretaceous age elsewhere in the Santa Ana Mountains.

Table 2. Generalized stratigraphic column for the part of the Peninsular Range province between Corona and Lake Henshaw (see Maps 4-8).

AGE				MAP SYMBOL	ROCK UNIT		GENERAL THICKNESS (Feet)	LITHOLOGY
CENOZOIC	QUATERNARY	Recent		Qal	Alluvium		0–60	Gravel, sand, silt, and clay of alluvial-fan, flood-plain, swamp, and lacustrine origin.
		Pleistocene		Qft	Basin fill and terrace deposits		0–550	Gravel, sand, and silt, poorly consolidated; includes coarse fanglomerate and chaotic breccia in some areas; nonmarine.
				Qwa	Arkose of Warner basin		0–600+	Micaceous arkose and feldspathic sandstone, poorly consolidated, with local interbedded siltstone, marl, and white tuff; nonmarine.
				Qta	Temecula arkose		0–3,700	
				TQb	Basalt		20–110	Dark gray olivine basalt, in flows that cap several mesas.
	TERTIARY	Pliocene		TQa	Older arkose		0–60	Micaceous arkose and conglomerate; may correspond to lower part of Temecula arkose.
				Tr	Repetto formation		3,000±	White to buff sandstone, siltstone, and conglomerate; marine.
		Miocene	Upper	Tp	Puente formation		5,000±	Siltstone, sandstone, conglomerate, and diatomaceous sandstone; marine.
			Lower	Tvs	Vaqueros formation		2,300	Sandstone, conglomerate, and greenish gray siltstone; marine.
		Oligocene and upper Eocene(?)			Sespe formation			Gray to variegated sandstone, arkose, and conglomerate; nonmarine.
		Paleocene		Tsi	Silverado formation		4,000±	Siltstone, feldspathic sandstone, and conglomerate, with clay and lignite in lower part; partly nonmarine and partly marine.
MESOZOIC	UPPER CRETACEOUS			Klh	Ladd formation*	Holz shale member	1,850	Dark gray to black siltstone and shale, with subordinate sandstone and conglomerate; marine.
				Klbc		Baker Canyon conglomerate member	1,500	Interbedded coarse conglomerate and feldspathic sandstone; marine.
	CRETACEOUS			Kgd	Granodiorite, quartz monzonite, and granite		Intrusive rocks of the southern California batholith	Light to medium gray, fine- to coarse-grained felsic rocks; inclusions locally abundant.
				Kt	Tonalites			Light to medium gray, medium- to coarse-grained rocks; inclusions very abundant in some areas.
				Kgb	Gabbroic rocks			Norites and gabbros that vary considerably in composition and texture.
	JURASSIC (?)			Js	Stonewall granodiorite and related gneisses		Intrusive and hybrid rocks that antedate the southern California batholith	Medium gray, medium- to coarse-grained intrusive rock, with associated hybrid gneisses derived from Julian schist.
				Jgp	Granodiorite porphyry and quartz monzonite porphyry			Medium to dark gray, fine- to medium-grained, even-grained to porphyritic rock.
				Jtw	Temescal Wash quartz latite porphyry			Dark gray, fine- to medium-grained porphyritic rock with locally abundant inclusions.
				Jsp	Santiago Peak volcanics		8,000+	Slightly metamorphosed agglomerates, breccias, tuffs, and flows of andesitic to quartz latitic composition; volcanic conglomerate at base.
?	TRIASSIC ?			Trbc	Bedford Canyon formation (includes Julian schist and other rocks that may be in part older)		20,000±	Slightly metamorphosed argillite and slate, with abundant quartzite and local lenses of limestone and conglomerate; includes mica schists and amphibole schists in southern part of area; marine.

*This unit is both overlain and underlain by other formations of Upper Cretaceous age on the southwestern side of the Santa Ana Mountains.

northeast dips. Few large folds can be recognized, but the rocks have been considerably broken, sheared, and contorted in detail. All appear to have been deformed and metamorphosed prior to emplacement of the southern California batholith, and many of them also show the effects of later contact metamorphism attendant upon this episode of igneous intrusion. Both the igneous and the metamorphic rocks have been converted into flaser gneisses and mylonites along some major zones of shearing.

The younger rocks have been compressed into numerous open folds whose flanks are complicated in places by faults, unconformities, or by minor wrinkles and bulges. Most of the large folds trend west-northwest to north-northwest, and appear to be genetically related to faults that lie beneath or adjacent to them. Indeed, the younger sedimentary sections in many of the basins can be regarded as moderately wrinkled and ruptured blankets that conceal a much more severely disturbed terrane of older rocks.

Numerous episodes of deformation are recorded by unconformities in the Cenozoic section, particularly around the margins of the sedimentary basins. In the Santa Ana Mountains, Paleocene deposits rest upon an ancient surface of erosion that truncates tilted and folded strata of Upper Cretaceous age, as well as older igneous and metamorphic rocks. Much of Oligocene and lower Miocene time must have been characterized by widespread erosion and local deposition, which

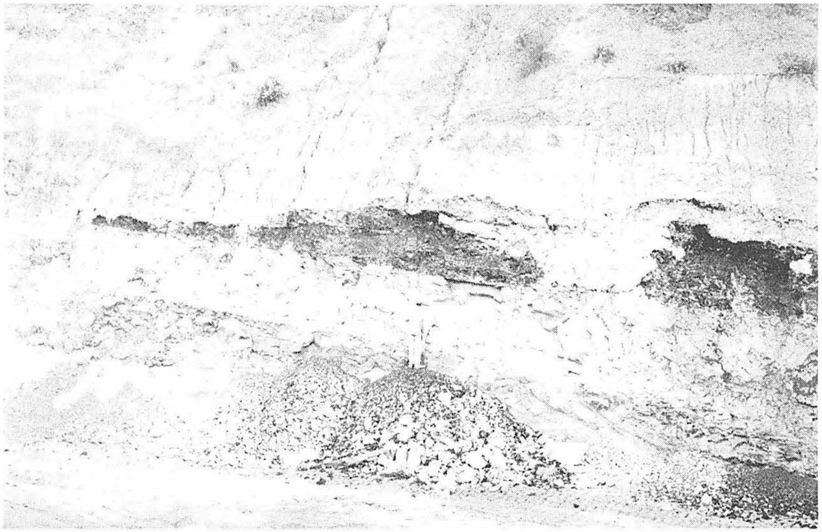


FIGURE 6. Fresh exposure of lignite and clay in upper pit at the Alberhill clay mine. The coaly bed above the man is overlain by light-colored, blocky clay, and is underlain successively by gray high-alumina clay with conchoidal fracture and by pinkish, dark-appearing clay that is in part of residual origin. All of the exposed material is in the lower part of the Paleocene Silverado formation.

were interrupted in middle Miocene time by major pulses of faulting and uplift that caused fundamental changes in the pattern of drainage and the sizes and shapes of the sedimentary basins. Additional pulses of milder deformation followed during upper Miocene and Pliocene time. Severe diastrophism in late Pliocene and middle Pleistocene times is demonstrated by major unconformities in both marine and nonmarine sections. Much of the present landscape was developed during the widespread middle Pleistocene orogeny, and deformation in many areas has continued to the present time.

Geomorphology

The geomorphic history of the region is intimately related to the history of movements within and between the major fault blocks during late Cenozoic time. Many features of the modern landscape owe their gross form and position more to recent diastrophism than to the effects of erosion on contrasting types of rocks, but the known interplay of diastrophism and erosion ordinarily is difficult to resolve in detail.

In the higher interior areas are unusual (and commonly anomalous) combinations of prominent ridges and peaks (figs. 2, 21, 22), broad erosion surfaces of low relief (fig. 21), narrow and steep-walled canyons (fig. 22), longitudinal trenches, benches, and valleys that are defined by zones of faulting (figs. 11, 22), and many wide valleys and basins (figs. 2, 19). The broad upland surfaces appear at various levels, and have prompted much argument as to whether they are parts of a single, once-extensive surface of erosion that was dislocated by faulting in Quaternary time (e.g., Bryan and Wickson, 1931; Miller, 1935), whether they were formed independently at different levels (Sauer, 1929) and perhaps at different times, or whether some of them are older features that have been exhumed from beneath a cover of younger Cenozoic rocks (Dudley, 1936). Several of these surfaces show evidence of Quaternary upwarping, and several of the shallow basins appear to have been bowed downward during late Quaternary time.

Recent alluvial fans are impressive features of the lowland areas, and remnants of even more extensive Pleistocene fans are widely preserved (figs. 11, 17). Many of these can be correlated with gravel-veneered fluviatile terraces in adjacent canyons and valleys. Recent uplift in the coastal areas is attested by wave-cut marine terraces, some of which have been warped, tilted, or offset slightly by faulting. Several anticlinal folds in the Los Angeles Basin have been formed so recently that their structure is reflected by the present topography, and the uplift of some evidently was so rapid that pre-existing streams were unable to breach them. Others are cut by antecedent streams, and, on a much larger scale, the Los Angeles, San Gabriel, and Santa Ana Rivers may well be antecedent to the uplift of the Santa Monica Mountains, Repetto Hills, and Santa Ana Mountains. Recent movements along faults are evidenced in several parts of the region by scarplets in alluvium, sag ponds, anomalies in stream profiles, offset drainage lines, and by historic records of numerous earthquakes.

Economic Features

By far the most important natural resources in the region are soil, water, and petroleum. Extensive settlement and agricultural development in many areas have led to full use of available sources of both surface water and ground-waters, and during recent decades it has become necessary to import increasing quantities of water from sources in other regions.

The sedimentary deposits of the Los Angeles basin have yielded an enormous amount of petroleum, as well as sand and gravel, brick clays, foundry and other specialty sands, diatomite, non-swelling bentonite, and iodine that is recovered from oil-field brines. Tertiary strata elsewhere in the region have been worked commercially for glass sand, fire clay, china clay, gypsite, lignite, and optical-grade calcite.

The rocks of the southern California batholith have been quarried for dimension stone, aggregate, or rip rap in many areas, and the pegmatite deposits of Riverside and San Diego Counties have yielded commercial feldspar, quartz, and lithium minerals in addition to the gem minerals for which they are best known. Deposits of amphibole asbestos and magnesite occur in small bodies of altered ultrabasic rock in the San Jacinto Mountains and areas adjacent on the west.

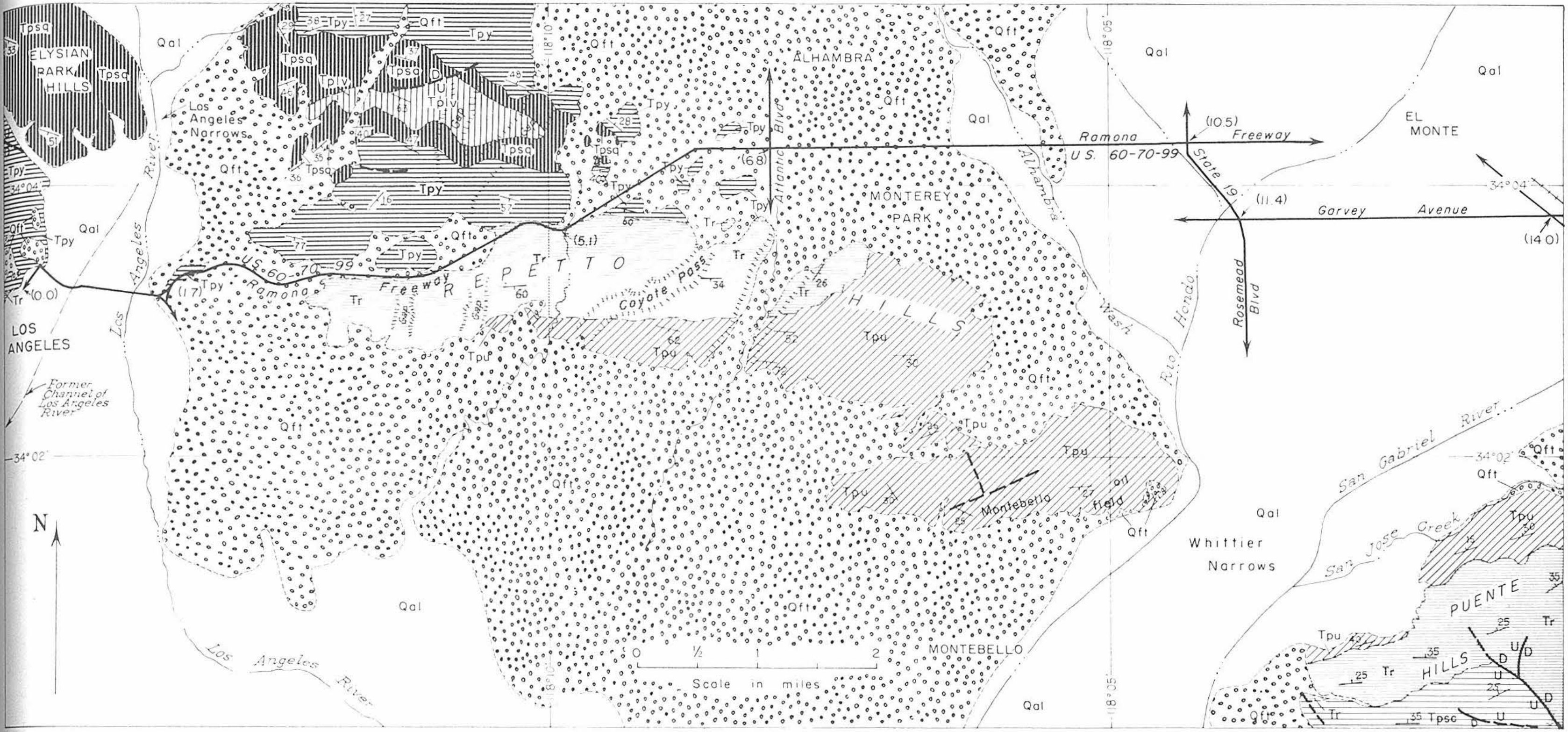
The pre-batholith rocks supply very large quantities of limestone for cement making, as well as the raw material for a substantial production of roofing granules. Vein deposits in both igneous and metamorphic rocks have been mined in several districts for gold, lead, zinc, copper, and tungsten, and with less success for nickel, tin, and molybdenum. Most of these districts are noted in the following road-log descriptions.

ROAD LOGS

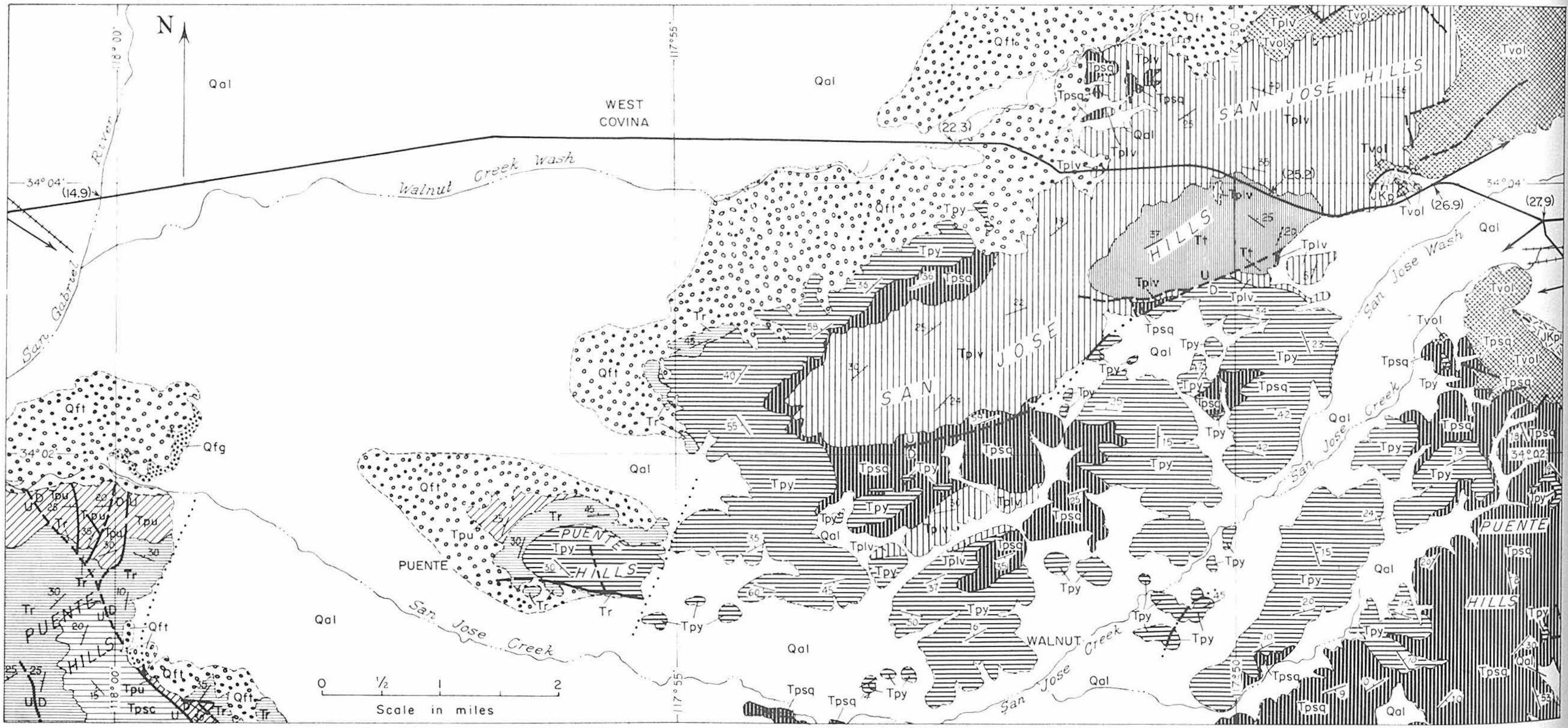
Los Angeles to Pomona—30.4 Miles

(Maps 1, 2, 3; Table 1)

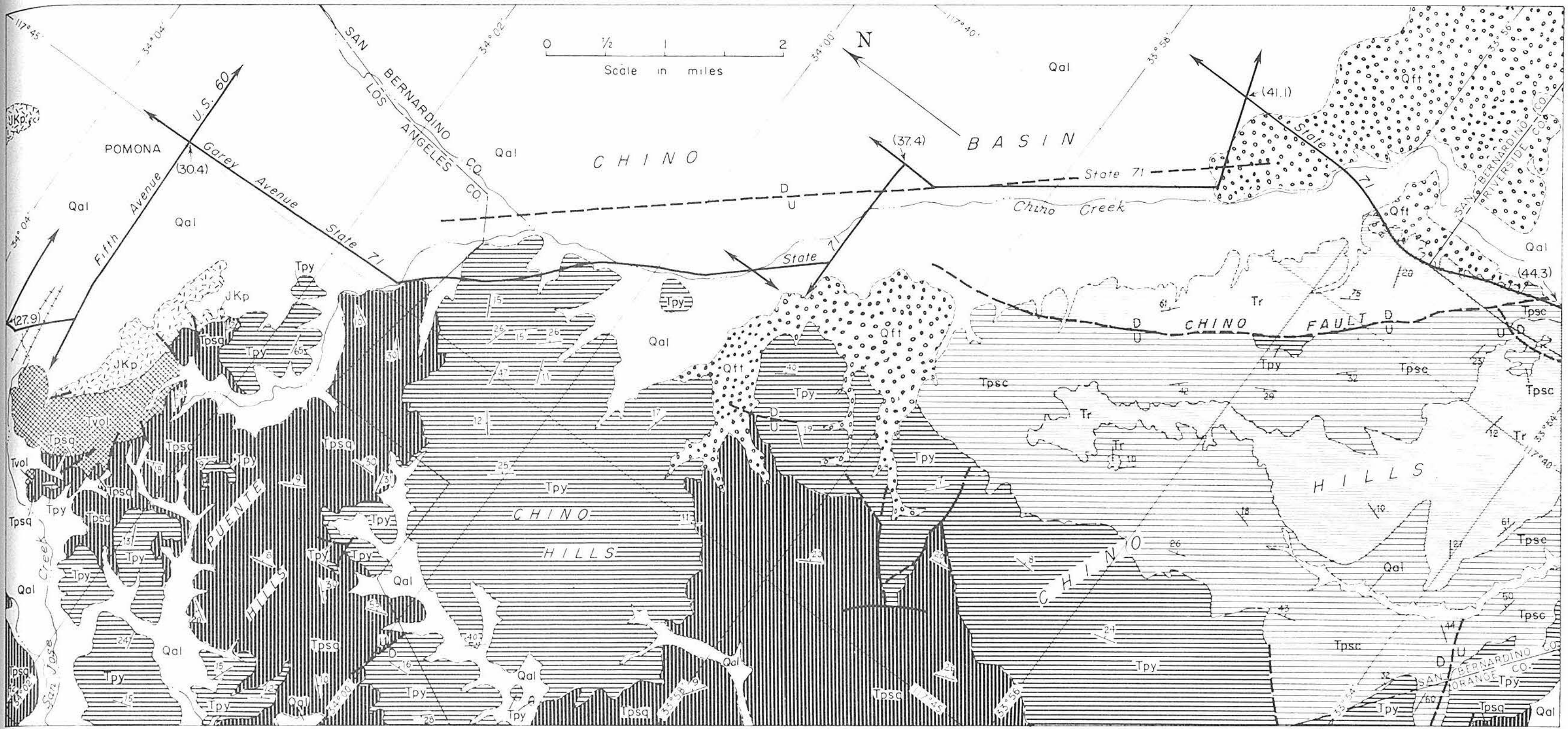
The Los Angeles Basin. The lowland area that lies between the Pacific Ocean on the southwest and the Santa Monica Mountains, the elongate Repetto and Puente Hills, and the Santa Ana Mountains on the northeast is known geographically as the Los Angeles Basin (fig. 1). It is about 50 miles long, as measured in a northwest-southeast direction, and about 20 miles wide. Northwest of it lies the San Gabriel Valley, from whose broad floor rise additional elongate hills



MAP 1. Los Angeles to El Monte. Qal—alluvium; Qft—older alluvial deposits; Tpu—upper Pliocene deposits; Tr—Repetto formation; Tpsc—Sycamore Canyon member of Puente formation; Tpy—Yorba member of Puente formation; Tpsq—Soquel member of Puente formation; Tplv—La Vida member of Puente formation. See Table 1 for stratigraphic relationships and descriptions of these geologic units. *Geology after Woodford, et al. (1954).*



Map 2. El Monte to San Jose Hills and Pomona. Qal—alluvium; Qft—older alluvial deposits; Qfg—fanglomerate; Tpu—upper Pliocene deposits; Tr—Repetto formation; Tpsc—Sycamore Canyon member of Puente formation; Tpy—Yorba member of Puente formation; Tpsq—Soquel member of Puente formation; Tplv—La Vida member of Puente formation; Tvol—volcanic rocks; Tt—Topanga formation; JKp—plutonic igneous rocks. See Table 1 for stratigraphic relationships and descriptions of these geologic units. *Geology after Woodford, et al. (1954).*



MAP 3. Pomona to Prado Dam. Qal—alluvium; Qft—older alluvial deposits; Tr—Repetto formation; Tpsc—Sycamore Canyon member of Puente formation; Tpy—Yorba member of Puente formation; Tpsq—Soquel member of Puente formation; Tvol—volcanic rocks; JKp—plutonic igneous rocks. See Table 1 for stratigraphic relationships and descriptions of these geologic units. *Geology after Woodford, et al. (1954).*

(fig. 2). These two areas contain the greatest concentration of population in the State.

The Los Angeles Basin marks the site of a more extensive trough of middle and late Cenozoic sedimentation to which the name Los Angeles basin has been attached in a purely geologic sense. Both marine and nonmarine deposits were laid down in parts of this area during late Cretaceous and early Tertiary time, but it was first defined as a single broad trough in middle Miocene time, when its irregular surface was completely covered by a widespread marine embayment. As the basin gradually subsided, to a much greater extent in some places than in others, it received considerable thicknesses of marine sediments. Some parts of it were filled to points above sea level by early Pleistocene time, and from then on marine sediments were deposited mainly in its southwestern parts.

The Cenozoic section of the Los Angeles basin is 10,000 feet or more thick in all but the marginal areas, and geophysical evidence indicates a thickness of slightly more than 40,000 feet in the central deep, southwest of the Puente Hills (fig. 3). In this area the Pliocene section alone is more than 10,000 feet thick. The basin filling is dominantly fine to medium grained and clastic, but it represents a great variety of sedimentary environments, particularly in areas that lay along and near the margins of the embayment. These and other stratigraphic features have been summarized by Driver (1948), Woodford, et al. (1954), and others.

The 40 oil fields in the Los Angeles basin have yielded more than 4 billion barrels of petroleum since 1880, which accounts for more than two-fifths of the production from the entire State. Average recovery in the proved fields has amounted to more than 100,000 barrels per acre, a remarkable performance that reflects the richness of the accumulations, together with the occurrence of producing zones at more than one stratigraphic level in most of the fields.

Most of the known accumulations are in strata of early Pliocene and late Miocene age, and the remainder of the production is obtained from upper Pliocene and middle Miocene strata, and from fractured masses of older rocks. More than half of the oil produced thus far has been extracted from two series of en echelon faulted anticlines that extend northwestward across the basin (fig. 3). The remainder has been obtained from other anticlines, fault traps, and stratigraphic traps, chiefly in areas near the margins of the basin.

0.0 Start of trip. Los Angeles Civic Center.

From First Street drive northeastward on Spring Street or Broadway to Hollywood Freeway. Ahead and to left (north-northwest) is Fort Moore Hill, which consists of upper Miocene marine siltstone and sandstone (Puente formation) capped by reddish brown Quaternary gravels. The Miocene strata dip southward, and in downtown Los Angeles they are overlain conformably by marine strata of the lower Pliocene Repetto formation. Still farther south in the downtown area are upper Pliocene marine strata. All of these rocks lie on the south flank of the Elysian Park anticline, the axis of which extends through the northeastern part of the Elysian Park Hills and into the Repetto Hills east of the Los Angeles River (Map 1).

0.3 Turn right (southeast) onto Hollywood Freeway. The old Los Angeles Plaza lies about two blocks to the left (north). Continue past Los Angeles Union Station and cross floodplain of the Los Angeles River.

1.1 Bridge over Los Angeles River. About 1½ miles north of this point the river issues from the Los Angeles Narrows, whence it flows southward across a broad alluvial plain to discharge into the ocean near Long Beach. Its channel has shifted considerably during Recent time, and at least once in the recent past the river has flowed westward to empty into the ocean via an alternate channel now occupied by Ballona Creek (Map 1, fig. 1). The river probably is antecedent where it crosses the Elysian Park anticline in the narrows, as it appears to have maintained its course while this fold was developing in late Pliocene and Quaternary time.

1.3 Turn left (northeast) onto Ramona Freeway (U.S. 60-70-99).

1.7 Roadcut exposures of upper Miocene sandstone and gray to bluish gray siltstone (Yorba member of Puente formation), overlain by late Recent rubble.

3.5 City Terrace district. The freeway skirts the northern edge of the Repetto Hills, which are composed of light gray siltstone and subordinate sandstone, mudstone, and conglomerate that are characteristic of the Pliocene section in the northern part of the Los Angeles basin. These sedimentary rocks dip moderately to steeply southward. The hills on the north (left) side of the freeway are underlain by siltstone, diatomaceous shale, and coarser-grained sediments of the Puente formation (Yorba member).

Several of the roadcuts expose Quaternary gravels that occupy a basin-like area about half a mile in diameter; this depression is a part of a former line of drainage across the hills, and well-defined wind gaps lie both north and south of it (Map 1). The hills evidently were uplifted athwart the prevailing direction of drainage in this general area, probably in middle and late Pleistocene time. During its late stages this uplift must have been more rapid than the downcutting of several of the streams, which thus were forced to abandon the channels that they had cut during earlier stages of the uplift. At least four well-defined wind gaps, or passes, cross the Repetto Hills, and others are present in the hills to the northwest.

5.1 Bricks in yard on the right (south) are made from siltstone of the lower Pliocene Repetto formation. A few hundred feet north of the freeway is the conformable contact between this unit and the underlying Puente formation, three members of which are exposed in the hills to the northwest. They dip southward off the crest of an anticline that plunges gently to the east (Map 1).

5.3 Large roadcut exposure of Repetto strata.

5.4 Angular unconformity between Repetto formation and Quaternary gravels is revealed in the roadcut on right (south).

6.5 Edge of San Gabriel Valley. The hills that rise above the valley floor are underlain by fine-grained Puente strata. About a mile to the south is the head of Coyote Pass, a wind gap through the Repetto Hills.

6.8 Atlantic Boulevard. About a mile south of this point is the head of a gap through the Repetto Hills that was once occupied by a through-flowing stream, but was later abandoned and became a wind gap. It now is drained by a small, underfit, intermittent stream. Exposed along the west side of this gap is the type section of the lower Pliocene Repetto formation (Reed, 1932).

The Repetto section, about 2,500 feet thick in this area, consists chiefly of micaceous siltstone that rests conformably upon diatomaceous shales of the Puente formation. It contains an abundance of Foraminifera, many of which suggest deposition of the sediments in waters at least 4,000 feet deep (Natland, 1952). Conformably overlying the Repetto strata is a section of upper Pliocene siltstone, with subordinate sandstone and conglomerate. These beds, which underlie much of the eastern Repetto Hills, ordinarily are distinguished from the lithologically similar Repetto formation on the basis of their contained Foraminifera. They have been correlated by some geologists with the Pico formation of the Ventura basin, about 30 miles to the northwest, but the two units probably are only in part equivalent.

The upper part of the Pliocene section is featured in some areas by numerous isolated pebbles, as well as lenses of conglomerate in which shallow-water megafossils are preserved. The siltstone that encloses these pebbles and lenses contains Foraminifera characteristic of a deep-water environment. This anomalous association, together with abundant slickensides, contortion, and local kneading together of the rocks, suggest that masses of near-shore deposits were transported down slope into deeper waters by sliding or turbidity flows during deposition of the finer-grained parts of the section.

San Gabriel Mountains. North of the Ramona Freeway the floor of the San Gabriel Valley extends gradually upward toward the bold south face of the San Gabriel Mountains, 8 to 10 miles distant. This east-trending mountain mass is a major element of the Transverse Range province, which bounds the Peninsular Range province on the north. It is lens-shaped in plan, is about 60 miles long, and rises to general altitudes of 5,000 to 9,000 feet. On clear days Mt. Wilson, with its observatory buildings and bristle of television transmission towers, is visible in a northerly direction.

The range is essentially a gigantic horst that is bounded on all sides by major faults, and consists of plutonic igneous rocks of late Mesozoic age, together with a very complex series of older intrusive and metamorphic rocks. It is transected by several large faults, and by countless shear and shatter zones. Its south face is defined by the Sierra Madre fault zone, a group of branching and en echelon breaks whose prevailing dip is northward beneath the mountains.

Intermittent uplift of the range probably took place during a large part of Tertiary time, and this great mass doubtless contributed much sedimentary material to the Los Angeles basin. The last major uplift probably dates from middle Pleistocene time, and subsequent erosion has scored the range with numerous deep canyons. Higher parts of the range, which lie to the northeast, may mark an axis of broad transverse upwarping.

10.5 Turn right (south) onto Rosemead Boulevard (State Highway 19).

11.2 Bridge over Rio Hondo. The San Gabriel River, one of the major streams in the region, debouches onto the valley floor from the mouth of a steep-walled canyon about 11 miles to the northeast (fig. 1). It traverses a very large alluvial fan (fig. 2), on whose surface it splits into two channels. The more westerly of these, the Rio Hondo channel, drains south-

southwestward to join the Los Angeles River; the other, the San Gabriel channel, drains southward to the ocean at Seal Beach.

Both branches of the river flow through the Whittier Narrows, about 2½ miles to the south. This is a gap, nearly 2 miles in width, that separates the Repetto Hills from the Puente Hills farther east. It may well have been a channel-like feature in lower Pliocene time, as suggested by the distribution of coarse detritus in the Repetto formation (M. L. Natland, in Kundert, 1952, pp. 7-8), but its present form is the result of later trenching. A wide, alluvium-floored trough has been cut into older alluvium that was deposited in the narrows during late Pleistocene time.

Immediately west of the narrows is the Montebello oil field, in which oil is obtained from lenticular zones in the Repetto formation, and to a lesser extent from upper Miocene strata. The main structural element in this field is an eastward-plunging anticline, parts of which have been ruptured by faults.

11.4 Turn left (east) onto Garvey Avenue.

14.0 Five Points; cross Valley Boulevard.

14.9 Bridge over San Gabriel River. For the next few miles the road crosses a broad alluvial plain that slopes gently and uniformly southwest. To the south are the western Puente Hills, which are underlain by upper Miocene and Pliocene strata. A striking angular unconformity between upper Pleistocene gravels above, and lower Pleistocene and upper Pliocene strata below, is well exposed in the gorge cut by San Jose Creek through the northern tip of these hills.

The Whittier fault zone, a major structural feature of the Los Angeles basin, extends along the south flank of the hills as a series of anastomosing breaks. It dips northward, and has had several thousand feet of reverse movement (fig. 3). Evidence of large right-lateral displacements also has been recognized (Kundert, 1952; Woodford, et al., 1954), especially in areas farther east.

Several oil fields are present along the south side of the western and central Puente Hills. Most of the accumulations are related to the Whittier fault, and the subsurface structure of the fields is locally very complex.

22.3 Bridge over Walnut Creek Wash. For about a mile beyond this point the road traverses a dissected bench of reddish brown older alluvium that is known in this area as the San Dimas formation. It probably is late Pleistocene in age.

23.9 San Jose Hills. These hills are essentially an anticlinal mass of Miocene rocks, but their structure is complicated in detail by numerous faults and smaller folds. Most extensively exposed is the upper Miocene Puente formation, which in the Puente Hills has been divided into four members (Schoellhamer, et al., 1954). In ascending order, these are the La Vida, Soquel, Yorba, and Sycamore Canyon (table 1). The Yorba and Soquel members appear along the northwest margin and in the southern part of the San Jose Hills, and the La Vida member is exposed in their higher parts. Older rocks, chiefly the middle Miocene Topanga formation and volcanic rocks, crop out along the crest and in the northeastern part of the hills.

For the next mile, in the Covina Knolls section of the hills, are roadcut exposures of thin-bedded La Vida siltstone and sandstone. The effects of widespread recent slumping are clearly visible, and mass movements of these fine-grained rocks have been a serious problem to property owners in this area.

25.2 Crest of hills. The roadcuts expose pebbly sandstone and pebble to cobble conglomerate of the Topanga formation (Buzzard Peak conglomerate member), which is about 2,000 feet thick in this area. Conglomerate is interbedded with much finer-grained rocks in roadcuts beyond this point.

26.1 The highway here traverses an area of considerable landsliding, mainly involving fine-grained beds of the Puente formation (La Vida member). A large slide that once blocked the road was by-passed for several years. Attempts have been made to stabilize the larger slides by means of broad excavations and drainage of their source areas.

Preferential growth of prickly pear cactus outlines the general distribution of sandstone and conglomerate beds on the hillside to the north. To the south, the main mass of the Puente Hills is visible across the valley occupied by San Jose Wash.

26.6 Puddingstone Road. Middle Miocene volcanic rocks rest upon dacite porphyry, here inconspicuously exposed, and are overlain by La Vida strata. Similar dacite porphyry is intrusive into gneissic plutonic rocks of late Mesozoic age in a spur of these hills about 2 miles to the east-northeast.

26.9 Bear right (east) off freeway onto U. S. Highway 60.

Large roadcuts along the freeway expose light-colored, compact, thinly laminated tuff and fine-grained tuff breccia overlain by gently dipping volcanic breccia that is darker, much coarser grained, and contains abundant fragments of brownish to greenish gray flow rocks. These are parts of a thick volcanic series, known as the Glendora volcanics (Shelton, 1946), that crops out extensively in areas to the north. The rocks of this series are mainly andesitic in composition, and pyroclastic accumulations are dominant over intrusive and flow rocks. The formation is as much as 3,500 feet thick beneath Covina, about 5 miles to the west, where it has been penetrated by wells (Shelton, 1954).

The Glendora volcanics appear at or near the top of the Topanga formation in several areas, and probably are correlative with the volcanic rocks of middle Miocene age in the Santa Ana Mountains, Santa Monica Mountains, Palos Verdes Hills, and other areas within or near the Los Angeles basin.

27.9 Turn right (south) and continue on U. S. Highway 60, crossing railroad tracks on overpass. From this overpass a large quarry, developed in andesitic volcanic rocks, is visible to the right (southwest). Low on the slopes of the hills to the south, these rocks rest unconformably upon quartz diorite of late Mesozoic age.

28.6 Turn left (east) onto Fifth Avenue.

30.4 Pomona, Fifth and Garey Avenues.

Pomona to Corona—20.3 Miles
(Maps 3, 4; Table 1)

30.4 Pomona. Turn right (south) onto Garey Avenue (State Highway 71).

For the next 13 miles the route of travel follows the margin of the broad San Bernardino Valley, which is bounded on the southwest by a part of the Puente Hills known as the Chino Hills. These hills are composed mainly of northeasterly dipping upper Miocene strata. The adjacent part of the San Bernardino Valley has the structure of a narrow, elongate basin, the Chino basin, which is bounded on both sides by northwest-trending high-angle faults whose positions are outlined by sharp differences in ground-water levels. This basin contains at least 1,300 feet of Quaternary fluviatile deposits and several thousand feet of upper Tertiary marine strata (Woodford, et al., 1944). The basin and adjoining parts of the valley have been filled to the same general level by Recent alluvium derived from the San Gabriel Mountains to the north.

33.2 Sandstone and siltstone of the Puente formation (Yorba member) are exposed in roadcuts for 1.3 miles, beyond which the road traverses the valley floor. This part of the valley is used mainly for dairying and the raising of field crops.

36.4 Turn left (east) and continue on State Highway 71.

37.4 California Institution for Men. Turn right (south).

41.1 Turn right (south) onto Euclid Avenue Freeway (State Highway 71). From this point the highway crosses a low terrace of upper Pleistocene gravels before dipping into the shallow trench of Chino Creek. The eastern end of the Chino Hills lies ahead, and the Santa Ana Mountains rise steeply in the distance.

42.4 The freeway rises onto a dissected terrace of Quaternary gravels, beyond which it cuts through coarse-grained clastic strata of the Repetto formation. This formation is finer grained farther south, where roadcuts expose siltstone with abundant light-colored, cobble-size concretions.

44.2 The freeway crosses the Chino fault, a steeply dipping reverse fault that separates Repetto strata on the northeast from finer-grained Puente strata on the southwest.

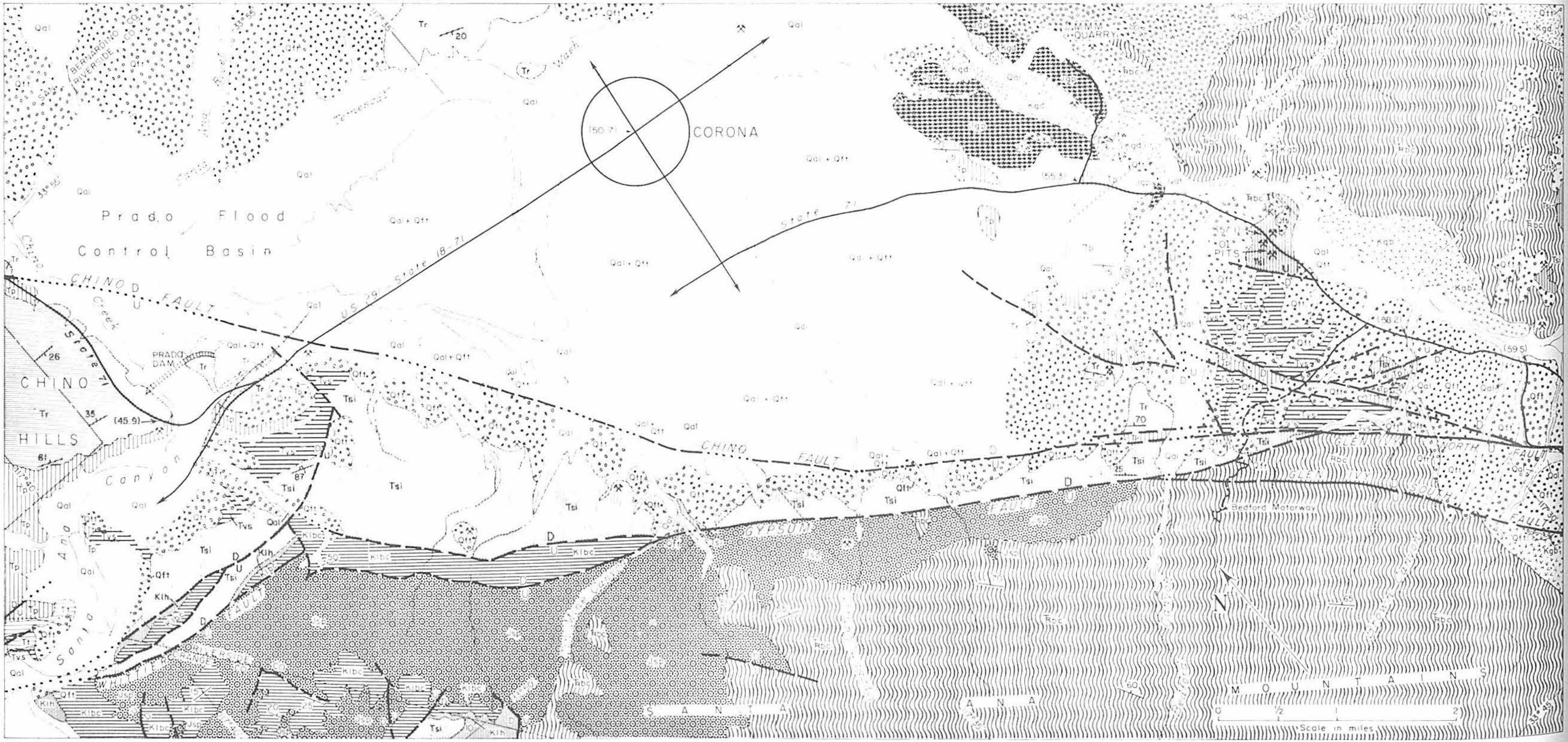
44.3 Large roadcut exposures of steeply dipping siltstone, sandstone, and conglomerate of the Puente formation (Sycamore Canyon member). The siltstone contains many calcareous concretions, and the fine-grained, dark-colored beds have been contorted on a small scale by slumping.

This upper Miocene section is overlain by Repetto strata in the small canyon immediately to the south. Both formations lie on the northeast flank of the Arena Blanca syncline, a large asymmetric fold that plunges southeast and is truncated by the Chino fault.

45.1 Cliffs of Repetto sandstone and conglomerate. Lenticular bedding, cut-and-fill structure, and sandstone dikes are prominent; only the thin beds of siltstone are continuous and of uniform thickness.

45.4 Axial region of the Areña Blanca syncline. The beds dip very steeply, and the trough of the fold evidently has been wrinkled sharply downward.

45.7 Steeply dipping Repetto strata in deep roadcuts. Siltstone, sandstone, and conglomerate are intertongued in a complex way, and some of the relations suggest submarine slumping and sliding (fig. 4). These beds continue east-southeastward



MAP 4. Prado Dam to Glen Ivy. Qal—alluvium; Qft—older alluvial deposits; Tr—Repetto formation; Tp—Puente formation; Tt—Topanga formation; Tvs—Vaqueros and Sespe formations, undivided; Tsi—Silverado formation; Klh—Holz shale member of Ladd formation; Klbc—Baker Canyon conglomerate member of Ladd formation; Kgd—granodiorite, quartz monzonite, and granite; Kt—tonalite; Kgb—gabbro and norite; Jgp—granodiorite porphyry and quartz monzonite porphyry; Jtw—Temescal Wash quartz latite porphyry; Jsp—Santiago Peak volcanics; TRbc—Bedford Canyon formation. See Table 2 for stratigraphic relationships and descriptions of these geologic units. *Geology after Gray (1954), Larsen (1948), and Woodford, et al. (1954); modified by R. H. Jahns.*

across the canyon of the Santa Ana River, and can be seen in large roadcuts on the opposite side.

45.9 Prado Dam. Visible in a southerly direction from this point are the rugged northeast face of the Santa Ana Mountains, a bordering lowland area of great structural complexity, and the head of Santa Ana Canyon (Map 4). Low on the main slope of the Santa Ana Mountains, the Whittier fault zone butts against or merges into the Elsinore fault zone, which extends southeastward beyond this area for a distance of at least 125 miles. The Chino fault, whose trace lies about a mile northeast of the view point, represents the northwestern extension of the Elsinore fault zone.

Exposed in the longest roadcut to the southeast, on the opposite side of Santa Ana Canyon, is the very steep, northeast-dipping contact between the Repetto formation and the underlying Puente formation, which in this area is only about 1,000 feet thick. Nonmarine strata of the Oligocene (?) Sespe formation are poorly exposed beyond the first main ridge above the roadcut, and farther in the distance is a much dissected area, not visible from this point, that is underlain by the Paleocene Silverado formation (Map 4; tables 1, 2). A fault slice of Upper Cretaceous strata separates the Tertiary section from the Jurassic (?) Santiago Peak volcanics, on which the main slope of the mountains has been developed. Preserved on the highest ridge that appears along the skyline are erosional remnants of Upper Cretaceous strata that rest unconformably on the metavolcanic rocks.

Santa Ana Canyon was cut by the Santa Ana River during Quaternary time, and remnants of a once-continuous apron of upper Pleistocene alluvial gravels are clearly preserved in terrace segments on the south side of the canyon. The river is thought to have flowed through this area prior to the last major uplift of the mountain mass, and to have maintained its course by downcutting during the uplift. It has been suggested (English, 1926, p. 65) that the river may have been deflected slightly in a northward direction by the core of hard crystalline rocks in the range.

Prado Dam is an earth-fill structure built for flood-control purposes by the U. S. Army Corps of Engineers. It is 2,280 feet long and 106 feet high.

46.9 Grade separation. Continue on State Highway 71 and cross Santa Fe railroad tracks.

47.6 Junction with U. S. Highway 91. Continue eastward across a series of large alluvial fans into Corona. Located in an area of citrus groves, Corona is known as "the Circle City" because one of its main streets describes a perfect circle, 0.9 mile in diameter. This street was used for horse and automobile racing many years ago.

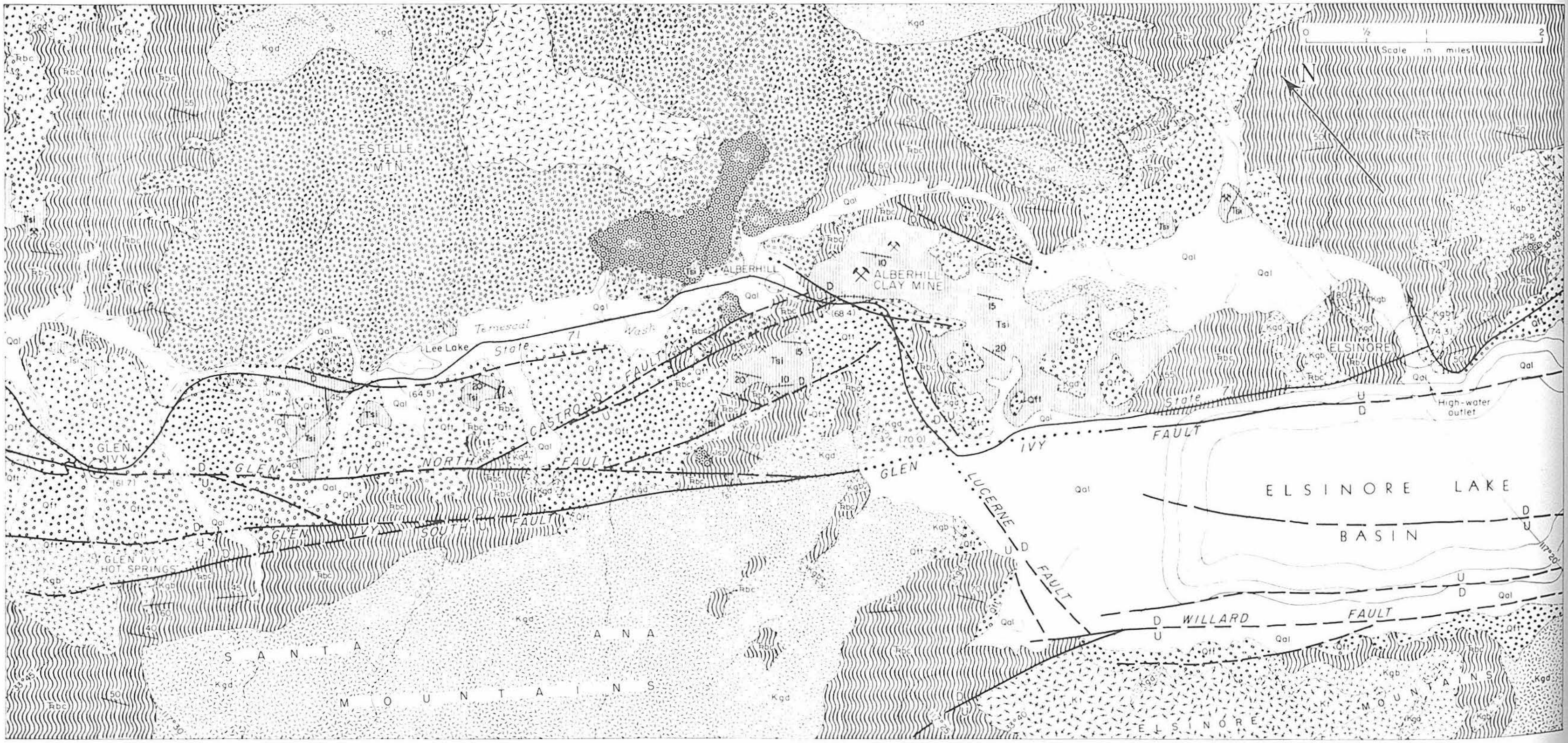
50.7 Corona, Sixth and Main Streets.

Corona to Elsinore—23.6 Miles
(Maps 4, 5; Table 2)

Santa Ana Mountains and Temescal Trough. The northwest-trending Santa Ana Mountains have a distinctly asymmetric transverse profile, and both their steep northeast face and their longer and more gently sloping southwest flank are gashed by numerous deep canyons. Most of the range is composed of igneous and metamorphic rocks, chief among which are the Bedford Canyon formation, the Santiago Peak volcanics, and several representatives of the southern California batholith (table 2). Sedimentary rocks of Upper Cretaceous to middle Miocene age dip off the lower parts of the range on its southwest side, and are preserved at progressively higher levels toward its northwest end.

In general, the foliated rocks of the older sequence appear to form a northeast- to east-dipping homocline that is interrupted in many places by masses of intrusive rocks and is otherwise very complex in detail. A broad, northerly plunging anticline is suggested by the distribution and attitude of the metasedimentary and metavolcanic rocks in the northwestern part of the range. The younger structure of these mountains, as revealed by the flanking sedimentary strata, is essentially that of a large uplifted block, tilted to the southwest and much broken by faults; the part of the range immediately southwest of Corona, however, may be gently anticlinal (Gray, 1954).

Flanking the Santa Ana Mountains on the northeast is an elongate, trough-like depression that is drained by Temescal Wash. It extends from Corona to Elsinore Lake, a distance of about 18 miles, and is in part defined by fault zones of the Elsinore system. Cenozoic sedimentary rocks and older crystalline rocks are exposed on its floor, and the much higher ground on both sides consists almost wholly of the older rocks. Parts of this narrow trough are truly graben-like, but much of it is bordered by faults on the southwest side only (Maps 4, 5); it may well owe its present topographic position as much to erosion of relatively soft sedimentary rocks as to recent block faulting.



Map 5. Glen Ivy to Elsinore. Qal—alluvium; Qft—older alluvial deposits; Tsi—Silverado formation; Kgd—granodiorite, quartz monzonite, and granite; Kt—tonalite; Kgb—gabbro and norite; Jtw—Temescal Wash quartz latite porphyry; Jsp—Santiago Peak volcanics; TRbc—Bedford Canyon formation. See Table 2 for stratigraphic relationships and descriptions of these geologic units. *Geology after Gray (1954) and Larsen (1948); modified by R. H. Jahns.*

In the area southeast of Corona the floor of the depression is about 3 miles wide, and is underlain by fault-bounded slices of folded Tertiary strata. The principal fold is a moderately tight syncline that may correspond to the Arena Blanca syncline of the Chino Hills, on the opposite side of the Chino fault (Gray, 1954). Several of the faults in this area probably extend northwestward beneath the alluvium of the San Bernardino Valley, and may define parts of the basin that lies immediately northeast of the Chino Hills.

50.7 Corona. Drive south on Main Street (State Highway 71).

52.1 Turn left (east), and continue on State Highway 71 through an area of extensive citrus groves.

54.4 The highway enters the lower part of the Temescal trough. This part of the valley is floored with alluvial-fan detritus, mainly of late Pleistocene and early Recent age. Several low mounds and ridges that project through this cover are underlain by southwest-dipping strata of the Puente formation. The low hill to the left (northeast) consists of fine-grained granodiorite porphyry.

55.3 Turn left (northeast) for side trip into Temescal Canyon.

Temescal Canyon Side Trip

(0.4) The road crosses a small creek and thence extends across a thick, dike-like body of granodiorite that is a part of the southern California batholith. This body is flanked by masses of older and somewhat finer-grained granodiorite porphyry.

(0.9) Roadcuts in deeply weathered granodiorite porphyry.

(1.2) Quarry and plant of Minnesota Mining and Manufacturing Company. The large quarry has been developed in the Temescal Wash quartz latite porphyry, a fine-grained, dark-colored intrusive rock that antedates the rocks of the southern California batholith.

Roofing granules are produced in the plant, which was erected at the site of an old quarry in 1948. The major output is fine-grained material for processed roofing; additional smaller amounts of coarse granules are produced for built-up roofing. A ceramic coating is applied to the material in a wide range of colors. The plant is the largest of its kind on the Pacific Coast, and the product is shipped to points as far distant as Vancouver, British Columbia.

Some of the very large quarry blasts in this operation have furnished valuable data for seismological and other geophysical research projects.

About 2 miles east of this point is the Cajalco mine, from which tin valued at about $60,000 was produced during the period 1890-92. The cassiterite occurs in veins and irregular masses of quartz and tourmaline that transect granodiorite of the southern California batholith. Few deposits have stimulated as much activity and have yielded as proportionately little tin as this and others in the vicinity.

Retrace route to State Highway 71.

55.3 Continue southeastward on State Highway 71.

55.5 The highway crosses a broad, low ridge that is underlain by southwest-dipping sandstone and siltstone of the Puente formation. These strata are flanked and overlapped by reddish-brown alluvial-fan deposits of Quaternary age.

56.2 To the left (northeast), on the opposite side of the canyon, is the remnant of a terrace cut on slaty rocks of the Triassic Bedford Canyon formation.

56.5 Brick yard. Alluvial deposits are worked locally as a raw material for bricks, but the principal source material for brick and tile making in this valley is clay from the Paleocene Silverado formation.

57.1 Pits and plant of Owens Illinois Glass Company. The large pits have been excavated in poorly consolidated, fine-grained arkosic sandstone and subordinate pebble conglomerate of the Silverado formation. These beds underlie a low ridge and several small hillocks, where they are capped by patches of Quaternary terrace gravels. The unconformity between the two units is well exposed on the wall of an older pit that lies immediately east of the road.

The sandstone, which contains about 40 percent of clay and silt, is washed and scrubbed in the plant on the east side of the road. Biotite, magnetite, and other iron-bearing minerals are removed magnetically. The product, a clean, high-silica sand, is used mainly in the manufacture of bottles.

58.2 Turn right (west) for side trip on Bedford Motorway.

Bedford Motorway Side Trip

(0.2) The road rises onto a low, gravel-veneered ridge that is underlain chiefly by coarsely clastic nonmarine beds of the Oligocene(?) Sespe formation.

(0.5) Terrace deposits that cap the ridge to the north have shed coarse debris over the lower slopes, on which Sespe strata are poorly exposed. Beyond this point the road crosses a thin, essentially vertical fault slice of Puente strata (Map 4).

(0.8) Forest Service gate. Proceed on foot for approximately 1 mile. Beyond the gate the Bedford Motorway and the canyon immediately southeast of it cross fault blocks of Sespe and Silverado strata, which are in part concealed by as much as 80 feet of coarse, reddish-brown gravels of late Pleistocene age. In this area the Chino and Gypsum fault zones converge southeastward to form the Glen Ivy fault zone (Map 4). The Bedford Canyon formation underlies the mountain slopes beyond the area of faulting.

Retrace route to State Highway 71.

58.2 Continue southeastward on State Highway 71.

59.1 Deadman Curve. The road skirts a projection of Quaternary gravels. The brownish, smoothly rounded hills to the left (northeast) are underlain chiefly by the Bedford Canyon formation. The pits farther east on these hills have been excavated in patches of Silverado clay and sandstone that lie upon the older crystalline rocks.

59.5 Turn right (southwest) onto Temescal Ranch road, along which a considerable thickness of reddish-brown Quaternary gravels is exposed.

60.2 Turn left (southeast) onto a gravel road and follow the trace of the Glen Ivy North fault. This active break has distinct topographic expression, and here has formed an anomalous southwest-facing scarp in Quaternary gravels; this scarp lies athwart the general direction of drainage in the area (fig. 5). To the northwest the position of the fault is marked by saddles and aligned gullies in several ridges. The trace of the Glen Ivy South fault lies at the base of the mountain front to the right (southwest).

60.7 Bear left on gravel road. The large white buildings ahead and to the right are at Glen Ivy Hot Springs, on the trace of the Glen Ivy South fault.

61.2 Turn left (northeast) and cross a canal, continuing on dirt road to rejoin State Highway 71. The road crosses a linear depression and sag pond of the Glen Ivy North fault.

61.4 Turn right (southeast) on State Highway 71.

61.7 Glen Ivy. The fault, which lies immediately southwest of the road, has some surface expression here, but its trace is partly concealed by deposits of Recent alluvium.

62.5 Santa Fe Railway underpass.

63.9 Arkosic sandstone and conglomerate of the Silverado formation are exposed beneath Quaternary gravels in several railroad cuts. The Silverado strata have been faulted against Temescal Wash quartz latite porphyry to the northeast, and the trace of the fault appears about 100 yards from the road on the left. The position of this fault to the southeast is marked by springs, clusters of trees, and dense growths of chaparral.

Temescal Wash swings around the hill northeast of the road, where it occupies a gorge cut into hard crystalline rocks. The stream appears to have been superimposed from a cover of Tertiary sedimentary rocks that once filled the valley to much higher levels (Dudley, 1936).

64.5 Lee Lake.

65.0 The road traverses an area of dissected alluvial-fan gravels, which lie upon Silverado strata and locally lap against projections of older crystalline rocks.

67.3 Alberhill. This is an area of long-time clay mining, wholly in residual and transported deposits that are parts of the Paleocene Silverado formation (Hill, 1923; Sutherland, 1935). The three main commercial products have been fire clays, refractory-bond clays, and red-burning common clays, and during recent years the annual production has amounted to about 200,000 tons.

The low hill on the far side of the railroad tracks and immediately west of the large brick and tile plant consists of Santiago Peak volcanics, the formation that was weathered to yield most of the clay in this area. The higher hills west and south of the plant are underlain by the older Bedford Canyon formation.

The large open pits southeast and southwest of Alberhill have been developed in the basal part of the Silverado section, which dips moderately southwest and rests mainly upon the Santiago Peak volcanics and genetically related intrusive rocks. The general structure of the Tertiary strata may be synclinal, but they have been much dislocated by faulting.

68.4 Alberhill clay mine. This is by far the largest mine in the district. It was worked sporadically for lignite, chiefly by underground methods, during the period 1894-1902, and much coaly material is visible on the dumps. In more recent years open-cut operations have yielded large amounts of clays from deposits whose general downward succession is as follows:

1. Yellowish, blocky clay; used mainly for sewer pipe	15-20 feet.
2. Gray to white, blocky clay, sandy in upper part and locally carbonaceous near base; used mainly for fire brick and terra cotta	26-38 feet.
3. Lignite and lignitic coal with high ash content	0-9 feet.
4. Gray high-alumina clay, locally pisolitic, generally with conchoidal fracture; non-plastic parts used in refractory wares, and plastic parts used as refractory-bond clays	4-6 feet.
5. Pinkish to reddish brown, red-burning clay, with local fragments of highly altered crystalline rocks; used mainly for brick, sewer pipe, and common tile	0-20+ feet.

The lowermost unit is in large part residual, and its downward gradation into metasedimentary rocks and quartz latite porphyry is well exposed on the north slope of the hill. The other units consist entirely of transported material. All but the uppermost of these units are illustrated in figure 6.

69.3 The hill to the left (east) is underlain by stratigraphically higher parts of the Silverado formation, chiefly arkosic sandstone with lenses of pebble conglomerate.

70.0 Summit of grade. About 0.2 mile ahead, the road crosses the Glen Ivy fault zone, which here is relatively narrow.

Elsinore-Temecula Trough. A well-defined elongate valley, known geologically as the Elsinore-Temecula trough, extends southeastward from the basin of Elsinore Lake to the Agua Tibia Mountains, a distance of about 25 miles. It is 1 to 3 miles wide, and its northwestern part is bounded on both sides by much higher ground. Structurally it is a graben within the broad Elsinore fault zone, and thus is a southeastward continuation of the Temescal trough. High-angle faults are present on both sides of the valley, and several other faults branch east-southeastward from its northeastern margin.

The central part of the trough is underlain by as much as 3,000 feet of upper Pleistocene and Recent nonmarine deposits, which rest mainly upon pre-Tertiary crystalline rocks. The structure is complicated in detail by numerous fault blocks and slices, some of which contain sedimentary rocks that may be Tertiary in age.

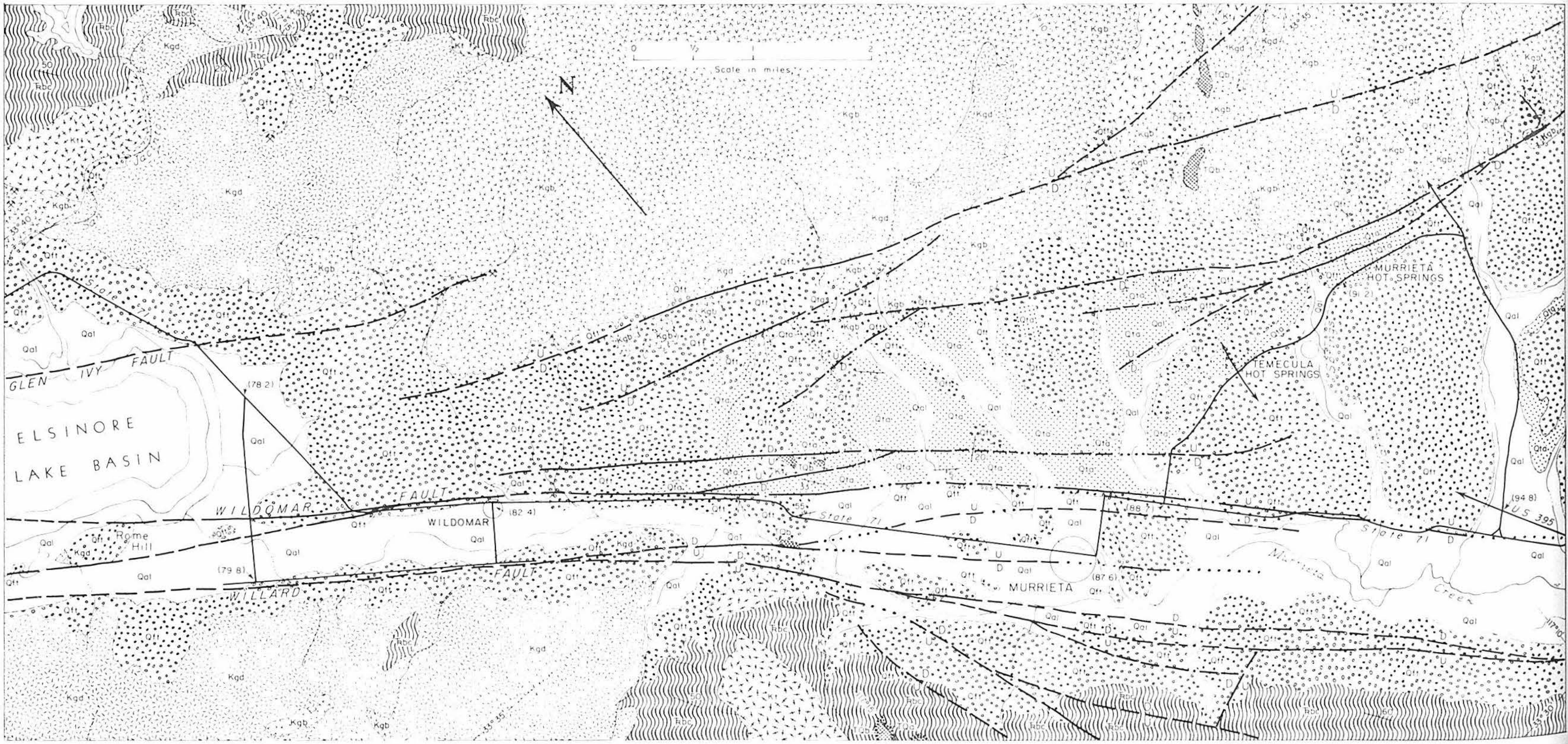
Erosional surfaces of low relief are preserved at several levels in the southeastern extension of the Santa Ana Mountains, southwest of the valley, and in the broad area known as the Perris block, northeast of the valley. The history of their development, which has not yet been deciphered to the satisfaction of all geologists familiar with the region, is intimately related to the history of the Elsinore-Temecula trough. It has been discussed by Dudley (1936), Larsen (1948, pp. 5-15), and others, and only its latest chapters need be considered here.

It seems likely that a widespread mature surface had been cut on the crystalline rocks of the region prior to mid-Pleistocene time. Its continuity was interrupted by numerous monadnocks, and older surfaces were present at higher levels. Parts of this early Pleistocene surface are preserved on the Perris block at a general altitude of 1,700 feet, and it may be represented in the southeastern extension of the Santa Ana Mountains by broad surfaces at altitudes near 2,200 feet (Larsen, 1948, pp. 10-12). The early Pleistocene San Jacinto River probably flowed southwestward across what is now the Elsinore-Temecula trough and past the southeastern end of the Elsinore Mountains to the sea. The Temecula Creek-Santa Margarita River drainage seems to have followed a somewhat similar course in areas to the southeast.

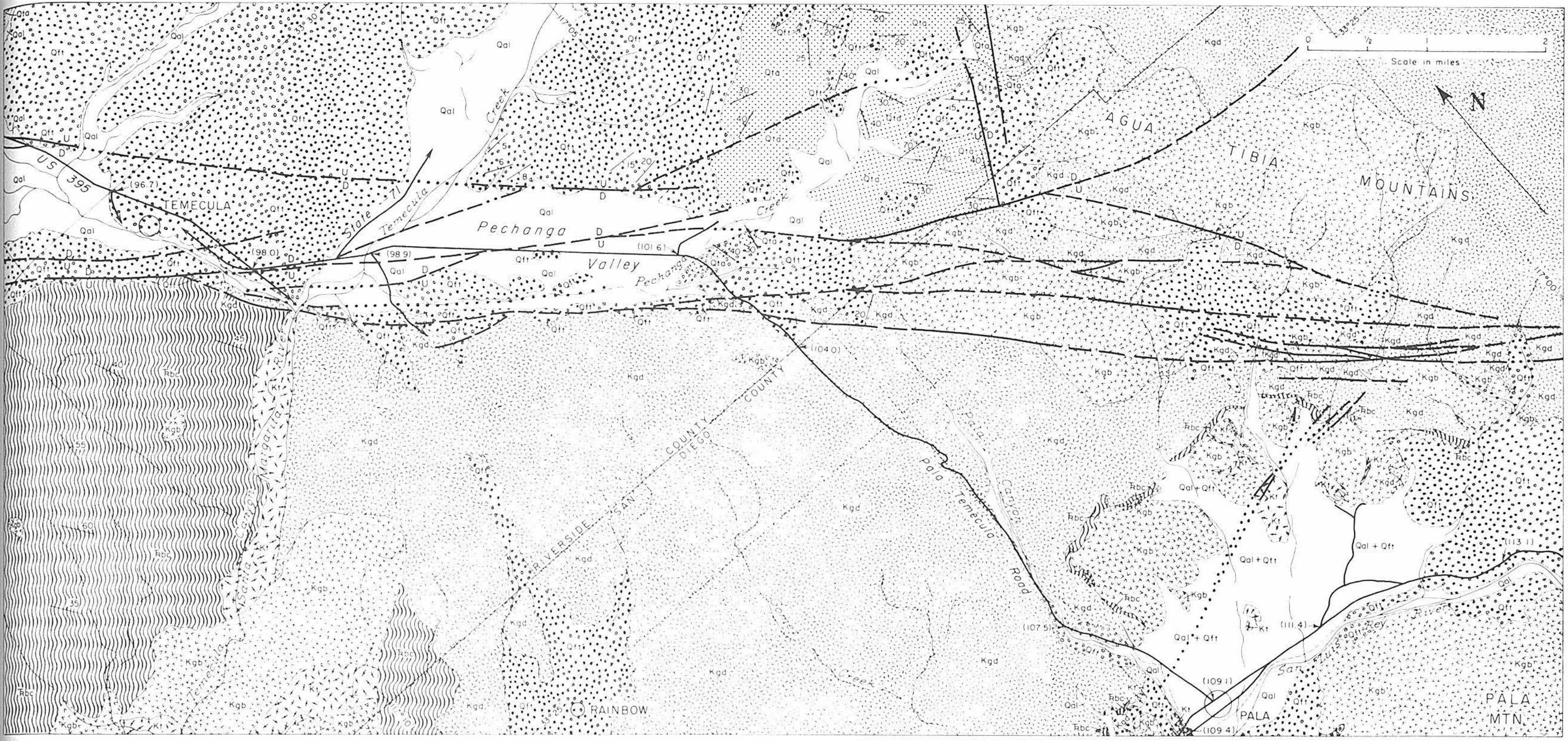
Diastrophism in middle Pleistocene time developed the Elsinore-Temecula trough along a pre-existing zone of faulting, and in effect raised the Santa Ana Mountains and the mountains to the southeast as a barrier against the general course of drainage. The Santa Margarita River evidently was able to cut downward in pace with this uplift, and developed an antecedent gorge (Temecula Canyon) through the mountains. The San Jacinto River, in contrast, was deflected along the floor of the trough, and may well have flowed southeastward to join Temecula Creek and the Santa Margarita River. Later it probably was captured by Temescal Creek to the northwest.

One or more lakes undoubtedly occupied the floor of the trough during parts of late Pleistocene and Recent time. The present basin of Elsinore Lake is a result of Recent warping and faulting, and is bounded on the southeast by a low divide. During prolonged periods of wet years the basin fills and discharges through the town of Elsinore into Temescal Creek; during drier periods the lake drops to levels well below its outlet, and it is known to have disappeared completely several times during the period of historic record.

72.3 The highway skirts the northeast side of the Elsinore Lake basin, and lies immediately above a recent fault scarp that has been modified by wave action. The fault is a part of the Glen Ivy zone. The hill on the left (northeast) is underlain by schistose rocks and quartzite of the Bedford Canyon formation.



Map 6. Elsinore to Murrieta Hot Springs and Temecula. Qal—alluvium; Qft—older alluvial deposits; Qta—Temecula arkose; TQb—basalt; TQa—older arkose; Kgd—granodiorite, quartz monzonite, and granite; Kt—tonalite; Kgb—gabbro and norite; Tʀbc—Bedford Canyon formation. See Table 2 for stratigraphic relationships and descriptions of these geologic units. *Geology after Larsen (1948) and Mann (1951); modified by R. H. Jahns.*



Map 7. Temecula to Pala. Qal—alluvium; Qft—older alluvial deposits; Qta—Temecula arkose; Kgd—granodiorite, quartz monzonite, and granite; Kt—tonalite; Kgb—gabbro and norite; Ʀbc—Bedford Canyon formation. See Table 2 for stratigraphic relationships and descriptions of these geologic units. *Geology by R. H. Jahns.*

On the opposite side of the lake is the Willard fault zone. This zone, together with the Glen Ivy zone and the north-trending Lucerne fault, outlines the northwest end of the Elsinore-Murrieta graben (Map 5).

74.2 The road crosses the surface outlet of Elsinore Lake.

74.3 Elsinore, Graham Avenue and Main Street.

Elsinore to Pala—34.8 Miles
(Maps 5, 6, 7; Table 2)

74.3 Turn right (southwest) onto Main Street.

74.7 Rome Hill, an uplifted slice of Pleistocene fanglomerate between the Wildomar and Willard faults, rises from the lake plain on the opposite side of the basin.

76.2 Bridge over San Jacinto River.

76.8 Plutonic rocks of the southern California batholith (Cretaceous) form the hills to the left (east-northeast). Coarse-grained granodiorite yields light-colored, bouldery exposures, whereas gabbroic rocks weather to brownish slopes on the lower hills farther east.

In the area between here and Perris, 10 miles to the north, are numerous small gold mines and prospects. The mineralization is in quartz veins, most of which cut tonalite and other batholith rocks. A few others are in the older metamorphic rocks. Production from the area has amounted to about $2.5 million, mainly in gold and some silver (Sampson, 1935).

78.2 Bear right (southwest) onto a paved road, and cross the lake plain.

79.2 The road crosses the small trench of a fault that extends along the base of a low, elongate ridge of upper Pleistocene alluvial-fan gravels. To the left (southeast), a similar upraised mass lies on the opposite side of the same active fault. The road crosses a second fault about 0.2 mile beyond this point.

These and other faults in the valley are effective ground-water barriers, and several of them separate blocks of ground in which the water levels are known to differ by 200 feet or more.

79.8 Turn left (southeast) on a paved road.

80.1 To the left (northeast and east) is a distinct southwest-facing scarp on the valley floor. It marks the trace of the Wildomar fault. The Willard fault zone trends parallel with the road at the right and only a few hundred feet away. Much of its trace is buried beneath modern alluvium; but several anomalous cols and knobs on the low ridges probably are surface expressions of the fault zone. These are present for a strike distance of more than a mile.

81.9 Turn left (northeast) on the road to Wildomar.

82.4 Wildomar. Turn right (southeast) onto State Highway 71.

83.6 The hills immediately adjacent to the highway on the left consist of arkosic sandstone and siltstone of the Pleistocene Temecula arkose (Mann, 1951). This formation constitutes the oldest known part of the exposed sedimentary fill in the Elsinore-Temecula trough, and is overlain by younger and less deformed fluviatile deposits that also are Pleistocene in age. These are exposed in the dissected valley-bottom area to the right (southwest).

84.9 The road jogs to the right around a spur of highly deformed sandstone and conglomerate that are younger than the Temecula arkose. The steep dips of the beds probably are the result of drag along several subparallel breaks in the Wildomar fault zone. The Willard fault zone is only about a quarter of a mile to the right (southwest) in this area, and its position probably is marked by a Quaternary dike of nepheline basalt that crops out along Murrieta Creek. The deepest part of the graben thus is very narrow here, but it widens considerably to the southeast.

The mountain spur on the opposite side of the valley consists of tonalite, whose light-colored, bouldery outcrops are in marked contrast to the brownish, smoothly sculptured slopes underlain by the Bedford Canyon formation farther southeast. About 4 miles due south is Mesa de Burro, a remnant of an old erosion surface that is capped by olivine basalt of late Tertiary or Quaternary age.

85.2 The small quarry about 0.2 mile to the left (northeast) exposes a bed of white rhyolite tuff, which is underlain by bluish clay and overlain by sandstone and fine-grained siltstone. The section dips about 35° southwest, and occupies a narrow fault block. It might be of Miocene age, as suggested by Larsen (1948, p. 107), but more likely it is a part of the Temecula arkose.

87.4 Murrieta. Several wells in this part of the valley provide data that not only establish the positions of at least six subparallel faults within a strip about a mile wide, but plainly indicate the graben-like structure beneath the valley floor. As much as 2,500 feet of the Temecula arkose is present in the deepest block, where it is overlain by 300 to 500 feet of younger Pleistocene deposits (fig. 7). The olivine basalt of

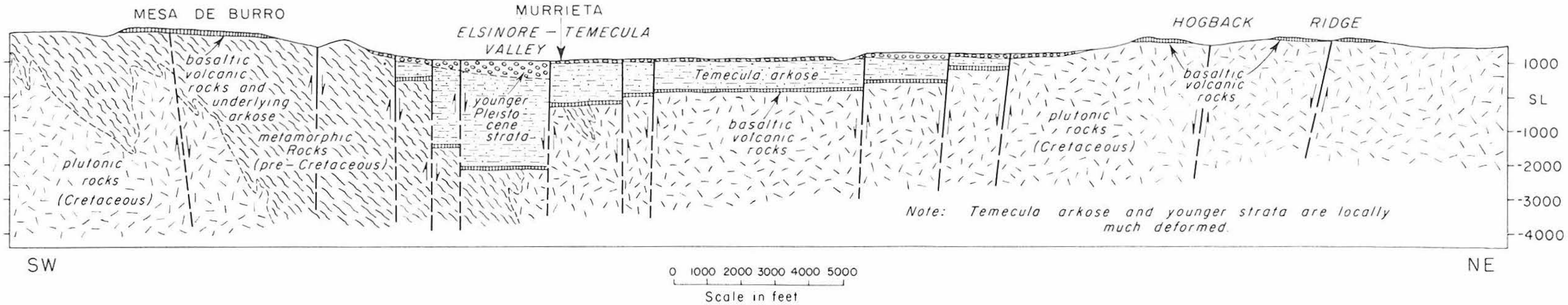


FIGURE 7. Cross-section through the Murrieta area from Mesa de Burro to Hogback Ridge, showing the general structure of the Murrieta graben. This is a local feature of the Elsinore fault zone, and dates from early or middle Pleistocene time. *Based in part upon data from Larsen (1948) and Mann (1951).*

Mesa de Burro is an excellent index of the vertical components of displacement in the faulted area, as it has been penetrated in the subsurface and also crops out on Hogback Ridge, about 3½ miles northeast of Murrieta (fig. 7). The maximum vertical offset indicated by this basalt is about 4,000 feet.

87.6 Turn left (northeast) at corner.

88.2 Turn right (southeast) at corner.

88.7 Turn left (northeast) onto Murrieta Hot Springs road, which traverses gently rolling country underlain by upper Pleistocene valley fill (Map 6).

89.9 Cross U. S. Highway 395.

90.5 Temecula Hot Springs. The springs mark the trace of a fault that extends eastward from the vicinity of Murrieta.

91.2 Murrieta Hot Springs. A group of subparallel, east-trending faults extends through this area, and separates strata of the Temecula arkose from gabbroic rocks of the southern California batholith on the north. The trace of the main break lies immediately beyond the large cluster of buildings.

92.4 Turn right (south) onto Winchester Road.

94.8 Turn left (southeast) onto U. S. Highway 395, which crosses the trace of the Wildomar fault at a very acute angle.

95.5 The southeast-facing scarp of the Wildomar fault is at the left, and the trace of the fault is marked by several springs that contribute water to the swampy ground crossed by the highway.

96.7 Roadcut exposures of typical upper Pleistocene valley fill, chiefly arkosic sandstone and pebble conglomerate that are locally cross-bedded (fig. 8). This poorly consolidated material is a part of the Pauba formation of Mann (1951), and is younger than the Temecula arkose.

96.8 Temecula lies to the right (southwest).

97.9 About half a mile ahead and to the right (south) is the slot-like upper end of Temecula Canyon, through which the antecedent Temecula Creek-Santa Margarita River drainage crosses the mountains that adjoin the Elsinore-Temecula Valley. This rugged defile has been the scene of several spectacu-

FIGURE 8. Roadcut exposure of poorly consolidated arkosic sandstone and pebble conglomerate near Temecula. This valley fill is late Pleistocene in age, and is a part of the Pauba formation of Mann (1951).

lar floods during historic times. In 1884, for example, the original San Diego line of the Santa Fe Railway, which had been built through the canyon only two years earlier, was obliterated by flood waters that in places were more than 25 feet deep; many of the ties and bridge timbers were encountered by ships 100 miles out at sea. After much of the line was again washed out a few years later, it was abandoned in favor of a more practical route along the coast.

The brownish hills northwest of the canyon are underlain by schists and quartzite of the Bedford Canyon formation, and those to the southeast by coarse-grained granodiorite of the southern California batholith.

98.0 Turn left (southeast) onto State Highway 71.

98.1 The Agua Tibia Mountains lie directly ahead.

Agua Tibia Mountains. The Agua Tibia Mountains, which rise to heights of slightly more than 6,000 feet, are approximately 20 miles long and 8 miles in average width. Their southeastern end slopes into the Warner Basin, and their northwestern end is separated from the Elsinore-Temecula Valley by a foothills area of complex block faulting. This rugged and bold-faced range is essentially an uplifted block of pre-Tertiary crystalline rocks that is bounded on the southwest by the Elsinore fault zone and on the northeast by the Aguanga fault zone. These zones converge northwestward, and merge to from the Elsinore fault system in the areas beyond Murrieta.

The range is composed of plutonic rocks (chiefly tonalites), older metamorphic rocks that probably are in part correlative with the Bedford Canyon formation of the Santa Ana Mountains, and a wide variety of injection gneisses and other hybrid rocks. At least three large faults are known to cut these rocks within the main mountain block, and a cover of Pleistocene sedimentary rocks is preserved in several depressed fault blocks at the northwest end of the range.

98.7 Bear right onto Temecula Road.

98.9 Bridge over Temecula Creek; bear left onto Pala-Temecula Road immediately beyond.

99.2 The road traverses the smooth floor of Pechanga Valley, which is flanked by dissected low benches of upper Pleistocene fluviatile deposits. The low scarp on the northeast side of the valley is associated with one of the principal faults of the Elsinore zone; this same fault extends through the prominent saddle in the skyline ridge directly ahead. The rolling hills between the valley floor and the main slope of the mountains to the east and southeast are underlain chiefly by the Temecula arkose.

101.6 Turn left (northeast) onto a paved road that extends up the valley of Pechanga Creek.

102.1 A small knob of Temecula arkose lies to the right (south), at the far side of the creek. The beds dip steeply southwest, and probably have been dragged along one of the breaks in the Elsinore fault zone. The arkose consists chiefly of quartz, muscovite, and essentially fresh feldspars and biotite, together with small pebbles of granodiorite. Analyses indicate that, within the limits of sampling error, its bulk mineralogical and chemical composition is the same as that of the granodiorite exposed on nearby hills. Evidently the sediments were derived mainly from disintegrated granodiorite, were not transported far, and were laid down rapidly under conditions that permitted little chemical weathering.

Retrace the route to Pala-Temecula Road.

102.6 Turn left (southeast) onto Pala-Temecula Road.

103.3 Some of the low, rolling hills in this area are underlain by upper Pleistocene arkose, and others by granodiorite. It is very difficult to distinguish the two rocks in areas of weathered exposures.

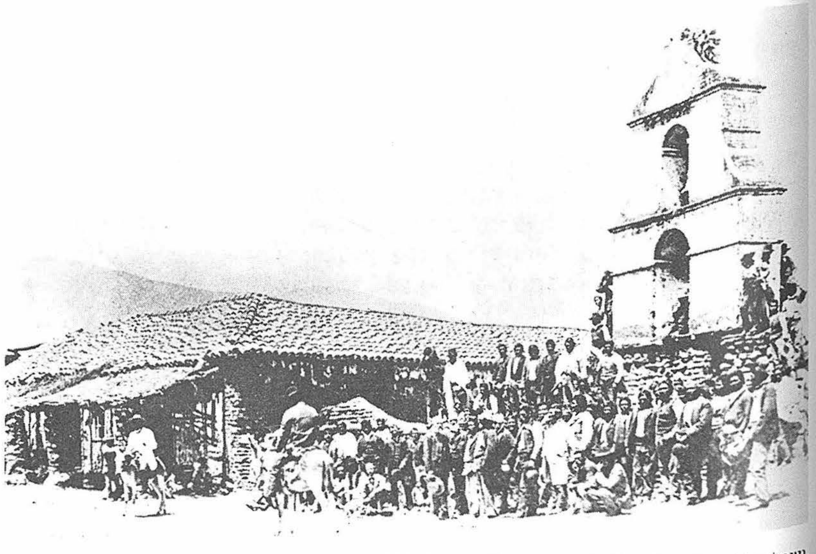


FIGURE 9. The Mission Asistencia at Pala, as it appeared shortly after the turn of the present century. *Photo courtesy of Mrs. Frank A. Salmons.*

FIGURE 10. The detached bell tower of the reconstructed Pala mission, as it appears today.

104.0 Riverside-San Diego county line.

104.1 Summit. This pass is only about 250 feet above Temecula Creek 4 miles to the northwest, but is more than 900 feet above the San Luis Rey River, which is an equal distance to the south. Pala Creek, a south-flowing tributary of the San Luis Rey River, has carved a deep canyon and is working briskly headward at the present time; it seems likely that it will capture Temecula Creek and the drainage of much of the Elsinore-Temecula Valley within a short period of geologic time.

104.8 Roadside outcrop of Woodson Mountain granodiorite, one of the principal rock types in the southern California batholith. The coarse-grained rock here exposed contains an unusually large number of inclusions, but otherwise is typical for this area.

105.5 Pala Canyon is at the left (east).

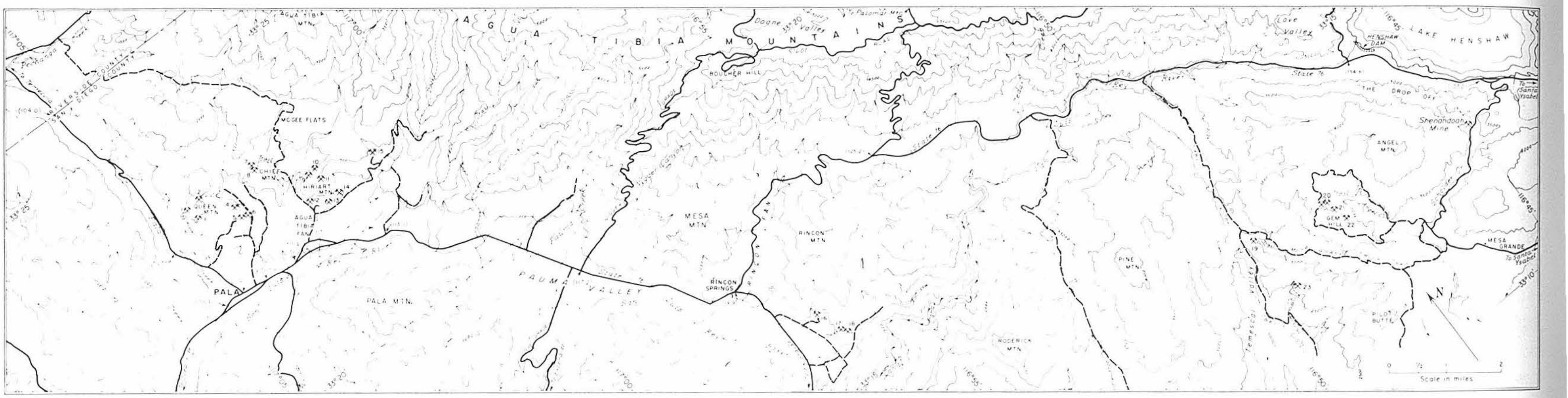
105.9 Numerous roadcut exposures of Woodson Mountain granodiorite with well-developed planar structure that is emphasized by weathering. The structure is thought to be a result of primary flowage during intrusion. The same rock is well exposed on the opposite side of the canyon, where its outcrops are markedly different in appearance from those of the gabbro and norite on the upper slopes of Queen Mountain to the south. The granodiorite is separated from the gabbroic rocks by a screen of quartzite, schist, and fine-grained granodiorite that probably is in part of metasomatic origin.

The old dumps and two small buildings below and to the right of the summit of Queen Mountain mark the position of the Tourmaline King mine, one of the gem mines of the Pala district.

107.5 Cross Pala Creek.

108.2 The road crosses the alluvial floor of the San Luis Rey River Valley. Pala Mountain, a large mass of gabbroic rocks, lies ahead; the cliff-faced mountain ahead and to the right (southwest) consists mainly of leucogranodiorite.

109.1 Pala. The outstanding feature of this small Indian settlement is its mission, which is on the east side of the plaza. Founded in 1815 as an assistencia, or branch, of Mission San Luis Rey, it was allowed to deteriorate in later years (fig. 9) and was further damaged by a flood in 1916. It was subsequently restored in full (fig. 10), and still remains in service. It is the only one of California's mission establishments with a detached bell tower.



Map 8. Pala to Warner Basin and Mesa Grande. Numbered mines and quarries are as follows: (1) Tourmaline King—tourmaline, quartz. (2) Tourmaline Queen—tourmaline, quartz. (3) White Cloud—tourmaline, quartz. (4) Gem Star—tourmaline, quartz. (5) Stewart—lepidolite, amblygonite, tourmaline. (6) Douglass—tourmaline, quartz. (7) Ocean View—beryl, quartz. (8) Pala Chief—spodumene, tourmaline, beryl, quartz. (9) Senpe—beryl, lepidolite, quartz, tourmaline. (10) San Pedro—beryl, spodumene, quartz, tourmaline. (11) Vanderburg—spodumene, beryl, quartz, tourmaline. (12) Katerina—spodumene, lepidolite, quartz, beryl, tourmaline. (13) Fargo—tourmaline, quartz. (14) El Molino—beryl, quartz. (15) Johnson (McGee)—dimension stone. (16) Mack—beryl. (17) Victor—beryl, tourmaline, spodumene, garnet. (18) Clark—quartz, beryl. (19) Esmeralda—tourmaline, beryl, quartz. (20) Himalaya—tourmaline, beryl, quartz. (21) San Diego—tourmaline, quartz. (22) Mesa Grande—tourmaline, beryl, quartz. (23) Rose Quartz—quartz, garnet.

Pala to Warner Springs—40.8 Miles
(Maps 7, 8, 9; Table 2)

Pala Pegmatite District. The Pala district has been a widely known source of gem and lithium minerals, and its total recorded mineral output is valued at nearly $800,000. Formal mining operations began in the eighteen-nineties, and activities were greatest during the period 1900-1914. Lepidolite, tourmaline, and gem spodumene have been the chief products, and small amounts of amblygonite, beryl, feldspar, and quartz also have been mined. The district has been studied and described by several investigators, and the reader is referred to the papers and reports of Waring (1905), Kunz (1905), Merrill (1914), Schaller (1925), Donnelly (1936), and Jahns and Wright (1951) for more detailed treatment of its geology and pegmatite deposits than appears in the following paragraphs.

The district has an area of about 13 square miles, and includes several small mountain masses on both sides of the San Luis Rey River. It is immediately southwest of Agua Tibia Mountain, and is separated from it by a broad topographic bench that marks the trace of the Elsinore fault zone (fig. 11). The district is underlain chiefly by granodiorite, tonalite, gabbro, and norite of the southern California batholith, and in some places by older metamorphic rocks. At least 400 bodies of granitic pegmatite are exposed within its borders.

Most of the pegmatite occurs as tabular masses that trend north to north-northwest and dip gently to moderately westward. They are remarkably persistent, with strike lengths of as much as a mile, and they range from thin stringers to large dikes with bulges nearly 100 feet thick. In several places they occur as swarms of closely spaced, subparallel dikes (figs. 11, 12). The dikes in some swarms branch and converge along their strike, and locally they form thick composite bodies in which each member dike retains its identity (fig. 14).

The pegmatites are most abundant in the gabbroic rocks, which are known collectively as the San Marcos gabbro (Miller, 1937; Larsen, 1948, pp. 41-53), and they appear to have been emplaced along a single well-developed set of fractures. These fractures are independent of the primary structural features of the enclosing rocks, and they transect contacts between major rock units; they may well have been subhorizontal at the time of pegmatite emplacement, and probably were developed as contraction features while the rocks of the southern California batholith were cooling on a regional scale.

Some of the pegmatite bodies are essentially homogeneous in mineralogy and texture, but most are composed of units that differ from one another in lithology. Graphic granite is

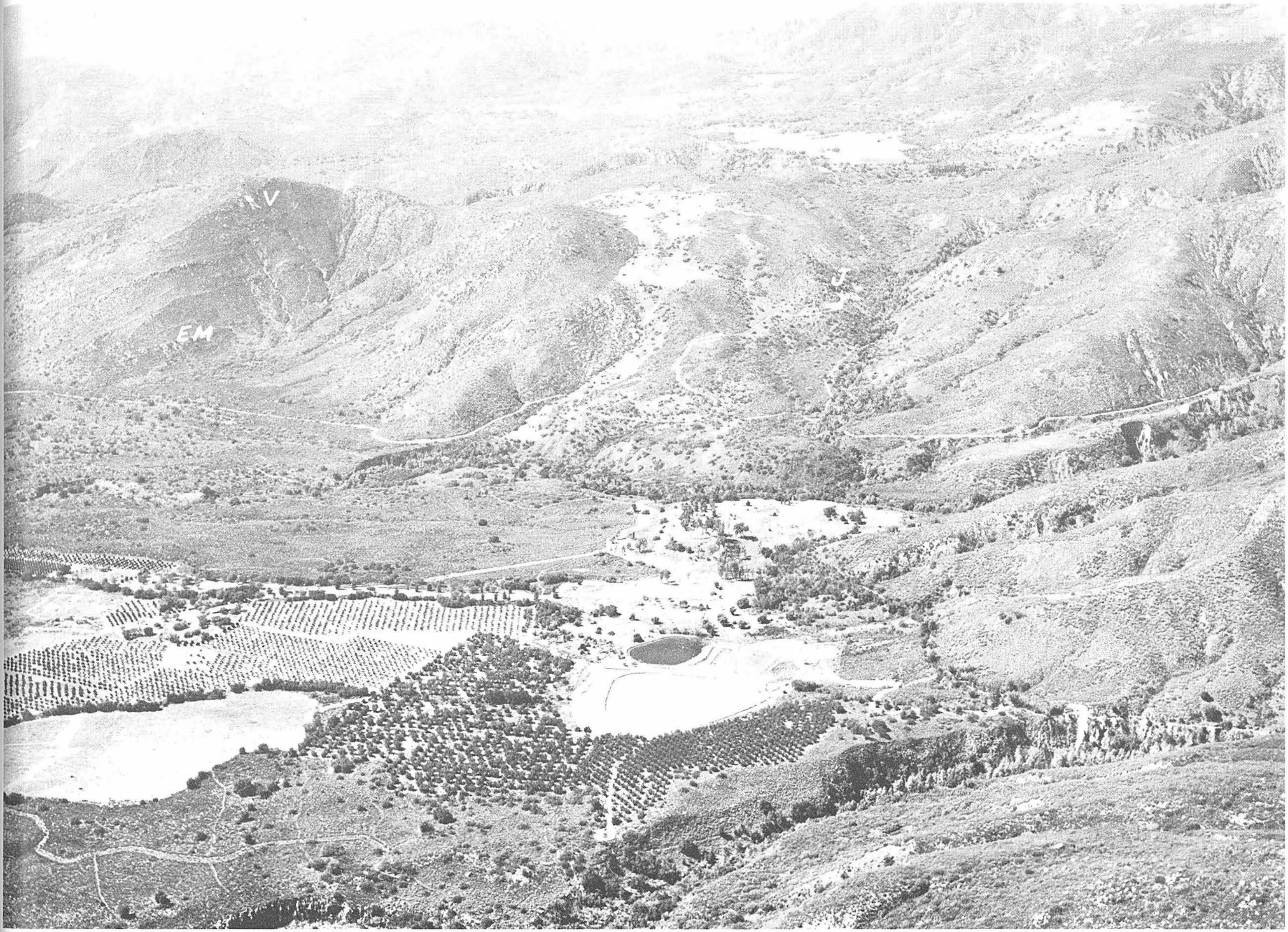


FIGURE 11. Aerial view northwestward across a part of the Pala district. The apical part of the Agua Tibia fan is in the foreground, the spurs of the Agua Tibia Mountains are at the right, and the Pechanga Valley is in the distance. The broad bench in the middle distance marks the trace of the Elsinore fault zone, here nearly a mile in width. The brecciated and sheared rocks within this zone are well exposed in Castro Canyon (CC). Numerous subparallel dikes of pegmatite form rib-like outcrops on the brushy slopes of Hiriart Mountain, at the left beyond the Agua Tibia fan. Note the contrast between the smooth slopes that are underlain by gabbroic rocks and the light-colored, bouldery slopes underlain by granodiorite; contacts between these rock types are indicated in several places by arrows. Mines visible in this view include El Molino beryl mine (EM), the Vanderburg gem spodumene mine (V), and Johnson (McGee) "black granite" quarry (J). *Pacific Air Industries photo.*

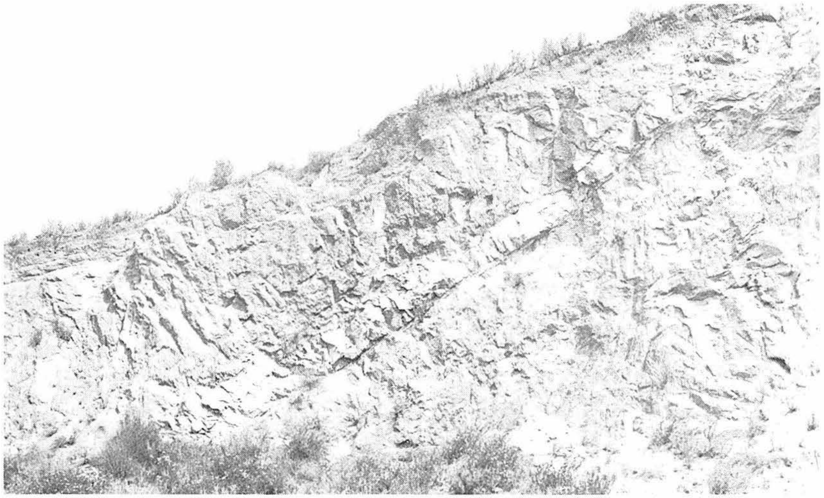


FIGURE 12. Dike and parallel strings of fine- to medium-grained pegmatite in Bonsall tonalite, small quarry west of Pala. The dike, about 2 feet in average thickness, comprises a hanging-wall layer of graphic granite and a footwall layer of fine-grained, aplitic rock.

the chief constituent of the outermost units, or border zones, which generally are thin, discontinuous, and fine grained. It also composes most of the adjacent, coarse-grained wall zones, which ordinarily are the thickest and most persistent of the pegmatite units (fig. 13). In general, it is more abundant in the hanging-wall parts of the larger dikes than in their footwall parts, and it constitutes nearly the full thickness of many smaller dikes.

Discoidal to highly irregular masses of coarse- and very coarse-grained pegmatite form the innermost zones, or cores, of many dikes. Some are composed of quartz, perthite, or an aggregate of these minerals, and others consist of quartz and giant crystals of spodumene. Spodumene of gem quality occurs wholly within the cores, and represents the relatively small amount of this mineral that has escaped hydrothermal alteration (fig. 15). Some of the cores are separated from nearby wall zones by one or more intermediate zones, which form discontinuous or complete envelopes around them (fig. 13). These units are present mainly in the largest dikes, and generally are rich in coarse-grained perthite.

Fracture-filling units are widespread, and consist chiefly of quartz, albite, fine-grained muscovite, or combinations of these minerals (fig. 15). Fracture-controlled replacement bodies are superimposed upon the zonal pattern of nearly all the pegmatites. They are composed mainly of albite, quartz, and muscovite, and, less commonly, of lepidolite and tourmaline. Similar mineral aggregates occur in the central parts of many dikes, where they generally appear to have corroded the surrounding pegmatite zone or zones. These centrally dis-

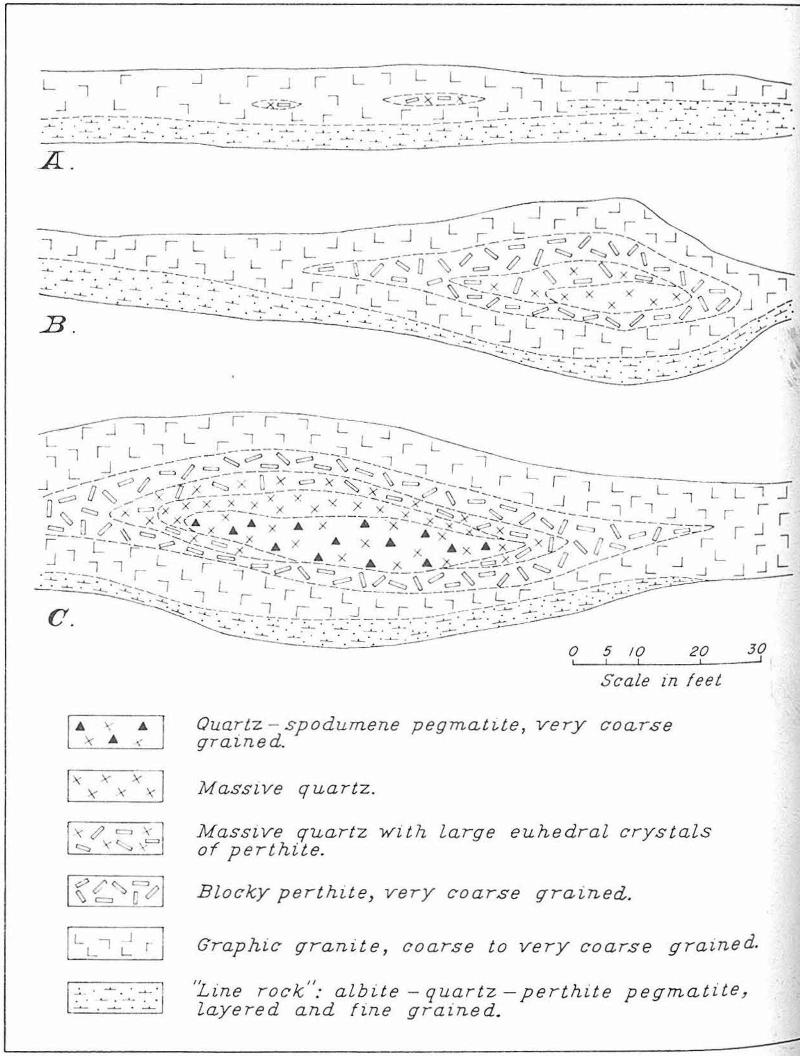


FIGURE 13. Idealized sections of pegmatite dikes in the Pala district, showing typical zonal structure. A. Simply zoned dike with fine-grained lower part (Tourmaline King, Tourmaline Queen). B. Bulging dike with more numerous inner zones (Ocean View, El Molino). C. Bulging dike with complex zonal structure (Stewart, Vanderburg-Katerina).

FIGURE 14. Northwestward aerial view of a part of Queen Mountain, Pala district, showing open cuts of the Stewart lepidolite mine. These workings are in the thick and bulbous southern end of a pegmatite dike that dips away from the observer, and they lead to tunnels and stopes that underlie much of the hill slope beyond the crest of the foreground ridge. The dike splits northward into two or more juxtaposed dikes whose outcrops are visible on the brush-covered slopes. Workings of the Gem Star mine appear below the cliffs in the right-hand part of the view. *Pacific Air Industries photo.*

FIGURE 15. Fracture-controlled replacement masses and small fracture fillings of albite (light) in very coarse-grained quartz (dark), Pala Chief mine, Pala district. Above this striped rock is a layer of "pocket pegmatite" that has been worked for gem spodumene, and exposed in the back of the small stope is coarse-grained perthite-quartz pegmatite. Below the striped rock is albite-quartz-perthite pegmatite with subordinate muscovite and schorl.

posed units, which commonly contain residual masses of earlier minerals, include much of the district's so-called "pocket pegmatite," a rock type composed mainly of fine- to coarse-grained, subhedral to euhedral quartz, albite, potash feldspar, muscovite, lepidolite, and tourmaline.

All of the gem tourmaline, beryl, and quartz, as well as the commercial concentrations of lepidolite and much of the gem spodumene, occur in the pocket pegmatite. Very little open space is present in this type of rock, and the few large cavities that do occur are partly or completely filled with a clay through which gem crystals are scattered. The pocket pegmatite is largely restricted to cores and immediately adjacent zones, and is found chiefly along the footwalls or in the footwall parts of the cores.

Fine-grained granitoid rocks, composed mainly of quartz and albite, are common in the footwall parts of many dikes (fig. 13), and also occur elsewhere in some dikes. Several varieties are essentially uniform in texture and structure. Others, known collectively as "line rock," are strikingly marked by alternating thin layers of garnet-rich and garnet-poor pegmatite, or of schorl-rich and schorl-poor pegmatite. Layering in some of these rocks also is caused by distinct variations in texture.

The Pala pegmatite bodies are thought to have been formed by crystallization of liquid that was injected along fractures during the final stages of consolidation of the southern California batholith. The pegmatite zones appear to have developed from the walls of the bodies inward, probably by fractional crystallization and incomplete reaction with the residual liquid. Many, if not all, if the relations in the central parts of the most complex pegmatites seem best explained in terms of progressive accumulation and late-stage crystallization of mineralizing fluids, with accompanying deuteric replacement of earlier-formed minerals (Jahns and Wright, 1951, pp. 44-45). In order to develop a few of the larger replacement bodies, material may have been derived from other parts of the dikes. The origin of the line rock and other fine-grained parts of the dikes is less clear. They appear to have formed in part by replacement of earlier graphic granite, as first pointed out by Schaller (1925), but they are older than many stringers, lenses, and pods of graphic granite that occur within them.

Approximately 75 minerals are known from the pegmatites of the Pala district, and most of them still can be collected by persons with patience and a practiced eye. Indeed, the district has long been a happy hunting ground for mineral collectors. Visitors should be cautious, however, in entering the old mines, as many of them are in poor or dangerous condition. The underground workings of the Stewart and Tourmaline Queen mines (Map 8) are badly caved, and should be avoided entirely. None of the deposits should be visited without the knowledge and consent of the owners, who have suffered in the past from the thoughtless actions of some collectors.

109.1 Leave Pala, traveling west from the plaza.

109.4 Bridge over Pala Creek. Immediately beyond this bridge, a small quarry exposes a pegmatite dike and several parallel pegmatite-aplite stringers that transect medium-grained tonalite (fig. 12). This is the Bonsall tonalite, one of the most extensive rock types in the Peninsular Range province (Hurlbut, 1935; Larsen, 1948, pp. 58-67). It is younger than the gabbroic rocks and older than the granodiorites of the southern California batholith, and contains numerous mafic streaks and ovoid inclusions of partly digested gabbro, quartzite, and schist. A nearly vertical dike of aplite is exposed near the east end of the quarry.

109.7 Turn sharply left (east) onto Pala Road (State Highway 76).

110.6 Dumps of the Stewart mine are visible on the lower slopes of Queen Mountain to the left (north). This and other mines on Queen and Chief Mountains can be reached from Pala over trails and unimproved roads, as shown on Map 8.

110.8 Junction with old road into Pala.

111.4 Bear left onto paved road for side trip to Hiriart Mountain.

Hiriart Mountain Side Trip

(0.35) Turn left (northeast) onto narrow paved road.

(0.7) The broad surface of the late Pleistocene Agua Tibia fan lies to the right (southeast). Ahead is Hiriart Mountain, a mass of gabbro and tonalite whose slopes are ribbed by the outcrops of numerous pegmatite dikes.

(1.0) Bear left on McGee Road. The road on the right leads to the headquarters of George Ashley, mineral dealer and owner of several mines on Hiriart Mountain.

(1.2) Workings of the Katerina (Ashley) mine are on the hillside at the right (east). This mine has been developed in a thick and very continuous series of juxtaposed pegmatite dikes, which contain examples of all types of pegmatite found in the district. The first known occurrence of the gem spodumene kunzite was discovered on this property, which has been worked intermittently since 1902. Substantial quantities of lepidolite and gem spodumene, quartz, and beryl have been recovered from the mining operations.

Retrace route to State Highway 76.

111.4 Continue eastward on State Highway 76.

111.5 Numerous roadcuts beyond this point expose extremely coarse-grained detritus that constitutes much of the large Agua Tibia fan (figs. 11, 16). Termed the Pala conglomerate by Ellis (Ellis and Lee, 1919, p. 70), these fan deposits were derived principally from Agua Tibia Mountain and other high areas to the north. Most prominent among them are bouldery layers, some as much as 35 feet thick, that show little sorting or bedding and evidently represent old debris flows. Extensively fractured granodiorite within and near the Elsinore fault zone probably was a major source of the detritus. The deposits contain scattered vertebrate remains of late Pleistocene age, and probably are in part correlative with the younger arkosic fill of the Elsinore-Temecula trough.

113.1 Surface of the Agua Tibia fan. This point provides an excellent general view of the Pala district, and especially of the pegmatite dikes that crop out on the east sides of Queen, Little Chief, and Hiriart Mountains (Map 8, figs. 11, 14). Several boundaries between masses of gabbro and norite and younger plutons of granodiorite are clearly shown by differences in surface expression of these rocks (fig. 11). In this area most of the gabbroic plutons contain numerous pegmatite dikes, but a few appear to be pegmatite-free.

The mass of fine- to medium-grained hornblende norite on Slice Mountain, about 1½ miles to the north-northeast (fig. 11), has been quarried for dimension stone (Hoppin and Norman, 1950). This so-called ''black granite,'' which is used mainly for monuments, is obtained from large boulders of fresh rock that are surrounded by thoroughly weathered material. Some of the residual boulders are parts of a surface layer of creep debris, whereas others have not been moved from the positions they occupied prior to weathering of the rock (fig. 17).

FIGURE 16. Roadcut exposure of the chaotic debris-flow deposits that constitute much of the Agua Tibia fan, Pala district. Nearly all of the fragments are Woodson Mountain granodiorite.

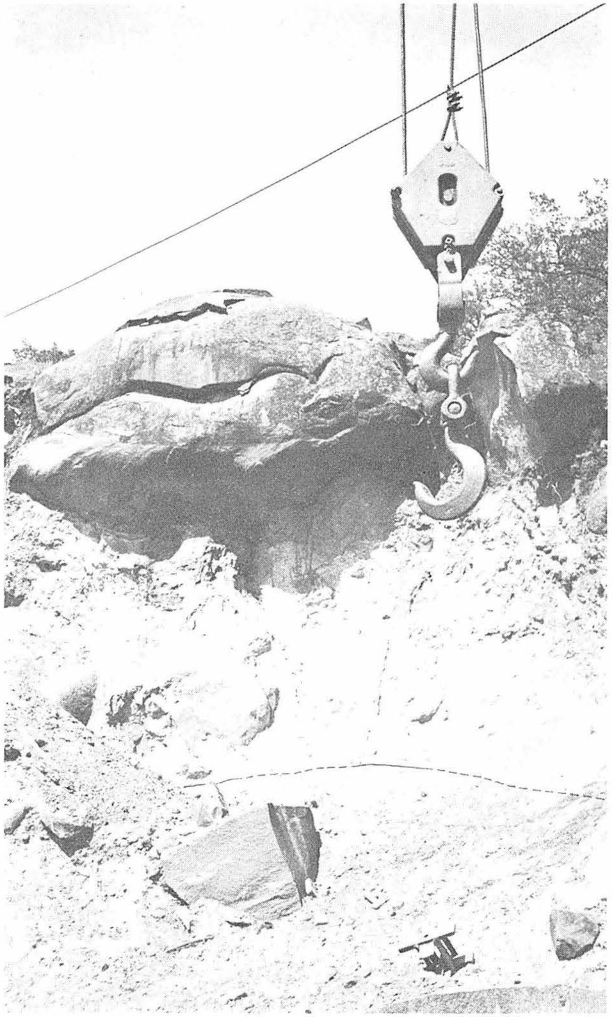


FIGURE 17. Residual boulders of hornblende norite in the Johnson (McGee) "black granite" quarry, Pala district. The dashed line indicates the base of a surface layer of "creep" debris, below which is partly weathered rock that has not been moved from its original position. Note the concentric spalling around the margins of some boulders.

The Agua Tibia fan must have been built so rapidly during late Pleistocene time that it choked the valley and dammed the San Luis Rey River, as fine-grained lacustrine deposits have been penetrated by numerous wells in Pauma Valley to the southeast. These deposits contain abundant plant fossils of Quaternary age. Later on, after the episode of major fan building had ended, the river breached the lower part of the fan and cut a trench as much as 350 feet deep. The rim of this trench is immediately south of the highway.

A large warm spring once issued from one of the breaks in the Elsinore fault zone at a point near the apex of the Agua Tibia fan. The main part of the fault zone crosses the high spurs and deep canyons about 2 miles east of the view point, and is in large part concealed by huge masses of slump and landslide debris.

114.3 Exposure of fine-grained, thinly and evenly bedded arkosic sand and silt. This material probably was deposited at the margins of the lake that once occupied Pauma Valley.

114.6 Pauma Valley. The scarp and well-defined benches ahead and to the left (east) are associated with the Elsinore fault zone. Some of the benches are underlain by landslide material.

117.2 Nigger Grade road. High on the slopes to the left (east) are broad benches that mark the trace of the Elsinore fault zone. Large slump and landslide masses are common in this area, which is underlain chiefly by schists and gneisses.

To the right (southwest and south), on the opposite side of the valley, are rugged slopes developed mainly on tonalite. Above them is an upland surface of low relief, which is mantled by soil and other residual material, as well as by local thin accumulations of alluvium.

119.3 Roadcut exposures show typical transitions between weathered and unweathered gabbro. This is one of the more felsic rock types that have been grouped with the San Marcos gabbro of the southern California batholith. A small excavation beyond the main roadcut exposes a thin pegmatite dike that can be traced continuously for a distance of more than a mile to the north.

Rincon Pegmatite District. Small quantities of gem beryl, spodumene, and tourmaline have been obtained from the pegmatite dikes of the Rincon district, which embraces an area of approximately 10 square miles. Most of the mining was done during the period 1903-11, and was restricted to only a few of the numerous dikes that are present in the area (Map 8). The geology and mineral deposits of the district have been treated in detail by Hanley (1951), and the complex mineralogy of the Victor pegmatite has been described by Rogers (1910).

As in the Pala district, the pegmatite occurs mainly as subparallel dikes that appear to have been emplaced along regional joints. In general they strike north-northwest and dip at moderate angles in a southwesterly direction. Unlike those of the Pala district, the Rincon dikes occur chiefly in plutons of tonalite, rather than gabbro.

Most of the dikes are mineralogically simple, and consist of quartz, perthite, and albite with subordinate muscovite and some accessory garnet, schorl, and beryl. Lithium-bearing minerals are present in only a few localities. The most abundant types of pegmatite are graphic granite, quartz-perthite pegmatite, massive quartz, and fine-grained, aplitic rocks that include typical line rock. The dikes ordinarily consist of three zones—a border zone, a wall zone, and a simple or segmented core. Other units of fine-grained rock, or of lithium-bearing pegmatite, occur locally. Few composite dikes have been recognized.

119.9 Rincon. Bear left (east) on State Highway 76.

A 5-mile side trip on the road to Escondido (bear right at Rincon) provides excellent exposures of the Bonsall tonalite, by far the most widespread rock type in this area. All gradations between weathered and unweathered rock can be seen in roadcuts on the grade south of the San Luis Rey River Valley. Residual masses of fresh tonalite are typically surrounded by disintegrated material (gruss) in which original textures and structures are remarkably well preserved (fig. 18); these masses have been referred to as "boulders of disintegration" by Larsen (1948, pp. 114-117). Many of the boulders represent the cores of original joint blocks, and where they rise above the surface of the ground they are grouped in regular patterns that reflect the original pattern of jointing.

120.0 State Highway 76 ascends the steep alluvial fan of Yuima and Potrero Creeks.

120.3 A ridge of bedrock beneath the surface of the fan in this area is an effective ground-water barrier, and much water is pumped from the basin above it for irrigation of avocado and citrus groves.

The rib-like projections of many pegmatite dikes appear low on the slope of Mesa Mountain at the left (north).

121.6 Directly ahead (north) are steep-walled natural cuts in sheared rock and landslide debris along the Elsinore fault zone. The main mountain mass is composed of tonalite that flanks a large septum of schist.

123.2 From this point to the top of the grade are many roadcut exposures of tonalite, schist, granodiorite, and hybrid gneisses.

124.3 Roadcut exposure of mafic Bonsall tonalite beneath lush growths of poison oak.

124.9 The highway traverses an irregular bench that is capped discontinuously by Quaternary gravels. The San Luis Rey River flows through a deep canyon about 2½ miles to the south (right).

125.2 Bear left for side trip to Palomar Mountain.

Palomar Mountain Side Trip

(1.1) Roadcut exposures of very coarse-grained alluvial-fan and landslide debris.

(1.6) The highway traverses an area underlain by fault-shattered tonalite, capped in places by landslide masses.

(2.2) Roadcut exposures of sheared and shattered rock in the Elsinore fault zone.

(2.7) Additional exposures of severely fractured tonalite and granodiorite, covered locally by very coarse-grained slump and slide deposits.

(3.2) The broad upland surface of the Mesa Grande appears to the southeast, beyond the canyon of the San Luis Rey River.

(3.6) The trees of the Agua Tibia Mountains clearly show the effects of altitude on the distribution of life zones. Here mixed stands of oak and Bigcone spruce appear in the canyons at an altitude of about 4,000 feet.

(4.0) Large exposures of shattered tonalite and hybrid schists and gneisses mark the major break that defines the Elsinore fault zone on the northeast.

(4.7) Roadcut exposures of Bonsall tonalite and foliated rocks of hybrid origin.

(5.0) Beginning of pine and cedar forest, although oak and spruce remain dominant at this level.

(5.5) Roadcuts expose foliated rocks of the Julian schist (Triassic?), which dip moderately to steeply east-northeast.

(6.0) Stand of small Coulter pine trees.

(6.9) Summit. Turn left (north).

(7.0) Junction with Ridge Road. Continue straight ahead on Observatory Road, which passes through heavy stands of incense cedar. Numerous roadcuts expose rocks of the Julian schist.

(10.3) The road crosses a swale that marks the trace of the south branch of the Agua Tibia fault, a longitudinal break that lies within the range.

(10.9) The road crosses the north branch of the Agua Tibia fault, whose general trace is marked in the area to the southeast by elongate shallow depressions and by aligned gulches and canyons.

(11.7) Palomar Observatory. The main observatory building houses the telescope with the famous 200-inch mirror. The museum and observation gallery are open to visitors daily from 8 A.M. to 5 P.M.

Retrace route to State Highway 76.

125.2 Continue eastward on State Highway 76.

127.2 Large cliff-making exposures of Woodson Mountain granodiorite are visible on both sides of the San Luis Rey River Canyon ahead and to the right (southwest). Several roadcuts expose Bonsall tonalite and associated hybrid gneisses.

128.5 The highway traverses an area in which very coarse-grained landslide debris conceals most of the bedrock.

129.4 Large roadcut exposures of thoroughly shattered and sheared rocks in the Elsinore fault zone. For the next 5½ miles the highway lies within this zone of severe disturbance, which has controlled the general course of the San Luis Rey River in this area.

132.9 San Luis Rey Campground.

134.6 Turn left (north) for side trip on Palomar Ridge Road.

Palomar Ridge Road Side Trip

(0.05) Cross the San Luis Rey River and Elsinore fault zone. Henshaw Dam, a large earth-fill structure, is at the right (east).

(0.5) Deep roadcuts expose shattered tonalite and granodiorite.

Warner Basin. The Warner Basin, also known as the Valle de San José, is a broad, saucer-like depression about 6 miles in diameter (fig. 17). It is separated from the Mesa Grande upland area on the southwest by a very steep scarp along the Elsinore fault zone, and from Hot Springs Mountain on the northeast by less prominent scarps associated with the Aguanga fault zone (Map 9). The Agua Tibia Mountains and Volcan Mountain rise to the northwest and southeast, respectively. The basin is transected by the Agua Tibia—Earthquake Valley fault zone, which bounds Volcan Mountain on the northeast.

The floor of the basin is underlain by alluvium and by arkosic valley fill of late Pleistocene age. The fill probably is correlative in age with parts of the fill in the Elsinore-Temecula trough. It rests upon plutonic igneous rocks, some masses of which project up through it as knobs and ridges, and it evidently was laid down upon a very irregular surface. In general it is thickest in the western part of the basin, and gives way in an eastward direction to a thin and discontinuous layer of gruss and residual boulders that lies directly upon crystalline rocks.

Sauer (1929, pp. 224-231) has divided the basin geomorphically into two parts, a southwestern area of Quaternary aggradation and a slightly larger northeastern area in which degradation has been the dominant process. The distribution of the upper Pleistocene fill suggests that this view may be somewhat oversimplified. Certainly the history of the basin is intimately related to movements, including some of lateral nature, along at least three major zones of subparallel faulting, and some transverse downwarping may have been involved, as well.

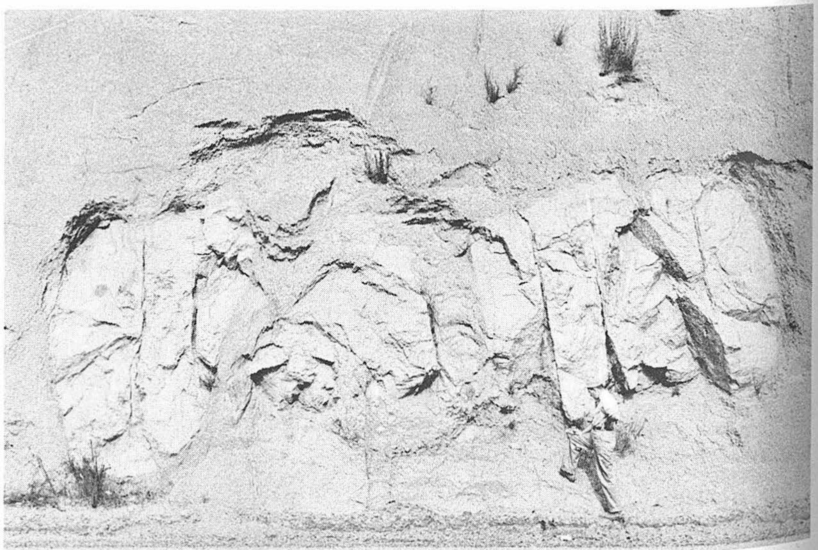


FIGURE 18. Weathered and unweathered Bonsall tonalite in roadcut about 4 miles south of Rincon. The fresh rock appears as large boulders of disintegration, which were drilled and blasted during excavation of the cut; the surrounding weathered rock was trimmed to a smooth face by means of shovels.

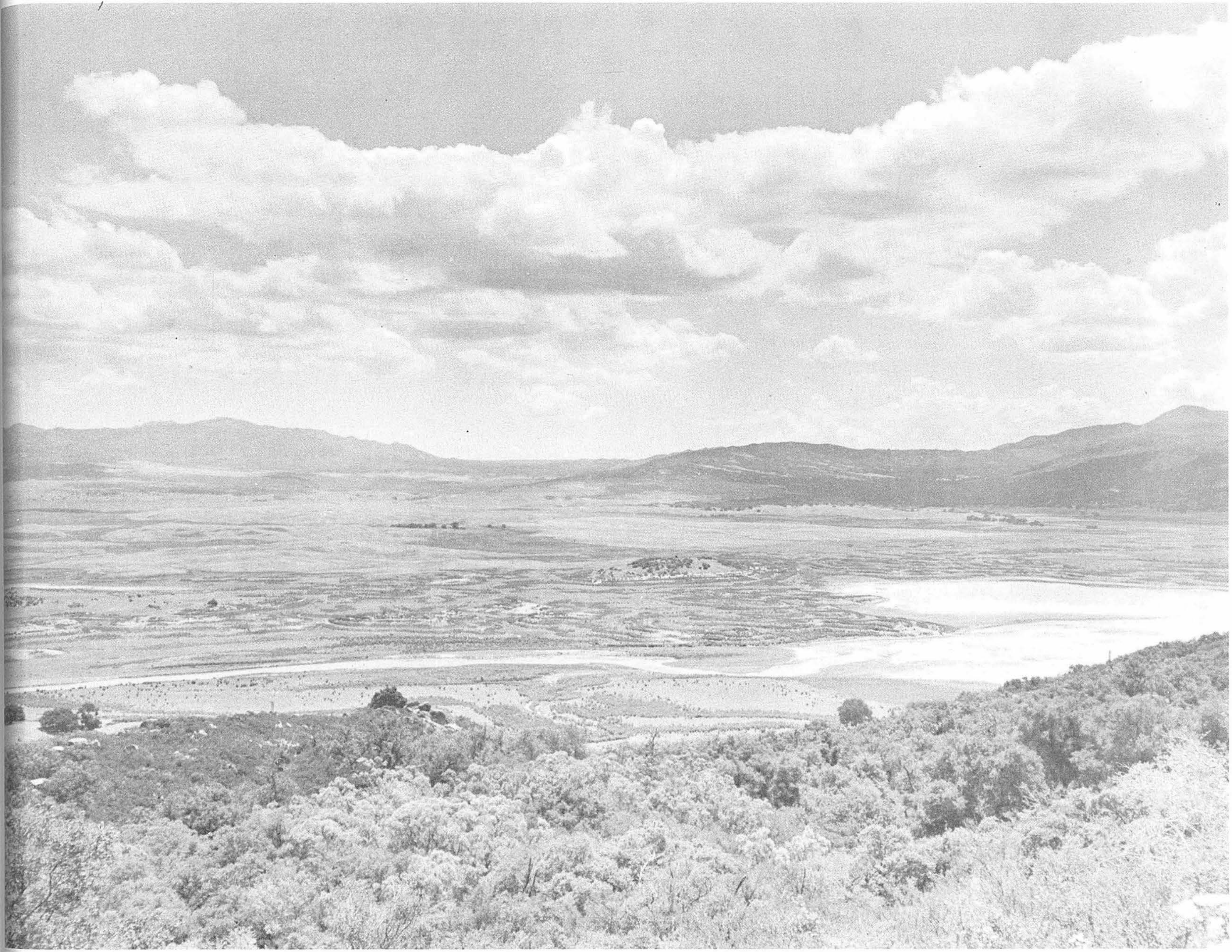


FIGURE 19. A part of the Warner Basin and Lake Henshaw, viewed southeastward from the end of the Agua Tibia Mountains. A dissected fill of upper Pleistocene arkosic sandstone and conglomerate occupies much of the lowland area. Shorelines corresponding to higher stages of the lake are outlined by stripes of vegetation in the middle distance. Volcan Mountain is at extreme right.

FIGURE 20. Large boulders of disintegration resting on a smooth bedrock surface, south side of the Warner Basin. The rock is the Lakeview Mountain tonalite.

(0.6) Broad view of the Warner Basin. The floor of the valley is occupied mainly by a dissected fill of poorly consolidated arkosic sandstone and conglomerate. Monkey Hill, a knob of tonalite, rises above the floor near the southeast end of Lake Henshaw. Abandoned shorelines of this reservoir lake are outlined by curving stripes of vegetation during periods of low water (fig. 19).

(2.0) View of the northern part of the Warner Basin and the mountains beyond. The bouldery, light-colored slopes in the distance to the northeast are underlain by coarse-grained granodiorite and felsic tonalite, and the darker-colored ridges are underlain by foliated rocks of possible Paleozoic age. The belt of metamorphic rocks terminates northwestward at Beauty Peak, visible near the left-hand end of the skyline ridge.

(3.2) Turn around and retrace route to State Highway 76.

134.6 Continue eastward on State Highway 76.

135.2 The small hill to the left (east) is an uplifted slice of upper Pleistocene arkose within the Elsinore fault zone. For the next 3 miles the highway traverses an irregular alluvial apron that skirts the southwest side of the Warner Basin. On the right is the steep scarp, known locally as "The Drop Off," that marks the northeastern edge of the Mesa Grande upland area.

137.0 Deep roadcut in foliated rocks of the Julian schist. Bear right onto old road for side trip to Mesa Grande.

Mesa Grande Side Trip

(0.2) Turn right (south) onto a narrow road that ascends The Drop Off. Exposed in numerous cuts on the 2-mile grade are schist, quartzite, and several varieties of hybrid gneiss, as well as tonalite and granodiorite that probably antedate the southern California batholith.

(1.9) Dumps of the old Shenandoah mine are at the right (northwest). This gold mine, like numerous other small mines in areas farther south, was developed in a lenticular quartz vein that cuts schist and gneiss.

(2.8) The road follows Scholder Creek, in a typical small valley of the Mesa Grande country. To the right (north) is Angel Mountain, which consists of gabbroic rocks and older foliated tonalite. Several roadcuts expose this tonalite, which has been correlated by Merriam (1946) with the Stonewall granodiorite of the Julian area to the southeast.

(4.3) Junction with road to the mines on Gem Hill.

Mesa Grande Pegmatite District. The pegmatite deposits of the Mesa Grande district, which occupies an area of about 2 square miles, have yielded an impressive amount of gem tourmaline, as well as small quantities of gem beryl, garnet, and quartz. The Himalaya and San Diego mines, on Gem Hill, probably have been the world's foremost source of gem and specimen tourmaline. Activities in the district were greatest during the priod 1902-12, and only a few mines have been worked intermittently since that time. Descriptions of the deposits have been published by Kunz (1905), Merrill (1914), Schaller (1922), and several other investigators.

As in the Pala and Rincon districts, most of the pegmatite occurs as subparallel dikes that trend north to north-northwest and dip moderately toward the west. At least 90 of these dikes are present within the district. They are enclosed mainly by gabbroic rocks.

The internal structure and lithologic units of the dikes are similar to those of the pegmatite bodies in the Pala district, although their average thickness is much less. The gem minerals occur typically in pocket pegmatite, chiefly in the central parts of a few dikes. In general, lithium-bearing varieties of tourmaline are more abundant than in the Pala district, whereas gem spodumene is relatively rare.

The principal gem deposits can be reached by road, as shown in Map 8, but travel over many of these roads by ordinary automobile is not recommended. With few exceptions, the underground workings of the mines are badly caved or are in otherwise unsafe condition, and they should not be entered.

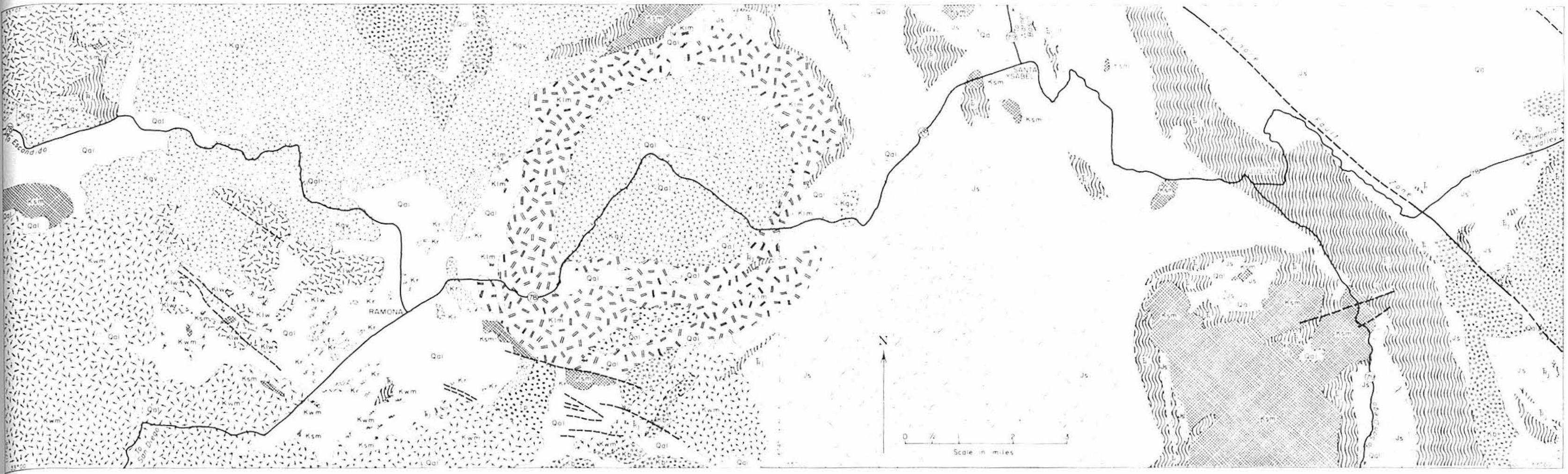
(4.7) Mesa Grande school, and junction with road to mines west of Gem Hill.

(5.5) Mesa Grande. Retrace route to State Highway 76, or continue southeastward 6.9 miles to State Highway 79 and thence 5.3 miles northward to rejoin the main route of travel at Morettis Corner.

137.0 Continue southeastward on State Highway 76.

138.3 Ahead is the valley of Carrista Creek, which marks the trace of the Elsinore fault zone. The slopes of Volcan Mountain, on the northeast side of the valley, are underlain by tonalite and granodiorite that probably are older than the rocks of the southern California batholith.

Map 9. Warner Basin and adjacent areas. Qal—alluvium; Qwa—arkosic basin fill; Kt—tonalite; Kgb—gabbro and norite; Js—Stonewall granodiorite and associated schists, quartzite, and hybrid gneisses; Trj—Julian schist. See Table 2 for stratigraphic relationships and descriptions of these geologic units. *Geology by R. H. Jahns and Richard Merriam.*



MAP 10. Ramona-Julian area. Qal—alluvium and terrace deposits (Pleistocene and Recent); Tp—Poway conglomerate (Eocene); Kwm—Woodson Mountain granodiorite (Cretaceous); Klw—Lake Wolford granodiorite (Cretaceous); Kr—Ramona tonalite (Cretaceous); Kb—Bonsall tonalite (Cretaceous); Klm—Lakeview Mountain tonalite (Cretaceous); Kgv—Green Valley tonalite (Cretaceous); Ksm—San Marcos gabbro (Cretaceous); Js—Stonewall granodiorite and associated schists, quartzite, and hybrid gneisses (Jurassic ?); TRj—Julian schist (Triassic ?). *Geology by Richard Merriam.*

139.2 Morettis Corner; end of State Highway 76. Turn left (north) onto State Highway 79.

139.7 Roadcut exposures of well-bedded arkose and conglomerate. These upper Pleistocene beds lie on tonalite that is exposed immediately to the north. This crystalline rock, which is a part of the southern California batholith, weathers to form slopes that locally are very smooth.

142.0 Smooth slopes developed on felsic, quartz-rich tonalite that contains few inclusions. The rock in this general area has been correlated by Larsen (1948, p. 68) with the Lakeview Mountain tonalite of the Perris block to the northwest. Boulders of disintegration are scattered over parts of the area (fig. 20), and arkosic sediments lap against the bedrock in the low hills to the left (northwest).

143.1 An even terrace surface, underlain by upper Pleistocene deposits, is visible directly ahead.

143.6 Junction with highway to Borrego Valley. The trace of the Agua Tibia—Earthquake Valley fault zone is crossed here. Immediately beyond is a roadcut exposure of typical coarse-grained, cross-bedded arkosic sandstone and conglomerate.

146.8 Continue ahead (eastward) on the road to Agua Caliente.

147.0 The road crosses a depositional contact between the basin-filling sediments and a complex of tonalite and more basic intrusive rocks.

147.2 The Aguanga fault zone is crossed here. The crystalline rocks on the ridge at the right (southeast) have been thoroughly shattered and sheared. Continue up the canyon, keeping on the right-hand (upper) road.

148.3 Agua Caliente. Continue around loop and return to State Highway 79 via the lower road.

149.7 Turn right (north) onto State Highway 79.

149.9 Warner Springs.

Alternate loop from Pala to Warner Springs via Escondido, Ramona, and Julian—82.2 Miles

(Maps 8, 9, 10; Table 2)

This alternate route extends through a part of the Peninsular Range province that is relatively unbroken by large faults. It contains a wide variety of pre-Tertiary crystalline rocks, comprising numerous representatives of the southern California batholith, as well as older plutonic, metasedimentary, and metavolcanic rocks. The geology of large parts of this area has been described by Merriam (1946) and by Larsen (1948), and several of the principal rock types also have been discussed in detail by Donnelly (1934), Hudson (1922), Hurlbut (1935), F. S. Miller (1937), W. J. Miller (1946), and others.

(0.0-5.7) Pala to U. S. Highway 395, via State Highway 76. The road extends westward down the San Luis Rey River Valley, which is bordered on the north by gabbroic rocks and some tonalite, and on the south by tonalite and light-colored granodiorite. For the last mile of this segment of the route, the valley is flanked by leucogranodiorite that crops out boldly.

(5.7-21.5) San Luis Rey River to Escondido, via U. S. Highway 395. Numerous large roadcuts provide excellent exposures of weathered and unweathered leucogranodiorite, Bonsall tonalite, Woodson Mountain granodiorite, Santiago Peak volcanics, and, near Escondido, San Marcos gabbro (see map in Larsen, 1948).

(21.5-39.1) Escondido to Ramona, via State Highway 78. The route traverses an area underlain chiefly by the Green Valley tonalite, a medium-grained, medium gray, moderately mafic tonalite which in general lacks the dark inclusions that are so abundant in parts of the Bonsall tonalite. Much of the rock is deeply weathered.

(39.1-53.7) Ramona to Santa Ysabel, via State Highway 78. The western part of the area traversed is featured by a large ring-dike complex involving several varieties of tonalite (Merriam, 1941), and the eastern part is underlain principally by older tonalite, granodiorite, schist, and hybrid rocks (Map 10). In an area about 4 miles east-northeast of Ramona are several mines and prospects in pegmatite dikes that have yielded small amounts of gem beryl, garnet, topaz, and tourmaline.

(53.7-60.7) Santa Ysabel to Julian, via State Highway 79. Igneous and metamorphic rocks that antedate the southern California batholith are traversed on this segment of the route. The Julian district lies within a broad, northwest-trending belt of schists, quartzite, and gneisses that constitute the type Julian schist. These rocks may be in part correlative with the Triassic Bedford Canyon formation of the Santa Ana Mountains to the northwest.

Gold valued at about $6 million has been obtained from quartz veins that cut the foliated rocks in an elongate area that extends eastward and southeastward from the vicinity of Julian, and in a small area on the south side of Cuyamaca Lake, about 7 miles south of Julian. The mining activities were most vigorous during the periods 1870-76 and 1888-93, and only a small fraction of the total output from the district represents work done since 1900. According to Donnelly (1934), the veins contain tourmaline, mica, pyrite, pyrrhotite, arsenopyrite, gold, and petzite. The veins are typically interlayered with schist, are discontinuous, and have complex detailed structure.

Some nickel mineralization is associated with gabbroic rocks in an area about 3 miles south-southeast of Julian (Hudson, 1922; Creasey, 1946).

(60.7-82.2) Julian to Warner Springs, via State Highway 79. This segment of the route traverses an area underlain almost wholly by pre-batholith plutonic rocks and hybrid schists and gneisses before reaching the Warner Basin from the southeast.

Warner Springs to Anza—35.2 Miles
(Map 9; Table 2)

149.9 Leave Warner Springs, traveling northward on State Highway 79.

153.4 Gently rolling country underlain by the arkosic fill of the Warner Basin.

154.5 The road crosses a ridge of tonalite, schist, and hybrid rocks that is bounded on the northeast by the south branch of the Aguanga fault zone. The San Luis Rey River, which drains the broad valley to the north, crosses this ridge in a short, steep-sided trench.

157.9 Upper part of Cañada Aguanga. The trace of the north branch of the Aguanga fault zone lies a few hundred feet to the right (northeast). Its position is marked by several springs and topographic sags. On the left (southwest) is a wide apron of alluvial material that was deposited on an irregular bedrock surface.

158.8 Holcomb Village. The broad floor of this pass between the drainages of the San Luis Rey River and Temecula Creek occupies the block between the north and south branches of the Aguanga fault zone, here about half a mile apart.

160.7 Huge ledges and bouldery exposures of coarse-grained hornblende-biotite tonalite. This is the Lakeview Mountain tonalite of the southern California batholith, and is very widespread in areas to the north and northwest.

162.7 The lower part of Dodge Valley lies ahead, and beyond it is the steep scarp of the Agua Tibia Mountains. Near the crest of the range, and about 3½ miles due south of this point, is the old Mountain Lily (Ware) mine, in which gem tourmaline and topaz were once obtained from pockets in an irregular pegmatite dike.

163.9 Oak Grove. This is the site of Camp Wright, which was occupied by the U. S. Army from 1861 to 1866 to guard communications between California and Arizona.

164.2 Site of the Oak Grove stage station, which was opened in 1858 on the Butterfield Overland mail route from St. Louis and Memphis to San Francisco. This stage line was operated for only three years.

Ahead and to the left (west-northwest) is a valley that marks the trace of the Aguanga fault zone. Northwestward from this area, Temecula Creek flows alternately through deep canyons cut in crystalline rocks and across broad valleys that have been alluviated by tributary drainage from the northeast. The steep slopes of the Agua Tibia Mountains are underlain chiefly by schist and quartzite in this area, whereas plutonic rocks are dominant in the lower hills and ridges north of the range.

In the mountainous area about 5 miles northeast of Oak Grove are several mines and prospects that have been developed in scheelite-bearing rock of contact-metamorphic origin. This tactite occurs between masses of calcareous metamorphic rocks, possibly of Paleozoic age, and tonalite of the southern California batholith.

167.8 San Diego-Riverside county line.

168.5 Aguanga Valley lies below and to the west. The lower part of its floor, which is covered with alluvium, rises gradually northward and northeastward into an area of terraces, beneath which are fault-bounded slices and blocks of tonalite (Cretaceous) and Temecula arkose (upper Pleistocene). Most of the faults trend west, and converge in this direction with the Aguanga fault zone.

170.0 Aguanga. Turn right (northeast) on road to Anza.

170.2 Roadcuts for the next 0.4 mile expose Temecula arkose that is cut by at least three subparallel faults with westerly trends.

171.6 Exposures of reddish brown upper Pleistocene conglomerate and sandstone. These strata dip about 5 degrees to the west, and lie upon a section of Temecula arkose that dips northwest at slightly higher angles.

172.1 To the left (west) is Lancaster Valley, on the south side of which a highly dissected area is underlain by the Temecula arkose.

172.5 A depositional contact between brownish upper Pleistocene alluvial-fan deposits and underlying tonalite is exposed in a roadcut. This tonalite, which crops out over a large area to the north and northeast, is finer grained and contains less hornblende than the typical Lakeview Mountain tonalite. It has been termed the Aguanga tonalite by Mann (1951).

173.9 Side road to Sage. The broad area of subdued relief to the left (north-northwest) is typical of several upland surfaces in the region between the Agua Tibia Mountains and the San Jacinto Mountains to the north.

176.4 The wide, alluvium-floored Coahuila Valley lies ahead. Its surface rises southeastward to higher parts of the broad Anza Upland, which are mantled by residual soil and accumulations of disintegrated tonalite. Northward beyond the valley is Coahuila Mountain, a large mass of schist and quartzite that encloses a smaller pluton of tonalite. This intrusive rock crops out on the south and southeast sides of the mountain, where it forms light-colored cliffs that contrast sharply with the more somber-appearing slopes that are underlain by the metamorphic rocks (fig. 21).

Numerous pegmatite dikes are present on and near Coahuila Mountain, chiefly within masses of tonalite and more basic intrusive rocks. Dikes on the south side of the mountain have yielded commercial feldspar and quartz, and several on its east side and on Little Coahuila Mountain to the northwest have been worked for lepidolite and gem tourmaline, beryl, and spodumene. Production from this area never was large, and most of the mines have been idle for many years.

183.5 Terwilliger Valley is ahead and to the right (southeast). It occupies a part of the widespread Anza Upland, and its alluvium-covered floor lies at a distinctly lower level than several nearby surfaces of low relief that have been developed on fine- to medium-grained tonalite and granodiorite. The general level of this area is about 2,000 feet higher than that of the Perris block to the northwest, and the problems of its geomorphic development and correlation with adjacent areas remain to be solved.

184.1 Exposures of highly sheared tonalite, which may mark the trace of a fault that some geologists have postulated as a bounding feature along the southwest side of Terwilliger Valley.

185.1 Anza.

Anza to Banning—47.9 Miles
(Map 11, Table 2)

185.1 Continue eastward on the highway through Anza.

FIGURE 21. Coahuila Mountain, viewed from the southeast. A pluton of tonalite forms the prominent, light-colored cliffs, and the darker slopes are underlain by older schists and quartzite. The alluviated floor of Coahuila Valley, in the foreground, rises in the distance to a broad surface of erosion developed on tonalite and other crystalline rocks.

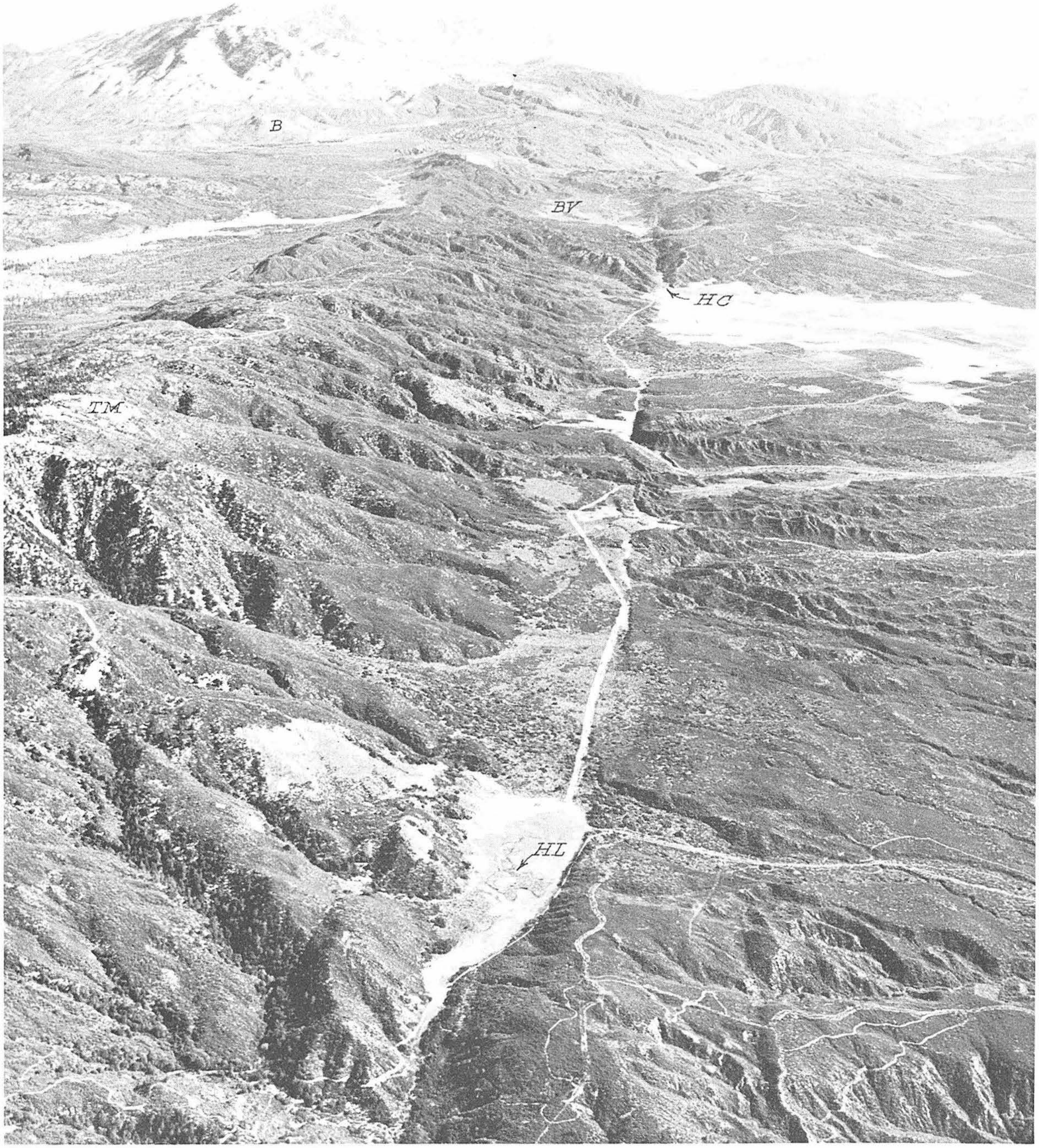


FIGURE 22. Aerial view southeastward along the San Jacinto fault zone toward the Santa Rosa Mountains and Borrego Valley. The traces of individual faults are plainly marked by trenches, small scarps, aligned saddles and gulches on several ridges, and by offsets in lines of drainage. Hog Lake (HL), a sag pond, is in the foreground. The Thomas Mountain ridge (TM), an elongate fault-bounded mass of tonalite, separates Hemet Valley at the left from the broad Anza Upland at the right. A thick section of upper Pleistocene arkosic deposits, the Bautista beds (B), is preserved at the upper end of Hemet Valley. Burnt Valley (BV), a small fault-flanked basin, lies beyond Hamilton Canyon (HC) in the middle distance. See Map 11 for the geology of this area. *Photo by J. S. Shelton and R. C. Frampton.*

185.6 Lookout Mountain rises as a distinct peak directly ahead. About 4½ miles to the left (north) is Thomas Mountain, a large mass of felsic tonalite that is bounded on both its northeast and southwest sides by major faults. High on the southwest slope of this mountain is the pegmatite dike in which gem tourmaline was first discovered and mined in California. The deposit was opened in 1872 and yielded some excellent gem material, but the mine has been idle for more than half a century.

San Jacinto Fault Zone. The San Jacinto fault zone, one of southern California's master breaks, diverges from the San Andreas fault zone on the north side of the San Gabriel Mountains. It extends southeastward across the San Bernardino Valley, along the southwestern margin of the San Jacinto Mountains, and through the area west, south, and southeast of the Santa Rosa Mountains into Imperial Valley. Its known length is approximately 180 miles.

In places the fault zone consists of one or more simple, well-defined breaks, especially where it cuts rocks of Tertiary or Quaternary age. More generally, however, it comprises several zones of subparallel to broadly anastomosing breaks separating masses of rocks that are profoundly shattered to almost undeformed. These fault-bounded masses range from slivers and slices a few feet thick to gigantic pinching-and-swelling slabs that are hundreds or even thousands of feet in maximum thickness (Map 11, fig. 22). Although they are parts of the San Jacinto zone, the faults and fault zones that define these larger masses are themselves major features, and commonly are given individual names.

The pattern of ramifying faults is especially broad in the area southwest of the Santa Rosa Mountains, where at least six major subparallel breaks are spaced half a mile to 3 miles apart. Indeed, the San Jacinto fault zone seems to widen southeastward into a series of very slightly diverging faults and fault zones that are separated by blocks of essentially unbroken rock, and hence loses its identity as a single zone or even as a single braid of zones. The Elsinore fault zone splits up in the same manner southeast of Elsinore, as does the San Andreas fault zone in the area north and east of San Bernardino.

The major breaks in the San Jacinto fault zone appear to dip very steeply, and the entire zone almost certainly is a very deep-rooted feature. Although it has not been studied in as much detail as the San Andreas fault zone (Noble, 1954), it seems to be similar to it in many respects. There is much evidence for vertical displacements both within and along the zone, and evidence for large-scale lateral movements has been reported from several areas (e.g., Dibblee, 1954). It seems probable that the San Jacinto fault zone is a major right-lateral break whose activities date back at least to early Tertiary time, but no meaningful estimate of the direction or amount of its net slip has been made as yet.

Some effects of the fault movements are beautifully expressed by elements of the present topography, which include scarps and scarplets, elongate trenches, sag ponds, anomalous benches and valleys, aligned gulches and canyons, and unusual patterns of drainage (fig. 22). Recency of movement is attested by some of these features, as well as by offset streams and records of numerous earthquakes.

188.0 The road enters the canyon of Hamilton Creek, which has been carved in the San Jacinto fault zone. Many roadcuts expose profoundly shattered and sheared schists, gneisses, and fine-grained tonalitic rocks. Zones of trituration are common.

188.8 The rocks in this area have been so thoroughly brecciated and crushed that they are readily eroded into badlands.

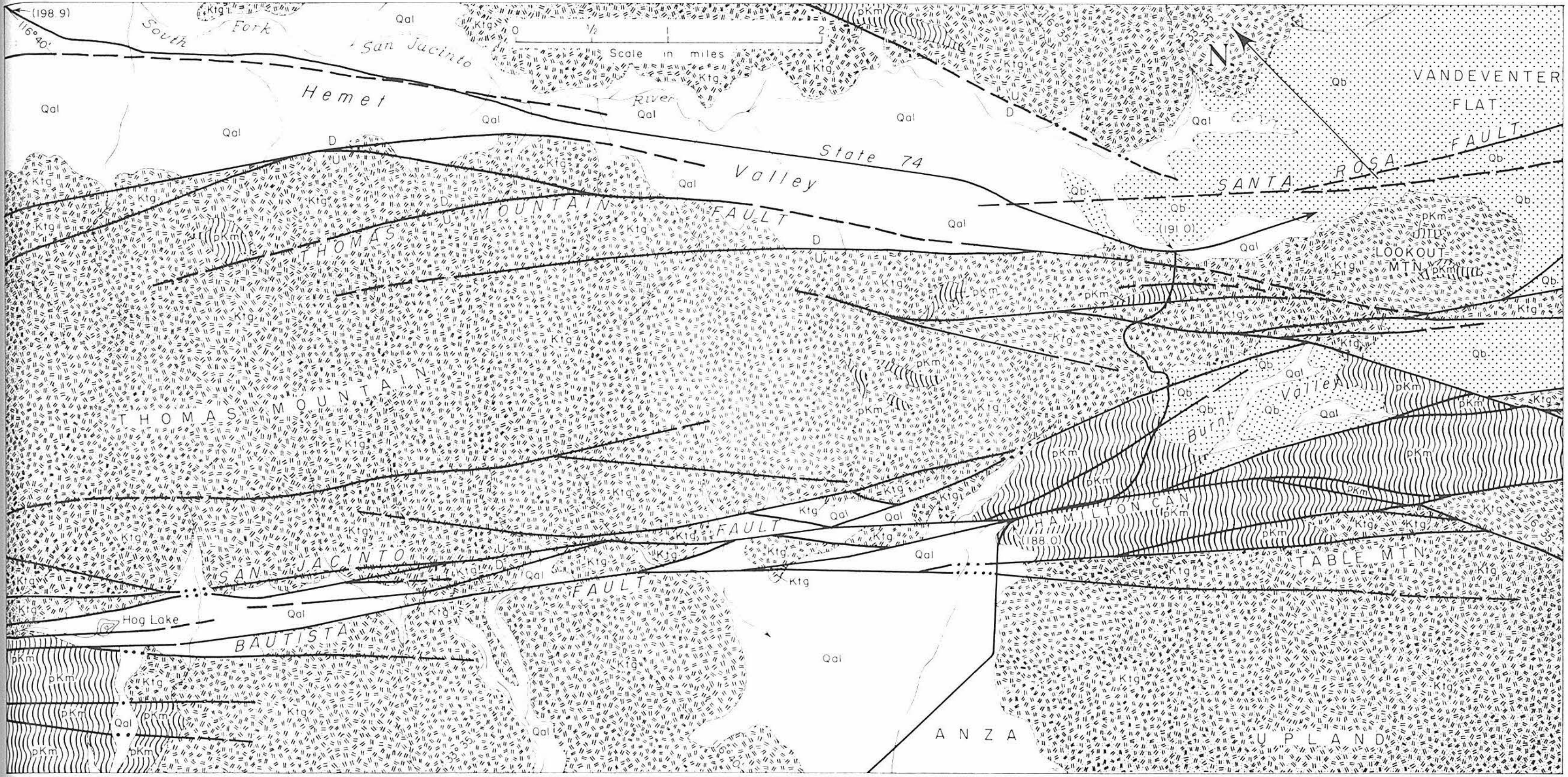
189.2 Roadcut exposures of severely disturbed schist that constitutes a block between two major zones of rupture. Beyond this are exposures of upper Pleistocene arkose.

189.9 Additional exposures of broken and sheared metamorphic rocks.

190.7 Summit.

191.0 Turn left (northwest) onto State Highway 74. About 0.1 mile to the left (southwest) is the trace of the Thomas Mountain fault zone, which here lies within a terrane of plutonic rocks but contains some slices of older metamorphic rocks. To the southeast, in the upper end of Hemet Valley, is a large remnant of upper Pleistocene arkosic deposits that once blanketed much of the valley floor. According to Fraser (1931, pp. 515-516), these deposits, which are as much as 500 feet thick, probably correspond to the Bautista beds in the area southeast of San Jacinto (Frick, 1921).

For the next 4 miles the highway traverses an apron of older alluvial-fan deposits that probably are in part correlative with the arkosic deposits to the southeast. They are concealed in many places beneath accumulations of younger alluvial debris.



Map 11. San Jacinto fault zone and adjacent areas, east of Anza. Qal—alluvium and terrace deposits (Pleistocene and Recent); Qb—Bautista beds (Pleistocene); Ktg—tonalite and granodiorite (Cretaceous); pKm—metamorphic rocks, chiefly schists and quartzite (pre-Cretaceous; possibly Paleozoic). *Geology by R. H. Jahns.*

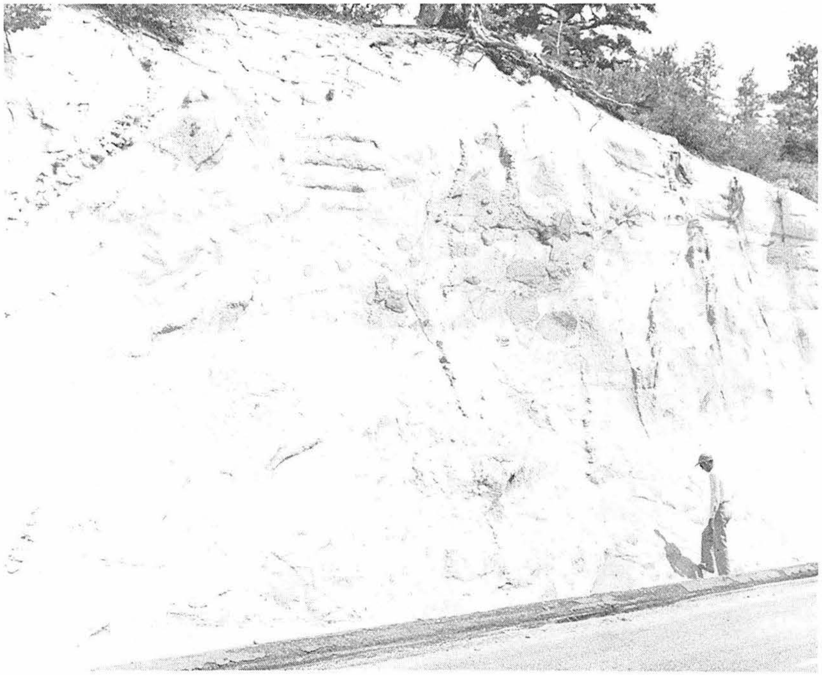


FIGURE 23. Roadcut exposure of coarse-grained tonalite, showing numerous mafic inclusions and irregular dikes and stringers of pegmatite. Idyllwild-Banning highway, on the west side of San Jacinto Peak.

197.4 The main mass of the San Jacinto Mountains rises ahead and to the right (north-northeast). It consists chiefly of plutonic rocks in the tonalite range, which probably are related to the southern California batholith. Older schists, gneisses, marble, and other metamorphic rocks appear as scattered inclusions, pendants, and septa, and also form one very large mass that crops out along the crest and east slopes in the southeastern half of the range.

Typical Lakeview Mountain tonalite is well exposed on the opposite side of Hemet Valley. This rock underlies nearly all of the mountain slope, and is in contact with the older metamorphic rocks at and near the top of this slope.

199.1 Hemet Reservoir, at the left (west), occupies the lower end of Hemet Valley. The elongate valley evidently owes its anomalous form and position to the Thomas Mountain fault along its southwestern margin, and possibly to another zone of faulting near its northeastern margin. It may have been occupied by a lake during a part of late Pleistocene time, and it is now tapped by the deep gorge of the South Fork of the San Jacinto River, most of which has been excavated along the Thomas Mountain fault zone.

200.6 Several roadcuts expose landside deposits that contain gigantic fragments of plutonic rock. This material was derived from the scarp of the Hot Springs fault, a break that is parallel to the Thomas Mountain fault and about 2 miles northeast of it.

201.9 Keen Camp summit, elevation 4,917 feet.

203.6 Turn right (north) onto Idyllwild-Banning highway.

207.6 Bear left and continue on the main road.

208.1 Idyllwild. Continue through town. For the next 12 miles the road skirts the highest part of the San Jacinto Mountains, passing through rugged country that is forested with oak and pine.

Numerous roadcuts expose medium- to coarse-grained felsic plutonic rocks, chiefly the Lakeview Mountain tonalite. Inclusions of more mafic rock are abundant in some areas, and small, irregular dikes of aplite and pegmatite are widespread (fig. 23). Much of the tonalite is weathered to depths of 10 feet or more, and yields gruss-covered slopes with numerous boulders of disintegration. Transitions between weathered and unweathered rock are exposed in many of the roadcuts.

211.0 Pine Cove.

213.6 Road to upper camp area.

217.7 Excellent view of San Jacinto Valley to the left (west).

218.2 Lake Fulmor. For the next 7 miles the road crosses an area that is underlain chiefly by very light gray, medium-grained, quartz-rich granodiorite.

222.3 First view of the San Gorgonio Pass area, with the San Bernardino Mountains in the distance to the north. Hurley Flat lies below and about 2 miles northeast of the view point.

224.2 Side road to Poppet Flat.

226.0 The road traverses a rugged area that is underlain by fine- to medium-grained leucocratic tonalite that resembles the tonalite of the Aguanga area to the south.

228.5 Excellent panoramic view of the San Gorgonio Pass area (fig. 24).

San Gorgonio Pass. San Gorgonio Pass is essentially a deep, nearly flat-floored trench that separates two of the highest mountain ranges in southern California. It trends east-

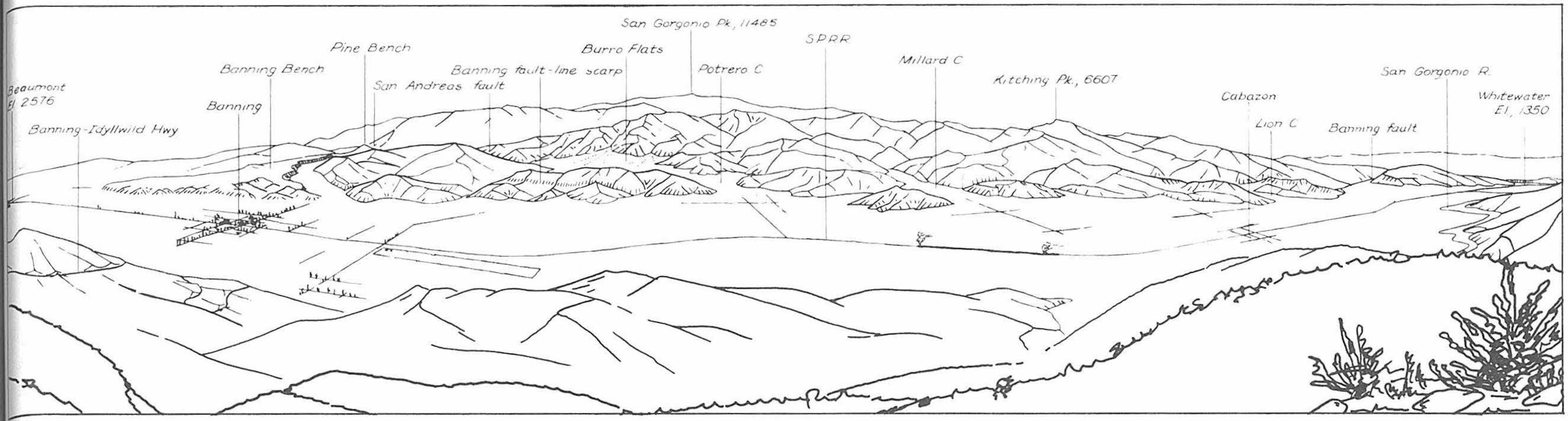


FIGURE 24. San Gorgonio Pass and the San Bernardino Mountains, viewed northward from the San Jacinto Mountains. A narrow and irregular strip of upper Tertiary and Quaternary rocks fringes the pass on the north, and is in fault contact with the gneisses and other crystalline rocks of the San Bernardino Mountains beyond. *Sketch prepared by Clarence R. Allen.*

west, and is bounded on the south by the impressive scarp of the San Jacinto Mountains. On its north side the foothills of the San Bernardino Mountains occupy an area of great topographic irregularity and complex structure. Exposed along the southern margin of this foothill area is a sequence of nonmarine sedimentary rocks that reflects a history of recurrent deformation and fluviatile deposition during late Tertiary and Quaternary time. A thin unit of marine strata attests the northwestward incursion of waters from the Gulf of California area early in Pliocene time.

The pass and the foothills north of the pass occupy an area in which faults of the northwest-trending San Andreas zone and faults with the characteristic east-west trend of the Transverse Range province intersect with and butt against one another to form an intricate mosaic of juggled blocks and slices. Involved in this faulting are the crystalline rocks of the San Bernardino Mountains, comprising plutonic types of Mesozoic age and gneisses and schists that may be in part much older. The dissimilar plutonic and metamorphic rocks of the San Jacinto Mountains seem to lie south of the zone of major disturbance.

The Banning fault zone is the principal structural break that is exposed within the pass area. It trends westward and west-northwestward along the north side of the pass (fig. 24), where it brings sedimentary rocks of Cenozoic age into contact with the older crystalline rocks to the north throughout the 25-mile interval between Whitewater Canyon and Yucaipa Valley west of Beaumont, and it probably extends still farther west to the San Jacinto fault zone (Allen, 1954). It is a vertical or steep reverse fault except in the vicinity of Millard Canyon (fig. 24), where there is a zone of low-angle thrusting from the north.

The break that has been termed the San Andreas fault in the pass area extends in a southeasterly direction across Pine Bench and Burro Flats, and thence appears to swing abruptly south and butt into the Banning fault zone near the mouth of Potrero Canyon (Allen, 1954). The Mill Creek fault, Mission Creek fault, and other members of the San Andreas zone lie farther north within the area shown in figure 24. Allen (1954) has noted that the San Andreas fault zone in the San Gorgonio Pass area is distinguished by several unusual features, and that there is little evidence for the very large-scale lateral displacements that have been deduced in areas to the northwest (e.g., Hill and Dibblee, 1953; Noble, 1954).

At least a mile of vertical displacement along the Banning fault since Pliocene time is indicated by the distribution and thickness of sedimentary rocks south of this break (Allen, 1954), and right-lateral offsets of somewhat greater total magnitude are suggested by less direct evidence. Earlier displacements may have been much larger. A fault similar to the Banning fault probably bounds San Gorgonio Pass on the south, but its trace is buried beneath thick alluvial-fan deposits of Quaternary age. The pass seems to owe its present form much more to vertical displacements along faults than to erosion. Warping may well have been important also, and even some of the Quaternary gravels in this area have been gently folded. Repeated uplift of the San Gorgonio Mountains is attested by unconformities within the Cenozoic section, and by the present relative positions of several well-defined terraces on the north side of the pass.

231.9 Base of the grade. The road crosses the alluviated floor of the pass. The Quaternary fan deposits derived from the San Bernardino Mountains dominate those derived from the San Jacinto Mountains, and hence the longitudinal drainage through the pass area lies against the base of the latter range.

233.0 Banning, San Gorgonio Avenue and Ramsey Street (U. S. Highway 60-70-99).

Whitewater Canyon Side Trip

(0.0) Turn right (east) onto U. S. Highway 60-70-99.

(1.0) The hills about 2 miles to the north (left) are underlain by Pliocene or lower Pleistocene sedimentary and volcanic rocks. The Banning fault separates this section from coarse-grained gneiss that crops out on the higher slopes.

(2.9) The mouth of Potrero Canyon is to the left (north). In this area the San Andreas and several other fault zones butt into the Banning fault zone, which itself is offset by a cross fault about half a mile west of the canyon. The prominent hill 1½ miles ahead and to the left (northeast) is underlain by Pleistocene fanglomerate.

(6.1) Cabazon. The Banning fault zone traverses the steep-sided foothills about 2 miles to the north, where it includes large slices of Pliocene or lower Pleistocene nonmarine strata that are bounded on the south by younger fanglomerate and on the north by coarse-grained gneiss.

Near the base of the San Jacinto scarp, about 1½ miles southeast of Cabazon, is the north portal of the Metropolitan Water District tunnel through the mountains to the San Jacinto Valley. This 13-mile tunnel is a part of the Colorado River aqueduct to the Los Angeles and San Diego regions.

(8.8) Side road that extends northeastward to the mouth of Stubby Canyon, where the Banning fault zone includes low-angle thrusts along which gneiss and other crystalline rocks have moved southward over upper Tertiary and Quaternary sedimentary rocks. This zone of thrusting is traceable for a distance of approximately 2 miles eastward along the base of the foothills.

(12.0) Junction with State Highway 111. Bear left and continue on U. S. Highway 60-70-99. Ahead and to the left (northeast) is Whitewater Hill, a large mass of Pleistocene fanglomerate that is separated by the Banning fault from highly deformed gneisses to the north. The fault in this area dips to the north at angles of 50 to 65 degrees.

(14.0) Bear left onto old road to Whitewater.

(14.3) Turn left (north) onto Whitewater Canyon road. Beacon Hill, 1½ miles to the east, is a mass of Pleistocene fanglomerate that has been warped into a broad anticline.

(15.8) The Banning fault, which commonly has been termed the San Andreas fault in this area, crosses Whitewater Canyon. Its effect on ground-water distribution can be inferred from the growth of vegetation upstream from its projected trace on the canyon bottom. The fault dips steeply north in this area, and on the east wall of the canyon it separates Pleistocene fanglomerate on the south from gneiss that is overlain by deformed conglomerate on the north. This conglomerate probably is older than the rocks exposed on the south side of the fault.

West of the canyon the fanglomerate on the south has been faulted against profoundly crushed and sheared gneiss and schist. The fault zone is well exposed in the side canyon that drains from the west, and can be observed by means of an easy traverse on foot.

Retrace route to Banning.

Banning to Riverside—30.8 Miles

233.0 Leave Banning in a westward direction on U. S. Highway 60-70-99.

234.2 About a mile to the right (north) is a large, well-defined terrace, the Banning Bench, which is capped by fanglomerate. Beneath this coarse-grained deposit are north-dipping beds of Pliocene or lower Pleistocene sandstone and conglomerate.

237.7 The road crosses Smith Creek, which flows southward down the eastern part of a broad alluvial fan and thence eastward through San Gorgonio Pass as part of the Coachella Valley drainage. The western part of this same fan is occupied by creeks that drain westward to the San Bernardino Valley via San Timoteo Canyon. A small part of the fan southwest of the view point is drained by Potrero Creek, which flows south-

FIGURE 25. Interbedded conglomerate, sandstone, and siltstone of the upper Pliocene San Timoteo formation, U. S. Highway 60 south of San Timoteo Canyon. Note the offsets along faults in the left-hand part of the view.

ward through the low western part of the San Jacinto Mountains into San Jacinto Valley (fig. 1).

238.7 Summit of San Gorgonio Pass, elevation 2,616 feet. This inconspicuous crest is merely a high point on the transverse profile of the broad alluvial fan that has been built southward across a part of the pass area by drainage from the San Bernardino Mountains.

239.6 Turn left (west) onto U. S. Highway 60.

240.6 The highway crosses a broad terrace that is underlain by reddish-brown alluvial-fan deposits of probable late Pleistocene age.

242.8 For the next 1½ miles the route follows the southwestern margin of San Timoteo Canyon. The hills on both sides of this canyon are underlain by upper Tertiary nonmarine sedimentary rocks.

245.1 Conglomerate, arkosic sandstone, and siltstone of the upper Pliocene San Timoteo formation (Frick, 1921, 1933) are exposed in badlands to the right (north). An extensive badlands area to the south is underlain in part by these buff to gray strata, and in large part by strata of the lower Pliocene Mount Eden formation (Axelrod, 1937, 1950; Fraser, 1931; Frick, 1921, 1933, 1937), which are finer grained and commonly variegated.

245.6 Roadcut exposures of interbedded siltstone, sandstone, and lenticular conglomerate. Cut-and-fill structure is widespread, and the strata are broken by numerous faults of small displacement (fig. 25).

248.2 Junction with State Highway 79. To the left (south and southeast) is the nearly flat-floored San Jacinto Valley.

248.5 Prominent scarp that marks one of the main breaks in the San Jacinto fault zone. This active fault separates valley alluvium on the southwest from Pliocene nonmarine strata on the northeast. To the left (south) is Mt. Russell, a mass of medium- to coarse-grained Bonsall tonalite.

250.4 The highway crosses the trace of a major fault that bounds Mt. Russell on its northeast end. This fault, one of several in the San Jacinto zone in this area, evidently has been active during Recent time. Its trace on the valley floor to the southeast is marked by subdued trenches, offset drainage lines, and upthrown slices and wedges of Quaternary deposits.

251.7 Roadcut exposures of weathered tonalite.

253.0 On the left (south and southwest) is Moreno Valley, which forms the northeastern part of a very broad area of low relief. This and adjacent valleys, together with old erosion surfaces and small mountain masses at higher levels, are known collectively as the Perris Upland. The complex geomorphic history of this large area is yet to be deciphered completely, especially as it relates to adjacent areas; it has been discussed by Dudley (1936), Larsen (1948, pp. 8-15), and others.

255.5 Ahead and to the right (northwest) are the Box Springs Mountains, a large mass of Bonsall tonalite.

257.9 Junction with U. S. Highway 395.

258.1 Bridge over Santa Fe Railway. To the right (north) is the bold southwest face of the Box Springs Mountains. A zone of crushed and sheared rock along the base of this scarp suggests the presence of a northwest-trending fault.

258.9 The large quarry at the right (east) has been worked mainly for rip rap.

259.8 Mt. Rubidoux, which is underlain by leucogranite of the southern California batholith, rises above the valley floor directly ahead. Farther in the distance and slightly to the right are the Jurupa Mountains, which consist of plutonic rocks and irregular masses of older metamorphic rocks (MacKevett, 1951). The igneous rocks of this small range are the northernmost exposed representatives of the southern California batholith.

263.8 Riverside, Eighth Avenue and Main Street.

Riverside to Los Angeles—58.3 Miles
(Maps 1, 2; Table 1)

263.8 Continue westward through Riverside on U. S. Highway 60, and skirt the northern end of Mt. Rubidoux on the west side of the city.

265.0 Bridge over Santa Ana River.

266.0 Turn right (northeast) onto Bloomington Avenue. The main mass of the Jurupa Mountains rises to the left (west).

266.8 Directly ahead is the remnant of a once-prominent hill that has been quarried for nearly half a century by the Riverside Cement Company.

268.4 Crestmore plant of the Riverside Cement Company.

*The Crestmore Hills.** The mine and quarries at the Crestmore Hills, about 3 miles north of Riverside, have yielded many millions of tons of limestone for the manufacture of cement since the first quarry was opened on Chino Hill in 1908 by the Riverside Portland Cement Company. Quarrying operations later were extended to the north side of Sky Blue Hill, the northeastern of the twin hills (figs. 26, 27), and the North Star, Lone Star, and Wet Weather quarries were successively opened. During World War II the old North Star and Lone Star quarries were nearly obliterated by westward extension of the Wet Weather quarry. Rip rap was taken from the Commercial quarry on the east side of Sky Blue Hill beginning about 1912, and not until recent years has limestone from this opening been used for the manufacture of cement. The Crestmore mine, in which a modified block-caving system of mining eventually was employed, was opened about 1930 beneath the floor of the Chino quarry, between the two hills. Most of the production of limestone at Crestmore during the past two decades has been from this mine.

The many quarry exposures and mine openings, together with tens of thousands of feet of diamond-drill cores, have presented an unusual opportunity for highly detailed studies of the compositions, spatial positions, and time relationships of the highly complex rock and mineral assemblages in this small area.

The limestone at Crestmore occurs chiefly as two crudely lenticular bodies. The lower or Chino limestone has been exploited in the Chino quarry and the Crestmore mine, and the upper or Sky Blue limestone has been worked in the other quarries. These two bodies are parts of a thick series of predominantly siliceous metasedimentary rocks that probably are of late Paleozoic or early Mesozoic age. These metamorphic rocks trend slightly west of north and dip moderately eastward in this area; locally beneath Sky Blue Hill, however, both limestone bodies have been deformed into a shallow syncline that plunges eastward. A section of siliceous metasedimentary rocks that probably did not exceed 200 feet in original thickness separates the Sky Blue limestone from the Chino limestone, and in general is conformable with them.

This section of older rocks occurs as a large screen in the Bonsall tonalite of the southern California batholith, which is the principal rock type in the area west and south of Crestmore. The tonalite also is present as sill-like bodies in the siliceous rocks between the two masses of limestone. Intrusion was accompanied by considerable plastic deformation in the upper parts of the Chino limestone and in the lower parts of the Sky Blue limestone, and in places this deformation was severe enough to pinch off the Chino limestone along an east-west line in the southern part of the area.

Metamorphism associated with the intrusion of the Bonsall tonalite consisted of: (1) conversion of the pure limestone beds into a coarse-grained, white to gray calcite marble, (2) conversion of the interbedded magnesian limestones into periclase marbles that subsequently were altered to predazzites, (3) metasomatic alteration of about a foot of limestone at the contact to a diopside-wollastonite-grossularite rock, (4) conversion of the less calcium-rich siliceous sediments into feldspathic hornblende and biotite-bearing quartz gneiss, hornfels, and schist, and (5) conversion of the more calcium-rich siliceous sediments into pyroxene hornfels and gneiss, and locally into wollastonite-bearing gneiss and schist.

Subsequently, the part of this suite of igneous and metasedimentary rocks that underlies Sky Blue Hill and the Commercial quarry was intruded by a relatively small pipe-like mass of aplitic quartz monzonite porphyry. The porphyry magma appears to have entered the area of the quarries from the southeast, and to have been intruded upward and northward through the tonalite to the contact with metasedimentary rocks, and thence mostly westward up the dip of these rocks beneath the Commercial quarry and Sky Blue Hill. The porphyry does not appear to have extended more than about

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* This statement was kindly furnished by C. Wayne Burnham, of the California Institute of Technology.

FIGURE 26. Air photograph of the Crestmore Hills and the plant and quarries of the Riverside Portland Cement Company. Contacts between major rock units are shown by means of dashed and dotted lines (see fig. 27). *MacPherson Aerial Surveys photo.*

50 feet west of the present east face of the caved area above the Crestmore mine, nor much beyond the south face of the Wet Weather quarry. The intrusion of this magma deformed the lower parts of the Sky Blue limestone into an eastward plunging anticline, the axis of which lies somewhat south of the ridge between the Commercial and Wet Weather quarries (figs. 26, 27).

In contrast to the minor metasomatic effects associated with the Bonsall tonalite, metasomatizing solutions from the porphyry magma, which were carrying mainly silica, alumina, and iron, produced a silicate contact aureole in the lower parts of the Sky Blue limestone that in places is as much as 50 feet thick. Approximately the inner two-thirds of this aureole consists principally of brown grossularite with lesser but variable amounts of diopside and wollastonite. Approximately the inner half of the remaining one-third of the aureole consists mainly of idocrase, whereas the outer half is characterized by monticellite. Important and highly variable amounts of other minerals associated with the monticellite include chondrodite, custerite, ellestadite, forsterite, melilite, merwinite, spinel, spurrite, tilleyite, and xanthophyllite. Retrograde hydrothermal alteration of all the mineral assemblages of the contact aureole resulted in formation of many hydrous minerals, among which are afwillite, chlorite, crestmoreite, hillebrandite, hydromagnesite, jurupaite (discredited?), nontronite, okenite(?), opal, riversideite (discredited?), and thaumasite.

Subsequent to its formation, the silicate contact aureole was intruded by pegmatites that originated in the crystallizing porphyry magma. Some of the dikes are zoned, with quartz cores that contain both wollastonite and calcite. Other pegmatitic bodies consist predominantly of quartz and/or calcite, and commonly contain a variety of minerals in addition to the major constituents. These minerals include allanite, apophyllite, axinite, centrallasite, clinozoisite, danburite, datolite, epidote, laumontite, opal, phillipsite, prehnite, scapolite, stilbite, and zoisite.

271.4 Bloomington. Turn left (west) onto U. S. Highway 70-99, and cross the broad alluvial plain of the San Bernardino Valley.

278.2 The Kaiser blast furnaces and steel plant are to the right (north). The principal raw material for this operation is magnetite-hematite ore from contact metamorphic deposits in the Eagle Mountains, in the eastern part of Riverside County.

Continue westward into Ontario via A Street.*

288.2 Ontario. Cross Euclid Avenue.

292.1 Pomona. Cross Garey Avenue and continue westward on Holt Avenue.

294.2 Bear right onto U. S. Highway 60, and continue westward into Los Angeles by retracing the route outlined in the early part of this log.

295.2 Junction with freeway (U. S. Highway 70-99).

307.2 Bridge over San Gabriel River.

322.1 Los Angeles Civic Center, and end of the route.

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* The freeway to Los Angeles (new Highway 70-99, under construction at the time this road log was prepared) can be taken as an alternate route, but an adjustment in mileage figures should be made.

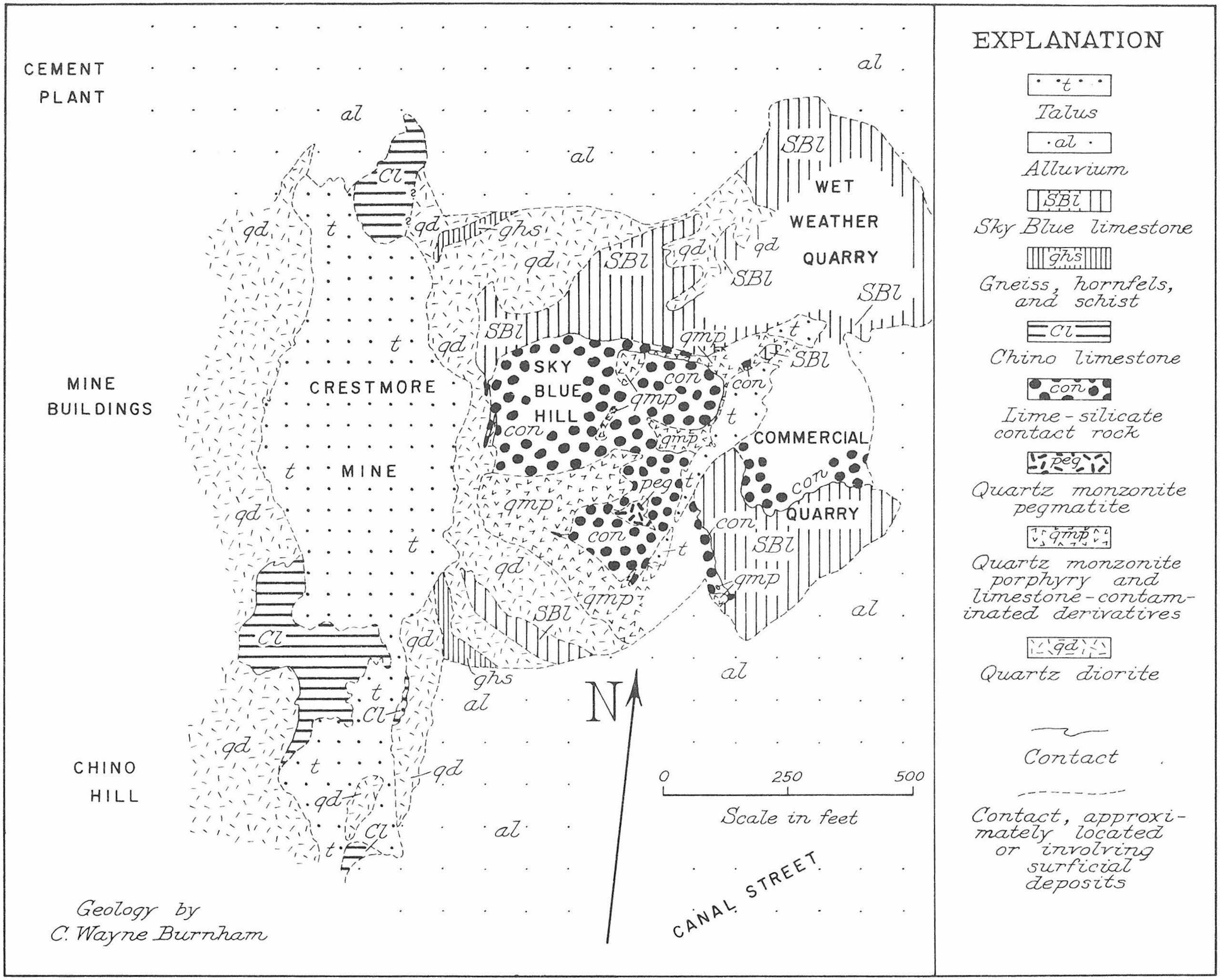

FIGURE 27. Geologic map of the Crestmore Hills, about 3 miles north of Riverside.

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