UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC MAP OF SWEENEY PASS QUADRANGLE, SAN DIEGO COUNTY, CALIFORNIA

By

Wendy C. Hoggatt

1979

Pamphlet to accompany

Open-File Report

79-754

Geologic map of the Sweeney Pass quadrangle,
San Diego County, California

Purpose of Project

Published geologic maps indicate that rocks of the Peninsular Ranges batholith in San Diego County comprise a relatively unfaulted block, but topographic maps and imagery at all scales reveal numerous prominent lineaments that cross the block in many directions. The purpose of this project, which began in 1974, is to evaluate the structural stability of the block, and in particular, to determine whether lineaments are related to faulting. Figure 1 shows the project area. The primary product of the project will be geologic maps at a scale of 1:24,000 to be used to evaluate the age, magnitude, and direction of fault displacements. Mapping of the bedrock geology of the batholith became an important part of the project because the geologic maps that were available when the study began were not detailed enough for determination of fault displacements. The Sweeney Pass quadrangle is the seventh of this series. Previous maps in the series include the Cuyamaca Peak, Descanso, Agua Caliente Springs, Viejas Mountain, Monument Peak, and Mount Laguna quadrangles.

Introduction

The Sweeney Pass quadrangle lies on the eastern edge of the Peninsular Ranges in eastern San Diego County, within the boundaries of the Anza-Borrego Desert State Park. It is underlain by granitic rocks of the mid-Cretaceous Peninsular Ranges batholith (fig. 1) and metamorphosed prebatholithic sedimentary rocks of uncertain age. These rocks are overlain by middle to late Cenozoic volcanic, marine, and continental strata. The quadrangle is crossed by the southern portion of the Elsinore fault zone (fig. 2).

Lithologic units

Marble (TRm): A large part of Sweeney Pass quadrangle is underlain by a complex assemblage of metasedimentary and gneissic rocks which ranges from schist, to migmatite, to heterogeneous gneiss showing evidence of both metasedimentary and igneous parentage. Metasedimentary rocks crop out in a north-south band near the western edge of the quadrangle, and smaller belts occur elsewhere in the quadrangle, especially in the Coyote Mountains. The major part of the quadrangle is underlain by a heterogeneous complex of schistose to gneissose rocks which probably formed in large part by metamorphism and injection accompanying emplacement of the batholith in mid-Cretaceous time. Of the metasedimentary lithologies present in the complex, only the largest bodies of marble (TRm) have been mapped separately.

The metasedimentary rocks are tentatively assigned a Triassic age on the basis of their similarity to Triassic(?) metasedimentary rocks in the Cuyamaca and Laguna Mountains (Peninsular Range block) to the west. Metasedimentary rocks in Sweeney Pass quadrangle generally lack preservation of sedimentary structures, are coarser-grained (medium-grained), and have undergone more metamorphic differentiation than those of the Peninsular Range.

Marble (TRm) in the complex consists of irregular pods and lensoidal boudin-like bodies ranging in outcrop size from 1/2 m to hundreds of meters along strike. Weathered surfaces are buff-colored, rough and pitted. Fresh rock appears light grey to white, coarsely crystalline and approximately equigranular. Indistinct laminae are defined by subtle color changes from grey to white to shades of pink, yellow, and green, as well as by slight variations in grain size. The largest body occurs at the top of the northern Coyote Mountains, and has a length of at least 800 m before being cut off by a fault; other large bodies occur at the dolomite mine on the south side of the

Coyote Mountains (Elliott property) and at Dos Cabezas (Golden State and Heathman properties). These deposits have been worked intermittently on a small scale as a source of roofing granules, poultry grit, and decorative stone. Analyses reported in Weber (1963a, p. 174-178) show that the deposit at the Elliott property is dolomite, while the Golden State and Heathman properties are limestone.

Gabbro (Kc): Several small, discontinuous, wedge-shaped bodies of gabbro occur on the eastern flank of the In-ko-pah Mountains near the western edge of Sweeney Pass quadrangle. The gabbro is heterogeneous, medium- to coarse-grained and gneissic, and consists of roughly equal amounts of plagioclase and pyroxene. These small, deformed bodies are similar to small gabbro bodies found by Todd in Agua Caliente Springs quadrangle, and are tentatively correlated with the Cuyamaca Gabbro of Cretaceous age, which elsewhere in the project area appears to be the oldest intrusive unit.

Gneissic and metasedimentary rocks (Km): As previously described in this paper, a large part of Sweeney Pass quadrangle is underlain by a complex assemblage of metasedimentary and gneissic rocks which range from schist to migmatite to heterogeneous gneiss, the last showing evidence of both metasedimentary and igneous parentage. The assemblage has been assigned a Cretaceous age because the gneissic part, which is predominant, formed during Cretaceous intrusion and metamorphism (Todd, 1978). This complex (Km) was subsequently intruded by a network of fine- to medium-grained granite dikes and pegmatite dikes unmappable at this scale.

The metasedimentary rocks which occur as inclusions in, and are interlayered with gneiss, consist of a diverse assemblage of lithologies. Quartzo-feldspathic micaceous schist and semi-schist of variable grain size is by far the most common lithology. Interlayered with the quartzo-feldspathic schists are lesser amounts of pelitic schist, coarser-grained mica schist, phyllite, green chloritic semi-schist, biotite-bearing quartzite and calcareous quartzite, fine-grained black amphibolite, and pods of marble.

Quartzo-feldspathic schists and semi-schists are fine- to medium-grained, grey to light grey, depending on grain size and biotite content, and weather to a dull brown color. Fine laminae, probably metamorphic segregations, are from .5 to several mm in thickness, and consist of micaceous (biotite and white mica) partings alternating with quartzo-feldspathic layers. Quartz and feldspar are generally about equal in amount; mica typically makes up 30-40 percent of the rock. Garnet is locally abundant, either as numerous tiny crystals which impart a pronounced pink color to the rock, or as large pink crystals (up to 1 cm in diameter) which occur in pockets.

Small-scale isoclinal folds whose axial planes are concordant with foliation are ubiquitous. Fold hinges are commonly preserved in more competent quartzite and limestone beds. Schistose and semischistose rocks generally have steeply-dipping foliation, but where remnants of fold hinges are preserved it is evident that this foliation is parallel to the limbs of sheared-out folds. Rarely, outcrops of quartzite and sandy marble in the Coyote Mountains show large-scale primary compositional layering up to a meter in thickness. Christensen (1957) reports that relict bedding is locally seen in similar rocks in the eastern Coyote Mountains. This large-scale compositional layering is parallel to lamination in schist and semischist, so lamination may reflect transposed original bedding. Lamination in the larger pods of marble, and in both small and large pods of amphibolite is frequently discordant with foliation in surrounding rocks, as though some marble and amphibolite pods have been tectonically rotated within a schist or gneiss matrix.

Over large parts of the quadrangle schistose rocks grade into gneiss. Schist becomes increasingly coarse-grained while laminations become increasingly diffuse until the texture is that of a gneiss. Metasedimentary inclusions grade progressively into vague micaceous streaks and clots. The quartz-feldspar-biotite-white mica gneiss is medium- to coarse grained, and is characterized by punky yellowish feldspar grains up to .3 cm in diameter, spherical quartz segregations up to 2 cm in diameter, and dime- to quarter-sized flat micaceous clots. Irregular feldspathic and micaceous streaks form vague, irregular patterns probably related to folding, and foliation in gneiss is parallel to foliation in nearby schist. Migmatite, consisting of approximately equal amounts of complexly folded schist and fine-grained granitic rock, occurs locally, as do quartzose ptygmatic veins. Variations in grain size and degree of assimilation of metasedimentary inclusions do not seem to be related to proximity of intruding plutons or granitic dikes, at least at the present level of erosion.

The entire complex is identical to the migmatitic schist and gneiss (Km) described in Monument Peak and Mount Laguna quadrangles by Todd (1978 and 1979, respectively), a unit which she devised for rocks that fall between metasedimentary rocks (TRm) and the hybrid gneiss of Harper Creek (Khc). The hybrid gneiss unit is a grey- to yellow-weathering, cordierite- and sillimanite-bearing quartz-biotite-plagioclase-K-feldspar/muscovite gneiss containing abundant metasedimentary inclusions and micaceous lenses which grade into ghostly metasedimentary inclusions. It also includes rocks that closely resemble a plutonic unit, the granodiorite and tonalite of Cuyamaca Reservoir (Kcr), which is always spatially associated with the hybrid gneiss. Todd felt that, "Local relict igneous textures and gradation into Kcr indicate that the Khc unit originated by mixing of Kcr and TRm [metasedimentary rocks] enhanced by deformation and metamorphic temperatures that existed probably both before and after emplacement of Kcr." (Todd, 1978, p. 13). The plutonic unit Kcr has not been mapped in Sweeney Pass quadrangle, but several outcrops within the Km complex in the Coyote Mountains look identical to Kcr in hand sample.

The entire metasedimentary and gneissic complex is cut by a network of medium-grained granite dikes not obviously related to any plutonic unit in the quadrangle. Their distribution is not spatially related to the large tonalite pluton (Kt_1) to the west nor are they found within it. They are thus considered either earlier than, or coeval with, Kt_1. The dikes are fine- to medium-grained biotite-muscovite granite and frequently bear white dime-sized or smaller quartz clots. They have a distinct foliation which is generally parallel to that in the metamorphic-gneissic host rocks. When a dike is discordant to the country rock foliation, the foliation crosses dike walls at a high angle. Pegmatite dikes with pink or white K-feldspar, quartz, myrmekite, books of muscovite up to 5 cm across, and schorl are locally abundant. Pegmatite dikes cut the medium-grained quarz monzonite dikes and are both concordant and discordant with the foliation in metamorphic and gneissic rocks. Indistinct foliation in the pegmatite dikes may be either parallel to dike walls or may cut across dike walls parallel to country rock foliation. Pegmatite dikes are found throughout the quadrangle, and like the granite dikes, do not show a spatial distribution related to plutons in the quadrangle.

<u>Tonalite Kt_1</u>: Tonalite in the western part of Sweeney Pass quadrangle in the Tierra Blanca and In-ko-pah Mountains is continuous to the northwest with the tonalite body in Agua Caliente Springs quadrangle (fig. 2) which Todd (1977a) referred to as "Kt_1". It is probably a northern lobe of the vast La

Posta body (Miller, 1935) which underlies much of the Peninsular Ranges in southern San Diego County and northern Baja California. Todd's description fits the tonalite of Sweeney Pass quadrangle as well:

> "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.
>
> "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 2 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.
>
> "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 TRm. 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, 1977b; Hoggatt and Todd, 1977). Here it is tentatively considered a late-tectonic structural feature."

In the western part of Sweeney Pass quadrangle, Kt_1 intrudes metasedimentary rocks with a sharp contact which is generally concordant with foliation in the metasedimentary rocks. This contact is shown as a fault contact on the 1962 San Diego-El Centro Map Sheet (Strand, 1962). A fault of very small displacement follows the contact for a short distance in the southern part of the quadrangle, but appears to die out, so the contact is intrusive for most of its length. Schist 3 m from the contact is finer-grained than typical schist in the quadrangle, and is broken up by thin fingers of tonalite penetrating along foliation, but no other megascopic effects of the intrusion are evident. Blocks of schist enclosed in tonalite are increasingly assimilated away from the contact, and 10 to 20 m from the contact only indistinct biotitic schlieren remain.

K-Ar apparent ages on biotite from Kt_1 from Sweeney Pass and Agua Caliente Springs quadrangles range from 79 to 89 m.y. (Hoggatt, unpublished data). These dates represent the time of cooling through the temperature of biotite closure and are therefore minimum ages.

Anza Formation (Tan): The oldest unmetamorphosed sedimentary rock unit exposed in Sweeney Pass quadrangle is coarse conglomeratic sandstone correlated in this report with the Miocene Anza Formation. Defined by Woodard (1974), the Anza Formation was formerly known as a basal conglomerate member of the Miocene Split Mountain Formation. The Anza Formation at its type locality in Split Mountain Gorge (Borrego Mountain S.E. 7-1/2' quadrangle, fig. 2) is 540 m thick, but in Sweeney Pass quadrangle its maximum exposed thickness is only 5 m, and it is preserved only where covered by flows of the Miocene Alverson Andesite. The Anza Formation is unfossiliferous, but its age is estimated to be Miocene as it lies on an eroded surface on granitic and metamorphic rocks of the Peninsular Ranges batholith, and in Sweeney Pass quadrangle the formation grades upward into increasingly volcaniclastic beds whose deposition must have immediately preceded the first flows of Alverson Andesite.

In Sweeney Pass quadrangle the Anza Formation consists of indistinctly bedded coarse arkosic sandstone with conglomeratic lenses of angular to subangular pebbles and rather well-rounded cobbles and small boulders of metamorphic rock. Volcanic clasts are not present except for rare, very well-rounded volcanic cobbles with glomeroporphyritic texture unlike local volcanic rocks. These may have been derived from the Alverson Canyon area or the Fish Creek Mountains to the east, where similar textures in volcanic rocks have been described by Christensen (1957) and Woodard (1974). The uppermost 2 or 3 m of sandstone are commonly progressively enriched in volcaniclastic material, and may contain up to 75 percent coarse lithic ash. The ash-rich layers are brick red, often show well-defined layering 1 to 5 cm thick, and closely resemble the interbeds between flows of the overlying Alverson Andesite. Locally, vesicular bombs up to 15 cm in diameter are abundant, and the sandstone directly underlying the andesite appears to have been disrupted by the flows.

Alverson Andesite (Tal): Flows, breccia, and intercalated volcaniclastic rocks are well exposed in the Volcanic Hills area in the southeastern part of the quadrangle (fig. 2). Other isolated outcrops are found .5 km south of Rockhouse Canyon (1/4 sections joining sections 1, 2, 11, and 12, T16S, R7E), in the Jacumba Mountains west of Jojoba Wash (SE 1/4 sec. 5, T16S, R8E), and as fault-bounded slivers on the north side of the Coyote Mountains (NE 1/4 sec. 27, T15S, R8E).

The Alverson Andesite was named by Dibblee, 1954, from Alverson Canyon (Carrizo Mountain 7-1/2' quadrangle), where up to 120 m of flows are exposed. Volcanic rocks correlated with the Alverson Andesite also occur to the northeast in the Fish Creek Mountains (Dibblee, 1954; Woodard, 1974). In Sweeney Pass quadrangle volcanic rocks were extruded on an eroded batholithic surface locally overlain by conglomeratic sandstone of the Anza Formation. A fault-bounded slice of volcanic rocks on the north side of the Coyote Mountains just east of Sweeney Pass quadrangle is unconformably overlain by mudstones of the middle Pliocene to early Pleistocene Imperial Formation. The Alverson Andesite is considered Miocene in age because of its close lithologic similarity to the Jacumba Volcanics which lie seven miles to the south. A tholeiitic basalt from the Jacumba Volcanics dated by Hawkins (1970) yielded an age of 18.7 ± 1.3 m.y. (19.2 m.y. recalculated using new constants, W. C. Hoggatt, this report, Table 1), and Minch and Abbott (1973) obtained concordant hornblende and plagioclase dates of 18.5 ± 0.9 m.y. and 18.6 ± 0.8 m.y., respectively (recalculated ages 19.0 m.y. and 19.1 m.y., Table 1) from a clast in andesite breccia on Table Mountain near Jacumba. Janet Morton (U.S.G.S., oral commun., 1978) has also obtained Miocene ages on samples of Jacumba volcanics collected near Jacumba. An age of 16.9 ± 0.5 m.y. (Table 2) obtained by the author on the isolated outcrop of fine-grained olivine basalt in the Jacumba Mountains confirms that the Alverson Andesite is of Miocene age.

The volcanic rocks consist of massive flows, breccia, intercalated volcaniclastic deposits and minor air-fall cinder deposits. Individual flows generally consist of basal scoriaceous breccia of varying thickness, overridden by massive basalt which is increasingly vesicular toward the top of the flow. Individual flows average 4 to 6 m in thickness, and may be up to

15 m thick. Internal flow structures are rarely visible but flattened vesicles define a crude layering. Amygdules filled with calcite and zeolite minerals are common. Platy joints and fractures may be roughly parallel to flattened vesicles or at high angles to them. Where flows overlie country rock, granite or gneiss is reddened within 3 m of the contact. Beds of arkosic sandstone and oxidized volcaniclastic debris usually 1/2 to 2 m thick fill irregularities in flow surfaces as though flow surfaces were washed by streams. These interbeds usually consist of brick-red, very coarse sand, but where they are especially thick and unbaked, they are tan to yellowish, and may contain very distinctive pockets of fist-sized scoria floating in a sandy, unbedded matrix. Layering 1 to 10 cm thick is common in interbeds, and most attitudes on the volcanics were obtained on these layers. Where exposures are particularly good it can be seen that flows were generally preceded by an eruption of cinders and lapilli which blanketed the area up to 3 cm in thickness.

The stratigraphy of the Alverson Andesite in the Volcanic Hills area was not studied in detail, but flows vary widely in color and joint patterns, and some are very distinctive. Fresh massive rock generally has a dark grey aphanitic groundmass with minor greenish-brown phenocrysts. Study of one thin section from a typical flow in Mortero Wash (SW 1/4 sec., T16S, R8E, Carrizo Mountain 7-1/2' quadrangle, .5 km east of Sweeney Pass quadrangle) revealed very fresh, sparsely porphyritic olivine basalt consisting of corroded Mg-rich olivine phenocrysts in an intergranular matrix composed of labradorite laths (An 65) and very pale green subhedral clinopyroxene crystals. Olivine phenocrysts are commonly composed of clustered subhedral grains rimmed with iddingsite. Large grains generally have weathered cores. Magnetite and rare apatite are present in both olivine crystals and in the matrix. Other flows appear megascopically different, and may be of a less basic composition. At least one distinctive flow unit is mauve-grey in color, and weathers to a characteristic greenish sheen.

A possible vent area is located at the mouth of Lava Flow Wash (NE 1/4 sec. 14, T16S, R8E), where the greatest thickness of flows occurs, and where a large mass of highly fractured and chaotic breccia is found. A nearby deposit of up to 30 m of finely bedded brick-red cinders thinning rapidly to the southeast may be a remnant of a cinder cone.

A series of north-south trending faults which repeatedly bring the basal country rock/volcanic contact up on the east against later flows makes the thickness of flows difficult to estimate. The present thickness, however, of flows and chaotic breccia at Lava Flow Wash is approximately 150 m. Elsewhere the total thickness appears to be less.

Palm Spring (Qp) and Canebrake (Qc) Formations: The Palm Spring Formation was named by W. P. Woodring (1932) for non-marine sediments overlying the Imperial Formation on the north side of the Coyote Mountains. It was studied comprehensively by Woodard (1963) in the Arroyo Tapiado quadrangle (fig. 2) where badlands provide spectacular exposures. He described more than 3000 m of interbedded siltstone, claystone, arkosic sandstone, pebble conglomerate, and fresh-water limestone which represent alluvial floodplain deposits marginal to the gradually retreating Gulf of California. Marine interbeds containing impoverished marine faunules indicate intermittent marine transgressions as late as middle Pleistocene, and vertebrate fossils throughout the section provide evidence of continuous deposition from Irvingtonian to Blancan time.

In Sweeney Pass quadrangle Palm Spring Formation outcrops most extensively in the Carrizo badlands north of the Coyote Mountains, and in the heavily faulted badlands just south of the Coyote Mountains. Patchy deposits also lie on Alverson Andesite and on granitic and metamorphic rocks in the Volcanic Hills and along the fronts of the Jacumba and Tierra Blanca Mountains. As these mountains are approached Palm Spring Formation becomes coarser and grades laterally into Canebrake Formation (Qc) (Dibblee, 1954). Woodard (1963) describes the Canebrake Formation as coarse terrestrial pediment boulder to cobble fanglomerate and subordinate pebbly arenite which are the marginal equivalent of the Palm Spring and Imperial Formations. Where conglomerate is present in Sweeney Pass quadrangle, it is limited to exposures near the fronts of the ranges, and is clearly locally derived.

Woodard (1963) divided the Palm Spring Formation into 5 members, of which only the lowermost Diablo member is exposed in Sweeney Pass quadrangle. It consists predominantly of fine- to coarse-grained arkosic arenite alternating with discontinuous lensing mudstones and siltstones of various colors. The formation usually has a pinkish cast due to the nearly ubiquitous presence of variable amounts of pinkish-beige silt. Sandstone is generally well consolidated, massive or obscurely bedded; beds range from several cm to more than 10 m in thickness, and commonly are crossbedded. Sole marks are present locally. Silty sandstone and siltstone are more finely laminated and micaceous. Lenses of pebble- to boulder-sized gravel containing clasts of schist, quartzite, and fine-grained granitic rock, with lesser amounts of coarse-grained granitic rock, pegmatite, and volcanic rock are common. Gravel lenses most often are thin and discontinuous, but may be up to several meters thick and at least several hundred meters long. Conglomerate interbeds become more abundant near the mountain fronts, and where conglomerate predominates the unit has been mapped as Canebrake Formation.

Rapidly lensing beds of reddish-brown mudstone and mud- and claystones of yellowish-tan, chocolate brown, and grey colors are common in the Palm Spring Formation. They range in thickness from several mm to several meters. The beds are massive and often contain spheroidal clay gall concretions up to the size of a bowling ball as well as smaller calcareous nodules. Bone and silicified wood, commonly associated with a yellowish or rusty stain, are locally abundant in the mudstone, and may be found locally in silt- and sandstones.

Beyond the eastern edge of Sweeney Pass quadrangle, along the south face of the Coyote Mountains, the Palm Spring Formation grades into the underlying Imperial Formation. Irregularly-shaped beds and blebs of blue-grey claystone and green sandy silt are increasingly abundant toward the south, as are interbeds of fossiliferous olive green sandstone. One such bed, which bears numerous <u>Ostrea</u> valves and less common gastropods is overlain by a reddish-brown mudstone, and a gradation zone between the two contains abundant platelets of gypsum.

Hills underlain by Palm Spring Formation are typically covered by a lag deposit of well-rounded cobbles and boulders probably derived from the Mesa Conglomerate, a late Pleistocene to Recent formation which was deposited on eroded Palm Spring Formation.

In the Carrizo badlands, bedding in the Palm Spring Formation strikes from N30 to N70E and dips 30°-50° to the northwest. Woodard (1963) considered this structure to be the south limb of an east trending fold, which he named the Carrizo Wash syncline. South of the Coyote Mountains a wide northwest-trending fault zone (the Elsinore fault zone) has shattered the Palm Spring beds, so that attitudes in this area vary widely.

Mesa Conglomerate (Qm): The Mesa Conglomerate was defined by Woodard (1963) as pediment fan and alluvial outwash deposits of massive conglomerate, arenite, and gravel which cap the folded Imperial and Palm Spring Formations in the Vallecito and Carrizo badlands. In Sweeney Pass quadrangle rocks correlated with Mesa Conglomerate have been found to be more heterogeneous than those Woodard described, their character and thickness being strongly dependent upon lithology of the source area and proximity to mountain fronts. This report expands Woodard's definition to include lateral facies present in Sweeney Pass quadrangle which were not present in the area Woodard described. Mesa Conglomerate deposits in this report include massive or torrentially-bedded very coarse boulder conglomerate near mountain fronts, flat-lying poorly-bedded sandstone and conglomerate alluvial outwash deposits which filled and capped a gentle topography, and well-bedded silt- and sandstone deposits whose only source was Palm Spring Formation.

The thickest and coarsest exposure of Mesa Conglomerate is located in the canyons in the southeast corner of section 33, Sweeney Pass quadrangle. Here more than 12 m of coarse brown conglomerate consists of at least 6 massive beds, each 1.5 to 4 m thick, which grade from boulder conglomerate at the base to mixed sandstone and cobble conglomerate at the top. Exposures in side canyons near the Jacumba Mountains to the west indicate that Mesa Conglomerate deposits near their source consist of unstratified, angular, extremely poorly sorted deposits such as might be expected at the steep head of an alluvial fan. Downstream toward Sweeney Canyon the deposits become finer-grained, thinner, and more similar to Mesa Conglomerate described by Woodard. Downstream Mesa Conglomerate deposits consist of 3 to 5 m of tan or buff-colored poorly sorted pebbly arenite with conglomeratic lenses which define vague bedding. Sand to cobble rations vary widely, but probably average about 2:1. The uppermost 1 to 2 m are often cemented by calcium carbonate and closely resemble concrete aggregate. Calcium carbonate occasionally forms very thin laminae in these cemented zones, particularly in the uppermost 15 cm.

Flat-lying Mesa Conglomerate overlies folded Palm Spring Formation in the Carrizo badlands north of the Coyote Moutains, but aside from the difference in dip, is difficult to distinguish from Palm Spring Formation. The sediments of Palm Spring Formation were apparently the only source of the Mesa Conglomerate at this locality, as the Mesa Conglomerate deposits consist of fine-grained silty sand and minor conglomeratic lenses with prominent cross beds and large-scale cut-and-fill structures. The Palm Spring topography which Mesa Conglomerate covered was apparently rather flat, with small rounded hills and gentle valleys.

Tan-colored sandy deposits which lie nonconformably on Kt_1 in interior valleys near Mountain Palm Springs and Indian Valley are correlated with Mesa Conglomerate because of their similarity in character with valley filling Mesa deposits elsewhere which can be traced into typical Mesa Conglomerate. These sandy valley-filling deposits are also similar to those described by Todd (1977a) in Agua Caliente Springs quadrangle (fig. 2). Indistinct, thin layers of coarse sand, silt, and gravel form discontinuous bedding, with pebbles and cobbles both scattered through the sand and concentrated in lenses. Occasionally the upper 1/2 m is wind-blown sand, and is much lighter in color than the bedded parent sand because darker silt and fine sand has been winnowed out. Coarse sand commonly contains euhedral biotite books up to 1 cm in diameter which weathered intact from Kt_1.

Despite its heterogeneity, Mesa Conglomerate has several distinguishing characteristics. First, it is nearly always essentially flat-lying. Todd (1977a) describes fanglomerate in Agua Caliente Springs quadrangle which slopes off the mountain front with a primary dip of 23° but no such dips have been found in Sweeney Pass quadrangle. The angular unconformity between the flatlying Mesa Conglomerate and underlying moderately dipping beds of Palm Spring Formation is prominent throughout the area. Also characteristic are the broad, gently sloping surfaces for which the Mesa Conglomerate is named, and which are developed only on this formation. These surfaces are paved with a veneer of cobbles and small boulders having well-developed desert varnish. The surfaces appear to be eroded along their edges but show little downcutting in their interiors, and the surfaces are probably remnants of an original wide-spread pediment surface. Mesa deposits are unfossiliferous, but Woodard considers them to be of late Pleistocene to Holocene age.

Christensen (1957) described stratified deposits of buff to brown fanglomerate which lie unconformably over Imperial Formation, Alverson Andesite, and metamorphic and granitic bedrock along the crest of the Coyote Mountains in Carrizo Mountain and Painted Gorge quadrangles (fig. 2), and called them Garnet Formation. The character of the deposits Christensen describes is very similar to alluvial deposits which he called Terrace and Old Alluvium, and which are correlated with Mesa Conglomerate. But Christensen's Garnet Formation lies only at elevations greater than 1500 feet, up to 1000 feet above Mesa Conglomerate in that area. Christensen concluded that Garnet Formation must represent deposits of an earlier erosional interval, most likely in the earliest part of the Pleistocene. An analogous situation exists in Sweeney Pass quadrangle. Several patches of poorly exposed, apparently stratified conglomeratic sand occur at the crest of the western Coyote

Mountains, nonconformably overlying metamorphic and granitic bedrock. These sediments lie between elevations of 1400 and 1600 feet, while nearby Mesa Conglomerate deposits occur at elevations up to 1160 feet, a difference of only a few hundred feet. Both the north and south sides of the Coyote Mountains have been extensively faulted, and if deposits at the crest of the mountains are assumed to be uplifted remnants of Mesa Conglomerate, the elevation difference is readily explained.

Modern alluvium (Qal): Modern alluvium in this report consists of sand and gravel moved intermittently by seasonal floods, and is restricted to major drainages. In the north-central part of the quadrangle two major eastward-draining streams, Carrizo and Bow Willow Creeks, have created a broad alluvial valley. Here modern alluvial deposits form a thin veneer (0 to 1 m thick) lying conformably on Mesa Conglomerate or unconformably on Palm Spring Formation. Factors used in this area to distinguish Mesa Conglomerate from Qal are degree of consolidation, grain size, and positive relief. Other alluvium mapped as Qal consists of sand and gravel in narrow modern washes. The only classic, cone-shaped fan in the quadrangle is at the head of Indian Gorge, where mud- and debris flows extend out at least .3 km from the steep, faulted face of the Tierra Blanca Mountains.

Faults of the Sweeney Pass quadrangle

Strand's 1962 small-scale compilation shows the Elsinore fault entering Sweeney Pass quadrangle at the northwest corner, striking along the frontal face of the Tierra Blanca Mountains, then disappearing under Quaternary alluvium. A west-northwest-trending segment is shown cutting Palm Spring Formation in the western Carrizo Badlands. The fault is then shown striking along the southwest face of the Coyote Mountains. The only other fault shown is along the contact between granitic and metasedimentary rocks near the western edge of the quadrangle. This fault has already been discussed in the section on Kt_1.

The present study shows that faulting is present in all of the above areas. But additional, previously unmapped faults make the structural relations between these fault segments too complex to link them into a single throughgoing fault. Faults not previously shown on published maps, principally in the Jacumba Mountains, strike both parallel to the predominantly northwest trend of the Elsinore fault zone, and at high angles to it. These faults have been a controlling factor in shaping the modern topography.

Vertical or near-vertically-dipping faults in the quadrangle strike in all directions (fig. 3a), but three trends predominate: N72W, N30W, and N33E. Measured faults have been broken into five categories, according to the age of the rocks they cut (figs. 3b to 3f).

Faults that show unequivocal evidence of cutting modern alluvium are rare in Sweeney Pass quadrangle. The only one found in this study extends about one kilometer in Sweeney Canyon (SE 1/4 sec. 30 and SW 1/4 sec, 29, T15S, R8E), and trends approximately N64W. Where the fault cuts across small tributaries, alluvium is ponded behind small (.5 m) scarps in alluvium, with the southwest side uplifted. A friable crushed zone marks the fault where it cuts bedrock.

Far more numerous are faults which cut Mesa Conglomerate. A plot of these faults (fig. 3b) shows a strong maximum at N75W, with lesser peaks at N67W and N53W. This is the approximate trend of the Elsinore fault zone as shown on Strand's 1962 compilation map, and would also include the one fault known to cut Qal in Sweeney Pass quadrangle.

A third category contains numerous faults which cut Cretaceous or older bedrock (Kt_1 and Km) but show equivocal evidence or no evidence of cutting Mesa Conglomerate, whether because of unfavorable exposure or through erosion or non-deposition of Mesa Conglomerate. The rose diagram for this category (fig. 3c) shows faults of nearly all trends, with a great resemblance to the cumulative diagram (fig. 3a), which is to be expected because faults which cut bedrock could be of any age, from Cretaceous to Recent. Of particular interest, however, are the peaks at N72W and N33E. The N72W peak is identical to the peak for faults which cut Mesa Conglomerate (fig. 3b) and to the peak at N72W on the cumulative diagram (fig. 3a). Nearly all faults which defined the peak at N72W on the cumulative diagram fall into two categories, those which cut Mesa Conglomerate, and those which cut bedrock and may or may not cut younger rocks; thus it is likely that most faults in the quadrangle having trends from N60W to N75W are younger than Mesa Conglomerate. The strong peak at N33E is very near the peak at N27E on the diagram for the category "Cuts bedrock but not Mesa Conglomerate" (fig 3d). This is a peak which does not show up strongly on diagrams for faults cutting rocks younger than Cretaceous bedrock; thus it seems likely that faults trending approximately N30E may be old. Crushed rock along the major faults in the Jacumba Mountains having this trend generally consist of highly weathered, sheared gneiss with variable thicknesses of greenish-brown to black, flinty, very coherent cataclasite which may have formed at moderate depth.

Faults that cut Alverson Andesite but not the overlying Palm Spring Formation or Mesa Conglomerate show a pronounced peak at approximately N7E (fig. 3e). This trend is not a peak on the cumulative diagram because faults of this trend are rarely found cutting rocks younger than the andesite or outside the Volcanic Hills area. An unnamed canyon (NW 1/4 sec. 11, T16S, R8E) cuts perpendicularly across the main set of faults, exposing an excellent section through the faulted area. The faults comprise a series of westward-dipping step faults, down-dropped to the west, repeatedly bringing volcanic flows against the underlying gneissic basement. The unconformity between gneiss and volcanic rocks in each block appears to dip toward the east, which may reflect an original dipping surface on which the volcanics were deposited, or eastward tilting.

Faults which cut Palm Spring Formation but cannot be shown to cut Mesa Conglomerate do not have a single strong peak (fig. 3f), but trends are quite similar to those of faults that cut Mesa Conglomerate. This means that faulting which may have accompanied folding of Palm Spring Formation before deposition of Mesa Conglomerate was similar in trend to faults cutting younger rocks.

Faults of the frontal zone of the Tierra Blanca Mountains

The southern extension of the frontal fault zone of the Tierra Blanca Mountains (Todd, 1977a) extends across the southwest corner of Arroyo Tapiado quadrangle (fig. 2), the northwest corner of Sweeney Pass quadrangle, and then apparently is concealed by modern alluvium. In the Indian Gorge and Mountain Palm Springs areas, innumerable short and discontinuous northwest-trending faults are crossed by faults of many other trends, producing a .5 to 1 km-wide zone of the intensely fractured, hydrothermally altered tonalite (Kt_1). This zone was not mapped in detail. In Sweeney Pass quadrangle evidence for Quaternary movement near the range front includes northeast-facing scarplets in Mesa Conglomerate, abruptly truncated bedrock spurs, and a prominent 2.5 m scarp at the foot of the range at the mouth of Indian Gorge. To the northwest in Agua Caliente Springs quadrangle faults of the zone cross modern washes, producing scarps approximately 1 m high (Clark, 1975). Sense of movement along the frontal fault zone in Sweeney Pass quadrangle appears to be normal with the valley (eastern) side down-dropped relative to the mountain block, as it is in Agua Caliente Springs quadrangle (Todd, 1977a).

In the southwest corner of Arroyo Tapiado quadrangle, a reverse fault dipping approximately 40° toward the valley (eastward) brings Mesa Conglomerate over brecciated tonalite (Kt_1) (Todd and Hoggatt, unpublished mapping).

Sweeney Canyon fault zone:

A series of subparallel vertical faults striking approximately N60W are found in Sweeney Canyon, 3 km southeast of the canyon mouth. These faults displace the unconformity between Palm Spring or Canebrake Formation and Mesa Conglomerate upward 9 to 13 meters on both the southwest and northeast sides of the canyon, forming a graben .3 km wide and 2 km long. Crushed bedrock (Km) and powdery-appearing Mesa Conglomerate may define the zone northwest of the 2-km long segment, and the segment strikes directly toward the series of faults near the mouth of Sweeney Canyon which cut Qal. A southeasterly projection of the 2-km segment would strike into the northwest-trending Ocotillo Valley (Carrizo Mountain quadrangle).

The Sweeney Canyon fault zone is directly on strike with the frontal fault zone of the Tierra Blanca Mountains, and may represent an extension of that zone. In Sweeney Pass quadrangle, bedrock (Km) does not crop out northeast of the Sweeney Canyon fault zone until the Coyote Mountains frontal fault zone is crossed; the Sweeney Canyon zone may mark the edge of a buried bedrock escarpment produced by normal faulting having the same sense of displacement (northeast side down) as the Tierra Blanca frontal fault zone.

Coyote Mountains frontal fault zone:

The prominent fault which extends the length of the southwest side of the Coyote Mountains has traditionally been considered a right lateral extension of the Elsinore fault. The present study has found that in Sweeney Pass quadrangle and the adjacent part of Carrizo Mountain quadrangle this fault is a reverse fault which dips 48^{o} to 54^{o} (and locally up to 60^{o}) to the northeast. The fault has brought rocks of the gneissic and metamorphic complex over Palm Spring Formation, Mesa Conglomerate, and locally, over coarse talus material probably shed from the mountain face as a result of uplift along this fault. Within 10 m of the fault, the overriding gneissic-metasedimentary complex is intensely sheared and brecciated, with a zone of blackish-green cataclasite generally 1.5 to 2 m thick at the base; but underlying sediments are disturbed for only 1.5 - 3 m (locally up to 10 m). Locally the flat-lying angular unconformity between Mesa Conglomerate and Palm Spring Formation strikes directly into the reverse fault. The fault trace is typically expressed as a prominent southwest-facing scarp or as a narrow, linear bench. Thus the Coyote Mountains in this area appear to consist of a slice of crystalline bedrock overriding valley-filling sediments to the south. On the northeast side of the bedrock slice, Palm Spring Formation and older sediments overlie the metamorphic rocks depositionally or are faulted against them (structure section A-A'). Christensen's (1957) mapping shows complex faulting in the eastern Coyote Mountains implying that the structure is undoubtedly more complex than the simplistic bedrock slice model, yet many of the structural features he struggled to explain assuming right lateral movement on the "Elsinore fault" are readily explained by invoking compressive tectonics.

The Palm Spring Formation and Mesa Conglomerate exposed in the badlands immediately south of the Coyote Mountains are broken by innumerable small, discontinuous faults which show up to 1.5 m vertical displacement on individual breaks. These faults have powdery whitish crush zones up to .3 m in thickness which are sometimes filled with $CaCO_3$, causing the zones to stand up as small resistant ridges. $CaCO_3$ also fills cracks in the sediments.

In the western Colorado desert region tectonic syntheses have primarily assumed right lateral movement along the Elsinore fault zone. However, Todd's studies of the Elsinore fault zone in quadrangles to the northeast of Sweeney Pass quadrangle have found no evidence of major right lateral displacement, but rather of predominantly normal faulting (oral commun., 1978). The tectonic setting is further complicated by the discovery of reverse faults.

Reverse and thrust faults which cut sediments as young as Mesa Conglomerate have been found elsewhere in the area. A reverse fault in the southeast corner of Arroyo Tapiado quadrangle has been described previously in this report. Todd (1977a, p. 15) describes a structure in the northern part of Arroyo Tapiado quadrangle which appears to be a thrust slice of tonalite (Kt_1) over Palm Spring Formation.

R. V. Sharp (1967) describes a segment of the right lateral San Jacinto fault zone along which crystalline rocks were thrust over Pleistocene sediments. He felt that these faults probably steepen at relatively shallow depth and may have accompanied or followed horizontal movements. He also describes a structure in which the overthrust crystalline rocks occur only in a narrow slice which he felt probably pinches out downward. Weber, 1975, describes an eight-mile-long, shallow-dipping reverse fault southwest of Corona in Riverside County as a segment of the Elsinore fault. He considered the sense of displacement of the Elsinore fault zone in north-western Riverside County to be both right-oblique normal and right-oblique reverse.

Weber (1977, p. 524) suggests that correlation of metamorphosed limestone terranes across the Coyote Mountains frontal fault zone from the Dos Cabezas area to "directly north of the fault in the western part of the Coyote Mountains" would restrict possible lateral offset along the Elsinore fault in this area to 1 or 2 km. The current study has found that such terranes occur more widely than previously thought, and that even the largest marble pods may have been tectonically rotated within the gneissic matrix; thus the marble terranes are probably not reliable stratigraphic markers. An attempt to correlate the occurrences of Alverson Andesite across the fault, from the Volcanic Hills (Sweeney Pass quadrangle) to the type area in Alverson Canyon (Carrizo Mountain quadrangle) might be more fruitful. Such a tentative correlation would suggest approximately 2 km right lateral offset. A detailed stratigraphy of flows could undoubtedly be erected in the Volcanic Hills, but would be more difficult in Alverson Canyon where this unit is fault-bounded.

REFERENCES CITED

Christensen, A. D., 1957, Part of the geology of the Coyote Mountain area, Imperial County, California: University of California, Los Angeles, Master's Thesis, 188 p.

Clark, M. M., 1975, Character and distribution of recent movement along the southeastern part of the Elsinore fault zone, southern California: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 304.

Dibblee, T. W., Jr., 1954, Geology of the Imperial Valley region, California; California Division of Mines Bulletin 170, Chapter 2, Contribution 2, p. 21-28.

Hawkins, J. W., 1970, Petrology and possible tectonic significance of late Cenozoic volcanic rocks, southern California and Baja California: Geological Society of America Bulletin, v. 81, p. 3323-3338.

Hoggatt, W. C., and Todd, V. R., 1977, Geologic map of the Descanso 7-1/2' quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 77-406, 1:24,000.

Miller, W. J., 1935, A geologic section across the southern Peninsular Ranges of California: California Journal of Mines and Geology, v. 31, p. 115-142.

Minch, J. A., and Abbott, P. L., 1973, Post batholithic geology of the Jacumba area, southeastern San Diego County, California: San Diego Society of Natural History, Transactions, v. 17, no. 11, p. 129-135.

Sharp, R. V., 1967, San Jacinto fault zone in the Peninsular Ranges of southern California: Geological Society of America Bulletin, v. 78, p. 705-730.

Strand, R. G., 1962, Geologic map of California, Olaf P. Jenkins edition, San Diego-El Centro sheet, California Division of Mines and Geology, scale 1:250,000.

Todd, V. R., 1977a, Geologic map of Agua Caliente Springs quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 77-742, 1:24,000.

_____, 1977b, Geologic map of Cuyamaca Peak 7-1/2' quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 77-405, 1:24,000.

_____, 1978, Geologic map of the Monument Peak quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 78-697, 1:24,000.

Weber, F. H., Jr., 1963, Geology and mineral resources of San Diego County, California: California Division of Mines and Geology County Report 3, 309 p.

_____, 1975, Character and recency of movement along the Elsinore and Chino fault zones in northwestern Riverside County, California: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 386.

_____, 1977, Total right lateral offset along the Elsinore fault zone, southern California: Geological Society of America Abstracts with Programs, v. 9, no. 4, p. 523-524.

Woodard, G. D., 1963, The Cenozoic succession of the west Colorado Desert, San Diego and Imperial Counties, southern California: University of California, Berkeley, Ph.D. Thesis, 173 p.

_____, 1974, Redefinition of Cenozoic stratigraphic column in Split Mountain Gorge, Imperial Valley, California: American Association of Petroleum Geologists Bulletin, v. 58,p. 521-526.

Woodring, W. P., 1932, Distribution and age of the Tertiary deposits of the Colorado Desert: Carnegie Institution of Washington Publication 148, p. 1-25.

ACKNOWLEDGMENTS

I wish to thank the San Diego County Department of Parks and Recreation for allowing our field party to use the Agua Caliente Springs County Park as homebase, and the rangers there for their help and friendly interest. I am especially grateful to Vicki Todd for her encouragement and aid, and for making this study possible. I also thank Kate Foley, ranger of the Anza-Borrego State Park. Jack Hillhouse assisted me in the field during parts of the study.

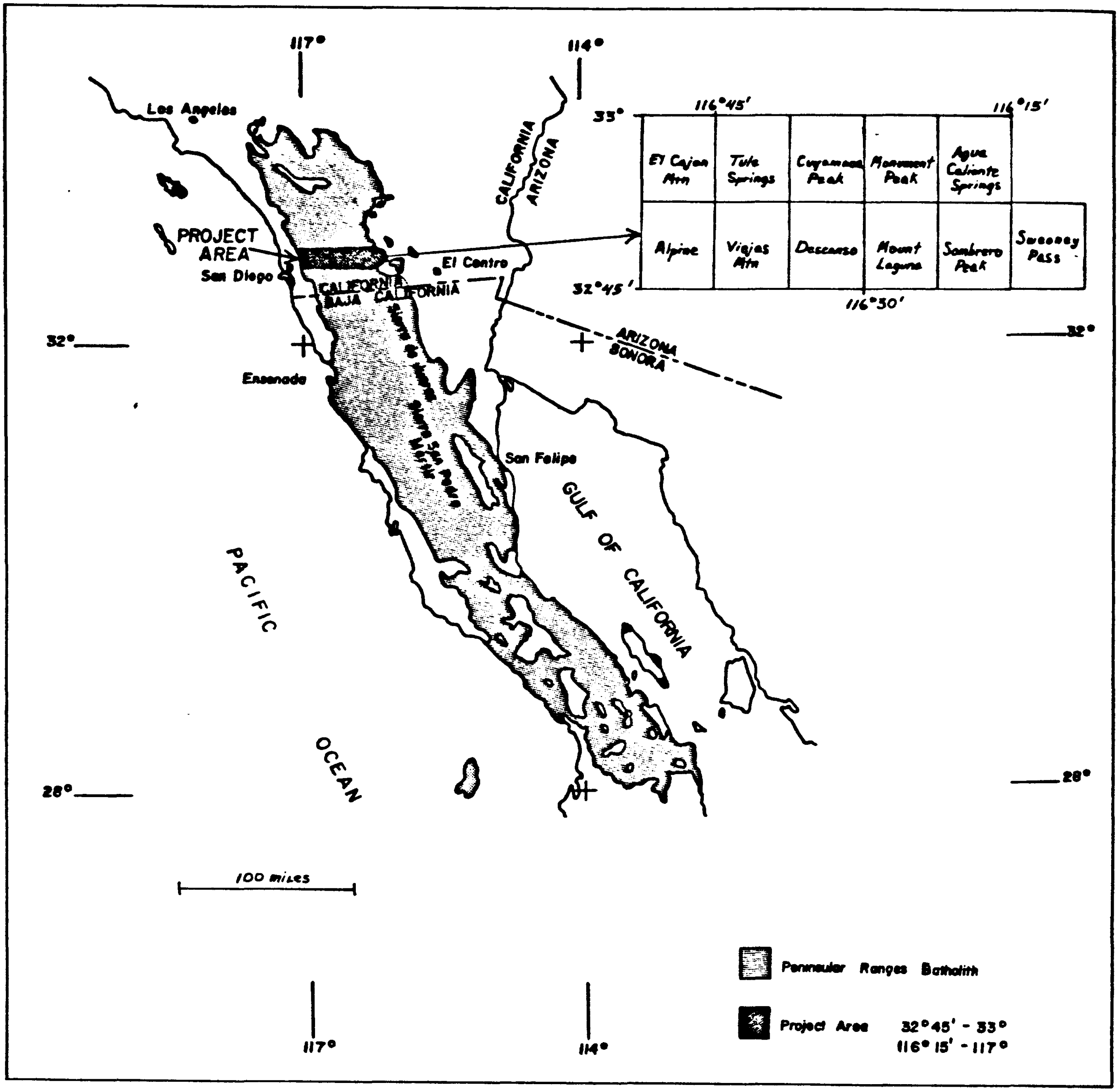


Figure I. Peninsular Ranges batholith in southern California and Baja California and project area.

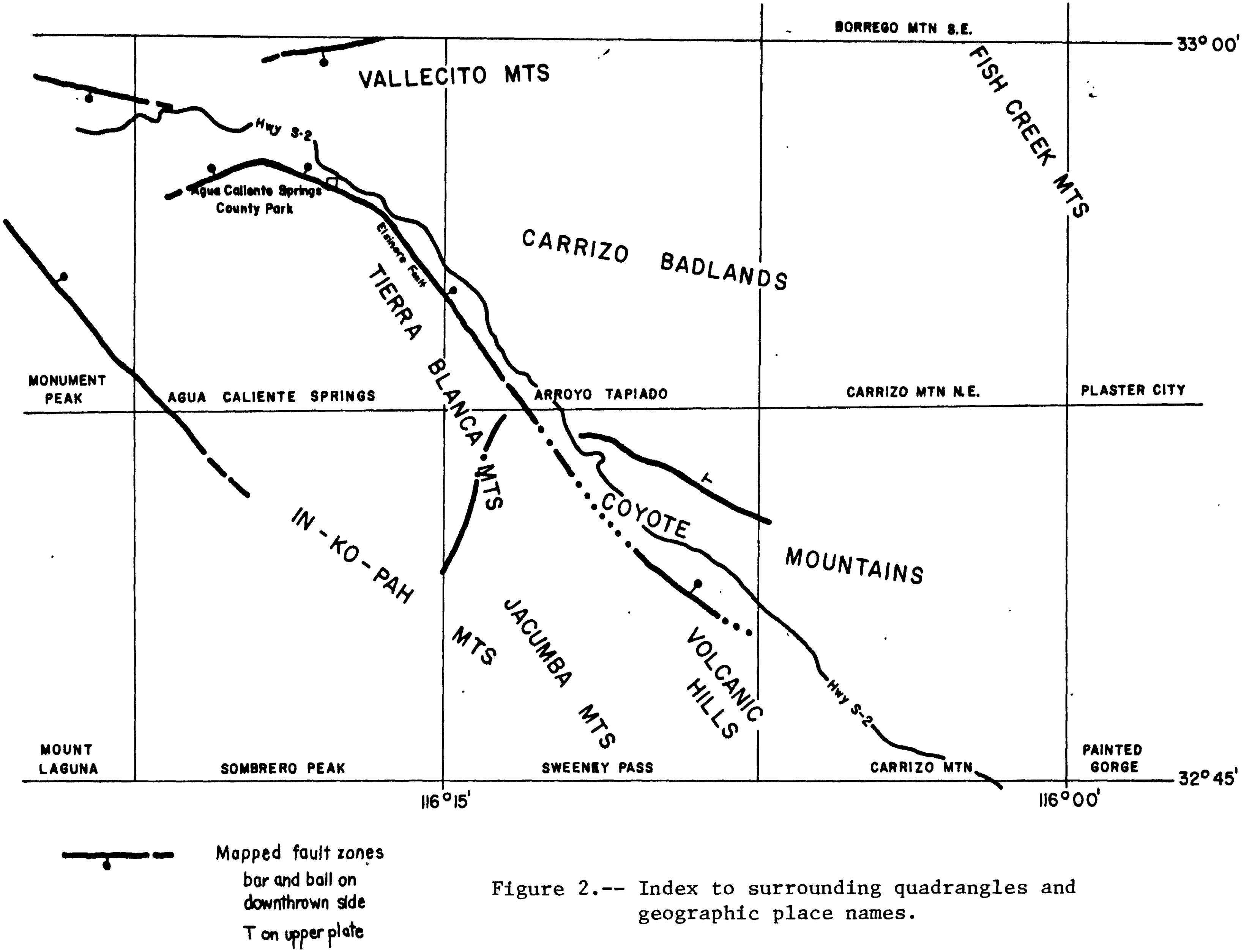


Figure 2.-- Index to surrounding quadrangles and geographic place names.

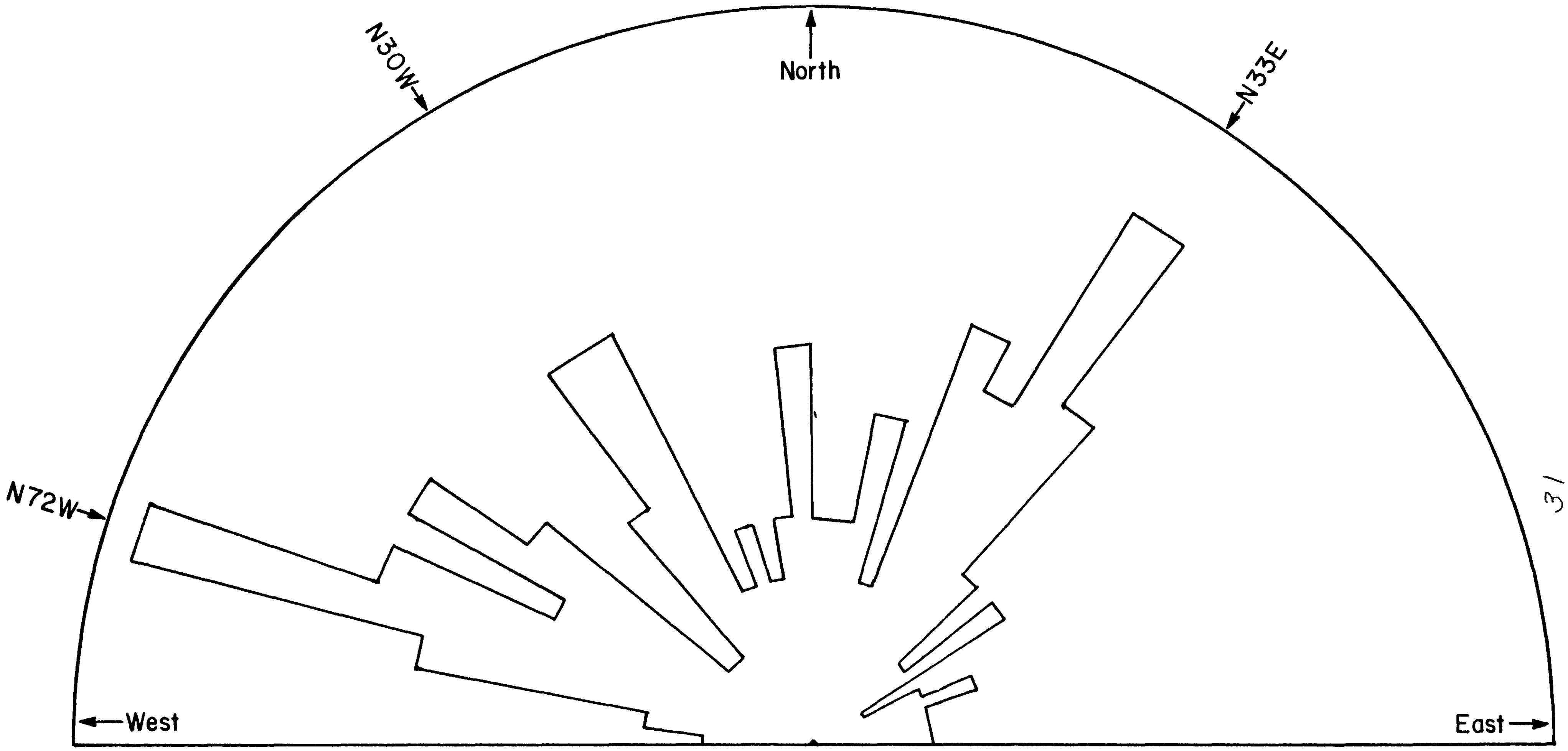


Figure 3a: Strikes of 170 measured fault planes, Sweeney Pass quadrangle. Rose diagrams are used only to display data. They are not meant to imply statistical accuracy.

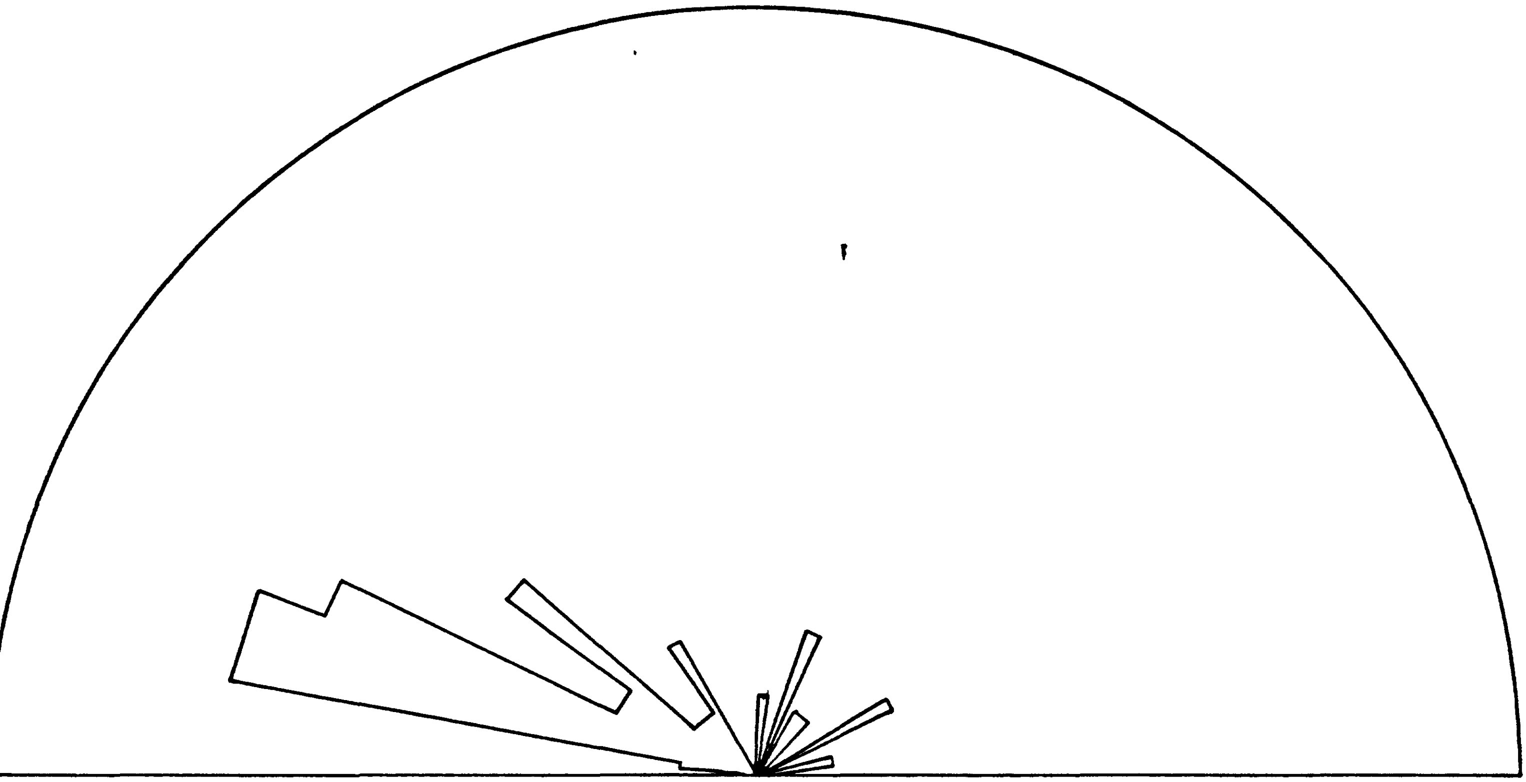


Figure 3b: Strikes of 45 measured fault planes which cut Mesa Conglomerate (Qm).

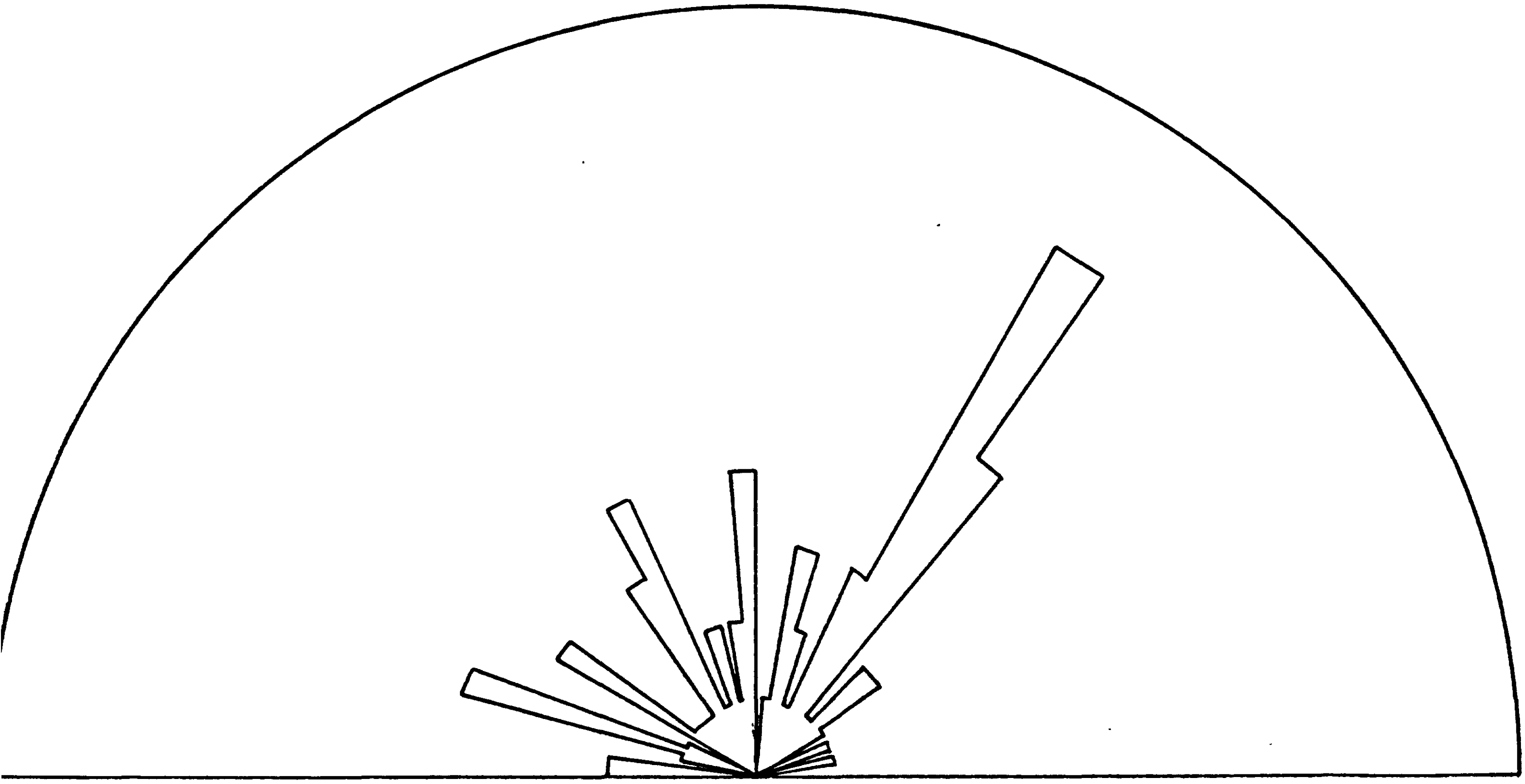
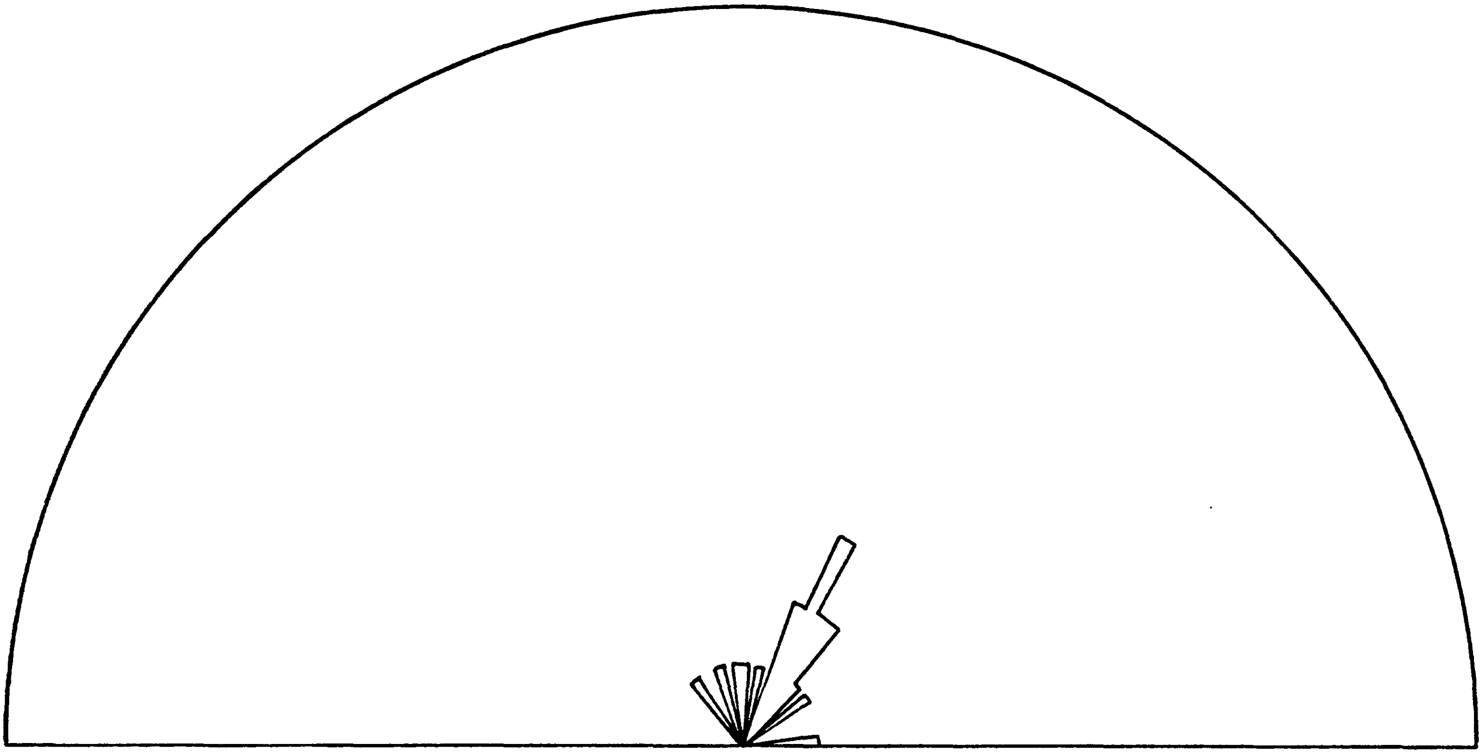
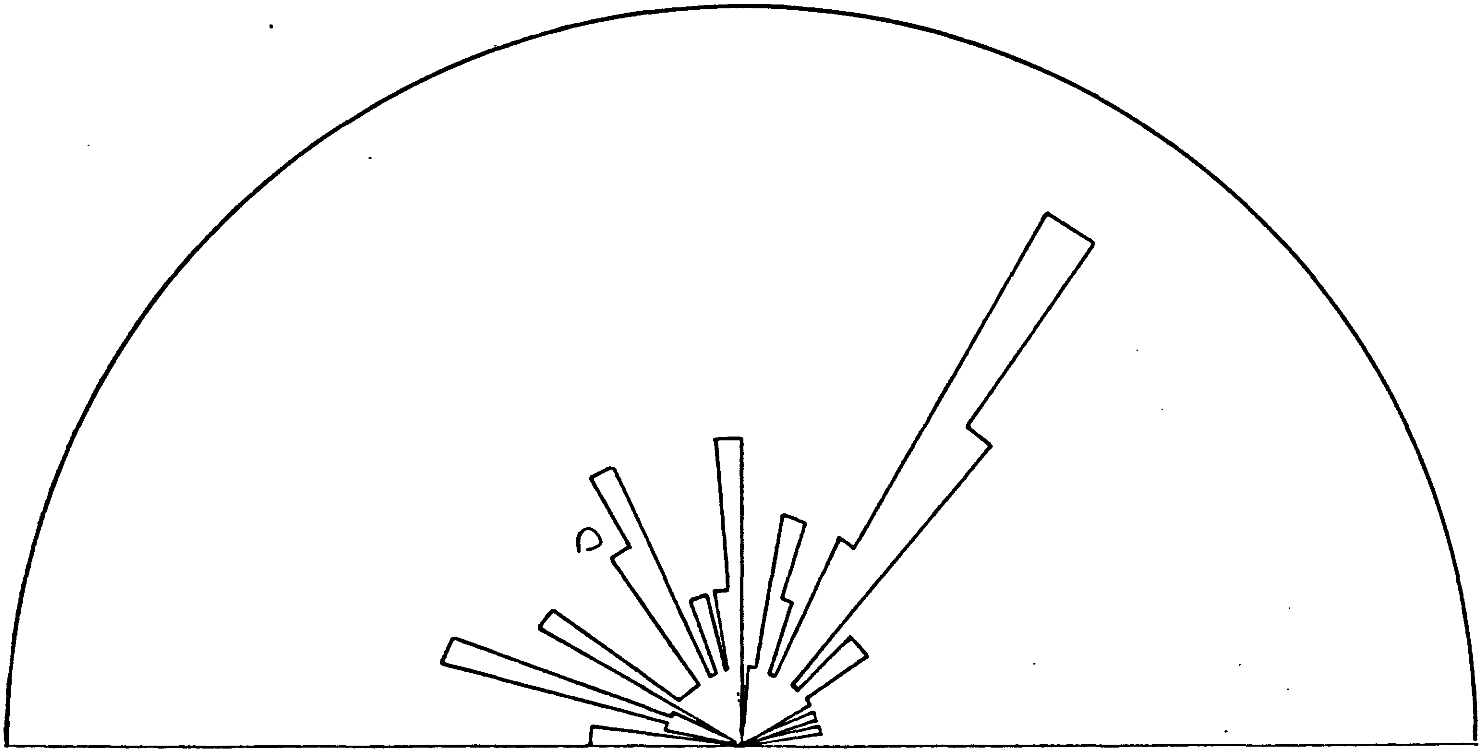


Figure 3c: Strikes of 37 measured fault planes which cut Cretaceous or older bedrock but show ambiguous or no evidence of cutting younger rocks.



<u>Figure 3d:</u> Strikes of 17 fault planes which cut Cretaceous or older bedrock but do not cut Mesa Conglomerate.



<u>Figure 3c</u>: Strikes of 37 measured fault planes which cut Cretaceous or older bedrock but show ambiguous or no evidence of cutting younger rocks.

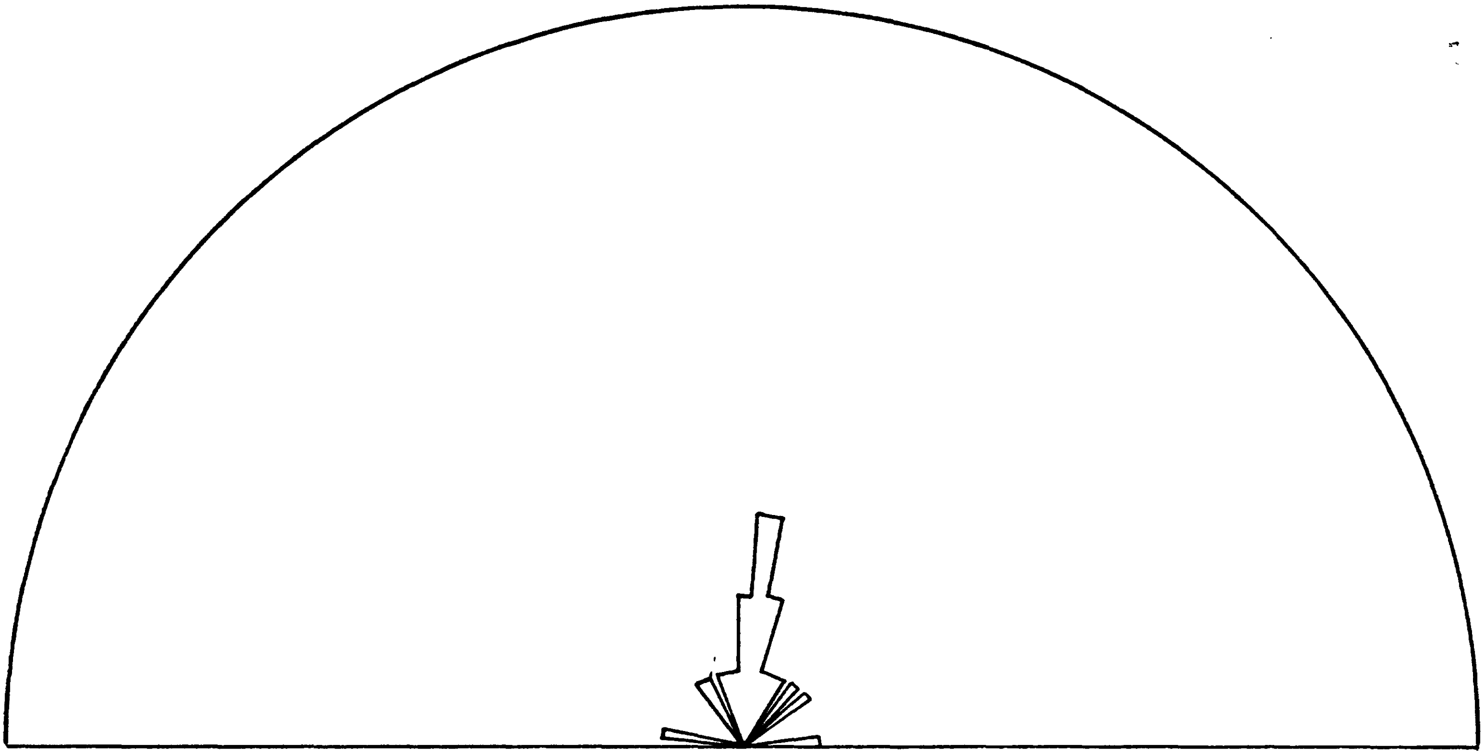


Figure 3e: Strikes of 20 fault planes which cut Alverson Andesite but show ambiguous or no evidence of cutting younger rocks.

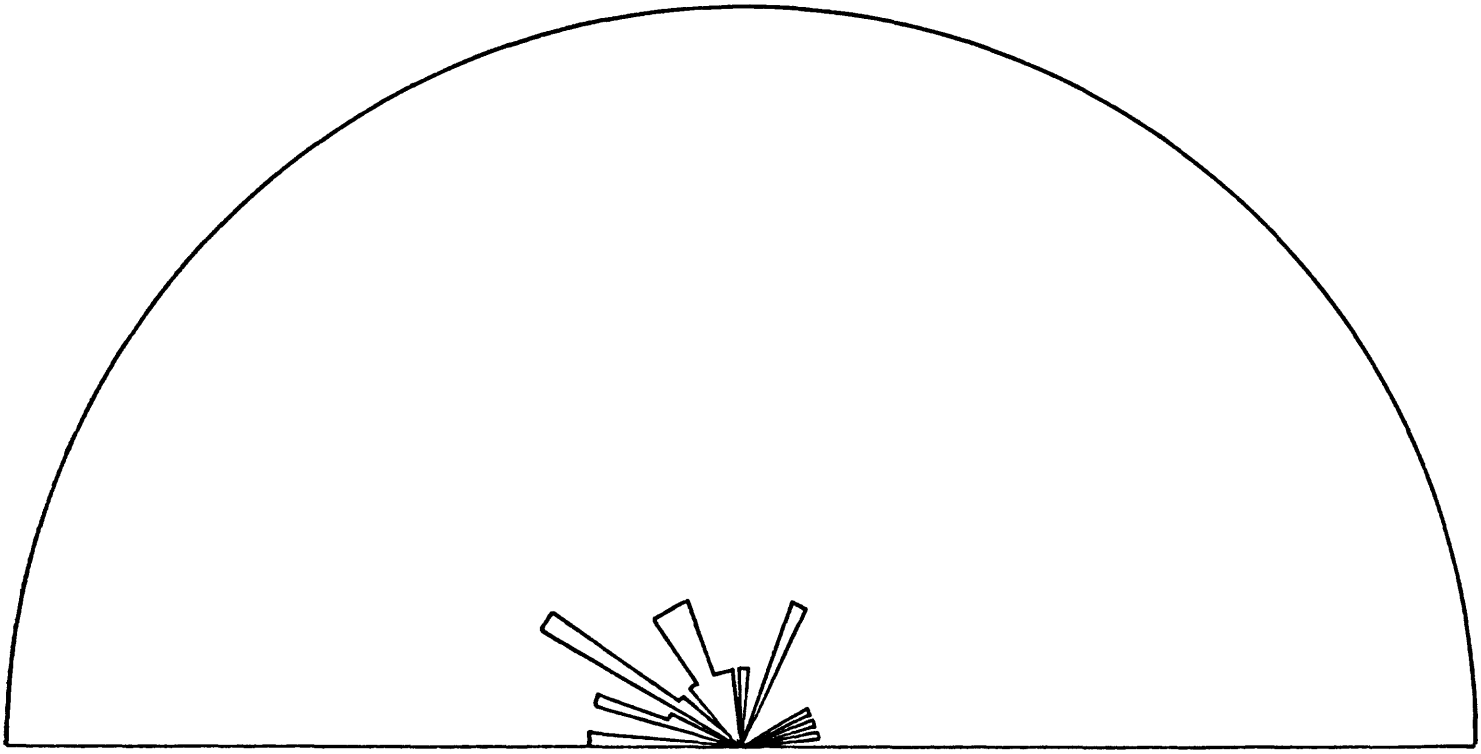


Figure 3f: Strikes of 25 fault planes which cut Palm Spring Formation but show ambiguous or no evidence of cutting younger rocks.

Table 1.--Recalculation of K-Ar ages using new decay and abundance constants

Reference	Mineral	Reported Age	Recalculated Age	λ_{ε} (yr.$^{-1}$)	$\lambda_{\varepsilon'}$ (yr^{-1})	λ_{β} (yr^{-1})	K^{40}/K_{total} (mole/mole)
1)	whole rock	18.7±1.3 m.y.		0.585x10^{-10}		4.72 x10^{-10}	1.22x10^{-4}
this study			19.2 m.y.	0.572x10^{-10}	8.78x10^{-3}	4.963x10^{-10}	1.167x10^{-4}
2)	hornblende	18.5±0.9 m.y.		- not reported -			
this study			19.0 m.y.	0.572x10^{-10}	8.78x10^{-3}	4.963x10^{-10}	1.167x10^{-4}
	plagioclase	18.6±0.8 m.y.		- not reported -			
this study			19.1 m.y.	0.572x10^{-10}	8.78x10^{-3}	4.963x10^{-10}	1.167x10^{-4}

References:

1) Hawkins, J. W., 1970, Petrology and possible tectonic significance of late Cenozoic volcanic rocks, southern California and Baja California: Geological Society of America Bulletin, v. 81, p. 3323-3338.

2) Minch, J. A., and Abbott, P. L., 1973, Post-batholithic geology of the Jacumba area, southeastern San Diego County, California: Transactions of the San Diego Society of Natural History, v. 17, no. 11, p. 129-135.

Table 2.--K-Ar Age of a Basalt Sample, Sweeney Pass quadrangle

Sample no.	Mineral Dated	Calculated Age	Lat.	Long.
WSP-79	whole rock basalt	16.9±0.5 m.y.	32°48'09"	116°10'47"

K_2O=2.452, 2.492, 2.482, 2.458; $*Ar^{40}=6.032\text{x}10^{-11}$mole/gm; $*Ar^{40}/\Sigma Ar^{40}=72.9\%$.

Potassium analyses were performed by Sarah T. Neil by flame photometer using lithium metaborate fusion. Argon was analyzed by standard isotope dilution techniques; the author was the analyst. The uncertainty in reported age (± 3%) represents only analytical uncertainty at one standard deviation.

Constants used in the calculations are $\lambda_\varepsilon=0.572\text{x}10^{-10}\text{year}^{-1}$; $\lambda_{\varepsilon'}=8.78\text{x}10^{-13}\text{year}^{-1}$; $\lambda_\beta=4.963\text{x}10^{-10}\text{year}^{-1}$; and $K^{40}/K_{total}=1.167\text{x}10^{-4}$mole/mole.