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GEOLOGICAL SURVEY

GEOLOGIC MAP OF AGUA CALIENTE SPRINGS QUADRANGLE,

SAN DIEGO COUNTY, CALIFORNIA

By

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Explanation for geologic map of Agua Caliente Springs quadrangle, San Diego County, California

Introduction:

The Agua Caliente Springs quadrangle is underlain by rocks of the mid-Cretaceous Peninsular Ranges batholith of southern California and Baja California (Fig. 1). The purpose of this project, which began in 1974, is to evaluate the structural stability of the Peninsular Ranges block in southern San Diego County (Fig. 1). The age, magnitude and direction of displacement of faults within the block and along its eastern margin (Elsinore fault zone) are being evaluated. The Agua Caliente Springs quadrangle is the third map of a series of maps that show the structure of the batholith and the distribution of the crystalline rocks.

Lithologic units:

Metasedimentary rocks:--Metasedimentary rocks (ℜm) form a minor part of the crystalline bedrock exposed in the Agua Caliente Springs quadrangle. Locally, the metasedimentary rocks are intimately mixed with plutonic rocks to form a complex which was mapped previously as a hybrid gneiss-granodiorite-quartz diorite unit (Weber, 1963). In sections 10 and 15, T. 14 S., R.6 E., this complex consists of metasedimentary rocks which were intruded sequentially by associated gabbro and diorite, mafic tonalite (Kt_2) and its distinctive pegmatite dikes, fine- to medium-grained tonalite dikes, and a younger tonalite (Kt_1) and its associated pegmatite dikes. The abundance of pegmatite dikes of two generations lends this complex a distinctly chaotic aspect. The complex has been shown on this map as Kt_2 when it predominates, and as ℜm or Kt_1 when these rocks are most abundant, but it could be differentiated on a larger scale map.

The predominant metasedimentary lithologies are quartzo-feldspathic, micaceous semischistose rock and schist, and dark micaceous quartzite. The semischistose rock and schist contain thin (several mm to 0.5 cm) metamorphic quartzo-feldspathic segregations, commonly in isoclinal folds. The semischistose rock and quartzite typically are finely laminated and although sedimentary structures have been transposed, lamination is parallel to larger-scale compositional layering that probably reflects original bedding. Less metamorphosed sedimentary rocks in the Laguna Mountains block typically are thin-bedded. Relict low-angle crossbeds were seen in a metaquartzite clast (derived from ℜm) in Qp conglomerate near Agua Caliente Springs County Park. Interbedded with these rocks is very fine-grained, black amphibolite. Minor amounts of green tremolite-epidote-wollastonite schist; gneissic granitic rock resembling the hybrid gneiss unit of the Cuyamaca Mountains (Khc) (Todd, 1976); and porphyroclastic gneissic rock occur sparsely in this map unit.

The metasedimentary rocks are very similar in appearance and composition to those in the Cuyamaca Mountains, but lack preservation of sedimentary structures, are coarser-grained (medium-grained), and have undergone more metamorphic differentiation. They appear to have originated as thin-bedded, impure siltstones and sandstones, which were interbedded with basic flows and/or tuffs, and are of higher metamorphic grade than ℞m exposed in the Peninsular Ranges block.

Diorite and gabbro:--Minor fine- to medium-grained diorite and gabbro intrudes ℞m and is intruded by the other plutonic rocks. The diorite forms very fine-grained dikes in ℞m. Both rock types have a gneissic fabric which is concordant with the metamorphic fabric of ℞m and discordant with dike walls.

Mafic tonalite:--Medium- to coarse-grained, mafic tonalite (Kt_2) intrudes both ℞m and diorite and gabbro. The tonalite is strongly foliated (dynamothermal metamorphic fabric) with textures ranging from gneissic to porphyroclastic and locally, mylonitic. Hornblende and biotite constitute about 25 percent of most rock--in some rocks, hornblende is replaced by epidote-actinolite intergrowths. Mafic inclusions are abundant and characteristic of the unit. The inclusions are derived in part from incorporation of sedimentary rock. The heterogeneity, higher color index, and abundant inclusions help to distinguish Kt_2 from Kt_1. Heterogeneous fine-grained, tonalitic biotite gneiss occurs in Kt_2 with both gradational and sharp contacts. It is not clear whether this represents a finer-grained variety of Kt_2, hybrid gneiss (Khc), or another tonalite. The rock does not resemble either Kt_1 or the fine- to medium-grained tonalite dikes which intrude all units. South of Vallecito Stage Station (T. 14 S., R. 6 E., secs. 10 and 15), Kt_2 is coarse-grained, leucocratic, and grades into garnetiferous pegmatite consisting of quartz, plagioclase and biotite. In addition to gradational contacts, the pegmatite intrudes Kt_2 as sharp-walled dikes. The pegmatite is compositionally heterogeneous due to assimilation of ℞m. Foliation in both average and pegmatitic Kt_2, except where the latter is exceptionally coarse-grained, is parallel to that in ℞m.

Fine- to medium-grained tonalite dikes:--A network of fine- to medium-grained, generally sharp-walled dikes crosscuts all of the above units. The dikes are too small to be shown on the geologic map at 1:24,000 scale, but they undoubtedly represent a significant plutonic event for they are widespread. The dikes are foliated parallel to the host rocks rather than to dike walls (synkinematic fabric). The rock contains lenticular aggregates of quartz, relict subhedral plagioclase grains with locally preserved euhedral oscillatory zones and markedly calcic cores, and reddish brown biotite (about 25 percent). Accessory minerals include sphene and allanite . Locally, these dikes are schlierically interlayered with Kt_2 which may indicate either that they are related to it, or that the two rocks became intimately mixed during deformation. The tonalite dikes may be a chilled, early phase of Kt_1. In this case, deformation must have waned between the time of emplacement of the dikes and the main body of Kt_1, because Kt_1 has a late-tectonic fabric. Alternatively, the dikes and main body of Kt_1 may have been emplaced simultaneously but the dikes may have cooled and solidified more rapidly than the large parent pluton, at a time when deformation was still going on.

Younger tonalite:--The younger of the two tonalites (Kt_1) exposed in the Agua Caliente Springs quadrangle underlies most of the Tierra Blanca Mountains. It is probably a northern lobe of the vast La Posta body (Miller, 1935) which underlies much of the southeastern Peninsular Ranges in San Diego County and Baja California.

In the eastern frontal fault zone of the Tierra Blanca Mountains, the tonalite is intensely and freshly fractured and hydrothermally altered to a dazzling white color--hence the name, "white earth". Westward toward the rim of the Laguna Mountains escarpment, the color ofthe tonalite darkens to reddish buff and joint spacing increases significantly so that from a distance, it isn't clear that the rock forms a single pluton. This change is due to several factors--the presence of a leucotonalite border zone against TRm, less fracturing westward, and greater oxidation of the rock at higher elevations.

Average Kt_1 is homogeneous, light-colored tonalite with color index (due chiefly to biotite) ranging from 8.5 to 14 percent. It has few inclusions or dikes except near its margins. Where inclusions are present in the interior, they appear assimilated, with faint borders that grade into biotitic schlieren with pseudo-graded and rhythmically layered structures. Dikes of fine-grained, dark gray rock texturally resembling Kt_1 (large quartz grains and large biotite books) were seen in the unit locally in upper Canebrake wash.

Quartz ranges from 29-35 percent and occurs in distinctive 1 cm grains with polyhedral (some blocky to subrectangular) shapes in less foliated rock, and as ovoid grains in more foliated rock. Thin section views show either highly strained single quartz grains or polygonized aggregates apparently derived from large single grains. Quartz is interstitial to, and replaces, plagioclase and it contains small, early euhedral plagioclase and biotite grains. K-feldspar ranges from two to 5.5 percent and occurs as two-inch poikilitic grains that show large, reflective cleavage surfaces on rock faces. Plagioclase has retained hypidiomorphic texture--delicate euhedral oscillatory zoning and synneusis aggregates--with minor recrystallization. Biotite occurs as euhedral, approximately barrel-shaped 0.5-1 cm books in less foliated rock, and as more abundant-appearing, finer, scaly, recrystallized aggregates in more foliated rocks. The average tonalite has sparse euhedral biotite books scattered in rock with abundant, finer-grained biotite aggregates. Most tonalite contains very sparse acicular hornblende grains 0.5-1 cm long. Accessory minerals are sphene, allanite, epidote, apatite, zircon and black opaque.

Although the contact between Kt_1 and Kt_2 is in part a thrust fault (T. 14 S., R. 6 E., secs. 10 and 15), the intrusive contact can be seen in the large canyon extending northwest from the Agua Caliente Springs County park; in the TRm-Kt_2 complex south of the Vallecito Stage Station; and in the upper Potrero (T. 15 S., R. 6 E., sec. 9). Although Kt_1 occurs as fine- to medium-grained dikes in TRm and Kt_2, locally it is medium- to coarse-grained up to a sharp contact with these units. A more leucocratic variety of Kt_1, grading from leucotonalite to micropegmatite and pegmatite dikes, occurs near its contacts. The large pegmatite dikes contain tourmaline and, like average Kt_1, contain large, euhedral biotite books which distinguish them from the Kt_2 pegmatite. A porphyritic variety of Kt_1 with subhedral white plagioclase phenocrysts and feldspar-quartz aggregates 2 cm across occurs near the margins of the pluton. Dikes of Kt_1 in Kt_2 may also have this texture. The porphyritic rock occurs in the area northwest of Agua Caliente Springs general store, and float of this rock is abundant in the fan material on the southern flank of the Vallecito Mountains.

Cross-cutting pegmatite dikes with pale pink or white K-feldspar, scaly biotite aggregates, minor quartz and tiny red garnets; white quartz veins; and layered pegmatite-alaskite dikes are also abundant in marginal parts of Kt_1. Abundant schlieren and inclusions are associated with Kt_1 margins. Schlieren, consisting of biotitic clots and streaks, or layers of more and less mafic tonalite less than 15 cm thick may be concordant or discordant to rock foliation. The layers have both sharp and gradational contacts. Elliptical to spherical inclusions up to 25 cm across appear to be partly assimilated Kt_2. Commonly, leucocratic Kt_1 increases toward the contact with ℞m, and highly injected and contorted ℞m inclusions occur in Kt_1. The adjacent metasedimentary rock is thoroughly diked by leucocratic Kt_1 and the contact between the units must be placed arbitrarily.

Kt_1 ranges from strongly to slightly foliated, and leucotonalite appears unfoliated. Foliation is produced by alignment of elongate quartz aggregates and grains and scaly biotite aggregates. In thin section the rocks show moderate strain and recrystallization of quartz, feldspar and biotite. Strongly foliated tonalite occurs near the margins of the body and less foliated rock is found in more central parts. The marginal rock tends to have higher apparent color index because of the breakdown and dissemination of biotite, and to be finer-grained than the rocks of the interior. Near the pluton's walls, foliation trends become more consistently oriented parallel to the walls, and to foliation in the surrounding Kt_2 and ℞m. Within the pluton, trends show some consistency over small areas (several square km). The foliation in Kt_1 arises from both deformation and attendant minor recrystallization and is similar to, but much less intense than, strain and recrystallization effects in plutonic rocks of the Laguna Mountains (Todd, 1977; Hoggatt and Todd, 1977). Here it is tentatively considered a late-tectonic structural feature.

Palm Spring and Canebrake Formations:--Plio-Pleistocene sedimentary deposits (Qp) crop out extensively in the northern part of the quadrangle. These rocks have been studied comprehensively by Woodard (1963) in the Arroyo Tapiado 7 1/2′ quadrangle and identified as the Palm Spring and Canebrake Formations. Patchy deposits occur along the northeastern front of the Tierra Blanca Mountains. The Palm Spring Formation is of early middle Pleistocene age in this area according to Woodard and represents alluvial floodplain deposits laid down adjacent to the Peninsular Ranges. Minor, intercalated marine beds represent periodic fluctuations of the last northern transgression of the Gulf of California into the Colorado Desert. Woodard considered the Palm Spring beds to be the marginal deposition that accompanied the gradual retreat of the Gulf. In the Agua Caliente Springs quadrangle, the Palm Spring Formation grades laterally and downward into the Canebrake Formation described by Woodard as coarse, marginal pediment boulder to cobble fanglomerate and lesser pebbly arenite. The Canebrake Formation is the marginal equivalent of both the Palm Spring Formation and of the older marine Imperial Formation of middle(?) Pliocene to early Pleistocene age.

Northeast of highway S-2, well-indurated, brown-weathering sandstone, silty sandstone and silty claystone beds dip gently to moderately southwest in a series of eroded hogbacks which are well-exposed in washes that drain the alluvial fan at the foot of the Vallecito Mountains. The rocks grade down-section (northward) into conglomerate through an interval of sandstone with increasingly abundant pebble and cobble interbeds. This section was mapped by Woodard as the Huesos member of his Palm Spring Formation and the conglomerate portion as Canebrake Formation. The east-trending hill northwest of Agua Caliente Springs County park provides good exposures of the Qp beds resting nonconformably on granitic bedrock (here, chiefly Kt_2). In most places in the quadrangle, the depositional contact has been obscured by normal faulting. The Qp deposits consist chiefly of poorly indurated, pale gray-weathering sands with abundant pebble and cobble interbeds with fluvial cross-bedding, cut and fill structure and gravel lenses. The rocks were deposited upon a surface with relief similar to the arroyos and hills of the present mountain front.

Conglomerate is not abundant in the quadrangle. In the northeastern part, conglomerate (shown by the circle pattern) occurs in a narrow interval where it has been upfaulted, and possibly exposed along the axis of an east-trending anticline (Woodard, 1963); upsection (to the south), conglomeratic sandstone appears to be the dominant lithology. In the section exposed northwest of Agua Caliente Springs County park, well-rounded cobbles and boulders (lag gravel) derived from conglomerate cover much of the sedimentary exposure, but out-cropping conglomerate is rare and washes cutting the bouldery material expose chiefly pebbly and cobbly sands. Where conglomerate crops out, it contains Kt_1 and Kt_2 ($Kt_1 >> Kt_2$), as well as porphyritic Kt_1, pegmatite, and the distinctive, foliated muscovite-garnet alaskite seen in the area as dikes in Kt_1. Metasedimentary clasts are abundant, range from cobble to small boulder size and are commonly rounded to well-rounded. They consist of all of the lithologies found in the nearby TRm-Kt_2 complex in approximately the same relative proportions. The same granitic and metamorphic lithologies occur in coarse clastic interbeds in the sands. The source of granitic and metamorphic clasts appears to be very local. The absence of volcanic clasts also supports a local source because Pliocene volcanic rocks crop out to the south in the Jacumba Mountains and they occur as clasts in Qp deposits in the Bow Willow Canyon area of the Sweeney Pass 7 1/2′ quadrangle (W. C. Hoggatt, 1976, oral commun.)

A remnant of Qp is exposed along the northeastern front of the Tierra Blanca Mountains where it has been faulted and partly covered by younger sediments and by slopewash. Pink- and tan-weathering, well-bedded sands are exposed in sec. 28, T. 14 S., R. 7 E., beneath coarse, poorly sorted and rounded fanglomerate composed chiefly of Kt_1 clasts. The poorly sorted fanglomerate lies with angular unconformity on the bedded sands and is therefore correlated with the Mesa Conglomerate (Qm) (Woodard, 1963). The well-bedded sands are considered to be Palm Spring Formation. At higher elevations, both here, and on the southern flank of the Vallecito Mountains, massive deposits of indistinctly-bedded fanglomerate lap onto highly fractured Kt_1 which they greatly resemble. At lower elevations, the fanglomerate grades into an old alluvial fan which is intact on the north side of Carrizo Valley but which is disrupted by high-angle faults and greatly dissected on the south side of the valley. The massive fanglomerate at higher elevations occupies the same topographic position that the Canebrake conglomerate has elsewhere outside Agua Caliente Springs quadrangle, but the fanglomerate differs from the Canebrake conglomerate in environment of deposition and source area. This, plus the gradation into the old alluvial fan (Mesa Conglomerate) on the north side of Carrizo Valley suggests that the massive fanglomerate is a head-of-fan equivalent of the Mesa Conglomerate.

No Palm Spring-Canebrake Formation rocks are shown on small scale compilations west of Agua Caliente Springs quadrangle (Weber, 1963), but patchy deposits are present north of highway S-2 in the Monument Peak 7 1/2′ quadrangle (Fig.2). The present distribution of Qp outcrops, thus, is a narrow wedge thinning west-northwest. Although it is not known how far northeast and southwest Qp deposits may have extended originally, the distribution of coarse- and fine-grained facies and preservation of on-lap relations on both sides of Carrizo Valley suggest that the original Qp basin of deposition occupied approximately its present position and has not been broken by lateral faults.

Although Qp deposits were not mapped in detail, the rocks appear to be folded broadly on east to west-northwest-trending axes, agreeing with Woodard's structural study of Qp in the Arroyo Tapiado quadrangle and eastern part of Agua Caliente Springs quadrangle. The folded sediments were eroded to a landscape of low relief and alluvial fan deposits (Qm) were laid down on this essentially flat surface. June Wash and surrounding washes expose this relationship beautifully. Qm locally laps upon but does not cover Qp hills. The margins of the flat Mesa surface in Agua Caliente Springs quadrangle generally coincide with the lower limit of exposure of the resistant conglomerate. Exceptions are places where Qm grades into the steep, massive, fan-head fanglomerate.

Mesa Conglomerate:--The Mesa Conglomerate (Qm) was described by Woodard (1963) as poorly to unstratified deposits consisting of two components--a basal conglomerate overlain by massive and cross-laminated, poorly sorted, unconsolidated deposits of well-rounded, coarse-grained sand and gravel. Some massive conglomerate was reported. Clasts in the conglomerate included rounded granite and metamorphic lithologies with some boulders. Woodard considered the Qm deposits to be late Pleistocene to recent. Qm represents pediment fan and broad sheet-flood deposits that accumulated during and after uplift and erosion of the older Pleistocene rocks.

In the Agua Caliente Springs quadrangle, deposits correlated with Woodard's Mesa Conglomerate include massive fan-head deposits; broad, flat terrace-capping conglomerate or fanglomerate; and sandy deposits in areas along relatively inactive parts of the fault zone and inner valleys. The steep, massive, fan-head deposits occur on the western portion of the Vallecito Mountains fan and on the northeastern front of the Tierra Blanca Mountains northwest of the mouth of Canebrake Canyon. These deposits are well-indurated, very poorly sorted mixtures of pebbles, cobbles and boulders (including car-sized boulders on the Vallecito fan) set in a sparse granitic sand-silt-clay matrix. They closely resemble the coarse colluvial material forming at faulted mountain fronts today. Typically the sub-rounded to subangular clasts consist chiefly, and in some places, exclusively of Kt_1, with minor Kt_2 and scattered small cobbles of metamorphic materials. The matrix varies in color from pale greenish-gray or tan, to red depending upon the development of oxidized coatings on grains. Locally the unit is cemented by calcium carbonate. Washes cutting the deposits expose indistinct bedding, local poorly developed size grading and small channel deposits of pebbly and cobbly, well-bedded sand within the fanglomerate.

Northwest of the mouth of Canebrake Canyon, this fanglomerate grades northwest along the mountain front into well-bedded conglomeratic sands that dip off the tonalite at about 23°. Locally, the coarse fanglomerate deposit seems to grade imperceptibly through an interval of sedimentary breccia or talus into highly fractured granite of the frontal fault zone.

On both sides of Carrizo Valley, the fanglomerate grades into an old alluvial fan deposit which is essentially intact on the south flank of the Vallecito Mountains but which is largely removed from the Tierra Blanca Mountains. The surface of the fan is a lag gravel of desert-varnished, very large, rounded boulders of Kt_1 and scattered, sparse metasedimentary clasts. The size of the old fan material is larger than that in the present washes. Bedded sands and gravel of the fan lie nonconformably on weathered Kt_1 along the front of the Tierra Blanca Mountains and continue southwestward into the range as disconnected, eroded stream terrace deposits mantled by colluvium. The Vallecito fan deposit grades southeastward into the relatively thin (up to 4-5 m) terrace deposits which cap erosional remnants of Qp. The terrace deposits are horizontally bedded, poorly rounded sand and gravel, predominantly Kt_1, which lie in angular unconformity upon a Qp surface of gentle relief. Bedding is typically indistinct, but graded beds, crossbedding and horizontally oriented planar clasts occur locally.

The finer-grained facies of Qm occurs in Inner Pasture, a large interior valley in the Tierra Blanca Mountains, and probably also in Agua Caliente Springs County park and the area immediately to the south. In Inner Pasture, remnants of poorly indurated yellowish-tan cross-bedded, pebbly granitic sands with scattered subangular cobbles and boulders and gravel lenses lie nonconformably on Kt_1. Locally, the sand deposits are at least 30 m thick.

Bedding in the sands is planar and horizontal, and the larger clasts are mainly Kt_1 with some rounded (often broken) small cobbles and pebbles of TRm, and other plutonic rocks, and rare porphyritic volcanic clasts.

The linear, higher, northwest wall of Canebrake Wash in Inner Pasture consists of this alluvium, with a well-cemented, horizontal brown-weathering sand layer near the top, on which lies an unevenly distributed deposit of pale, fine, windblown sand. The distribution of sand suggests that the prevailing wind is from north to south across Inner Pasture. A lineament in the alluvium near the western end of this wall may be a fault, and it is possible that the western wall of the wash itself is fault-controlled.

The Inner Pasture deposits are correlated with the coarser-grained Qm deposits in Carrizo Valley because they lie at about the same elevation as eroded stream terrace deposits which can be traced westward up the through-going canyons into Inner Pasture. The Qm sands appear different from the Qp sandstones in composition, induration, degree of dissection and degree of deformation. The sandy deposits in Agua Caliente Springs County park are at the same elevation (1400 ft) as adjacent Qp outcrops (the latter in part down-dropped by a normal fault) but are different in lithology. They may correlate with a stream terrace deposit at 1400 ft which is cut partly in Qp. Also, these patches of sand locally appear to overlap faults which cut Qp. To the south, in the Sweeney Pass 7 1/2′ quadrangle, very similar gravelly sands lie unconformably upon Qp along the front of the Tierra Blanca Mountains (W. C. Hoggatt, 1976, oral commun.).

Older alluvium:--An older alluvium unit (Qoa) has been mapped in the western part of the quadrangle. Some of this material probably correlates with Qm, but it differs from Qm in composition and environment of deposition. Unconsolidated, flat-bedded, bouldery deposits consisting chiefly of TRm, Kt_2, Khc and leucocratic dike rock occur in the upper reaches of the large canyons that drain northeastward into the desert from the Laguna Mountains rim. The Potrero in the western part of Agua Caliente Springs quadrangle is the southernmost of these canyons. This material locally merges into modern fan material (Qal).

Younger alluvium:--Only small amounts of modern alluvium (Qal) occur in the Agua Caliente Springs quadrangle. It consists of two phases, older sand deposited on dissected Qm and Qp and younger sand and gravel in narrow modern washes. These materials are probably coeval. Qal deposits are generally finer-grained than Qm fan detritus except at the mountain fronts. In many places Qal consists of reworked Qm and forms a thin veneer on it. No detailed study was made of the alluvial fan, but in general, materials of different ages show up well on 1:24,000 aerial photographs.

Faults:

<u>Introduction</u>:--Small-scale compilations (Strand, 1962; Weber, 1963) depict the southern portion of the Elsinore fault as having two principal branches, one that follows the northeastern face of the Tierra Blanca Mountains, and a second that lies south of it and crosses Vallecito Valley, Sawtooth Mountains and Inner Pasture from northwest to southeast (Fig. 2). The present study indicates that Tierra Blanca Mountains have been broken repeatedly in a complex manner during Quaternary time with the net result being that the mountain block has risen relative to Carrizo Valley. The rock relations within the quadrangle do not require any strike-slip displacement and probably do not permit large-scale lateral displacement.

Three predominant fault trends are present among measured fault planes--N70W, N20W and N60E (Fig. 3). Typically, two sets of faults are present in any given area, one intersecting the other at a large acute angle. For the purpose of description, faults will be divided into those cutting crystalline bedrock and faults that cut consolidated or unconsolidated sediments. These two groups are subdivided by geographic area. Roughly, this separates the faults into groups with similar characteristics, although undoubtedly, the same tectonic forces have acted upon the whole area.

<u>Faults cutting crystalline bedrock</u>:--The oldest and largest fault is a thrust fault which has been mapped by Robert V. Sharp over a large area east of the Elsinore fault zone and in reconnaissance in the Agua Caliente Springs quadrangle (1975, oral commun.). This fault is cut by high-angle faults and apparently dies out within the Tierra Blanca Mountains. It is well-exposed in a down-dropped fault block in sections 10 and 15, T. 14 S., R. 6 E., where it consists of three imbricate thrust slices, from structurally highest to lowest: Kt_1 over Kt_2; Kt_2 over Kt_1; and Kt_1 over Kt_1. The highest slice may reappear about 3 km to the east, and the middle slice(?) (Kt_2 over Kt_1) is exposed behind Agua Caliente Springs store. The thrust apparently developed near the intrusive contact of Kt_1 into Kt_2, which is preserved locally in the thrust slices. Presumably, the thrust sheets were once present over the Tierra Blanca Mountains but have been eroded from the upfaulted block. The largest fault is the middle imbrication with a crush zone averaging 5-6 m and up to 9 m thick. The crush zone consists of one or more zones of dark greenish-brown cataclasite and waxy-appearing gouge surrounded by brecciated and hydrothermally altered tonalite with many thin cataclasite planes. In contrast, although a few of the high-angle faults attain thicknesses up to 6 m most are no more than 3-4 m thick. Where thrust faults have not been modified by later faulting, they dip consistently from 30 to 40 degrees and can be distinguished from younger faults by their broad, brightly colored zones of crushed rock. The thrust may continue northward under the alluvium of Vallecito Valley and exit the quadrangle in its northwest corner. The large granitic lobe (T. 14 S., R. 6 E., sec.4) resembles a landslide deposit but consists of brecciated, in situ Kt_1 on its eastern and western flanks; a broad crush zone is exposed on the eastern margin of this lobe with Kt_1 in a flat contact above Kt_2 (and TRm). The eastern margin is cut by north-trending high-angle faults. The lobe may be a segment of the thrust fault modified by normal faulting and landsliding. Qp deposits overlap Kt_2 on the downdropped, southern margin of the lobe.

The thrust fault cuts Cretaceous crystalline rocks in the Agua Caliente Springs quadrangle and is overlapped by Qp with which it is in high-angle fault contact locally.

One of the imbrications (Kt_1 over Kt_1) may continue across the frontal fault zone westward into the Tierra Blanca Mountains (Moonlight Canyon, south of Agua Caliente Springs County park). The thickness of this fault and its local shallow dip (40°) support this view, but the fault has been cut and locally steepened by high angle faults and its dip has been reversed so the case is not conclusive. It isn't clear which if any of the north-trending faults in the south wall of Inner Pasture may be the continuation of this fault. One line of evidence which suggests that the Moonlight Canyon fault is the thrust is that the rocks of its upper plate (block to the east) are broken into much smaller joint blocks, are more faulted and hydrothermally altered than are those of the lower plate. This contrast continues southeastward through Inner Pasture between the rocks of its north and south walls, but disappears east of Canebrake Wash where more broken tonalite grades imperceptibly southward into less broken tonalite.

Faults of the frontal zone:--The prominent range-bounding faults form an arcuate zone trending northwest to west-northwest in the eastern part of the quadrangle and curving to east and east-northeast trends in the western part. Although the largest and most obvious faults are near the eastern margin of the range and parallel to it, the zone of intensely fractured and faulted rock extends on the average about 1.5 km into the range. Although fractured and hydrothermally altered to a white color, the rock of this zone was found to be in situ Kt_1 through which internally consistent mineral foliation can be traced. The broken blocks have not been displaced except in discrete zones adjoining fault planes. This is not immediately obvious, because rock debris flows (subangular boulders in a silt matrix) have moved down side-canyons, many eroded along faults having the trend of the frontal zone. This unconsolidated material presently is being eroded exposing the underlying fault planes and it tends to be plastered over bedrock. When it is scraped away, the underlying rock is tonalite, in place. The rock debris flows conform to present topography, are closely associated with faults, and are less dissected than the Qm alluvial fans.

To the south in the Sweeney Pass quadrangle, the frontal faults trend approximately north (W. C. Hoggatt, 1976, oral commun.). The frontal zone contains the high-angle faults with the largest crush zones. They are crossed at large acute angles by faults which controlled the development of the canyons and washes that drain the mountains. Those cross faults are less well-exposed because they are largely covered by alluvium in the canyons. The most noticeable faults are those which cross the main canyons and are exposed in their walls. These faults control the development of the northwest to west-northwest-trending tributary canyons. When number of faults of several size categories (crush zone less than 30 cm; 30 cm to 2 m; 2 m and larger) were plotted against strike, the maxima were similar for each size category except that faults less than 30 cm tended not to show the N60E maximum. Otherwise, no one particular fault trend was associated with large crush zones. There is considerable bias in measurement of fault trends because the northwest to west-northwest faults are best exposed and most accessible. The northwest and west-northwest-trending faults of the frontal zone dip about 50 to 90 degrees; many of the large faults dip valleyward, but a significant number dip into the range. Although faults can be tracked from one canyon into another, a major fault (6 m crush zone) in one canyon may be expressed as a series of breccia zones (less than one meter) containing thin gouge zones a few cm thick along the axis of a small tributary wash in the adjacent canyon. This suggests that the faults are for the most part short and discontinuous. The frontal zone apparently underwent repeated movement because there are several kinds of crushed material, one type locally crossing another. One kind of crushed material is a dense, flinty, green to brown cataclastic rock lying within a zone of brecciated and hydrothermally altered rock that consists of powdery white clay, green chlorite, pink K-feldspar and iron oxide. The total zone, including cataclastic rock, can be over 2.5 m thick and up to 6 m. These faults are shown by the heavier line weight on the map. A second type of crushed material seems equally common in the frontal zone where it locally crosses the green cataclasite, and probably involved less intense movement. It consists of 5-10 cm-thick, tan-weathering, well-cemented breccia or gouge of variably-sized granite fragments, mostly sand-sized, on an undulating fault plane that can be traced from one canyon into another. The gouge is surrounded by well-indurated, brecciated tonalite within a wider zone of punky, altered tonalite containing closely spaced, thin, greenish cataclastic zones.

Low-angle faults, some with broad (up to 3 m) crush zones are not uncommon but because of the abundance of steep faults of several trends, pervasive fracturing, and rock debris flows, they are almost impossible to track for any distance. A rather extensive low-angle fault is exposed at the southern boundary of Agua Caliente Springs County park, and the relations suggest that much of the park area may be located on the upper plate of this fault.

Where fault displacement can be observed, the sense of displacement is normal, with the northeastern or valley block dropped down relative to the Tierra Blanca Mountains block. Thus, the onlapping Pleistocene sedimentary rocks and sediments have been down-dropped by faults of one or two intersecting trends along the northern and northeastern flanks of the range. Actually, the movement picture is more complex, for while linear features on fault planes generally plunge steeply to the northeast and east, a number of polished fault planes show overlapping slickensides which plunge in all directions, from horizontal to vertical. Indeed, the frontal zone looks as though rock moved in every conceivable direction. The Qm alluvial fan which rests nonconformably on tonalite has been down-dropped about one to two meters (T. 14 S., R. 7 E., sec. 28, northwest wall of large throughgoing canyon) by a fault that trends N19W and dips NE67; to the southeast (eastern margin of section 28), faults of a similar trend cut across modern washes, producing scarps about one meter high (Clark, 1975). Bedrock spurs are obviously truncated by faults along the range front and the old alluvial fan has been truncated and step-faulted to several levels.

Virtually no evidence was seen in the field to show which, if any, of the high angle fault trends was older, and no systematic relationship is clear from the map pattern. Two faults typically cross with no offset of one by the other. This is especially apparent in the area north of the mouth of Canebrake Wash (T. 14 S., R. 7 E., secs. 28 and 29) where on low-sun angle and

1:62,500 aerial photographs, the ground is seen to be crisscrossed by closely-spaced breaks with no mutual offset; many of these are identifiable as faults on the ground. That there may have been minor lateral or oblique slip is indicated by the occurrence of broad, closely fractured and whitened zones (stipple pattern) where one or more fault trends intersect. Low angle faults both cut and are cut by high angle faults.

The arcuate pattern of the faults of the frontal zone precludes large-scale lateral motion. If the large fault in Moonlight Canyon is an imbrication of the thrust fault, then the map relations across the high angle fault zone allow (but do not require) about 3 km maximum apparent left-lateral offset.

In the northern part of the Tierra Blanca Mountains, high angle faults cut Qp but are overlain nonconformably by Qm deposits. Old stream terraces with gravel deposits, and high, alluviated valleys with dissected colluvium, soil profile and stable vegetation have been eroded across those faults. These features are believed to correlate with Qm or even younger alluvium. These relations are well-displayed in the canyon northwest of the Agua Caliente Springs store, and in the large canyon immediately south of the park. South of the latter canyon, rock spurs are truncated but debris flows emanating from the small canyons between them are not. The debris flows are stable and are being dissected. Further south, Qm deposits and modern washes are cut by faults of the frontal zone. Thus fault activity appears to become progressively younger from north to south.

Faults of the interior part of the Tierra Blanca Mountains:--These faults are, on the average, fewer in number and have involved less crushing than those of the frontal zone. In general, their strikes parallel the faults in the frontal zone, but their traces are longer and more irregular. Dips along portions of these faults may be considerably flatter than those in the frontal zone, and dip direction may change along strike. Locally, parallel faults dip toward one another (T. 14 S., R. 6 E., sec. 34). At least one low angle fault with a major crush zone is exposed within the range (T. 14 S., R. 6 E., sec. 27) and another occurs to the south in the Sombrero Peak quadrangle. Unfortunately, both faults lie near the floor of Inner Pasture and disappear beneath alluvium. Although there are a few major faults within the interior of the range, most breaks have crush zones consisting of one to several meters of freshly fractured rock with multiple, anastomosing green and brown cataclasite bands coalescing locally to form a thicker zone. Locally, cataclasite is as much as one meter to several meters thick. Hydrothermal alteration and earthy, carbonate-cemented gouge and breccia may be present along these faults. These fractured zones show up as white, linear bands crossing the darker-weathering tonalite.

To the south (Sombrero Peak quadrangle) the In-ko-pah Mountains are underlain by La Posta tonalite and are systematically and closely jointed by extensive, steeply-dipping, nearly orthogonal fractures that strike approximately east-northeast and north-northwest. The strikes may vary somewhat, but at least two intersecting joint sets are present everywhere. The faults of the higher Tierra Blanca Mountains probably developed along both of these major joint directions as well as others. A fault might follow one joint for some distance, then another, thus explaining the irregularity of some planes. Some of these faults may be shear joints which have undergone slight movement. All of them, except those with broad crush zones, have a small letter J next to the fault trace.

Since Quaternary formations have been eroded from the higher Tierra Blancas, it is not possible to date these faults exactly. If, as seems likely, the Inner Pasture sediments are late Pleistocene to recent (Qm), then the interior faults could be that young because it seems likely that Inner Pasture was eroded along a series of faults. The zigzagging northern wall, in particular, has the appearance of a relatively fresh scarp. The curious absence of appreciable amounts of boulder-size tonalite debris in Inner Pasture suggests that through-draining streams have always had steep enough gradients to remove this material as quickly as it accumulated. Sparse metamorphic pebbles and small cobbles which cannot be derived locally are found on the highest flat summits of the Tierra Blancas, indicating that Qp was once present but has been eroded after faulting and uplift. Finally, there are 3 lineaments, one a scarp-like feature, in the Inner Pasture alluvium which may be faults.

Faults cutting Quaternary sedimentary rocks and sediments:--Northeast- and northwest-trending faults cut Quaternary deposits with no obvious offset of one group of faults by the other. The northwest faults blend into those of the frontal zone, whereas the northeast-trending faults are less obviously related to, but locally continue into, faults in crystalline rocks in the northwest part of the quadrangle. These trends mirror a fundamental fracture pattern in the late Pleistocene to recent alluvial fan of the Vallecito Mountains as can best be seen on 1:62,500 aerial photographs. Where displacement can be assessed, both northwest and northeast faults are normal, tending to raise the Vallecito and Tierra Blanca Mountains blocks relative to Vallecito and Carrizo Valleys. The valley thus is a post-middle Pleistocene graben which has been modified by post-late Pleistocene normal faulting during which the down-dropped area perhaps has shifted northwestward. The group of northeast-trending faults in the northeastern quarter of section 1, T. 14 S., R. 6 E., are marked by northwest-facing scarps with ponded sand at their feet. One scarp is about 2 m high. Dips are variable but in general, near vertical. Two of these faults are expressed by vee-shaped valleys in Qm to the northeast. Several small, steep, northeast-trending faults which cut Qp have not been plotted. Their northwest sides are down about 6-7 m and they are marked by earthy, caliche-cemented gouge about 3 m thick.

Several faults cut recent alluvium in the Agua Caliente Springs quadrangle (T. 14,, R. 6 E., secs. 9, 12, 15, and 16; T. 14 S., R.7 E., sec. 17) and the zone of young faults continues westward into the Monument Peak quadrangle. The faults marked by prominent vegetation stripes and scarplets with the southwestern sides raised in Vallecito Valley cut older alluvium (Qm equivalent?) but are crossed by most recent washes with no offset. One of these faults may continue into crystalline bedrock.

In the northeastern corner of the map, a normal fault with a probable lateral component of slip has raised a slice of Kt_1 which is enclosed by Qp. In upper June Wash, Qp conglomerate lies depositionally on highly fractured Kt_1 with a gentle to moderate southwest dip (about 25 degrees). Northeastward through Sandstone Canyon, fine-grained Qp also resting depositionally on Kt_1 has been upfaulted from an approximately horizontal dip to dip 54 degrees northwest. In the Arroyo Tapiado quadrangle, this Kt_1 gives way to increasingly brecciated, hydrothermally altered tonalite which tails out eastward to a thin, northwest-dipping slice between undisturbed beds of Qp. The underlying Qp beds dip concordantly with the overlying Qp and Kt_1 sliver (37 degrees). Within the Kt_1 sliver are two reddened gouge and breccia zones which parallel these contacts. The lower contact between Kt_1 and fine-grained Qp is a low angle fault, either gravity slide or thrust. The Kt_1 does not appear to be a tongue of sedimentary breccia nor would such be likely in a sequence of fine-grained sediments. This structure coincides with the nose of a large, east-trending anticline in Qp mapped by Woodard over much of the Arroyo Tapiado quadrangle. It is not known how extensive the slide or thrust is, because its exposure here is due to up-faulting, and possibly up-arching. The "fault" which raised the Kt_1 structure appears to consist of many small, steep faults in Qp, one trending N38E 74 SE which had a 5-8 cm gouge plane bearing approximately horizontal slickensides (plunging a few degrees to the south). A group of small faults in this zone had northwest sides down about 30 cm each. If this fault is followed southwestward, its continuation appears to be several breaks which have uplifted the southeastern block so that Qm has been almost completely eroded. A small fault in the lower part of June Wash (not shown on map) trends N70E 85 NW and has its northwest side down about one meter.

The history of fault displacements of the fan is much more complex than indicated here. The flat Qm terrace shows a number of abrupt jumps in elevation trending in various directions. These almost certainly are faults. Yet the expression of these structures in outcropping Qp and Qm may be absent or ambiguous.

Folding on east-trending axes noted by Woodard in Qp appears in the Agua Caliente Springs quadrangle, but has not been mapped in detail. The east-trending hill of Qp south of highway S-2 exposes reversals of dips of west-northwest to east-striking beds suggesting the presence of folds. The crumpling of Qp beds and the thrust(?) of Kt_1 over Qp indicate that a period of compressive tectonics may have preceded the development of late Pleistocene to Recent normal faults. R. V.Sharp (1967) described thrust faults of crystalline rocks of the Peninsular Ranges over Pleistocene sediments in the right-lateral San Jacinto fault zone. These faults may steepen at relatively shallow depths and may have accompanied or followed horizontal movements.

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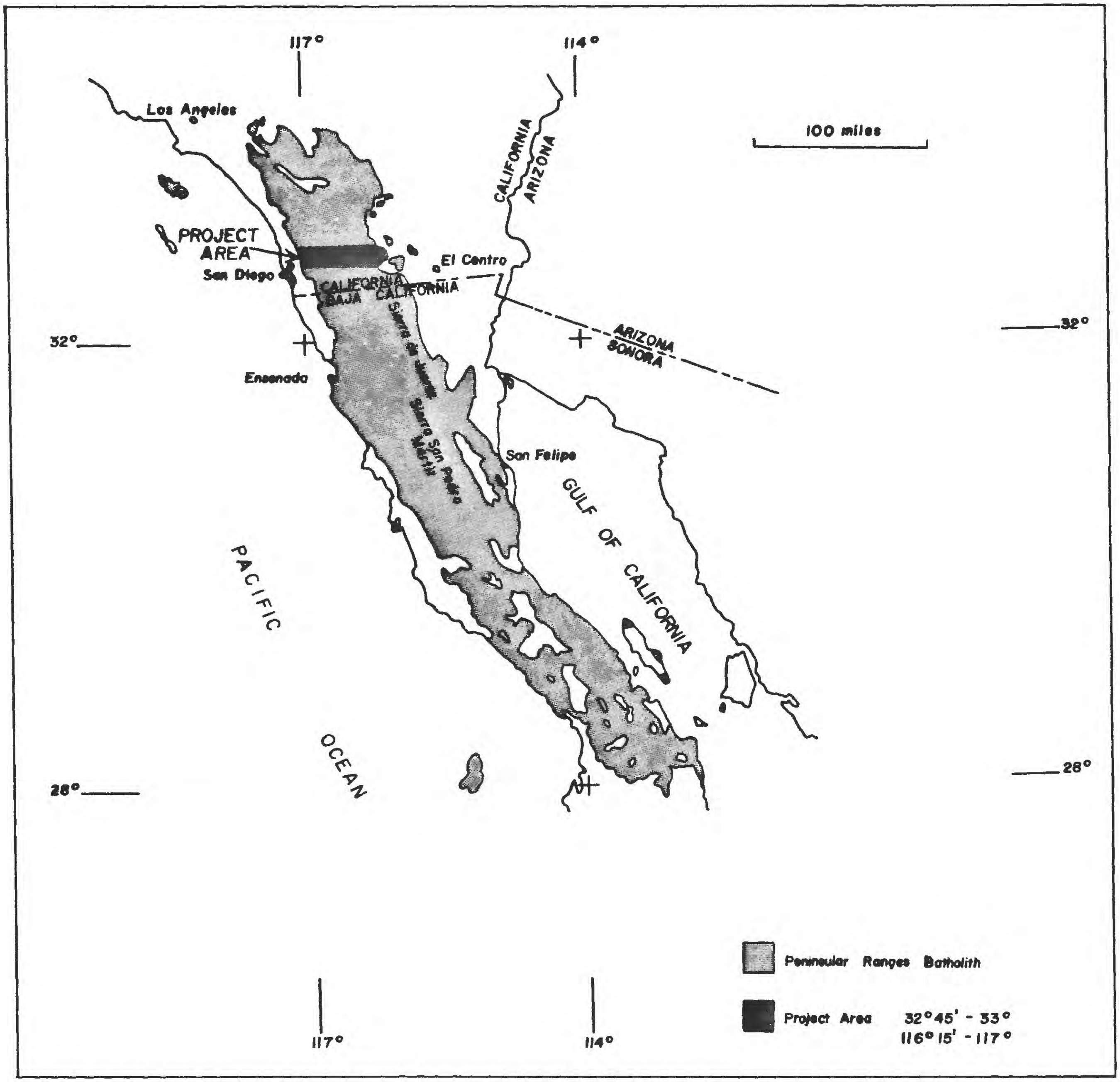

Figure I. Peninsular Ranges batholith in southern California and Baja California and project area.

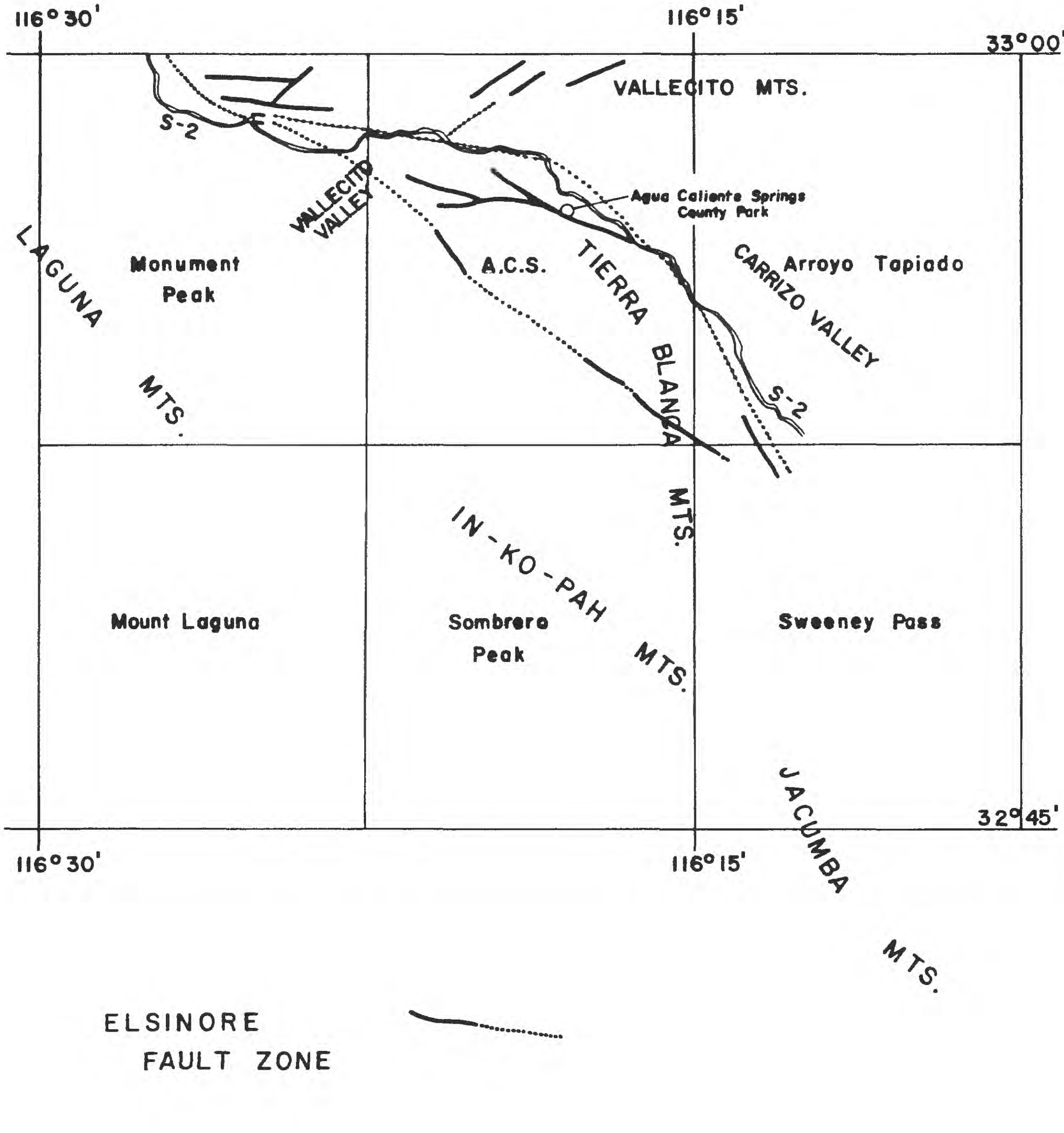

Figure 2. Southern part of Elsinore fault zone, San Diego County, California (after Strand, 1962 and Weber, 1963).

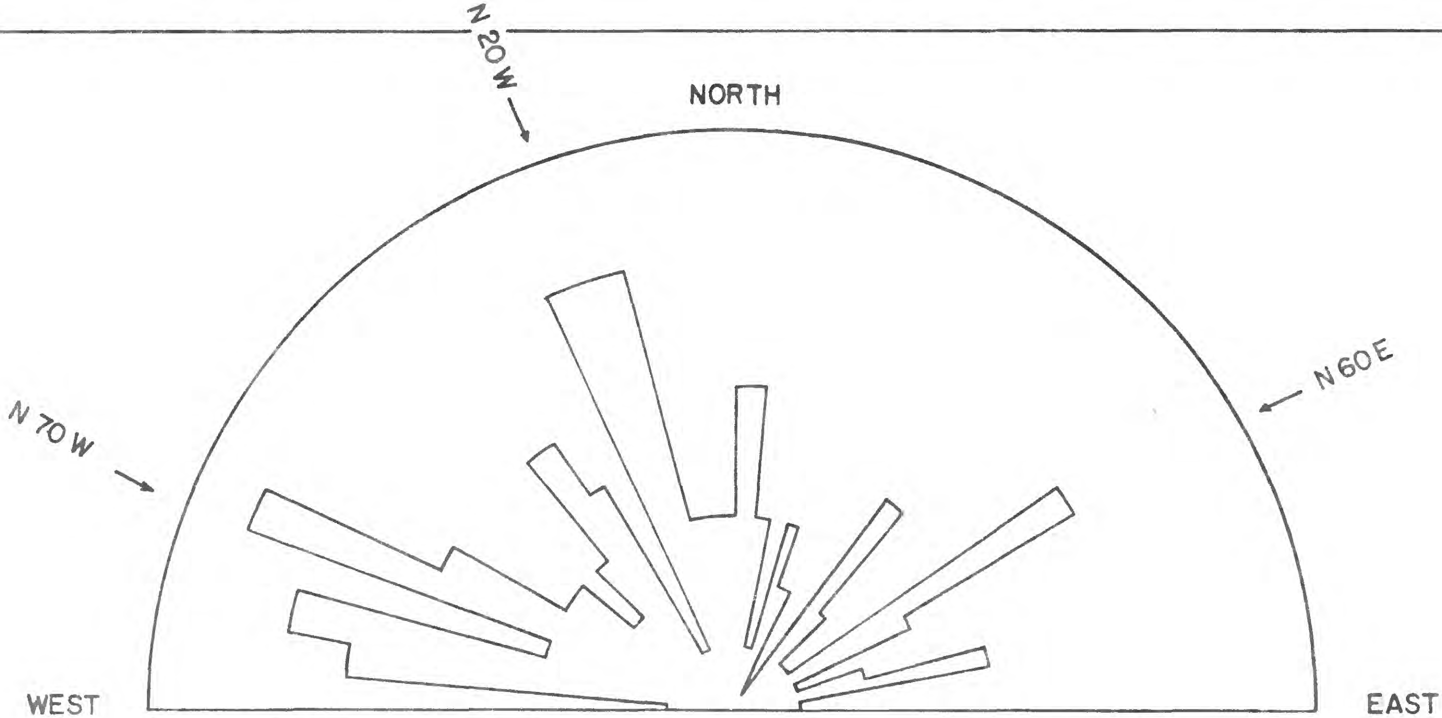

Fig. 3. 113 STRIKES OF MEASURED FAULT PLANES
Agua Caliente Springs quadrangle