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Pliocene-Pleistocene History of the Perris Block, Southern California



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ABSTRACT

The Perris Block, 30 to 90 mi southeast of Los Angeles, is an eroded mass of Cretaceous and older crystalline rock, sculptured by six erosion surfaces. Two are narrow valley systems and the other four nearly horizontal planes or remnants thereof. The oldest surface is a bowl and narrow valley system with its base at an elevation of 1,100 to 1,400 ft; it is partially filled with alluvium which has yielded a lower Pliocene (Clarendonian) mammalian fauna. It was probably warped slightly before any of the younger surfaces were cut. The nearly horizontal erosion surfaces, listed in the proposed order of their formation, are now at elevations of approximately 1,700, 2,500, 2,100, and 1,500 ft and are thought to be in quasi equilibrium with the present major drainage systems. The second narrow valley system has a base near sea level; it was probably formed just after the 1,700 ft horizontal surface.

The Perris Block lies between the Los Angeles Basin and the lofty San Jacinto Mountains. The latter are marked by an elevated, low-gradient valley system. During Pliocene and Pleistocene time the Los Angeles Basin sank many thousands of feet, the San Jacinto Mountains rose considerably, and the Perris Block oscillated vertically. The vertical tectonics must have been governed by deep horizontal flow, isostatic in nature, and related to the somewhat greater flow-couple indicated by right-lateral strike-slip faulting on the San Jacinto fault system.

INTRODUCTION

The Perris Block, a mass of moderately high land 30 to 90 mi southeast of Los Angeles, is composed chiefly of crystalline rocks of Cretaceous and earlier ages. Thin sedimentary and volcanic units mantle the crystalline rocks in a few places. Two of these units have been determined to be early Pliocene in age from paleon-

tologic and radiometric data. The datum horizons fix in time a Pliocene-Pleistocene succession of episodes of erosion and sedimentation. We present first the observed data, then we discuss the implications of relative age inherent in the data, the relation of the block to the Los Angeles Basin, the local Pliocene-Pleistocene geologic history, and the place of the block in its late Cenozoic environment.

The Perris Block was defined by English (1926) as the mass between the San Jacinto and Elsinore-Chino fault zones, bounded on the north by the "San Gabriel" (Cucamonga) Fault (Fig. 1). The southern and southeastern boundaries of the block, which are vague, were left undefined by English. We use an approximate southern boundary against the Temecula and other small basins, determined by a rather complex group of faults that extends southeast from Murrieta (Fig. 2). We also use a doubtfully faulted eastern boundary along Wilson Creek, at about 116° 50' W. long. The highest point in the block thus defined is Red Mountain (Fig. 2), 4,573 ft, in the southeast, and the lowest point is at 530 ft on the Santa Ana River north of Corona. The climate of the block is semi-arid with a typical annual rainfall of 13 in. The Santa Ana River, which rises in the high, relatively humid San Bernardino Mountains, flows southwest across the northwest end of the block (Fig. 1). The San Jacinto River has its headwaters in the high and relatively humid but smaller San Jacinto Mountains. It flows southwest across the central part of the block and empties into Lake Elsinore, a sink in the Elsinore fault zone. In 1862, 1884, and 1916 to 1917, this lake overflowed into Temescal Creek, which follows a structural and topographic low along the Elsinore fault zone northwest to the Santa Ana River. The southern part of the Perris Block drains into Temecula Creek (Santa Margarita River) and through the mountains to the sea.

The crystalline bedrock complex includes

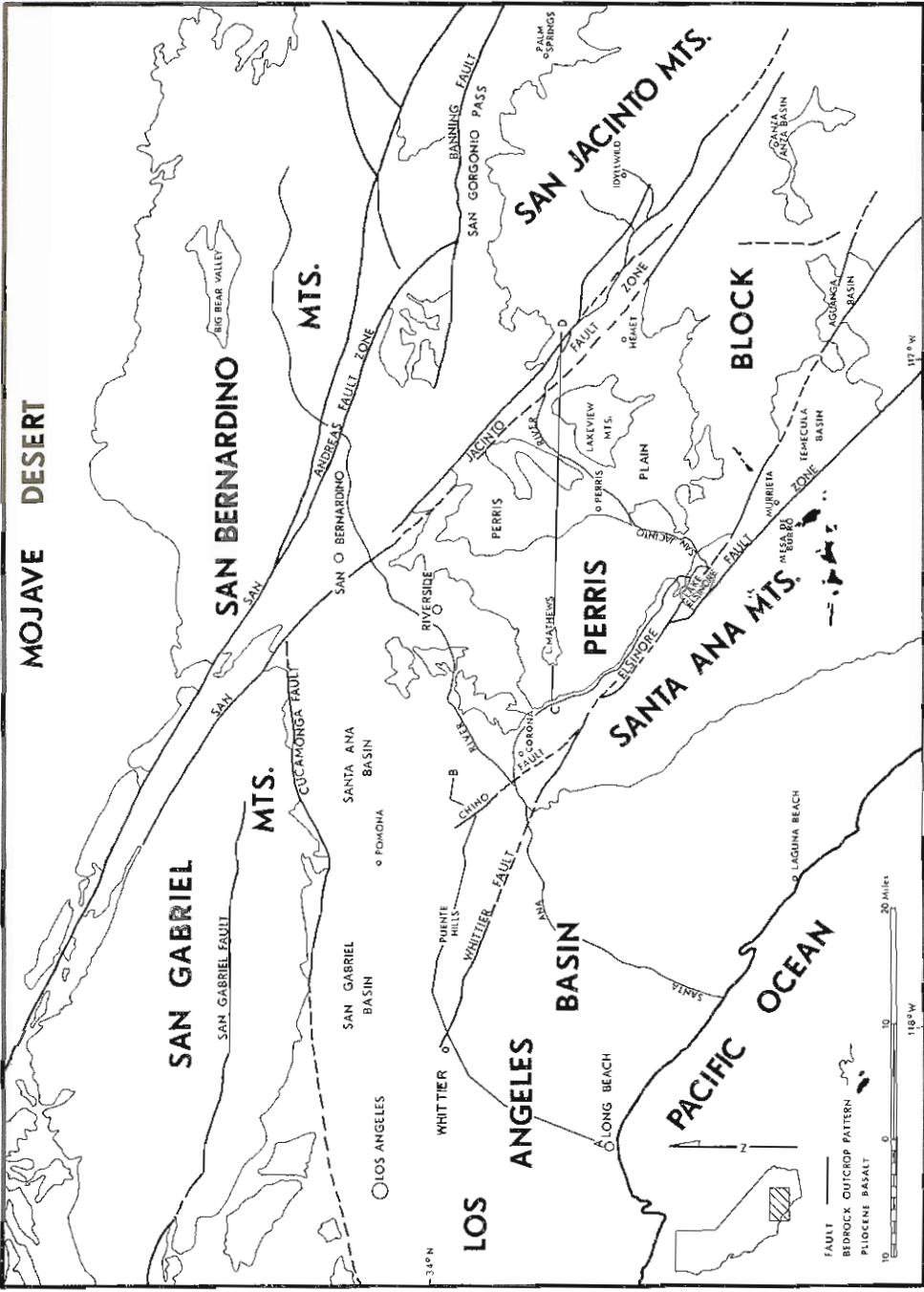


Figure 1. Map of Perris Block and Los Angeles Basin, showing faults, main drainage lines, and locations of Fig. 3 sections (after Smith, 1964; Rogers, 1965).

metamorphosed siliceous sedimentary rocks, metavolcanic rocks, and intrusive mid-Cretaceous plutons (Dudley, 1935; Larsen, 1948). Local superjacent (and adjacent), slightly consolidated, valley-filling continental sediments are in part lower Pliocene (Fig. 3, CD; Proctor, 1961; Proctor and Downs, 1963), in part Pleistocene (Frick, 1921; Merrill, 1963). Details of superjacent and bedrock geology have been mapped by Henderson and Aultman (1934), Jenney (1968), and Morton (1969).

An important unit in the southwest is the Santa Rosa Basalt (Mann, 1955). This flat-lying lava caps the Hogbacks, on the Perris Block northeast of Murrieta, and also covers the much more extensive Mesa de Burro and other high-standing mesas southwest of the block. Locally, the lowest member of the lava sequence is an alkali basalt that is lower Pliocene by potassium-argon measurement (Hawkins, 1970).

The Perris Block is sculptured by erosion surfaces at several levels (Table 1). The most striking surface is the top of the 2,100 ft Gavilan plateau, cut across varied plutonic and metamorphic rocks, and separated from the surrounding lower areas by scarps. The few residual steep-sided peaks that surmount the plateau yield runoff that is wholly inadequate for the erosion of the broad flat surface. Other erosion surfaces on the block were even more clearly formed under circumstances different from those that now prevail. Study of the relations of all the surfaces leads, step by step, to the recognition of a series of geomorphic events and the historical order in which they occurred. One surface is older than the lower Pliocene sediments, another is later than these sediments but older than the overlying Pliocene basalt, and so on. The present coexistence of all the surfaces, now in part protected by overlying

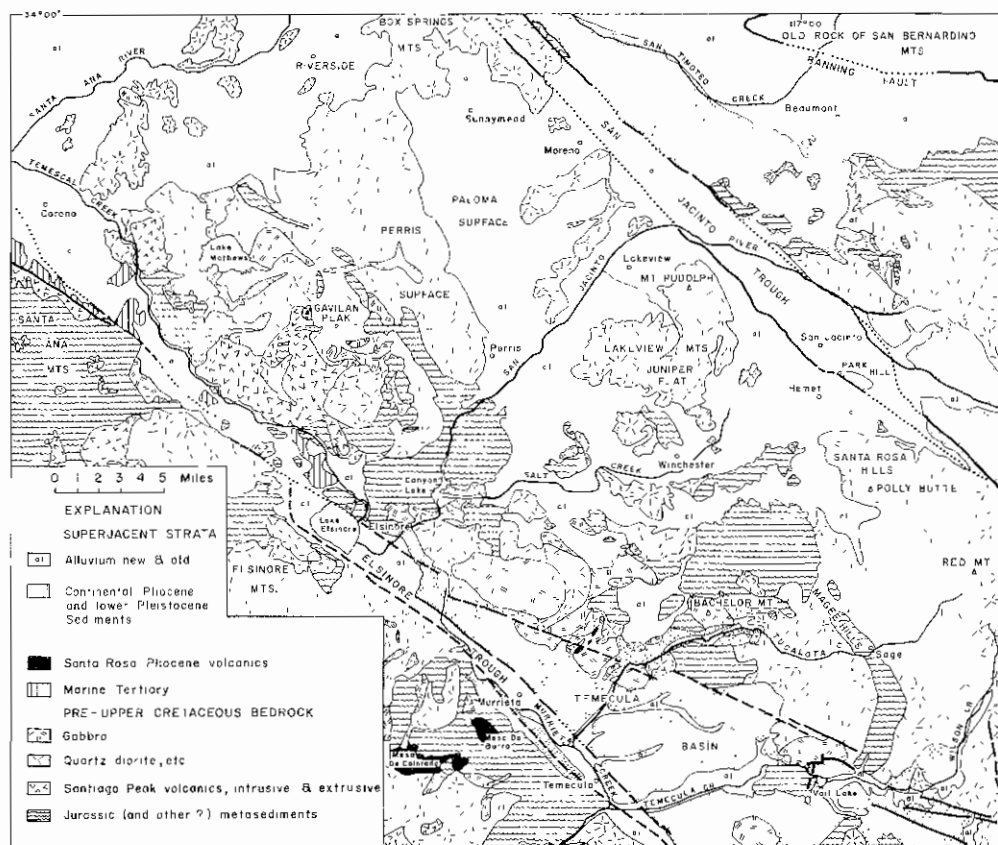


Figure 2. Geologic map central and southern parts of the Perris Block (modified from Rogers, 1965).

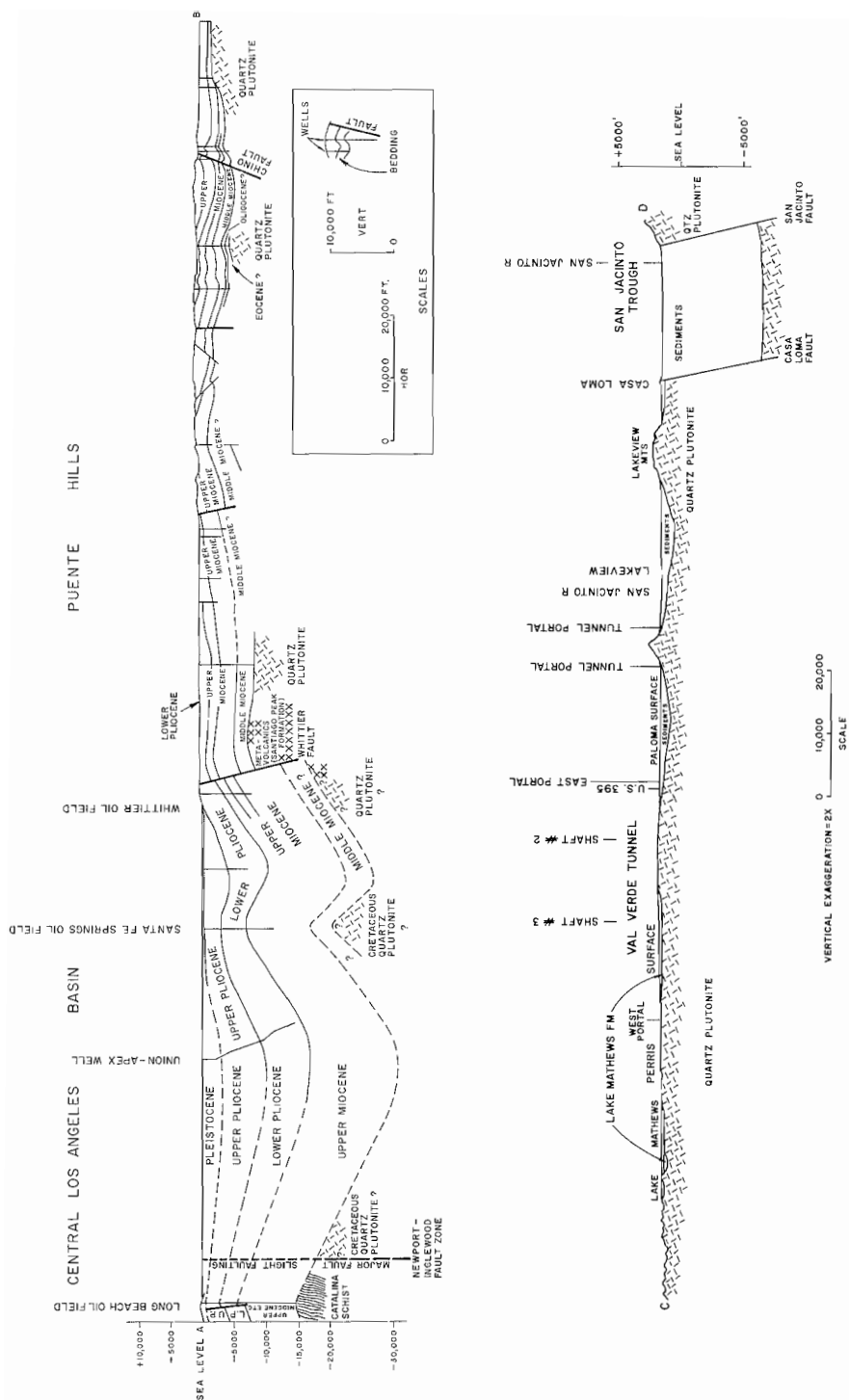


Figure 3. Structure sections, AB, Los Angeles Basin, unpublished sources. For east dip of Casa Loma fault see including Puente Hills; CD, Perris Block. AB *after* Durham and Yerkes (1964), Yerkes and others (1965) and Proctor (1962).

sediments or lava, but mostly exposed as a composite surface in quasi equilibrium, does not prevent the recognition of an age series.

The early geomorphic work in the region was done by Sauer (1929) and Dudley (1936) at a time when the models of W. M. Davis and Walther Penck were dominant. Dudley used a Davisian approach to the study of the Perris Block, while Sauer's work in a nearby part of the Peninsular Ranges was Penckian. Wahrhaftig (1965) studied local erosion surfaces on quartz plutonites in the Sierra Nevada of California. He hypothesized that the surfaces originate from local base levels which are established by retarded weathering-erosion rates of exposed bedrock. He also speculated that the mechanism may be applicable to the Peninsular Ranges as described by Sauer. Our methodology and results follow no single model but constitute a synthesis of concepts originating with Davis, Gilbert (1877), and Wahrhaftig (1965). We follow practically all

been buried by alluvium and later exhumed. Relics of old surfaces on bedrock have long persisted, even though they are constantly reduced in area and are fated to disappear if a single base level lasts long enough. An extreme contrast exists between the short life, in years, of a constructional or erosional surface on unconsolidated alluvium (or deeply weathered bedrock) and the long life of an erosional surface on unweathered crystalline bedrock.

BEDROCK GEOLOGY

The middle Cretaceous and older bedrock of the Perris Block, like that of the Santa Ana Mountains and the other western Peninsular Ranges, is made up of four principal units (Fig. 2). The most abundant rocks are quartz-bearing plutonites, mostly quartz diorite, in which the principal dark-colored minerals are biotite and hornblende. Gabbro is a second widespread plutonite. Southeast of Canyon Lake, gabbro is shown as mapped recently by D. M. Morton (Morton and Gray, 1971). It is somewhat less extensive than shown by Rogers (1965). The plutonites are Cretaceous, probably mostly middle Cretaceous; they intrude two types of slightly older rocks, the volcanic and shallow intrusive Santiago Peak Formation, and earlier metasedimentary rocks. The Santiago Peak Formation is mostly andesitic. In the Santa Ana Mountains the metasedimentary rocks are the partially recrystallized sandstone and slate of the Bedford Canyon Formation, which is at least in part Callovian Jurassic. Farther east, the more highly metamorphosed metasediments are, in part, probably the age equivalents of the Bedford Canyon Formation.

CENOZOIC SEDIMENTS AND LAVA

Continental sediments are moderately abundant on the Perris Block, and lava is also present. The two principal sedimentary units are the Lake Mathews Formation and the deep valley fill.

TABLE 1. EROSION SURFACES OF THE PERRIS BLOCK, IN THE ORDER OF THEIR FORMATION, WITH THE OLDEST AT THE BOTTOM

Paloma Surface	Approx 1,500 ft elev
Gavilan-Lakeview Surface	Approx 2,100 ft elev
Magee Surface	Approx 2,500 ft elev
Deep valley Surface	Base near 500 ft elev
Perris Surface	Approx 1,700 ft elev
Bowl and narrow valley Surface	Base near 1,100-1,400 ft elev

other students of semi-arid geomorphology in recognizing the existence of steep-sided residual mountains that project above the level of an erosional-depositional plain, but we leave these features unexplained. Our conclusions are close to those of Dudley (1936), with modifications and additions based largely on the work of Bean (1955) and Proctor (1961).

On the central part of the Perris Block we find evidence of repeated changes of local or general base level, without intra-block faulting or general tilting. Rejuvenation no doubt at first affected chiefly the trunk streams, whose gradients were markedly increased, probably beginning at or near the downstream edges of the block. At somewhat later stages, most streams attained nearly stable compound long profiles in quasi equilibrium¹, with alternate convexities and concavities, so that extensive areas continued to develop under the conditions that prevailed before the change of base level. Some erosion surfaces on bedrock have

¹Quasi, or approximate, equilibrium is a general term equivalent to steady state. We consider this the state of a stream whose gradients change smoothly and gradually, whether the bed is hard rock or mobile sediments. For mobile beds, Leopold and Maddock (1953, p. 52) concluded that bed roughness is determined by bed material size and suspended sediment concentration. Under such conditions, "slope tends to be adjusted to provide the velocity-depth relations necessary to carry the load in quasi equilibrium." We do not know what determines the smooth profile convexity in a bedrock stretch (compare Woodford, 1951, p. 824-830).

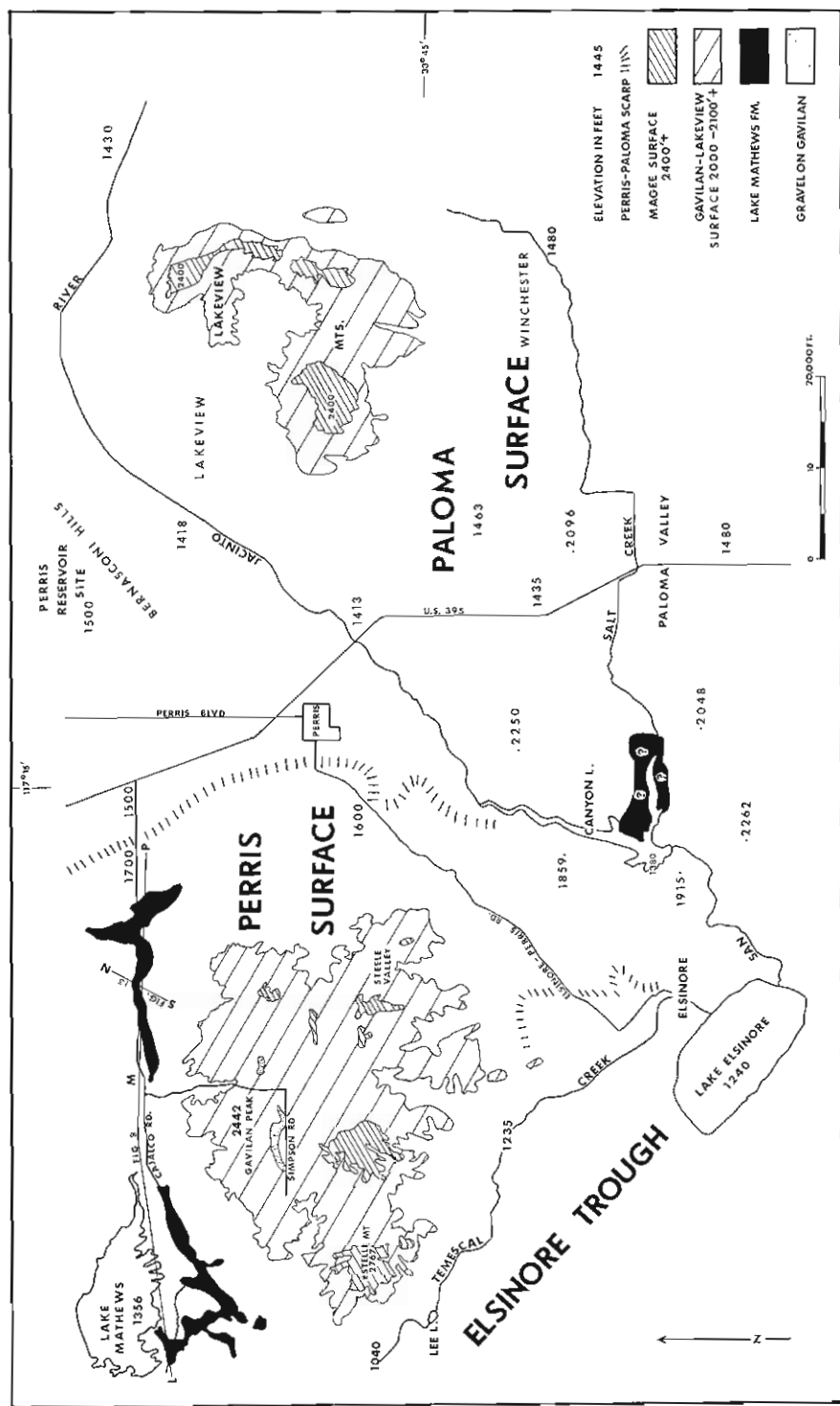


Figure 4. Map of the central part of the Perris Block, showing the distribution of the Lake Mathews Formation (lower Pliocene), Gavilan-Lakeview and Magee Sur-tion (lower Pliocene), and the locations of Figures 5 (LMP) and 6 (SN). Spot elevations on the Paloma surface are between 1,400 and 1,500 ft; higher points in the Paloma area (1859, 2250, 2096, and so forth) are monadnocks and other projecting peaks.

Lake Mathews Formation

We validate here Proctor's (1961) manuscript name—Lake Mathews Formation—for the horizontal, or nearly horizontal, continental sediments of early Pliocene (Clarendonian) age that locally fill most of the bowl-and-valley system in the bedrock of the western part of the Perris Block. The type locality is on the south side of Lake Mathews (Figs. 2 and 4), in the southwestern corner of sec. 7, T. 4 W., R. 5 S., San Bernardino base and meridian. The type area covers 2 or 3 sq mi south of and beneath Lake Mathews. Proctor and Downs (1963) reported the discovery of fossil mammals in borrow pits in this area, *Ustatochoerus* cf. *californicus* (Merriam) and a moderate sized camel. A second definite occurrence of this formation is the valley filling at about the same elevation east of Lake Mathews (Figs. 2 and 4). A third occurrence, somewhat less certain, is the valley fill, at least 25 ft thick, along the east arm of Canyon Lake east of Lake Elsinore.

The two areas of outcrop at and east of Lake Mathews were probably separated by erosion that occurred after central north-south upwarping. Near and beneath Lake Mathews the base of the formation is at about 1,100 to 1,300 ft elev, irregular but in general rising toward the east. The valley fill east of Lake Mathews is sinuous (Fig. 4), deep and narrow (Fig. 5), and discordantly truncated by the Perris Surface (Fig. 6). Its base is nearly horizontal, at 1,375 to 1,425 ft elev, rising toward the west (Fig. 5). These relationships imply warping previous to erosion, with uplift along a N.-S. line. A similar upwarp seems to have affected the west end of the probable equivalent of the Lake Mathews Formation at Canyon Lake. There the base is mostly concealed; it is probably at about 1,300 to 1,350 ft elev.

Richard J. Proctor (March 1, 1971, written commun.) considers well-consolidated, trough-filling sediments penetrated in drilling or excavation for two dams to be probably Pliocene and, we might add, possible equivalents of the Lake Mathews Formation. One such trough filling "extends to 290 feet below the ground surface under Perris Dam (under construction by the California Division of Water Resources)." At the other site, south of Bachelor Mountain (Fig. 2), where construction is by the Metropolitan Water District of Southern California, "the deposits are in a closed trough, are 132 feet thick, and are buried 90 to 120 feet beneath terrace deposits which in turn have

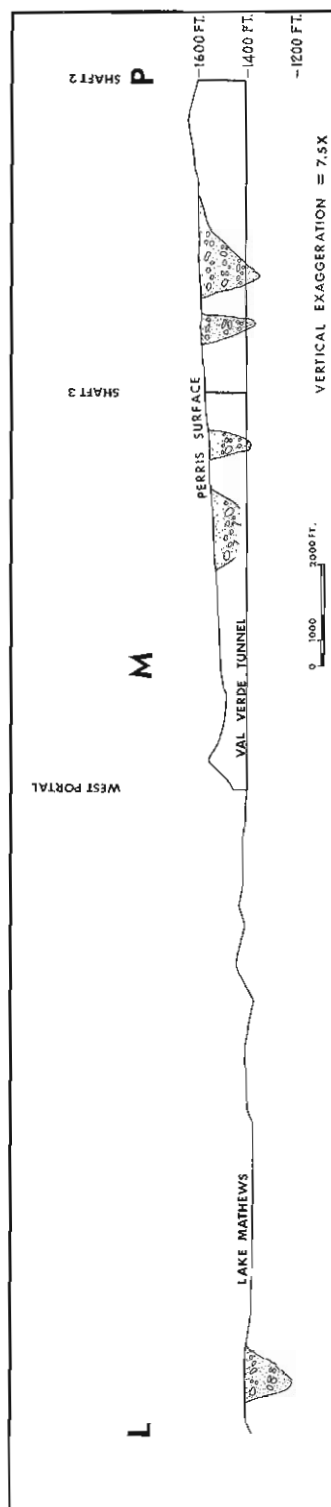


Figure 5. East-west section through the Perris Surface and the underlying Lake Mathews Formation, Lake Mathews to Val Verde Tunnel of Metropolitan Water District. Data from R. J. Proctor. Lake Mathews Formation patterned, bedrock blank. See Figure 4 for location.

been eroded and entrenched by the present Tualota Creek floodplain."

The sediments of the Lake Mathews Formation are moderately well consolidated greenish silty fine sandstone, coarser sandstone, pebbly sandstone, and conglomerate, in sections up to 25 ft thick in quarries, more than 200 ft thick in the eastern strip cut by the Colorado River aqueduct (Fig. 5), and at least 293 ft thick in a bore hole south of Lake Mathews (Proctor and Downs, 1963). Some boulders in the uppermost sandy bed south of Lake Mathews are up to 36 in across. The boulders of the conglomerates and bouldery sandstones were derived from the local quartz plutonites, gneisses, and tourmaline-quartz rock. The finer sediments are very rich in biotite, most of which is fresh, and in andesine feldspar. Quartz is common, but probably less abundant than plagioclase. Green hornblende and orthoclase are present. All the constituents might have been derived from the local quartz diorites and granodiorites. The sediments at Canyon Lake are similar to those near Lake Mathews. The finer sediments of the formation yield size analyses that range from moderately well sorted to pebbly and dirty, as shown by the phi values plotted in Figure 7. The better sorting of some samples (C and E) may be distinctive of the Lake Mathews Formation, as contrasted to the lower Pleistocene of the region, though the data are insufficient to establish more than a possibility.

Some sandstone beds in the Lake Mathews Formation are lithologically somewhat similar to biotite-rich beds in the Silverado (Paleocene) Formation of the Elsinore Trough. The Lake Mathews Formation, however, lacks the intensely weathered varicolored clays, completely decolorized biotite, and coal that characterize the continental facies of the Silverado Formation. One sandstone bed in the Lake Mathews Formation contains somewhat weathered andesine and biotite, but the biotite is still dark brown and the small amount of hornblende is still green; in general, the minerals of the formation are fresh and unweathered. A red-brown soil that tops the formation at Canyon Lake might be taken to be a Paleocene feature, but we consider it late Pleistocene.

Deep Valley Fill

The deep valleys in the bedrock of the eastern part of the Perris Block, adjacent to the San Jacinto Trough, are filled with alluvium to the level of the Paloma Surface, at about 1,500 ft elev. The alluvium is made up of clay, silt, sand,

and gravel, as shown by driller's logs for hundreds of wells drilled in search of water-yielding gravels and sands. The wells are concentrated in the centers of the deep valleys (Fig. 8; cross-section at Perris Reservoir site,

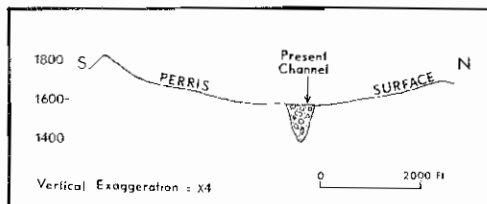


Figure 6. Southwest-northeast section through the Lake Mathews Formation and the Perris Surface. Just west of Shaft No. 3 of the Colorado River Aqueduct. Data from R. J. Proctor. See Figure 4 for location.

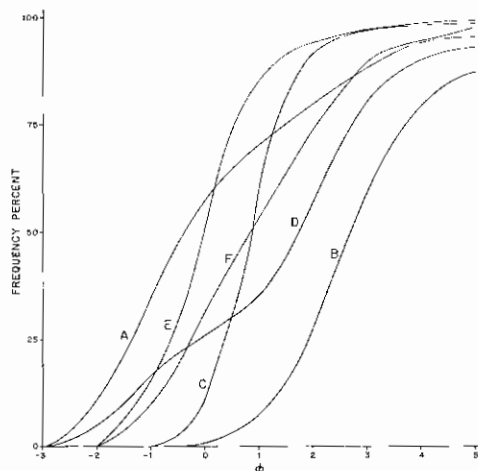


Figure 7. Phi values for size analyses of Perris Block sediments. A, B, and C, Lake Mathews Formation, SW. corner of sec. 7, T. 4 S., R. 5 W., S. B. & M., south edge of Lake Mathews. A, dirty pebbly grit. B, greenish silty fine sandstone, characteristic of the formation in drill cores. C, coarse sand. D, poorly sorted gritty sand, Lake Mathews Formation, dump at Shaft No. 3, Colorado River Aqueduct. E, gritty coarse sand, Lake Mathews Formation(?), south side of east arm of Canyon Lake. F, gritty sand, probably Pleistocene, southwest edge of Juniper Flat, Lakeview Mountains.

Figure 8. Contour map of the bedrock surface in the deep valleys of the east-central part of the Perris Block. From water-well, other bore-hole, and geophysical data. Filled circles: wells drilled to bedrock; open circles: wells bottomed in alluvium. Bedrock outcrops blank. Sets of well logs deposited at Eastern Municipal Water District, Hemet, and as Pomona College Geology Pamphlet 12908. RTU, line of section, Figure 9, and approximate position of proposed Perris dam. XY, long profile of tributary bedrock valley, Figure 10. Contours are elevations in feet above sea level.

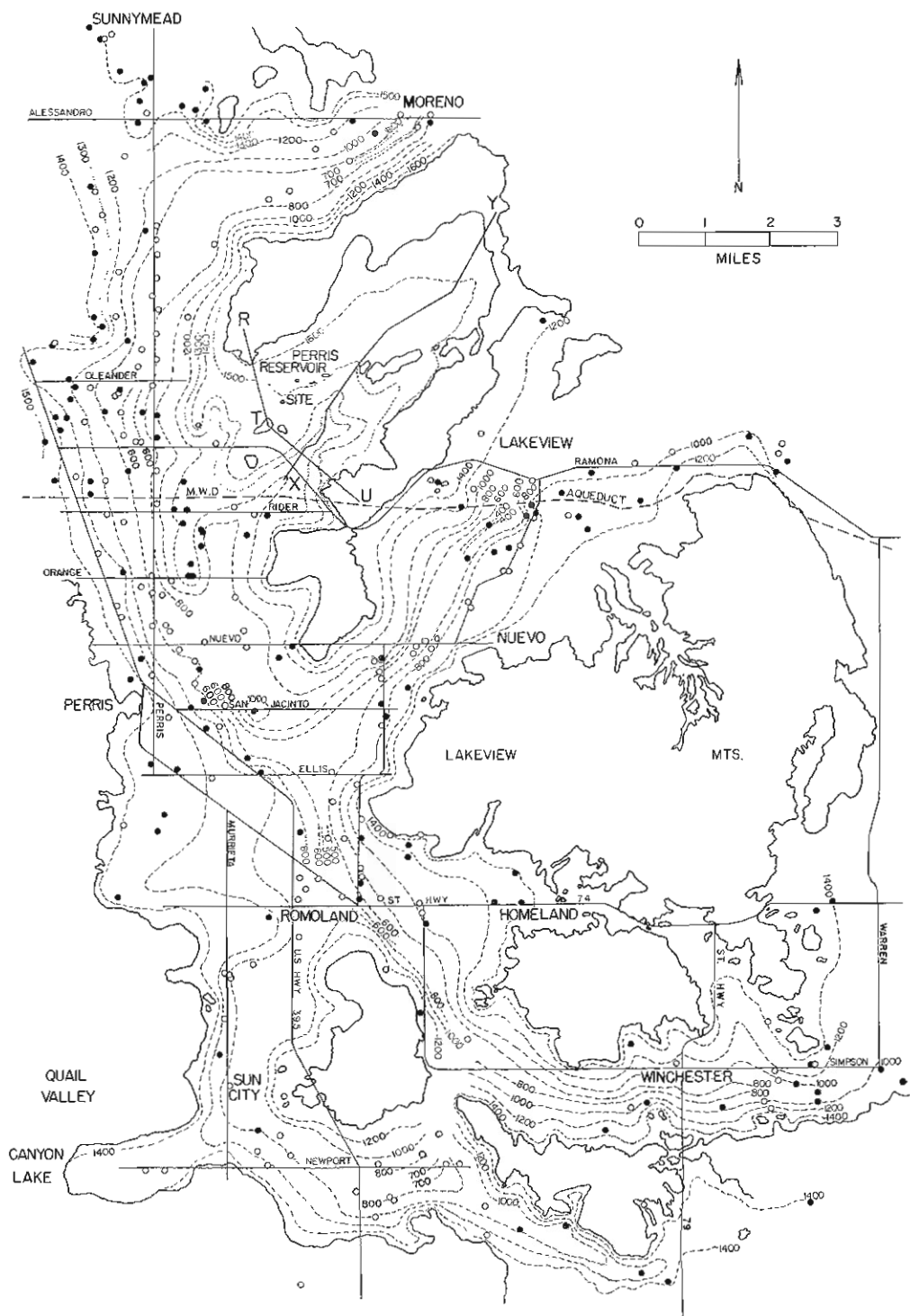


Fig. 9). Gravel and sand beds are also concentrated along the valley axes, mostly south of the Metropolitan Water District Aqueduct (Fig. 8), as shown especially well by the specific yield contours of Bean's (1955) Plares B-3A and B-3B. The deepest wells go down to about 500 ft above sea level; most of them bottomed in sediments. No specifically or generically determined fossils have been reported. Wood and bone were found in a well northeast of Lakeview, and Frick (1921, p. 279) mentioned probable proboscidean bones uncovered in an excavation near Winchester.

Drilling at the Perris Reservoir site in 1969 yielded data that suggest a lacuna at the base of the uppermost 40 or 50 ft of alluvium. Bedrock contours (Fig. 8) show that a barbed tributary of the north-draining deep valley system heads about 1 mi above the dam site, 3 mi downslope from the upper end of the flat floor of the present valley. For this uppermost 3 mi the broad valley is underlain by only 40 or 50 ft of alluvium (Fig. 10), above a flat bedrock surface that has a fall of 200 ft in the uppermost mile but only descends 40 ft in the third, lowest mile. The thin sheet of alluvium on bedrock appears to us to be an example of Bean's (1955) Qr, Residuum, though only a small part of the area was so mapped by Bean. Probably only Bean's Residuum and corresponding thicknesses of alluvium beneath the Paloma Surface outside the Residuum areas are late Pleistocene and Holocene. The remainder of the valley fill is probably much older.

Other Pliocene and Pleistocene Sediments

Several well dated Pliocene and Pleistocene mammalian faunas have been discovered just outside the Perris Block. At the southeast end of the San Jacinto Trough, Frick (1921) found lower Pleistocene sediments (his Bautista beds). At the south edge of the Perris Block, in a small basin east of Temecula Basin, Merrill (1963) mapped beds similar to the Bautista beds and found that they also contain a lower Pleistocene (Blancan-Villafranchian) fauna. In the San Timoteo badlands northeast of the San Jacinto Trough, Frick (1921) found two faunas, one lower Pleistocene (San Timoteo beds, originally called upper Pliocene) and the other lower Pliocene (Mt. Eden Formation; name modified to this form by Fraser, 1931). Since the San Jacinto Trough is a graben some 8,000 ft deep (Fett, 1967), it may contain pre-Bautista sediments, which (if present) are probably at least in part Pliocene.

On the central Perris Block, a few small occurrences of thin layers of probably Pleistocene sediments overlie bedrock (and locally the Lake Mathews Formation). The most extensive such occurrence is a more or less dissected sheet of brownish weathered gravelly alluvium, perhaps 20 ft thick, overlying bedrock and the Lake Mathews Formation south of Lake Mathews. This thin, discontinuous sheet is not shown on the geologic map (Fig. 2). Other, smaller but more interesting, remnants of gravel, or sand and gravel, are present on the Gavilan and in the Lakeview Mountains.

On the Gavilan, an isolated, nearly horizontal, probably Pleistocene gravel bed extends east-west for more than a mile along the north edge of Simpson Road (Figs. 2 and 4). It is up to 20 ft thick and lies on bedrock, with its base at elevations of 2,080 to 2,100 ft (Dudley, Jr., 1953). Most of the clasts are aplite, quartz plutonite, porphyry, and other rocks of local origin, but some foreign quartzite and volcanics are present. The transported boulders are up to 2 ft in diameter, and much larger blocks of the underlying porphyry and quartz diorite are incorporated in the basal portion. The base of the bed apparently sloped very slightly east and west from a central maximum elevation, but it may have been affected by slight deformation or creep. The bed has now been almost obliterated by citrus culture and grading for a trailer park. A smaller, similar relic gravel bed a mile to the northeast (Fig. 4) has a westward-sloping base at 2,000 to 2,020 ft elev. These gravel areas are relics of more extensive strips or a single sheet that may once have covered much of the Gavilan.

At the southwest corner of Juniper Flat, Lakeview Mountains, at the side of a ravine cutting headward into the flat, a thin, slightly consolidated mass of poorly bedded, nearly horizontal, rather poorly sorted, gray, gritty sand (Fig. 7F) directly underlies the Lakeview Surface. This sediment is composed chiefly of andesine, quartz, green hornblende, and brown biotite, the same minerals as those in the Lakeview Mountains pluton (Morton, 1969). Hornblende is the most abundant constituent of the 1/16-1/8 mm separate. The gritty sand is older than the rather deep dissection of the flat and is therefore pre-Holocene. It will be shown later to be probably early Pleistocene.

On the geologic map (Fig. 2), a principal modification of Rogers' (1965) mapping is the division of his continental Pleistocene between two of our map units. In the Beaumont, River-

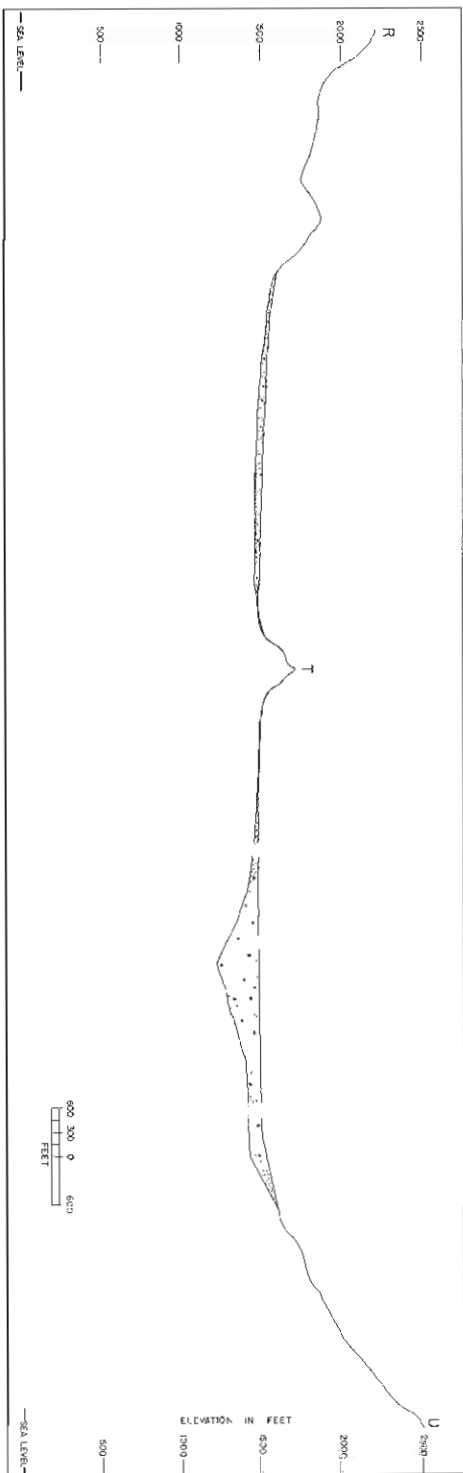


Figure 9. Structure section RTU approximately along proposed dam at site of Perris Reservoir of the California State Water System, showing a profile across a barbed tributary of the deep valley system. See Figure 8 for location.

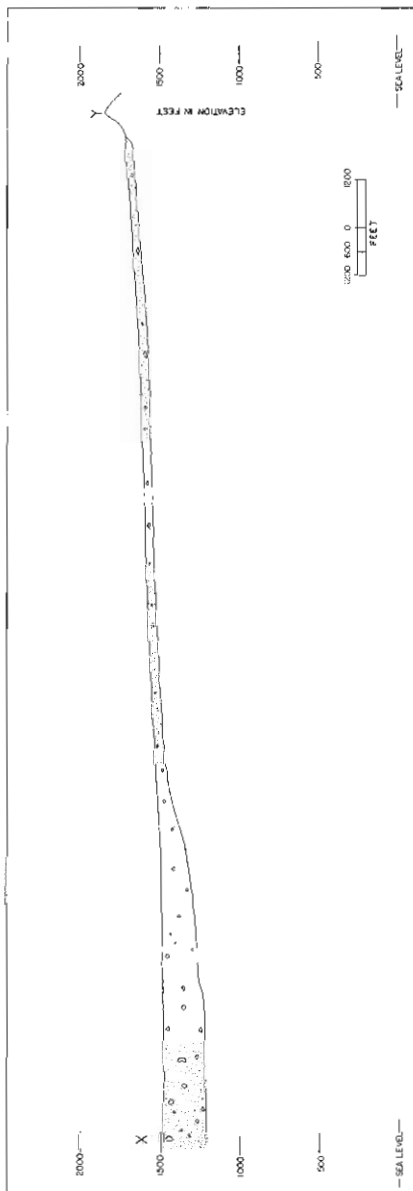


Figure 10. Structure section XY, long profile of the barbed tributary of the deep valley system. See Figure 8 for location.

side, and Corona areas, his continental Pleistocene is considered late Pleistocene and mapped with alluvium. The basis for this decision is the presence of the Rancho La Brea late Pleistocene fauna, especially the imperial elephant, in deposits outside the area of Figure 2 (Eckis, 1928). In the southern part of Figure 2, however, we have mapped most of Rogers' continental Pleistocene as "Continental Pliocene and lower Pleistocene," because Merrill (1963) and others have found in it lower Pleistocene (Villafranchian) faunas.

Pliocene Basalts

The Santa Rosa Basalt (Mann, 1955) is present above the southern part of the Perris Surface, on the Hogbacks northeast of Murrieta, and is much more widespread southwest of Murrieta, beyond the Elsinore Trough, in Mesa de Burro, Mesa de Colorado, and elsewhere. A local basal alkali basalt beneath the southeast end of Mesa de Burro is 8.3 ± 0.5 m.y. old by potassium-argon dating (Hawkins, 1970, and written commun. of May 5, 1969) and hence early Pliocene according to commonly accepted standards (Evernden and others, 1964). The overlying tholeiitic basalt sequence is much more widespread; its basal elevation is commonly between 1,800 and 2,000 ft. The basalts are at least 200 ft thick in some places, and represent 4 or 5 successive flows. They lie on a moderately smooth surface that has a local relief of at least 100 ft. At the Hogbacks and elsewhere, thin gravel sheets occur locally between the lava and the bedrock. Lava remnants are faulted up to basal elevations of 2,700 ft on Redonda Mesa, 9 mi southwest of Murrieta (Wilhelms, 1959), 3,600 ft on the Elsinore Mountains southwest of Lake Elsinore (Engel, 1959), and 4,000 ft on the Santa Ana Mountains just south of Trabuco Peak (Rogers, 1965).

EROSION SURFACES ON THE PERRIS BLOCK

We recognize six erosion surfaces on the Perris Block. Four are nearly flat and horizontal; they are at 1,400 to 1,600, 1,600 to 1,800, 2,000 to 2,300, and 2,400 to 2,800 ft elev. We call these four surfaces the Paloma, Perris, Gavilan-Lakeview, and Magee Surfaces (Table 1). The other two are sets of rather narrow valleys. One set of valleys, with floors at about 1,100 to 1,400 ft elev, is represented by a few remnants, largely filled with lower Pliocene sediments. The other set is a deeper valley system now partially filled by alluvium.

Paloma Surface

This flat surface (Perris Plain of Fig. 1), determined by a 1,400 ft local base level at Railroad Canyon (north arm of Canyon Lake), is covered by a thin layer of Holocene-latest Pleistocene alluvium that is mostly fine grained but locally is coarse and rubbly. This alluvium overlies much thicker alluvial fill in the valleys followed by the San Jacinto River and its tributaries north, northeast, and southeast of Perris (Fig. 4), and also covers considerably less extensive areas of bedrock at many places. The areas where bedrock is thinly covered were mapped as Qr, Residium by Bean (1955, Plate B1); they are commonly marked by small knobs of bedrock outcrops. The largest Residium area, 6 mi long, extends from the east arm of Canyon Lake southeast to U. S. Highway 395 and beyond; it includes Paloma Valley. The Paloma depositional-erosional surface extends north to Sunnymead and Moreno (Fig. 2), east to San Jacinto and Hemet (Figs. 2 and 11), where it covers most of the sediment-filled San Jacinto Trough, and south beyond Paloma Valley to the Hogbacks northeast of Murrieta (Fig. 2). Most parts of the surface are between 1,400 and 1,600 ft elev. The older, fanhead terrace portions of the surface rise as high as 1,800 or 1,900 ft elev and are commonly underlain by red-brown weathered zones and soils.

A somewhat doubtful correlative of the Paloma Surface, underlain by 20 ft or more of red-brown alluvium, is present at 1,400 to 1,600 ft elev along and south of Cajalco Road south of Lake Mathews (Fig. 4). This outlier is somewhat dissected by a set of north-sloping ravines.

Perris Surface

This well-drained, somewhat undulating erosion surface (Dudley, 1936) is mostly between 1,600 and 1,800 ft elev. Its main area (Fig. 4) extends as a curved north-south strip, developed mostly on Bonsall Quartz Diorite (Larsen, 1948) but in part on a narrow band of metamorphosed sediments west of Perris. Its relations to the Lake Mathews Formation and the bedrock plutonite are shown in Figure 12. No lithologic control of topography is apparent. The greater part of the strip drains west to the Santa Ana River, but the southernmost part drains southeast into the San Jacinto River and southwest into Temescal Creek.

The Perris Surface loses elevation westward along Cajalco Road southeast of Lake Mathews, and becomes a surface of unconformity south of



Figure 11. Southeastern part of the Paloma Surface. Looking north across the cities of Hemet and San Jacinto to the San Jacinto River sand, the scarp of the San Jacinto Fault, and the high hills beyond. In San Jacinto, the low ridge of Park Hill (right middle distance) is made up of

eroded lower Pleistocene sediments in the San Jacinto Trough. Hemet is southwest of the trough, on the unfaulted Paloma Surface, which is here very slightly higher than most of the trough. Photograph by J. S. Shelton, 1970.

the lake. The unconformity is overlain by a discontinuous sheet of Pleistocene sediments 20 ft or more thick and underlain by both bedrock and the Lake Mathews Formation. The Pleistocene sediments are not shown on our maps, as the thin, discontinuous sheet covers only strips and small areas of outcrop near Cajalco Road. The elevation of the unconformity is only about 1,300 to 1,600 ft, and the top of the sediments is taken as the Paloma Surface. In this area the relative elevations of the two surfaces are reversed.

In Figure 4, hachures represent the scarps between the main area of the Perris Surface and the lower Paloma Surface, to the east, and the Temescal Creek drainage, to the southwest. The eastern scarp is prominent and continuous in its northern part, but at the south it is deeply indented, irregular, and somewhat vague.

One outlier of the Perris Surface, about one square mile in area, is present at the southwest end of the Lakeview Mountains, east of Perris, and another, of about equal size, at Quail Valley between the arms of Canyon Lake. These outliers are, respectively, at 1,600 to 1,800 and 1,500 to 1,700 ft elev; both are cut in bedrock somewhat dissected by later erosion. Smaller outliers occur along the south edge of the Lakeview Mountains.

We also correlate with the Perris Surface the erosion surface beneath basalt and thin intervening gravel, at 1,600 to 1,700 ft elev in the Hogbacks northeast of Murrieta (Fig. 13). The sub-basaltic surface is also probably present somewhat below 1,360 ft subsea in the Barnard (Vernard) No. 2 well in the downfaulted Elsinore Trough, 1.5 mi east-southeast of Murrieta (Mann, 1955). Southwest of the Elsinore



Figure 12. The Perris Surface. Looking northeast from above the Gavilan, southeast of Lake Mathews. Wash in foreground carries drainage from the Gavilan. A portion of the long eastern outcrop of the Lake Math-

ews Formation extends (between dashed lines) from the left middle distance to the right far distance. Photograph by J. S. Shelton, 1970.

graben and fault zone, the surface is upfaulted to 1,800 to 2,200 ft elev and higher in Mesa de Burro and elsewhere. The surface beneath the lava is cut on Bonsall Quartz Diorite, Woodson Mountain Granodiorite, San Marcos Gabbro, and metamorphosed sediments (Larsen, 1948).

Gavilan-Lakeview Surface

The two erosional remnants of this surface (Fig. 4; Gavilan-Lakeview peneplain of Dudley, 1936), both at 2,000 to 2,300 ft elev, are high-level flat areas in the vicinity of Gavilan Peak west of Perris and in the Lakeview Mountains east of Perris. The monadnocks that rise above this surface are rather numerous. Of the 24 well-marked peaks on the Perris Block that rise above 2,400 ft elev, 17 are composed of quartz plutonite, 4 of metasediments, 2 of gabbro, and

1 of Santiago Peak volcanic rocks. Some monadnocks, including the gabbroic 2,442-ft Gavilan Peak (Fig. 14), are conical, but 2,767-ft Estelle Mountain, cut on a small portion of the extensive hypabyssal equivalent of the Santiago Peak volcanic rocks, is rather flat topped and surmounted by a remnant of the Magee Surface. In the Lakeview Mountains, Mt. Rudolph (2,649 ft, Fig. 2) is a low cone rising above a 2,500-ft-high remnant of the Magee Surface 3,000 ft long (Fig. 4), all cut on quartz diorite. The Gavilan-Lakeview Surface is mostly an erosion surface on plutonic and other bedrock, but thin sheets of alluvium cover the bedrock here and there.

We correlate with the Gavilan-Lakeview Surface the surface of Gibbel Flat, in the Santa Rosa Hills 3 mi southeast of Hemet. Gibbel

Flat is 0.5 mi across and at 2,100 to 2,200 ft elev.

Magee Surface

This surface (Rawson Surface of Larsen, 1948, p. 9-10)² is typically represented by a remnant at the top of the divide between Hemet and Sage (Fig. 15). The type area is at 2,420 to 2,500 ft elev, at the northeast edge of the somewhat higher Magee Hills, 1 to 3 mi northwest of Sage. Other flat summit and subsummit bedrock areas on the Perris Block are at about the same elevation. Examples on the Gavilan and in the Lakeview Mountains have already been noted. Other examples are present southeast of Hemet, including subsummit

²We have chosen a new name and type locality for this surface because it is so poorly developed along Rawson Canyon (5 mi south of Winchester).

flats on the Santa Rosa Hills and Polly Butte. All these flats may be the bedrock portions of an ancient erosional-depositional surface, the alluvial portions of which have been washed away. The amount of the alluvial fill thus implied, between the now isolated erosional relics, is truly amazing.

The Magee remnants may, on the other hand, never have been joined in one continuous, nearly horizontal surface; they may not even all be the same age. Each flat may have formed independently, at its own special time, perhaps by differential erosion controlled by a very local base level, as postulated by Wahrhaftig (1965) for the southern Sierra Nevada, perhaps under other special circumstances. One surface near the north end of the Perris Block may be an example of independence. The Box Springs Mountains, at the northeast edge of



Figure 13. Looking northeast along Hogbacks ridge, northeast of Murrieta (Fig. 1). Basalt and underlying gravel remnants of the ridge top overlie the Perris Surface, cut on Cretaceous quartz diorite (furrowed by ra-

vines). Paloma Surface in middle distance. Lakeview Surface on skyline at left. Photograph by J. S. Shelton, 1970.

Riverside (Fig. 2), have a steep southwestern scarp 1,300 ft high, and a summit surface that slopes down northeastward from 3,000 ft at the top of the scarp. The height and form of the Box Springs Mountains may, like that of Mt. Palomar south of the Perris Block, be due to faulting, or they may be indications of *wahrbhaftig* randomness.

Bowl-and-Valley System

An old erosion surface, probably, as we shall show later, the oldest on the Perris Block, is the irregular basin developed on the bedrock around Lake Mathews and the valley system connected with it (Fig. 4). The bedrock floor of the Lake Mathews bowl is close to 1,300 ft elev north of the Cajalco earth-fill dike and probably at 1,100 to 1,300 ft underneath the lower Pliocene sediments beneath the lake and at its southwest corner. The surface rises to a valley-floor elevation of about 1,400 ft in a narrow sediment-filled channel 4 mi long (section CD of Fig. 3; Fig. 4; Fig. 5), somewhat east of Lake Mathews.

Deep Valley System

East of the bowl-and-valley system, between Perris and the San Jacinto Trough, a system of deep valleys (Fig. 8) has been cut down to 500 ft elev and perhaps lower. These valleys are filled with alluvium to the Paloma level.

Bedrock contours (Fig. 8) indicate that the deep valleys are V-shaped. The V-shape appears conclusively in a cross section that follows a line of drill holes across a tributary at the Perris Reservoir site (Fig. 9). A similar, very symmetrical V-shape is shown by an east-west section across the filled trunk valley just east of Highway 395 and north of the M.W.D. Aqueduct (Fig. 8; Eaton and Watkins, 1969); this profile is based largely on gravity data. All the evidence indicates an unfaulted system of stream-cut valleys, originally northeast-sloping but now warped up slightly at the northeast, around Moreno. In particular, the shape, pattern, and symmetrical cross profiles of the valleys are incompatible with the hypothesis that the deep valley system is the downfaulted eastward continuation of the pre-early Pliocene bowl-and-valley system.

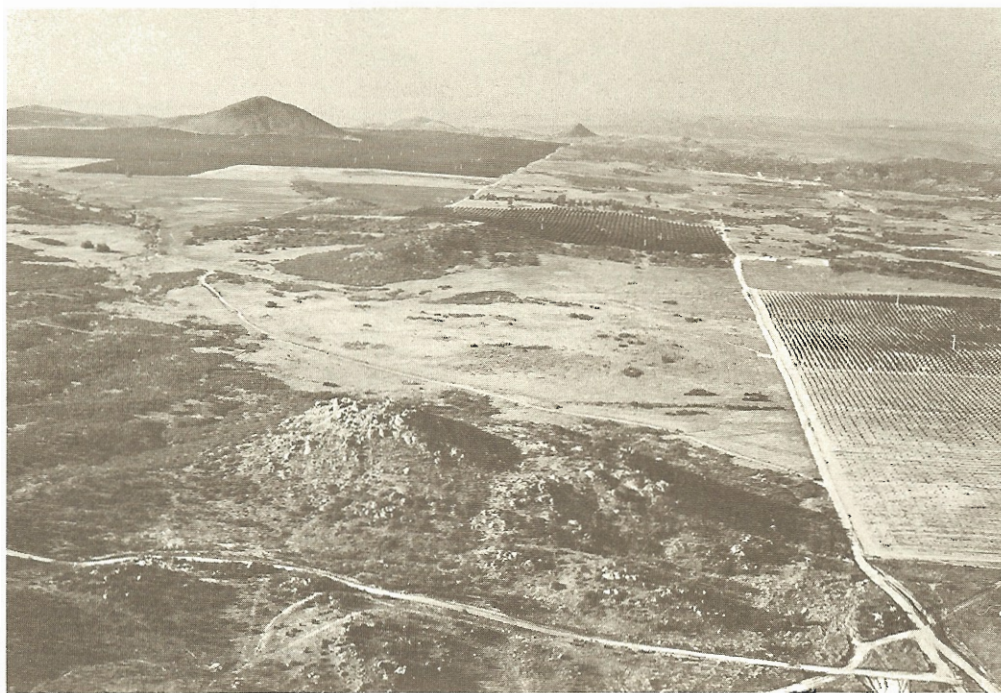


Figure 14. The Gavilan Surface. Conical gabbroic Gavilan Peak rises above the plateau surface at the upper left. Rows of young orange trees in the foreground; dark

blocks of older groves farther away. Photograph by J. S. Shelton, 1970.



Figure 15. Magee Surface. Summit flat on Riverside County, Calif., sign route R-3 south of Hemet. Looking

north. San Jacinto Mountains at distant right. Photograph by J. S. Shelton, 1970.

Stream Superposition

Dudley (1936) showed the significance of the peculiar course of the San Jacinto River. It wanders about over the alluvial Paloma Surface from San Jacinto to Perris and then traverses alternating bedrock and alluvial stretches. The first two bedrock stretches, at Canyon Lake between Perris and Elsinore (Fig. 16), cut through ridges with summits at 1,800 or 1,900 ft elev. The third, downstream from Lake Elsinore, beyond which the stream is called Temescal Creek, is in Walker Canyon (Fig. 17), whose walls rise to 1,700 to 1,800 ft. The fourth bedrock stretch is in an entrenched meander of Temescal Creek that envelopes a knob with 1,577 ft elev just north of Lee Lake, at the very edge of the Perris Block. It demonstrates meandering long before the Elsinore Trough attained its present topographic form. The bedrock stretches show the superposition of the San Jacinto River from a level above 1,800 ft.

QUASI EQUILIBRIUM IN THE DRAINAGE OF THE PERRIS BLOCK

The drainage within the Perris Block is in quasi equilibrium. This condition makes possible now, and may preserve for a long time to come, extensive high-level flat surfaces such as the Gavilan plateau. On adjacent blocks, however, some streams show sharp breaks in gradients. The contrast is especially striking if one compares gradients of the San Jacinto system in the San Jacinto Mountains with those of the same system on the Perris Block (Fig. 17). In the San Jacinto Mountains the southwest-flowing Strawberry Creek traverses the principal high-level valley, at Idyllwild, with a gradient of 90 ft per mi. Just downstream, at the edge of the high mountains, the grade is steepened by rejuvenation to 1,550 ft per mi. The profile of the North Fork of the San Jacinto River is similar, but the Idyllwild bench has been almost eliminated by erosion. In the next stretch of the Strawberry Creek-South Fork branch of the



Figure 16. Superposed course of San Jacinto River. Looking northeast along Canyon Lake toward Perris, in distance at left. Suburb of Elsinore in foreground. Between the two bedrock gorges followed by the river (and the north arm of the Lake), the broad part of the lake and

its eastern arm occupy part of an area of weak sediments probably belonging to the Lake Matthews Formation. To right of main lake and marked by dark trees: Perris Surface in Quail Valley. In right distance, Lakeview Mountains. Photograph by J. S. Shelton, 1970.

river, quasi equilibrium is fairly well established. This branch, and the combined stream, flow northwest through mountains and foothills for 7 mi with an average gradient of 150 ft per mi. San Jacinto River flows into and across the San Jacinto Trough at an average gradient of 25 ft per mi, and then southwest across the Paloma Surface at the very low gradient of 4 ft per mi. In the bedrock of Railroad Canyon (north arm of Canyon Lake) the gradient steepens somewhat, to 19 ft per mi, but again flattens out in alluvium before entering Lake Elsinore (Fig. 17). Occasional discharge from the lake is

through Temescal Creek, which in the first 4 mi falls only 4 ft per mi, as on the Paloma Surface, but steepens to 15 ft per mi in Walker Canyon and to about 35 ft per mi in the Elsinore Trough, where coarse alluvium comes chiefly from the Santa Ana Mountains. The stream falls 70 ft in the mile-long bedrock gorge of the entrenched meander at the edge of the Perris Block, below Lee Lake (Figs. 4 and 17). The gradient of the San Jacinto-Temescal River, on and near the Perris Block, is probably nicely adjusted to the rock resistance in the bedrock stretches and to the particle sizes of the al-

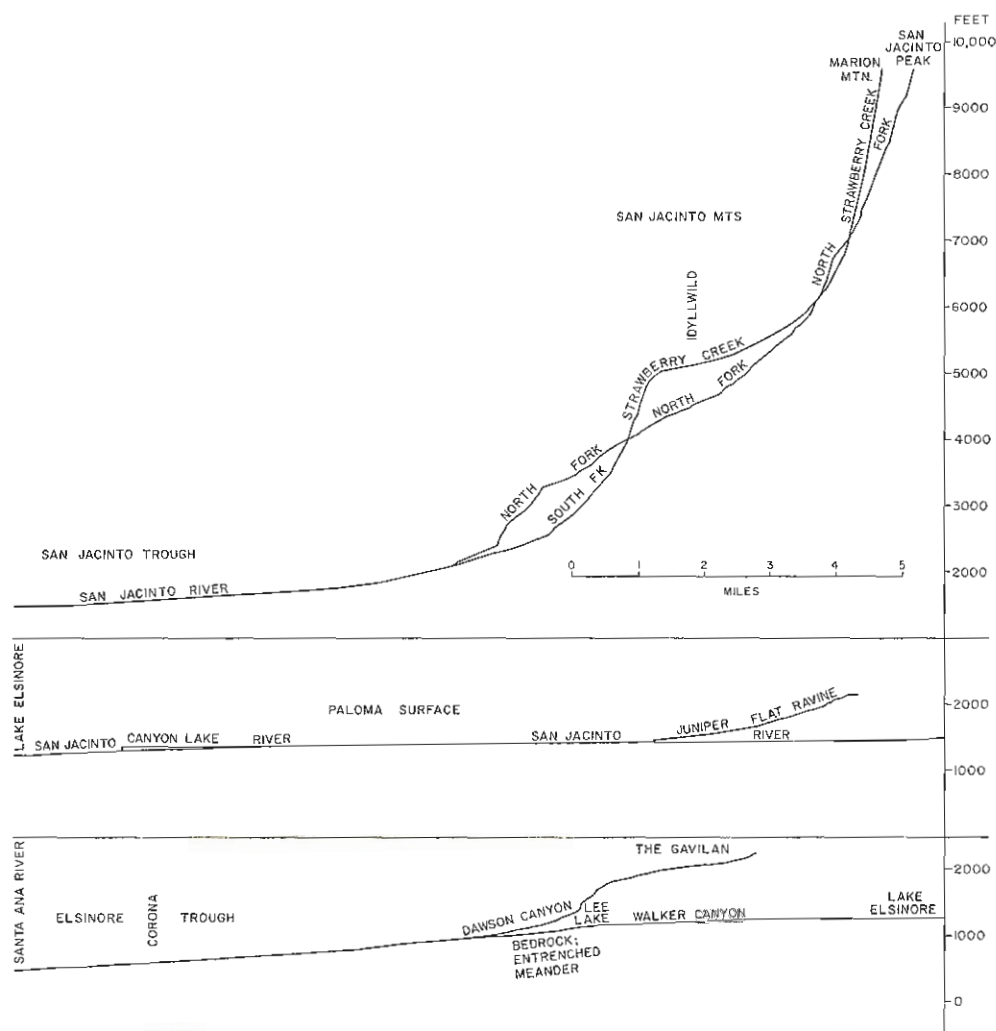


Figure 17. Long profiles of San Jacinto River-Temescal Creek and selected tributaries.

luvium in the alluvial stretches.

The flatness of the Paloma Surface, illustrated by the 4 ft per mi gradient of the San Jacinto River, is made possible by the fineness of the silt and clay carried beyond the sink of the San Jacinto Trough. Also important is the comminution of locally derived debris, under the conditions of weathering and erosion that prevail behind the rain shadow of the Santa Ana Mountains. In the Lakeview Mountains, for example, a drainage line (Juniper Flat ravine, Fig. 17), which extends northwest from the vicinity of Juniper Flat (on the Gavilan-Lakeview Surface) to the San Jacinto River near Lakeview, has a gradient concordant with that of the river, dropping from about 150 ft per mi along its rocky bed in the granitic mountains to 60 ft per mi at its fanhead, where the last plutonic boulders have disintegrated into arkosic sand easily carried by the stream at a lower gradient. The fan has had a complex history that includes the formation of a fanhead trench (Eckis, 1928), but both the old and the active fanhead surfaces merge downslope into the flatness of the Paloma Surface. The Paloma Surface functions as a local base level.

In the high, moist San Jacinto Mountains, the streams carry numerous plutonic boulders, and many of these boulders are still present in the very coarse alluvium of the San Jacinto River along the fault valley followed by South Fork, where the gradient gradually falls to 125 ft per mi (Fig. 17). The boulder beds come to an end where the river debouches onto the low fan at the southeast end of the San Jacinto Trough, and the gradient becomes 35 ft per mi.

On the Perris Block and in the Elsinore Trough, the gradient of the San Jacinto-Temescal River is determined by three local base levels. The highest is the head of Railroad Canyon, at about 1,400 ft, the next is the variable 1,220 to 1,265 ft elev of Lake Elsinore, and the lowest approximately 500 ft elev at the junction with the Santa Ana River. The tributaries of the San Jacinto River debouching onto the Paloma Surface (above Railroad Canyon) are all concordant. Those between Railroad Canyon and Walker Canyon (below Lake Elsinore) are few and small. Those below Walker Canyon, discharging directly from the Perris or Gavilan Surface into the Elsinore Trough, are rather sharply discordant. Dawson Canyon (Fig. 17), for example, has cut deeply into the edge of the Perris Block, traversing slate and metasandstone below 1,300 ft elev and quartz plutonites above that point. Above the canyon portion of

the stream's course, between 1,800 and 2,000 ft elev, the profile is convex upward. Above 2,000 ft the drainage follows a very shallow swale on the Gavilan Surface (Fig. 14).

No break occurs in the long profile at the 1,700-ft Perris level, but the Perris Surface is lower in the west (*see* Perris Surface) and may be represented in this long profile by a slight break at 1,500 ft elev.

The surface of the Gavilan is now being degraded very slowly. The patches of probably Pleistocene gravels previously described are remnants of more continuous swale fillings, or possibly of a sheet that once covered most of the surface. Between the alluvial remnants and elsewhere on the surface, four rather complex drainage systems occupy swales so shallow that most can barely be recognized. The deepest of the four systems cuts 50 to 100 ft below the plain and discharges north into Lake Mathews; the others discharge west into Dawson Canyon, south into Temescal Creek, and southeast into the San Jacinto River. The divide between Lake Mathews and Dawson Creek drainages can barely be made out in Figure 14, extending from the foreground hills across the plain to conical Gavilan Peak. This divide is geomorphically abnormal; Gilbert (1877, p. 116) wrote that declivities "are steep in proportion as they are near divides." The surface of the Gavilan plain must have formed under other drainage conditions than those now prevailing.

The relation of Dawson Creek to the Gavilan Surface is somewhat similar to that of Strawberry Creek to the high-level Idyllwild bench in the San Jacinto Mountains. An outstanding difference is the minuteness of the drainage area of Dawson Creek above the Gavilan and the tens of square miles draining into Strawberry Creek above Idyllwild. The Gavilan has lost the headwaters area that made possible its erosion to a flat plain.

Quasi equilibrium on the central part of the Perris Block is made possible by exceptional dryness behind the rain shadow of the Santa Ana Mountains. A wet epoch would cause great changes. It is true that sourceless Dawson Creek might under any regime take tens or hundreds of thousands of years to extend its gorge to the Gavilan, but a moderate increase in rainfall would invigorate the San Jacinto River, fill Lake Elsinore, first with water and then with sediment, and start a gorge at the exit into Temescal Creek. East of Riverside, Sycamore Canyon would be cut deep beneath the Paloma Surface (Perris Plain of Woodford,

1951, p. 825). With sufficient rainfall, vigorous through drainage would develop on the central Perris Block, the present equilibria would be upset, and the area would come to resemble more closely the neighboring regions to the north and south.

RELATIVE AGES OF THE EROSION SURFACES

One hypothesis for the relative ages of the erosion surfaces on the Perris Block would be a direct correlation between age and elevation above sea level. The Magee Surface would then be the oldest and the deep valley system the youngest. This hypothesis is obviously false. The deep valleys are partially filled with sediments and the overlying, now-active Paloma Surface must be younger. We must consider the relative ages of all the surfaces, step by step, and bring in the evidence from sediments and lavas. We use a diagrammatic section (Fig. 18) to show the relations.

The Paloma Surface, extensive parts of which are now forming, probably all formed within the last million years or so. The topmost sediments are frequently reworked, but the surface

is younger than all but a thin layer of the sediments beneath it. Some of the higher fanhead terraces south of the Box Springs Mountains, east of Riverside, which merge downslope into the alluvial plain (compare Eckis, 1928), have developed a thoroughly weathered red-brown soil; they probably formed late in the Pleistocene.

Stabilization at the Paloma level and the formation of the Paloma Surface have been the terminal events resulting from the superposition of the San Jacinto River at Canyon Lake. The river has cut down at least the 400 ft between the level of Railroad Canyon (north arm of Canyon Lake) and the 1,800-ft hills on either side. Only two erosion surfaces, the Magee and the Gavilan-Lakeview, are higher. The Gavilan-Lakeview remnants are larger than the Magee, still carry patches of preserved sedimentary cover, and are surrounded by steep scarps, some of which extend down directly from the Lakeview Mountains plateau to the Paloma Surface. We therefore think it probable that superposition was from the Gavilan-Lakeview level. The Magee Surface would then be somewhat older than the Gavilan-Lakeview.

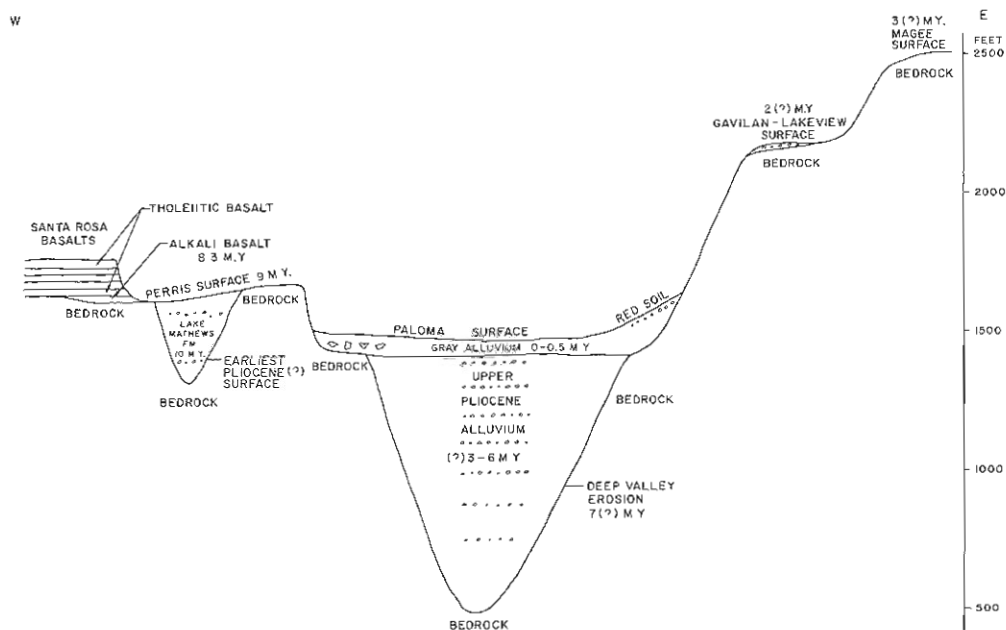


Figure 18. Generalized diagrammatic section across the Perris Block, very roughly east-west. Great vertical

exaggeration. Ages in millions of years before present.

Now we have established a probable succession of three surfaces: Magee, Gavilan-Lakeview, and finally Paloma.

Since the relics of the Magee Surface exhibit no known remnant patches of old sediments and are not directly associated with any older sediment or surface, we must now turn to another line of evidence. We begin with the paleontologically dated lower Pliocene beds at Lake Mathews and the contemporaneous channel filling to the east (Figs. 4 and 5). The channel walls and the Perris Surface are topographically discordant (Fig. 6). In general, either the steeper or the flatter surface might be the younger. Here, the narrow, short, be-headed channel valleys, the greater extent and completeness of the Perris Surface, and the smooth, continuous truncation by the Perris Surface of both the bedrock and the Lake Mathews Formation (Figs. 6 and 12) show that the Perris Surface is younger. The Perris Surface can be traced south, intermittently, to the Hogbacks northeast of Murrieta, where it is overlaid by the Santa Rosa Basalt (Mann, 1955). Southwest of Murrieta the Santa Rosa basaltic sequence has at its base the 8.3 m.y.-old alkali basalt. So the Lake Mathews Formation, the Perris Surface, and the Santa Rosa lavas form an age sequence that is wholly early Pliocene. The bowl-and-valley erosion surface is older, but may also be early Pliocene.

Two groups of events are closely dated: the lower Pliocene group, and the Gavilan-Lakeview-Paloma group that ends in the Holocene. The Magee Surface is a somewhat uncertain earliest appendage of the latter group. One erosion surface, the deep valley system, is left unplaced. It must be older than the Gavilan-Lakeview-Paloma group. As all of its constituent valleys conform in a general way to the present topography, it is probably less ancient than the early Pliocene set of surfaces and rocks. Moreover, the deep valley system has a southern arm, southeast of Perris (Fig. 8), that very nearly truncates the relics of the bowl-and-valley system and the overlying Lake Mathews(?) Formation along Canyon Lake's east arm. The deep valleys are therefore almost certainly post-Santa Rosa and pre-Gavilan-Lakeview. It is simple, but not essential, to make them pre-Magee.

A chronological summary can now be made complete, albeit somewhat tentative: (1) erosion of the bowl-and-valley system, (2) Lake Mathews Formation, (3) Perris Surface, (4) Santa Rosa lavas, (5) obstruction of northern

Perris Block drainage, (6) deep valley cutting, (7) deep valley fill, (8) Magee Surface, (9) Gavilan-Lakeview Surface, (10) erosion to about the Paloma level, (11) deposition of a thin sediment sheet at approximately the Paloma level. The necessity for step (5) will be made clear later. The relative ages of the Magee Surface and the deep-valley system remain uncertain. This problem would disappear if the Magee relics prove to be local features of somewhat varied ages.

LOS ANGELES BASIN AND ITS RELATION TO THE PERRIS BLOCK

The Pliocene-Pleistocene vertical oscillations of the Perris Block were contemporaneous with much more pronounced vertical movements in the central part of the adjacent greater Los Angeles Basin. That basin has a central deep, bounded by northeastern and southwestern shelves. The northeastern shelf is largely the area of the Puente Hills (Fig. 3AB). The Pliocene-Pleistocene movements in the Los Angeles Basin were not all vertical. The Miocene strata of the Puente Hills were moderately folded; the Whittier Fault (Fig. 1) is a line of strike-slip movement of many thousands of feet, dying out to the northwest, and a narrow belt along the fault at Whittier, just north of the section of Figure 3AB, is involved in a tight fold with a vertical axis. The tectonics were nevertheless predominantly vertical. In the central part of the basin the sedimentary fill may be 30,000 ft thick (McCulloh, 1960), much thicker than that in the San Jacinto Trough (Fig. 3CD), and enormously thicker than that of the deep valley system of the eastern part of the Perris Block. The principal deformation in the main part of the basin has been by selective subsidence of the central syncline and some other parts of the floor, and by compaction. at Santa Fe Springs (Fig. 3AB), dips of 45° developed on both anticlinal flanks without any actual rise of the anticlinal crest (mostly the crest sank). The structure of the eastern part of the central deep is shown especially well by T. H. McCulloh's unpublished structure-contour and isopach maps of the Meyer Zone, a sandy unit in the lower Pliocene. Its thickness varies from 400 ft on anticlines to 1,200 ft in synclines and 2,200 ft at the Whittier outcrop, near a northeastern source area. The variations in thickness go back to the time of deposition; the sinking synclines were filled level full during the deposition of each sedimentary unit. Each unit carries a characteristic foraminiferal assem-

blage, and each sub-unit was probably deposited chiefly as a turbid flow, originating at the northeast and extending southwest across part of or all the width of the basin. The clasts are mostly quartz, feldspar, biotite, and plutonic rock fragments; the minerals and rocks of the western Catalina blueschist are found only in the Miocene of the southwestern margin of the basin (Woodford, 1925). The Pliocene turbid flows of the central basin were derived ultimately from the Perris Block, the San Jacinto Mountains, and other high ranges, but their immediate sources were in part the moderately folded, uplifted, and eroded sediments of the Puente Hills, the eastern marginal belt of an earlier and larger middle- and late-Miocene Los Angeles Basin (compare Fig. 3AB). Many sedimentary units, however, have been traced from the complete thick central section of the basin to the thinner, less complete, and mostly Miocene section of the Puente Hills. Marine Pliocene strata occur locally in the hills and in the Chino and Corona basins east and southeast of the hills. The structure of the Corona Basin, 8 mi west of Lake Mathews, is especially complex (Gaede, 1969, pl. IV); it includes a pronounced Miocene-Pliocene angular unconformity. In Pliocene and Pleistocene times, drainage from the San Jacinto and other high mountain ranges swept across a rigid, nearly stationary Perris Block, through the somewhat unstable Puente Hills, and discharged its debris load into the subsiding central deep of the Los Angeles Basin.

ORIGINAL ELEVATIONS OF SURFACES

Quasi equilibrium of stream gradients, with local base levels, makes difficult the determination of the original elevations of old surfaces. The Paloma Surface, however, is forming today, mostly at elevations of 1,400 to 1,600 ft. The early Pliocene(?) bowl and valley probably had floors within 300 or 400 ft of sea level, as the valley floor gradient was flat, and the probably contemporary sea reached a point 4 or 5 mi west of Lake Mathews (Gray, 1961, p. 36). The Perris Surface, surely early Pliocene, may have formed at similar low elevations above sea level. The Gavilan-Lakeview Surface was probably originally nearly horizontal, as flat as the major part of the Paloma Surface is today. Its drainage may have discharged into an embayment of the Pleistocene sea at the Coyote Hills in the east-central Los Angeles Basin, 30 mi west of the Gavilan (compare Hoskins, 1954).

A Gavilan-Lakeview trunk stream, even if it followed a route as devious as the present course of Temescal Creek and Santa Ana River, probably had a fall, from the Gavilan to the sea, of 1,000 ft or less. We do not dare to hazard guesses as to the original elevations of the Magee or deep valley surfaces.

PLIOCENE-PLEISTOCENE GEOLOGIC HISTORY

Early in the Pliocene, some 10 m.y. ago (compare Evernden and others, 1964), the Los Angeles Basin was mostly rather deep sea, probably between 2,500 and 4,000 ft deep. This sea shoaled at its eastern edge, and became very shallow marine in the Elsinore Trough, 5 mi southeast of Corona and just north of Bedford Wash (near C, west of Lake Mathews, in Fig. 1; see Gray, 1961). This locality was probably in an embayment, behind the slowly rising peninsula of the Santa Ana Mountains, which projected into the Los Angeles Basin from the southeast. The crest of the incipient Santa Ana Mountains may not have exposed any rocks older than early Cenozoic. East of Temescal Canyon, continental deposition was going on in the Lake Mathews bowl and in a narrow channel that extended eastward from the south side of the bowl (Figs. 4, 5, and 6).

The Perris Surface developed slightly later in the Pliocene. It was probably more widespread than its surviving representatives, and may have covered the greater part of the Perris Block, including most of the area now occupied by the Paloma Surface (Fig. 4). Relics are left 5 mi southeast of Perris and at Quail Valley between the arms of Canyon Lake (Fig. 16). Some southwest-sloping barbed tributaries of the deep valley system at and near the Perris Reservoir site are probably deepened relics of the upper courses of parts of the Perris Surface drainage.

The Perris Surface extended far to the southwest, across what is now the Elsinore Trough. The Santa Rosa basalts spread over the southern part of the surface, from the Hogbacks northeast of Murrieta southwest to Mesa de Burro, Mesa de Colorado, and other mesas. Since the age of the basal basalt is about 8.3 m.y., the more widespread overlying members are no doubt about 7 or 8 m.y. old and the underlying Perris Surface about 9 m.y. old.

The drainage on the Perris Surface may have been concentrated in two principal systems, a northern ancestral San Jacinto River and a southern Murrieta River. We can speculate about details of the San Jacinto River's history,

but at this time we are in doubt as to the history of the Murrieta River.

The ancestral San Jacinto River in early Pliocene time probably received drainage from both the ancestral San Jacinto Mountains and more northern sources. The San Jacinto Mountains were probably located, with respect to the Perris Block, 11 mi northwest of their present position (Fig. 1). H. D. English (1953) found 11-mi right-lateral offsets on the San Jacinto fault for both the lower Pliocene Mt. Eden Formation and the lower Pleistocene San Timoteo Formation. This offset is roughly consistent with the post-middle Cretaceous offset of 15 mi found much farther south on the San Jacinto fault zone by Sharp (1967) and the 18-mi reinterpretation of Sharp's data by Bartholomew (1970). Bartholomew suggested that 10 mi of offset has occurred since the late Pleistocene.

The early Pliocene drainage probably flowed onto the Perris Block from the northeast in three main branches. The northern branch may have cut the Moreno gap to the level of the Perris Surface, the central branch may have cut the gap at Lakeview, and the southern branch may have cut the Hemet-Winchester (Salt Creek) gap. The northern and central branches may have joined on the Perris Surface above the present site of Perris, and the combined stream may have followed approximately the line of the Perris-Elsinore road to a junction with the southern branch, which had passed through the gap now occupied by the east arm of Canyon Lake (Fig. 4).

The cutting of the Moreno, Lakeview, and Hemet-Winchester gaps to the level of the Perris Surface, and a combination of other events, made possible the cutting of the deep valley system of the northeastern part of the Perris Block (Fig. 8). Other significant events were the strike-slip fault movement of the San Jacinto Mountains to a more southeastern position, the faulting and fault-block depression that produced the San Jacinto Trough, and the diversion of the northern drainage. After these events, the only considerable source of water flowing over the northeastern Perris Block was from the San Jacinto Mountains, which had already reached a position that was largely southeast of the San Jacinto Trough. The water mostly entered the Trough at its southeast corner, in an ancestral San Jacinto River. In deep-valley time, subsidence of the trough must have been checked, so that the river piled upon the graben surface a narrow and rather steep cone of alluvium 12 or more mi long and 2 to 5 mi

wide. The fanhead at the southeast corner of the graben must have been high, corresponding to a present elevation of at least 1,700 ft; the toe, at the northwest, was probably below 500 ft. The river, wandering on its fan, at times discharged into the beheaded Hemet-Winchester stream valley. This valley must have been blocked at Canyon Lake, perhaps by volcanic debris, now removed by erosion. This debris may have come from cinder cones related to the Santa Rosa lavas, or from the same sources as the siliceous tuffs widespread in the lower Pliocene of the Los Angeles Basin (Wissler, 1943, p. 216). The volcanic vents have not been located; they may be hidden by alluvium. Alternatively, the west-flowing drainage may have been interrupted by minor faulting west of Canyon Lake or by a north-south upwarp. In one way or another, the Hemet-Winchester stream was diverted northward east of Canyon Lake, and followed either the Lakeview or the Moreno course back to the San Jacinto Trough. In this way, the deep valleys were cut. Perhaps the return to the trough was at first through the Lakeview gap; later, when that exit had been dammed by the rising surface of the growing fan in the trough, the deep valley through Moreno was cut.

The hypothetical fan and gorge system of the ancestral San Jacinto River has rather remotely similar modern analogs in and near San Antonio fan, at the northwest corner of the Perris Block in the vicinity of Pomona and Claremont (Eckis, 1928; Eckis and Gross, 1934). San Antonio fan has a north-south length of 17 mi, a 2,100-ft elevation at its head, and a 500-ft elevation at its toe; it has a distributary, San Jose Creek, that cuts west through a rocky gorge somewhat similar to the gorges of the deep-valley system. San Jose gorge, however, is cut mostly in Miocene sediments of the Los Angeles Basin's east side, and discharges into San Gabriel River at a level below that of the San Antonio fan.

In deep-valley time, a lake may have existed at least temporarily at the north end of the San Jacinto Trough. It may possibly have been, at times, an enclosed playa, but more probably it discharged continuously northwest, either along the line of San Timoteo Creek, north of Riverside, to the Santa Ana River, or northeast around the San Jacinto Mountains into Salton Trough. Sediments of this age are not known in the San Timoteo badlands, through which the discharge must have gone; the time may be represented by a lacuna in the badland sedi-

ments, as an unconformity was found in those sediments by English (1953).

Next, probably in late Pliocene time, somewhat more than 3 m.y. ago, the deep valley system was filled, and the whole central and northern parts of the Perris Block were covered by a blanket of alluvium that rose to the Gavilan-Lakeview level and perhaps to the Magee level. The evidence for the lost alluvial fill is chiefly the superposition of the San Jacinto River, previously described.

The Magee Surface may have been cut in earliest Pleistocene time, beginning some 3 m.y. ago. The Gavilan-Lakeview Surface may have developed in mid-Pleistocene time, 2.5 to 1.5 m.y. ago. At the end of that time, just before the downcutting began that led to the superposition of the San Jacinto River, that river must have had about its present course. Farther north, the Gavilan-Lakeview Surface shows the presence of at least one other trunk stream, perhaps flowing northwest from the Gavilan and joining the Santa Ana River between Riverside and Corona (Fig. 2).

During Pleistocene time, most of the mantle of Pliocene sediments and volcanics was removed from the Perris Block by erosion. Some of the basalt debris was deposited in the Temecula Arkose of the Temecula Basin (Mann, 1955; dated as earliest Pleistocene Villafranchian by Merrill, 1963, and Seay, 1964), but much of it was probably carried out of the region by the Temecula-Santa Margarita River and more northern streams. Finally, the Paloma and other new portions of the present compound surface were formed. Erosion to the Paloma level was mostly in areas of alluvial fill, but moderate sized areas of the Perris Surface were probably destroyed at this time. One such area of Perris Surface was probably above Paloma Valley and extended south to the lava-capped Hogbacks near Murrieta.

STRUCTURAL ENVIRONMENT OF THE PERRIS BLOCK

The Perris Block is probably bounded everywhere by fault zones, but at the south and southeast the displacements on the faults are small, probably only hundreds or a few thousands of feet. That is, Perris Block belongs structurally with the mountainous Peninsular Ranges to the southeast, between the Elsinore and San Jacinto fault zones.

Right-lateral strike slip, almost everywhere accompanied by smaller dip slip, characterizes the fault zones that bound the blocks. Strike slip

on the San Jacinto fault zone has been 15 to 18 mi since the mid-Cretaceous (Sharp, 1967; Bartholomew, 1970); most of this movement may be post-Pliocene, as indicated above. Post-Miocene right-lateral movement on the Elsinore-Whittier-Chino fault zone has been much less, probably not over 3 mi at most, dying out to the north. Farther west in the Los Angeles Basin, some right-lateral movement, probably totaling several thousand feet, has occurred in the Pliocene, Pleistocene, and Holocene along the Newport-Inglewood zone. Significantly greater movements cannot have taken place in the Los Angeles Basin, for numerous local sedimentary units, including several tuff beds, can be correlated across the fault zone.

The Perris Block has been repeatedly uplifted, and occasionally depressed, since the beginning of Pliocene time. The net uplift has been only a thousand feet or so, much less than the many thousands of feet of uplift undergone by adjacent mountain masses, notably the San Jacinto range (Fraser, 1931, p. 538-540). Other nearby areas, notably the central part of the Los Angeles Basin, have been depressed tens of thousands of feet. All these vertical tectonic changes must have been accompanied by sub-crustal movements in more or less horizontal directions. The subcrustal adjustments must have been deep; they did not result in southwest-northeast horizontal movements sufficiently large and shallow to be detected by surface observations or by borings. The adjustments were probably chiefly isostatic. The deep isostatic flow must have been integrated with the somewhat greater post-Pliocene flow indicated by right-lateral strike slip on the San Jacinto fault system.

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