GEOLOGY OF THE SAN JACINTO FAULT ZONE IN THE PENINSULAR RANGES OF SOUTHERN CALIFORNIA

Thesis by

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ABSTRACT

The San Jacinto fault zone is one of the major branches of the San Andreas fault system in southern California. The straightness, continuity, and high seismicity of the San Jacinto fault zone suggest that it may be currently the most important member of the system.

Although alluvium conceals much of the San Jacinto fault, intrusive rocks of the mid-Cretaceous southern California batholith are exposed together with prebatholithic metamorphic rocks along a 50-mile segment in the northeastern Peninsular Ranges. The prebatholithic terrane on both sides of the fault consists of migmatitic gneiss and minor amounts of amphibolite, quartzite, marble, and metaconglomerate. Between San Jacinto and Clark Valleys, various members of a distinctive sequence of metamorphic rocks and gabbroic, tonalitic, and adamellitic plutons are separated by the fault 13 1/2 to 15 miles in the right-lateral sense. A marker section of relatively marble-rich metamorphic rocks within and parallel to a regionally unique post-intrusion zone of cataclastic deformation exposed at the southern end of the Santa Rosa Mountains and at Coyote Mountain is separated between 8 and 13 miles.

Geometric extrapolation of the various contacts suggests the southwestern block has risen between 1/2 and possibly 8 miles near Anza and between 0 and 6 miles near Clark Valley. Small net vertical movement near Clark Valley may correspond to relatively large vertical offsets near Anza. The sense of vertical movements probably has reversed repeatedly throughout the history of the fault.

The right-lateral component of the net displacement probably increases southeastward from about 14 miles near San Jacinto Valley to between 14 1/2 and 17 miles, but conceivably as much as 22 1/2 miles, near Clark Valley. North of Anza, Quaternary gravels are offset at least 2 miles, and stream courses are displaced at least 2300 feet and possibly 3200 feet. Drainage lines north of Clark Valley have been offset possibly 3 miles in Quaternary time.

The displacement on the San Jacinto fault suggests that (1) the line of major displacement within the San Jacinto fault zone extends southeastward into the central part of Imperial Valley and may connect with the Imperial fault, (2) the Banning fault at the southern margin of the San Bernardino Mountains may be the offset continuation of the Sierra Madre fault on the southern flank of the San Gabriel Mountains, and (3) if the displacement on the San Andreas fault is as large as 160 miles, the San Jacinto fault has not always been as important a member of the larger system as its current activity suggests.

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INTRODUCTION

The presently active system of northwest-trending faults that extends the length of California is one of the dominant elements in the regional tectonic framework of the state. The most prominent and continuous member in the system through much of California is the San Andreas fault. Within the Transverse Ranges however, the San Andreas fault zone loses many of the features that characterize its trace to the northwest, and southeastward splaying of the fault leaves the question of the "main" break in doubt.

In many ways the San Jacinto fault zone appears to be currently the most important member of the San Andreas system south of the Transverse Ranges. Although its intersection with the San Andreas zone near the northern margin of the San Gabriel Mountains is complex (Noble, 1954), the San Jacinto fault can be considered as a gradually divergent branch. The zone is relatively straight and continuous from the San Bernardino Valley across the northeastern Peninsular Ranges to Imperial Valley. Its geographic relationship to the major faults in the system is shown in Figure 1. High seismicity associated with the San Jacinto fault zone suggests that it is presently the most active member of the system of faults in southern California.

The fundamental problem posed by the San Jacinto fault, and indeed by all of the major faults in southern California, is that of the magnitude of their cumulative horizontal and vertical components of displacement. Because of the tectonic importance of these faults, understanding of the regional deformational history depends to a large degree on knowledge of their displacements, together with

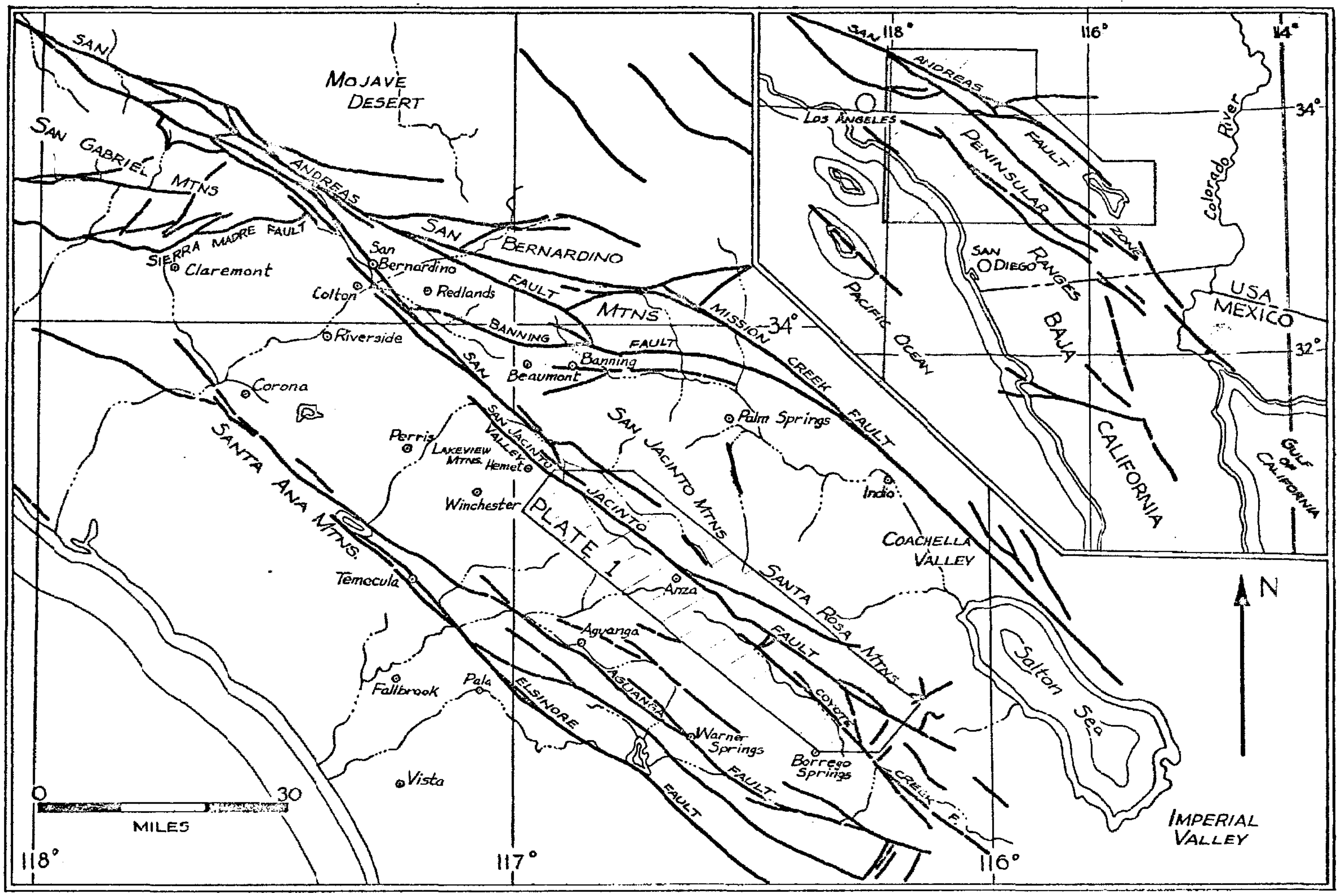


Fig. 1 - Index map showing relationship of the San Jacinto fault to the San Andreas fault system. Inset shows the position of the index map in southern California.

their histories of movement, and their relative ages. Equally important is the definition of those aspects of regional tectonism which cannot be attributed directly to displacement on the major faults.

The San Jacinto fault transects crystalline rocks exposed nearly continuously for about 50 miles in part of the northeastern Peninsular Ranges. An additional 30-mile segment on the northwest end of this interval is also underlain by related rocks but exposures are less continuous and at considerable distance from the fault trace. Previous reconnaissance work, principally by Fraser (1931), Larsen (1948), and Dibblee (1954), has shown that intrusive rocks exposed on both sides of the fault in this region are similar and are related to the Cretaceous southern California batholith. Geologic mapping was conducted by the author along the 50-mile segment of the fault between San Jacinto Valley and Borrego Valley. The location of the mapped area is shown in Figure 1. This area was chosen for the following reasons: (1) it is the only large segment of the fault with relatively continuous exposures, thus affording the highest probability of locating a displaced sequence of plutonic bodies and prebatholithic rocks; (2) features of the fault trace had not been documented in detail; and (3) the degree of exposure and great local relief along much of the fault trace provided an unusual opportunity for observing the complexity of the zone in 3 dimensions.

The field work was conducted between 1961 and 1963. Although the scale of the map included with this report (Pl. 1) is approximately 1:62,500, most of the area was mapped on 1:24,000 topographic bases or on aerial photographs.

CRYSTALLINE ROCKS

GENERAL STATEMENT

Crystalline rocks of three distinct ages occur in the map area. Regionally metamorphosed prebatholithic rocks are exposed intermittently along the San Jacinto fault zone and underlie less than one half of the total area of exposed crystalline rocks. Gabbroic to adamellitic plutonic rocks related to the Cretaceous southern California batholith make up more than one half of the exposed crystalline terrane. A zone of cataclastically deformed rocks of post-batholithic age is exposed over a limited area at the south end of the mapped strip.

Previous reconnaissance mapping in this region, chiefly by Fraser (1931), Dibblee (1954) and Weber (1963), has provided only limited knowledge of the distribution of the metamorphic and intrusive rocks. Although both workers recognized the compositional range of the plutonic rocks, neither attempted to subdivide them in their mapping. Crystalline rocks exposed in various specific parts of the area have also been discussed by Wright (1946), Miller (1946, p. 481), Larsen (1948, p. 67) and Lockwood (1961).

The determination of the cumulative displacement on the San Jacinto fault zone depends entirely on correlation of crystalline rock masses. Inasmuch as several crystalline bodies of approximately the same lithology are transected by the fault zone, particular attention in the following discussion will be paid to their contrasting features. Although some of the offset crystalline bodies appear to be regionally unique, correlation across the fault zone rests not on single offset bodies presumed to be unique but on the entire sequence of transected rocks whose spatial and temporal relationships are known. The following descriptions of the lithologies and relative ages of the crystalline rocks, together with the distributions of the various bodies as shown in Plate 1, will demonstrate that such a sequence is exposed on each side of the San Jacinto fault zone within the map area.

PREBATHOLITHIC METAMORPHIC ROCKS

General Statement

Migmatitic gneiss together with relatively minor amounts of marble, amphibolite, quartzite, and metaconglomerate, form about 35 percent of the exposed crystalline terrane included in Plate 1. These rocks have been regionally metamorphosed to a nearly uniform high grade throughout the area, and nowhere have low grade metamorphic rocks been found. Effects of later superposition of contact metamorphism associated with batholithic intrusions are discontinuous and of minor extent.

The most abundant metamorphic rock is fine- to medium-grained migmatitic gneiss which amounts to about 90 percent of the prebatholithic rocks. The migmatites are composed of alternating dark bands of mica-rich, quartzofeldspathic rock and granoblastic-textured leucocratic rock containing generally the same minerals in different proportions. The banding defines a pronounced foliation which is often folded sharply on a fine scale or cut by discordant ptygmatic veins of "granitic" material.

Preferred orientation of mica in the dark bands is generally parallel to the compositional banding. The thickness, spacing, and proportions of the bands vary widely, but a typical specimen would exhibit nearly equal amounts of dark and light layers less than one half inch in thickness.

That at least some of the metamorphic section is derived from sedimentary rocks is demonstrated by the widespread intercalations of calcitic marble and quartzite beds, and by very minor quartzite-clast metaconglomerate. Bedding contacts between layers of contrasting lithology were parallel to metamorphic foliation wherever they were observed.

Structurally, the prebatholithic metamorphic rocks form steeply dipping septa, roof pendants, and xenoliths between and within individual plutons of the batholithic sequence. It is not possible to reconstruct an original pre-metamorphic section on a regional scale because of internal structural complexity of the metamorphic bodies, interruption by batholithic intrusive bodies, and the lack of continuous lithologically distinctive units. Similarly, the thickness of an equivalent unfolded and unfaulted section cannot be estimated accurately.

Age of the Metamorphic Rocks

No evidence of fossil preservation was found in any part of the map area, but a molluscan fauna recovered from similar rocks near the southern margin of Borrego Valley south of the map area has been tentatively assigned a Mississippian age

(Mueller and Condie, 1964, p. 404; Mueller, personal communication). Supposed Paleozoic fossil material found in Palm Canyon several miles north of the central part of this area is not reliable, according to Miller (1944, p. 25). The occurrence of a single Mississippian fossil near Winchester, a few miles west of the north end of the map area, was originally described by Webb (1939) but has been discredited by Schwarcz (1960, p. 79, 80). Some of the metamorphic rocks exposed in the eastern part of the Peninsular Ranges could be even younger than the Triassic to Upper Jurassic Bedford Canyon formation in the Santa Ana Mountains (Silberling, et al., 1961; Schwarcz, 1960; p. 80). Sedimentary rocks of Albian age that are exposed in northern Baja California are the youngest known prebatholithic rocks in the Peninsular Range province (Silver et al., 1963). Inasmuch as the batholithic rocks underlie Turonian beds in the Santa Ana Mountains (Popenoe, 1954, p. 17), the regional plutonism took place in mid-Cretaceous time. The prebatholithic rocks in the present area are therefore considered to be mid-Cretaceous or older. Although metasedimentary rocks at least as old as Mississippian age probably occur in the map area, no lower limit can be placed on the possible ages represented by the prebatholithic rocks.

Migmatitic Gneiss

Banded migmatitic rocks composed of alternating layers of foliated, mica-rich quartzofeldspathic rock and typically unfoliated "granitic" veins dominate the prebatholithic terrane. Because the scale of the layering is variable from inches to fractions of an inch, hand specimens range in color from very dark to very light gray. The most abundant type of migmatitic gneiss is composed of layers ranging in thickness from about 1/4 to 3/4 inch and contains nearly equal amounts of light and dark fractions. The sequence of alternating layers is sometimes folded isoclinally on an equally fine scale. Structures of this type range in size from about an inch to several feet. The small-scale folding pervades much of the migmatitic gneisses, whereas larger flexures tend to be concentrated in certain localized areas of extreme structural complexity. In these localities, as well as in others, the migmatites possess a swirled and ptygmatically crumpled aspect created either by intricate folding of the compositional banding or by wrinkled "granitic" veins that are discordant to essentially undisturbed folia of the enclosing dark bands.

Because of generally poor fissility of the banded gneisses and the tendency of outcrop form not to be strongly influenced by exposed surfaces of foliation, only locally can axes of the folds be observed in a consistent orientation across outcrops. Many of the more intensely deformed migmatites are swirled in an apparently unsystematic manner.

Samples of migmatitic gneisses from all parts of the map area are essentially fine- to medium-grained potash feldspar-biotite-plagioclase-quartz rocks, in order of increasing mineral abundance. White mica, hornblende, diopside, sillimanite, and garnet occur in some of the migmatites. Textures of the felsic minerals are typically granoblastic, especially in the leucocratic bands. The darker layers show a distinct preferred orientation of biotite tablets parallel to the foliation defined by compositional layering. The dark bands are nearly always of slightly finer grain size than the alternating leucocratic layers. Major mineral proportions in the biotite-rich and granitic bands of migmatitic gneisses from several localities are listed in Table 1 in the appendix.

The dark layers of typical specimens of migmatitic gneiss are composed of 10 to 30 percent subhedral red-brown biotite, 0 to 5 percent subhedral white mica, 0 to 20 percent anhedral orthoclase or incipiently twinned microcline, 45 to 70 percent anhedral plagioclase (andesine to sodic labradorite) and quartz. Felsic grains show granoblastic texture and generally are smaller than 1 mm. Mica tablets are also typically less than 1 mm in size.

The light bands of the migmatitic rocks are composed of 0 to 10 percent subhedral red-brown biotite, 0 to 15 percent subhedral white mica, 0 to 50 percent anhedral orthoclase or incipiently twinned microcline, 60 to 90 percent anhedral quartz and plagioclase (andesine to sodic labradorite). Micas typically show no preferred orientation and are no larger than in the dark bands. Felsic grains exhibit granoblastic texture and are usually smaller than 1 mm but occasionally are as big as 3 mm.

One unusual specimen of migmatitic gneiss from Thomas Mountain near Hamilton Creek is a quartz-biotite-hornblende-plagioclase rock. The plagioclase in the dark hornblende-rich layers is zoned from anorthite to sodic labradorite, but in the light bands it is not distinctly zoned and has a composition of sodic labradorite.

Quartzite

Minor amounts of relatively pure quartzite are exposed at many widely separated localities in the map area. The thickness of the quartzite beds ranges from a few inches to a maximum of about 15 feet observed at a flaggy-weathering outcrop near the head of Dry Wash. Individual beds are traceable at most only a few hundred feet.

Most of the quartzite is medium gray to tannish gray, weakly foliated rock that forms sharp contacts with the enclosing migmatitic rocks. Typical specimens are fine- to medium-grained and are composed predominantly of sutured grains of quartz. Minor amounts of white mica, biotite, and ore are sprinkled through the rock but tend to concentrate slightly in foliation planes.

Feldspathic quartzites that contain abundant biotite also occur in the map area. Because these rocks show strong foliation and fine lamination, they cannot be distinguished from migmatitic rocks in the field. Indeed, they may be gradational into the migmatitic rocks.

Marble

Fine- to very coarse-grained calcitic marble beds crop out at many places in the map area, but they generally constitute a very small part of the prebatholithic metamorphic terrane. Two notably marble-rich sections of metasedimentary rocks are exposed on the eastern slope of Coyote Mountain and at the south end of the Santa Rosa Mountains, mostly east of Rattlesnake Canyon. At both of these localities, marble beds are enclosed in zones of cataclastic deformation which transect batholithic intrusive rocks as well as the metasedimentary rocks. The marble beds have been intricately folded and intersheared with other cataclasites along belts which are generally parallel to the orientation of the marble-rich section. The marbles make up about 10 percent of all of the rocks within the zone of cataclastic deformation.

The thickness of marble beds varies greatly over short distances of outcrop, but most are less than 20 feet thick. Individual beds may extend laterally for several hundred feet, but most are less than a hundred feet long. The discontinuous and lenticular nature of marble layers probably resulted in part from deformation during prebatholithic metamorphism.

The color of the marble ranges from dark gray in fine-grained beds to very light gray in coarsely crystalline layers. Most beds have banding caused by concentrations of graphite inclusions which often are swirled and contorted in a manner similar to the ptygmatic folding in the surrounding migmatitic gneiss. Aside from graphitic banding and local development of calc-silicate layers, the marble beds are relatively homogeneous.

Most of the marble beds in the area are composed almost entirely of calcite in grains up to 1 inch in size. One specimen from upper Dry Wash contained intergranular graphite and traces of dolomite, tremolite, phlogopite and chlorite, all of which totaled less than 5 percent of the rock.

Amphibolite

Fine-grained, weakly foliated amphibolite is widespread but only occasionally abundant on a very local scale within the map area. Most of the amphibolites occur as isolated, relatively thin beds aligned parallel to the foliation of the surrounding migmatitic rocks. Individual beds of amphibolite are generally less than 10 feet in thickness and average 2 to 4 feet. None of the amphibolites could be traced laterally more than a few hundred feet.

All of the amphibolites are fine-grained and nearly black in hand specimen. The average grain size is generally less than 1 mm. The amphibolites contain 0 to 25 percent diopside, 30 to 45 percent plagioclase, 30 to 65 percent hornblende, and about 5 percent opaque ores. Sphene, apatite, and traces of biotite are ubiquitous accessories. Stubby subhedral prisms of olive-green hornblende are weakly aligned in planes of foliation. Equant, anhedral plagioclase of andesine to sodic labradorite composition varies somewhat in the proportion with which it is mixed with hornblende, and the contrasting mixtures define a weak laminar foliation visible in hand specimen. In some samples diopside occurs as minute rounded grains distributed throughout the rock or as coarse grains associated with carbonate and plagioclase in concordant veins.

Metaconglomerate

Only two beds of coarse clastic rocks were found in the entire area. Layers of quartz-pebble metaconglomerate with a high proportion of reddish-brown feldspathic quartzite matrix identical to the other quartzite beds are exposed near the county line about 5 miles east of the San Jacinto fault. The beds are only a few feet thick and extend laterally less than one half mile.

Most of the clasts are slightly elongated parallel to the bedding and are composed of a lighter colored quartzite than the matrix. A few weathered-out pits suggest that some of the clasts are carbonate rocks.

Parent Lithologies

The widespread distribution of sparse marble and quartzite beds suggests that much of the prebatholithic metamorphic terrane is sedimentary in origin. Amphibolites could have been derived from either intrusive or extrusive basic igneous rocks, calcareous shales, or basic tuffaceous strata. The parent materials of the migmatitic gneisses could have included graywacke, shaley arkosic sands, volcanic rocks and sedimentary rocks of volcanic derivation. At least some of the migmatitic rocks probably were derived from coarse-grained igneous rocks of basic composition.

The only definite sedimentary structures preserved in the metamorphic rocks other than migmatites are bedding surfaces separating layers of contrasting lithology. The fine-scale laminations within the migmatitic rocks could have resulted from either sedimentary compositional inhomogeneity, metamorphic differentiation, or both. More subtle sedimentary structures such as cross-bedding or graded bedding have not been observed in any of the metamorphic rocks.

No relict textural features of volcanic rocks were seen in representative samples of the migmatitic gneisses. In view of the high grade of regional metamorphism, textural relationships in either sedimentary or volcanic rocks probably would have been obliterated completely. The most suggestive evidence for a volcanic derivation of the migmatitic gneisses is that the average composition of most of them corresponds approximately to that of dacitic rocks. The calcic composition of plagioclase in many of the specimens is consistent with a volcanic origin for the migmatitic gneisses.

Regional Metamorphism and Structure

The prebatholithic rocks have been regionally metamorphosed to a nearly uniform high grade throughout the map area. No difference in rank of metamorphism was observed on the two sides of the San Jacinto fault or other major faults in the area.

The typical assemblage (white mica)-biotite-potash feldspar-plagioclase (An_{35-55})-quartz of the migmatitic gneisses indicates the regional metamorphism reached almandine amphibolite facies at least to the level of staurolite-quartz subfacies (Turner, 1958, p. 229). The typically calcic composition of plagioclase suggests a somewhat higher grade was reached.

About 10 percent of one specimen of migmatite gneiss consisted of diopside grains concentrated in the dark bands. This specimen has the average composition of adamellite and occurs as a thin migmatitic septum surrounded by an adamellitic intrusive body three miles northeast of Middle Willows. Although the presence of diopside suggests the metamorphic grade reached pyroxene granulite facies, the presence of abundant biotite and sphene argues against it. Because other samples from the same area contained no diopside, the anomalous specimen was considered to have no regional significance.

The amphibolitic assemblage of diopside-plagioclase (An_{30-50})-hornblende indicates regional metamorphic conditions of at least sillimanite-almandine subfacies of the almandine-amphibolite facies (Turner, 1958, p. 231). This same assemblage could persist into the hornblende granulite facies (Turner, 1958, p. 235), but the occurrence of sphene instead of rutile suggests the assemblage is of the lower grade as are the associated migmatitic rocks.

Although much injection of intrusive material into the metamorphic rocks has taken place, probably most of the migmatitic development preceded intrusion and was associated with the regional metamorphism. The compositional banding in the migmatitic gneisses probably is the product of metamorphic differentiation of the parent rock because the intensity of migmatitic development is not spatially related to the distribution of plutons. Some leucocratic bands that appear to be complementary in composition to unusually dark adjoining layers suggest that partial fusion of the rock has occurred. The discordance of some of these leucocratic veins to the foliation is compatible with this interpretation. Only a single regional metamorphic episode need be invoked to explain both the foliation and the veins discordant to the foliation.

Whether large-scale folding of the metamorphic rocks is contemporaneous with the regional metamorphism is not clear from evidence in this area. That many small plutons, particularly in the southern part of the area, have destroyed the structural continuity of the metamorphic rocks suggests that at least some of the deformation can be related to forceful intrusion. Schwarcz (1960, p. 233) has shown in the region immediately west of the north end of this area that an east-trending gradient of increasing regional metamorphism has been superimposed on a system of northwest-trending fold structures and hence is younger.

Emplacement of the large plutonic masses in the area has divided the exposed prebatholithic terrane into several separate bodies (Plate 1). The original stratigraphic interrelations between those bodies exposed within the same fault block are unknown. On the southwest block of the San Jacinto fault, the Bautista complex is defined as the metamorphic body exposed between Anza and San Jacinto Valley. The ridge between the San Jacinto fault and Coyote Canyon and the metamorphic rocks exposed on it are herein respectively termed Coyote Ridge and Coyote Ridge complex. The Tule Canyon complex lies west of the upper part of Coyote Canyon, and the Henderson Canyon complex lies west of the north end of Borrego Valley. Northeast of the San Jacinto fault, the Burnt Valley complex is exposed from southern Thomas Mountain to Lookout Mountain and the Buck Ridge complex lies east of Dry Wash and Jackass Flat.

All of these metamorphic complexes are intermixed to various degrees with intrusive bodies of a wide range of compositions and sizes. Only the largest of these intrusive units have been separated from the metamorphic rocks in the mapping.

Large-scale folding in the metamorphic rocks is shown only by systematic changes in attitude of the foliation. Because of the general lack of beds of distinctive lithology which are laterally extensive, relatively small-scale folds have not been documented. There probably is a continuum of sizes of folds from the smallest wrinkles in the migmatites to broad folds many miles in dimension, and much of this folding may be nearly isoclinal.

The internal structure of the Bautista complex is grossly that of a warped arch which plunges steeply to the northwest. The margin of the complex is subparallel to the internal foliation, as are most of the intrusive bodies within the complex. Near its northern and southern margins, foliation in the Bautista complex strikes nearly east-west.

Most of the other complexes appear to be gently folded on a broad scale, and the foliation within them generally follows closely the orientation of their margins. Although no single direction overwhelmingly dominates the orientations of the foliations on a regional scale, nearly east-west strikes and steep dips occur at many localities.

The Coyote Ridge complex is the most intensely folded body of metamorphic rocks in the map area. Because of disruption by numerous intrusive bodies, no systematic regional attitude or folding pattern is apparent.

Contact Metamorphism

Relatively thin and discontinuous contact aureoles around plutonic bodies are widespread in the map area. The contact effects are characterized by a generally weak hornfelsic texture superimposed on the older foliation of the regionally metamorphosed rocks, by the appearance of megascopic crystals of sillimanite or other contact minerals, and locally by the development of porphyroblastic texture. Contact zones visible in outcrop were no wider than a few tens of feet. Although the megascopic evidence of contact metamorphism is discontinuously distributed along the margins of plutonic bodies, zones of incipient development of contact minerals probably surround most of the plutonic bodies.

Contact metamorphism of the migmatitic gneisses is most frequently characterized by the presence of bundles of sillimanite which are oriented randomly through the rock and cut all the older minerals. Depending on the amount and size of the sillimanite, the older rock fabric shows varying degrees of obliteration. In some of the migmatitic gneisses, poikiloblastic white mica with no preferred orientation forms up to 40 percent of the rock.

Calc-silicate contact rocks in marble beds were encountered in minor amounts at several localities in the area. Tonalitic veinlets injected into marble east of upper Dry Wash reacted to form bands of wollastonite, diopside, garnet, and clinozoisite. A massive calc-silicate outcrop one mile northeast of Middle Willows close to an adamellitic intrusive body is essentially a monomineralic tremolite hornfels. Another calc-silicate hornfels exposed one mile west of the head of Butler Canyon is an idocrase-diopside-wollastonite-anorthite rock.

Contact metamorphism imposed on the migmatitic gneisses reached hornblende hornfels facies, as shown by the presence of sillimanite and andesine plagioclase (Turner, 1958, p. 207). The contact assemblages developed in marbles also indicate hornblende hornfels facies of metamorphism (Turner, 1958, p. 207, 208).

The equivalent grades of contact metamorphism observed on both sides of the San Jacinto fault suggest that there was no gross difference in conditions of temperature and pressure at the time of intrusion within the metamorphic terrane now exposed on the two blocks. Vertical components of displacement less than about 10 miles are permissible on this evidence (Turner, 1958, p. 237).

PLUTONIC ROCKS

General Statement

A sequence of plutonic rocks related lithologically to the southern California batholith, described principally by Larsen (1948) in more westerly parts of the Peninsular Ranges, are widely exposed in the map area. The plutonic rocks constitute more than half the exposed crystalline terrane. The composition of the sequence ranges from olivine norite through several intermediate but predominantly tonalitic types to garnetiferous adamellite. Most of the intrusive rocks are exposed as mappable bodies of a variety of sizes and shapes. Rocks of true granitic composition are known only as late dikes and were not mapped because of their relatively small size. As discussed previously, the age of the intrusive rocks has been established as mid-Cretaceous by stratigraphic relations observed elsewhere in southern California and Baja California. Mid-Cretaceous plutonism throughout the southern California batholith is also indicated by lead-alpha age determinations (Larsen, et al., 1958; Bushee, et al., 1963) and by uranium-lead ages (Banks, 1963; Silver, et al., 1963).

Although many of the exposed intrusive bodies may possibly be continuous with others of the same or even different composition either at depth or outside of the present map area, the term pluton will be applied to them in this report. For convenience, individual names will be applied to the most important plutons.

Gabbroic Rocks

Two distinctive classes of gabbroic rocks occur in the map area: (1) olivine- and hornblende-bearing norite and gabbro, which generally are poor in quartz and biotite and which form sharp contacts with associated plutonic rocks, and (2) quartz gabbro which grades into tonalitic rocks and locally forms dark inclusions within the latter. Both of these gabbroic types have been recognized and included under the name "San Marcos gabbro" by Miller (1937) and Larsen (1948). Some of the gabbroic rocks occurring within the present map area were briefly discussed by Fraser (1931, p. 508, 522).

Gabbroic rocks of the Bautista complex. -- At least five gabbroic to noritic bodies of various sizes occur within the Bautista complex. The largest of these masses is about 3 miles in length. Four of the bodies lie against or within a sill-like, foliated body of adamellitic composition. The contacts between these rocks are not exposed and the age relations are not known. The best evidence for the relative age of the noritic rocks is shown in exposures on Thomas Mountain that will be discussed below.

The four largest bodies are predominantly medium-grained, dark-gray olivine-hornblende norite, but the eastward-projecting lobe of the westernmost body and the inclusion north of it consist of fine- to medium-grained hornblende gabbro. Typical exposures of the noritic bodies are made up of small, subangular boulders strewn over rounded slopes which are mantled by a relatively thick, brownish-red residual soil. Exposed rock fragments generally weather to a dark-gray mottled surface, but many are coated a red color similar to that of the soil.

The most abundant noritic rock is composed of zoned mafic clots consisting of olivine cores and successive shells of hypersthene and hornblende set in a matrix of medium-grained, anorthitic plagioclase. The amount of mafic minerals ranges from about 15 to 55 percent, and the lighter varieties are locally interbanded with darker types on a scale of a few inches. Mafic minerals in the dark norites form a coalescing network of rounded clots. A typical clot is 3 to 5 mm in size and usually contains a deeply resorbed remnant of olivine surrounded by a polycrystalline mantle of colorless hypersthene. An outermost shell of pale-green, slightly pleochroic hornblende riddled with pale-green vermicular spinel forms about half the volume of the clot. Minor amounts of ore are sprinkled through the hornblende rims.

Gabbroic rocks of the Burnt Valley complex.-- A single gabbroic body composed predominantly of medium- to coarse-grained hornblende-olivine norite and biotite-hornblende gabbro, including some fine-grained quartz gabbro, is exposed at the south end of Thomas Mountain within the Burnt Valley complex. This roughly elliptical mass, together with a septum of metamorphic rocks, lies almost entirely within a sill-like body of strongly foliated biotite adamellite. Inclusions of norite occur within the foliated rocks.

The mass consists mostly of a heterogeneous mixture of fine- to coarse-grained rocks covering a compositional range from olivine-hornblende norite to biotite-hornblende gabbro. Smaller bodies of more acid rocks, including fine-grained quartz gabbro and medium-grained tonalite and foliated granodiorite, all cut by dikes of pegmatitic granite, pervade the outcrop area. The mapped contact was drawn to include all rocks of gabbroic affinities.

Norite underlies a large part of the outcrop area, and some of it is equivalent in mineralogy, texture, and grain size to norite exposed in the Bautista complex. Much of the norite is coarse grained and contains anorthitic plagioclase grains up to 7 mm in size and resorbed olivine up to 6 mm. Successive reaction layers of hypersthene and pale-green hornblende riddled with spinel mantle olivine grains. Minor amounts of pale biotite occur in both the hypersthene and hornblende layers of the mafic clots. Typical norite specimens contain about 40 percent unzoned anorthite (An_{92} to An_{100}), 15 percent olivine, 30 percent hypersthene, 10 percent hornblende, and minor biotite, spinel, and ore.

A considerable part of the body is made up of a texturally distinctive biotite-hornblende gabbro which contains equant plagioclase phenocrysts up to 1-1/2 inches in size. Olivine and orthopyroxene are lacking, and biotite and hornblende form a medium-grained matrix between the plagioclase grains.

Gabbroic rocks of the Buck Ridge complex.-- Gabbro and minor amounts of noritic rock occur both within and adjacent to the adamellite pluton exposed in the Buck Ridge complex. Although the compositional and textural ranges shown by these rocks nearly coincide with the gabbroic rocks of the Burnt Valley complex, the most abundant types are medium-grained hornblende gabbro and biotite-hornblende quartz leucogabbro. Olivine-hornblende norite and both foliated and unfoliated tonalitic to granodioritic rocks are also present, but the former contributes probably less than 5 percent to the total and the latter group about 25 percent. The gabbroic rocks enclosed by the adamellitic pluton are mostly small bodies of hornblende leucogabbro, ranging from several tens to several hundreds of feet in maximum dimension.

The mafic content of the leucogabbros ranges from about 15 to 40 percent and is about 20 percent in the most typical rocks. One specimen of quartz leucogabbro contained about 50 percent zoned plagioclase with anorthitic cores and andesine to labradorite outer zones, 35 percent pale greenish-brown hornblende, 15 percent quartz and small amounts of biotite and ore. Hornblende and biotite grains characteristically are gathered in clots, even in the most leucocratic phases.

Gravels exposed in fans east of the southern part of Buck Ridge contain a similar suite of leucogabbro and hornblende norite. These gravels were probably derived from the southwest face of the highest ridge of the Santa Rosa Mountains east of the map area. The relationship of these rocks to garnetiferous adamellite, which is also a widespread rock type in this part of the Santa Rosa Mountains, is presumed to be identical to that found on Buck Ridge.

Quartz gabbro.-- Quartz gabbro that is locally gradational into tonalitic rocks occurs at several places in the map area, but it is not abundant at any locality. Dark inclusions in some of the tonalitic bodies in the southern part of the map area are also composed of quartz gabbro that is very similar in composition and texture.

Most of the known occurrences of quartz gabbro lie within the Coyote Ridge complex and the Tule Canyon complex. They are generally small homogeneous bodies intruded into the migmatitic gneisses, but some lie within and grade into tonalitic rocks. None of the quartz gabbro bodies have been shown in Plate 1.

Representative samples of quartz gabbro are distinctive in hand specimens because of their relatively fine grain size and dark color. The mafic mineral content ranges from about 40 to 60 percent. Gradation of quartz gabbro into tonalite is generally characterized by a reduction in the mafic content, coarsening of the rock texture, and the disappearance of very calcic cores in plagioclase. The rocks consist of 30 to 40 percent plagioclase that is smoothly zoned from cores of labradorite to anorthite to rims of andesine or labradorite, 15 to 45 percent pale-green hornblende, 5 to 25 percent reddish-brown biotite, 5 to 20 percent quartz, and minor amounts of ore, apatite and zircon.

Tonalitic Rocks

Large bodies of tonalite, in part gradational into grandiorite and adamellite, underlie nearly one third of the map area and easily predominate in area of exposure of the various intrusive rocks. Tonalitic rocks of various parts of the northern half of this area have been briefly described by Fraser (1931), Wright (1946), Miller (1946), Larsen (1948), and Lockwood (1961). In the following discussion, only the most important tonalitic bodies will be described. Several small masses of similar tonalite have been shown in Plate 1, but they will not be described.

Coahuila Valley pluton -- The largest single mass of tonalitic rock in the map area stretches more than 30 miles from San Jacinto Valley on the north to the vicinity of Fig Tree Valley on the south. Although alluvium conceals the pluton still farther north, it probably underlies a considerable area beneath San Jacinto Valley. It may also include the tonalitic rocks exposed in the Lakeview Mountains and even farther northwest (Fig. 1). From the vicinity of Anza, the body extends southwestward about 16 miles where it is truncated by the Aguanga fault (Fig. 1).

The earliest reconnaissance mapping that included this pluton was done by Fraser (1931), but he neither differentiated the intrusive rocks of his "San Jacinto batholith" nor described any tonalitic rocks southwest of the San Jacinto fault. Miller (1946, p. 481) considered this tonalite to be correlative with the La Posta quartz diorite of southeastern San Diego County, largely on the basis of rock textures. Except for exposures south of Coahuila and Terwillinger Valleys, this body was thought by Larsen (1948, p. 68) to be correlative with the Lakeview Mountain tonalite exposed northwest of the present map area. Other tonalitic rocks exposed southwest of the map area near Aguanga are part of the Coahuila Valley pluton but are distinctive from the Lakeview Mountain tonalite, according to Larsen. These rocks have been named the "Aguanga tonalite" by Mann (1955, Pl. 1). Tonalitic rocks exposed at Diamond Valley a few miles west of the north end of this map area were mapped as Lakeview Mountain tonalite by Schwarcz

(1960). This region lies along part of the western margin of the Coahuila Valley pluton.

Within the map area, the Coahuila Valley pluton consists predominantly of rocks ranging from equigranular, medium-grained biotite-hornblende tonalite to biotite tonalite. Numerous small bodies of younger inequigranular biotite granodiorite and adamellite chiefly concentrated in the southeastern part of the pluton have been included with the tonalitic phases in Plate 1.

Variability in the tonalitic rocks is confined almost entirely to the proportion of hornblende to biotite and, to a lesser extent, to the size ranges and textures exhibited by the dark minerals. The potash feldspar content of the tonalitic phases is uniformly very low.

The most abundant rock is hornblende-biotite tonalite containing mafic grains that are uniformly dispersed without preferred orientation. This rock is gradational locally into biotite-hornblende tonalite, but the amount of this phase is subordinate. A more striking variant, however, is a weakly foliated biotite tonalite in which the hornblende is nearly lacking. The hornblende-poor rock, found principally between Table Mountain and the southeastern corner of the pluton, locally exhibits a striking texture created by hexagonal biotite plates of relatively large and uniform size. Biotite in the other phases generally is ragged and somewhat smaller than in the biotite tonalite. Because of its unique texture and mineralogy, its restricted distribution within the Coahuila Valley pluton, and its position adjacent to the San Jacinto fault zone, this variant has been used as a distinctive marker lithology in correlation of the displaced pluton.

Another distinctive phase of the Coahuila Valley pluton consists of the typical tonalitic phase in which unusually abundant sphene forms large crystals. This variant is exposed in and possibly for a few miles south of the Santa Rosa Hills at the northern end of the map area. Sphene crystals as large as 4 mm are easily seen in most hand specimens.

The tonalites of the Coahuila Valley pluton are composed of 40 to 50 percent plagioclase showing oscillatory zoning through a broad compositional range, 20 to 35 percent quartz, 10 to 30 percent combined hornblende and biotite, 0 to 3 percent potash feldspar, and 1 to 4 percent accessory minerals sphene, apatite, allanite, epidote, ore, and zircon. The most abundant tonalites contain 5 to 15 percent biotite and 5 to 15 percent hornblende. The hornblende-poor phase contains 16 to 24 percent biotite and 1 to 5 percent hornblende. The mineral abundances of several samples of the Coahuila Valley pluton are listed in Table 2 in the appendix.

Plagioclase forms anhedral, thickly tabular to equant grains commonly between 2 to 5 mm in size but occasionally as large as 8 mm. Although grain boundaries are closely subparallel to crystal planes, faces are not developed except in minor extent. In some specimens, the plagioclase tablets exhibit crude subparallel alignment.

The compositional zoning of plagioclase is characteristically oscillatory. The range of composition is usually large in single grains and is somewhat variable in different grains in a specimen. The most sodic zones normally occur near the margins of the grains and range fron An_{26} to An_{59} in composition. The most calcic zones usually occupy the central portions of the grains as well as several concentric bands distributed throughout the grains. These zones range from An_{40} to An_{71} in composition.

Potash feldspar forms thin interstitial patches less than 1 mm in size when it is present. Well-defined twinning typical of microcline is not developed, but irregular extinction of the grains suggests incipient development of microcline twinning. Myrmekitic quartz is developed on the margins of plagioclase grains that border on potash feldspar. Quartz occurs as irregularly shaped grains mostly less than 3 mm in size but infrequently as large as 11 mm. All grains are anhedral. Weakly undulatory extinction in quartz is found throughout the pluton, and the degree of its development appears to be unrelated to proximity to known faults, suggesting that the straining is primarily due to mild protoclastic deformation.

In many hand specimens, biotite forms ragged- to hexagonal-shaped grains between 2 and 4 mm in size. The hexagonal shape is developed to a conspicuous extent in the biotite tonalite phase. Crystals as large as 7 mm occur in these rocks. In spite of the tendency toward megascopic hexagonal shape, biotite is generally anhedral under microscopic view. Biotite is characteristically pleochroic from dark brown to straw yellow throughout the pluton. Some deuteric alteration of biotite to chlorite is present in nearly every speciman.

Subhedral and occasional euhedral prisms of hornblende range in length from 1 to 4 mm. Hornblende is typically pleochroic in shades of olive green. Lineation of hornblende prisms in foliated representatives of this pluton is only vaguely developed.

Subhedral to anhedral sphene of greatly variable size, small euhedral apatite prisms, minute rounded zircon inclusions in biotite, and small rounded ore grains are nearly ubiquitous accessory minerals in the tonalitic rocks. Allanite prisms and anhedral epidote and carbonate grains are somewhat less uniformly distributed.

Along a zone within 2 miles of the southern contact of the Coahuila Valley pluton, small irregularly shaped bodies and thin dikes of inequigranular biotite granodiorite and adamellite intrude the tonalitic phases. Because of the generally small size of the bodies and the intimate scale of intrusion, this lithology was not differentiated from the medium-grained rocks in the mapping. Except for relatively large, bold outcrops at the south end of Terwillinger Valley, most of the bodies are no larger than several tens of feet in greatest dimension. These rocks cut locally developed foliation in the tonalitic rocks and contain inclusions of the latter near Nance Canyon.

In hand specimen these rocks appear to be equigranular and uniformly fine grained, but occasionally large, colorless, sieve-textured potash feldspar crystals up to an inch in size can be observed. In thin section, 12 to 35 percent of the rock is composed of large potash feldspar grains that poikilitically enclose all other minerals. Small crystals of normally zoned plagioclase ranging in composition from sodic oligoclase to labradorite forms 30 to 45 percent of the rock. The rock contains about 25 percent quartz, 7 to 20 percent biotite, and 0 to 3 percent white mica. Accessory minerals are the same as in the tonalitic rocks.

This inequigranular rock probably corresponds to the light-gray 1- to 2-mm grained rock with a "pepper and salt" appearance originally described by Larsen (1948, p. 68).

Small amounts of similar cross-cutting inequigranular rock have been recognized in several other tonalitic bodies as well as in the metamorphic rocks. However, a distinctive spotted variant of this rock was found only in the Coahuila Valley pluton and in the Clark Valley pluton (discussed below). The spotted rocks contain leucocratic spheroidal clots up to 8 mm in size that are randomly distributed and form up to 1/3 of the total rock volume. The clots are quartzo-feldspathic accumulations usually containing a small dark core consisting of hornblende, allanite, epidote and sphene.

A gneissoid marginal phase of tonalite, locally carrying abundant dark inclusions, is intermittently developed along part of the southern contact of the Coahuila Valley pluton. The marginal tonalites are mineralogically equivalent to and grade into the more interior parts of the pluton. They generally contain about the same proportion of dark minerals arranged in thin, streaked-out trains less than an inch in length. Both the general shape of the border zone and the orientation of its internal foliation are subparallel to the contact of the pluton. Near Fig Tree Valley, the marginal phase contains abundant dark tabular inclusions composed primarily of quartz gabbro. The inclusions are oriented subparallel to the foliation of the enclosing rock.

Two of the several phases found in the southern part of the Coahuila Valley pluton are apparently unique to this body and the Clark Valley pluton. In addition, the compositional range shown by the various phases of one body completely encompasses that of the other. For these reasons, the two plutons are thought to be correlative. Similarly, the only tonalitic bodies displaced by the San Jacinto fault within the map area that contain large sphene crystals are the northern part of the Coahuila Valley pluton and the Thomas Mountain pluton.

<u>Thomas Mountain pluton</u> -- Tonalitic rocks underlying the region from Thomas Mountain to Baldy Mountain constitute a part of a much larger mass extending northward to a little beyond the north fork of San Jacinto River on County Highway R-1 (Larsen, 1948, p. 68). The north-south dimension is thus about 15 miles of which about 5 miles lie north of the map area. The San Jacinto fault bounds the pluton on the southwest for 11 miles between lower Blackburn Canyon and the vicinity of Anza. A broad embayment of Quaternary sediments overlapping the pluton forms part of the northern boundary in the map area. The southeastern contact is intrusive against a thin septum of metamorphic rocks which pinches out eastward, giving way to a foliated adamellitic intrusion presumably younger than the Thomas Mountain pluton. Tonalitic rocks underlying Garner Valley and most of the western slope of the southeastern spur of the San Jacinto Mountains are part of the same body.

The entire area of the Thomas Mountain pluton was included with acidic intrusive rocks of the "San Jacinto batholith" in reconnaissance mapping by Fraser (1931). His description (p. 528) of a "typical specimen of quartz diorite from the southeastern side of Thomas Mountain near the edge of Hemet [now Garner] Valley" corresponds approximately to the rather uniform mineralogy and texture found in this pluton. The tonalitic rocks east and west of Lake Hemet and northward were correlated with the Lakeview Mountain tonalite by Larsen (1949, p. 68).

Most of the Thomas Mountain pluton is composed of medium-grained, light-gray hornblende-biotite tonalite identical to the tonalite exposed at the northern part of the Coahuila Valley pluton. Subordinate amounts of biotite-hornblende tonalite and biotite tonalite occur locally. With the exception of a small area underlain by coarsely porphyritic rock north of Lake Hemet, the entire pluton appears to be uniformly equigranular. The most striking characteristic of this tonalite in hand specimen is the consistent appearance of sphene crystals up to 5 mm in size throughout most of the pluton. Within the map area, the Thomas Mountain pluton and the northern part of the Coahuila Valley pluton are the only tonalitic bodies offset by the San Jacinto fault zone that were observed to contain large sphene crystals.

Except for slightly greater amounts of potash feldspar and plagioclase in some samples, the mineral abundances and compositions of the Thomas Mountain tonalites fall exactly within the range of values determined for the Coahuila Valley pluton (appendix, Table 2). Texturally the dominant type of tonalite of each body is equivalent. In view of all of these similarities, the northern part of the Coahuila Valley pluton is thought to be the only possible body within the map area that could be correlative with the Thomas Mountain pluton.

Clark Valley pluton -- The Clark Valley tonalitic pluton underlies a large area of northeastern Clark Valley and the mountains bordering it on the north and east. The San Jacinto fault bounds exposed parts of the pluton on the southwest for more than two miles near Hidden Spring. Presumably the fault zone borders the southeastward extension of the body beneath the cover of Quaternary deposits in Clark Valley to a point near Little Clark Lake. The eastern part of the Clark Valley pluton is cut off by a broad zone of cataclastically deformed rocks comprising garnet adamellite, a marble-rich sequence of metasedimentary rocks, and tonalite, possibly entirely derived from the Clark Valley pluton. At least one zone of tonalitic cataclasite occurs within the pluton near the eastern contact.

The Clark Valley pluton intrudes metamorphic rocks along its northern contact near the Riverside-San Diego County line. This contact probably extends eastward to the summit of the Santa Rosa Mountains beyond which it presumably is cut off by the north-trending zone of cataclastic rocks.

The Clark Valley pluton consists chiefly of medium-grained, equigranular hornblende-biotite tonalite and biotite tonalite. Considerable amounts of inequigranular biotite granodiorite and adamellite which cut the tonalitic rocks have been included with the pluton as shown in Plate 1. Biotite tonalite is the dominant type of rock in the northwestern part of the pluton near the San Jacinto fault, but it grades eastward into hornblende-biotite tonalite. Except for a relatively high potash feldspar content in one sample, the biotite tonalite of the Clark Valley pluton is identical in composition and texture to the distinctive biotite tonalite phase of the Coahuila Valley pluton. These two bodies and a fault slice exposed in Dry Wash constitute the only masses of biotite tonalite of significant size in the area. The mineral abundances of several samples of the Clark Valley pluton are listed in Table 2 in the appendix.

In the eastern and southern parts of the pluton there is a tendency for mafic minerals to cluster into small, ragged nests, in contrast to the evenly distributed and isolated grains found in the biotite tonalitic phase.

Much of the tonalitic rock exhibits weakly developed foliation defined by preferred orientation of biotite and hornblende and by streaking of mafic nests. Schlieren and some drawn-out dark inclusions occur locally near and subparallel to the northern contact of the body. These planar structures fade eastward and southeastward into a weak foliation in the typical rock.

Granodioritic to adamellitic bodies which appear to be fine-grained in hand specimen are distributed throughout this entire pluton. Although most of these bodies are small, some relatively large masses lie within the tonalitic rocks at the northern contact about one mile east of the San Jacinto fault. That these bodies are definitely younger than the tonalites is shown at many localities by their cutting the foliation of the latter rocks.

In thin section, these rocks are identical to the inequigranular biotite granodiorite and adamellite associated with the Coahuila Valley pluton. The characteristic seive-texture of interstitial potash feldspar phenocrysts is abundantly developed in these rocks. The spotted variety of these rocks, seen elsewhere only in the southeastern part of the Coahuila Valley pluton, is common in the Clark Valley pluton. The size, abundance, compositional zoning, and the matrix rock surrounding the ovoid clots are identical in specimens from the two plutons. Because of these similar textural and compositional features of the various phases, the Clark Valley pluton and the southern part of the Coahuila Valley pluton are thought to be correlative bodies.

Horse Canyon pluton -- A tonalitic mass at least seven miles in its longest dimension lies between the San Jacinto fault zone and the Buck Ridge fault south of Vandeventer Flat. The northwestern part of the pluton is concealed by Quaternary deposits west of Garnet Queen Creek. The southeastern contact is intrusive against metamorphic rocks whose foliation is generally subparallel to the contact. A large mass of mixed tonalite and metamorphic rocks form an east-trending septum that nearly divides the tonalitic body about a mile north of White Wash. A large part of this septum and the tonalitic rocks bordering it on the south are concealed by Quaternary gravels.

The bulk of the Horse Canyon pluton is composed of medium-grained, equigranular hornblende-biotite tonalite and biotite tonalite, but some biotite granodiorite was also found. Most of the rock is mineralogically and texturally equivalent to the hornblende-biotite phase of the Coahuila Valley pluton. Hornblende-poor biotite tonalite exposed near the trace of the San Jacinto fault zone is generally distinguishable from the juxtaposed biotite tonalite phase of the Coahuila Valley pluton on the basis of the much coarser biotite grains that occur in the latter body. Inequigranular granodiorite and adamellite which is a relatively abundant cross-cutting rock in the Coahuila Valley pluton near White Wash was not observed in the Horse Canyon pluton, although it may be present in small amounts.

The mineral abundances and compositional range of plagioclase in the tonalites of the Horse Canyon pluton generally fall within the range of values found in the Coahuila Valley pluton. The mineral abundances of several samples are shown in Table 2 in the appendix.

Santa Rosa pluton -- The Santa Rosa pluton is herein defined as comprising the tonalitic rocks exposed northeast of the Buck Ridge fault southeast of Vandeventer Flat. These rocks are widely distributed eastward in the Santa Rosa Mountains, as shown by mapping by Wright (1946) and Lockwood (1961). The Santa Rosa pluton, as herein defined, may possibly connect with the Clark Valley pluton, the Thomas Mountain pluton, or both east of the map area. Parts of this pluton near Vandeventer Flat are dike-like bodies that conformably intrude metamorphic rocks.

The Santa Rosa pluton is composed of medium-grained equigranular hornblende-biotite tonalite and biotite tonalite, which are texturally equivalent to the most abundant phases of both the Coahuila Valley and Horse Canyon plutons. Near Pines-to Palms Highway the rocks are distinctly foliated and contain abundant schlieren. The mineral abundances of a single sample are listed in Table 2 in the appendix.

Horse Creek pluton -- A body of medium-grained, hornblende-biotite tonalite, less than two miles in exposed length, lies within the Bautista complex east of Bautista Creek and southeast of Horse Creek. It intrudes metamorphic rocks along its northeastern contact, and Quaternary gravels conceal it along its southwestern margin. The rock is identical in every respect to the hornblende-biotite tonalite of the Coahuila Valley pluton. The mineral abundances in a single specimen are listed in Table 2 in the appendix.

Coyote Creek pluton -- A multi-lobed plutonic body, distinctly zoned in composition but predominantly tonalitic, is exposed southwest of the Coyote Creek fault between Parks Canyon on the north and Borrego Valley on the south. Its exposed length is over eleven miles. The body is formed by two lobes which probably converge under alluvial cover on Ocotillo Flat near Middle Willows. North of Collins Valley, the northern lobe forms intrusive contacts with metamorphic rocks both west and east of Coyote Creek. Much of this lobe is concealed by Quaternary deposits. Southeast of the northern part of Collins Valley, both lobes of the pluton are bounded by the Coyote Creek fault. The southern lobe is itself composed of lobate to sill-like bodies that intrude metamorphic rocks.

A major part of the northern lobe consists of medium-grained equigranular tonalite in which either hornblende or biotite is the dominant dark mineral. South of the latitude of Monkey Hill, the rocks are megascopically identical to the tonalitic phase but contain enough interstitual potash feldspar to be granodioritic. The contact between these rocks is gradational. Opposite the central part of Collins Valley the granodioritic phase grades southward into a porphyritic adamellitic rock which extends to Ocotillo Flat. The tonalitic and granodioritic rocks which compose the southern lobe of the pluton are assumed to be gradational northward into the adamellitic phase beneath Ocotillo Flat.

Superimposed on this pattern of compositional variation within the pluton is a broad zone within which dark inclusions consisting of quartz gabbro are abundant. The inclusion-rich belt extends from northern Collins Valley to the latitude of Lower Willows, and the inclusions are equally prominent in both the granodioritic and adamellitic matrix rocks. South of Ocotillo Flat, tonalitic rocks of the southern lobe have incorporated many small masses of metamorphic rocks as well as at least one body of fine-grained quartz gabbro.

Typical inclusion-rich rocks in the northern lobe contain 2 to 10 volume percent of the dark inclusions, but in some localities relatively large tabular masses contain up to 75 percent. The inclusions are mineralogically and texturally similar to many of the quartz gabbros exposed in the Coyote Ridge complex. Typical inclusions are several inches to a few feet in size, and they are consistently flattened and oriented so that the surfaces of flattening are generally about vertical. The matrix rock does not exhibit an obvious foliation parallel to the preferred orientation of the inclusions.

The tonalitic and granodioritic rocks in both lobes of the pluton are texturally equivalent to hornblende-biotite tonalite of the Coahuila Valley pluton. Although most of the tonalitic rocks are not foliated, the sill-like body extending from Lower Willows to Indian Canyon along the south side of Collins Valley shows a pronounced foliation parallel to the contacts of the body. The foliation is defined by strung-out nests of mafic minerals, often several grains in length. Hornblende prisms and tabular grains of biotite are aligned in the plane of foliation. The foliation of this rock fades southward in the main portion of the southern lobe.

The contact between granodiorite and porphyritic adamellite defined by the first appearance of relatively abundant, coarse-grained microcline-perthite phenocrysts, is gradational and is only approximately located in Plate 1. The phenocrysts generally are less than one inch in size. Although hornblende occurs in the rocks on both sides of this contact, it is a very minor constituent in the porphyritic rock.

Dikes of white mica-biotite adamellite, in hand specimen resembling the seive-textured granodiorite and adamellite exposed in the Coahuila Valley pluton, cut the porphyritic adamellite in Lower Box Canyon.

The abundances of constituent minerals of several samples of the various compositional phases of the Coyote Creek pluton are shown in Table 2 in the appendix.

Thin discontinuous layers of strongly mylonitized rock are exposed both north and south of Lower Willows. They show no obvious preferred orientation within the pluton, and they are discordant to the strong foliation developed in the tonalite along the southern margin of Collins Valley. The mylonitic shearing is definitely younger than the foliation of these rocks.

Coyote Ridge pluton -- A predominantly tonalitic pluton lies east of the Coyote Creek fault on Coyote Ridge between the latitude of Monkey Hill and the western apex of Coyote Mountain. The Coyote Ridge pluton, as herein termed, includes rocks on both sides of the Box Canyon fault.

As in the case of the Coyote Creek pluton, this body contains medium-grained rocks ranging from tonalite to adamellite, and a zone of inclusion-rich rock extends across its central part. The sequence of compositional variants from north to south in this body is also the same as the Coyote Creek pluton, but the relative abundances are different. Northwest of Box Canyon medium-grained hornblende-biotite tonalite grades southward successively into granodiorite, adamellite and inclusion-rich granodiorite. Farther south, inclusion-rich adamellite forms some isolated exposures east of Ocotillo Flat.

East of the Box Canyon fault, medium-grained hornblende-biotite tonalite makes up nearly all of the Coyote Ridge pluton. Some exposures of equigranular, medium-grained adamellite occur less than a mile south of the northern contact, but they are minor in amount. Neither porphyritic adamellite nor inclusion-rich adamellite was found east of the Box Canyon fault.

Inclusion-rich tonalite is exposed for about 1 1/2 miles north of Alcoholic Pass. The inclusions are composed of fine- to medium-grained, dark-gray quartz gabbro identical in every respect to the inclusions contained in the Coyote

Creek pluton. The inclusions are flattened and generally dip southward at steep angles.

Most of the tonalitic and granodioritic rocks are identical in hand specimen to samples of similar composition taken from the Coyote Creek pluton. The abundances of constituent minerals of several samples from all of the compositional variants are listed in Table 2 in the appendix.

A thick belt of strongly mylonitized tonalite that strikes nearly due north and dips steeply to the east cuts the Coyote Ridge pluton near Alcoholic Pass. Lenticular bodies of relatively unsheared tonalite within the belt are identical to the tonalitic rocks on each side of the mylonite. A smaller, nearly east-trending mylonite zone is exposed in Butler Canyon in the northeastern part of the pluton. The two mylonitic bodies may connect with each other along a curving path beneath the cover of Quaternary gravels.

Because of the similar north-to-south variation in composition, the distribution and orientation of inclusions, and similar positions relative to the large cataclastic shear zones exposed farther south, the Coyote Ridge pluton is thought to be correlative with the Coyote Creek pluton.

Granodioritic Rocks

Although rocks of granodioritic composition are widespread as rather small intrusive bodies cutting several of the tonalitic and adamellitic plutons or as local variants of tonalitic plutons, only one relatively large mass of homogeneous granodiorite was found in the map area. Granodioritic rocks were recognized in the "San Jacinto batholith" of Fraser (1931), but those occurrences presumably lie outside of the present map area.

Collins Valley pluton -- The eastern tip of a large mass of homogeneous biotite granodiorite projects into the map area along the west side of Collins Valley. On air photos, the body appears to be a roughly elliptical pluton of nearly 8 miles length in the east-west direction. However, this body may be much larger and possibly may connect with the Coahuila Valley pluton, as suggested by mapping compiled by Weber (1963).

In hand specimen this granodiorite is massive and strikingly inequigranular. Colorless potash feldspar grains up to two inches in size poikilitically enclose much smaller grains of all other minerals. Because of the similarity in color of both feldspars and because about three quarters of the total volume of the host potash feldspar grains is made up of other minerals, the rock often appears to be equigranular and relatively fine-grained.

Large sieve-textured crystals of orthoclase with patches of incipient microcline twinning, as well as some microcline, are filled with other minerals to the extent of 70 to 80 volume percent. The phenocrysts are equant, anhedral, and always interstitial to every other mineral in the rock. Grain sizes typically are widely variable from minute to nearly 2 inches, but most are probably less than 8 mm. Very large crystals are apparently dispersed at intervals at least as large as their average size.

Plagioclase grains occur in two distinct forms: (1) slightly resorbed tabular euhedra from 1/2 to 2 1/2 mm size as inclusions in potash feldspar, and (2) anhedral tabular grains of the same size range forming a plagioclase-quartz-biotite network outside potash feldspar. Oscillatory zoning over a range from calcic oligoclase to labradorite is abundant in all of the plagioclase.

Quartz is anhedral in either interstitial grains or irregular patches enclosed by potash feldspar. Most grains are 1 to 4 mm in size. Myrmekitic vermicules of quartz are developed in borders of some plagioclase grains.

The remainder of the rock is composed of subhedral tabular biotite in grains less than 1 mm in size, very small interstitial patches of white mica, and traces of allanite, epidote, apatite, sphene, zircon, and ore. Some deuteric alteration is shown by partial alteration of biotite grains to chlorite and by shreds of white mica and clouds of clay minerals in calcic cores of plagioclase.

Both the inequigranular texture and the compositional similarity suggest affinity of the Collins Valley pluton and the widely distributed, small cross-cutting bodies found in parts of several other plutons. Its correlation with various granodioritic rocks described elsewhere in the southern California batholith by Larsen (1948) is unknown.

Adamellitic Rocks

Three distinctive types of adamellite, in addition to those already discussed, occur within the map area: (1) relatively coarse-grained, garnetiferous adamellite that forms several widely distributed bodies of a wide range of sizes, (2) strongly foliated, medium-grained but locally porphyritic biotite adamellite, and (3) fine- to medium-grained white mica-bearing biotite adamellite. The latter two rocks have rather limited distributions in the map area.

No rocks of adamellitic composition have previously been described in this region. Although adamellite was noted in the "San Jacinto batholith" by Fraser (1931), these occurrences apparently lie well north or east of this map area. Garnet-bearing adamellitic rocks exposed a few miles east of the central part of the map area have been described by Lockwood (1961). An outcrop of quartz monzonite a few miles southwest of the north end of the Salton Sea was mentioned by Larsen (1948, p. 67); this body may be correlative with the garnetiferous adamellite which apparently is a widespread rock type in the Santa Rosa Mountains.

Garnetiferous adamellite -- Several bodies composed of relatively coarse-grained garnetiferous adamellite intrude metamorphic rocks from Coahuila Mountain on the north to the southernmost exposures of crystalline rocks in the map area. As shown by their unique mineralogy which contrasts distinctly with all the intrusive rocks exposed in this region, all of the bodies are clearly related. A large body of this rock has been mapped on the eastern slope of Santa Rosa Mountain just east of the central part of the map area by Lockwood (1961, p. 14, 15). It closely resembles the Rattlesnake Granite which underlies a small area in the Cuyamaca Peak quadrangle in San Diego County (Everhart, 1951, p. 87, 88). Another mass of identical rock underlying Mt. Eden in the Perris Quadrangle in Riverside County has been called the Mt. Eden granite by English (1953, p. 27).

A roughly elliptical body about one and one quarter miles in length composed of leucocratic garnetiferous adamellite forms prominent exposures on the south face of Coahuila Mountain. This body was named the Coahuila Stock by Fraser (1931, p. 522) although he did not recognize its adamellitic composition. Several masses of very irregular shape lie within the Coyote Ridge complex mostly east and north of Middle Willows; the largest of these is over two miles in its greatest dimension. The largest and most continuously exposed body of garnetiferous adamellite that underlies much of Buck Ridge and the area east of its southern tip is at least 10 miles in length. Another mass lies within the Henderson Canyon complex south of the mouth of Henderson Canyon. This body grades eastward into cataclastically sheared adamellite. Other bodies of adamellitic cataclasite and mylonite are exposed on the eastern slope of Coyote Mountain and at the south end of the Santa Rosa Mountains.

Most of the garnetiferous adamellite is composed of 18 to 42 percent normally zoned plagioclase of albite to oligoclase composition, 21 to 38 percent perthitic to microperthitic microcline and orthoclase, 24 to 45 percent quartz, traces to 4 percent reddish-brown garnet, traces to 6 percent biotite, traces to 2 percent white mica, and traces of ore, apatite, and zircon. These rocks are generally very leucocratic, but east of southern Buck Ridge garnetiferous adamellite grades into a coarse-grained, garnet-free rock containing about 10 percent biotite. The abundances of constituent minerals of samples taken from all of the bodies mentioned above are listed in Table 3 in the appendix.

Plagioclase in the garnetiferous adamellite forms anhedral equant grains up to 6 mm in size, but most grains are 1 to 3 mm. The compositional zoning is generally normal but some oscillatory zones were observed in some grains. Broad sodic oligoclase cores are mantled with very thin albite rims in typical specimens.

Anhedral, irregularly shaped microcline and orthoclase perthite and microperthite ranges up to 11 mm in size, but most grains are 1 to 5 mm.

By clustering into patches up to 20 mm in size, anhedral quartz gives almost all of the specimens a very coarse-grained aspect. Individual grains in the clusters are typically 4 to 10 mm in size. Most quartz shows weakly undulatory extinction. Some myrmekitic vermicules occur in plagioclase adjacent to grains of potash feldspar.

Both white mica and biotite occur as subhedral tablets up to 2 mm in size, but most are less than 1 mm. Biotite aggregates up to 4 mm long are found in some specimens. Most samples show some chlorite as an alteration product of biotite.

In hand specimen, deep brownish-red garnet crystals averaging about 3 mm in size are generally ubiquitous, but in some bodies they are sparsely distributed or absent. In thin section, the garnets are pale pink in color and are somewhat corroded and occasionally skeletal.

A striking feature of the garnetiferous adamellites is their very uniform massive texture. No obvious planar or linear structure was observed in any of the bodies. The grain size is uniformly coarse throughout all of the bodies.

Foliated adamellite -- A sill-like body of strongly foliated equigranular to locally porphyritic biotite adamellite transects the Bautista complex from the mouth of Blackburn Canyon to the vicinity of Juan Diego Flat. A similar body lacking the porphyritic phase has intruded the Burnt Valley complex on southeastern Thomas Mountain and Lookout Mountain. These bodies are herein termed the Bautista Sill and the Thomas Mountain Sill. Both the general trend of the bodies and their internal foliation defined by streaked-out accumulations of mafic minerals are subparallel to the foliation of the enclosing metamorphic rocks. Both bodies are intimately related spatially with masses of gabbroic and noritic rock.

Both the mineralogy and texture of the rock composing the Bautista Sill are variable along its length, but the body appears to be relatively rich in potash feldspar everywhere. Near Bautista Creek some of the rocks show little or no foliation and are unusually rich in biotite and hornblende. From a mile south of Bautista Creek to its southern extremity, the rock is distinctly porphyritic and strongly foliated. Coarse potash feldspar phenocrysts up to an inch in size are set in a matrix of medium-grained equigranular rock. The phenocrysts form up to 25 percent of the rock locally. They are anhedral and either tabular or augen shaped, and their long axes are subparallel to the foliation on the rock. Single grains and aggregates of biotite are aligned in the plane of foliation. Hornblende was not observed in the porphyritic rock.

Adamellite of the Thomas Mountain Sill is lithologically similar to the non-porphyritic phase of the Bautista Sill that is exposed near Bautista Creek. Foliation and lineation defined by thin streaks of mafic minerals are strongly developed in this body. Most of the rocks contain less than 10 percent dark minerals, but near the east side of Thomas Mountain some of the rock has up to 20 percent. Some of these darker rocks may be granodioritic in composition. In view of their compositional and structural uniqueness within the map area, the Thomas Mountain Sill and the Bautista Sill are considered to be correlative.

In both bodies, about 30 to 40 percent of the rock consists of weakly zoned plagioclase ranging from calcic oligoclase to sodic andesine in composition. Anhedral grains of microcline form about 25 percent of the typical rocks, but somewhat more in the porphyritic phase of the Bautista Sill. About 25 percent of the rock is quartz, and 10 to 20 percent consists of biotite and minor hornblende.

The mineral abundances of a sample from each body are listed in Table 3 in the appendix.

Fine- to medium-grained adamellite -- A broad region in the central part of the Coyote Ridge complex between upper Collins Valley and the head of Butler Canton is underlain by several bodies of fine- to medium-grained biotite adamellite. Similar rocks lie west of the Coyote Creek fault in upper Collins Valley. All of these rocks are massive, equigranular, and light-colored.

Typical specimens contain about 25 to 40 percent normally zoned plagioclase ranging from calcic oligoclase to calcic andesine, 25 to 30 percent quartz, 25 to 40 percent interstitial microcline, 5 to 8 percent reddish-brown biotite, 0 to 3 percent white mica, and traces of accessory minerals. Most of the rocks consist of 1 to 2 mm grains.

Except for the lack of large interstitial phenocrysts of potash feldspar, this rock is texturally identical to the inequigranular seive-textured granodiorites and adamellites that transect many of the plutons in the map area. The abundances of constituent minerals of a few specimens are listed in Table 3 in the appendix.

POST-INTRUSION CATACLASTIC ROCKS

Distribution and Lithology

Cataclastic deformation has been superimposed on both the prebatholithic metamorphic rocks and the intrusive rocks along a north-trending belt underlying the eastern slope of Coyote Mountain. Similar zones are exposed west of Borrego Valley and at the south end of the Santa Rosa Mountains. The zone west of Borrego Valley extends from Henderson Canyon southward about 13 miles to San Felipe Creek, the southern 10 miles of which lie outside the map area. Although cataclastically deformed rocks are also exposed south of San Felipe Creek (Mueller and Condie, 1964, p. 401), the zone may have been displaced somewhat by the San Felipe fault. The cataclastic rocks exposed on the south end of the Santa Rosa Mountains extend northward out of the map area along the eastern slope of the range and probably connect with a previously mapped cataclastic zone exposed between Palm Springs and the eastern slope of Santa Rosa Mountain (Fraser, 1931, p. 509; Lockwood, 1961).

All of the cataclastic zones involve an identical suite of rocks and are similarly oriented. They are generally north-trending, moderately east-dipping, and disposed along the eastern flanks of topographically high masses which share the same general trend. In view of these similarities and the fact that they are regionally unique, these three zones are thought to be segments of a single deformational belt that has been displaced by the San Jacinto and Coyote Creek fault zones.

None of the cataclastic belts is exposed in its entire thickness in the map area, but the zone on Coyote Mountain is at least 1 mile thick. The total thickness probably is significantly greater than this amount.

The cataclastic zones are generally made up of slightly sheared to mylonitic intrusive and prebatholithic rocks. Mylonitic bands are thin and minor in volume, and they are gradational into less intensely deformed cataclasites which make up the typical rock. The transition from sheared to unsheared rocks within and adjacent to the cataclastic zones is marked by abrupt inhomogeneities in the degree of deformation superimposed upon a more gradual deformational gradient. Thus, strongly mylonitized zones persist into essentially undeformed rocks but diminish in abundance toward them.

On Coyote Mountain the deformed rocks are complexly folded on both large and small scale about axes that generally strike nearly eastward. Because of the structural complexity, the apparent continuum of scale of folding, and the lack of extensive marker units, the folding was not studied in detail. However, there appears to be a definite correspondence between the intensity of the folding and the degree of pervasive cataclasis. Thus, the orientation of foliation in the cataclastic rocks near the eastern margin of Coyote Mountain is extremely variable, but foliation near the gradational contact of the zone at the summit is nearly constant and parallel to the contact.

A megascopic lineation defined by streaking of light and dark minerals in the plane of the shear foliation is developed in some of the cataclasites. This streaking is a widespread but not universal feature of the cataclasites derived from intrusive rocks. It was not observed in sheared metamorphic rocks. In general the lineation appears to plunge subparallel to axes of major folds and minor drag folds and is therefore considered to be a b - lineation (Turner and Verhoogen, 1960, p. 622). A similar relationship of lineation and fold axes was found in the cataclastic zone exposed on the eastern slope of Santa Rosa Mountain (Lockwood, 1961, p. 47, 48).

Prebatholithic metamorphic rocks lying within the cataclastic zones are represented by marble beds, migmatitic gneiss, and minor amounts of amphibolite, all of which are lithologically similar to rocks previously described. A striking distinction to prebatholithic rocks elsewhere in the map area is the large proportion of marble to other lithologic types; possibly 50 percent of the outcrop area of prebatholithic rocks on Coyote Mountain and the southern Santa Rosa Mountains is underlain by marble beds. The proportion of marble in the cataclastic zone west of Borrego Valley is not as great, but only a small portion of that zone is exposed within the map area.

Marble beds generally are recrystallized, but they show distinct evidence of intense shearing and plastic flow in intricately folded and swirled graphite-rich bands. Much of this deformation may have occurred during the regional metamorphism of the prebatholithic terrane. However, local development of blastomylonitic texture in marble and the occurrence of thin, folded sheets of partially mylonitized biotite tonalite smeared into marble beds show that some of the internal structure is due to the cataclastic deformation. Post-deformational recrystallization probably has obliterated cataclastic fabrics in many of the marble beds. The lack of contact metamorphism in some marble beds lying against or containing stringers of deformed intrusive rocks suggests that juxtaposition has been caused by shearing. Conformable calc-silicate bands found in many of the marble beds do not show obvious signs of shearing. These bands probably represent reacted layers of original sedimentary quartzo-feldspathic rock which remained relatively undeformed during the episode of cataclasis.

Banded migmatitic rocks also are abundant within the cataclastic zones. The field recognition of sheared migmatitic rocks is difficult because the prebatholithic foliation, as well as bedding in the metasedimentary rocks, is generally parallel to the shear foliation produced by the cataclasis. However, occurrences of thin mylonitized zones enclosed by concordant migmatitic rocks show that locally the migmatites are intensely sheared.

Deformed intrusive rocks that have been recognized within the cataclastic belts include biotite tonalite, garnet adamellite, quartz gabbro, and granite pegmatite. Although the original igneous textures have largely been destroyed, the mineralogy and maximum grain size of the cataclasites correspond exactly with biotite tonalite and garnet adamellite as described in adjoining parts of the map area.

Samples of typical tonalitic cataclasite consist of relatively large plagioclase porphyroclasts set in a fine-grained matrix composed of quartz and biotite shreds. The porphyroclasts are generally equant to eye-shaped grains aligned parallel to the shear foliation. They range from 1 - 5 mm in long dimension. The margins of the porphyroclasts are ragged to smoothly rounded, and the twin lamellae are generally bent to a slight degree. The porphyroclasts range from andesine to labradorite in composition.

The fine-grained matrix forms about half the rock volume in the most typical cataclasites but the proportion of matrix is much larger in the truly mylonitic representatives. Small biotite grains in the matrix aggregate in thin stringers that exhibit fluxion structure around the porphyroclasts. The matrix mostly consists of quartz grains less than 1/2 mm in size. Small tabular quartz grains typically are unstrained, indicating that recrystallization subsequent to deformation has altered and possibly coarsened, the original cataclastic texture. The long dimensions of the tabular grains lie subparallel to the plane of foliation in the rock. C-axes of quartz show a strong preferred orientation in the plane of the foliation aligned perpendicular to the lineation of mineral streaking and the fold axes. This alignment of the c-axes of quartz parallel to the a fabric axis is typical of mylonitic rocks (Turner and Verhoogen, 1960, p. 638). A similar c-axis fabric for quartz was found by the author in samples of mylonitic rock from the vicinity of Palm Springs. The same relationship was also observed in this zone of cataclastic deformation farther south near Santa Rosa Mountain by Lockwood (1961, p. 47).

Adamellitic cataclasite, equivalent in mineralogy to undeformed garnetiferous adamellite, exhibits identical textural features as those of the tonalitic rocks. Adamellitic cataclasites probably exceed the tonalitic rocks in abundance in the exposed parts of the zones west of Borrego Valley and at the south end of the Santa Rosa Mountains, but the abundances are probably about equal on Coyote Mountain. Quartz gabbro found in relatively small amounts on Coyote Mountain is fine grained and shows very little evidence of cataclasis, although rocks adjoining it are strongly deformed.

In addition to the major zones of cataclastic deformation, several localized bands of mylonitic rocks occur at other places in the southeastern part of the map area. The largest of these lies just east of Alcoholic Pass. It appears to be genetically related to the other cataclastic belts because of its northward trend, moderate eastward dip and prominent lineation plunging eastward. Lenticular bodies of relatively undeformed rock form a major part of this zone, but some of the sheared layers have been mylonitized to nearly aphanitic textures. Most of the other mylonitic zones are of relatively small size, and they bear no apparent systematic geometric relationship to the major zones of cataclasis.

Origin and Age of the Cataclastic Zone

The cataclastic deformation is attributed to displacement on a fault zone which is not presently active. The cataclastic textures are characteristic of deformation under deep-seated conditions, and their presence at the surface indicates considerable unroofing of the crystalline terrane subsequent to the deformation. The folding about eastward-plunging axes, the prominent b-lineation subparallel to the fold axes, and the preferred orientation of quartz c-axes parallel to the a fabric axis all suggest that the displacement has been essentially horizontal in the north-south direction (Turner and Verhoogen, 1960, p. 628, 633). The sense and amount of displacement are unknown.

The age of the cataclastic deformation within the map area is probably entirely post-batholithic. No intrusive bodies cutting the cataclastic foliation were found anywhere in the three zones. In all other parts of the crystalline terrane, the youngest intrusive rocks are consistently dikes of granite pegmatite. In the cataclastic zones granite pegmatites are transected by the shear foliation. Although the lower limit of the age of the cataclastic deformation is definitely established only by Quaternary deposits which conceal the zones, the shearing may have occurred not long after the episodes of intrusion. Similar cataclastically deformed rocks exposed a few miles east of the central part of the map area were mylonitized after intrusion for the most part, but the emplacement of some intrusive bodies was essentially contemporaneous with the deformation (Lockwood, 1961, p. 53, 54). Cataclastic deformation of crystalline rocks south of the map area at San Felipe Creek took place after intrusion of batholitic rocks (Mueller and Condie, 1964, p. 401).

Both the deformation and subsequent erosion which has exposed the relatively deep-seated "roots" of the zone probably preceded any movement on the San Jacinto fault. No evidence of mylonitization of the rocks in the fault zone was found. Because the products of rock-crushing in the fault zone consist only of incoherent brecciated material, rock-flour, and gouge, the San Jacinto fault must be younger than the zone of cataclastic deformation.

QUATERNARY SEDIMENTS

GENERAL STATEMENT

Poorly consolidated clastic sediments, ranging in coarseness from bouldery gravels to lacustrine silts and clays are widely distributed in the map area. A large part of them accumulated in broad intermontane basins and rest unconformably on a crystalline-rock surface that locally has great relief. The remainder of the deposits occur as alluvium or relatively thin terrace accumulations lying on both crystalline rocks and earlier Quaternary sediments. All of the deposits are continental in origin and of probable Pleistocene to Recent age.

BAUTISTA BEDS

The term Bautista beds was first applied by Frick (1921) to the thick section of silts, clays, and arkosic sands exposed at the northwestern end of the map area near the mouth of Bautista Canyon. A vertebrate fauna collected from these beds by him indicated a Pleistocene age. Sediments exposed near Vandeventer Flat and at the intersection of Horse Creek and Bautista Canyon later were included under the same name by Fraser (1931, p. 515). His correlation of these isolated exposures was based on their similarity in lithology and degree of induration to rocks of Frick's type area. The Quaternary deposits underlying Vandeventer Flat were renamed the Vandeventer formation by Lockwood (1961, p. 57). Inasmuch as these sediments both are lithologically similar to Bautista beds and formerly may have been geographically continuous with the type area through Garner Valley, the original name of Frick (1921) is herein retained.

Although only relatively fine-grained sediments have previously been included under the formational name, the Bautista beds are herein redefined to embrace both lacustrine strata and the coarser clastic deposits into which they grade laterally and vertically. The coarse lithologies range from pebbly sands to sandy gravels containing boulder-sized clasts. They are abundant in regions of high elevation in the central and northern parts of the map area and at all elevations in the southern part. Bouldery sands exposed between lower Coyote Canyon and Clark Valley have been mapped as Canebrake conglomerate by Dibblee (1954, pl. 2). Not only are these sediments similar in lithology and degree of consolidation to gravels stratigraphically higher than lacustrine Bautista beds in the central part of the map area, but they also include a lens of lacustrine beds containing two rhyolitic tuff layers identical to Bautista tuffs exposed north of Anza. Two beds of rhyolitic tuff exposed in the Pleistocene Temecula arkose several miles west of this map area have also been described by Mann (1955, p. 11). Although rhyolitic tuffs could have been deposited throughout much of Cenozoic time in this region, the only known occurrences are limited to Pleistocene deposits. That the Canebrake conglomerate is correlative in age with Pleistocene Bautista beds has also been established by Downs (1957).

Bautista beds lying between San Jacinto River and Bautista Creek were described as the type section by Frick (1921, p. 291). They are composed of at least 1000 feet of massively bedded, coarse arkosic sand with subordinate amounts of intercalated clays and silts. The typical pale buff color of the sands is similar to that of weathered tonalite outcrops which, through granular desintegration, have provided the bulk of the clastic debris. Spheroidally-weathered boulders set in a matrix of grus which is indistinguishable from the overlying sand beds are common along the basal contact. Lenses of sandy gravel occur sparsely throughout the section, but they are always of small lateral extent. Except for minor amounts of hard calcareous concretions, the sands are poorly consolidated.

Intercalations of brownish-gray gypsiferous clays and silts, as well as the paucity of gravels, indicate that the type section was deposited on a relatively flat basinal surface which periodically changed from a fluviatile to lacustrine environment. This facies variation probably occurred in response to contemporaneous warping or movement along the San Jacinto and related faults. In view of the fine grain size and the lack of a broad bouldery facies near the basal contacts, relief on the crystalline rock surface bordering the basin may have been relatively small in Bautista time.

Although Fraser (1931, p. 515) pointed out that Bautista beds exposed near the confluence of Bautista and Horse Creeks are lithologically similar to those of the type area, large parts of these deposits are pebbly to bouldery sands. The exposures recognized by Fraser lie at the northwest end of a sediment-filled, pre-Bautista trough extending southeastward to the vicinity of Hog Lake. In its upper parts, this valley drained the same area that Bautista Creek does at present. South of that point, the trough widens into a much broader sediment-filled basin underlying Anza and Terwillinger Valleys. Fine sands, silts, and clays compose a large part of the exposed Bautista sediments southeast of Hog Lake Road. At least 8 unconsolidated rhyolitic tuff beds associated with thinly bedded silt and clay beds are exposed in the badlands, a mile southeast of Hog Lake Road. At least 2 beds of a similar tuff are exposed nearly midway between Baisley Creek and Cottonwood Canyon about 1 1/2 miles southwest of the San Jacinto fault. The tuffs are composed almost entirely of silt-sized glass fragments ($n \approx 1.495$) in the beds least diluted with other clastic material. Because of their short lateral extent and the large number of individual beds, the tuffs will not serve as marker units. However, they do indicate that folding and faulting have deformed the lacustrine beds in a complex way. At least 1500 feet of steeply-dipping lacustrine sediments are exposed along the badland ridges a mile southeast of Hog Lake road, but parts of this section may have been repeated by faulting. Southeastward from the southern boundary of Ramona Indian Reservation the lacustrine beds grade laterally and vertically into pebbly and cobbley sands which contain a variety of clasts derived from Thomas Mountain. The lithologies represented by the gravel clasts and their relationship to Quaternary displacement on the San Jacinto fault will be discussed later in this report.

Although Anza and Terwillinger Valleys probably are underlain mostly by sands or pebbly sands, a large part of the sedimentary filling may be composed of clays and silts. Small exposures of lacustrine beds occur at the eastern end of Terwillinger Valley and on both sides of the San Jacinto fault northeast of Anza. A rhyolitic tuff layer a few inches thick is interbedded with silts and sands at the former location.

Both coarse and fine sediments, here assigned to the Bautista beds, are exposed intermittently along the northeast and southwest margins of Garner Valley in the northern part of the map area. Prior to Bautista deposition, a southeast-trending valley extended from the vicinity of Mountain Center through Garner Valley to southern Vandeventer Flat. Spurs of bouldery gravels at least 800 feet thick at Keen Ridge project from the San Jacinto Mountains into northern Garner Valley. Most of this material was probably derived from the San Jacinto Mountains inasmuch as Bautista beds resting on slopes west of Garner Valley are primarily sands. Southeast of Vandeventer Flat bouldery gravels mantle ridges up to the base of the southern face of Santa Rosa Mountain. Although these high gravels presumably extended over Vandeventer Flat and possibly coalesced with the gravel spurs east and northeast of Garner Valley, most of the coarse sediments have been eroded away. Underlying finer deposits are composed predominantly of sand, silt, and clay beds. A thickness of about 400 feet of these sediments is exposed in the badlands southwest of Vandeventer Flat, but their total original thickness probably was much greater. A few very thin but laterally extensive beds of a light-gray color exposed in the bluff at the eastern margin of the badlands are rhyolitic ash beds diluted with large amounts of non-volcanic clastic debris.

Inasmuch as the Bautista sediments dip gently northeastward beneath Vandeventer Flat, no known major faults displace them, and the underlying crystalline rock surface is lower in elevation south of Lookout Mountain than at northeastern Vandeventer Flat, the direction of sedimentation probably had a southwestward component. No internal structures indicating directions of sedimentation were observed in the massive deposits.

Bouldery gravels and pebbly sands resting with depositional contact on crystalline rocks north of Burnt Valley dip gently to the southeast and, at depth, grade into massively bedded sand and silt deposits exposed in badlands between Lookout and Table Mountains. The badlands exposures are at least 800 feet in maximum thickness and are lithologically identical to the sediments underlying Vandeventer Flat. Although bedding is moderately tilted near the Horse Canyon thrust, dips are gentle toward the northeast over most of the badlands area. A fragmented fossil horse tooth recovered by the author from sediments in Horse Canyon was identified by Dr. R. H. Tedford of the University of California at Riverside (1964, personal communication) as very likely Equus. In his opinion, it is comparable to teeth found in the San Timoteo and Bautista formations. A vertebrate fauna previously recovered near Vandeventer Flat also indicated a Pleistocene age (Lockwood, 1961, p. 59).

Bouldery gravels herein assigned to the Bautista beds are widely distributed in the southern half of the map area. Because the gravels cap the highest topographic features as well as lower erosional surfaces within individual fault blocks, local relief of the pre-Bautista surface must have been at least as large as it is today. Nearly flat-lying coarse deposits formerly extended from the southern face of Santa Rosa Mountain southeastward across Clark Valley to the south end of the Santa Rosa Mountains. Toward the south and southwest the gravels mantled both Buck and Coyote Ridges but probably did not extend much farther west than Coyote Creek. Sandy accumulations possibly correlative with the Bautista beds occur at scattered places west of Coyote Canyon between Terwillinger Valley and Borrego Valley, but the gravels and pebbly sands are exposed only in the area east of the canyon. Steep and locally overturned attitudes found in deposits along the eastern margin of Coyote Canyon suggest that alluvium within the canyon is underlain by gravels correlative with those capping Coyote Ridge (section B-B', Pl. 2).

Fine clastic sediments are much less widespread in the southern half of the map area than in the northern part. Deformed silt and clay beds are exposed locally east of Clark Lake and presumably underlie much of Clark Valley. The thickness of sedimentary fill under Clark and Borrego Valleys may be as much as 5000 feet (Biehler, 1964, personal communication). At higher elevations in the southern part of the map area, lacustrine beds occur only as relatively thin lenses. Two miles east of Santa Catarina Spring, silt beds contain two intercalated rhyolitic tuff beds identical in lithology and degree of consolidation to the ash beds already described.

Massive beds of poorly consolidated coarse sands are exposed in Box Canyon, east of Ocotillo Flat, in Rockhouse Canyon, and on the east wall of Alder Canyon. These beds grade laterally and vertically into cobbley sands and gravels which form the bulk of the deposits. Sands and pebbly sands in the lower part of the section exposed between Ocotillo Flat and Box Canyon fault are moderately folded. The intensity of deformation diminishes upward in the overlying gravels. Although deformation appears to have been contemporaneous with deposition, no marked unconformities were observed within the sedimentary section.

Although the Bautista gravels are poorly bedded and do not exhibit obvious directional structures in the southern part of the map area, some parts of the former drainages can be reconstructed through the distribution of gabbro and norite clasts in the gravels. Because exposures of gabbro are limited to the central part of Buck Ridge and a large part of the Santa Rosa Mountains, occurrences of gravel clasts of that composition near lower Box Canyon suggest that drainage was southwestward during at least part of Bautista time and that Dry Wash was bridged by gravels. Similarly, gabbro clasts in gravels near White Wash show that sedimentation was northwestward either from a source area on Buck Ridge or the Santa Rosa Mountains. That gravels were not preserved west of Coyote Canyon suggests that area was structurally high and was subjected to erosion during Bautista time. Thus the present course of Coyote Canyon probably coincides in location with its ancestral counterpart in Bautista time.

TERRACE DEPOSITS

Although deposition of clastic material probably has been continuous through all of Quaternary time up to the present in some parts of the map area, post- Bautista time generally has been characterized by widespread erosion associated with broad uplift of the entire eastern Peninsular Range region. In this time interval, much of the pre-Bautista landscape has been exhumed. Thin terrace gravels and sands overlying surfaces developed in this erosional cycle rest unconformably on crystalline rocks and

Bautista beds. Where underlying Bautista sediments have not been deformed, the distinction between them and terrace deposits is difficult because of their lithologic similarity and conformable contacts. However, preserved depositional terrace surfaces at elevations lower than Bautista beds in the immediate vicinity allow them to be differentiated. Where no depositional surfaces are preserved, terrace deposits may locally have been included with the Bautista beds. Terrace gravels resting on crystalline rocks are indistinguishable from Bautista gravels except where they are associated with an erosional surface whose age is known to be post-Bautista from independent evidence. In general, the terrace deposits are higher than Recent alluvium and are little deformed.

RECENT ALLUVIUM

Inasmuch as the lithologic variations and the degree of consolidation of all of the quaternary deposits are essentially identical, no age distinction can be made on those bases. The assignment of Recent age to alluvium is herein based on its being actively transported or deposited at the present time.

POST-INTRUSION STRUCTURAL FEATURES

Faulting, primarily along northwest-southeast lines, has dominated the post-batholithic deformation of the rocks within the map area. Although intense folding on a small scale can be documented locally in exposures of Quaternary sediments, it is difficult to determine exactly to what degree underlying crystalline rocks have similarly responded to deformational forces.

As used herein, the term "fault" is defined as a fracture having one of the following properties: (1) In areas of exposed bedrock: A tabular zone of variable thickness within which shearing has been both intense and localized, and within which the products of shearing (gouge) generally have accumulated to some degree; (2) In areas of no bedrock exposure: (a) A surface of shearing delineated at ground level by a trace along which occurs any combination of physiographic features of faulting, either primary or secondary in origin (Sharp, 1954); or (b) a surface marked by gouge development in relatively unconsolidated sediments. Inasmuch as condition (1) prevails in much of this area, this fault definition is of primary importance. The restrictive nature of this definition serves to distinguish zones of differentially concentrated fault displacement from the broader enclosing zones of pervasive but less intense deformation typically characterized by brecciation. The gouge zones of definition (1) generally coincide with contacts between juxtaposed rocks of contrasting lithology.

SAN JACINTO FAULT ZONE

REGIONAL FEATURES

The San Jacinto fault zone includes a belt of generally steeply-dipping subparallel and interlacing fractures extending southeastward from the northern slope of the San Gabriel Mountains across the San Bernardino Valley and the Peninsular Ranges to Imperial Valley (Fig. 1). Divergent branching in the southeastward direction is characteristic along much of its length, particularly in the following areas: (1) at its point of origin near Valyermo where it appears to be a slightly divergent branch of the San Andreas fault zone (Noble, 1954a); (2) along the eastern margin of San Jacinto Valley where there is doubt as to the identity and location of the main break among its various branches (Bean, et al., 1959; Proctor, 1962); and (3) east of Anza within the map area.

Because of splaying of the fault zone, nomenclatural problems are introduced. If all the branches are considered as defining the fault zone, the name San Jacinto fault best applies to the linear trace of most recent activity, according to the "master break" concept of Noble (1926, p. 416, 417) and A n (1957, p. 337). Because several of the branches show evid of Recent activity within the present map area, the "master br ' is herein considered to be the fault on which displacement n nearly coincides with the total displacement across the zone ndeed, where such information is available, this definition shou nerally be preferred over one based on relative recency of mov nt, particularly in view of the interpretive nature of age as observed in the field.

In spite of the southeastward splaying of the San Jacinto fault zone, certain branches within it exhibit remarkable straightness along much of their length, particularly south of the San Gabriel Mountains. This straightness, in combination with a significantly greater seismicity than that associated with other major fault zones in southern California, suggests that much of the regional right-lateral shear strain along the San Andreas fault zone currently may be relieved on the San Jacinto fault (Allen, 1957, p. 346).

Topographic evidence of Recent right-lateral displacement on the San Jacinto fault has been cited by Jahns (1954a, p. 45). Seismic data are also consistent with right-lateral movement on all of the northwest-trending faults in the northern Peninsular Ranges (Dehlinger, 1952, p. 171). Although two of the most intense earthquakes centering in southern California (1899 and 1918) were associated with the San Jacinto fault, clear evidence of ground displacement, other than cracking and local areas of subsidence, was lacking (Claypole, 1900; Danes, 1907; Rolf and Strong, 1918).

NOMENCLATURE AND PREVIOUS WORK

The earliest investigations relating to the then-unnamed San Jacinto fault were concerned with effects of the earthquake of December 25, 1899 near Hemet (Claypole, 1900; Danes, 1907). Following the San Francisco earthquake of 1906, reconnaissance of the San Andreas fault and other prominent faults in California led to the mapping and naming of the San Jacinto fault by Lawson _et al._, (1908, p. 47, 48). At that time, the San Jacinto fault was thought to extend continuously from the southwestern face of Coyote Mountain northwestward to the southwestern margin of the San Jacinto Mountains. Beal (1915, p. 136) first located the trace of the San Jacinto fault along the drainage of Dry Wash and Clark Lake, essentially as shown in Plate 1 of this report. The fault was thought by Beal (1915) and Kniffen (1932) to extend southeastward to the region near the head of the Gulf of California.

Subsequent investigation of faulting within the present map area was conducted by Townley (1918), Rolfe and Strong (1918), Arnold (1918), Brown (1922), Eckis (1930), Fraser (1931), Osterholt (1934), Dibblee (1954), and Jahns (1954b). Although several of these authors introduce new names for some of the faults, most have followed the nomenclature of Lawson _et al._, (1908) and Eckis (1930).

Hydrologic evidence obtained in connection with ground water studies in San Jacinto Valley (Bean _et al._, 1959) has provided additional data on the extensions of the San Jacinto fault under valley alluvium and has pointed up problems of concealed branching. Similar studies in the region of Anza Valley (Bookman _et al._, 1956, p. 73) suggest possible ground water damming several miles west of the San Jacinto fault.

ORDER OF PRESENTATION IN THIS REPORT

Inasmuch as a number of branching fractures of the San Jacinto fault zone lie within the map area but are clearly distinct from the master break, these will be discussed briefly before returning to the major problems of the master break itself.

COYOTE CREEK FAULT

Nomenclature and Previous Work

The northwest-trending fault lying along the eastern margin of Coyote Canyon has been called the San Jacinto fault by many previous workers in this area (Brown, 1922; Eckis, 1930; Dibblee, 1954). Inasmuch as this name will herein be applied to the subparallel fault 3 to 5 miles to the northeast for reasons to be described below, the break in Coyote Canyon is termed the Coyote Creek fault, following the nomenclature of Hill (Arnold, 1918). This structure has also been called the Coyote fault by Osterholt (1934).

Features of the Fault Trace

The Coyote Creek fault lies near the base of the relatively straight, southwest-facing scarp bordering Coyote Canyon between Turkey Track and Coyote Mountain. Southeast of Monkey Hill in northern Collins Valley, the fault is exposed only near lower Box Canyon, but its trace is marked elsewhere by a prominent furrow in crystalline rocks northwest of Box Canyon, by ridge notches and hillside benches in Bautista beds southeast of Box Canyon and by the southwest-facing scarp of Coyote Mountain. Exposures of the fault near lower Box Canyon indicate a steep northeastward dip, and the straightness of the aligned topographic features also suggests a near vertical orientation of this entire segment. Near Monkey Hill the fault bends to a more northerly trend, but a branch that is aligned with the fault trace to the southeast continues into Collins Valley. The straight branch of the fault probably dies out beneath Collins Valley alluvium inasmuch as it does not reappear on the west side of the valley, but it could also curve northward to Middle Willows and possibly farther up Coyote Canyon.

Between the latitudes of Monkey Hill and Middle Willows the Coyote Creek fault is delineated by hillside benches, aligned gullies, and notches in ridges near the base of the southwest-facing scarp. The straightness of the trace over ridges and gullies suggests that this segment is nearly vertical. Northwest of this interval, the Coyote Creek fault is a complex zone of curving fault branches which converge from the east and turn northwestward into subparallelism with Coyote Canyon. In this zone the westernmost exposed break, which at many locations marks the boundary between crystalline rocks and unconsolidated sediments, is considered to be the master fault. At several localities shattered crystalline rocks rest with thrust fault contact on Bautista sands or terrace deposits. Near Middle Willows, Bautista beds have been steeply overturned beneath the thrust (section B-B', Pl. 2). That the fault steepens with depth, at least near Middle Willows, is shown by dip measurements that are greater in canyons than those observed on exposures on ridges. Immediately north of Middle Willows, no single continuous fault has been mapped, although several gouge zones of limited extent occur within a broad zone of pervasively shattered rocks.

Northwestward from Fig Tree Valley the Coyote Creek fault lies mostly beneath alluvium. Both it and faults converging with it from the east must die out near Turkey Track because neither displaced contacts, crushed zones, nor topographic evidence of faulting occur in the crystalline rocks exposed farther northwest. It is possible that a concealed fault branch extending down lower Horse Canyon connects the San Jacinto fault and the Coyote Creek fault, approximately as shown by Jahns (1954a, Pl. 3). However, because crush zones exposed in the walls of lower Horse Canyon are distinctly misaligned with the trend of the canyon and because the foliated marginal phase of the Coahuila Valley pluton is not offset, the existence of such a fault is questionable.

Deep canyons carved in thoroughly shattered crystalline rocks expose many of the branch faults which diverge eastward from the northern third of the Coyote Creek fault. Most of these structures are subparallel to the Coyote Creek fault at the west, but their traces curve to a northeastward trend generally within a mile. Steepening of dips eastward and at higher elevations suggests that some of the fault surfaces are doubly curved about "centers" toward the northwest. The northeast-trending faults apparently do not extend across or displace the San Jacinto fault.

Exposures of the Coyote Creek fault and its curving branch faults typically exhibit a sheet of dark gray, clayey gouge several inches to a few feet in thickness. The crystalline rocks bordering the gouge zone generally are pervasively shattered for a few tens of feet away from the fault. Due to the relatively close spacing of shear zones cutting the Coyote Creek fault scarp near Middle Willows, the layer of shattered rock is several hundred feet thick. Fault exposures lying entirely within Bautista beds near Box Canyon are generally marked by a gouge zone composed of dark-gray clayey material a few inches thick.

Three springs occur along Coyote Creek at those points where crystalline rocks constrict the width of the canyon. Although the springs at Middle Willows and Fig Tree Valley could possibly be due to ground water damming along a concealed fault, Santa Catarina Spring cannot be related to any fault. Tilted gravels southwest of the Coyote Creek fault suggest that upwarping of the crystalline rock surface beneath the alluvium has constricted the canyon and dammed ground water at Santa Catarina Spring. Presumably the springs higher in the canyon have similar origins.

Displacement and Age

The broad erosional surface developed over much of Coyote Ridge was mantled by Bautista Gravels after formation of a southwest-facing scarp on the Coyote Creek fault. The height of the pre-Bautista scarp was at least 500 feet near Middle Willows and about 1000 feet at Coyote Mountain, but some of this relief probably was due to erosion in crushed rocks along the fault zone subsequent to the raising of Coyote Ridge. The broad erosional surface capping Coyote Ridge may have corresponded in pre-Bautista time to the lowest parts of a broad step-like surface intermittently preserved on ridges west of Coyote Canyon. Deposition of Bautista gravels in the trench eroded along the fault zone as well as on the higher surface was then followed by renewed uplift and overthrusting on the Coyote Creek fault. This uplift amounted to possibly a few hundred feet near Middle Willows and probably at least 900 feet near Ocotillo Flat. Bautista beds were dragged into steeply dipping and overturned orientations at several points along the fault.

During the regional uplift which followed this episode of faulting on the Coyote Creek fault, much of the Bautista deposits were stripped from the erosion surface on Coyote Ridge and the pre-Bautista trench along the fault. Terrace deposits related to the lowered base level of Coyote Creek rest unconformably on deformed Bautista beds near Middle Willows. After terrace deposition a new episode of uplift and thrusting on the Coyote Creek fault raised crystalline rocks over the terrace deposits at Middle Willows and caused additional upwarping by drag on the southwestern block. At Box Canyon crystalline rocks of the southwest block have been raised against Bautista sediments. Constriction of Coyote Canyon resulting from the upwarping has caused ground water damming at three locations and formed a closed depression on the hill between Collins Valley and the Coyote Creek fault. Reduction of the gradient of Coyote Creek and its tributaries from the west produced by the upwarping has caused accumulation of sandy alluvium over most of Collins and Fig Tree Valleys. That these relatively flat-bottomed valleys are deeply reentrant into steep-walled canyons west of Coyote Creek indicates the former stream channels have been deeply buried by alluvium. A similar reentrant relationship of sand-bottomed canyons shows the western margin of Borrego Valley is also being drowned by alluvial deposition.

Evidence for lateral components of displacement along the Coyote Creek fault is limited to discontinuity of crystalline rock bodies and a single exposure of subhorizontal slickensides observed in Box Canyon. A tuff bed exposed east of Middle Willows is broken by several faults subparallel to the Coyote Creek fault. Although small right-lateral separations are evident, the displacements are unknown. A significant right-lateral component of displacement as indicated by the distribution of crystalline rocks across the Coyote Creek fault will be discussed below with the displacement on the Box Canyon fault.

That the Coyote Creek fault dies out near Turkey Track indicates strain must have been absorbed on associated faults, in pervasive brecciation of the crystalline rocks, or both. The orientation of the normal faults on northwestern Coyote Ridge suggests that some of the movement on the Coyote Creek fault may have been relieved on them and on the San Jacinto fault zone northwest of White Wash. Indeed, tensional faults would be expected between en-echelon, strike-slip faults of this orientation and sense of movement.

The faults crossing northwestern Coyote Ridge are of at least two ages (section E-E', Fig 2). An older, shallow-dipping fault of unknown displacement forms part of the lower contact of the Coahuila Valley pluton. Gravels of Bautista age that lie across this fault along the crest of Coyote Ridge are not displaced by it. The younger set of normal faults displace both the gravels and the older fault. Although some of these post-Bautista faults are nearly vertical near the crest of Coyote Ridge, their dips decrease significantly toward the west and at lower elevations. The pre-Bautista fault actually forms the southern contact to the Coahuila Valley pluton but foliation in its border phase indicates the faulting has probably taken place on the surface of the intrusive contact. Although the magnitude of the displacement on this fault is unknown, the small thickness of gouge developed at this contact suggests it is not great. The sense of displacement is inferred from the younger set of faults which are similarly oriented and exhibit shallow dips at depth.

Summary of Geologic History along the Coyote Creek Fault

1. Faulting older than any element of the present landscape.
2. Erosion of surface of low relief on Coyote Ridge and west of Coyote Canyon.
3. Uplift of Coyote Ridge.
4. Erosion of Coyote Canyon and its tributaries.
5. Deposition of Bautista sediments in Coyote Canyon up to and above the erosional surface on Coyote Ridge.

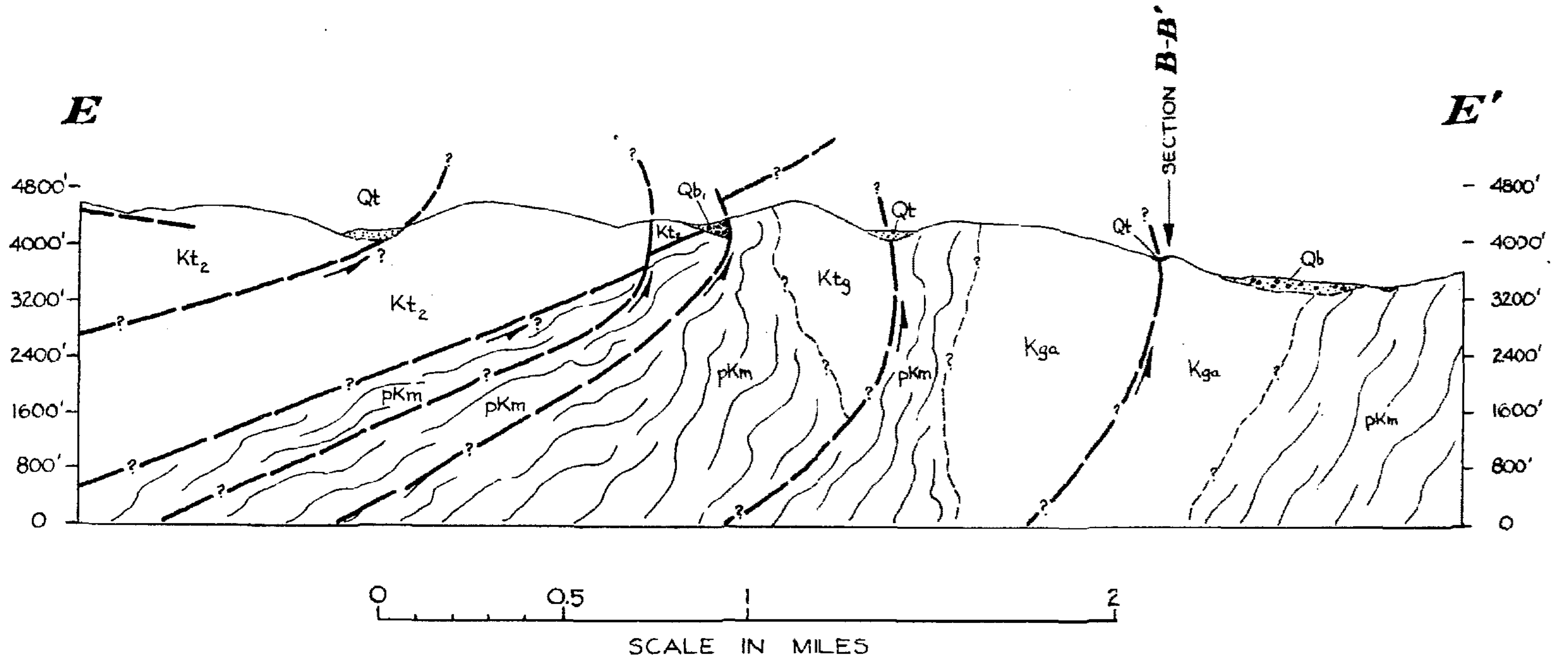


FIG. 2

AGE RELATIONSHIPS OF NORMAL FAULTS ON NORTHERN COYOTE RIDGE

SYMBOLS EXPLAINED IN PLATE 1

6. Uplift and overthrusting of Coyote Ridge on Bautista beds. Overturning of some of the latter beneath the thrust.
7. Regional uplift with exhuming of Bautista sediments.
8. Deposition of terraces on deformed Bautista beds in Coyote Canyon.
9. Uplift and thrusting of Buck Ridge over terraces in Coyote Canyon. Upwarping of the southwest block near Santa Catarina Spring.
10. Erosion or deposition in various parts of Coyote Canyon in response to continued fault movements and local warping.

BOX CANYON FAULT

Nomenclature and Previous Work

The fault subparallel to and about 1 mile east of the Coyote Creek fault between Box Canyon and Alcoholic Pass was originally recognized and named the San Jacinto fault by Lawson et al., (1908, p. 47). They believed this fault was continuous from the southwest scarp of Çoyote Mountain northwestward to Horse Canyon. Inasmuch as this continuity does not exist and the master break lies a few miles to the east, this fracture is herein renamed the Box Canyon fault.

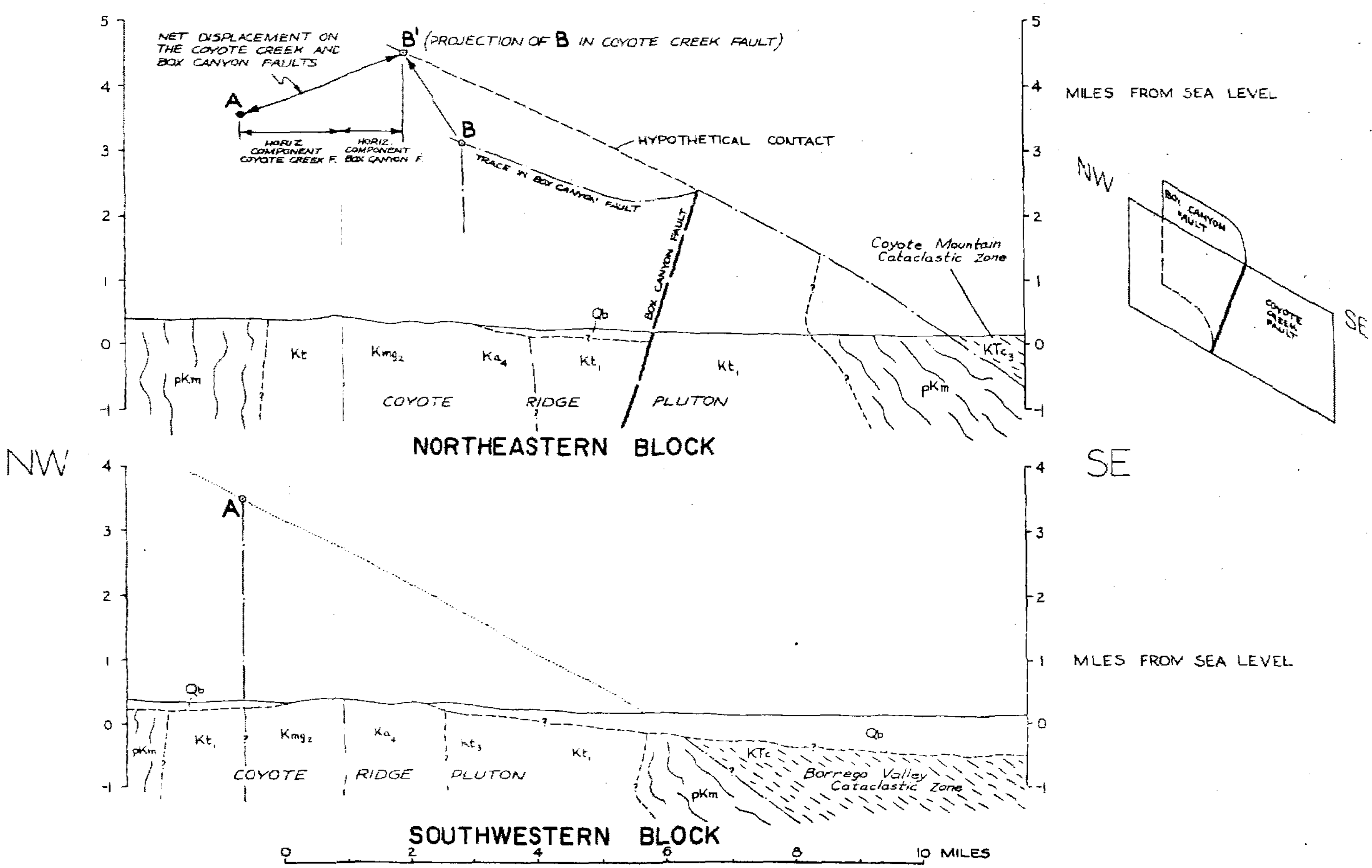
Features of the Fault Trace

A prominent southwest-facing scarp marks the trace of the Box Canyon fault for about 1 1/2 miles northwest of Alcoholic Pass. The relief of the scarp is largely due to erosion of Bautista sediments southwest of the fault. Good exposures of a gouge zone along the southern part of the trace indicate vertical to moderate southwestward dips on the fault surface. Gouge exposed along the trace in Box Canyon dips moderately to steeply northeastward. For a mile southeast of Box Canyon, gullies are eroded along the trace. Farther southeast, remnants of a broad terrace surface conceal the trace and indicate that the fault is not presently active (section C-C', Pl. 2).

Displacement on the Box Canyon and Coyote Creek Faults

Fault surface sections showing the distribution of crystalline rocks at depth on both blocks of the Coyote Creek fault are shown in Plate 3. Because the Box Canyon fault converges with the Coyote Creek fault toward the southeast, the displacement of the two faults are shown together. A unique point defined by the intersection of the gradational boundary separating inclusion-rich and poor phases of the Coyote Ridge pluton and the gradational contact between the Coyote Mountain cataclasites and undeformed crystalline rocks was located in the Box Canyon fault surface (point B in Pl. 3). In this construction the inclusion-defined boundary was assumed to be vertical. The point of intersection was then projected into the Coyote Creek fault along the line of

PLATE 3



GENERALIZED FAULT SURFACE SECTIONS ALONG THE COYOTE CREEK FAULT

1. Dotted line represents contact whose slope is taken from opposite fault block.
2. Other symbols are explained in Plate 1.
3. Only major Quaternary deposits have been shown.
4. Lettered points are explained in the text.

intersection of the two contacts (point B' in Pl. 3). In the fault surface section for the southwestern block a corresponding point of intersection between the inclusion-defined contact within the Coyote Creek pluton and the contact of the cataclastic rocks exposed west of Borrego Valley was located (point A in Pl. 3). The location of A was determined by using the same slope observed on the contact of the cataclastic rocks on the northeastern block. This construction requires that no large-scale rotation has taken place on the Coyote Creek fault. Averages of dip components parallel to the fault surface taken from attitudes in the cataclasites on both blocks indicate that rotation along large segments of the faults probably has been negligible.

According to this construction, the horizontal component of displacement on the Box Canyon and the Coyote Creek faults has totaled about 2 2/3 miles in the right-lateral direction. This component is composed of about 1 2/3 miles of movement on the Coyote Creek fault and 1 mile on the Box Canyon fault. The block northeast of the Box Canyon fault has been raised about 1 mile relative to the block southwest of the Coyote Creek fault. Quaternary deposits southwest of the Box Canyon fault suggest that at least 800 feet of vertical movement has occurred on that fault. However, pre-Quaternary vertical movements on the Box Canyon fault could have been reversed in sense, and the net offset could be less than this amount.

BUCK RIDGE FAULT

Nomenclature and Previous Work

The San Jacinto fault was thought to extend between the southwestern base of Thomas Mountain and southeastern Burnt Valley by Fraser (1931). Farther southeast he considered the San Jacinto fault to bifurcate and the unnamed eastern branch to continue in line with the trace in Burnt Valley. The name Buck Ridge fault was later applied to this branch north of Clark Valley by Dibblee (1954, p. 26).

Features of the Fault Trace

Between southeastern Burnt Valley and the point of its convergence with the San Jacinto fault, the Buck Ridge fault is delineated by faceted spurs and canyons eroded along its trace. No exposures of the fault surface were found in this segment.

Between Lookout Mountain and Garnet Queen Creek, the Buck Ridge fault is marked by gullies eroded along the trace and by a low, south-west-facing scarp. An exposure of the fault in Bautista sands shows a moderate northeastward dip. On the north bank of Garnet Queen Creek, a zone of crushed metamorphic rocks several tens of feet thick indicates a near vertical dip on the fault.

Southeast of Garnet Queen Creek to Nicholias Canyon the trace is delineated by aligned canyons and a low side-hill ridge on the southwest-facing slope of Toro Peak. At several points alluvium has accumulated behind the ridge. Springs aligned on the fault trace indicate ground water damming.

Between Nicholias Canyon and upper Rockhouse Canyon, there are no obvious topographic expressions or exposures of the fault. However, its continuity is suggested by the presence of faults aligned with its projected trace near the head of Rockhouse Canyon.

About 3/4 of a mile north of the San Diego County line, the Buck Ridge fault is offset slightly by another fault. Southeast of this point the trace of the Buck Ridge fault is mostly concealed by Bautista gravels. It curves nearly to an eastward trend at the margin of the map area, and, about 1 mile farther east it is again exposed in a gouge zone. At that point it has a shallow northward dip. Exposures in the deeply incised canyons on the southwest face of the Santa Rosa Mountains farther east do not suggest the presence of the Buck Ridge fault as a single zone of shear. Instead, a broad area of pervasively shattered rock lies along the eastward projection of the fault. There is no obvious evidence that this fault or related faults extend in a southeastward direction into Clark Valley, as indicated by Eckis (1930) and Dibblee (1954).

Displacement and Age

Because Bautista sediments and younger deposits conceal contacts between intrusive and metamorphic rocks near Burnt Valley, their separation on the Buck Ridge fault can only be estimated. Possible separation of the Horse Canyon pluton and the Santa Rosa pluton ranges from 1.6 to 6 miles in the right-lateral direction. Adamellitic rocks on Lookout Mountain may be separated less than 2 miles or more than 4 miles and not be observed on the southwestern block. Because a large lateral displacement on the Buck Ridge fault is not demanded by the known distribution of crystalline rocks and indeed would increase dimensional incompatibilities in correlating across the San Jacinto fault, a separation of less than 2 miles is assumed.

The contribution of a net vertical component of displacement on the Buck Ridge fault in separating contacts of crystalline rocks is unknown. If the intrusive contacts dip northward or northwestward subparallel to foliation in the metamorphic rocks, the separations are compatible with downward displacement of the northeastern block. However, southwest-facing scarps about 75 feet high south of Lookout Mountain and several tens of feet in height northwest of Nigger Jim trail indicate that relatively recent displacement has raised the northeastern block. Inasmuch as reversals of vertical offset are widespread along the length of the San Jacinto fault, similar occurrences on the Buck Ridge fault are not unreasonable.

The apparent offset of Bautista sediments near Lookout Mountain is largely due to the shape of the pre-depositional basin and subsequent erosion. Bouldery gravels exposed less than a mile southeast of the intersection of Garnet Queen Creek and the Buck Ridge fault suggest the Horse Canyon unit stood as a positive mass in part of Bautista time. The shape of the basin thus may have been partially controlled by earlier faulting. In addition, most of the northwestern half of the Horse Canyon pluton and much of Lookout Mountain were overlain by Bautista sediments. The southeastern contact of Bautista beds probably has migrated about 3 miles toward the northwest as exhuming of the Horse Canyon unit has progressed. Erosional shifting of the Bautista contact on Lookout Mountain probably has been about 1/2 mile in the southeast direction. The combination of these shifts has grossly enhanced the apparent offset of the Bautista sediments.

The five-mile segment of the Buck Ridge fault southeast of Vandeventer Flat exhibits no marked difference in elevations between the two sides. Displacement probably has been essentially horizontal since the development of the erosional surface on the crystalline rocks.

Southeast of this interval, the Buck Ridge fault juxtaposes Bautista sediments on the southeast block and crystalline rocks on the northeast. Sediments on the northeast side of the fault form only a thin and discontinuous veneer. Although sediments have apparently been downdropped against crystalline rocks a few hundred feet, the amount and direction of post-Bautista displacement is unknown. At least one later episode of movement on part of this segment has raised the southeastern block and formed a side-hill ridge several feet high. This feature has been partially destroyed by erosion and concealed by alluvial deposition behind the ridge.

At its southeasternmost point in the map area, the Buck Ridge fault is concealed by sediments deposited in an east-trending trough. Crystalline rocks exposed north of the trough are about 150 feet higher than on the south. This difference in elevation dies out a short distance east of the map area.

Although the net displacement on the Buck Ridge fault is not exactly known at any point along its trace, the evidence suggests that it is not more than 2 miles. This amount probably diminishes towards the southeast, and the fault may die out east of the map area. The reversals in sense of vertical displacement along the length of the fault indicate its history has been complex and similar in many respects to the Coyote Creek fault. It contrasts with the latter fault in that its displacement probably diminishes southeastward and it has not been active in very recent time.

THOMAS MOUNTAIN FAULT

A fault thought to extend southeastward along the south fork of the San Jacinto River to the eastern margin of Thomas Mountain was named the Hot Springs fault by Arnold (1918) and later renamed the Thomas Mountain fault by Fraser (1931). That the isolated exposures observed by Fraser (1931, p. 518) lie along a single fault is questionable. Indeed, the existence of any major fault in the lower part of the south fork of the San Jacinto River is doubtful. The fault marked by a thick gouge zone exposed in the canyon west of Lake Hemet (Fraser, 1931, p. 518) strikes east-west, and there is no evidence that it turns to a more northwesterly trend at either end. At the southwestern corner of Lake Hemet, tonalite of the Thomas Mountain pluton has been thrust northward over unconsolidated sands of probable Bautista age at least a few tens of feet.

The northwest-trending fault exposed near the eastern base of Thomas Mountain is herein termed the Thomas Mountain fault, following Fraser's nomenclature. Because the fault lies entirely in tonalitic rocks at its only point of exposure, its sense of displacement is unknown. Its moderate southwestern dip as well as its approximate alignment with the eastern margin of southern Thomas Mountain suggests the possibility of thrust movement. Bautista beds resting with depositional contact along southeastern Thomas Mountain and Lookout Mountain are apparently not displaced. Thus, the Thomas Mountain fault and possibly other subparallel faults concealed in Garner Valley may have been inactive in post-Bautista time.

HOT SPRINGS FAULT

A fault branches eastward from the Claremont fault, which marks the boundary between the San Jacinto Mountains and San Jacinto Valley northwest of the map area, and extends southeastward across Baldy Mountain to northern Garner Valley. The segment lying northwest of Dry Creek was recognized and named the Hot Springs fault by Fraser (1931).

The Hot Springs fault in Dry Creek juxtaposes tonalites of the Thomas Mountain pluton on the northeast and Bautista sands and gravels on the southwest. The northeastern block has been relatively raised probably several hundred feet a short distance northwest of the fault's intersection with the creek.

An exposure of the Hot Springs fault west of Herkey Creek Camp on the Pines to Palms highway shows the Thomas Mountain pluton thrust northeastward over very coarse bouldery gravels of Bautista age. These poorly bedded gravels are preserved up to an elevation of about 5000 feet. The post-Bautista vertical movement has been at least 500 feet on eastern Baldy Mountain. The Hot Springs fault thus has a rotation displacement between eastern Baldy Mountain and Dry Creek. The horizontal component of displacement is unknown.

SAN JACINTO FAULT

In the following discussion of the San Jacinto fault, segments of the trace as shown in Plate 1 will be considered individually starting from the northwest. The first interval extends from San Jacinto Valley on the north to Hog Lake which lies about 4 1/2 miles on a line N25°W from the town of Anza. The second segment continues from Hog Lake to Hamilton Creek due east of Anza. The third segment runs from Hamilton Creek to the head of Dry Wash which lies about 12 miles on a line S63°E from Anza. The last interval extends from the head of Dry Wash to the southeastern limit of the map area.

Surficial Features of the Fault Trace

San Jacinto Valley - Hog Lake interval -- A zone of crushed crystalline rock several hundred feet thick is exposed nearly continuously in the aligned canyons and ridge saddles between Hog Lake and the intersection of Blackburn Canyon and Bautista

Creek (Pl. 1 and Pl. 4). Farther northwest in San Jacinto Valley the fault zone is mostly concealed by Quaternary alluvium. Recognizable scarps are generally lacking between San Jacinto Valley and Hog Lake although a low southwest-facing bank in the saddle near the head of Blackburn Canyon possibly is a scarp. Shutterridge-like topography is developed on the major spurs projecting southwestward from Rouse Hill and Horse Creek Ridge, but this may be principally an erosional effect in the crush-zone rather than a primary feature of displacement. Although most of the fault trace in this segment is being actively eroded at present, local areas of alluviation have concealed the fault trace within relatively recent time. These localities are also currently being dissected.

Inasmuch as the fault zone is several hundred feet broad and involves crushed material derived from the juxtaposed rocks, the trace of the fault as shown in Plate 1 represents the contact between contrasting types of rock. Because of the lack of metamorphic inclusions in the Thomas Mountain pluton near the fault zone, intermixing along the contact is known to be negligible. Greenish- to bluish-gray clayey gouge, usually in a sheet a few inches thick, lies in the steeply-dipping contact zone. Thinner bands of gouge found elsewhere in the crushed zone commonly are aligned with the fault contact, but in many cases are distinctly angular to it.

Near the intersection of Horse Creek and the San Jacinto fault, unconsolidated monolithologic gravels derived from the Thomas Mountain pluton rest with shallow-dipping contact on metamorphic rocks for a distance of a mile. The contact is marked

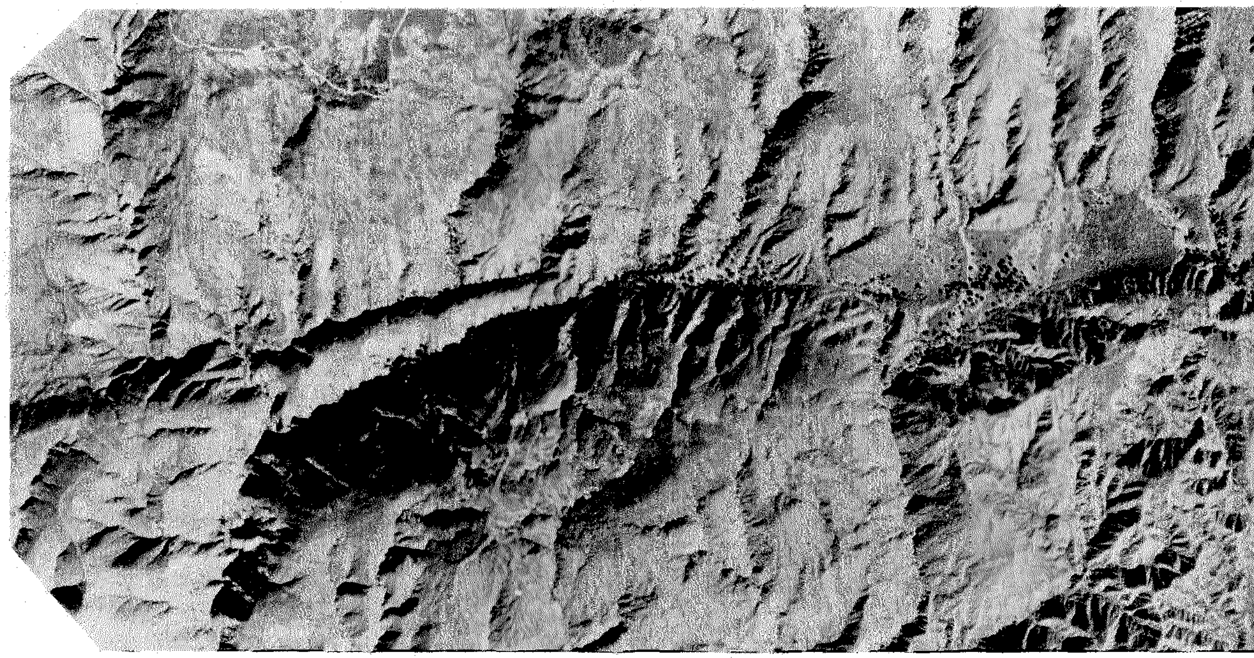


PLATE 4

Aligned canyons and drainage discontinuities along the trace of the San Jacinto fault between 2.1 and 5.0 miles northwest of Hog Lake. NE block is at top of air photo.

by a gouge zone that dips northeastward beneath the gravels toward the trace of the main fault. Although the contact could conceivably represent a depositional surface against a pre-existing scarp coated with gouge, the lack of fragments of metamorphic rock or gouge in the gravels suggests it is a contact resulting from fault movement.

Metamorphic rocks lying on the southwest side of the San Jacinto fault within about 3 miles of Hog Lake have been thrust over Bautista sediments and form a fault-slice ridge about 1/2 mile wide. This structure is herein named the Cottonwood Canyon thrust. Both the sinuous trace and dips measured on the thrust fault suggest that it either intersects the San Jacinto fault at relatively shallow depth or steepens and possibly intersects it at greater depth (section A-A', Pl. 2). The former maximum southwestward extent of the overthrust mass is unknown because a post-thrusting erosional surface bevels both it and the underlying sediments. This terrace surface is preserved on the ridge north of Cottonwood Canyon, along the Cottonwood firebreak, and possibly along much of the crystalline ridge southwest of the fault as far north as the hill northwest of Baisley Creek. A thin accumulation of terrace gravel locally caps this surface. The elevation range of the surface suggests possible correlation with an erosional bench preserved east of the fault along Horse Creek Ridge, on Baldy Mountain, and along much of the southwestern slope of the San Jacinto Mountains northwest of the map area (Fraser, 1931, p. 503).

Hog Lake - Hamilton Creek interval -- Southeast of Hog Lake the San Jacinto fault is delineated by aligned scarps and other abrupt topographic discontinuities beginning on the west side of the sag pond at Hog Lake and extending into and along Hamilton Creek. This segment of the trace has been called the Bautista fault by Fraser (1931) and Jahns (1954b). The fault cuts unconsolidated Bautista sediments and terrace deposits or is concealed by Recent alluvium. The strike of the trace in this segment is consistently N55^{o}W and it is parallel to the San Jacinto Valley - Hog Lake interval. Other fault traces expressed as subparallel scarplets indicate relatively young displacements east of the main fracture in the southern part of the Ramona Indian Reservation. These scarps are not laterally extensive, however.

Inasmuch as the projection of the San Jacinto Valley - Hog Lake interval lies slightly northeast of the exposed fault trace in this interval, the contact between the crystalline rocks of the two blocks presumably also lies a little northeast of the trace. The relatively young scarp represents presumably only the most recent break in a broad zone of shattered and pulverized crystalline rocks at depth. At the south end of this segment, the trace lies within a half-mile-wide zone of shattered metamorphic rocks and is marked by an increasing degree of crushing toward Hamilton Creek, whose course has been eroded along the fault zone.

A large part of this segment of the fault is marked by a low northeast-facing scarp in Quaternary deposits. The scarp crosses shallow transverse drainage lines along the base of the high southwest-facing scarp of Thomas Mountain. Within a mile of Hog Lake, the low scarp has been breached by a stream channel and buried under a fan currently forming at the mouth of a deep canyon in Thomas Mountain. This fan has similarly buried another scarp higher on the slope. The terrace surface on the southwestern block has been raised about 100 feet near Hog Lake, but the height of the scarp diminishes southeastward to about 20 feet near the south end of Ramona Indian Reservation. From the region of Hog Lake, the terrace surface capping the Bautista sediments on the southwestern block has been partially destroyed by both pre- and post-scarp badlands erosion. Southeast of the reservation, the fault trace is marked by shutterridges of pre-scarp ridge and gully topography carved in Bautista beds and the overlying terrace deposits (Pl. 5). Lateral displacements indicated by these shutterridges are discussed later in this report. In this area of shutterridge scarps the sense of vertical offset is reversed, and the intermittently preserved terrace surface on the eastern block is higher than on the west.

In the southeastern third of the Hog Lake - Hamilton Creek segment, the fault trace is mostly concealed by alluvium. However, an erosional furrow on the northeastern flank of a small hill underlain by Bautista beds marks the fault trace. The hill itself is elongate parallel to the fault zone, and, in view of its structurally high position relative to the surrounding areas, it probably is a fault-slice ridge. Low hills underlain by lacustrine Bautista sediments northeast of the fault trace are terminated abruptly along a line connecting the furrow and the mouth of Hamilton Creek.

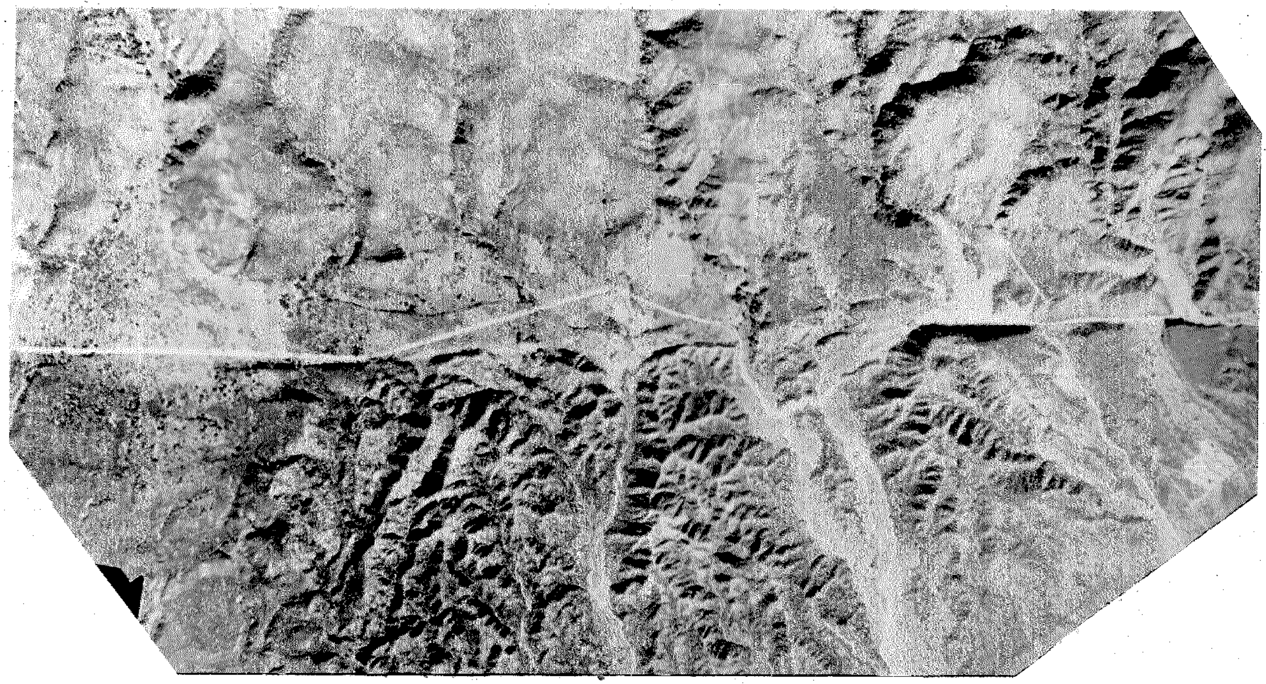


PLATE 5

Shutterridges and headless canyons along the trace of the San Jacinto fault between 0.3 and 3.8 miles southeast of Hog Lake. NE block is at top of air photo. Drainage is toward bottom of photo.

A gouge zone composed of dark-gray, clayey material is exposed on the fault trace in a road-cut just southeast of the Ramona Indian Reservation. The zone is about 2 feet thick and dips 70 degrees to the northeast. A near-vertical zone of crushed sandstone and siltstone about 15 feet thick is exposed in a stream bank at the south end of the fault-slice hill near Hamilton Creek.

The only presently closed depression along the fault in this interval is that occupied by Hog Lake. This depression is probably a sag pond resulting from relative subsidence between separate breaks within the fault zone. Other formerly closed basins of small dimensions lie immediately east of the fault trace about 1.25 miles southeast of Hog Lake and about 0.35 miles northwest of the mouth of Hamilton Creek. Both of these former basins are now barely drained.

That ground water has been dammed by the fault zone is shown by the presence of Hog Lake and several springs within and southeast of the Ramona Indian Reservation. Well levels are distinctly higher northeast of the fault zone (Bookman <u>et al.</u>, 1956 v. 2, p. G-37). Several areas that support a distinctive floral assemblage similar to that found near the springs also attest to a relatively shallow water table elsewhere along the fault trace.

<u>Hamilton Creek - upper Dry Wash interval</u> -- From the broad crushed zone into which Hamilton Creek has carved its course, the San Jacinto fault zone extends southeastward along the eastern margin of Table Mountain to the head of Dry Wash, essentially

as shown by Beal (1915). The northernmost 2.7 miles of this segment is marked by aligned trenches eroded in crushed metamorphic rocks and Bautista beds, by a very straight fresh scarp facing southwestward, and by abrupt drainage discontinuities along several branches within the zone (Pl. 6). The traces arc slightly from a strike of N55°W at Hamilton Creek to about N42°W at the head of Horse Canyon. Southeastward along Horse Canyon, the fault zone loses its identity as a distinctive topographic feature. The course of the canyon meanders through a zone of chaotically distorted and crushed metamorphic rocks to a point nearly a mile below the head of the canyon where the crushed rocks are exposed overlying relatively undisturbed Bautista sands. The southwestward-dipping contact is a thrust fault, herein termed the Horse Canyon thrust, that underlies the ridge paralleling the main fault zone along the southwestern margin of Burnt Valley. The thrust probably extends northwestward beneath the ridge to within 1/4 mile of Table Mountain road, at which point it presumably steepens and converges with the main fault zone.

Crushing in the overthrust mass is developed through a thickness of several hundred feet and extends upward into overlying tonalite of the Coahuila Valley pluton along the southwestern wall of Horse Canyon within a mile of its head. The contact between the tonalite and metamorphic rocks is exposed farther southeast as a southwestward-dipping thrust fault, herein named the Table Mountain thrust. This fault converges northwestward with Horse Canyon at a point where it is nearly aligned with the most southerly topographic expressions of the San Jacinto fault zone.

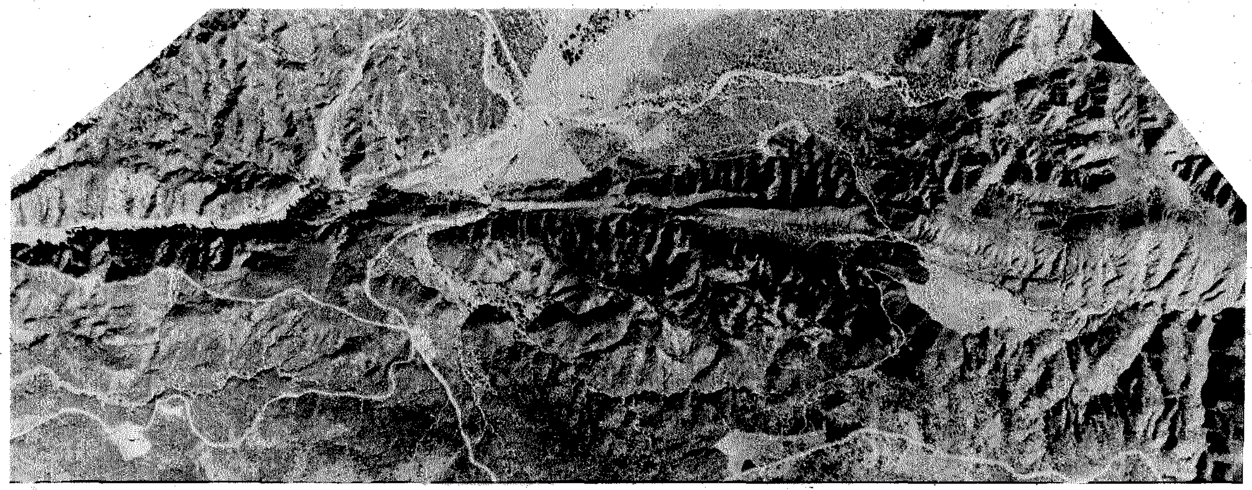


PLATE 6

Aligned canyons and drainage discontinuities along the trace of the San Jacinto fault between 0. 2 and 3. 2 miles southeast of the mouth of Hamilton Creek. NE block is at top of air photo.

The fault surface of both thrust faults probably steepens with depth, but, regardless of the curvature at depth, the trend of the faults is necessarily more southerly than it is farther northwest (Fig. 3). The strike of the trace of the Horse Canyon thrust where it crosses to the southwest wall of Horse Canyon is observed to be about N30°W.

The Horse Canyon thrust segment dips 42° beneath Table Mountain where it crosses upper Horse Canyon. To the north and northeast, the fault surface generally becomes flatter, passes through the horizontal, and locally reverses its dip. The strike swings from a northwest direction in the lowest exposures to about ENE near the exposures nearest the toe of the thrust. The contact is thus an extremely irregular surface, and the toe of the thrust extends at least a half mile northeast of the steepest-dipping exposures (Fig. 3). Post-thrusting erosion has deeply dissected both the thrust sheet and the underlying Bautista sediments. At least 11 klippen, the largest of which is about 1/4 mile in length, are preserved on badlands ridges. The exposed local relief on the thrust surface is over 500 feet. Some of the irregularity of the thrust surface may be due to post-thrust faulting which cuts the surface, but no definite evidence of this is known. Inasmuch as all the known reversals of dip and marked variation of strike occur in the higher part of the sheet, the thrust surface may in part be controlled by pre-thrust slopes eroded on Bautista sediments. Inhomogeneities in the strength of various beds in the sedimentary section relative to the strength of the overthrust material could be reflected in

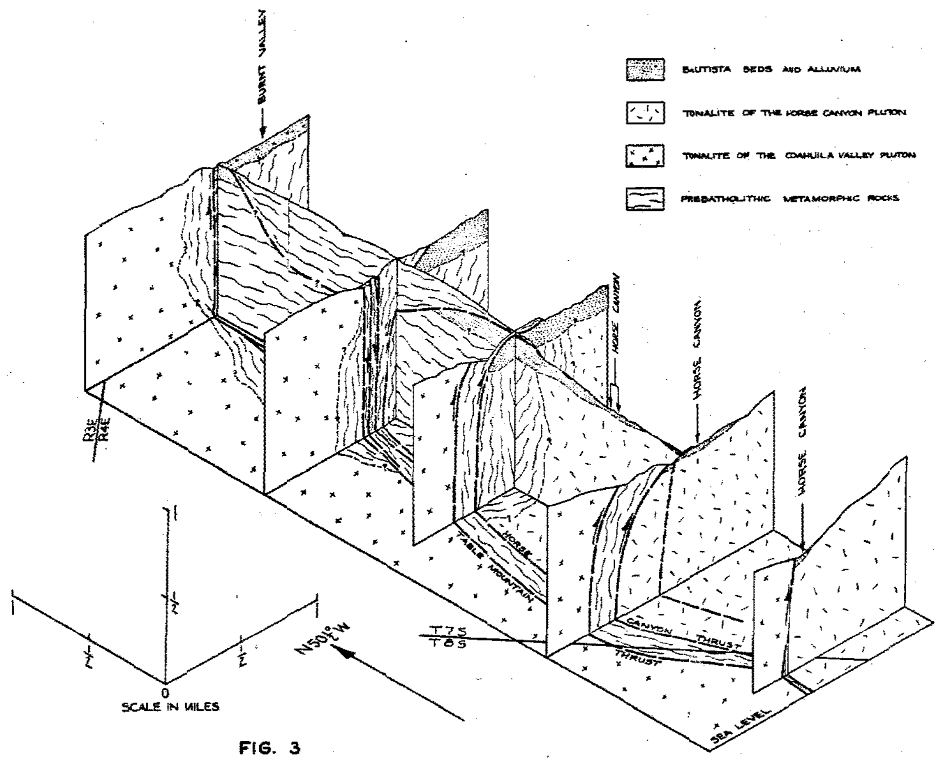


FIG. 3

ISOMETRIC DIAGRAM OF THE SAN JACINTO FAULT ZONE BETWEEN BURNT VALLEY AND THE SOUTHERNMOST CROSSING OF HORSE CANYON

SENSE OF MOST RECENT VERTICAL COMPONENT OF MOVEMENT SHOWN BY ARROWS variation of the dip angle at which the sediments sheared off (if the thrusting were not subaerial). The traces of the Table Mountain and Horse Canyon thrust segments extend southeastward on the southwestern wall of Horse Canyon for nearly 2 miles, and both converge into a single steeply-dipping fault zone about 2 3/4 miles below the head of Horse Canyon. Dips on the trace of the Table Mountain thrust segment are generally moderate toward the southwest, but in the southern 3/4 mile of this segment the strike swings to about N80°W and then returns to about N45°W at the point of convergence. The point of convergence is nearly perfectly aligned with the projection of the Hog Lake-Hamilton Creek interval of the fault. Dips observed on the trace of the Horse Canyon thrust west of Horse Canyon range from 17° to 42° but generally are more gentle than those of the Table Mountain thrust. Projection of these dips to depth suggests that either the sheetlike mass of crushed metamorphic rocks caught in the fault zone diminishes in thickness or the fault surface curvature observed along the trace continues at depth and the sheet has essentially constant thickness at depth (Fig. 3).

Although the entire sheet of metamorphic rocks is pervasively shattered, the intensity of crushing is greatest just above the Horse Canyon thrust. A characteristic dark-gray to black aphanitic layer of pulverized but coherent rock up to several inches in thickness immediately overlies the thrust contact. Strongly foliated clayey gouge is often associated with, or occurs in place of, the aphanitic zone. Several tens of feet of pulverized metamorphic rock including discontinuous bands of rock flour overlie the gouge zones. The degree of brecciation gradually decreases upward and zones of only slightly disturbed rock are common in the upper parts of the mass. Numerous thin gouge zones of short lateral extent and a variety of orientations are common throughout the body but are most abundant near the upper fault contact with the Coahuila Valley tonalite. Brecciated tonalite is thrust on very small patches of bedded monolithologic debris derived from it in the steep-walled tributary canyon 1 1/2 miles below the head of Horse Canyon.

Several springs and seeps are aligned along the trace of the Horse Canyon thrust segment in this interval of the San Jacinto fault zone; no springs were found along any part of the Table Mountain thrust. Well data (Bookman, et al., 1956, vol II, p. G-42) indicate a significant drop in elevation of the water table from Table Mountain across the fault into Burnt Valley.

From the point of convergence of the Horse Canyon thrust with the Table Mountain thrust the trace of the San Jacinto fault becomes very straight and steeply dipping for 3 miles to the southeast, but its N45°W strike is misaligned with the average N55°W strike to the northwest. The trace south of its recrossing of Horse Canyon is marked by aligned hillside trenches and drainage discontinuities for 1 1/2 miles. Farther southeast, the fault is not exposed along the base of the linear southwest-facing escarpment bounding the triangular valley crossed by White Wash. Immediately north of White Wash, the fault zone is exposed in a broad, nearly vertical crush zone developed in a sheetlike, fault-bounded body of metamorphic rocks separating the Coahuila Valley pluton from the Horse Canyon pluton.

On entering White Wash, the San Jacinto fault is concealed by alluvium for nearly 2/3 mile, but the confined nature of the canyon indicates the strike of the fault must swing to a nearly east-west orientation. Upstream the fault is exposed as a shallow-dipping thrust on which pulverized metamorphic rocks of the southwestern block have overridden tonalite of the Horse Canyon pluton and unconsolidated gravels resting on the pluton (Fig. 4). This fault is herein termed the White Wash thrust. Its trace is very sinuous, but it extends generally eastward up White Wash to upper Dry Wash. Both of the washes have been eroded largely in the overthrust sheet of crushed metamorphic rocks. Dips on the south wall of White Wash are generally shallow to moderate toward the south, but gentle northward dips locally indicate an extremely irregular thrust surface. Four small klippen of crushed metamorphic rocks cap the ridge forming the north wall of White Wash, and these dip southward into the canyon.

About 1000 feet southwest of the point where the San Jacinto fault enters White Wash, a similarly oriented fault bounding the Coahuila Valley pluton crosses the badlands-eroded southern wall of White Wash. This fault is steep near lower White Wash, but its dip and strike swing into subparallelism with the lower thrust surface and become gently southward-dipping near the head of White Wash (Fig. 4). This fault, herein named the Coyote Ridge thrust, is typically marked by a thin gouge zone separating shattered metamorphic rocks from overlying tonalite. No definite evidence of its having thrust displacement was found; it is inferred to be a thrust because of its parallelism to the White Wash thrust.

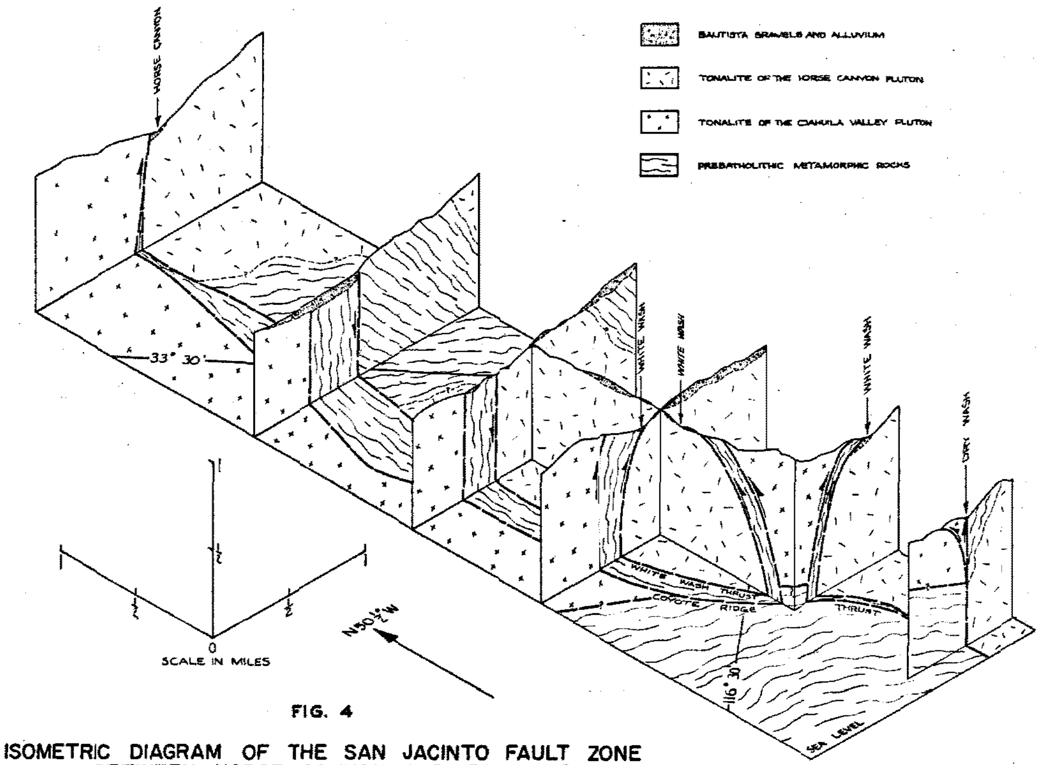


FIG. 4

ISOMETRIC DIAGRAM OF THE SAN JACINTO FAULT ZONE BETWEEN HORSE CANYON AND DRY WASH

SENSE OF MOST RECENT VERTICAL COMPONENT OF MOVEMENT SHOWN BY ARROWS

The overlying tonalite is profoundly shattered and pervaded by thin gouge zones from its fault contact to the crest of the north end of Coyote Ridge. A maximum relief of 1200 feet of shattered tonalite is exposed below the crest, and deep dissection has carved badlands amphitheaters in it. The excavated debris has been carried out along White Wash and, in part, redeposited in the triangular valley on the White Wash fan. Due to post-faulting deposition on this fan, the northwestward extension of the Coyote Ridge thrust is concealed. Projection of its last exposed trace suggests that it crosses the small hill projecting through the White Wash fan, but there is no topographic evidence of a recently active fault on it. However, a distinct lithologic contact between the inequigranular adamellite phase of the Coahuila Valley pluton and metamorphic rocks lies close to, and in parallel orientation with, a branch of the San Jacinto fault projected from the northwest. On this evidence, the contact is thought to be a branch of the San Jacinto fault zone extending from the fault complex near its southern crossing of Horse Canyon and connecting southeastward with the Coyote Ridge thrust.

About 1/2 mile southeast of the head of Dry Wash, the White Wash thrust and the Coyote Ridge thrust segments reconverge into a single steeply dipping zone. This intersection lies exactly on a N55°W line drawn from the vertical zone at the southern convergence of the Table Mountain thrust and Horse Canyon thrust, and this trend is maintained, on the average, along the San Jacinto fault from upper Dry Wash to northern Clark Valley. It thus appears that the two zones of thrusting in the Hamilton

Creek - upper Dry Wash interval of the San Jacinto fault are each associated with a southwestward convex bulge in the fault surface bounded by a steeply-dipping fault zone at depth and that the shallow-dipping faults with thrust components of displacement are relatively shallow effects. The difference in appearance of the two structures in plan view is due essentially to the difference in depth of erosion and the difference in sense of displacement on various parts of some branches.

The intensity of brecciation within the overthrust sheet of metamorphic rocks in White Wash is distributed essentially as above the Horse Canyon thrust fault. Gray clayey gouge a few inches in thickness forms the base of the thrust sheet, and it is overlain by a zone of pulverized rock containing zones of rock flour. The thickness of this zone reaches a maximum near the central part of White Wash where it includes nearly the entire fault slice of metamorphic rocks. Near the head of White Wash the crushed rock is lacking locally, and relatively undeformed metamorphic rocks rest concordantly on the thrust surface (Pl. 7). In general the degree of brecciation decreases away from the base of the thrust. Above the Coyote Ridge thrust, the tonalitic rocks are pervasively shattered, but zones of extreme pulverizing are limited to relatively thin gouge bands, many of which are at large angles with respect to the thrust surface. Broad layers of pulverized rock and sheets of rock flour are not developed in the tonalitic rocks.

A peculiar set of minor cross fractures both break and are broken by the lower thrust surface 0.25 miles northwest of Dry Wash Pass (Fig. 5). A fault surface marked by a thin gouge zone

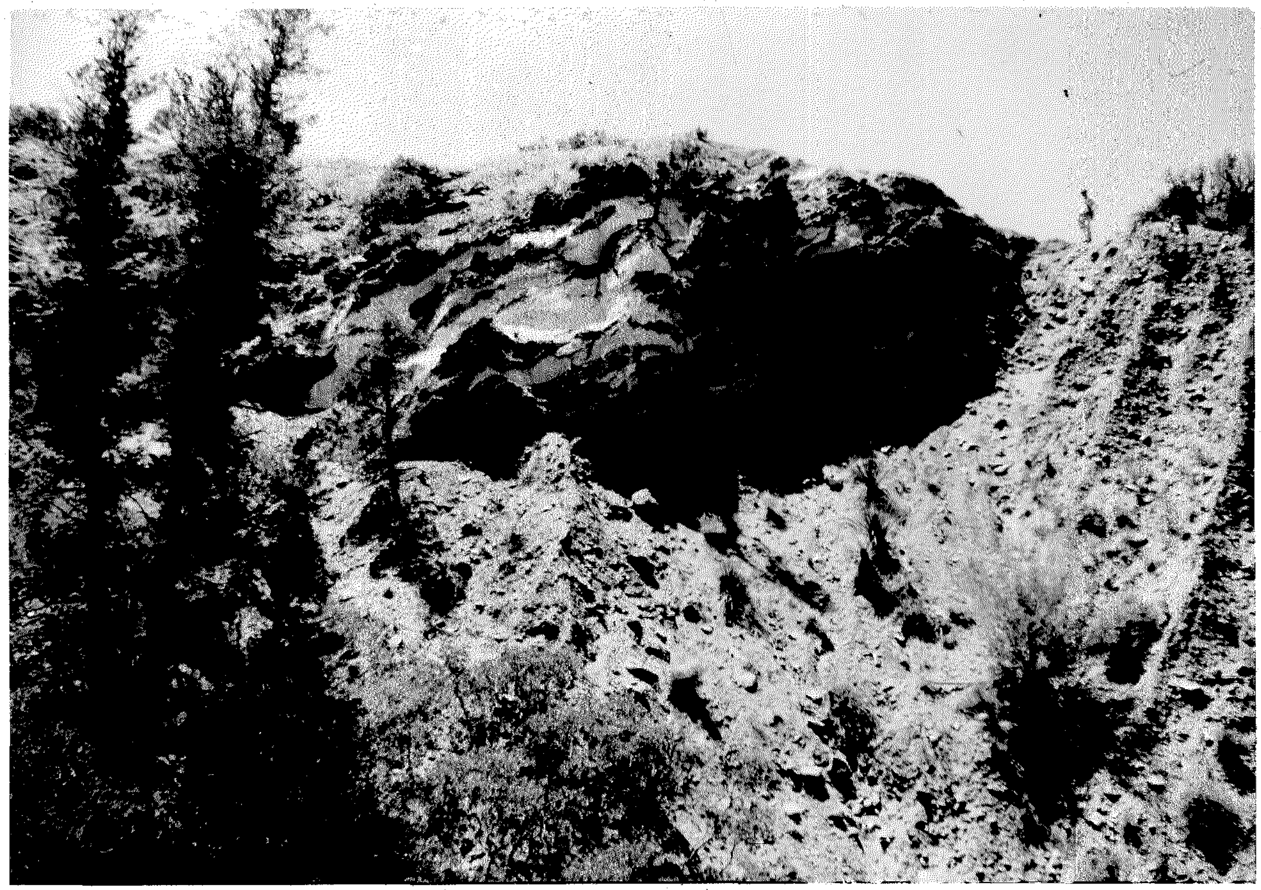


PLATE 7

Dry Wash thrust fault near the head of Dry Wash. Relatively unsheared metamorphic rocks rest on Bautista gravels. View is toward SW.

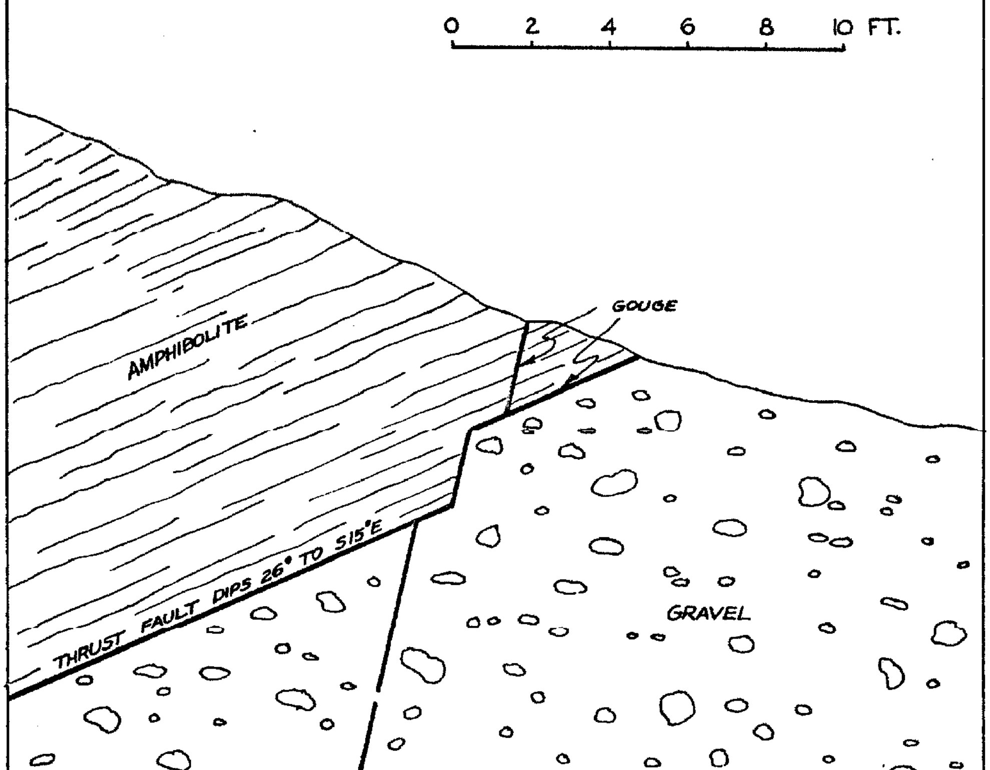


FIG. 5

SKETCH OF CROSS FRACTURES ON THE WHITE WASH THRUST. VIEW TOWARD S50°W. INTERPRETATION IN TEXT.

dipping 77 degrees toward S40°E drops the thrust contact by about 2 feet on the southeast side. Possible subsequent slip on the thrust moved the cross fracture an apparent displacement of 2 feet, 1 foot on each of the 2 displaced parts of the thrust. Because no gouge formed in this presumed second episode, an alternative interpretation that all the breaks formed during a single episode of movement is suggested. A similar break dipping about 55° to WNW drops the Coyote Ridge thrust fault an apparent vertical displacement of about 100 feet on the southeast side and subsequent movement of unknown amount on the lower surface has truncated the cross fracture. This structure is exposed about 2/3 mile southeast of the point where the San Jacinto fault enters White Wash.

Local reversals of dip direction indicate that the shapes of the thrust surfaces are very irregular. From the klippen exposed on the ridge north of White Wash the White Wash thrust segment drops over 300 feet at an average slope of about 15 degrees to the bottom of White Wash. South of White Wash the dip reverses for at least 120 vertical feet with an average slope of about 15 degrees. Horse Canyon tonalite exposed in windows in the overthrust mass can be distinguished from the Coahuila Valley tonalite by its texture, deeper weathering, and its unshattered condition. Sediments caught under the thrust near upper White Wash suggest that an old drainage channel filled with stream gravels influenced the shape of the thrust sole. The advancing thrust may possibly have followed a subaerial surface. Angular clasts of Coahuila Valley tonalite incorporated in the gravels beneath the thrust indicate that some part of the overthrust mass was topographically higher than the basal gravels while deposition progressed.

That the thrust structures in this interval of the San Jacinto fault zone are tectonic in origin, in contrast to the alternative mechanisms of gravitational sliding or subsequent gravitational deformation of an originally steeply-dipping tectonic fault contact is suggested by the following evidence: (1) generally increasing angle of dip with depth of exposure, and dip directions that are opposed to the directions of thrusting; (2) lack of great topographic highs to drive gravity slides; (3) lack of independent evidence of Recent sliding parallel to slopes; (4) local occurrence of relatively undeformed sediments beneath the thrusts; (5) generally smooth, small-scale continuity of thrust surfaces in cross section; gravitational deformation of the thrust surfaces in heterogeneous coarse breccia would result in secondary disruption of the thrust along discrete zones.

<u>Upper Dry Wash - Clark Valley interval</u> -- That this segment of the fault zone is structurally continuous with the San Jacinto fault farther northwest was first recognized by Beal (1915). Subsequent investigators have named this interval the Clark fault (Eckis, 1930; Dibblee, 1954) and the Santa Rosa fault (Osterholt, 1934).

From upper Dry Wash to the southern end of the map area, the San Jacinto fault trace is marked mostly by aligned topographic features developed on unconsolidated gravel deposits. Although much of the trace is concealed under Recent alluvium, several scarps have broken the alluvial surface in Clark Valley. The fault is exposed within crystalline rocks only near the head of Dry Wash, and it separates crystalline rocks from gravels in various localities between upper Dry Wash and near Rockhouse

Canyon. Although complicated branching is evident in Dry Wash, the fault is nearly straight and continuous as far southeast as northern Clark Valley, and its S55°E trend is nearly perfectly aligned with most of its trace to the northwest.

About a mile southeast of the junction of the White Wash thrust and Coyote Ridge thrust segments at the head of Dry Wash, the easternmost branch of the San Jacinto fault zone dips gently toward the southwest. This break is presumably a thrust fault. Several other branches of steeply-dipping and subparallel faults and an eastward-dipping thrust near the head of Dry Wash anastomose southeastward and converge into a nearly straight, simple break about 4 miles downstream.

Exposures of the various fault branches in crystalline rocks exhibit dark gray clayey gouge zones several inches in thickness separating pervasively brecciated rock several tens to hundreds of feet thick. Similar-appearing gouge zones in the younger unconsolidated gravels are always thin and the adjoining sediments apparently are little disturbed. Gullies crossing the fault trace marked by a sidehill bench northwest of Jackass Flat do not expose any gouge. No obvious evidence of shearing within the gravels is apparent.

Stream courses have been incised along most of the fault branches in upper Dry Wash. In gravel deposits farther southeast the locations of the fault traces are indicated by aligned gullies, notches in ridge lines, sidehill benches, or sidehill ridges. The fault is concealed by Recent alluvium for about 2 miles across Jackass Flat, but in the vicinity of Rockhouse Canyon, gouge zones in gravels and sidehill benches delineate its trace (Pl. 8). Between Rockhouse Canyon and northern Clark Valley, eroded remnants of a northeast-facing scarp form an intermittent sidehill ridge. Erosion and deposition along the fault trace have only slightly modified the relief of the scarp, but gullies transverse to the trace have breached the scarp at many points.

A striking feature of the San Jacinto fault trace between upper Dry Wash and Rockhouse Canyon is that it lies largely within Quaternary gravels deposited in a trench eroded along the fault zone. The ridges of relatively resistant crystalline rocks bounding this fault-line valley are themselves locally capped by Bautista gravels. A similar fault-line valley lies along part of the Buck Ridge fault between Buck Ridge and the crest of the Santa Rosa Mountains.

The trace of the San Jacinto fault in Clark Valley is delineated by discontinuous scarps that break Quaternary alluvium at several points. A single, somewhat eroded scarp at least 20 feet in height breaks the fan surface in northern Clark Valley and faces northeastward. Southeast of Clark Lake a steep, fresh scarp about 120 feet in maximum height similarly faces northeastward, but along the southern half of its 3 mile length the scarp is reversed and faces to the southwest (Pl. 9). The maximum height of the latter segment is about 10 feet. The N60°W strike of this section of Recent scarps is distinctly more westerly than any steeply-dipping, straight segment known to the north. Because large segments of the trace are concealed, the continuity of a single major break across Clark Valley cannot be proved. Indeed, connecting the Recent scarps requires slight bending from the projected trace

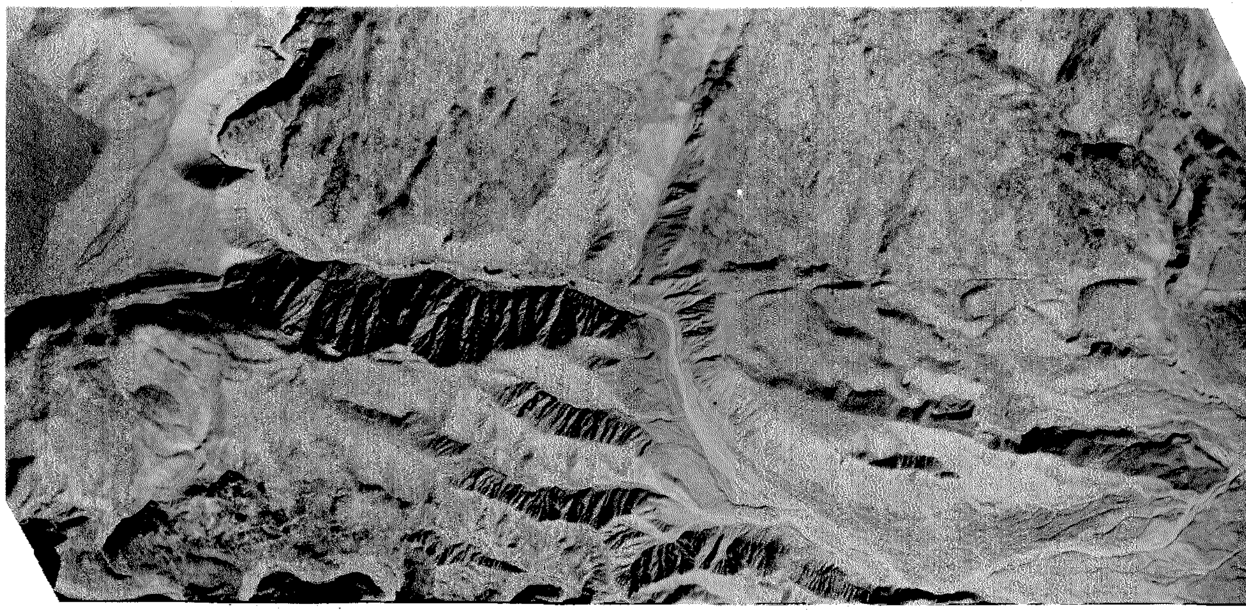


PLATE 8

Sidehill trenches marking the trace of the San Jacinto fault near Rockhouse Canyon. NE block is at top of air photo. Photo covers 3.2-mile segment of the fault.

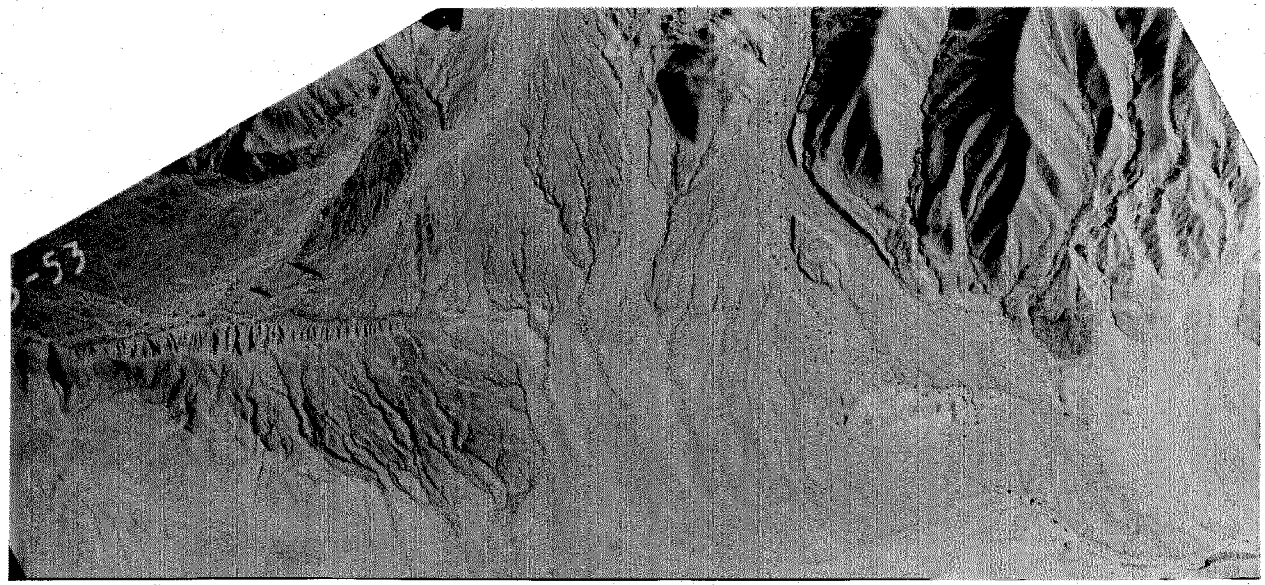


PLATE 9

Scarps marking the trace of the San Jacinto fault near the south end of the Santa Rosa Mountains. NE block is at top of photo. Photo covers 3.2-mile segment of the fault.

of the very linear 6 1/2 mile-long segment immediately to the northwest. In view of the possibilities of concealed branching and en echelon relationships, the trace of the San Jacinto fault may correlate with one of the equally well-aligned faults exposed near Little Clark Lake. The fault connecting the scarps southeast of Clark Lake may die out northwestward near the north end of Coyote Mountain. The existence of the concealed branch fault along the eastern margin of Coyote Mountain (section D-D', Pl. 2) is based solely on gravity data. A steep east-west gravity gradient in this area demands a dip of at least 60 degrees on the contact between the crystalline rocks of Coyote Mountain and sediments under Clark Valley (Biehler, 1964, Fig. 20, Biehler, 1964, personal communication). Although such a fault was proposed by Eckis (1930) and Osterholt (1934), there is no surficial evidence to support its existence other than the linearity of the eastern margin of Coyote Mountain.

Except near the head of Dry Wash, dips observed on the San Jacinto fault in the Dry Wash - Clark Valley interval are generally steep. The southwestward-dipping thrust fault near the head of Dry Wash probably converges with a vertical crush zone exposed a mile downstream. Dip directions reverse from southwestward to northeastward as the fault crosses Rockhouse Canyon from north to south. Elsewhere, the fault surface is inferred to be steep because of the linearity of the trace over topographic irregularities.

Consistent right-handed offsets of gullies transverse to the fault trace on the northwest wall of Rockhouse Canyon and about a mile north of the head of Box Canyon appear to be primary fault features. In each case the offsets are measurable in a few tens of feet.

Quaternary Displacements

Because the displacement indicated by crystalline rocks is large with respect to the length of segments being presented here, discussion of the cumulative movement will be deferred to a later section of this report. Only the relatively recent and small offsets will be discussed here.

San Jacinto Valley - Hog Lake interval -- Unequivocal evidence of Quaternary lateral displacement in this interval is lacking. The deeply incised canyons on the southwest face of Horse Creek Ridge are certainly younger than the erosional surface capping the ridge, and abrupt changes in direction of the stream courses at the fault suggest right-lateral displacement since their incision (Pl. 4). However the intact ridge at the head of Blackburn Canyon suggests that canyons have been cut by erosion largely after any episodes of displacement. To have juxtaposed two separate ridges neither of which had previously retreated from the fault zone by erosion is so unlikely that neighboring canyons certainly are younger than the ridge.

Although the canyons probably are younger than any major lateral offset, their distribution could have been controlled in part by an ancestral stream pattern, possibly one existing during the evolution of the erosion surface on the Horse Creek Ridge or the lower terrace surfaces. The shutterridge-like topography in the present canyons could then possibly be due to downcutting subsequent to right-lateral movement of 1.1 to 1.4 miles. Such displacement would be older than the unconsolidated alluvial material which locally conceals the fault trace, but younger than Bautista sedimentation.

The overthrust ridge of metamorphic rocks near Hog Lake has risen at least 800 feet in post-Bautista time. Whether the movement on this fault has been entirely vertical is unknown. That Bautista beds west of the thrust block are about as high as sediments east of the San Jacinto fault suggests that the ridge of metamorphic rocks has also risen with respect to the block east of the San Jacinto fault. The thrust has been inactive since the cutting of the erosional bench across it, at which time the surface probably was continuous with the erosion surface on Thomas Mountain and Horse Creek Ridge. Because of the similarity of elevations of the erosion surfaces on southern Horse Creek Ridge and the thrust ridge, no major vertical component of displacement on the San Jacinto fault in this vicinity is inferred in post-thrust time. However, the northwestward extensions of those surfaces in the vicinity of Rouse Hill suggest the southwestern block has been relatively depressed about 1200 feet. Thus, post-Bautista vertical movement on the San Jacinto fault in this interval probably has been rotational.

Bautista sediments northwest of Rouse Hill are exposed from the level of San Jacinto Valley up to elevations of about 4000 feet, but similar deposits are not exposed southwest of the San Jacinto fault. This distribution of the Bautista beds is due either to displacement on the San Jacinto fault zone, irregularities in the shapes of the sedimentary basins that possibly were fault-controlled, differentially greater resistance to erosion on the northeastern block, or to combinations of these factors. If sediments correlative with the Bautista beds have been partially stripped from the San Jacinto Valley block, as suggested by Dudley (1936, p. 376), the separation of Bautista sediments on the northeastern block and correlative deposits concealed beneath San Jacinto Valley may in large part be due to differential erosion on the two blocks. If the original distribution of Bautista beds were linear across the fault zone, the horizontal component of subsequent displacement would be less than the apparent separation of Bautista sediments. Post-Bautista movement may thus be less than 5 miles in the right-lateral direction. That the margin of the depositional basin was linear across the fault zone cannot be proved, however.

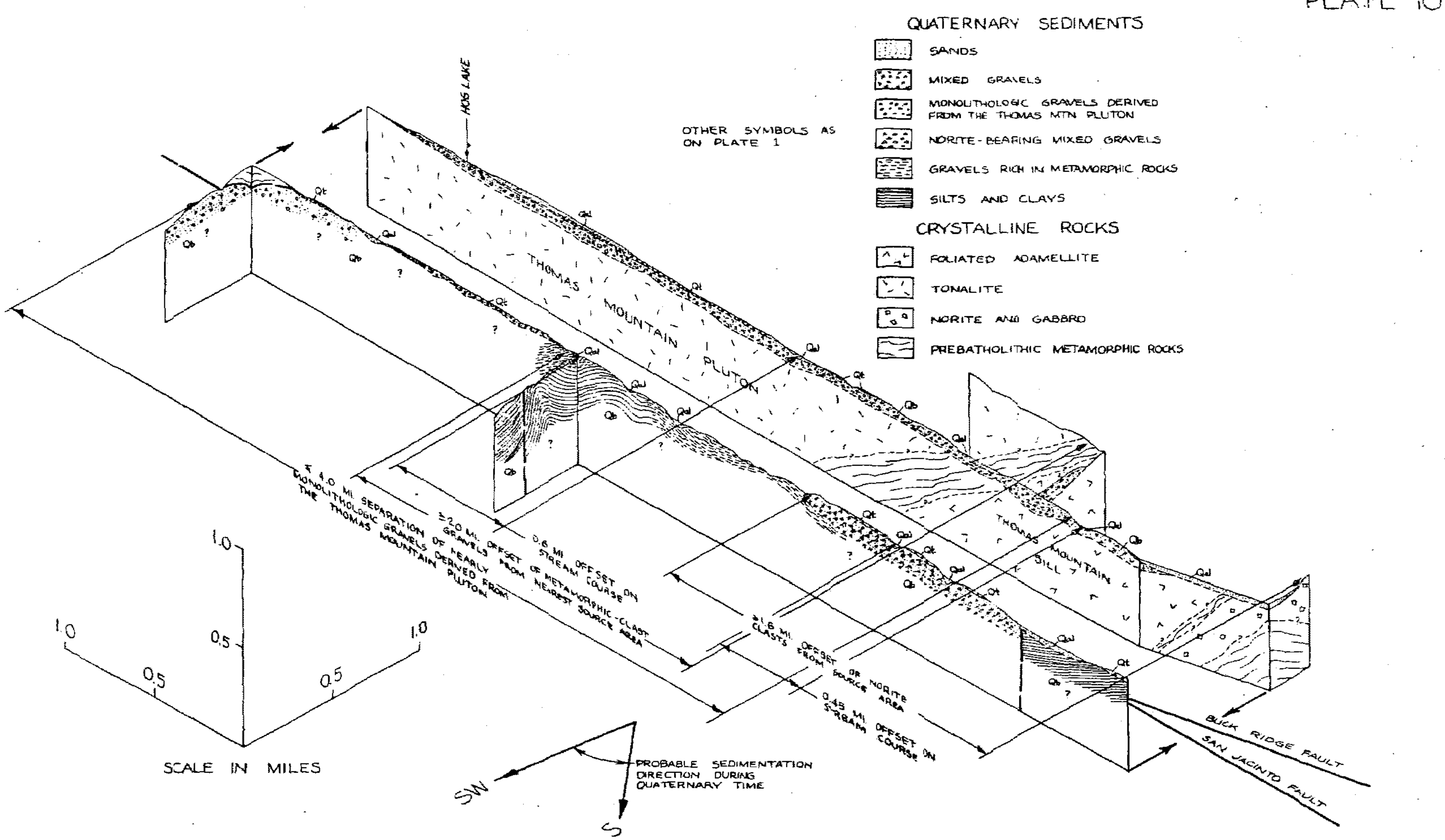
Hog Lake - Hamilton Creek interval -- The displaced erosional surface corresponding to Horse Creek Ridge slopes either to the southwest or south on both sides of the San Jacinto fault in this interval. Because the southeast component of slope on the terrace surface is steeper on the southwest block and because the scarp is northeast-facing near Hog Lake but southwest-facing farther southeast, post-terrace rotational displacement is indicated. The sense of rotation in this segment of the fault is opposite to that deforming the same terrace in the San Jacinto Valley-Hog Lake interval discussed above.

Post-terrace stream courses forming the shutterridges in the central part of this segment of the fault indicate at least 0.45

mile of right-lateral component of displacement (Pl. 10). The two broad-channeled, headless canyons southwest of the fault trace 3.25 and 3.55 miles southeast of Hog Lake cannot be fault-line features. A minimum of 0.15 mile of right-lateral displacement has offset the head of one channel, but prior to this faulting event, the next canyon 0.30 mile to the northwest was similarly left without a head. Thus, a total movement of 0.45 mile is required to account for both stream courses. The rotational vertical movements may have largely preceeded these offsets, or down-faulting on the southwest coupled with right-lateral displacement would have favored the stream maintaining a connection with its former head if each faulting increment was less than the width of the channel ($\sim$ 400 feet). If single displacement episodes greater than the channel width occurred, the observed rotational movement and lateral displacement could have been contemporaneous.

An alternative explanation is that the displaced channels did maintain connection and, in so doing, carved the V-shaped trench along this segment of the fault trace. Subsequent capturing of the head by more southerly streams could then have isolated them. A problem raised by stream flow along the trace is that the V-shape would have to be entirely erosional in origin, whereas all the transcurrent channels, both upstream and downstream are broader, flat-bottomed and older in appearance. Another problem of maintenance of channel connection in right-laterally displaced, southward-flowing streams is that the acute-angled stream banks formed by the intersections with the fault would rapidly be eroded away; there is no evidence of this having happened in this segment of the

PLATE 10



DIAGRAMMATIC SECTIONS SHOWING QUATERNARY DISPLACEMENTS ON THE SAN JACINTO FAULT NEAR HOG LAKE

San Jacinto fault. Probably a less objectionable explanation of the groove along the trace is slumping in the disturbed sediments with removal of the debris by transport and redeposition along the older channels, but of such local scale that no capturing took place.

Three similar displaced canyons occur between 1 and 2 miles southeast of Hog Lake. Fault movement probably has beheaded each of these stream courses. They have subsequently been ramped over by alluvium eroded upstream and redeposited downstream from the fault trace (Fig. 6). The two most northerly channels have been offset about 0.6 and 0.35 miles from the nearest possible head, which currently is juxtaposed against the third displaced canyon. This canyon, in turn, has been offset from its probable former head by 0.6 mile (Pl. 10).

Although the shutterridge scarps are very fresh and little modified by subsequent erosion, the Recent fan burying the northeast-facing scarps for a mile southeast from Hog Lake has not been broken. Recent alluvium near Hamilton Creek similarly is not displaced.

Because of the occurrence of distinctive crystalline rocks on the south end of Thomas Mountain and their distributions roughly parallel to the drainage lines which sample them, the present distribution of clast types in alluvium at the base of the mountain are sharply delineated. Bautista gravels exposed on each site of the fault in this interval also contain clasts of the same distinctive rocks. This is the only known segment of the San Jacinto fault zone within the map area in which clasts in

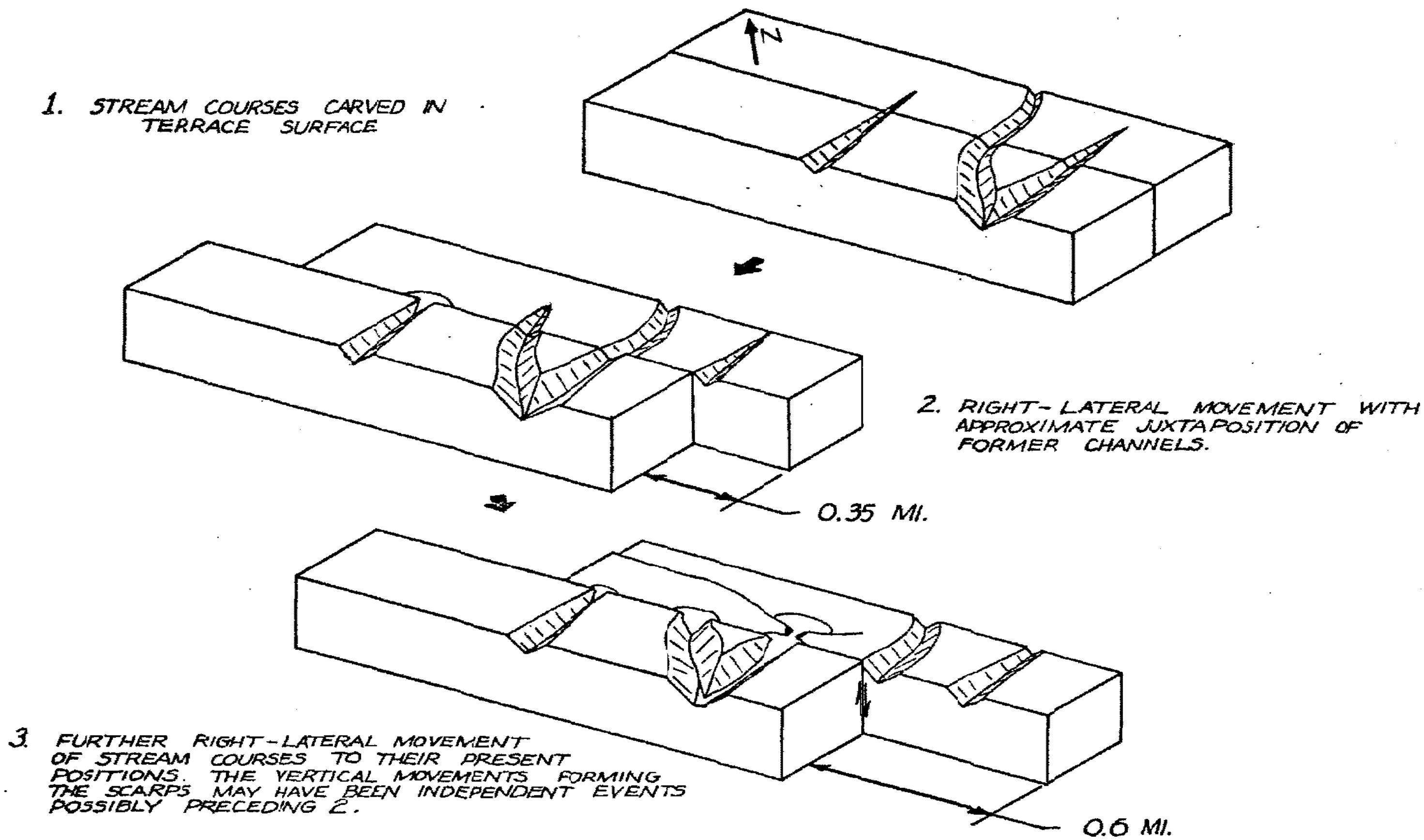


FIG. 6

POSSIBLE ORIGIN OF PARTIALLY - FILLED HEADLESS CANYONS 1-2 MILES SOUTHEAST OF HOG LAKE

(DIAGRAMMATIC REPRESENTATION)

Bautista gravels can be directly related to a local source area. Thomas Mountain probably has remained a positive barrier against introduction of foreign debris from drainages farther east through much of Bautista time to the present. A general southwestward and southward decrease in clast size in Bautista sediments and terrace gravels on the southwest side of the fault, as well as the general dip of the terrace surface, suggest deposition was in this direction, at least since late Bautista time. No evidence of current structures was found in the poorly bedded gravelly facies of the Bautista beds on either side of the fault. Clasts derived from the Thomas Mountain pluton occurring in Bautista beds east of the San Jacinto fault are also distributed southward from the most southerly exposed outcrop, and clasts of Thomas Mountain norite are absent from the same deposits (Pl. 10). Juxtaposed against these across the San Jacinto fault are norite-rich Bautista gravels which extend 1.6 miles northwest of the nearest outcrop of norite. Norite-bearing gravels may formerly have extended even farther northwestward, but erosion has stripped them away. The most southerly monolithologic gravels derived from the Thomas Mountain pluton known southwest of the fault occur as terrace patches resting unconformably in canyons carved in deformed Bautista beds about 1.5 miles northwest of their monolithologic counterparts east of the fault. These monolithologic gravels on the southwestern block are probably much younger than those on the opposing side. However, Bautista gravels exposed west of Hog Lake beneath the thrust ridge are nearly identical in lithology to the southernmost monolithologic gravels on the northeastern block about 4 miles away. Displacement of the monolithologic gravels in post-Bautista time probably has been less than this amount, but concealing by terrace gravels on the southwest block prevents estimation of the amount (Pl. 10). Metamorphic rocks are the predominant type of clast in exposed Bautista gravels between the monolithologic and the norite-bearing gravels on the southwest side of the fault, and all are displaced against monolithologic gravels derived from the Thomas Mountain pluton. Gravels containing metamorphic clasts but lacking tonalite from the Thomas Mountain pluton are found as far as 2 miles northwest of the nearest source area on the opposite side of the fault, but these gravels are stratigraphically lower than the norite-bearing gravels. Their displacement is compatible with contemporaneous right-lateral displacement and Bautista sedimentation across the fault zone.

The occurrence of lacustrine Bautista sediments east of the San Jacinto fault near Hamilton Creek can be explained by lateral lithologic variation from bouldery gravels beneath the terrace surface to the northwest. The elongate shape of the small hill traversed by the San Jacinto fault suggests that it has been raised on both the Buck Ridge fault and a southwestern branch of the San Jacinto fault. In view of other evidence for right-lateral movement of presumably younger Bautista beds exposed farther northwest, the lacustrine beds underlying the small hill could reasonably be displaced laterally as much as 2.5 miles. This interpretation requires that the main break of the San Jacinto fault pass south of the hill. Because of alignment of the youngest appearing topographic features of faulting to the southeast and the projected trace along this entire segment favors continuity of the San Jacinto fault across the hill and into Hamilton Creek, an alternative interpretation is favored. The structurally and topographically high position of lacustrine beds on the hill relative to the southwest block probably is the result of uplift of correlative beds lying at depth under northeastern Anza Valley. Vertical displacement of this sense is in agreement with warping of the terrace surface on the southwest block farther northwest. Lacustrine sediments lying east of the fault trace crossing the hill could then be correlative with similar beds exposed to the northwest.

Abundant norite pebbles and cobbles mantling the southern slope of the small hill suggest that uplift of the hill has been relatively recent and has not been followed by significant lateral displacement on the Buck Ridge or San Jacinto faults. The hill is located very close to the only norite source area, but lies partly north of the distribution of norite in Recent alluvium. Similarly, the hill underlain by Bautista silts one half mile northwest of the mouth of Hamilton Creek is mantled by marble boulders and lies just north of a canyon with distinctive marble-rich alluvium.

In view of the evidence for right-lateral components of displacement presented by gravels offset from their source areas, the Bautista depositional basin underlying northeastern Anza Valley must have interconnected with a part, if not much, of the basin now exposed in Burnt Valley and southeastward.

That the southwest face of Thomas Mountain is a fault scarp is suggested by its parallelism to the trace of the San Jacinto fault, its height, and the lack of a matching prominence anywhere on the southwestern side of the fault. The maximum relief of Thomas

Mountain above the terrace surface on its southwest slope and the bench developed on Horse Creek Ridge is more than 1600 feet. Displacements that produced this relief are certainly pre-terrace in age and probably preceded most of Bautista sedimentation. The relatively great depth to the concealed bedrock surface immediately southwest of the San Jacinto fault in this segment and the vertical change in facies from lacustrine deposits to gravelly sands suggests that Thomas Mountain was relatively uplifted while Bautista deposition was in progress. Evidence for contemporaneous sedimentation and right-lateral offset found along this segment of the fault suggest oblique-slip movements, at least during the deposition of the conglomeratic phases of the Bautista beds. Inasmuch as the stratigraphically lowest deposits are lacustrine beds and they are distributed in the immediate vicinity of the fault trace, either vertical movements raising Thomas Mountain in that interval of Bautista time were very small or the lacustrine basin had not been juxtaposed against the rising scarp. This, together with the relatively minor thicknesses of all of the coarse Quaternary deposits and the slight difference in elevations of the terrace surface across the San Jacinto fault indicate that the vertical components of displacement that raised Thomas Mountain were largely pre-Bautista in age.

<u>Hamilton Creek - upper Dry Wash interval</u> -- Exposures along this segment of the San Jacinto fault zone emphatically document vertical components of displacement in post-Bautista time. Although evidence for significant right-lateral movement in the same time interval is not equally as impressive along this part of the fault, post-Bautista lateral offset northwest of Hamilton Creek suggests

by reason of continuity that equivalent horizontal faulting has occurred, possibly combined in individual oblique displacement episodes. Slickensides observed at the large klippen north of White Wash suggest oblique motion on the White Wash thrust. Generally, however, slickensides are indicative of only the last direction of movement, and no interpretations of the net direction of many individual episodes of displacement can be made solely on them.

In post-Bautista time Table Mountain has been raised at least 800 feet on the Horse Canyon thrust and an unknown additional amount on the Table Mountain thrust (Fig. 3). The lower thrust sheet extended laterally at least 1/2 mile over the north-eastern block. Although the thrusting may have been accompanied by a large strike-slip component, most of the movement probably was dip slip. Some of the displacement may be Recent in age, as suggested by multiple shallow-dipping breaks on the Horse Canyon thrust appearing on one wall of a tributary to Horse Canyon and not on the other at their projected levels (Fig. 7). Slopewash debris derived from the Coahuila Valley pluton that is caught under the Table Mountain thrust also attests to relatively recent episodes of movement.

The paucity of coarse clasts in the Bautista formation beneath the Horse Canyon thrust suggests that either (1) the depositional basin extended well across the trace of the fault, or (2) the basin was bordered by crystalline rocks exposed on a surface of low relief west of the fault trace. In view of the probable lateral displacements of gravel clasts in the upper portions of the Bautista formation at the foot of Thomas Mountain, alternative (1) permits

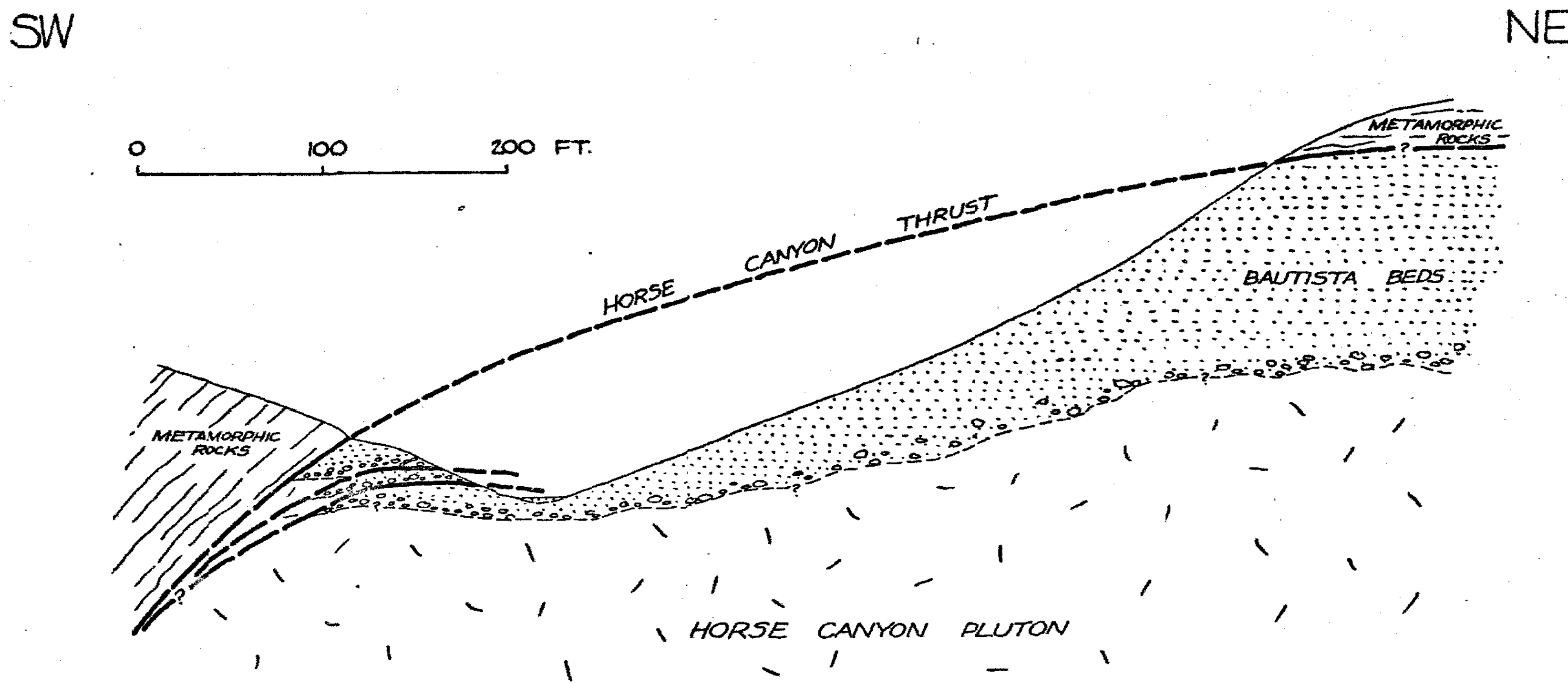


FIG. 7

MULTIPLE THRUSTING ASSOCIATED WITH THE HORSE CANYON THRUST FAULT

DIAGRAMMATIC SECTION 4.6 MILES SOUTHEAST OF THE MOUTH OF HAMILTON CREEK lateral continuity of at least part of the two offset basins during Bautista time. The northwestern surface of Table Mountain may have coincided with the pre-Bautista erosion surface on the northern exposures of the Horse Canyon pluton, but right-lateral displacement of about 6 miles in post-Bautista time is required to account for the separation of the overlying deposits as they are now distributed. Although the inferred directions of sedimentation in the two basins are compatible, the abundance of lacustrine beds are not comparable. Lack of exposure in critical areas and unknown locations of facies boundaries with respect to the fault trace prevent correlation of Bautista beds between these basins. However, evidence for at least 2 miles of lateral slip northeast of Anza in post-Bautista time indicates that parts of the basins were juxtaposed.

After most of the vertical movement took place on the Horse Canyon thrust, an erosional surface was developed over broad areas, including the crest of Table Mountain, the top of the thrust slice south of Burnt Valley, southeastern Thomas Mountain near Coahuila Road, and along the ridge joining Lookout and Thomas Mountains. Because this surface not only marks the highest exposures of Bautista sediments everywhere in this region, but also lies within the same range of elevations (4700 to 5200 feet), it is considered to be correlative with the erosional bench on Horse Creek Ridge and farther northwest (Fraser, 1931, p. 503). Erosion subsequent to the development of this surface has partially destroyed it and formed lower surfaces represented by Vandeventer Flat and Burnt Valley. Successively lower terraces formed in the badlands south of Lookout Mountain and on the eastern slope of Table Mountain as erosion continued.

The erosional events were followed by faulting near the head of Horse Canyon which formed a southwest-facing scarp about 100 feet in maximum height. Although right-lateral displacement probably accompanied the formation of this scarp, its relief must be due to a vertical component of displacement inasmuch as the fault is traversing a relatively flat segment of terrain. That the scarp is relatively recent and not a fault-line feature is shown by the lack of dissection on its face and by both sides of the scarp being underlain by similar metamorphic rocks. The scarp is exposed for about one mile. Two stream courses flowing northward into Burnt Valley breach the scarp, but they probably were incised prior to formation of the scarp. Down dropping on the southwest side of the scarp dammed the upstream parts of the drainages and caused the accumulation of Recent alluvium.

Erosional remnants of shallow-dipping Bautista sediments rest against the lower part of a steep, southwest-facing pre-Bautista scarp at least 1600 feet high 1/2 mile southeast of the junction of the Table Mountain and Horse Canyon thrusts. Post-Bautista vertical movements in the 1 3/4 mile fault interval to the southeast has raised the northeastern block at least 400 feet along part of this interval, as indicated by the difference in level of Bautista deposits on each side of the scarp. That the lower White Wash - Horse Canyon area is structurally depressed is also indicated by headward broadening of lower Horse Canyon and the shallow southward dip of lacustrine Bautista sediments on southern Table Mountain. The presumably southward pre-deformation drainage of Horse Canyon may have been temporarily dammed before being recaptured by relatively recent incision near its mouth.

In view of post-Bautista horizontal displacements observed on the San Jacinto fault to the northwest, the high gravels deposited against the scarp and overriden by the thrust sheets in White Wash probably once extended to Table Mountain. Inasmuch as a thickness of nearly 1600 feet of gravels are exposed east of the fault in contrast to the thin section of sands and silts west of the fault on southern Table Mountain, the western block either stood as a high area or progressively rose as the gravels were being deposited. A drainage route from the fault zone to Coyote Canyon may have allowed much of the clastic debris to be transported away. However, no high gravels are preserved in the vicinity of Horse Canyon, and slope wash is composed only of tonalitic rocks, whereas the gravels east of the fault have sampled terranes composed of both gabbroic and garnetiferous adamellite. The presence of these clast types suggests a generally westward sedimentation direction east of the fault. It is also possible that these high gravels interconnected with the finer sediments south of Burnt Valley along drainage lines flowing northwestward along the fault trace in Bautista time.

The unconsolidated gravels distributed along the southwestern base of northern Buck Ridge shows the steep, southwest-facing scarp is pre-Bautista in age. The height of the scarp northeast of White Wash is about 2700 feet of which the lower 1600 feet is locally covered with gravels. Much of this relief probably is due to pre-Bautista erosion in crushed rocks distributed along the San Jacinto fault. Post-Bautista movements on the White Wash and Coyote Ridge thrusts in White Wash have raised crystalline rocks at least 400 feet over unconsolidated gravels lying north of the wash and extended the southwestern block horizontally at least 1/4 mile toward the north (Fig. 4). Inasmuch as the thrust sheet is highly dissected, its former maximum extent may have been considerably greater.

The direction and magnitude of displacement on the Coyote Ridge thrust fault is unknown. Slickensides with consistent orientation developed through a considerable thickness of gouge at the base of the largest klippen on the ridge north of White Wash suggest a thrust direction from slightly west of south. If the secondary shears and the principle thrust surfaces which they displace, as discussed previously, were developed simultaneously, their lines of intersection would be the only directions compatible with movement on both surfaces; the two examples cited would indicate thrusting from the southwest, nearly perpendicular to the average strike of the fault zone. If this assumption is valid, then the thrusting would appear to be directly in response to vertical displacement without a right-lateral component; if the slickensides in gouge are significant, oblique movement with thrust and right-lateral components is indicated.

Upper Dry Wash - Clark Valley interval -- Inasmuch as gravels northwest of upper Dry Wash partially bury the northwestward extension of the southwest-facing scarp of Buck Ridge, the scarp is pre-Bautista in age. Similar gravels rest on the erosional bench on the crest of Buck Ridge, on the slightly lower erosional surface between Rockhouse Canyon and northern Clark Valley, and on the south-facing slope immediately north of Clark Valley. The distribution of the gravels indicate that at least 4000 feet of the relief existed between northern Buck Ridge and the crystalline rocks surface beneath Clark Valley in pre-Bautista time. If the highest bench was developed in Bautista time, as suggested by its regional association with the upper limit in elevation of Quaternary deposits, then the lower surfaces are probably older. A similar sequence of erosional surfaces has been postulated for the San Jacinto Valley area by Dudley (1936).

At the period of the greatest extent of Bautista deposits, gravels probably filled Clark Valley nearly to the elevation of Buck Ridge. If Salton basin served as the local base level at that time, it must have been rising relative to the region of deposition that includes much of the map area. Post-Bautista regional uplift which may have been accompanied by vertical displacements on the northwest-trending faults in the map area caused widespread exhumation of the pre-gravel surface. The regional uplift was accomplished either by upwarping of the Peninsular Ranges relative to Salton basin or by faulting along the eastern margin of the ranges. Only isolated patches of the gravels are now preserved.

The height of the southwest-facing scarp of Buck Ridge is smaller at the present time than it was in pre-Bautista time. This is shown by the remnants of Bautista gravels presently exposed along the bottom of the erosional trench occupied by Dry Wash. Relief on the southwestern face of Buck Ridge is due partly to pre-Bautista vertical components of displacement on the San Jacinto fault, but mostly to erosion along the fault trace that also took place prior to deposition of Bautista beds. Inasmuch as the southwestern block has been thrust up on the northeastern side in the vicinity of upper Dry Wash in post-Bautista time, the amount of pre-Bautista vertical displacement on the Buck Ridge scarp may have been greater than the 1500 feet of elevation difference presently separating the highest levels of Buck Ridge and northern Coyote Ridge.

Post-Bautista movements on the San Jacinto fault near Jackass Flat have juxtaposed crystalline rocks on the southwest block against Bautista beds concealed beneath Recent alluvium. Either horizontal or vertical components of displacement can account for this relationship. However, post-Bautista uplift of the western block does not explain the juxtaposition of gravelly sands against tonalite along the San Jacinto Fault in lower Rockhouse Canyon. The basal contact of the Bautista deposits shows an apparent separation of about 3 miles in a right-lateral sense, but part of this apparent separation may be attributable to erosion. During the earliest phase of this displacement, upper Rockhouse Canyon probably drained through Box Canyon until it was captured by Butler Canyon. After further right-lateral offset Butler Canyon was captured in turn by lower Rockhouse Canyon. Post-capture rotational displacement accompanied by right-lateral movement of a few tens of feet has slightly raised the eastern block immediately north of the point where Rockhouse Canyon crosses the fault trace, and the western block has been slightly raised south of the same canyon. The center point of the rotational movement appears to lie near the intersection of the canyon and the fault trace. The side hill ridges formed by this rotational movement are less than 20 feet high and probably are very young. Similar structures on the trace of the San Jacinto fault near the head of Box Canyon indicate the same sense of clockwise rotational movement. The region between these two areas of clockwise rotation is by necessity a zone of counterclockwise rotation, although there is no field evidence to substantiate this.

Three small drainage basins situated southwest of the head of Butler Canyon may owe their closure to Recent uplift of the southwestern block of the San Jacinto fault. Some of the broad stream courses that drained towards the southeast probably were tilted westward through angles greater than their former slight gradients. Other alluvium-filled valleys on Coyote Ridge that drained westward or southward have not been closed.

Recent counterclockwise rotational displacement is also exhibited on the trace of the San Jacinto fault in the extreme southeast corner of the map area. Part of the scarp in Recent alluvium faces southeastward but a short distance toward the northwest, the sense of vertical movement reverses. The high northeast-facing scarp exposes gravels containing abundant tonalite but practically no clasts of cataclasite which abound in the adjoining alluvium. Inasmuch as this scarp lies across the divide separating the Clark Valley drainage from that of Salton basin, closure of the Clark Lake basin is indicated within the time interval represented by the gravels exposed in the scarp. Thus, until relatively recent time gravels derived from upper Clark Valley were transported across to the Salton basin drainage. At least one other episode of basin damming is indicated in Clark Valley by moderately deformed lacustrine deposits which unconformably underlie modern lake sediments in Little Clark Lake. These beds must be older than the gravels exposed to the southeast in the scarp whose clasts were derived from north of Clark Lake and which were transported across the site of the present lake.

The occurrence of a closed basin on the eastern slope of Coyote Mountain probably was caused either by the Recent upwarping in southeastern Clark Valley, or by movement on the fault lying just east of Coyote Mountain. The absence of any faults near the basin suggests that closure was caused by westward tilting through an angle larger than the gradient of the parent canyon.

Summary of the Quaternary Structural History

San Jacinto Valley - Hog Lake interval --

1. Pre-Bautista faulting and erosion.
2. Bautista deposition.
3. Formation of Cottonwood thrust.
4. Erosion of bench on Horse Creek Ridge and across Cottonwood thrust. Terrace gravels locally deposited.
5. Movement on San Jacinto fault. Rotational displacement of erosional bench. Deformation of Bautista beds (3-5).
6. Rejuvenation of streams and erosion along the fault trace. Terrace gravels deposited on deformed Bautista beds. Possible movement on San Jacinto fault.
7. Deposition of alluvium along fault trace.
8. Erosion (present regime).

Hog Lake - Hamilton Creek interval --

1. Pre-Bautista right-lateral faulting with some vertical component or separate vertical movements raising Thomas Mountain. Erosion of pre-Bautista surface.
2. Bautista sedimentation with contemporaneous deformation. Continued movement on San Jacinto fault with some additional uplift of Thomas Mountain.
3. Erosion of Bautista sediments and development of terrace surface across them. Displacement on fault separates distinctive Bautista gravels at least 2.0 miles.
4. Dissection of terrace surface. Right-lateral movement separates stream courses at least 0.45 mile and possibly as much as 0.6 mile. Warping of terrace surface by rotational displacement and formation of northeast-facing scarp.
5. Erosion of northeast-facing scarp and alluvial deposition across terrace.

Hamilton Creek - upper Dry Wash interval --

1. Pre-Bautista faulting and erosion of southwest-facing fault scarp.
2. Deposition of Bautista beds.
3. Right-lateral faulting that separates sedimentary basin under Burnt Valley from at least part of the basin northeast of Anza.

4. Northeastward thrusting at Table Mountain and at White Wash. Southwest-facing scarp heightened between White Wash and Horse Canyon. Questionable lateral displacements. Deformation of Bautista beds (2-4).
5. Erosional surface formed across thrusts east of Table Mountain. Slightly lower erosional surface represented by Burnt Valley and Vandeventer Flat formed. Several lower terraces formed.
6. Southwest-facing fault scarp formed at head of Horse Canyon.
7. Recent erosion and local burial of the fault trace.

<u>Upper Dry Wash - Clark Valley interval</u> --

1. Pre-Bautista faulting and erosion of trench along fault trace in Dry Wash.
2. Bautista deposition and possible erosion of several benches on crystalline rocks as deposition proceeded.
3. Lateral movement on San Jacinto fault possibly as much as 3 miles. Widespread erosion of Bautista gravels due to regional uplift.
4. Southwestern block raised slightly along parts of the fault. Northeast thrusting at upper Dry Wash. Damming of Clark Lake basin.
5. Scarps reflecting generally small scale rotational movement formed along much of fault trace.
6. Recent erosion and alluvial deposition.
7. Scarps formed in Recent alluvium in Clark Valley.

Generalized Summary of the Cenozoic Structural History of the San Jacinto Fault Zone

The position of the line of major pre-Quaternary displacement on the San Jacinto fault coincides closely with the most recent offsets of the Quaternary deposits. The maintenance of a single major zone of movement throughout its history accounts for the breadth of the zone of brecciation and the prominence of the topographic furrow eroded along much of its trace. Prior to Bautista time the relief of this trench locally exceeded that at the present. Much of the relief on the southwest-facing scarps bordering the trench was due to vertical movements that preceded erosion along the fault trace. This episode of erosion probably resulted from uplift accomplished by regional arching or possibly by faulting along the eastern margin of the Peninsular Ranges.

The Peninsular Ranges probably constituted a positive block undergoing erosion and contributing clastic debris to the Imperial depression during much of Cenozoic time (Dibblee, 1954, p. 21). In Bautista time, however, alluvial material began to accumulate over broad areas in relatively high portions of the Peninsular Ranges. This period of alluviation possibly was initiated by a rising base level in the Imperial depression caused by sedimentary filling. Some of the intermontane depositional basins were faulted apart or deformed by warping while sedimentation was in progress, and lacustrine deposits accumulated in those basins temporarily closed by the deformation. At their maximum extent, the Bautista sediments concealed most of the crystalline terrane and only the highest parts of ridges near the fault zone remained exposed.

During and subsequent to Bautista sedimentation, the southwestern block was raised slightly or locally thrust over the northeastern side along most of the southern half of the fault. Southwestward thrusting took place locally in the northern part of the area. Bautista sediments were folded or tilted in various degrees at many localities. During a new period of erosion, terrace surfaces were carved across some of the overthrust masses as well as over broad areas underlain by Bautista deposits. Some parts of these erosion surfaces were mantled by terrace gravels.

Further stream rejuvenation initiated the widespread exhumation of the pre-Bautista erosional surface. Nearly all of the Bautista sediments have been stripped from the erosional trench aligned on segments of the fault trace, but the local relief at present is still somewhat less than in pre-Bautista time in parts of the region. At least one interval of interrupted erosion in this period is documented by a terrace surface intermediate in position to the older terrace gravels and present stream beds. Along the northwestern segment of the fault trace, the trench has been eroded deeper than in pre-Bautista time, and only small remnants of the youngest terrace gravels are preserved. Post-Bautista erosion in some portions of the central part of the area probably has been relatively minor.

New episodes of faulting have formed scarps that in most cases face opposite to the directions of earlier thrusting in the same vicinity. These scarps partially transect the overthrust bodies. Probably the same fault movements have laterally offset the transverse stream courses in the central part of the area. Rotational displacements, some of which are of Recent age, have formed generally small scarps at many places along the fault trace. Relatively recent large-scale tilting has formed several closed drainage basins in the southern part of the area.

Recent alluvial deposition and erosion have obliterated the fault trace at many points along its entire length. However, movement on the fault has broken this alluvium in the southern part of the area.

NET DISPLACEMENT ON THE SAN JACINTO FAULT

General Statement

That rocks of contrasting lithology are juxtaposed for considerable distances along the San Jacinto fault suggests its total displacement is relatively large. Consideration of whether vertical or horizontal components of movement account for the juxtaposition of dissimilar bodies brings to focus the fundamental problem in establishing fault displacements. As emphasized by Crowell (1962, p. 13, 14), unique points of intersection of geological "lines" in the fault surface must be determined to fix the total displacement of a fault. It must be kept in mind, inasmuch as the net displacement is the summation of movements of many faulting episodes, that the total displacement implies nothing with respect to the paths correlative points have followed during separate episodes of movement.

Within the map area, the sequence of various types of plutonic rock, their textural and mineralogical characteristics, and their approximate equivalence in size and spacing permit only one reasonable scheme of correlation across the San Jacinto fault. These correlations are listed in Table 4.

The correlative bodies have been separated between 15 and possibly as little as about 8 miles in the right-lateral sense. The fact that all of the separations are not identical shows that vertical components of movement have occurred. The arguments to be used in resolving the components of displacement relate to extrapolated geometry of the contacts of several of these bodies.

The distribution of the various crystalline rocks as projected at depth are shown in fault surface sections for each side of the fault in Plate 11. For reasons of clarity, some of the relatively thin Quaternary deposits have been omitted from these sections. Contacts have been extended in the fault surface from their exposed or projected intersections at the fault trace. The dips of some contacts are very poorly known. Most contacts have been shown as subparallel to foliation within adjoining metamorphic rocks because this relation generally appears to be valid in horizontal view.

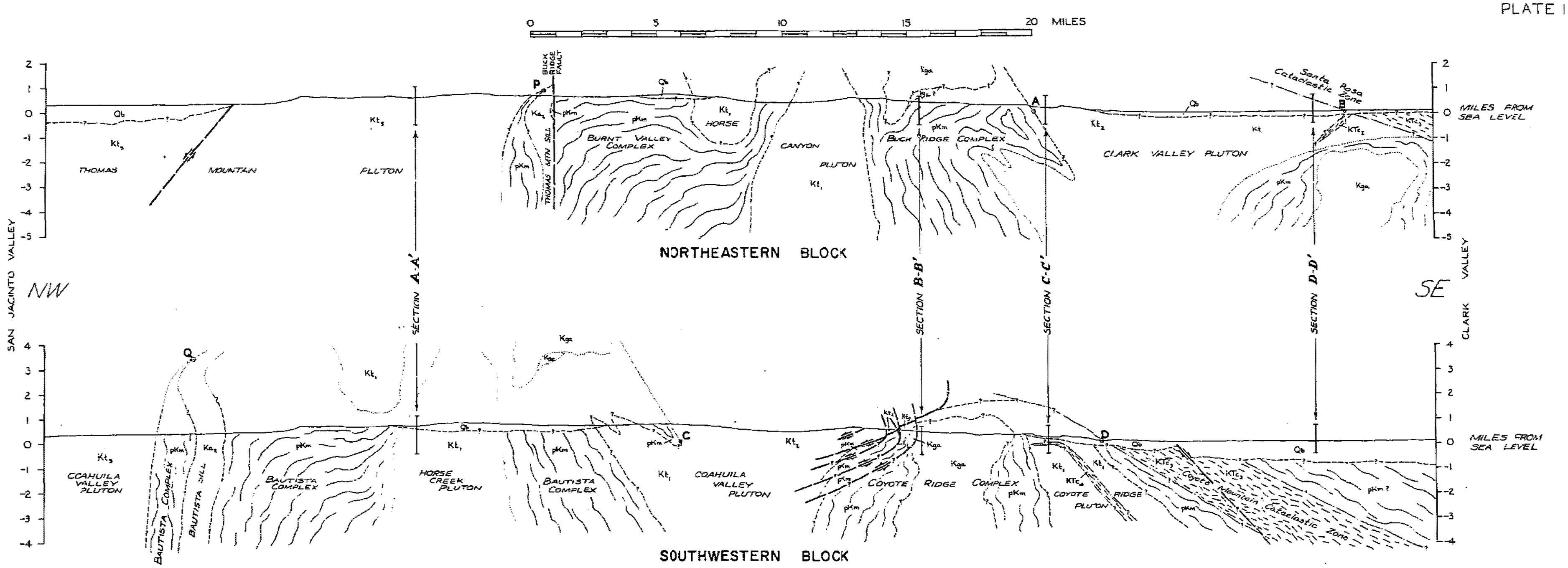
Southern Area

The displacement on the San Jacinto fault in the southern part of the map area can be estimated by considering the positions of the zones of cataclastic deformation and the Coahuila Valley and Clark Valley plutons. Inasmuch as there is marked discrepancy in the fault separations of the tonalitic plutons and the zones of cataclastic rocks (Plate 1), and all of these bodies are older than movement on the San Jacinto fault, a significant vertical component of displacement is indicated. The Coyote Mountain cataclastic zone lies

TABLE 4 - CORRELATION OF ROCK UNITS ACROSS THE SAN JACINTO FAULT

Order in sequence NW to SE	Names of correlative bodies 1. NE block 2. SW block	Rock types	Other features suggesting correlation
I	1. Thomas Mtn pluton 2. Coahuila Valley pluton (northern part)	Hornblende-biotite tonalite and biotite-hornblende tonalite	Characteristic large sphene crystals
II	1. Unnamed 2. Bautista complex (part of main body)	Prebatholithic metamorphic rocks and small intrusive bodies	Metamorphic lithologies and grade of metamorphism same. Orientations of foliation are compatible.
III	1. Thomas Mtn sill 2. Bautista sill	Foliated biotite adamellite	Concordant sill in prebatholithic terrane. Spatially associated with norite and gabbro.
IV	1. Burnt Valley complex 2. Bautista complex	Prebatholithic metamorphic rocks and small intrusive bodies	Metamorphic lithologies and grade of metamorphism same. Orientations of foliation are compatible.
V	1. Horse Canyon pluton 2. Horse Creek pluton	Hornblende-biotite tonalite	Nothing diagnostic
VI	1. Buck Ridge complex 2. Bautista complex	Prebatholithic metamorphic rocks and small intrusive bodies	Relatively large bodies of garnetiferous adamellite in both bodies. Metamorphic lithologies and grade of metamorphism same. Orientations of foliation are compatible.
VII	1. Clark Valley pluton 2. Coahuila Valley pluton (southern part)	Biotite tonalite, hornblende-biotite tonalite and biotite-hornblende tonalite	Coarse hexagonal biotite crystals in biotite tonalite. Associated bodies of inequigranular granodiorite and adamellite with sphene- and epidote-rich cores in leucocratic clots.
VIII	1. Not exposed 2. Coyote Ridge complex	Prebatholithic metamorphic rocks and small intrusive bodies	No correlation possible.
IX	1. Santa Rosa cataclastic zone 2. Coyote Mtn cataclastic zone	Slightly sheared cataclasites to mylonites of tonalitic and adamellitic composition. Prebatholithic metasediments	Intimate mixing of unusually marble-rich metasediments with sheared intrusive rocks. Generally northward trend and eastward dip of zones. Streaking in foliation plunges eastward or southeastward. Fold axes subparallel to streaking.

PLATE II



GENERALIZED FAULT SURFACE SECTIONS ALONG THE SAN JACINTO FAULT

1. Dotted lines represent contacts taken from the opposite fault block.
2. Other symbols are explained in Plate 1.
3. Only major Quaternary deposits have been shown.
4. Lettered points are explained in the text.

several miles south of the Coahuila Valley pluton, but the correlative Santa Rosa cataclastic zone transects the Clark Valley pluton on the northeastern block. The intersection of the Coahuila Valley pluton with the cataclastic zone has been eroded away, and the corresponding intersection with the Clark Valley pluton lies at depth. Thus, the northeastern fault block has been depressed relative to the southwestern block.

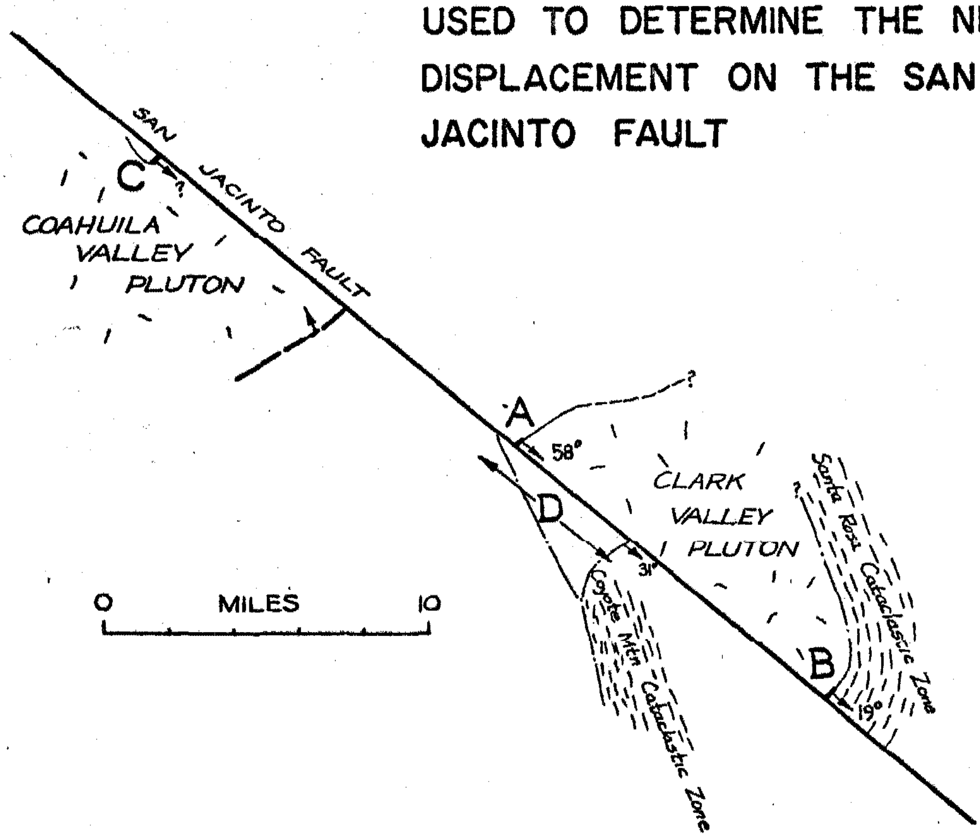
Possible ranges of horizontal and vertical components of displacement can be determined by considering the locations of correlative dimensions within the Clark Valley and Coahuila Valley plutons. The displacement cannot be established exactly because (1) the position of the intersection of the western contact of the Coyote Mountain cataclasite belt at the fault trace is uncertain because Quaternary deposits conceal it, (2) the difference in component of dip in the fault surface of the contacts of the cataclasite zones can be explained either by rotational displacement on the fault or by original structural complexity of the zones without rotation, (3) the dip of the northwestern contact of the Coahuila Valley pluton is unknown, and (4) the dips of contacts may change at depth.

The fault surface sections shown in Plate 11 have been drawn to represent what appears to be the most reasonable solution of fault displacement. In order to define the total range of possible solutions, four limiting cases must be considered. In the first two cases no significant rotation on the fault is assumed, and the difference in dip of the displaced cataclastic zone is considered to be unrelated to deformation on the San Jacinto fault. Two other cases are considered in which the difference in dip of the displaced cataclastic zone is attributed entirely to rotation on the fault.

The pertinent geometric data used to define the shapes of the structural units above and below the surface of exposure are shown in Figure 8. The horizontal dimensions have been scaled from Plate 11. Line AB is the horizontal dimension in the fault surface from the northern contact of the Clark Valley pluton to the western contact of the Santa Rosa cataclastic zone. Dimension AC is the distance between the northern contacts of the Clark Valley and Coahuila Valley plutons. Line CD is the horizontal distance in the fault surface between the northern contact of the Coahuila Valley pluton and the projected western contact of the Coyote Mountain cataclastic zone. The range in possible positions of point D is relatively large. The 13.5-mile minimum possible length of CD corresponds to projecting the Coyote Mountain cataclastic zone somewhat west of the trend on Coyote Mountain to an intersection with the fault near Jackass Flat. The 18.7-mile maximum length results if the contact of the cataclastic zone is extrapolated along a northeastward line from the most northerly exposures of deformed rocks on Coyote Mountain. The allowance for a wide range in the position of point D is required because (1) the foliations in the northernmost exposures of cataclasites suggest a possible bend in the zone to a somewhat more westerly trend than that found southward on Coyote Mountain, (2) the contact of the cataclastic zone could turn abruptly to the northeast and intersect the fault with an angular relationship similar to that occurring at the Santa Rosa cataclastic zone. Dimension CD may

FIG. 8

DIAGRAMMATIC HORIZONTAL SECTION SHOWING FEATURES USED TO DETERMINE THE NET DISPLACEMENT ON THE SAN JACINTO FAULT



DIMENSIONS (SCALED FROM PLATE II):

LINE	AB	=	12.4 MI
LINE	CD	=	13.5 MI TO 18.7 MI
LINE	AC	=	14.1 MI

DIP COMPONENTS IN FAULT SURFACE

DIP AT	A	=	58°
DIP AT	B	=	19°
DIP AT	C	=	UNKNOWN
DIP AT	D	=	31°

DIMENSIONS AND DIPS ARE DISCUSSED IN THE TEXT also have been lengthened somewhat by displacement on major cross faults on Coyote Ridge. The position of point D as shown in Plate 11 was located by linear projection of the western contact of the cataclastic zone along its trend as shown on Coyote Mountain.

The component of dip in the fault surface at point A was averaged from eight attitudes measured mostly in metamorphic rocks which are concordantly intruded by the Clark Valley pluton. The dip component at B was averaged from nine attitudes measured in the cataclasites near Rattlesnake Canyon. The internal structure of the cataclastic zone is generally subparallel to the margin of the zone. Although the location of point C is reasonably accurate, the dip of the contact is unknown because of poor exposure. The angle at D was averaged from twelve attitudes measured in the cataclasites on northern Coyote Mountain. The individual dip components that were used in calculating the angles at B and D varied over a broad overlapping range. However, the difference in the averages is assumed to be real.

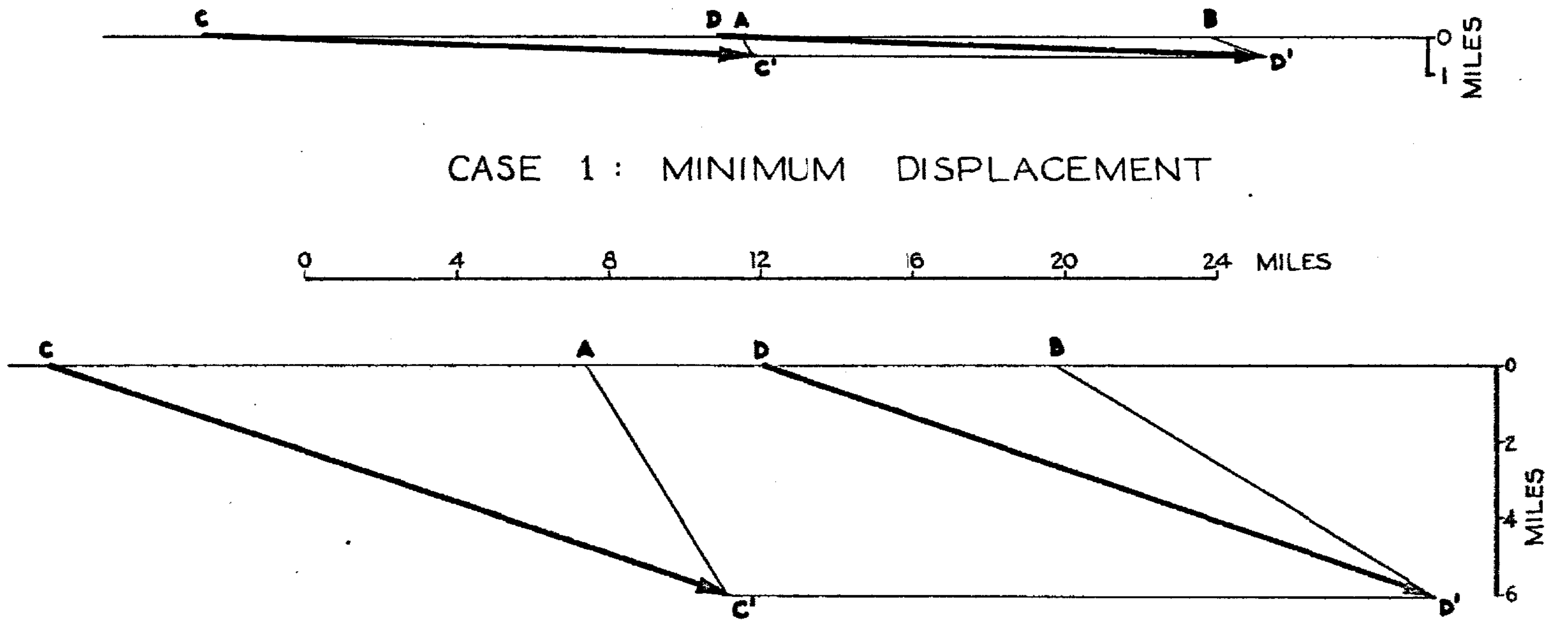
The fault-surface constructions that follow are based on linear extrapolation of the contacts in the fault surface as exposed nearest to the fault trace. In view of the curvature of contacts in horizontal view, these constructions are highly artificial and should be taken only as approximations.

<u>Case 1: Minimum displacement without rotation</u> -- By finding at depth a horizontal dimension through the Clark Valley pluton that is equal to the dimension CD as discussed above, a possible fault displacement may be determined. Because the length CD is not definitely known and the angle at B may steepen and become equal

to the angle at D, there are an infinite number of possible lines of equal horizontal dimension. From Figure 9 it can be seen that the minimum displacement results when length CD is minimal and the angle at B is maintained at depth. For this limiting case the displacement is about 14 1/3 miles in the right-lateral direction with the northeastern block relatively dropped. The horizontal component is also about 14 1/3 miles and the vertical component is about 1/2 mile.

Case 2: Maximum displacement without rotation -- Using the same type of construction as in Case 1, the maximum possible displacement is obtained when line CD is of maximum length and the angle at B steepens immediately below the surface to the value of the angle D (Fig. 9). For this case the displacement is about 23 miles in the right-lateral sense, and the northeastern block has dropped downward. The horizontal and vertical components are about 22 1/2 and 6 miles, respectively. However, this construction requires the northern intrusive contact of the Clark Valley pluton to be linear downward for over 7 miles. Inasmuch as this is very improbable, the displacement determined in this case may be seriously in error.

Displacement as shown in Plate 11 corresponds to an intermediate position of point D located in line with the exposed contact of the cataclastic zone. The resulting displacement and horizontal component is about 15 1/2 miles. The vertical component is slightly less than 2 miles.



CASE 1 : MINIMUM DISPLACEMENT

CASE 2 : MAXIMUM DISPLACEMENT

FIG. 9

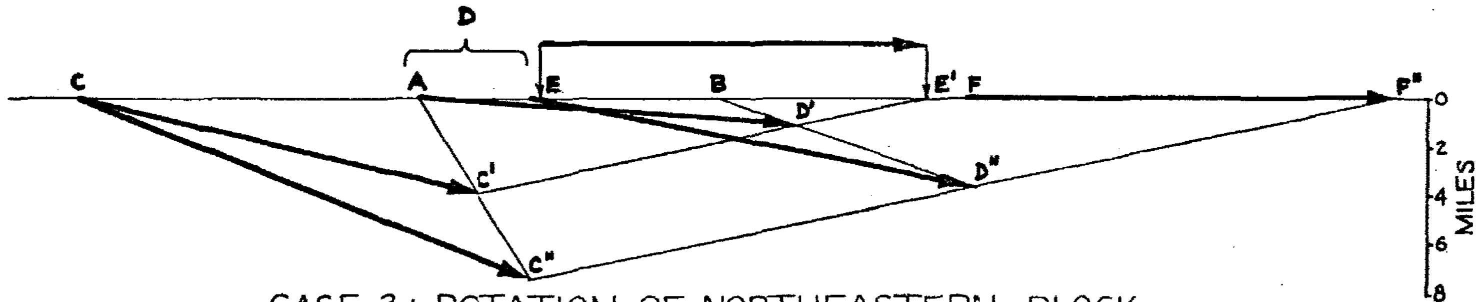
DISPLACEMENT WITHOUT ROTATION

POINTS **A , B , C , D** AS IN FIG. 8

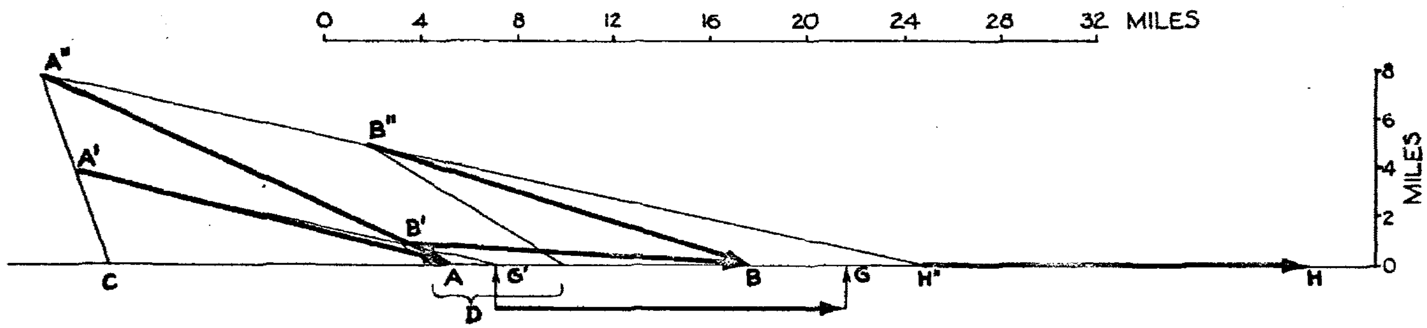
LINE **C'D' = CD** , DISPLACEMENT SHOWN BY LINES **CC'** AND **DD'**

Case 3: Displacement with rotation of the northeastern block -- The assumption that the difference in dips observed in the displaced cataclasite zones is due entirely to rotation of the northeastern fault-block as a locally rigid body leads to displacements as shown in Figure 10. The uncertainty of the position of D again leads to maximum and minimum values. In this construction distances equal to the limiting dimensions of line CD were found at depth in the Clark Valley pluton that have the same angular relationship to the dip of the cataclastic zone as exposed on the southwestern fault block. As shown in Figure 10, this construction suggests reversal of the sense of vertical displacement south of the map area and very great vertical components toward the northwest. Because prebatholithic structures in the northwestern part of the map area are incompatible with rotation in this sense, rotational displacement could only have affected the southern part of the area. The southern limit of possible rotational displacement is unknown because the crystalline rocks are concealed.

The possible displacements involving rotation of the northeastern fault block range from about 16 1/3 to 19 miles in the central part of the map area and from about 14 1/2 to 16 miles at the southern end of the map area. The corresponding horizontal and vertical components range respectively from 16 to 18 miles and from 3 to slightly over 6 miles in the central part of the area. Both displacement components decrease southeastward to a range of 14 1/2 to nearly 16 miles and a range of 1/2 to 2 2/3 miles at the southern tip of the area. As in the case for maximum displacement without rotation, the large displacement found in the central part of the area (CC", Fig. 10) must be regarded as unreliable because



CASE 3 : ROTATION OF NORTHEASTERN BLOCK



CASE 4 : ROTATION OF SOUTHWESTERN BLOCK

FIG. 10

POSSIBLE DISPLACEMENTS WITH ROTATION

POINTS **A, B, C, D** AS IN FIG. 8

IN CASE 3, **C'D'** = MIN. **CD**, **C"D"** = MAX. **CD**; DISPLACEMENTS MAY RANGE BETWEEN **CC'** AND **CC"**, **DD'** AND **DD"**, AND **EE'** AND **FF"**. IN CASE 4, **AB** = **A'B'** = **A"B"**; DISPLACEMENTS MAY RANGE BETWEEN **A'A** AND **A"A**, **B'B** AND **B"B**, AND **G'G** AND **H"H**.

it depends on extrapolation of an intrusive contact to great depth.

<u>Case 4: Displacement with rotation of the southwestern block</u> -- This construction is similar to case 3, but the dip of the cataclastic zone on the southwestern block is assumed to have been fault-rotated from the dip observed at B (Fig. 10). Dimensions equal to the exposed length of the Clark Valley pluton were located within the eroded portion of the Coahuila Valley pluton that bore the same angular relationship to the dip of the cataclastic zones. The displacements resulting from this construction decrease southward from 18 1/2 miles in the central part of the a area to 14 1/2 miles at the south end. The corresponding horizontal components range from nearly 17 miles in the central part to a minimum of 14 1/4 miles near the south end. The vertical components range from 0 to nearly 8 miles. Displacements found in the central part of the area are unreliable because they depend on large extrapolation of an intrusive contact whose dip has been inferred (A''C, Fig. 10).

<u>Summary of possible displacements</u> -- Because each of the cases discussed above is compatible with the exposed distribution and orientation of the rock units, the range of possible displacements must bracket all of these cases. The right-lateral component of displacement in the southern part of the map area probably is between 14 1/2 and 17 miles, but horizontal movements up to 22 1/2 miles conceivably could have occurred. The northeastern block has relatively dropped between 0 and 6 miles at the southern tip of the area and between about 1/2 and nearly 8 miles in the central

part of the map area. If rotation on the San Jacinto fault has occurred, small vertical movement near the southern end of the area may correspond to large vertical movement in the central part. Inasmuch as the large components of displacement, both horizontal and vertical, are based on extrapolation to great depth, they are more questionable than possible small components within their respective ranges.

Although the cases discussed above were presented independently, they may have occurred in combination (except for the combination of cases 1 and 2 together). The displacements resulting from such combinations are very close to the values established in the independent cases.

The absence of evidence of cataclasis under deep-seated conditions in the crushed rocks distributed along the fault trace may indicate that the vertical components of movement might be less than the maximum values permissible by geometric considerations. Because the minimum depth at which mylonites can be formed is unknown at present, a maximum possible vertical component of movement cannot be defined on that basis. However, mylonites quite possibly could form at levels in the crust considerably more shallow than 6 to 8 miles.

Consideration of the equal grade of regional metamorphism on each fault block does not limit the possible vertical displacement as much as the geometric constraints. Almandine amphibolite facies of regional metamorphism may reasonably have existed over a vertical range of about 10 miles in the crust (Turner, 1958, p. 237). The equal grade of contact metamorphism found on each fault block could also reasonably have existed over a vertical range of about 10 miles (Turner, 1958, p. 237).

Northern Area

The displacement on the San Jacinto fault in the northern part of the map area can be roughly estimated by considering the positions of the southeastern contact of the Thomas Mountain pluton and its correlative segment of the Coahuila Valley pluton. These bodies have been separated right-laterally about 15 miles. The Thomas Mountain sill converges with the Thomas Mountain pluton near the fault, and the projected line of intersection has been located approximately at point P in the fault surface (Pl. 11). Inasmuch as the Bautista sill and the northern part of the Coahuila Valley pluton are separated by a relatively thick septum of metamorphic rocks, the correlative point Q representing their convergence in the fault surface either must lie at depth or must have been eroded away. Vertical displacement is required in either case. Point Q in Plate 11 has been located above the land surface in agreement with the evidence from the southern part of the map area that the northeastern block has dropped relative to the southwest side. There is no evidence suggesting large-scale rotation on the San Jacinto fault which could have caused reversal in the sense of cumulative vertical displacement. The position of Q as shown is compatible with the structure in the metamorphic rocks, the curvature of the contacts of the intrusive bodies, and with the range of possible vertical components of movement found in the southern part of the map area.

The geometry of the contacts requires that the horizontal component of displacement be less than the separation, inasmuch as the vertical displacement also contributes to the right-lateral separation. By allowing for a vertical component of at least 2 miles, the horizontal component could not reasonably be greater than 14 miles. These estimates are based on the assumption that the contact of the Coahuila Valley pluton is relatively smooth as shown in Plate 11.

The fact that the largest probable displacement on the northern segment of the San Jacinto fault is less than the minimum established for the southern segment indicates the two fault blocks probably did not act as rigid bodies on a large scale. Furthermore, comparison of the horizontal dimension across the Bautista complex and the distance between the Thomas Mountain and Clark Valley plutons at correlative levels indicates a significant relative shortening of the southwestern block (Pl. 11). The shortening probably is greater than shown in Plate 11, because right-lateral displacement on the Buck Ridge fault has reduced the dimension of the Burnt Valley complex along the San Jacinto fault. Thus, the net horizontal movement found for the northern part of the San Jacinto fault includes the amount of lateral offset on the Buck Ridge fault. Although the displacement on the Buck Ridge fault is unknown, a separation of less than 2 miles is consistent with relations along its northern part.

That shortening has occurred in the southwestern block rather than stretching of the northeastern block is suggested by the contrasting degree of deformation of the Bautista sediments on each side of the fault. Bautista beds north of Anza locally dip steeply or are intensely folded, but the sediments exposed southeast of Burnt Valley show gentle dips and no obvious evidence of tensional faults. The dimensional difference may also be attributed to pervasive micro-faulting and brecciation, much of which may have preceded Bautista deposition.

Problem of the Vertical Component of Displacement

Although the distribution of crystalline rocks shows that the northeastern block has been relatively depressed along the southern part of the studied fault segment, some of the pre-Bautista vertical displacements were in the opposite sense. In pre-Bautista time the northeastern block had been dropped at least as much as the net vertical component of movement. Both sides of the San Jacinto fault were then eroded to approximately the same level. Along much of the fault trace, a prominent southwest-facing scarp a few hundred to a few thousand feet high subsequently was developed in pre-Bautista time. The sense of post-Bautista vertical movement changed back to that of the cumulative vertical component, but the amount of displacement has probably been small compared to that of the pre-Bautista reversal. Thus, the net vertical component of movement on much of this segment of the San Jacinto fault was at least slightly greater during part of pre-Bautista time than at present. The vertical component of individual movements may have reversed its sense repeatedly throughout much of the history of the fault.

Problem of the Age of the Fault Zone

Two lines of evidence strongly suggest that the displacement of the plutonic bodies does in fact represent the total offset of the fault and thus limits the fault to an age younger than mid-Cretaceous. The first relates to correlation of the metamorphic stratigraphy across the fault. Throughout the metamorphic terrane, lithologically distinctive layers are widely scattered and of short lateral extent. This monotony is broken only at the southern Santa Rosa Mountains and at Coyote Mountain where the metamorphic rocks are unusually rich in marble beds. Hence, the only possible correlation across the San Jacinto fault based on metamorphic stratigraphy indicates a displacement identical to that of the cataclastic belt which is younger than the intrusive rocks. Furthermore, internal structures within the prebatholithic rocks along the entire length of the map area are consistent with the displacement indicated by the younger intrusive and cataclastic rocks. The apparently uniform grade of prebatholithic regional metamorphism along the length of both fault blocks places no restrictions on the amount or age of displacement.

The second line of evidence that the offset of the plutonic bodies represents the total displacement is concerned with the absence of mylonitic rocks within the fault zone. The textures and the coherence of the rocks within the cataclastic zone obliquely transected by the San Jacinto fault indicate deformation at considerable depth in the earth's crust. Because similar textures do not occur in fragments of fault breccia anywhere along the trace of the fault, movement of rocks at the present surface must have taken place only under conditions of relatively low confining pressure. The occurrence of incoherent gouge, breccia, and rock flour along the fault is consistent with this interpretation. Movement on the San Jacinto fault must not have preceded the development of the transected cataclastic zone. Indeed, regional uplift and unroofing of the batholith probably had progressed to a considerable extent prior to movement on the San Jacinto fault. This sequence of events is consistent with Crowell's (1962, p. 49) conclusion that faults of the San Andreas system originated in early Tertiary time.

In the eastern part of the San Gabriel Mountains along Lytle Creek, alaskite dikes confined within the fault zone were interpreted as indicative of a Mesozoic age for the San Jacinto fault by Sprotte (1949, p. 318). However, some intrusive rocks elsewhere in the southeastern San Gabriel Mountains have been shown to be Miocene in age (Hsu et al., 1963, p. 511), and the dikes observed by Sprotte may be of similar age.

Problem of the Total Displacement

In the preceding sections, the bodies of crystalline rocks exposed on each side of the San Jacinto fault zone within the map area have been considered as correlative. The problem of whether these correlations are fortuitous and other correlative rock units exist elsewhere must also be considered. The sequence of crystalline rocks observed within the map area is not only composed of a wide range of lithologic types but also involves a complex geometric arrangement. That such a complex sequence is repeated across the fault is the most compelling evidence that the correlation is unique. The occurrence of another crystalline terrane with all of these features must be regarded as highly improbable.

The displacement herein proposed for the San Jacinto fault is consistent with the regional distribution of the various crystalline rocks as presently known. The zone of cataclastic rocks transected by the San Jacinto fault in the southern part of the map area is regionally unique. Except for the Coyote Mountain exposures, no cataclasites that converge with the fault zone from the south are known in the 80-mile interval between San Bernardino and Borrego Valleys. Minor amounts of northwest-trending cataclasites were observed a few miles west of the north end of the map area by Schwarcz (1960), but these rocks are probably very local in extent. Cataclastically deformed rocks exposed along the southern margins of the San Bernardino and San Gabriel Mountains involve rocks of completely different lithology and are oriented principally in the east-west direction (Allen, 1957, p. 320; Hsu, 1955). The regional uniqueness of the cataclastic shear zones in the map area is strong evidence that no other scheme of correlation is possible within the Peninsular Range province.

The distribution of crystalline rocks in the Peninsular Ranges northwest of the present map area is compatible with 14 to 18 miles of horizontal movement. Most of the rocks southwest of the fault zone in this interval have been mapped as tonalite by Larsen (1948) and others. These discontinuous exposures may be underlain by a single body of tonalite joining the Coahuila Valley pluton in the map area. Because of its great size the only probable correlative unit northwest of the fault is the Thomas Mountain pluton.

The separation of crystalline rocks along the San Jacinto fault zone in the eastern part of the San Gabriel Mountains, as mapped by Noble (1954b),is consistent with right-lateral displacement of 14 to 18 miles. The sense of net vertical movement is unknown in this region. In earlier work, Arnett (1949) had argued for 7 miles of right-lateral displacement on two branches within the fault zone along Lytle Creek.

Other workers have proposed Quaternary movement on the San Jacinto fault that is consistent with 14-18 miles of net horizontal displacement, but there are difficulties relating to the conclusiveness of the evidence presented by them. Post-Pliocene right-lateral displacement of 11 miles on the San Jacinto fault near the San Timoteo badlands has been postulated by English (1953, p. 82, 84). Movement of this magnitude is based on the similarity of clasts in basal Mt. Eden beds on the northwestern block and a tonalitic source area presently exposed on the southwestern block east of Riverside. Inasmuch as tonalitic rocks probably underlie much of the San Jacinto Valley and vertical displacements have been significant in this area, possible concealed source areas for the tonalitic clasts may lie much closer than 11 miles. Indeed, the presently exposed tonalitic mass on the southwestern block may have been raised since the time of accumulation of Mt. Eden beds.

Exposures of distinctive sedimentary beds on each side of the fault in the San Timoteo badlands area also have been cited as evidence of a movement of about 11 miles (English, 1953, p. 82; Dutcher and Garrett, 1963, p. 38). However, the separation of low-dipping beds is strongly affected by vertical movements, and the displacement of these units consequently could be much different than 11 miles.

Eckis (1930, p. 13) proposed that the lateral displacement on the San Jacinto fault (his Clark fault) was 10 to 11 miles near Clark Valley on the basis of the distribution of Bautista gravels (his Santa

Rosa Fanglomerate) and lacustrine deposits. Considering the fact that the original distribution of the sediments may not have been linear across the fault zone, the evidence in support of 10 to 11 miles of displacement must be regarded as inconclusive in spite of its compatibility with the net movement proposed herein.

Summary

The cumulative displacement on the San Jacinto fault within the map area is composed of a dominant right-lateral component and a subordinate vertical component which has relatively raised the southwestern block. The horizontal component probably increases southeastward from about 14 miles in the northern segment of the fault to between a little over 14 and about 17 miles in the southern segment. However, the lateral component of movement could possibly be as large as 22 1/2 miles in the southern area. This variation in the horizontal component takes place within a distance of about 20 miles.

The possible range in the magnitude of the net vertical component is 0 to about 6 miles at the southern tip of the map area and 1/2 to nearly 8 miles in the central part of the area. Limits cannot be placed on the vertical component in the northern part of the area, but it probably is within the range found in the other segment. The vertical component of the cumulative displacement probably was slightly greater during part of pre-Bautista time than it is at present. Quaternary vertical components of movement have been variable in sense in both time and space. Rotational displacements are common along the length of the fault. Vertical displacements amounting to several hundred feet have occurred both in accord and opposed to the sense of the net vertical component.

The evidence within the map area suggests that possibly as much as 3 miles of right-lateral movement has taken place in Quaternary time. Quaternary offsets up to 11 miles have been suggested by other workers in this area and to the northwest, but the evidence in support of this is not conclusive.

REGIONAL IMPLICATIONS OF THE DISPLACEMENT ON THE SAN JACINTO FAULT ZONE

Although the historic record of earthquakes in southern California is admittedly short, the high seismicity associated with the San Jacinto fault over the last half century suggests that it is currently the most active break within the San Andreas fault system (Hill, 1928, p. 35; Allen, et al., 1958; Biehler, et al., in press). Right-lateral slip of 160 to 175 miles on the San Andreas and closely associated faults has been proposed by Crowell (1962, p. 49). If the total movement has indeed been this great, then the relatively small displacement on the San Jacinto fault indicates that is has not always been as important a member of the system as its current activity suggests.

That the Banning fault in the San Gorgonio Pass region may correspond to one of the prominent east-west faults of the San Gabriel Mountains has been suggested by Allen (1957, p. 339). The distance separating the intersections of the Banning and the Sierra Madre fault zones with the San Jacinto fault zone is about 16 miles (Fig. 1). Unless the displacement on the San Jacinto fault as observed in the map area consistently diminishes toward the northwest, the separation of these transverse structures may correspond closely to its total horizontal slip. Correlation of these east-west faults requires that they be at least as old as the San Jacinto fault zone. Cataclastically deformed crystalline rocks that are distributed along the southern margin of the Transverse Ranges do indicate that east-west shearing is much older than the northwest-trending structures that transect them (Hsu, 1955; Allen, 1957). Thus, the present positions of the Sierra Madre and Banning faults may well reflect the net displacement of the San Jacinto fault.

Previous workers in the Imperial Valley region have generally considered fractures aligned with the Coyote Creek fault of this report to be the main break within the San Jacinto fault zone. Inasmuch as the line of major displacement herein has been shown to extend through Clark Valley, the San Jacinto fault probably lies well east of those breaks heretofore carrying the name in lower Imperial Valley and Baja California. The San Jacinto fault may in fact connect with the Imperial fault that extends from central Imperial Valley southeastward into Mexico.

RATES OF DISPLACEMENT ON THE SAN JACINTO FAULT ZONE

Uncertainties in the horizontal components of displacement and their absolute ages permit only approximations of past rates of movement on the San Jacinto fault. Data derived from offset stream channels, distinctive gravel beds, and bodies of crystalline rocks allow only a few approximations to be made. Recent triangulation data a few miles south of the map area also provide an estimate of the current rate of movement. Because of the lack of offset deposits whose ages are intermediate to the Quaternary deposits and the older crystalline rocks, both the variation of the rate of strain and the age of the inception of faulting are unknown.

Bautista gravel beds exposed north of Anza are offset at least 2.0 miles from the nearest possible source areas. Although they may represent a considerable range of age, all of these beds are probably of Pleistocene age and are less than 1 million years old. Thus, the average rate of displacement on the San Jacinto fault since Pleistocene time probably has been at least 1.0×10^{-2} feet per year.

If the rate of movement were constant throughout Pleistocene time, a stream course north of Anza that is displaced 0.45 mile would have a maximum possible age of about 240,000 years. This stream course is very likely much younger than this, in view of the very fresh appearance of its truncation. This implies that the average rate of displacement has been greater than the minimum value above and that the age of at least some of the Bautista beds is considerably less than 1 million years. By comparison, a fresh-appearing scarp on the Garlock fault in the central part of California has been shown to be at least 50,000 years old (Smith, 1960).

A current movement rate of at least 9.2×10^{-2} feet per year across the San Jacinto fault and associated faults to the southwest has been established by surveys of a network of triangulation stations in Imperial Valley between 1941 and 1954. This rate has been calculated from the movement between stations Granite and Coolidge shown in Figure 11, adapted from Whitten (1956, p.

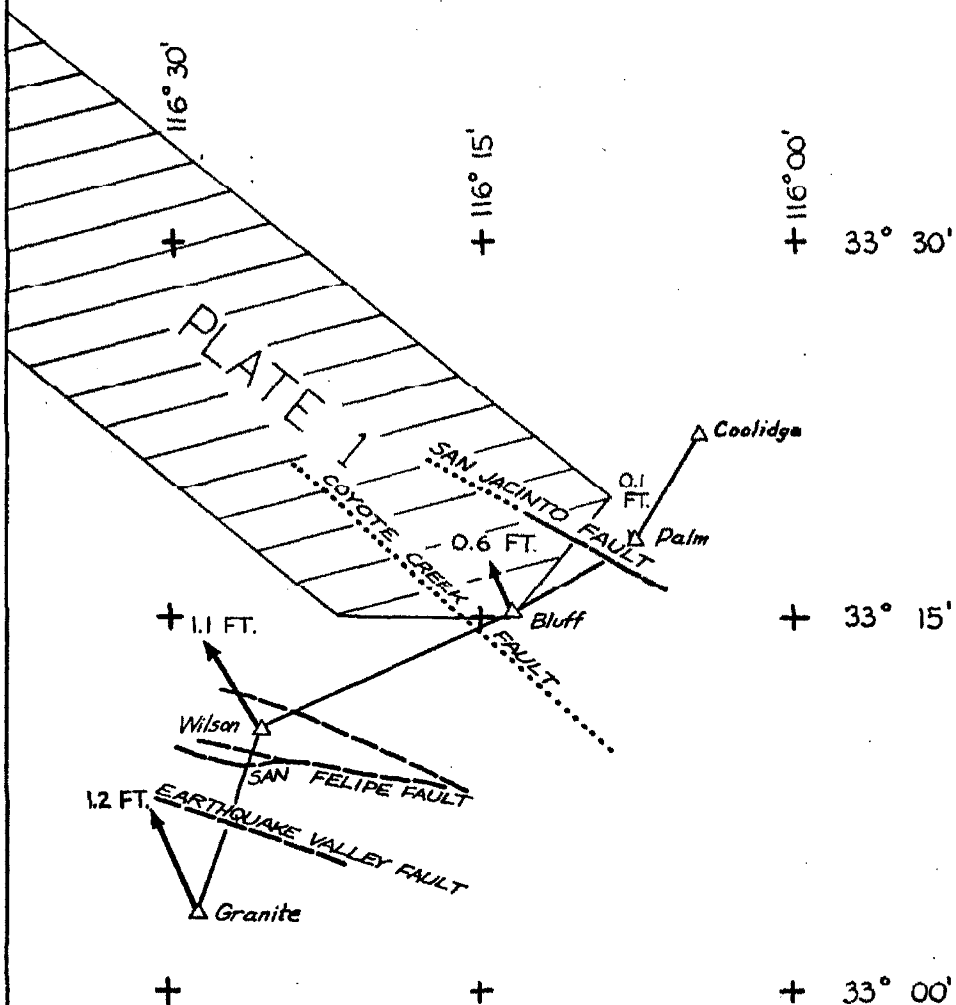


FIG. 11

HORIZONTAL MOVEMENT OF TRIANGULATION STATIONS WITH RESPECT TO STATION COOLIDGE BETWEEN YEARS 1941 AND 1954. (ADAPTED FROM WHITTEN, 1956)

396). A rate of at least 4.0×10^{-2} feet per year can be attributed to the San Jacinto fault alone. The angular distortion across the interval between stations Granite and Coolidge is about 1 second of arc per ten years. This figure is comparable to angular distortions determined in the vicinity of El Centro and across the trace of the San Andreas fault near Monterey Bay and San Luis Obispo (Whitten, 1956, p. 395, 398).

Because of the questionable absolute age of the Bautista beds, the average rate of Quaternary movement on the San Jacinto fault cannot be assumed to be significantly different from the present rate. However, if the minimum rate of Pleistocene displacement is used with the maximum possible horizontal movement of the crystalline rocks, an age for the fault zone of about 12 million years results. Although there is no evidence to support the constancy of the movement rate in pre-Pleistocene time, it is possible that the San Jacinto fault zone is no older than early Pliocene. If the age of the San Jacinto fault is as great as the postulated early Tertiary age of the San Andreas fault system (Crowell, 1962, p. 49), then the average rate of horizontal offset has been significantly less than the minimum value established for Pleistocene movements.

The large gap in the knowledge of displacement as a function of age for the San Jacinto fault zone may possibly be filled through detailed study of the Cenozoic sediments exposed in the western part of Imperial Valley.

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APPENDIX

MINERAL ABUNDANCES OF ROCK SAMPLES
(Sample locations are listed in Table 5)

Table 1 - Migmatitic Gneiss

Sample	db=dark bands lb=light bands	Quartz	Plagioclase	(comp.)	K feldspar	Biotite	White Mica	Hornblende	Diopside
52	db	35-45	15-25	An_{33-51}	5-15	20-30	Tr	-	-
	lb	45-55	25-35		15-30	3-10	Tr	-	-
147	db	10-50	20-60	An_{45}	-	30	-	-	-
	lb	50-90	10-25		0-20	0-5	-	-	-
205	db	65-70		An_{55}	0-5	25-30	-	-	-
	lb	45-65			30-50	5	-	-	-
292	db	0-5	20-40	An_{53-95}	-	5-35	-	40-60	-
	lb	5-15	40-50	An_{50}	-	1-5	-	0-3	-
309	db	55-65		?	20	20	-	-	-
	lb	50-60			5-10	5	3	-	-
314	db	45-60		An_{38}	10-20	10-20	-	-	10-15
	lb	50-80			20-40	0-5	-	-	0-5
315	db	70-90		?	0-5	10-20	0-5	-	-
	lb	60-80			0-10	0-5	10-15	-	-

Table 2 - Tonalitic rocks

	Sample	Plagioclase (zoned)	Quartz	Biotite	Hornblende	K feldspar	Sphene	Other Accessories
Coahuila Valley pluton	74	50 An_{26-59}	30	16	1	3	Tr	Tr
	89	40 An_{29-61}	28	24	5	-	1	Tr
	192	47 An_{33-68}	20	15	15	-	1	1
	247	43 An_{33-71}	30	20	5	-	Tr	2
	249	45 An_{30-70}	35	5	10	-	2	2
	521	50 An_{28-50}	25	8	12	3	2	Tr
	542	50 An_{35-61}	29	10	10	1	Tr	Tr
Thomas Mtn pluton	100	57 An_{29-49}	24	9	3	6	1	Tr

Table 2 (continued)

	Sample	Plagioclase (zoned)	Quartz	Biotite	Hornblende	K feldspar	Sphene	Other Accessories
Thomas Mtn pluton	148	50 An_{33-38}	40	6	4	-	Tr	Tr
	273	46 An_{25-62}	26	12	8	5	2	1
Clark Valley pluton	174	45 An_{27-65}	30	12	12	-	Tr	1
	178	45 An_{39-54}	23	20	10	1	Tr	1
	430a	46 An_{26-52}	30	15	-	7	Tr	2
Horse Canyon pluton	75	45 An_{31-64}	38	10	2	2	Tr	3
	197	50 An_{27-42}	31	9	-	8	Tr	2
	1220	50 An_{34-59}	32	13	2	1	Tr	2

Table 2 (continued)

	Sample	Plagioclase (zoned)	Quartz	Biotite	Hornblende	K feldspar	Sphene	Other Accessories
Santa Rosa pluton	268	45 An_{35-53}	32	20	1	Tr	Tr	2
Horse Creek pluton	150	40 An_{41-54}	32	15	10	1	1	1
	338	50 An_{34-57}	27	15	20	Tr	1	2
	220	32 An_{27-41}	36	10	15	5	2	Tr
Coyote Creek pluton	226	31 An_{22-52}	30	10	1	28	Tr	Tr
	378	30 An_{29-60}	35	5	-	30	-	Tr
	227	45 An_{32-55}	20	9	9	15	1	1
	235	51 An_{33-62}	20	15	12	Tr	Tr	2

Table 2 (continued)

	Sample	Plagioclase (zoned)	Quartz	Biotite	Hornblende	K feldspar	Sphene	Other Accessories
Coyote Ridge pluton	118	55 An_{32-67}	25	15	5	Tr	Tr	Tr
	122	41 An_{32-66}	25	15	15	2	Tr	2
	209	52 An_{32-74}	20	13	12	1	1	1
	224	33 An_{33-60}	25	10	10	20	1	1
	252	40 An_{25-31}	25	9	1	25	Tr	Tr
	255	48 An_{31-55}	20	18	12	1	1	1
	1150	47 An_{28-47}	25	8	8	10	Tr	2

Table 3 - Adamellitic Rocks

	Sample	Plagioclase (zoned)	Quartz	K feldspar	Biotite	Hornblende	White mica	Garnet	Other Accessories
Garnet-iferous Adamellite	107	An^{24}_{4-14}	45	25	6	-	Tr	Tr	Tr
	115	An^{35}_{3-19}	30	30	5	-	Tr	Tr	Tr
	123	An^{31}_{2-12}	29	38	Tr	-	1/2	1	1/2
	168	An^{18}_{10-24}	40	33	3	-	2	4	Tr
	264	An^{32}_{4-16}	35	30	1/2	-	1/2	1	1
	310	An^{42}_{0-20}	31	21	5	-	1/2	1/2	Tr
	313	An^{34}_{4-8}	24	38	1/2	-	1	2	1/2
	545	An^{25}_{5-13}	35	30	-	-	1	3	Tr

Table 3 (continued)

	Sample	Plagioclase (zoned)	Quartz	K feldspar	Biotite	Hornblende	White mica	Garnet	Other Accessories
Foliated Adamellite	523	An^{33}_{27-33}	25	25	10	5	-	-	Tr
	279	An^{39}_{27-31}	29	23	8	1	-	-	Tr
Fine- to medium-grained Adamellite	190	An^{26}_{25-30}	25	40	5	-	3	-	1
	207	An^{39}_{25-48}	25	25	8	-	2	-	1
	449	An^{36}_{26-36}	30	25	8	-	-	-	1

Sample Locations

17. NW Fig Tree Valley, 1.3 mi. W of spring in Coyote Canyon.
52. Parks Canyon, 1.3 mi. SW of Coyote Creek.
74. Upper White Wash, 2 1/2 mi. E of Horse Canyon.
75. N side of White Wash, 1 mi. W of its head.
89. W side of Horse Canyon, 1 mi. N of Turkey Track.
100. 0.5 mi. NW of Hog Lake.
107. 0.8 mi. N of San Diego Co. line, N of Yucca Valley.
115. Buck Ridge, 3.2 mi. NNW of Hidden Springs.
118. Butler Canyon, 2 1/2 mi. N of Alcoholic Pass.
122. Butler Canyon, 3 1/2 mi. NNW of Alcoholic Pass.
123. W of Jackass Flats, 1/2 mi. N of head of Butler Canyon.
147. Horse Creek, 0.35 mi. SW of San Jacinto fault.
148. W slope Rouse Hill, 0.6 mi. W of Milky Spring.
150. 0.5 mi. SW of San Jacinto fault in canyon 1.8 mi. SE of Horse Creek.
168. S of Galleta Meadows, 2 mi. N of Anza-Borrego Park headquarters.
174. 1.9 mi. ESE of Hidden Spring.
178. 3.5 mi. S72^{o}E from Hidden Spring.
190. Coyote Canyon, 0.8 mi. NNW of Monkey Hill.
192. E central Table Mtn, 2.1 mi. S of Lookout Mtn.
197. 0.1 mi. E of NW corner Clark Lake 15' quadrangle.
205. W of Jackass Flat, 1.8 mi. N85^{o}W from Hidden Spring.
207. 0.8 mi. E of Box Canyon, 1 mi. S of San Diego Co. line.
209. E of Box Canyon fault, 1.4 mi. NW of Alcoholic Pass.

Sample Locations (continued)

220. N Collins Valley, 1 1/4 mi. W of Monkey Hill.

224. Just E of Coyote Creek fault, 1 1/2 mi. N of Santa Catarina Spring.

226. Coyote Canyon, 1 mi. NNE of Lower Willows.

227. W side of Indian Canyon, 1 mi. S of Sheep Canyon.

235. Coyote Canyon, 1 mi. E of Santa Catarina Spring.

247. N Table Mtn, 3 1/4 mi. E of Anza.

249. N bank of Coahuila Creek, 2 1/2 mi. SW of Anza.

252. 2.1 mi. NNW of Alcoholic Pass.

255. Coyote Mtn, 2.4 mi. SE of Alcoholic Pass.

264. Rockhouse Canyon, 2.3 mi. NE of Hidden Spring.

268. 2.6 mi. NE of head of White Wash.

273. Thomas Mtn, 3 mi. SW of Hog Lake.

279. Thomas Mtn, 1.9 mi. NW of mouth of Hamilton Creek.

292. SW Thomas Mtn, 2.8 mi. N58°E from Anza Post Office.

309. Coyote Ridge, 5 mi. N60°W from Hidden Spring.

310. E side Dry Wash, 4.9 mi. NW of Hidden Spring.

313. W side of Dry Wash, 1 mi. NW of head of Box Canyon.

314. Coyote Ridge, 4.4 mi. N60°W of Hidden Spring.

315. Coyote Ridge, 4.7 mi. N60°W of Hidden Spring.

338. N Collins Valley, 1 mi. NW of Monkey Hill.

378. Mouth of Box Canyon.

430a. Just E of San Jacinto fault, 2 1/2 mi. SE of Hidden Spring.

449. Coyote Ridge, 1.2 mi. NE of Monkey Hill.

521. Ramona Bowl, Santa Rosa Hills (northwest end of area).

523. E bank of Bautista Creek, 1/2 mi. S of junction with Blackburn Canyon.

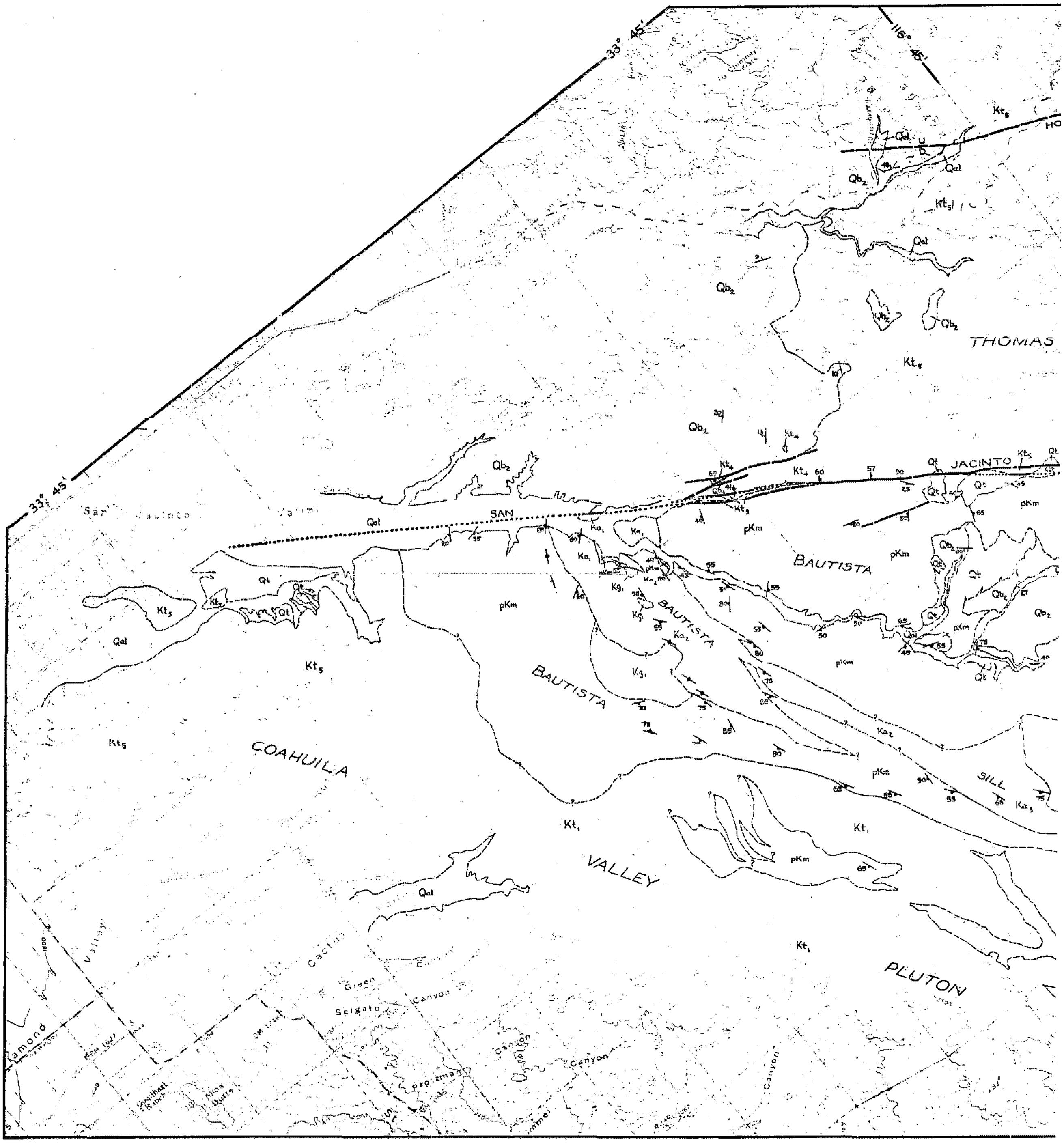
Sample Locations (continued)

542. 1/2 mi. E of Red Mtn.

545. Coahuila Mtn, 1 1/2 mi. SSW of Tripp Flats guard station.

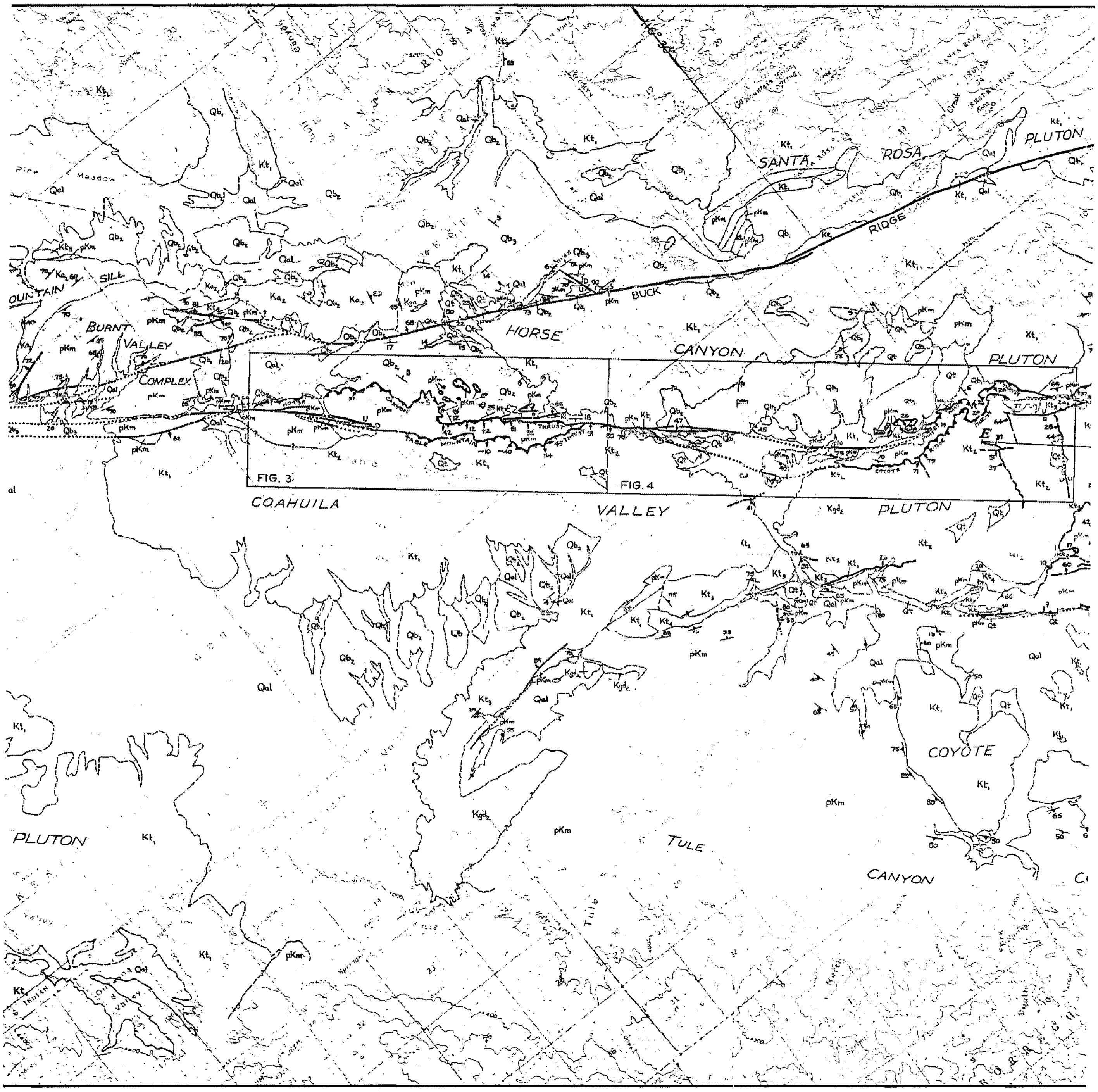
1150. Box Canyon, 1/4 mi. NE of Coyote Creek fault.

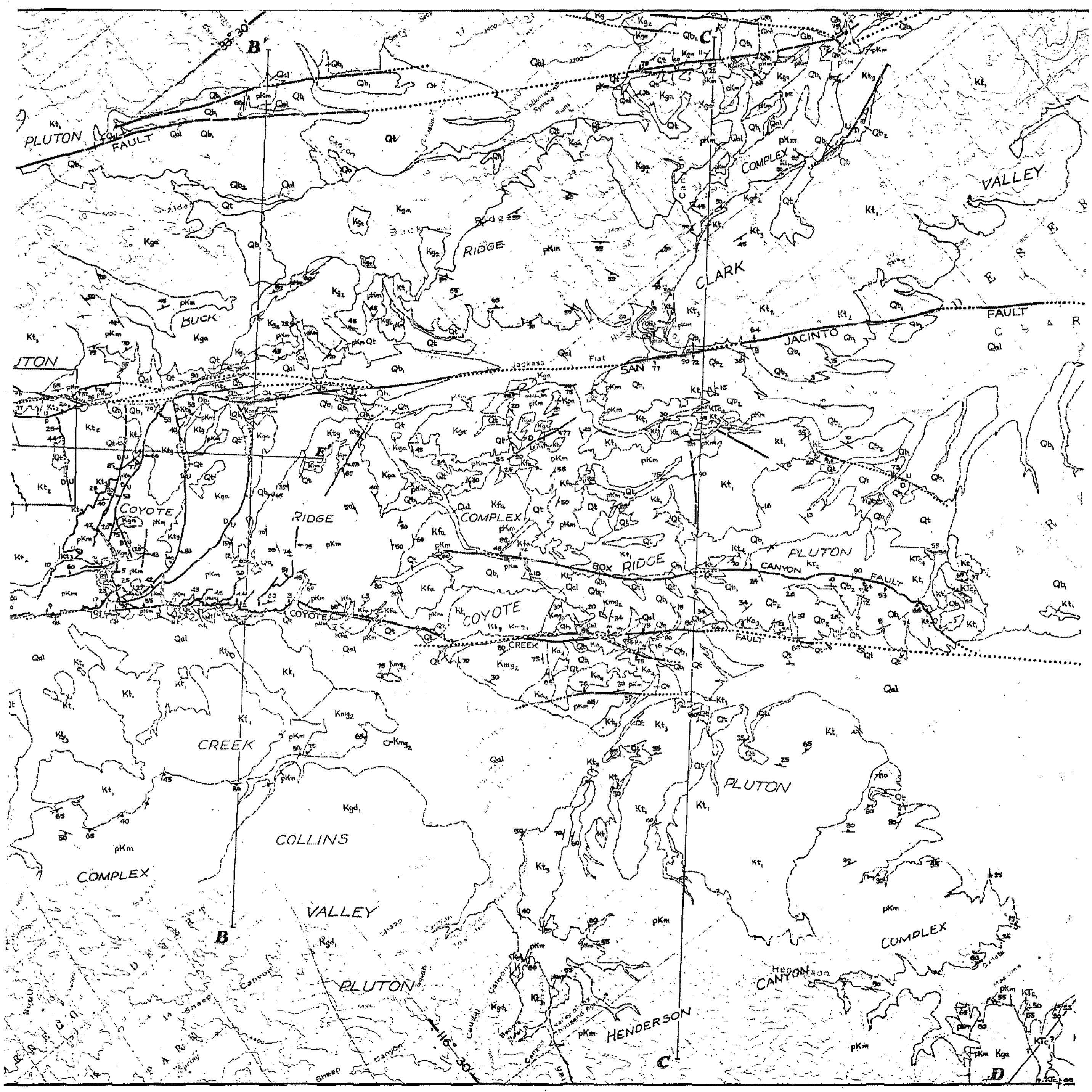
1220. Horse Canyon, 0.2 mi. downstream from Garnet Queen Creek.



33° 45'
116° 45'
SAN
JACINTO
THOMAS
BAUTISTA
COAHUILA
VALLEY
PLUTON
SILL
Qal
Qb₂
Qt
Kt₅
Kt₄
Kt₁
pKm
Kg₁
Ka₁
Ka₂
Ka₃
Cactus
Green
Selgato
Canyon
Mica Butte

HOT SPRINGS FAULT
GARNER VALLEY
THOMAS MTN. FAULT
THOMAS MOUNTAIN PLUTON
THOMAS MOUNTAIN SILL
BURNT VALLEY
COMPLEX
FAULT
CANYON THRUST
HORSE CREEK PLUTON
COMPLEX
VALLEY
PLUTON
COAHUILA
116° 45'
33° 30'
A
A'


SANTA ROSA PLUTON
BUCK RIDGE
HORSE CANYON PLUTON
BURNT VALLEY COMPLEX
FIG. 3
FIG. 4
COAHUILA VALLEY PLUTON
PLUTON
COYOTE
TULE CANYON
Qal
Qb2
Kt1
pKm


B'
C'
PLUTON
FAULT
COMPLEX
VALLEY
RIDGE
BUCK
CLARK
SAN
JACINTO
FAULT
COYOTE
RIDGE
COMPLEX
BOX
RIDGE
CANYON
PLUTON
FAULT
COYOTE
CREEK
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VALLEY
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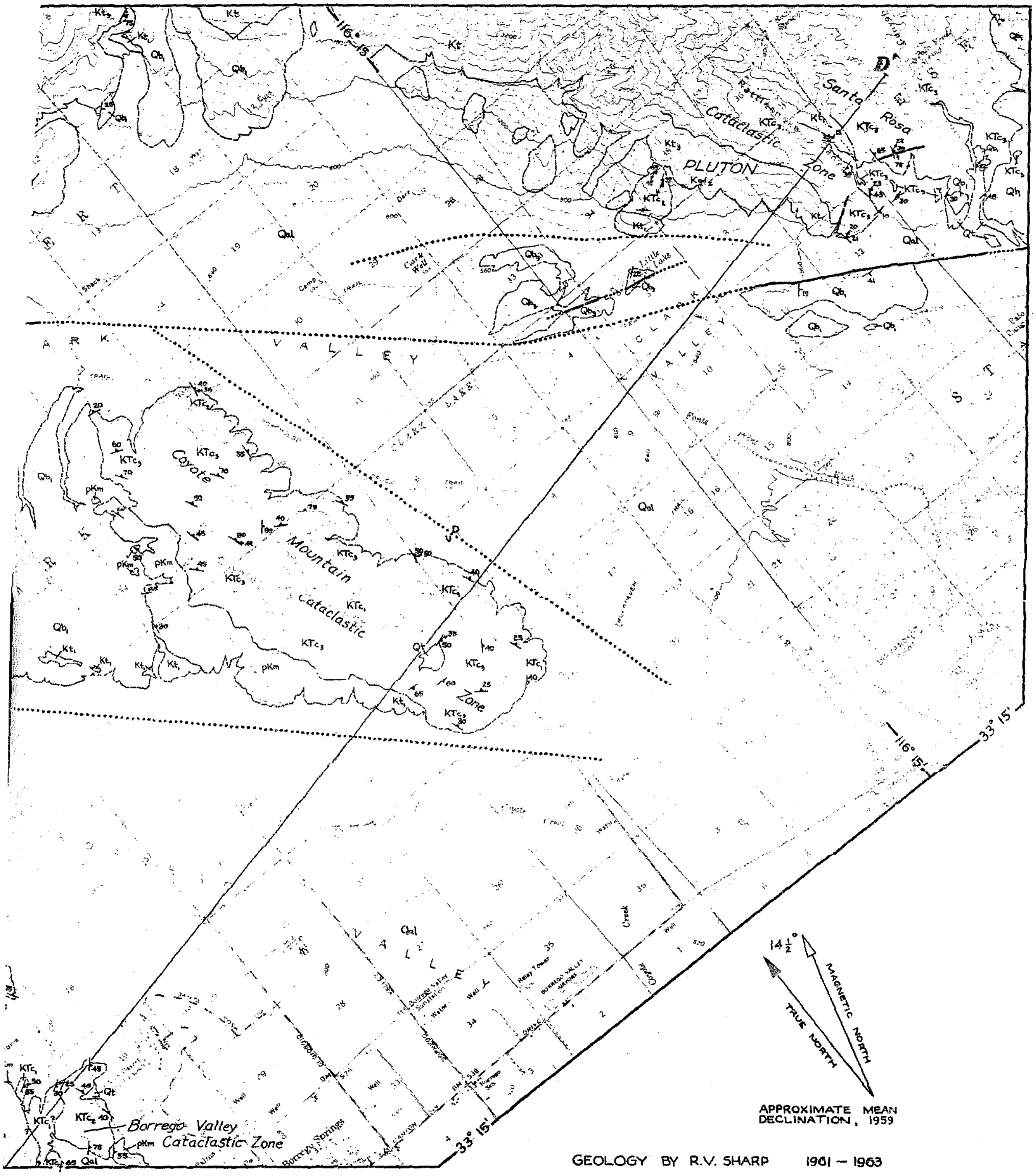
CANYON
COMPLEX
C
D



GEOLOGY BY R.V. SHARP 1961 – 1963

PLATE 1

EXPLANATION

CATACLASTICALLY DEFORMED ROCKS

CRETACEOUS OR TERTIARY

KTc

- KTc_1 ADAMELLITIC CATACLASITE
- KTc_2 TONALITIC CATACLASITE
- KTc_3 MIXED CATACLASITES AND MARBLE-RICH METAMORPHIC ROCKS
- KTc_4 MYLONITE

PLUTONIC ROCKS

MID-CRETACEOUS

Kfa — FINE- TO MEDIUM-GRAINED BIOTITE ADAMELLITE

Kga — MEDIUM- TO COARSE-GRAINED GARNETIFEROUS ADAMELLITE

Ka — MEDIUM-GRAINED ADAMELLITIC ROCKS :

- Ka_1 POORLY FOLIATED BIOTITE ADAMELLITE
- Ka_2 FOLIATED BIOTITE ADAMELLITE
- Ka_3 FOLIATED PORPHYRITIC BIOTITE ADAMELLITE
- Ka_4 INCLUSION-RICH PORPHYRITIC BIOTITE ADAMELLITE

Kmg — MEDIUM-GRAINED GRANODIORITIC ROCKS :

- Kmg_1 HORNBLENDE-BIOTITE GRANODIORITE
- Kmg_2 INCLUSION-RICH HORNBLENDE-BIOTITE GRANODIORITE

Kgd — INEQUIGRANULAR BIOTITE GRANODIORITE AND ADAMELLITE :

- Kgd_1 BIOTITE GRANODIORITE
- Kgd_2 BIOTITE GRANODIORITE AND ADAMELLITE (CONTACTS WITH INTRUSIVES NOT SHOWN)

Ktg — FINE- TO MEDIUM-GRAINED BIOTITE TONALITE AND GRANODIORITE

Kt — MEDIUM-GRAINED TONALITIC ROCKS :

- Kt_1 HORNBLENDE-BIOTITE TONALITE AND BIOTITE-HORNBLENDE TONALITE
- Kt_2 BIOTITE TONALITE
- Kt_3 FOLIATED HORNBLENDE-BIOTITE TONALITE
- Kt_4 INCLUSION-RICH HORNBLENDE-BIOTITE TONALITE
- Kt_5 HORNBLENDE-BIOTITE TONALITE WITH LARGE SPHENE CRYSTALS

Kg — GABBROIC ROCKS :

- Kg_1 OLIVINE-HORNBLENDE NORITE AND OLIVINE-HORNBLENDE GABBRO
- Kg_2 HORNBLENDE GABBRO AND HORNBLENDE LEUCOGABBRO

METAMORPHIC ROCKS

PRE-MID-CRETACEOUS

pKm — MIGMATITIC GNEISS WITH MINOR QUARTZITE, MARBLE, AMPHIBOLITE AND METACONGLOMERATE. INCLUDES SMALL UNMAPPED BODIES OF HORNFELSIC ROCKS, QUARTZ GABBRO, GRANITE PEGMATITE, AND OTHER INTRUSIVES COMPOSITIONALLY EQUIVALENT TO MAPPED BODIES.

SEDIMENTS

QUATERNARY

RECENT

Qal — ALLUVIUM

UNCONFORMITY

PLEISTOCENE

Qt — TERRACE GRAVELS AND SANDS

UNCONFORMITY

Qb — BAUTISTA BEDS

- Qb_1 GRAVELS
- Qb_2 SANDS
- Qb_3 SILTS AND CLAYS

UNCONFORMITY

CONTACT
DASHED WHERE APPROXIMATELY LOCATED
QUERIED WHERE INFERRED

GRADATIONAL CONTACT
APPROXIMATELY LOCATED

D U 60 90

FAULT, SHOWING DIPS
DASHED WHERE APPROXIMATELY LOCATED
DOTTED WHERE CONCEALED
D DOWNTHROWN SIDE, U UPTHROWN SIDE

THRUST FAULT AND KLIPPE
DASHED WHERE APPROXIMATELY LOCATED
DOTTED WHERE CONCEALED
QUERIED WHERE INFERRED
BARBS ON OVERTHRUST PLATE

60 STRIKE AND DIP OF BEDDING

75 STRIKE AND DIP OF OVERTURNED BEDDING

65 STRIKE AND DIP OF FOLIATION

STRIKE AND DIP OF VERTICAL FOLIATION

45 30 FOLIATION WITH BEARING AND PLUNGE OF LINEATION

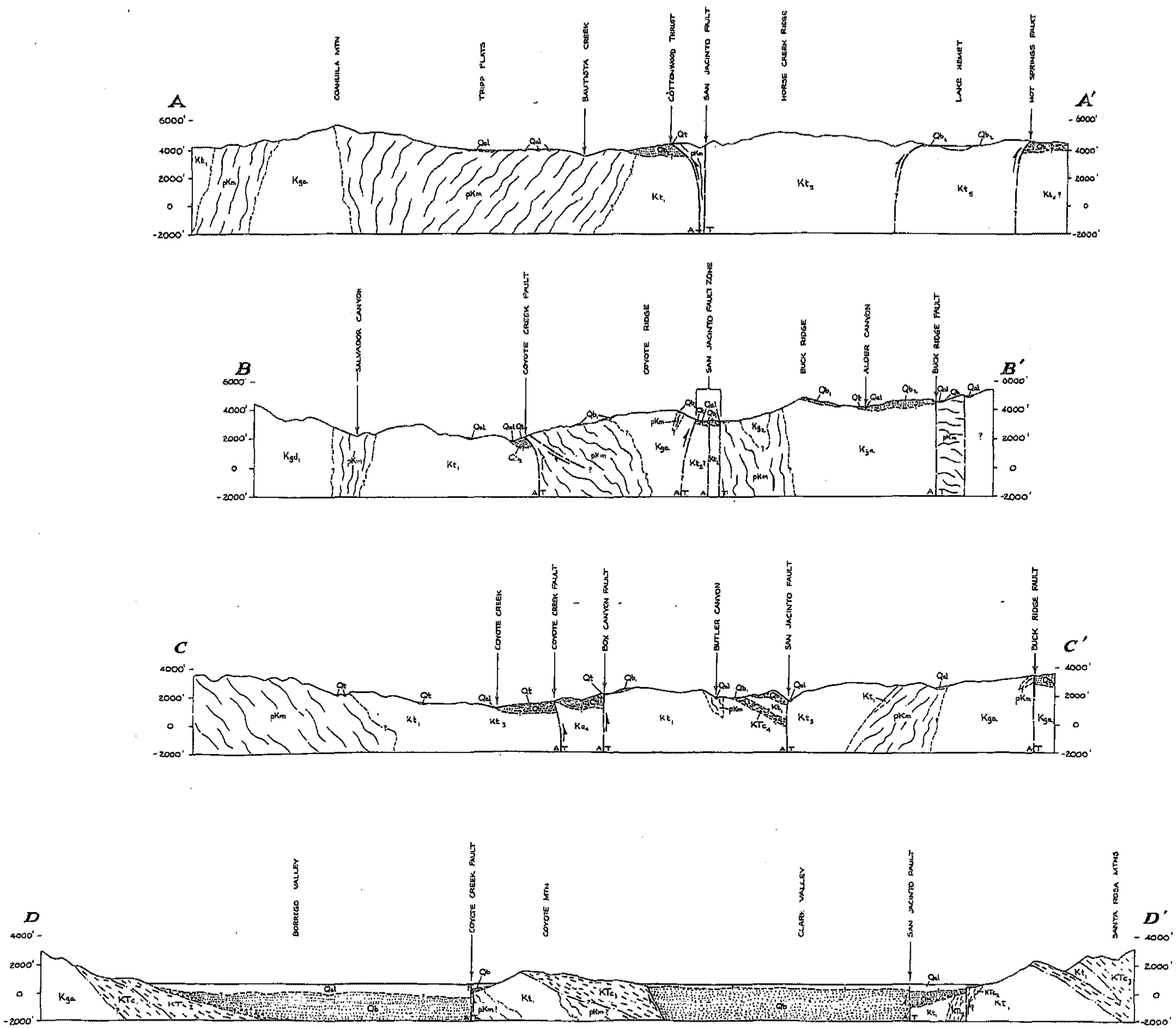
15 BEARING AND PLUNGE OF SLICKENSIDES

1.0 0.5 0 1 2 3 4 5 6 7 8 *MILES*

CONTOUR INTERVAL 80 FEET

GENERALIZED GEOLOGIC MAP OF THE SAN JACINTO FAULT ZONE IN PART OF THE PENINSULAR RANGES, SOUTHERN CALIFORNIA

PLATE 2



GEOLOGIC CROSS SECTIONS

SYMBOLS EXPLAINED IN PLATE 1
ARROWS INDICATE ONLY THE MOST RECENT SENSE OF DISPLACEMENT