UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGIC MAP OF MOUNT LAGUNA QUADRANGLE, SAN DIEGO COUNTY, CALIFORNIA

By

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This report is preliminary
and has not been edited or
reviewed for conformity with
Geological Survey standards
and nomenclature.

Geologic map of the Mount Laguna quadrangle, San Diego County, California

Purpose of project:

Published maps indicate that rocks of the Peninsular Ranges batholith in southern 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 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 age, magnitude and direction of displacement of faults within the block and along its eastern margin (Elsinore fault zone) are being evaluated. The primary product of the project is a number of geologic maps at a scale of 1:24,000. Mapping of the bedrock geology of the batholith is an important part of the project because available geologic maps are not detailed enough for determination of fault displacements. Other maps in the series include the Cuyamaca Peak, Descanso, Agua Caliente Springs, Viejas Mountain and Monument Peak quadrangles.

Introduction:

The Mount Laguna 7-1/2' quadrangle lies within the mid-Cretaceous Peninsular Ranges batholith of southern California and Baja California (fig. 1). Twelve plutonic units have been distinguished within the project area and informal names have been assigned to avoid confusion with earlier nomenclature. About half of the twelve units were not recognized previously and published names for rock units in the study area commonly included several of these unrecognized units. The name Cuyamaca Gabbro (Everhart, 1951) has been retained. Other bedrock units consist of recognizable metasedimentary and metavolcanic rocks of uncertain age which occur as roof pendants and screens in the batholith and a migmatitic schist and gneiss unit derived in part from metasedimentary rocks.

Previous usage has been followed in referring to the twelve rock units as plutonic, even though most of the rocks in this part of the batholith have undergone significant synkinematic recrystallization. The plutonic rocks are gneissic and their foliation consists chiefly of the planar orientation of recrystallized mineral grains and aggregates (fig. 2). Gneissic textures include augen gneiss and mylonite gneiss. Petrographic study reveals igneous textures modified by strain at temperatures high enough for recrystallization to occur, indicating that the plutonic rocks have undergone solid-state flowage at elevated temperatures.

Foliation, where noted by earlier workers, was considered to be a primary igneous structure or protoclastic structure. Metamorphism of the wall rocks was thought to pre-date emplacement of the batholith in this area (Everhart, 1951). However, foliations and plutonic contacts commonly parallel or are co-planar with similar features in the prebatholithic wall rocks and together they form a regional tectonitic fabric. Although commonly concordant with plutonic contacts, foliation locally crosses contacts and, therefore, is in part younger than the intrusion of the igneous rocks. These findings indicate that in this part of the batholith plutons were emplaced during regional metamorphism and deformation and that deformation and recrystallization continued long after emplacement.

Nature of plutonic contacts:

Although an overall sequence of intrusion of major plutonic units has been worked out, these age relationships locally appear reversed, so that the older of two plutons has a chilled margin against the younger pluton, sends dikes into the younger pluton, and carries inclusions of it (fig. 3). Plutonic contacts were deformed during the regional deformation, with the result that both normal dikes (younger pluton of an intrusive pair into older) and anomalous dikes (older pluton into younger) have been stretched, intricately folded, and pulled apart so that they resemble inclusions. Whether they originated as stoped inclusions or dismembered dikes, blocks of one pluton in the other are increasingly rounded and assimilated away from the contact between the two plutons. The resulting contact relations may be extremely ambiguous in any one place, but over the entire mapped area, contact relations between any pair of plutonic units indicate the same relative age relation, with local mutual intrusion. The prevalence of mutual chilled margins and quenched dikes between two plutons (fig. 3) suggests a continuing or recurring liquidity in rocks which apparently had crystallized. Rock textures and field relations suggest that these contacts were deformed when plutons were solid but still hot and responding structurally in a ductile manner. Intricate contacts of the above type between two plutons conform to regional deformational structure requiring that parts of plutons responded both as magma and as solid rock over a relatively short time interval.

Rock units:

Bedrock units are discussed below and their overall intrusive sequence is depicted in Figure 4. Modal and normative data for the plutonic units is given in Figure 5. The following discussion is based in part upon observations of rock units and contact relations in the adjacent quadrangles, which are shown in Figure 1, but it is fully applicable to the Mount Laguna quadrangle. Bedrock units are overlain locally by unconsolidated Quaternary deposits.

Metamorphosed prebatholithic rocks:--Prebatholithic rocks within the project area occur in steeply dipping screens within and between plutons. Metasedimentary rocks with locally well-preserved turbidite structures are interlayered with minor amphibolite, probably metamorphosed mafic flows or tuffs. The proportion of calcareous sediment and volcanic material increases gradually westward. This report follows Everhart (1951) in tentatively assigning the prebatholithic rocks a Triassic age.

The predominant metasedimentary lithologies are quartzo-feldspathic, micaceous semischistose rock and schist, and pink and buff-weathering calcareous quartzite. The semischistose rock and schist contain thin (0.2 to 0.5 cm) quartzo-feldspathic metamorphic segregations which commonly have been folded isoclinally along with the schist. Pelitic schist is crowded with 1 cm grains of andalusite. The semischistose rock and quartzite typically are finely laminated and although sedimentary structures have been transposed, lamination is parallel to large-scale compositional layering that probably reflects original bedding (perhaps preserved in the limbs of undetected isoclinal folds). Where compositional layers have been preserved in the Laguna Mountains, they are on the order of 15 cm or less thick. Interlayered with these rocks is fine-grained, black amphibolite (locally with greenish-gray diopsidic layers), graphitic phyllite, minor amounts of green tremolite-epidote schist, minor clean white metaquartzite, and carbonate-cemented grit and pebble metaconglomerate.

The metasedimentary rocks are very similar in appearance and composition to those in the Cuyamaca Mountains to the west (fig. 1). They appear to have originated as thin-bedded, impure calcareous siltstone, sandstone, and shale interbedded with mafic flows and/or tuffs.

Cuyamaca Gabbro:--The name Cuyamaca Gabbro was applied by Everhart (1951) to the mafic body in the Cuyamaca Mountains. He assumed that all of the large mafic bodies (Guatay Mountain, Viejas Mountain, Poser Mountain) in south-central San Diego County were coeval, and data of the present study support this interpretation. These bodies, consisting of peridotite, olivine gabbro, hornblende gabbro, and norite were considered by Everhart to post-date the granitic plutons in the northern part of the Cuyamaca Peak quadrangle, but in this study gabbro has been found to be the oldest plutonic rock. Because the granitic intrusive bodies form sheets in gabbro, it is difficult to determine which rock is older from map relations at any one locality. However, relations over a large area show that many of the gabbroic bodies are screens and lensoid bodies surrounded by sheeted complexes of younger granitic rocks. Discontinuous screens locally as thin as one meter or less occur between Kcr and Klb plutons in the Mount Laguna quadrangle (sections 16 and 21, R. 5 E., T. 16 S.). Thus, the present outlines of gabbroic bodies and their distribution do not necessarily reflect either the original extent of gabbro or the original shapes of gabbroic plutons.

The Cuyamaca Gabbro appears to be deformed and recrystallized. Much gabbro observed is strongly foliated and in most cases apparent primary compositional layering is parallel or near-parallel to the foliation of recrystallized mineral aggregates. Locally, a second foliation which also consists of recrystallized mineral aggregates has been superposed on the first. Along margins, foliation in the gabbro is concordant with regional foliation. Internal foliation is more complex--it may parallel regional foliation or show swirling patterns, possibly because of the presence of more than one foliation. Foliation within the gabbro appears to have formed at least in part by solid-state flow.

One reason for ambiguity over the relative age of Cuyamaca Gabbro is that locally the unit has fine-grained and porphyritic margins next to younger granitic plutons. Thin sections of gabbro from these margins show relict chilled igneous textures modified by recrystallization. These rocks are commonly associated with zones of intrusion breccia between gabbro and granitic plutons consisting of variably rounded blocks of fine-grained, porphyritic gabbro in a matrix of chilled, contaminated granitic rock. Orbicular gabbro occurs in these zones locally. In other places, contacts between gabbro and granitic plutons are sharp and the granitic plutons send dikes into gabbro. Both types of contact may occur together in a relatively small area.

The intrusion breccia zones are strongly deformed parallel to the regional foliation and they grade into highly contaminated margins of granitic plutons which contain abundant, large, fine-grained gabbro inclusions. Inclusions of metasedimentary rock occur in some intrusion breccia zones between gabbro and granitic plutons, but there are many places where no metasedimentary rocks appear to be involved and where grain size of gabbro decreases systematically toward contacts with granitic plutons.

Fine-grained gabbro dikes emanating from gabbroic plutons cut the intrusion breccia zones surrounding most of the large gabbroic bodies in the project area. Such dikes also cut units as young as the granite of Pine Valley (Kpv). This suggests that parts of the gabbroic plutons remained liquid after younger, granitic plutons had solidified. In many places, fine-grained gabbroic bodies appear continuous with, or cannot be distinguished in the field from, the fine-grained and porphyritic mafic dikes (Kmd) which cut all units. All of these dikes may in fact be late differentiates of the parent magma of the Cuyamaca Gabbro.

The linear, north-northwest-striking gabbro bodies in the western part of the Mount Laguna quadrangle are directly on strike with larger gabbro bodies in the Cuyamaca Mountains, but are not connected with them at the surface. The western margin of the Mount Laguna body is indistinct, because gabbro appears to be interlayered with granitic rock on a fine scale and heterogeneous mixed rocks occur near contacts. The northern and interior parts of the body are medium- to coarse-grained gabbro which gives way southward to hybrid mafic rocks that resemble parts of Kem plutons (see explanation) (and locally contain discrete, rounded gabbro inclusions) and to a system of large, fine-grained mafic dikes. Thus, the margins and "tail" of this small pluton of "normal" gabbro appear to have reacted extensively with surrounding granitic rocks, in part at a later time than the initial emplacement of both gabbro and granitic plutons.

Tonalite of Las Bancas:--The widespread tonalite unit called by previous workers Green Valley tonalite, after F. S. Miller (1937) has systematic compositional, textural and structural variations. The unit includes rocks formerly called Bonsall tonalite because of the presence of mafic inclusions (Hurlbut, 1935), but the inclusion-bearing tonalite is fully gradational into so-called Green Valley tonalite. The informal name, tonalite of Las Bancas (Klb), was given to one of the compositional and textural varieties, the first encountered in this study, which underlies the Las Bancas plateau southeast of Descanso (Descanso 7-1/2' quadrangle, Hoggatt and Todd, 1977) and this usage is followed here. This rock is dark gray on fresh surfaces, weathers to a reddish or buff-gray color, and typically forms extensive low bouldery outcrops. The rock is homogeneous and virtually inclusion-free. Typically it carries 1 cm poikilitic biotite or hornblende grains. Within the project area, Klb has a fine-grained margin against Cuyamaca Gabbro in a few places and it is intruded by the granodiorite and tonalite of Cuyamaca Reservoir (Kcr), the granite of Chiquito Peak (Kcp), the tonalite of Granite Mountain (Kgm), the granite of Corte Madera (Kcm) (probably a leucocratic facies of the granite of Pine Valley), and by fine-grained and porphyritic mafic dikes (Kmd).

The Las Bancas-type tonalite is a fine- to medium-grained weakly gneissic rock, approximately equigranular, with lenticular recrystallized mafic aggregates. The rock has 15-20 percent quartz, traces of K-feldspar, relict zoned phenocrysts of andesine to labradorite, and a color index ranging from 25-30 percent. Locally, in some cases next to gabbro, the tonalite is more mafic and contains less than 10 percent quartz and a plagioclase as calcic as bytownite. Thus, some of the Las Bancas-type rock is quartz gabbro according to the classification of Streckeisen (1973), but these rocks are petrographically similar to the tonalite and there is a complete gradation between quartz gabbro and tonalite. Most samples contain chiefly pyroxene and biotite, with the hornblende occurring as sparse, narrow rims on corroded pyroxene cores and both pyroxene and hornblende poikilitically enclosed by biotite. The reaction sequence of the mafic assemblage is opx -> cpx -> olive green hornblende -> yellowish-brown biotite. These igneous reaction textures have been modified by recrystallization.

The large Klb pluton which underlies most of the Mount Laguna quadrangle consists of Las Bancas-type rock with a marginal phase of coarser-grained, less mafic, more foliated tonalite. The marginal facies has large lenticular mafic grains and aggregates and contains both hornblende and biotite, locally with scattered larger biotite or hornblende grains giving it a near-porphyritic texture. Rusty-weathering spots are common. Sparse inclusions in the marginal facies are commonly large ($\sim$30 cm) rounded blocks of Las Bancas-type tonalite. Mafic inclusions are exceedingly sparse in the darker, finer-grained central part of the pluton (Klb). Where lighter colored rock occurs within the pluton, it is associated with minor TRm and Kc inclusions. The distribution of the marginal facies of Klb is indicated by a stippled pattern on the geologic map. Along the southeastern margin of the pluton, the marginal facies interfingers with Kcr, which it greatly resembles at the contact. Away from the contact, the two rocks can be distinguished readily. This relationship is discussed further below.

A third variety of tonalite, the Japatul-type (Klbj) (named after Japatul Valley in the Viejas Mountain quadrangle, fig. 1 and Todd, 1978a), occurs in the southwestern corner of the Mount Laguna quadrangle, in a complex zone composed of thin, steeply dipping sheets composed of most of the units in the project area. Elsewhere the Japatul facies is an extensive rock which grades into Las Bancas-type tonalite but is partly separated from it by screens of Kc and ℞m. The tonalite of Japatul Valley is distinctly different from the Las Bancas rock. It is lighter in color, less mafic, and its abundant mafic inclusions are typically weathered out in relief. They may be large and irregular in shape, or streamlined parallel to foliation. Many inclusions are fine-grained, but some are peppered with subhedral plagioclase grains and a few are gabbroic. Large inclusions of Las Bancas-type tonalite are fairly common. Characteristic of the rock are single subhedral plagioclase (An 42-48) and hornblende grains, although recrystallized mafic aggregates also occur. The tonalite is medium- to coarse-grained, distinctly equigranular, and the subhedral grains give it a more igneous-appearing texture than that of the Las Bancas or marginal varieties. However, the rock is strongly foliated and the subhedral grains are alined parallel to the regional foliation.

Granodiorite and tonalite of Cuyamaca Reservoir:--The granodiorite and tonalite unit of Cuyamaca Reservoir (Kcr) weathers to distinctive reddish and yellowish-brown colors and is light to dark gray on fresh surfaces depending upon the mafic content, which ranges from 14-29 percent. Where the unit is in contact with Kc, it consists of more mafic tonalite and contains abundant fine-grained mafic inclusions that are flattened parallel to foliation. Although grading from tonalite to granodiorite, the unit is texturally homogeneous--fine to medium-grained, very gneissic and, on the average, more deformed than the other plutonic units. In thin section, the granodiorite and tonalite unit of Cuyamaca Reservoir shows some of the most strained and recrystallized igneous textures in the region.

The granodiorite and tonalite unit of Cuyamaca Reservoir contains andesine (one sample has plagioclase An 37 as determined by electron microprobe), greatly modified by recrystallization, and pale reddish-brown biotite. Some samples contain no hornblende, others show a few hornblende relicts within biotite aggregates, but in most rocks intergrowths of actinolite and epidote have replaced hornblende. The chief accessory minerals are allanite and sphene. The mineralogical and textural differences between the granodiorite and tonalite unit of Cuyamaca Reservoir and other granitic units may be related to intimate mixing of the former with metasedimentary rocks. The unit is especially gneissic and is locally porphyroclastic and mylonitic next to large bodies of metasedimentary rock where it contains abundant partly assimilated inclusions of metasedimentary rock and is rich in mica. Fine-grained granodiorite and tonalite may grade into hybrid gneiss (Khc) which locally occurs as sheets between the granodiorite and tonalite unit and metasedimentary rocks.

The granodiorite and tonalite unit of Cuyamaca Reservoir locally has chilled margins against and sends dikes into Cuyamaca Gabbro. Contact relations between the granodiorite and tonalite unit (Kcr) and the tonalite of Las Bancas (Klb) have been observed over a wide area, and are summarized below. They suggest that Kcr is partly older than, partly coeval with, and partly later than, Klb.

1. Contact schlieric, interfingering; both rocks are texturally similar and compositionally similar, but Kcr is brown to orange-weathering and Klb is pinkish gray-weathering. Locally, they appear gradational.
2. Contact schlieric, interfingering, Kcr tends to be finer grained (fine to medium) next to Klb, and more leucocratic, Kcr sheared (porphyroclastic); Klb texturally unchanged right up to contact.
3. Neither rock shows textural change; they are separated by thin (locally <1 m) screens of Cuyamaca Gabbro, gabbro intrusion breccia,

or metasedimentary rock (TRm). (Kcr has inclusions of TRm; Klb does not).

4. Kcr occurs as large fine-grained dikes in Klb and as schlieric inclusions.

5. Contact relatively sharp; Klb texturally unchanged up to contact; Kcr also unchanged but occurs as blocky inclusions in Klb margins. This relation suggests that Kcr may be locally older in part than Klb, or the inclusions may be synplutonic in origin.

6. Dark gray-weathering fine-grained tonalite dikes (Klb ?) have been seen in Kcr in one place along the contact between the large Klb pluton in the Mount Laguna quadrangle and Kcr.

In that part of the Monument Peak quadrangle which lies within the western Colorado Desert, the tonalite mapped as Kt_2 in the Agua Caliente Springs quadrangle (Todd, 1977a) was found to consist of both Klb and Kcr, with the rocks either so intimately interlayered that they could not be mapped separately, or with Kcr concentrated along the contacts of the tonalite of Las Bancas with metasedimentary rocks. This is probably also the explanation of the compositional variations in Kcr in the Cuyamaca Mountains (granodiorite to tonalite; 14-29% mafic minerals). Kcr may be a comagmatic marginal facies of the Klb tonalite and the greater degree of deformation and deuteric alteration of the former may be the result of shearing against water-rich metasedimentary wallrocks.

Hybrid gneiss of Harper Creek:--The hybrid gneiss of Harper Creek (Khc) is a gray and yellow-weathering, cordierite-sillimanite-bearing, quartz-biotite-plagioclase-K-feldspar/muscovite gneiss. The unit, which is remarkably homogeneous over large areas, includes rocks that closely resemble Kcr as well as rocks that are clearly metasedimentary in origin. Khc contains abundant metasedimentary inclusions, up to several meters in length, as well as evenly and closely spaced micaceous lenses, several centimeters long, the latter locally grading into ghostly metasedimentary inclusions.

Study of thin sections indicates that the rock has undergone virtually complete recrystallization while being strained (synkinematic metamorphic texture). A few plagioclase grains retain delicate oscillatory zoning and locally, K-feldspar grains enclose small, early, subhedral plagioclase phenocrysts but typically, relict textures are lacking and the hybrid gneiss is too rich in quartz and mica to be a straightforward metaigneous rock. K-feldspar has been converted to muscovite in many samples.

The hybrid gneiss is not migmatite, although migmatite does occur locally at contacts with metasedimentary rocks (TRm) and with the granodiorite and tonalite of Cuyamaca Reservoir (Kcr). Contacts between hybrid gneiss and metasedimentary rocks may be sharp, or may be marked by alternating layers of Khc and TRm that are too small to be depicted at the map scale. Contacts between Khc and Kcr may be gradational or sharp. Where they are gradational, Kcr may be 1) fine-grained, containing abundant partly assimilated inclusions of TRm, or 2) coarse-grained, sub-pegmatitic, leucocratic and full of TRm inclusions and biotitic lenses. These rocks are interpreted as margins and/or dikes of Kcr plutons which were originally in contact with metasedimentary rock. Elsewhere, Kcr is interlayered with Khc near the contact. In a few places, Khc has intruded other plutons which indicates that the rock was locally as mobile as the plutonic units.

The abundant metasedimentary inclusions, presence of cordierite and sillimanite, and the high proportion of quartz and mica attest to the rock's partial sedimentary origin. Local relict igneous textures and gradation into Kcr indicate that the Khc unit originated by mixing of Kcr and TRm enhanced by deformation and metamorphic temperatures that existed over a considerable period of time probably both before and after emplacement of Kcr. Whatever the origin of this unit may be, it is always spatially associated with Kcr and TRm and for this reason, is probably essentially coeval with Kcr.

Migmatitic schist and gneiss:--In the Laguna Mountains and western part of the Colorado desert, a separate unit of migmatitic schist and gneiss (Km), contains rocks which fall between TRm and Khc. These rocks contain migmatitic metasedimentary schist, and Khc-type gneiss in a variety of contact relationships, as well as TRm quartzite and amphibolite as discrete layers, lenses and boudins. Limited outcrops of these rocks were seen in the Cuyamaca Mountains to the west where they were mapped with TRm or Khc. However, in the Monument Peak quadrangle and to a lesser extent in the Mount Laguna quadrangle, they underlie relatively large areas of outcrops between homogeneous Khc and typical TRm. Although to some extent this is a "wastebasket" unit (especially where the terrane is very brushy and steep), Km forms a fairly discrete outcrop band which may help in delineating the overall structure.

In traverses from TRm toward Khc through zones that vary from 0.1 km to 1 km, the schist in TRm becomes more segregated, migmatitic and abundant, with the more refractory quartzite and amphibolite occurring as screens, lenses, or boudins in the migmatitic rocks. This distribution of rocks gives way to a zone in which large migmatitic schist inclusions are embedded or suspended in Khc, which in turn changes to Khc with small schist inclusions, and finally, to Khc with micaceous spots. Locally, the segregation layering in the migmatitic schist widens and grain size becomes coarser until the texture is that of a gneiss. Elsewhere, recognizable TRm and Khc alternate over distances of only a few meters, and since these areas strike into the gradational type, they have also been mapped as Km.

Tonalite of Granite Mountain:--The tonalite of Granite Mountain (Kgm) is a distinctive rock that occurs in the Julian quadrangle, where it underlies parts of Granite and Chariot Mountains; in the southern part of the Mount Laguna quadrangle; and as far west as the Alpine quadrangle (fig. 1). Tonalite of this type also comprises the northernmost part of rocks mapped as Kt_2 in the Monument Peak quadrangle.

Outcrops are white due to white-weathering, euhedral to subhedral plagioclase and locally white-weathering quartz. Abundant hornblende prisms in a range of sizes up to 2 cm long are most diagnostic. Hornblende grains tend to be stubby or quite blocky (1 x 2 cm) rather than acicular. Biotite content is variable, but in general biotite is sparse and grains are small and appear recrystallized. Small subhedral grains are seen locally. The texture of the rock is typically idiomorphic, although in some areas it has been deformed and recrystallized to a considerable degree and the texture is then similar to that of older plutonic gneisses. However, even rock which has retained its igneous texture is well foliated, due to alignment of subhedral hornblende grains and biotite aggregates. Quartz is medium-grained, but 1 cm recrystallized lenticular grains or aggregates are seen locally. Mafic content is variable. Flattened and aligned mafic inclusions, some obviously gabbroic, are locally abundant. Rarely, sphene grains are large enough to be obvious in outcrop.

In thin section, the tonalite shows relict igneous texture with a widely varying degree of modification by strain and recrystallization. The rock consists of plagioclase (An 41 to 49), stubby pale brown and greenish-tan hornblende, dark reddish-brown biotite, and fine-grained, recrystallized sphene after biotite and hornblende. No K-feldspar has been seen. Some relict phenocrysts of sphene are more than 1 mm across. In some samples, hornblende contains large hypersthene cores with relict euhedral shapes, and the hornblende is jacketed by biotite. Biotite after pyroxene reaction pairs are also seen.

The tonalite of Granite Mountain is as widespread as the tonalite of Las Bancas; its full extent has not yet been mapped, and because of this, and the textural differences resulting from varying degrees of deformation and recrystallization, assignment of all occurrences of this rock to a single unit is still considered tentative. Where its texture is idiomorphic, Kgm has many features in common with rocks of the La Posta lithology (see section on Kt_1), the latter varying considerably in ratio of biotite to hornblende and in degree of deformation. Indeed, parts of plutons called Kgm in the project area were considered part of the La Posta tonalite by some workers. It was noticed early in the present study that Kgm bears a strong field and petrographic similarity to the Japatul facies of the tonalite of Las Bancas. Mapping thus far, largely outside the Mount Laguna quadrangle, tends to confirm the close relationship between Kgm and La Posta tonalite on the one hand, and between Kgm and the Japatul-type tonalite on the other. Kgm occurs as an envelope of variable thickness around La Posta plutons, lying between La Posta tonalite and Japatul-type tonalite. The contact between La Posta tonalite and the more mafic, hornblende-rich Kgm is both gradational and abrupt, the latter occurring where La Posta and Kgm are interlayered over a distance of a few meters. Contacts between these layers are sharp to indistinct, and layering is typically schlieric. A few dikes of La Posta in Kgm are seen in these zones. Kgm contains inclusions of a type previously seen only in La Posta plutons--rhythmically layered, pseudograded schlieren composed of coarse-grained, idiomorphic leucocratic and mafic rock whose overall mineralogy is the same as that of Kgm. In the western part of the project area, at lower elevations, La Posta and Kgm plutons are deeply weathered, covered by brush and the contact is not well exposed. However, it can be mapped approximately as an overall change from broad, flat, shield-like white outcrops of La Posta to pale grayish-white, rounded oblong boulders of disintegration of Kgm resembling vertical pillars.

The contact between idiomorphic Kgm and the Japatul facies of Klb is gradational. The chief difference is in the degree of recrystallization (and strain) modifying the igneous texture. The Japatul-type tonalite is the least deformed of the granitic plutons, excluding Kgm and La Posta tonalite, and in outcrop, there are many textural similarities between Kgm and Japatul-type tonalite. Thus there seems to be a spatial progression from deformed hornblende tonalite (Japatul facies) inward to less deformed, idiomorphic hornblende tonalite (Kgm), to moderately foliated La Posta tonalite to weakly deformed or undeformed La Posta leucotonalite. Kgm and Kt_1 plutons appear to be younger than Klb, perhaps emplaced when deformation had waned.

In the Mount Laguna quadrangle, Kgm intrudes Kcr and the marginal facies of the large Klb pluton. Large dikes of Kgm extend into Kcr, and locally slices of TRm, Kc, Kem and marginal Klb occur between Kcr and Kgm. Pegmatitic dikes with euhedral mafic grains appear to emanate from the Kgm pluton and intrude marginal Klb and Kcr. Although Kcr, marginal Klb and the slices of other rocks are highly deformed and mixed along the contact, only the very edge of the adjacent Kgm pluton is infolded and mixed with the slices of TRm, etc. However, there are places along this contact where Kgm is orange-weathering and texturally so similar to Kcr, with which it is interlayered, that the two rocks cannot be distinguished. Here a contact can be drawn accurately only to within about 10 meters. Likewise, Kgm appears to grade locally into marginal Klb by a change in degree of recrystallization and increase in biotite content.

Limited exposures of Kgm in Cottonwood Valley are crossed by dikes of Kpv, and the rock carries gabbro inclusions, fine-grained mafic dikes (Kmd) and forms intrusion breccia at contacts with small gabbro bodies. Kgm also carries large round inclusions of mafic, Las Bancas-type Klb. The age relations among those plutonic units are shown schematically in Figure 4.

Granite of Chiquito Peak:--The granite of Chiquito Peak (Kcp) is a medium-grained, strongly foliated, light-weathering rock with color index ranging from 5-12 percent. The plagioclase feldspar is oligoclase (An 29 in one sample) with relict euhedral zoning and the mafic minerals are chiefly dark greenish-brown biotite which appears to be derived from reaction of dark green to brown hornblende. Both biotite and hornblende have recrystallized but igneous relicts are present. Prominent accessory minerals are sphene and allanite. The unit was emplaced as a series of steeply-dipping, interconnected sheets and lenses.

The granite of Chiquito Peak intruded older plutons intimately, chilled against them, and locally shows a high degree of contamination through assimilation of stoped inclusions. This is particulary true where granite is in contact with TRm , Kc, and Kem. The contamination and post-intrusive deformation have given rise to complex hybrid zones between these plutons. A contaminated granite category (dashed pattern) has been used elsewhere [Hoggatt and Todd (1977), Todd (1977b)] to designate parts of Kcp plutons which are particularly inclusion-rich and contaminated. These rocks are intimate mixtures of granite, granodiorite, and tonalite representing both contaminated granite and mafic inclusions which have been variably assimilated.

In a number of places within the project area, the Japatul-type tonalite (Klbj) grades into, and also is intruded by, more leucocratic rock which is texturally identical to the tonalite but ranges to granodiorite in composition. At some localities this rock has abundant flattened mafic inclusions, but at others they are absent. This leucocratic rock is only found in association with the Japatul facies and in particular, with metasedimentary injection migmatite zones. In the field the leucocratic Japatul rock is indistinguishable from, and probably identical to, contaminated Kcp (shown by dashed pattern in Kcp on

Cuyamaca Peak and Descanso geologic maps). In these two quadrangles, the Kcp inclusion-rich granodiorite grades into and locally is intruded by, uncontaminated Kcp granite.

This rock association is important because it suggests a genetic relationship between tonalite and granite magmas (Klb and Kcp). Klb and Kcp seem to be partly coeval but in part, Kcp is younger. Kcp consistently intrudes the more mafic Las Bancas-type tonalite and quartz gabbro. If the contaminated Kcp is re-interpreted as being part of the Japatul-facies of Klb, then Kcp plutons consist of relatively small, discrete bodies (such as Chiquito Peak) and large, schlieric, partly gradational dikes. These pluton shapes and age relations suggest a differentiated sequence. The metasedimentary zones may be remnants of screens that once separated closely-related pockets of differentiating magma.

A textural variant of Kcp is a fine- to medium-grained, sub-porphyritic (1 cm relict euhedral white K-feldspar phenocrysts) rock locally contaminated by abundant mafic inclusions. This rock appears to be a chilled facies of average Kcp.

A granite with color index ranging from 2 to 7 percent that is locally devoid of hornblende and contains slightly more quartz than the average Kcp grades into and intrudes the more mafic granite. The leucogranite with abundant 1 to 2 cm relict euhedral K-feldspar grains which underlies Stonewall Peak is an example. Some of the leucocratic Kcp is alaskite and aplite that locally resembles the leucocratic facies of the younger granite of Pine Valley (Kpv). The thin-sheeted style of intrusion, extensive stoping and chemical reactions with mafic rocks, finer grain size and mafic mineral suite of Kcp help to distinguish it from the younger granite, Kpv.

Granite of Pine Valley:--The granite of Pine Valley (Kpv) forms large discrete plutons several km across, which are relatively inclusion-free and uncontaminated within the project area as a whole. The unit typically has been emplaced in steeply dipping sheet-like bodies.

The rock is white-weathering and underlies highlands except where faulted. It is chiefly coarse-grained granite with color index ranging from 5 to 10 percent. Mafic minerals are dark yellowish-brown biotite and small, skeletal relicts of dark bluish-green hornblende. Many samples contain no hornblende. The plagioclase feldspar is oligoclase (An_{24-25}) that occurs as relict, euhedrally zoned grains. Prominent accessory minerals are sphene, allanite, and epidote. In the Arroyo Seco area (Cuyamaca Peak quadrangle) and in the town of Pine Valley (Descanso quadrangle) the rock contains white, relict euhedral K-feldspar grains 2 cm long and has sub-porphyritic texture. Everywhere, elongate, gray, 2 to 3 cm recrystallized quartz lenticles, probably relicts of large igneous grains, are characteristic of Kpv. The unit locally has chilled margins against, and sends dikes into, all units with which it is in contact. The unit is strongly foliated.

Pegmatite, alaskite and aplite:--Leucocratic dikes (Kl) of pegmatite, alaskite and aplite occur in all units. In some areas they can be traced into a parent pluton, locally Kpv. Where no association with larger bodies was established, the dikes have been mapped separately. These dikes share the metamorphic fabric of the other plutonic rocks.

Tonalite, quartz diorite and gabbro of East Mesa:--The tonalite, quartz diorite and gabbro of East Mesa (Kem) is the most heterogeneous plutonic unit in the project area. In plan view the sizes and shapes of Kem bodies vary because the unit has intruded older plutons in multiple sheets which have moderate to steep dips. The sheets are interconnected and commonly are localized along older contacts. Kem plutons are strongly foliated, especially near their margins. The pluton at Deer Park, in the eastern part of the Cuyamaca Peak quadrangle, for example, consists almost wholly of mylonite gneiss. It is the extreme southeastern part of this body which forms the northernmost Kem exposure in the Mount Laguna quadrangle (northwest corner of map).

Tonalite and quartz diorite form the major part of the unit. The rocks are typically dark gray, fine- to medium-grained, and locally sub-porphyritic with relict subhedral phenocrysts of plagioclase and hornblende. A common textural variety has a spotted appearance due to poikilocrysts of biotite in a fine-grained groundmass. Pale tan to green hornblende is either the dominant mafic mineral or is about equal in abundance to pale reddish-brown biotite. Color index decreases in a regular manner as modal quartz increases. Color indices of quartz diorite samples range from 35 to 50 percent, while those of tonalites range from 25 to 35 percent. In some samples, hornblende has been altered to actinolite and biotite to chlorite. Relict phenocrysts of plagioclase show strong oscillatory zoning with calcic cores. Plagioclase in one dark, fine-grained sample is An_{39} by electron microprobe, and in a coarsed-grained tonalite, An_{47}. Medium-grained Kem carries abundant, fine-grained mafic inclusions, less than 0.3 m long, some of which are elongate parallel to foliation but many of which are angular or irregularly shaped blocks. Typically, these are only slightly darker than the host rock and therefore have a "faded" appearance.

Dark gray quartz diorite locally grades into fine-grained black dikes, some with scattered plagioclase relict phenocrysts and others choked with relict euhedral plagioclase grains.

Kem, whose hornblendes enclose pyroxene cores (opx -> cpx), grades into the less abundant gabbro of the unit. The gabbro is generally fine- to medium-grained and cannot be distinguished in the field from small bodies of fine- to medium-grained Kc. The distribution of tonalite, quartz diorite and gabbroic rocks within the Kem plutons shows no regular pattern. Although these plutons were not studied in detail, internal contacts were seen locally and undoubtedly the history of the unit is complex.

The Kem unit sends dikes into and has chilled margins against all plutonic units except Klb and Kmd. Kem is locally continuous with, and also cut by, dikes of Kmd. Locally, apparent age relations are reversed where host rocks have intruded Kem (Fig. 3). This is especially true where Kem intrudes Kcr and Kcp. In the southeastern part of the Descanso quadrangle, these three units are intimately interlayered, their contacts have been deformed, and granitic rocks and Kem have been contaminated by one another. A stippled map pattern for Kem indicates that it contains up to about 50 percent of granitic inclusions.

Well-exposed outcrops in the southeastern part of the Viejas Mountain quadrangle suggest a gradational relationship between Klb and Kem. Dark, fine- to medium-grained rocks in Horsethief Canyon were first identified as Kem but then were observed to grade westward into Japatul-type tonalite and eastward into Las Bancas tonalite. In Horsethief Canyon, this dark tonalite intrudes large bodies of black mafic rock ranging from medium-grained gabbro in the central parts of larger bodies to fine-grained mafic rock near margins and in smaller bodies. Elsewhere, such bodies have been called Kmd, but their close spatial relation with the frayed western margin of the large gabbro body north of Corte Madera Mountain suggests that they may be late synplutonic Kc dikes. The intruding Kem tonalite apparently has stoped inclusions from these mafic bodies and is noticeably darker in these areas. It also forms networks of chilled, isoclinally folded dikelets in the mafic bodies.

It can be seen from Figure 5 that Klb and tonalitic rocks of Kem overlap in modal composition. The chemical analyses available at this time indicate that they are indistinguishable chemically. Where Kem tonalite is medium- to coarse-grained with color index 25 to 35 percent, it is very similar to the

Japatul-type tonalite. Where Kem tonalite is fine-grained and especially mafic, its chemical composition overlaps with that of the Las Bancas-type tonalite. Everhart (1951) noted this similarity between these rocks, which he called Green Valley tonalite and Cretaceous diorite, and suggested that they were the same. The chief reason for mapping two units in the present study was that the rocks called Kem consistently intrude the granite units, Kcp and Kpv, whereas Klb plutons are intruded by the granites. Also, Kem and Klb tend to be mutually exclusive in their areas of outcrop. In the few places where they are in contact, the two units appear to grade into one another. This gradation is similar to contacts between the medium- to coarse-grained, more leucocratic-appearing Kem tonalite and the fine- to medium-grained darker Kem rocks.

Some dark-appearing Kem rocks are modally identical to the lighter tonalites and their darker appearance is due solely to their finer grain size. Other dark rocks are quartz diorites. Field evidence suggests that the dark fine-grained Kem rocks are a hybrid formed from Klb and Kc. The Kem bodies commonly occur where Cuyamaca Gabbro is in contact with Klb, particularly in places where small gabbro lenses and screens are surrounded by tonalite. These zones appear to have undergone considerable physical and chemical mixing. Since the dark, fine-grained Kem bodies appear to be younger than Klb, they may be synplutonic hybrid rocks. In the Monument Peak quadrangle, small Kc bodies in the southeastern quarter give way along strike to the north to systems of large dikes consisting of variable, dark, fine- to medium-grained, porphyritic quartz diorite or tonalite which is identical to the dark fine-grained facies of Kem. Until more data are available, bodies which crosscut granite plutons will be designated Kem and those which are intruded by granite will be called Klb, even though parts of Kem bodies are probably composed of Klb.

Felsic tonalite:--The extreme southeastern part of the Mount Laguna quadrangle is underlain by a distinctive tonalite (Kt_1) which is probably part of the extensive

La Posta body (Miller, 1935) which underlies much of the southeastern Peninsular Ranges in San Diego County and Baja California. In the Agua Caliente Springs quadrangle (Todd, 1977a), this unit intrudes ₮Rm , Klb, Kt_2, Kcr and Km.

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 to rhomboid) shapes in less foliated rock, and as ovoid grains in more foliated rock. Thin sections show either highly strained single quartz grains or polygonized aggregates apparently derived from large single grains. Quartz is interstitial to, and replaces, plagioclase and contains small, early euhedral plagioclase and biotite grains. K-feldspar ranges from 2 to 5.5 percent. It occurs as 5 cm poikilitic grains that show large, reflective cleavage surfaces on rock faces. Plagioclase, sodic to intermediate andesine, has retained hypidiomorphic texture, delicate euhedral oscillatory zoning and synneusis aggregates, but shows 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 sparse acicular hornblende grains 0.5-1 cm long. Accessory minerals are sphene, allanite, epidote, apatite, zircon and black opaque minerals.

Some tonalite has approximately equal amounts of hornblende and biotite, and the more hornblende-rich samples tend to have medium-grained quartz rather than the large quartz phenocrysts contained in the more biotite-rich rocks. The hornblende-bearing La Posta may grade into Kgm locally. It has not been possible to subdivide the La Posta rocks into biotitic and hornblendic facies, even though there appears to be a non-systematic gradation between the two. For the purposes of this report, the name Kt_1 will be used to connote leucotonalite with euhedral biotite, large quartz phenocrysts and minor hornblende, as well as rock which has low color index, abundant medium-grained quartz and subequal euhedral biotite and hornblende. Both lithologies have large poikilitic K-feldspars.

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 textures indicating 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 plutonic rocks and TRm. Within the pluton, trends show some consistency over areas of several square kilometers. 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 older plutonic rocks of the Laguna Mountains. Hence it is tentatively considered a late-tectonic structural feature.

Within the Peninsular Range block, the only contact relations observed between Kt_1 and other plutonic rocks are 1) gradational and intrusive contact between Kt_1 and Kgm (Kt_1 dikes Kgm), 2) Kmd dikes in Kt_1, and 3) in the Alpine quadrangle, dikes of Kcm leucogranite (probably an age equivalent to Kpv) in Kt_1.

The lesser deformation of the unit supports its placement as one of the youngest plutonic rocks (see map explanation) but its exact age relative to Kcp, Kpv and Kem is not yet known.

Mafic dikes:--The youngest plutonic unit is an ubiquitous system of mafic dikes (Kmd) which cut all other plutonic rocks. Few are large enough to be shown at 1:24,000 map scale. The presence of dike swarms of Kmd is indicated on the geologic map by a symbol X. The dikes are dark gray to black, mostly fine-grained to very fine grained, but some have fine- to medium-grained centers with chilled margins, while others are variably porphyritic. The dikes consist of plagioclase, hornblende, local pyroxene, biotite, sphene and traces of quartz. The unit overlaps Kem in modal composition. Textures are dynamothermal metamorphic, indicating the rock recrystallized as it was strained, and only the plagioclase phenocrysts in porphyritic dikes show relict euhedral outlines and oscillatory zoning. A few dikes seen in the Descanso quadrangle were undeformed. The dikes are abundant in the vicinity of bodies of Kem, and locally grade into these bodies. They also cut Kem, and locally crosscut one another. They are also abundant near the margins of all of the large Kc bodies mapped to date. Here the dikes consist in part of gabbro and in several places appear to emanate from the Kc bodies. For this reason, they may be in part late synplutonic Kc dikes. Although in some places the mafic dikes crosscut regional foliation, for the most part the largest dikes were emplaced concordant to foliation or rotated into concordancy during regional deformation. With few exceptions, foliation of the dikes' mineral grains is parallel to the surrounding regional foliation, regardless of the dikes' orientation.

The mafic dikes have typically been re-intruded by their host rocks. Most of the dikes are highly deformed; many are pulled apart and resemble inclusions. They typically contain folded bodies of aplite that in some cases are continuous with the granitic host rock but in others are not.

Younger alluvium:--Only small amounts of modern alluvium (Qal) occur in the Mount Laguna quadrangle, principally in the larger drainages of Thing and Cottonwood Valleys. Bedrock is exposed in all of the streambeds, and the exposed thickness of alluvial lenses is about 6 m or less. Fine-grained sediments in the high meadows are chiefly residuum formed in situ by chemical weathering (Mayo and Lower, 1976) and even in the largest meadow, Laguna Meadow, this material is so thin that bedrock knobs form most of the surface. All of these sediments throughout the project area are being stripped from the meadows by headward-cutting gullies and streams.

Summary:--The data of this report suggest that rock units which are distinctly different in the field and which differ petrographically may be very closely related, in part coeval. Thus, in some areas relatively sharp contacts among Klb, Kcr, Kgm and Kcp plutons can be mapped with no ambiguity. Elsewhere, these units seem to grade one into another and clearcut contacts cannot be mapped at this scale. In addition, complex contacts record repeated mutual intrusion between plutons, implying that the classical methods of determining sequence of intrusion, such as chilled margins, presence of dikes and inclusions, cannot be applied here. Yet there is order in the data and the same contact and age relations are seen consistently throughout a large area.

Preliminary K-Ar ages on recrystallized biotite, hornblende and muscovite from plutonic rocks in the project area range from 70 to 110 m.y., suggesting that the Peninsular Ranges batholith in this region remained at metamorphic temperatures for a long period of time. Recrystallization was accompanied by deformation, which continued after emplacement of plutons, as indicated, for example, by the presence of isoclinally folded leucocratic dikes (Kl). The prevalence of synplutonic contacts indicates that early plutons remained capable locally of interacting magmatically with later ones. One would expect complex interplutonic contacts and ambiguous age relations to occur in a setting where temperatures remained high while the rocks were being strained. Detailed studies of specific plutonic problems and other kinds of data such as geochemistry and zircon geochronology are necessary to substantiate or amend this picture.

Structure of batholithic rocks:

The Mount Laguna quadrangle is unusual in that most of its area is underlain by a single pluton consisting of tonalite of Las Bancas. The western one-third of the quadrangle, in which plutonic units occur as steeply-dipping sheets and lenticular bodies, is more typical of batholithic structure throughout the project area. Within that area, small plutons tend to be sheet-like, whereas larger ones are lenticular. The sheets and lenticular plutons, together with screens of prebatholithic rocks which locally separate them, range from a few meters to several kilometers in thickness and larger ones continue along strike for tens of kilometers. In the Mount Laguna quadrangle, the orientation of the plutonic sheets and lenticular plutons, of prebatholithic screens, and of foliation within plutonic and metamorphic rocks, imparts a north-northwest-trending structural grain. Successive intrusions parallel to this structural grain have resulted in stratiform complexes in Kc, Kcr, Klb, Kpv, Khc, etc. The structural grain of the batholithic rocks throughout the project area is more complex, however, and that of the Mount Laguna quadrangle should be viewed as a part of the larger structure.

The structural grain varies over the project area (fig. 6). In the Cuyamaca Peak, Monument Peak, and Mount Laguna quadrangles it is predominantly north-northwestward, and the regional dip is eastward. In the Descanso quadrangle, the structural grain is north-northwest in the eastern half of the quadrangle and northwest to west-northwest in the western half; the regional dip is strongly to the northeast (Hoggatt and Todd, 1977). In the Viejas Mountain quadrangle, the structural grain is approximately east in the southern and central parts of the quadrangle, swinging to northerly trends in the northern part. The steep, northward and northeastward regional dip of contacts, which is seen in the Cuyamaca Peak and Descanso quadrangles, is also observed in the Viejas Mountain quadrangle: in the extrene northeast corner, contacts dip steeply northeast and in the central part, east-striking contacts dip northward (irrespective of local attitudes). The west-northwest- to east-striking structural grain of the Viejas Mountain quadrangle continues into the Alpine quadrangle as west-northwest to northwest trends, with most contacts dipping northward. The swing to northerly trends seen in the northern part of the Viejas Mountain quadrangle is repeated in the northwestern corner of the Alpine quadrangle and in the eastern part of the El Cajon quadrangle, suggesting the existence of a large-scale flexure or flexures in batholithic contacts and foliation, having a steep northeast plunge (fig. 6). It is interesting that this is also the direction and plunge of mineral lineation and concordant crenulation observed on foliation planes in both metasedimentary and plutonic rocks.

Locally, plutonic contacts and foliation describe smaller fold forms (10-15 km^2) about steeply plunging axes (fig. 6). Several of these fold forms include metasedimentary screens which are folded concordantly with plutonic contacts and foliation. One such structure occurs in the northeastern corner of the Mount Laguna quadrangle, involving Klb, TRm and hybrid units. A similar structure, involving Kc and Kcp, occurs just west of the center of the Cuyamaca Peak quadrangle. In the Descanso quadrangle, one involving TRm and Kcr occurs in the center of the map; a second, involving Kc, Kcp and TRm lies south of it. Several of these large fold forms occur in the Viejas Mountain quadrangle, e.g., and S-shaped one in the south-central part and another flexure in the east-central part. An open fold with a near-vertical axis involving TRm, a tonalite unit equivalent to Kgm, and Kc, with Kt_1 in the core occurs in the northeast corner of the Monument Peak quadrangle (Todd, 1978b). The structure of the northern part of the Alpine quadrangle consists of several of these folds in the hinge area of the larger flexure pictured in Figure 6.

The fact that foliation in the metasedimentary screens is folded along with plutonic contacts and foliation suggests that these structures are tectonic in origin. Yet, the distribution of TRm and Kc in the east-central part of the Viejas Mountain map suggests a pushing-apart of these screens and remnants by intruding magma and/or mechanical shearing of solid rock at elevated temperatures and under directed pressure, and the growth of cells or pods of granitic rock. These cells or pods of granitic rock occur in the hinge areas of the folded TRm screens which may have been relatively low strain sites initially for emplacement of magma. Magma also pried apart TRm screens parallel to layering. If TRm screens/and zones of TRm inclusions in Klb plutons are traced throughout the Viejas Mountain quadrangle, they appear to be parts of an once-continuous body which suggests that intrusion has been an important agent of deformation. The impingement of these folds upon one another suggests a condition of unsteady shearing rather than systematic tectonic folding. An alternative possibility is multiple folding--an early phase of isoclinal folding with axial planes parallel to overall foliation and contacts, followed by folding about steeply plunging northeast axes (or the two phases may have taken place in separate, side-by-side domains). Figure 6 suggests a third folding on north-northwest axes. The abrupt dying-out of phase two folds might be expected if the rocks were hot, ductile, and partly magmatic, conditions expected during syntectonic intrusion.

Locally, the dips of plutonic contacts within the project area appear to be gentle to moderate, such as along the western contact of the Rattlesnake Mountain pluton in the northeastern part of the Cuyamaca Peak quadrangle, and the Kc-Kcp contacts in the Buckman Mountain area, southeastern corner of the

Descanso quadrangle. In the Viejas Mountain quadrangle, a few Kcm dikes in the southeastern corner of the map are rather flat-lying and here, foliation in both dikes and host rock dips more steeply than plutonic contacts. In the Monument Peak quadrangle, some late leucocratic dikes are gently-dipping. Steeply-dipping foliation can be traced from the host rock into the dikes and back into host rock, crosscutting contacts at a high angle. Thus, it appears that deformation continued after intrusion.

Outcrops of Klb in the Mount Laguna quadrangle and locally in the Monument Peak quadrangle commonly display two foliations at large angles to one another, both of which appear to be recrystallized mineral foliations. Locally, the east-trending foliation is re-oriented by the north-trending foliation, and the latter is associated with black cataclastic rock, grading to gneissic tonalite, and parallel slabby jointing. The north-trending foliation may be in part a later, lower-temperature deformation structure. In general, the east-trending foliation in Klb appears to swing to an approximately northward trend near north-striking contacts and the degree of deformation and recrystallization have been most intense near the margins and in small satellitic bodies of tonalite as in Monument Peak and Agua Caliente Springs quadrangles. The doubly foliated rock has been indicated on the map by intersecting strike and dip symbols. The double foliation may account for some of the apparent fluctuations in foliation elsewhere in the project area, since only one foliation may show up well in a given outcrop. Two crossing foliations were also seen locally in Kc and Kt_1. The origin of superposed foliations may be related to polyphase folding, or to a change in the regional stress system while the rocks were still hot and ductile.

Geomorphology:

The highest part of the Laguna Mountains, including the Monument Peak quadrangle, is characterized by a topography rather different from that of the batholith at lower elevations. Whereas the large, homogeneous Klb plutons at lower elevations are eroded to an essentially flat or gently rolling surface, in the Monument Peak and Mount Laguna quadrangles they underlie an uneven surface broken by north-northwest-trending linear ridges and valleys, controlled by the structural grain of contacts and foliation. Some, if not all, of these striking linear features are fault-controlled and adjacent ridge-tops may lie at different elevations. Structural blocks are variably tilted so that drainage reversals are common. Meadows underlain by a single rock unit have been eroded into a series of steps (nick points), and are associated with hanging valleys. Predominantly dip-slip faults extending into the mountain block from the desert floor may be responsible for these features.

Faults of the Mount Laguna quadrangle:

There are roughly five major zones of discontinuous, short, en echelon faults in the Mount Laguna quadrangle: Cottonwood Valley-Scove Canyon, Thing Valley, Kitchen Creek-Crouch Valley, Laguna Meadow, and faults related to the Laguna Mountains escarpment (fig. 7). The quadrangle is probably much more broken than the map indicates. The problem with locating additional breaks is chiefly one of access, since much of the quadrangle is underlain by undeveloped, brushy National Forest and Indian Reservation lands. The control in location of faults has been twofold--the two largest zones, Cottonwood Valley and Thing Valley, follow the contacts of the large Klb tonalite pluton which underlies most of the quadrangle. Outside this pluton, steep concordant foliation and contacts have guided fault movements. Within the relatively homogeneous pluton, three major fracture directions trending northeast, north-northwest, and a less prominent east-trending joint system are visible on small-scale aerial photos. Faults have developed along both north-northwest and northeast joint systems within the pluton, and these systems have also controlled the development of major streams. The east-trending fractures are evident mainly as minor bends in the north-northwest and northeast stream canyons. Pegmatitic and leucocratic dikes probably emanating from the La Posta pluton (Kt_1) exposed in the southeast corner of the quadrangle trend consistently north-northwest, dipping westward, and intrude the Klb pluton (sections 14, 23, 24, 26, R. 5 E., T. 16 S.). This suggests that the north-northwest fracture system is as old as the batholith. Locally, these dikes may be slightly offset by northeast-trending faults but the evidence is not conclusive.

Cottonwood Valley-Scove Canyon faults:--Faults in Cottonwood Valley are generally north-trending, ranging from north-northwest to north-northeast. These two trends diverge in the southwestern part of the quadrangle where the valley widens, with the north-northeast-trending system of faults striking southwest along the western margin of the valley and the north-northwest-trending system of faults striking southeast at its eastern margin (fig. 7). Thus Cottonwood Valley thins to the northwest and widens to the south. The narrow northern reach of the valley may have been eroded along faults, but a series of benches separated by vegetation-free, oversteepened slopes and parallel vegetation lineaments on both its southwest and southeast margins is suggestive of down-faulting of the valley relative to the hills to west and east. On either side of Cottonwood Valley, the remnants of what appears to have been a relatively flat, mature surface, eroded into the same lithologies and structures, appears to be offset vertically about 275 m with the eastern side up. Elsewhere in the project area, lesser steps are seen where no faults are present, but the magnitude of this greater change in elevation suggests that it may be in part the result of vertical movement. The Cottonwood Valley-Scove Canyon faults merge northward into faults in the valley of Pine Creek, the en echelon extension of the Oriflamme Canyon fault zone (fig. 7).

On the eastern side of the valley, south of Buckman Springs, faults are marked by strong vegetation lineaments, a break in slope, and gouge. The faults are parallel to contacts and foliation in large Kpv granite dikes and thinly sheeted plutons composed of half a dozen units. Two cycles of erosion and deposition are represented by a gently sloping, dissected colluvial apron of gabbro debris below the fault, and by smaller clastic cones of Kpv clasts at the head of the older deposit, which are covering both the old apron and its gullies. Locally, the older colluvial surface appears to be offset vertically and along strike a swale marks the trace of the fault (sec. 21, R. 5 E., T. 16 S.). This fault, on the east side of the valley, lines up with linear ridges (fault slivers?) to the north and south.

In section 6, T. 16 S., R. 5 E of the Descanso quadrangle (Hoggatt and Todd, 1977), north-trending faults in the Cottonwood Valley zone appear to offset a Kc-Kpv contact about 250 m right laterally. These faults are marked by at least 2 m of cataclastic rock and gouge in Kpv granite and along strike to the south by numerous 1-2 cm cataclastic zones parallel to Kpv foliation. Directly east of Un Gallo Flat (sec. 5, R. 5 E., T. 16 S.), a probable fault trace is marked by a bench, a line of trees and cataclastic Khc, but no gouge is exposed. Small alluvial cones, consisting of Khc cobbles and small boulders, at the foot of the lineament indicate recent disequilibrium in this part of the Cottonwood Creek drainage. Two groups of lineaments extend southward from here, one group striking southeast up a straight canyon toward the Sheephead Mountain truck trail, and the second crossing southward into the eastern wall of Cottonwood Valley. The first group of faults follows an old cataclastic zone in the batholith and consists of multiple thin (1 meter) cataclastic zones in Kc and Khc superimposed on the older cataclastic fabric. The rocks are so thoroughly cataclastic here that it is difficult to tell what the original lithologies were or to distinguish older (synbatholithic) cataclasis from younger, fault-related crushing. These faults are also marked by benches, swales and vegetation lines. To the south, parallel benches and multiple, thin cataclastic zones (dense black cataclasite and brown-weathering, sheared Klb tonalite) are exposed near the photo lineaments.

The second group of faults are exposed in a south-trending tributary canyon where 4-5 m of gouge in a large mylonitic leucocratic dike and more than 3 m gouge and dense black cataclasite in Khc are exposed. On strike with this canyon to the south (sections 8 and 17, R. 5 E., T. 16 S.), this group of faults is marked by benches and notches in the east wall of Cottonwood Valley. Locally Kpv granite dikes are almost totally comminuted and contain abundant secondary epidote; at least 5-6 m of cataclastic rock is associated with one break.

The Cottonwood Valley faults continue to the north across Cottonwood Creek and Sunrise Highway, up the north-trending reach of Scove Canyon, and down into the Noble Canyon drainage. The faults are expressed as en echelon benches, oversteepened vegetation-free (slip?) surfaces, and zones of brown cataclastic rock in the west wall of Scove Canyon. As much as 3-4 m black cataclastic rock and breccia, parallel to N28E 88NW foliation in Khc, is exposed locally in the bottom of the canyon. This fault contains white quartz and sulfide mineralization.

Along highway 80 between Un Gallo Flat and Buckman Springs a number of small faults less than 15 cm wide have slickensides plunging steeply about N60W down polished planes in flinty, dark cataclasite. Kpv granite along the road is highly fractured.

Thing Valley faults:--Thing Valley is a north-northeast-trending, linear valley which shows up as a prominent lineament on high-altitude imagery. Its extension to the northeast is a zone of small faults in the Tierra Blanca Mountains (Agua Caliente Springs quadrangle, Todd 1977a) but its southwest extension is a topographically youthful-looking array of northeast-trending lineaments which separates the southern end of the Laguna Mountains on the west from La Posta and Cameron Valleys on the east. These lineaments consist of vegetation stripes and benches separated by oversteepened, vegetation-free (slip?) surfaces. In Mount Laguna quadrangle, the lineaments are marked by considerable gouge and cataclastic rock. The abrupt change in elevation, approximately 300 m, across the Laguna Mountains, La Posta and Cameron Valleys boundary coincides in part with a contact between Klb and Kgm, but the two tonalites do not show substantially different resistance to erosion elsewhere in the area. The valleys may be part of a fault-bounded block, down-dropped along the northeast-trending Thing Valley fault zone and west-northwest-trending faults in Kgm (southeastern corner of map).

North-northeast to north-northwest-striking minor faults are exposed in the walls of Thing Valley. They consist of multiple, thin (several cm) hard greenish epidote-rich cataclasite surrounded by narrow zones of bleached, more resistant rock. The intensity of this faulting decreases away from the valley floor to west and east, and higher notches and valleys parallel to the Thing Valley faults could well have eroded along subsidiary shears.

The group of faults with the thickest, loosest and probably youngest crushed material seen in the valley is a zone 7-10 m across consisting of east-trending faults that dip steeply north. Individual faults consist of as much as one meter cataclasite and gouge (west side of valley, south of Thing Ranch). Another zone in this vicinity trends N42W 84SW, is about 6 m wide, and consists of friable, brown, sheared tonalite with multiple 0.3 m faults marked by pale green cataclasite. Fault planes in this zone show steeply-plunging slickensides. A fault zone in the same vicinity trends N9W 70NE, approximately parallel to Thing Valley, and consists of about 5 m of loose cataclastic rock. The above relations suggest that the Thing Valley zone is complex and that there may well be a master fault or faults under the rather thick (for the Laguna Mountains) alluvium on the valley floor.

At the south end of the valley, there appear to be several faults cutting Qal which here is at least 6 to 8 m thick. One fault is marked by a step less than one meter high in the alluvium, by a distinct vegetation change across the step, and on strike by a swale and alined arroyo. The other faults are indicated by straight lineaments on aerial photos in the same area.

To the south, along Thing Valley road, Kgm tonalite is brown-weathering, friable and sheared. One fault in this sheared zone which is exposed in a roadcut appears to offset a TRm-Kgm contact about 0.6 km right-laterally (northeast corner sec. 18, R. 6 E., T. 16 S.).

Kitchen Creek faults:--The Kitchen Creek faults lie within a north-trending, narrow, linear zone followed by Kitchen Creek and Kitchen Valley for about two-thirds the length of the quadrangle. Very straight north-trending lineaments in Crouch Valley may represent the northern extension of this zone. The thickest cataclastic material seen is 4 to 5 m of dense black cataclasite in Klb tonalite. This site, about 1 mile north of Cibbetts Flat, is surrounded by less strongly sheared, epidote-rich cataclastic tonalite. There is no evidence for Quaternary movement on these faults.

Laguna Meadow faults:--The southernmost of the Laguna Meadow faults extends southward into Rasalies Ravine (sections 15 and 22, R. 5 E., T. 15 S.) where there is an apparent, slight offset in residuum/alluvium, east side up, which gives way southward to epidote-rich cataclastic rock in Klb tonalite. South of Sunrise highway, en echelon lineaments extend into upper Troy Canyon. They are accompanied by about 2 m of gouge exposed in a gully crossing Kitchen Creek road, as well as vegetation stripes, and subdued scarplets (up on the east) mantled by soil containing epidote-rich cataclastic rock. In upper Troy Canyon a lineament in this zone appears to cut Qal.

Faults of Laguna Mountains escarpment:--A portion of the Laguna Mountains escarpment fault zone (Todd, 1978b) is exposed in the northeast corner of the

Mount Laguna quadrangle. Numerous northwest-trending lineaments southwest of, and parallel to, this zone occur in the Mount Laguna quadrangle but are virtually inaccessible. Those that were examined consist of minor breaks or cataclastic shears developed within, and parallel to, an older cataclastic zone of batholithic age. The northern reach of La Posta Creek (northwest-trending part of Thing Valley) may be eroded along shears of this trend. This stretch of the valley coincides with an internal contact between dark, Las Bancas-type Klb and marginal Klb.

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Acknowledgments

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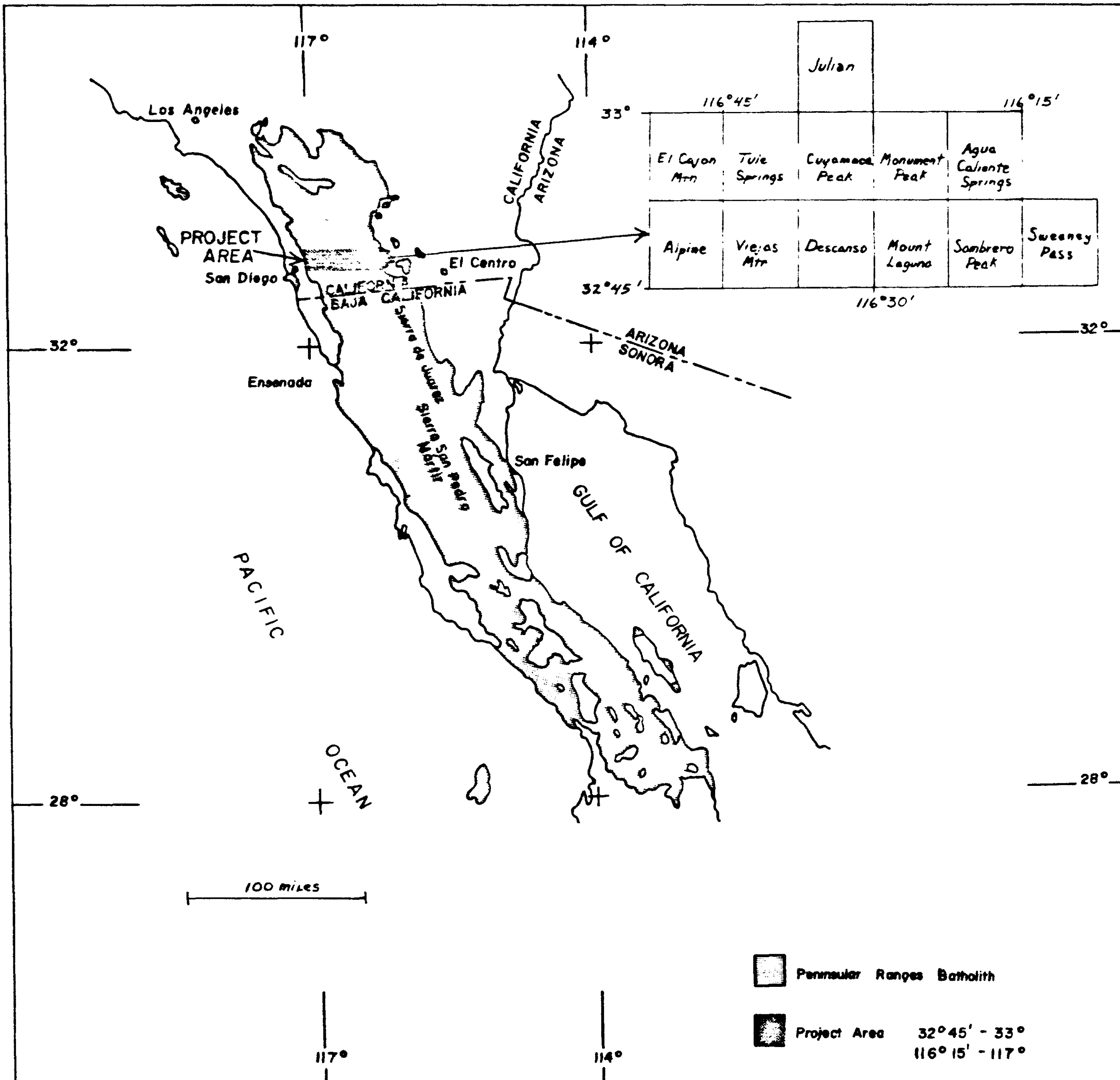


Figure 1. Peninsular Ranges batholith in southern California and Baja California and project area.

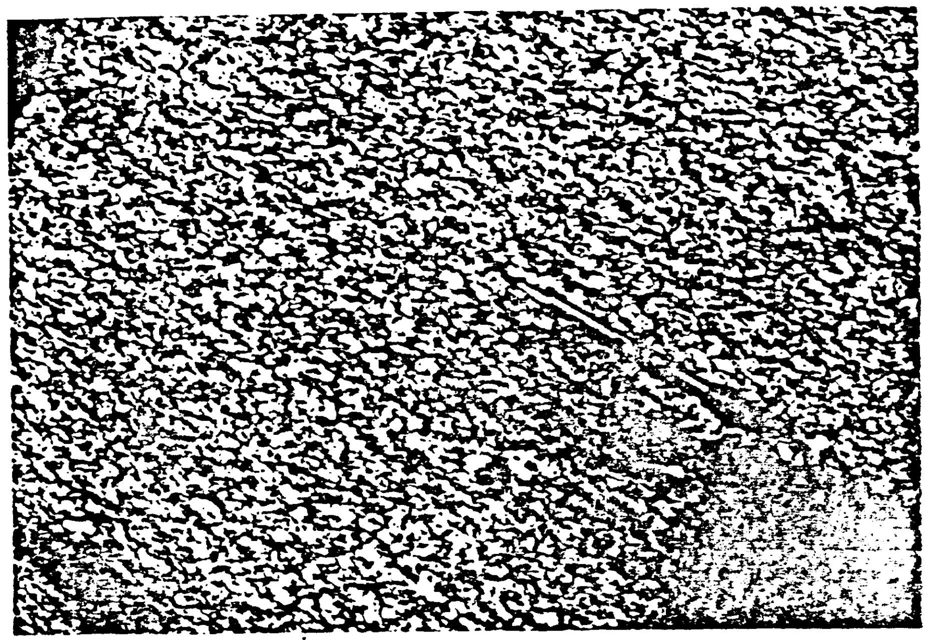


Figure 2a.--Kpv outcrop, trace of foliation parallel to pencil, color index appears higher than 5-10 percent because mafic minerals have broken down and recrystallized into fine-grained aggregates.

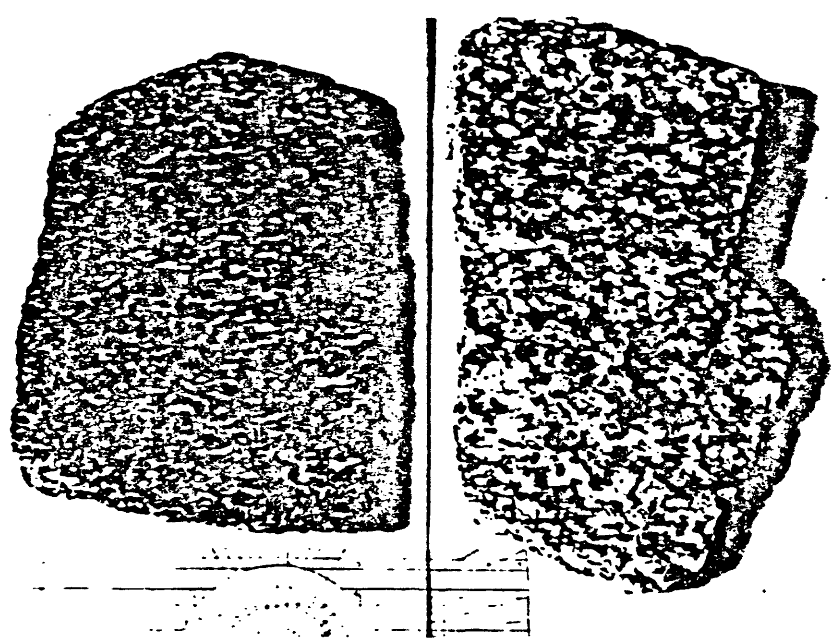


Figure 2b.--Slabs cut at right angles to foliation. Left, Kcp granodiorite; right, Kpv quartz monzonite. Stained for K-feldspar and plagioclase; 6-inch scale.

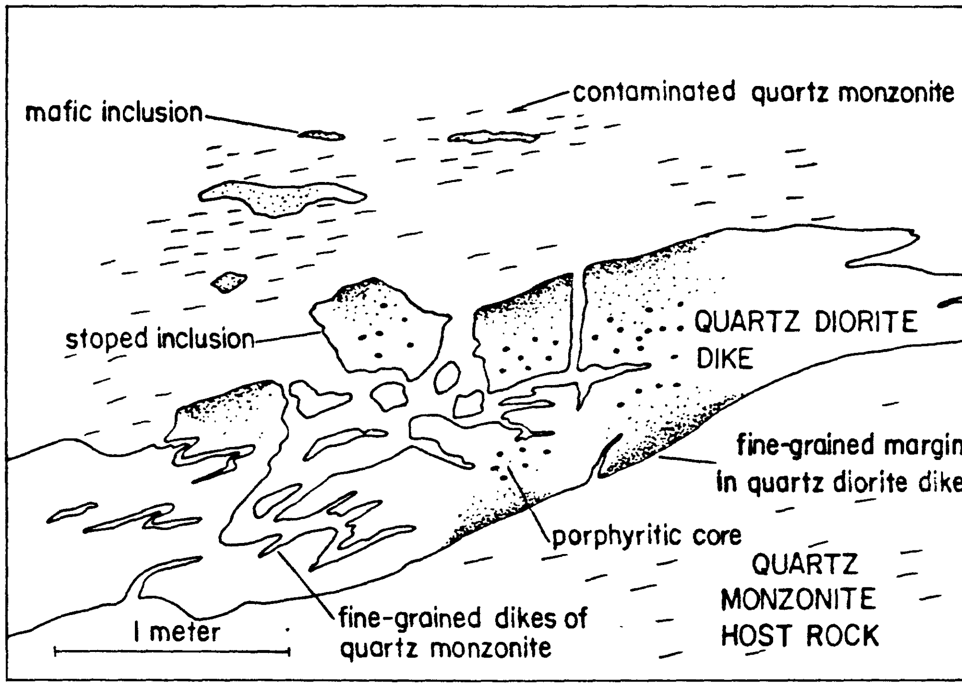


Figure 3. Sketch diagram of common relation between Kem dike and Kcp host rock. From field relations, sequence of intrusion was: 1) emplacememt of quartz monzonite

2) emplacement of quartz diorite dike with fine-grained (chilled) margin and coarser-grained, porphyritic core

3) fine-grained (aplitic) dikelets of quartz monzonite intrude quartz diorite dike; dikelets are continuous with surrounding coarse-grained quartz monzonite.

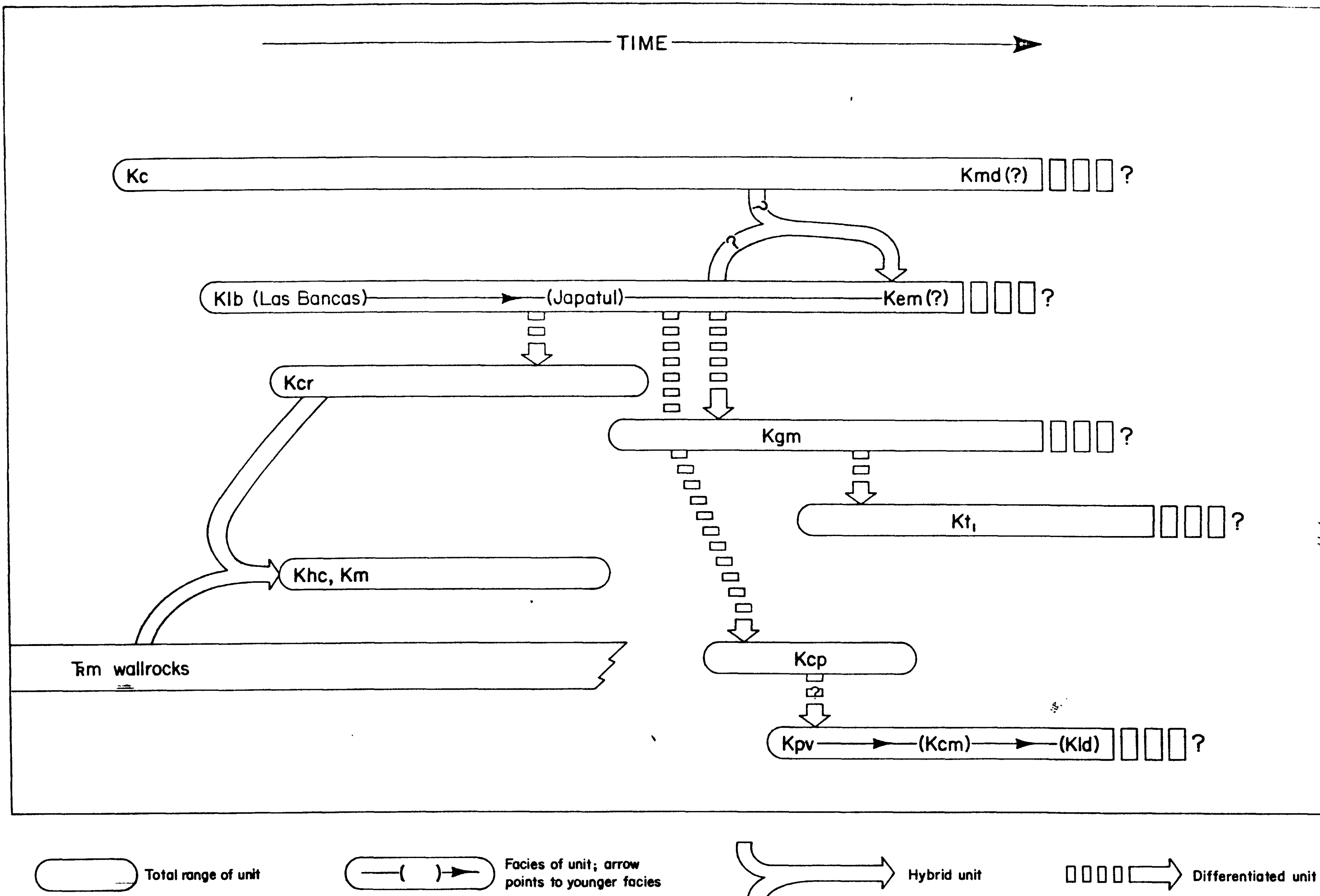


Figure 4.--Schematic diagram of intrusive sequence and relationships as indicated by field evidence. Units shown on same bar are probable phases of single magma. Overlap of bars means units are coeval. Probable hybrids , facies and differentiates are indicated.

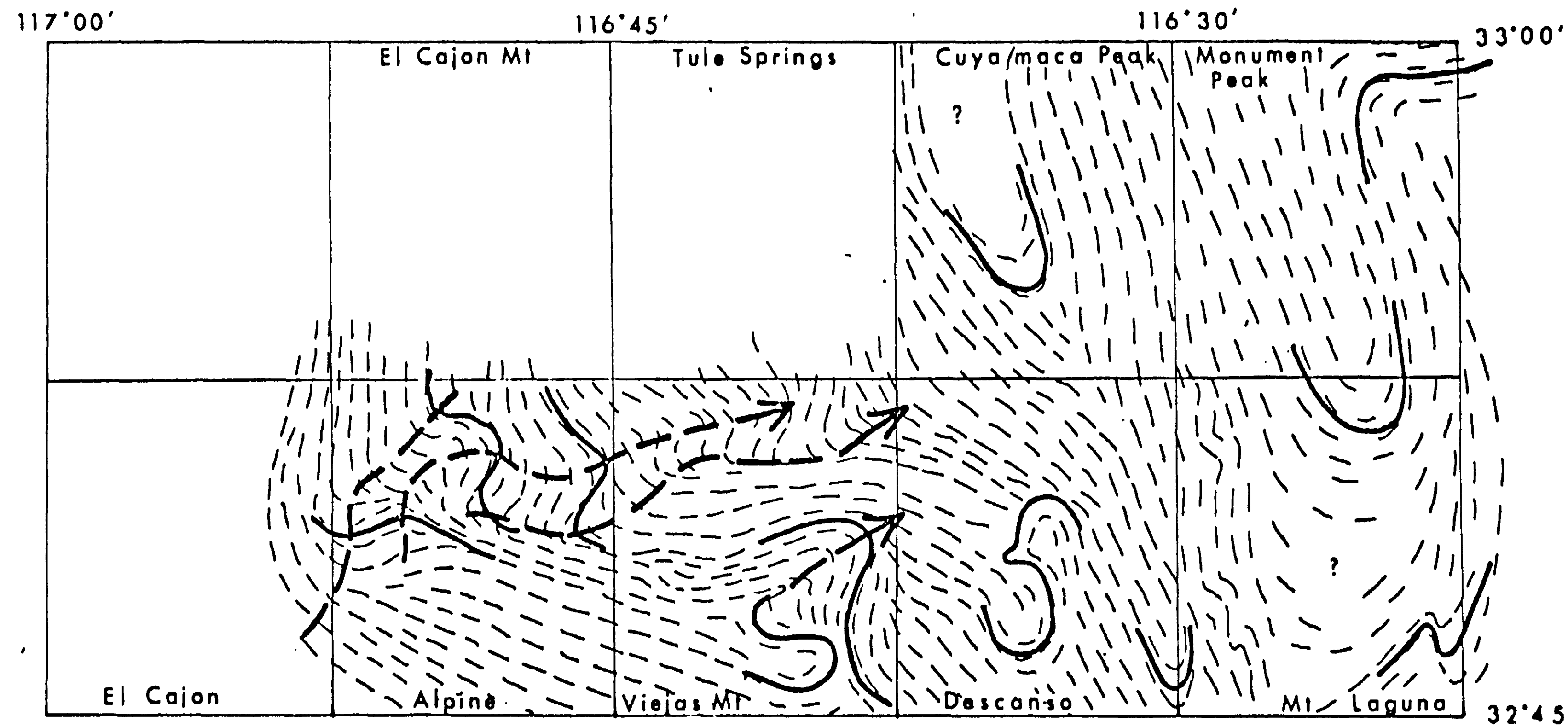
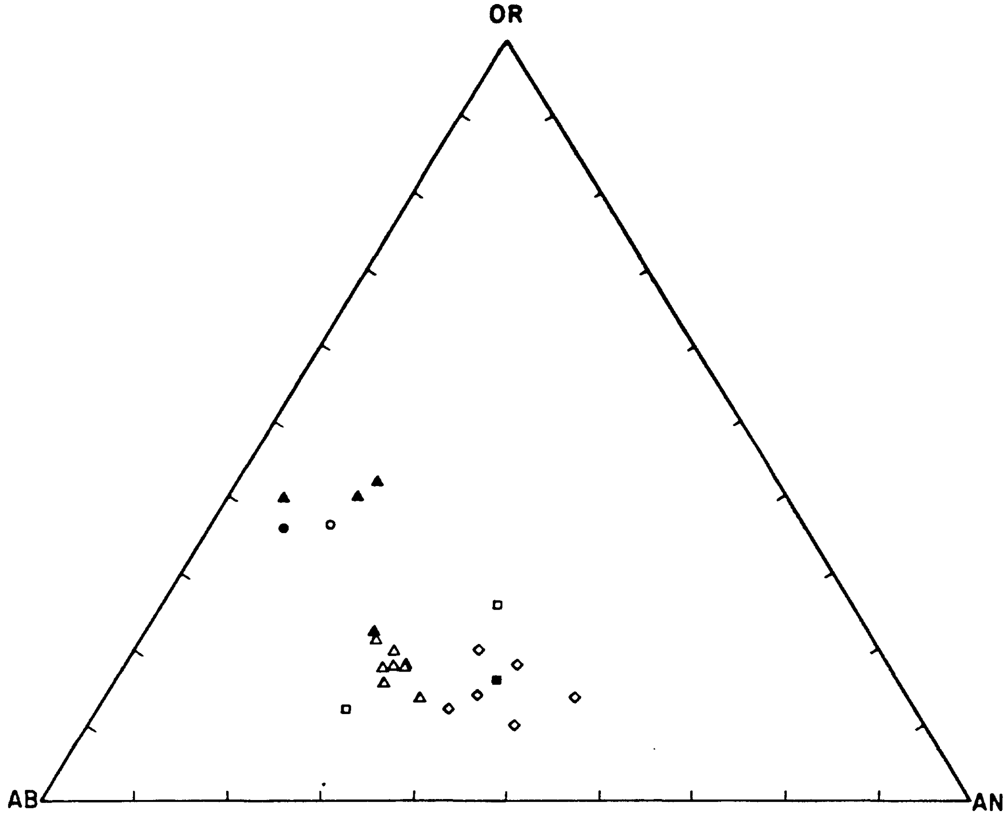


Figure 6. Sketch map of major Cretaceous structural trends in part of project area. Light dashed lines are generalized contact and foliation trends in plutonic and pre-batholithic rocks. Heavy dashed lines are conjectural axes of NE-plunging folds. Heavy solid lines outline small fold forms (10-15 kms^2) mentioned in text. Regional dips (not indicated) are steep to north, northeast and east.



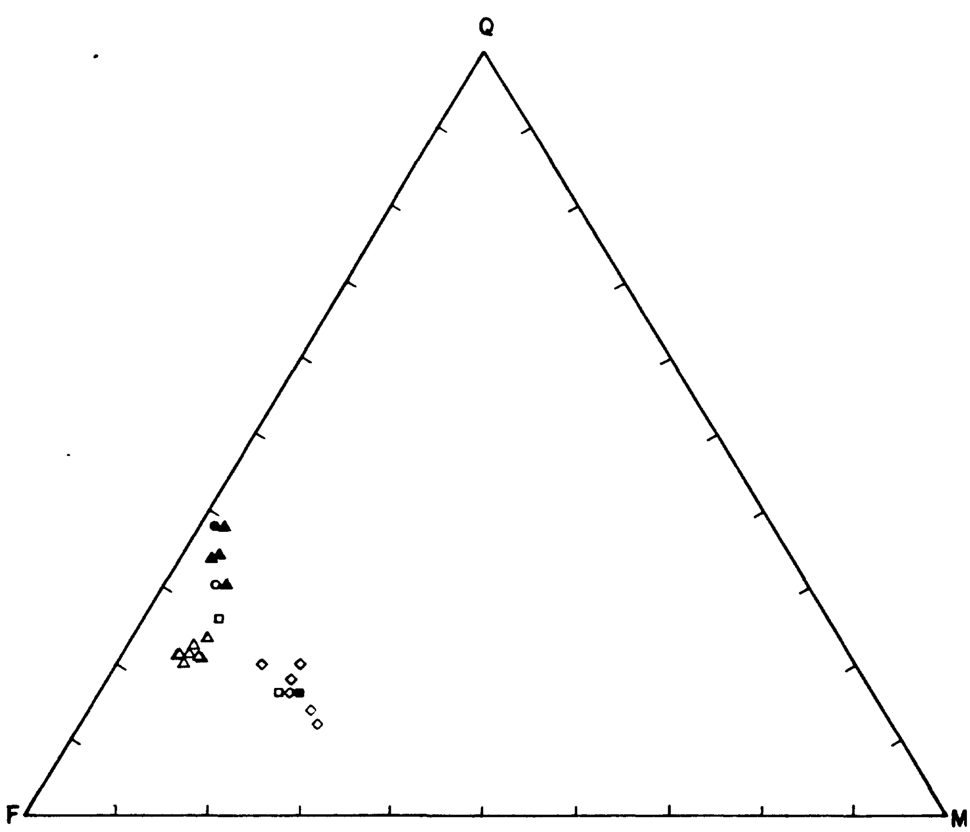


Figure 5b.--Normative OR-AB-AN and Q-F-M plots for some of the same rock samples as Figure 5a. Symbols same as Figure 5a.

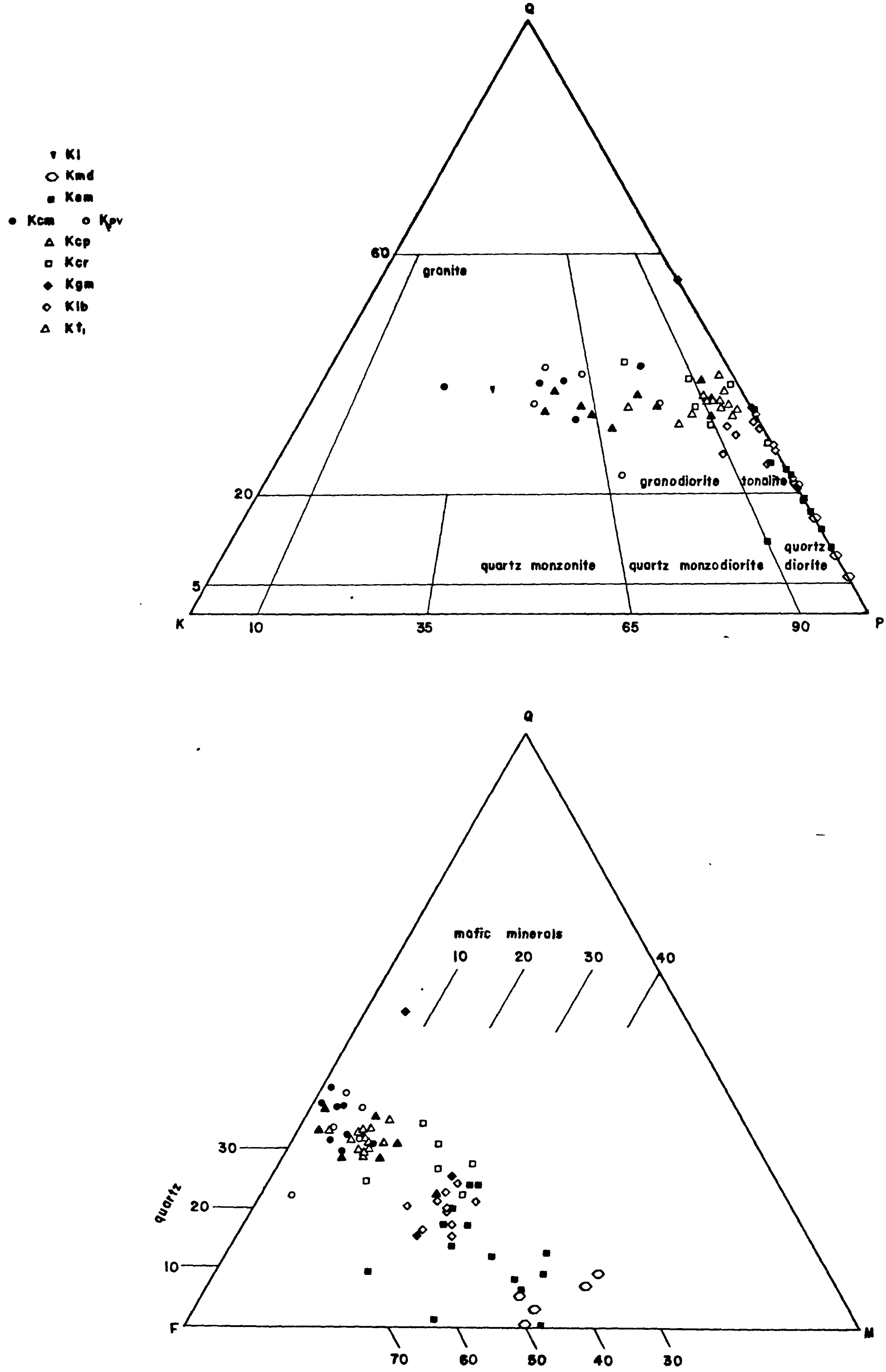


Figure 5a.--Q-K-P and Q-F-M plots of modal minerals of granitic rocks from Cuyamaca Peak and Mt. Laguna 15' quadrangles. Classification from Streckeisen, 1973.

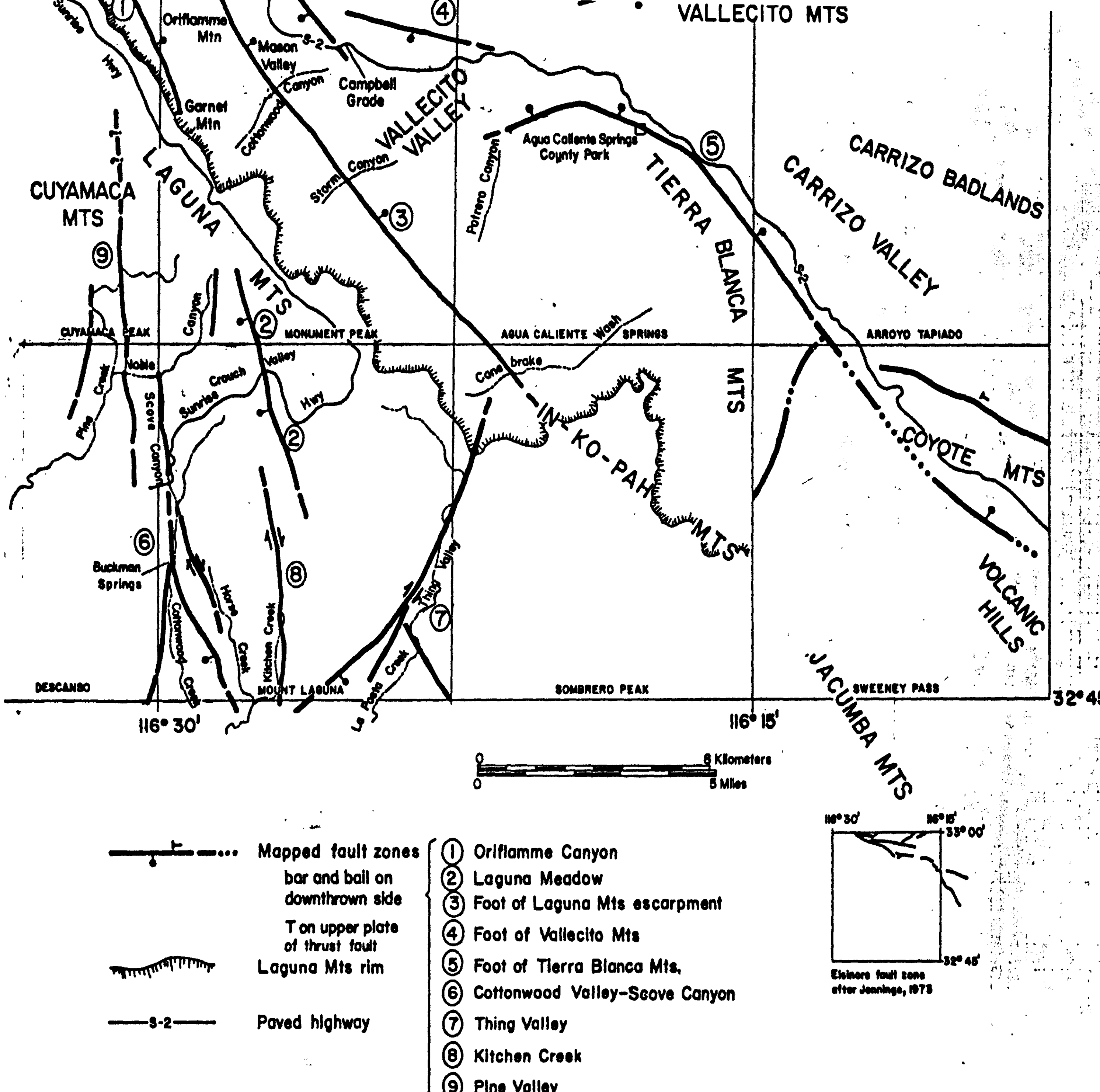


Figure 7.--Southern part of Elsinore fault zone, San Diego County, California. Faults northeast of the Laguna Mountains rim (hachured line) are part of the Elsinore fault zone.