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GEOLOGY OF THE MOUNT LAGUNA QUADRANGLE, SAN DIEGO COUNTY, CALIFORNIA

by

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INTRODUCTION

The Mount Laguna 15-minute quadrangle is located in the eastern part of San Diego County, California (fig. 1). The quadrangle lies within the Peninsular Ranges physiographic province of southwestern California and the Baja California peninsula, a province that is defined by elongate, northwest-trending mountain ranges and valleys underlain chiefly by rocks of the Jurassic and Cretaceous Peninsular Ranges batholith. The dominant topographic feature of the quadrangle is the escarpment of the Laguna Mountains, which bisects it from northwest to southeast and separates the mile-high Laguna Mountains on the west from the western Colorado Desert (fig. 2). The Laguna Mountains are part of a chain of mountain ranges that forms the backbone of peninsular California and locally rises more than 10,000 ft above the floor of the interior desert. The Laguna Mountains comprise part of the east edge of the Santa Ana structural block, which has been uplifted along the Elsinore fault zone and tilted westward (seaward) in Neogene time (fig. 2). From the peaks of the Laguna Mountains, a gently rolling erosion surface that developed across the Peninsular Ranges batholith in Late Cretaceous and early Tertiary time slopes northward to elevations of about 5,000 ft in the northern part of the quadrangle and southward to about 4,000 ft in the In-ko-pah Mountains. Conifer-forested hills and brush-covered moors in the western part of the Mount Laguna quadrangle give way eastward to the rugged, brushy Laguna Mountains escarpment, which is cut by deep, northeast-trending canyons that fall 1,000 ft per mile to the desert floor.

The northern and eastern parts of the Mount Laguna quadrangle include parts of two desert mountain ranges, the Tierra Blanca and Vallecito Mountains, which are separated from the Santa Ana block by a complex array of mainly dip-slip faults of the Elsinore fault zone (fig. 2). A series of grabens and half-grabens floored by Pliocene, Pleistocene, and Holocene sedimentary deposits (Mason, Vallecito, and Carrizo Valleys) separate the Laguna and Tierra Blanca Mountains from the Vallecito Mountains to the north. The Tierra Blanca Mountains are considered to be a fault-bounded, down-to-the-east block in relation to the Laguna Mountains.

GEOLOGIC SETTING

The Peninsular Ranges batholith in San Diego County consists of plutonic rocks of Jurassic and Cretaceous age that contain screens and inclusions of variably metamorphosed supracrustal rocks of Paleozoic(?) and Mesozoic age. The plutonic rocks include a group of plutons that have undergone ductile deformation and yield uranium-lead (U-Pb) ages (Silver and Chappell, 1988) greater than 105 Ma (pre- to syntectonic intrusive sequence), and a second group that is chiefly undeformed and generally younger than 105 Ma (late- to posttectonic intrusive sequence) (fig. 1). Field relations indicate that the older plutons were deformed during and after intrusion as part of one or more episodes of regional metamorphism and deformation that affected the prebatholithic rocks. By Late Cretaceous time, the western part of the batholith was emergent and by the end of Eocene time, the batholith was reduced to a low-lying peneplain (Minch, 1972; Kennedy and Peterson, 1975). Beginning in Neogene time, extension, basaltic volcanism, and block faulting in the eastern Peninsular Ranges signalled the opening of the Gulf of California and inception of the San Andreas transform (Gastil and others, 1981; Kerr and Kidwell, 1991). Normal faulting accompanied by a relatively small component of right lateral separation has continued to the present time in the Elsinore fault zone (fig. 2).

PREBATHOLITHIC ROCKS

Prebatholithic rocks in San Diego County occur as concordant screens and inclusions up to 40 km long and 4 km wide within, and between, plutons (fig. 1). In the western part of the county, the screens consist chiefly of metavolcanic rocks of greenschist and amphibolite grade that contain scarce metasedimentary layers and are lithologically similar to the Santiago Peak Volcanics (Larsen, 1948), which form the west wall of the batholith in southern California (fig. 1). Uranium-lead zircon dates from volcanic rocks in several localities, including the type locality of the formation in the northern Santa Ana Mountains, indicate an Early Cretaceous age with a maximum at 130 Ma (Kimbrough and others, 1990; Herzig, 1991; Herzig and Kimbrough, 1991; Anderson, 1991). The eastern screens consist of metamorphosed flysch of upper amphibolite grade interlayered with minor volumes of metavolcanic and metacarbonate rocks.

Prebatholithic rocks in the Mount Laguna quadrangle are assigned to the Julian Schist (see Hudson, 1922), which consists of semipelitic, pelitic, and siliceous schists, calcsilicate-bearing metaquartzite, and minor metaconglomerate, amphibolite, marble, and orthoquartzite. In addition to biotite and muscovite, metapelitic rocks contain plagioclase and potassium feldspar as well as sillimanite, andalusite, staurolite, and garnet (Grove, 1987a; 1987b). The only fossil found in the Julian Schist is a Triassic ammonoid imprint reported by Hudson (1922) and later lost (R.G. Gastil, oral commun., 1979). Prebatholithic flysch in the northern part of the batholith yielded isotopic and fossil ages that range from late Paleozoic to Mesozoic (Gastil, 1983). Gastil and others (1988) summarized age data for rock units of the prebatholithic flysch belt in southern and Baja California, including the Julian Schist, that indicate a Triassic and Jurassic age. For the purpose of this report, screens in the Mount Laguna quadrangle are assigned a Triassic and Jurassic age.

PLUTONIC ROCKS

Plutonic rocks in San Diego County have been divided into two intrusive sequences, a pre- to syntectonic sequence that was emplaced largely during regional deformation and a late- to posttectonic sequence that was emplaced late in, or following, regional deformation (Todd and Shaw, 1979) (fig. 1). The geochemical and isotopic characteristics of the pre- to syntectonic intrusive sequence indicate derivation from both primitive, igneous or metaigneous source rocks (I-type granitoids), and more evolved, metasedimentary source rocks (S-type granitoids) (Chappell and White, 1974; O'Neil and others, 1977; Shaw and Flood, 1981; Todd and Shaw, 1985). Uranium-lead zircon ages of some I-type plutons of the pre- to syntectonic intrusive sequence range from about 140 to 105 Ma, whereas ages of late- to posttectonic plutons are probably less than 105 Ma (Silver and others, 1979; Silver and

Chappell, 1988). Uranium-lead zircon dating of S-type plutons yielded ages that cluster in the Middle and Late Jurassic (Leeson and others, 1989; Todd and others, 1991; Thomson and others, 1994).

Pre- to syntectonic intrusive sequence

The deformed granitoid rocks in San Diego County are divided on the basis of mineralogic, geochemical, and isotopic characteristics into two groups: (1) a western group of Early Cretaceous I-type granitoids and (2) a central-eastern group of Jurassic S-type granitoids (fig. 1). Plutons of these two groups are interlayered in a 20-km-wide zone located in the east-central part of the county (fig. 1); part of this zone occupies the west half of the Mount Laguna quadrangle. The I-type granitoids are generally hornblende-bearing and have $^{87}Sr/^{86}Sr$ initial ratios less than 0.706, whereas the S-type granitoids are typically biotite-bearing, with $^{87}Sr/^{86}Sr$ initial ratios greater than 0.706. Modal analyses of plutonic units of the pre- to syntectonic intrusive sequence are shown in figure 3.

The volume of gabbroic rocks varies systematically from west to east across San Diego County. The Mount Laguna quadrangle contains the approximate boundary (gabbro line, fig. 1) between a western terrane of large gabbroic plutons that were approximately coeval with Cretaceous I-type granitoid plutons, and an eastern terrane in which gabbro occurs mainly as small concordant bodies and synplutonic dikes.

The 140- to 105-Ma U-Pb ages cited by Silver and others (1979) and Silver and Chappell (1988) are from the western belt of I-type plutonic rocks. As mentioned above, recent dating studies of the central-eastern S-type plutons indicate chiefly Middle and Late Jurassic ages for this group.

Late- to posttectonic intrusive sequence

The central part of the Mount Laguna quadrangle includes the boundary between the older, deformed plutonic terrane and the younger, late- to posttectonic terrane (fig. 1). The eastern part of the quadrangle is underlain by the western part of a large, relatively homogeneous and undeformed pluton that is in part equivalent to the La Posta Quartz Diorite of Miller (1935) and is informally called the tonalite of La Posta (unit Klp) in this report. The pluton crops out over an area that extends for at least 100 km from north to south and at least 50 km from west to east in southern California and Baja California (Walawender and others, 1990). Except for locally intense marginal deformation, the plutonic rocks are massive to weakly foliated, and are marked by leucocratic character (color index 1 to 20), idiomorphic texture, and distinctive chemistry (high strontium and low yttrium). Uranium-lead zircon ages of 95 ± 3 Ma are reported by Clinkenbeard and others (1986) for samples of the pluton from eastern San Diego County. A relatively mafic and more deformed unit that is marginal to the tonalite of La Posta, the tonalite of Granite Mountain (unit Kgm), yielded a U-Pb age of 98-100 Ma for a sample collected 5 to 10 km north of the Mount Laguna quadrangle (L. T. Silver, oral commun., 1979). These ages, which are younger than the radiometric ages reported for the pre- to syntectonic intrusive sequence, are in accord with field relations in the Mount Laguna quadrangle: the tonalite of La Posta intrudes both pre- to syntectonic plutons and the tonalite of Granite Mountain, whereas the latter unit intrudes pre- to syntectonic plutons. Modal analyses of rocks of the late- to posttectonic intrusive sequence are given in figure 3.

BATHOLITHIC STRUCTURE

The older, deformed plutons and prebatholithic screens that underlie the western and central parts of San Diego County share a structural grain that is evident at many scales. This structural grain is reflected at map scale by the elongation of plutons and concordant screens; in outcrop by the concordance of steeply dipping contacts, foliation, and the axial surfaces of folds; and in thin section by the parallel alignment of recrystallized mineral grains and aggregates. Steeply plunging lineation that lies in the principal foliation plane is present in both plutonic and prebatholithic rocks. In detail, plutonic foliation shows both concordant and discordant relations to contacts. The folding and boudinage of granitoid dikes in wallrock screens indicate that the viscosity of granitoid magma and metamorphosed wallrocks was similar during intrusion, that is, that both were deformed as ductile solids (Berger and Pitcher, 1972; Todd and Shaw, 1979). These relations suggest that the ductile flow of highly crystallized magma rather than the flow of crystals suspended in fluid magma was principally responsible for batholithic structure. In the western part of the batholith, a single metamorphic fabric is present in amphibolite-facies wallrock screens and adjacent plutons. There, regional metamorphism and intrusion probably occurred during a single event, whereas a more complex sequence of thermal and deformational events apparently took place in the central-eastern, older, more deep-seated part of the batholith (Grove, 1987a, 1993, 1994; Girty and others, 1994; Thomson and others, 1994).

An exception to the regional structural grain occurs in the interior part of the large hypersthene tonalite pluton (the tonalite of Las Bancas, unit Klb) in the southwestern part of the Mount Laguna quadrangle, where an east-trending foliation is crossed in many places, particularly near the pluton's margins, by the north-northwest foliation that dominates the terrane to the north and west. From the overall shape of this pluton, and the intense, locally mylonitic, north-northwest-trending marginal foliation, it might be inferred that this 104-Ma (Silver and others, 1979) pluton was intruded as a diapir with an east-striking magmatic foliation and was subsequently deformed along its margins during a period of waning deformation. However, this interpretation may be too simple. Outcrop relations show that a single foliation and lineation fabric cross continuously from surrounding plutons of the granodiorite of Cuyamaca Reservoir (unit Jcr) into marginal hypersthene tonalite, thus suggesting that the two were deformed simultaneously. Similar relations are seen in the western part of San Diego County, where the interior parts of large plutons composed of the tonalite of Las Bancas appear less deformed than either their margins or the surrounding, more silicic granitoid plutons, yet a single fabric appears to cross all three rocks. It seems likely that the hypersthene tonalite pluton was emplaced during the major episode of regional deformation but was mechanically stronger than the surrounding, more silicic granitoid plutons. It also appears that the size of a pluton played an important role in localizing deformation; smaller plutons and the marginal parts of large plutons typically are most deformed. The fabric produced by this protoclastic deformation is penetrative on a regional scale, which indicates that intrusive flow was guided by a stress field that acted broadly over the region.

As the result of field and experimental studies of plutonic and metamorphic rocks in the central and eastern Pyrenees, Soula (1982) proposed a model that features diapiric intrusion of highly crystallized magmas during regional metamorphism in order to explain the simultaneous development of concordant and discordant foliations among plutons and between plutons and wallrocks. The Pyrenean structures described by Soula are strikingly similar to those of the pre- to syntectonic intrusive sequence and associated wallrock screens in the Peninsular Ranges batholith.

Ductile shear in the batholith seems to have been localized in an axial zone about 10 to 15 km wide (Cuyamaca-Laguna Mountains shear zone, Todd and others, 1988), part of which is exposed in the southwestern part of the Mount Laguna quadrangle. Five to ten thin, intersheeted plutons whose textures range from gneissic to mylonitic crop out in the walls of Cottonwood Valley (Todd, 1979). Ductile shears within this zone commonly have served as loci for younger, brittle shear faults.

The Mount Laguna quadrangle contains part of a regionally extensive intrusive contact between mid- to Late Cretaceous plutons of the late- to post-tectonic intrusive sequence on the east and those of the Jurassic and Early Cretaceous pre- to syntectonic intrusive sequence on the west. Along much of this contact, the late- to posttectonic tonalites of Granite Mountain and La Posta (units Kgm and Klp, respectively) intruded prebatholithic metasedimentary rocks that remain as a series of large screens along the contact. Where this contact crosses the north-central border of the quadrangle, it was affected by Late Cretaceous folding and Neogene faulting. From the south end of the Sawtooth Mountains (fig. 2), the contact trends north-northwest, bends northeast in the vicinity of Campbell Grade, and then bends northwest just before crossing the northern border of the quadrangle. In this area, the quadrangle border lies just north of the axial trace of a large anticline that plunges gently to the east. This fold is one of a series of large-scale folds in the western Vallecito Mountains that involve metasedimentary rocks, ductilely deformed tonalite of Granite Mountain (unit Kgm), and relatively undeformed tonalite of La Posta (unit Klp) (Grove, 1987a, 1987b). Regional relations indicate that folding probably occurred late in, or soon after, intrusion of unit Klp.

POST-BATHOLITHIC GEOLOGIC HISTORY

Intrusion of the Peninsular Ranges batholith was followed rapidly by uplift, erosion, and, on the west, marine sedimentation. The oldest sedimentary rocks that overlap the batholith in San Diego County are the Upper Cretaceous Lusardi Formation (Nordstrom, 1970), which consists of continental fanglomerate of local derivation and is overlain unconformably by marine deposits containing Campanian-Maastrichtian fossils (Kennedy, 1975). In northern Baja California, the oldest onlap deposits belong to the marine Rosario Formation, which Silver and others (1963) found to be only slightly younger than the bevelled plutonic and metamorphic rocks it overlies. An early Tertiary episode of erosion was followed by deposition of the Eocene Poway Group (Kennedy, 1975; Kennedy and Peterson, 1975), which crops out about 40 km west of the Mount Laguna quadrangle. The Poway Group consists of fluvial conglomerate and sandstone deposited by a broad system of braided rivers that flowed westward across the peneplaned batholith into the Pacific Ocean in Eocene time (Minch, 1972). The presence of exotic clasts of rhyolite and quartzite in the conglomerate indicates that the Peninsular Ranges batholith has been displaced tectonically since Eocene time from an eastern source area of these clasts (Abbott and Smith, 1989). Sonora, Mexico is the most likely provenance for these clasts, which would suggest about 300 km of northwest movement of the Peninsular Ranges on the San Andreas fault system (Woodford and others, 1968; Abbott and Smith, 1989). Recent paleomagnetic studies that suggest more than a thousand kilometers of northward displacement of the batholith since Eocene time are controversial but may lead to identification of previously unrecognized sources for exotic clasts in the Poway Group (D. Howell, oral commun., 1982). If, as seems likely, Upper Cretaceous and lower Tertiary deposits once covered the Mount Laguna quadrangle, they have been removed by erosion.

The northeast part of the Mount Laguna quadrangle exposes part of a low-angle imbricate fault system of regional extent that involves plutons of the late- to posttectonic intrusive sequence. This fault system is preserved in the graben of Vallecito Valley where eroded low-angle fault-bounded plates are overlain by the Palm Spring Formation. The timing of low-angle faulting is poorly constrained but is bracketed by the ~95-Ma age of the youngest posttectonic pluton in the area and by overlying Pliocene sedimentary rocks. Regional evidence indicates that low-angle faulting occurred in two or more episodes; an episode of Late Cretaceous and early Tertiary deep-seated east-to-west thrusting followed by early and middle(?) Tertiary west-to-east, ductile-to-brittle detachment faulting (Todd and others, 1988). Landslides in and near the Mount Laguna quadrangle locally involve the Palm Spring Formation (Hart, 1991), which suggests Quaternary reactivation of the low-angle fault system.

Basaltic eruptions took place in Miocene time in the axial region of the batholith in San Diego County and in northern Baja California (Minch and Abbott, 1973). These eruptions accompanied the beginning of normal faulting (extension) in the eastern part of the batholith related to the opening of the proto-Gulf of California (Elders and others, 1972; Dokka and Merriam, 1982; Kerr and Kidwell, 1991). Miocene basalt crops out about 9.6 km east of the Mount Laguna quadrangle. The volcanic rocks are offset between positions near the crest of the Peninsular Ranges and at its foot in the western Colorado Desert by late Tertiary and Quaternary faults that form the east margin of the southern Santa Ana block. In eastern San Diego County, these faults comprise the Elsinore fault zone (fig. 2).

The Elsinore fault zone is the westernmost on-land strand of the San Andreas fault system, and it is currently active. Three subzones of the Elsinore system cross the Mount Laguna quadrangle: faults of the Laguna Mountains escarpment, frontal faults of the Tierra Blanca Mountains, and frontal faults of the Vallecito Mountains (fig. 2; table 1)(Todd, 1977a, 1978a). Predominately dip-slip movements on these faults have led to the formation of an arcuate series of grabens and half-grabens, which comprise Mason, Vallecito, and Carrizo Valleys (Todd and Hoggatt, 1979). The faults of the Laguna foothills are more deeply eroded than those of the Tierra Blanca and Vallecito Mountains and are partly covered by coalescing Quaternary alluvial fans. Because Pliocene and Pleistocene marginal continental deposits associated with an early northern incursion of the Gulf of California (Palm Spring

Formation, unit QTp) are restricted to Mason, Vallecito, and Carrizo Valleys, uplift of the Laguna Mountains either began before Pliocene time, in which case the Palm Spring Formation was not deposited in the Laguna Mountains, or uplift began after middle Pleistocene time, in which case the Palm Spring Formation was deposited and subsequently completely eroded from the Laguna Mountains. Faults of the en echelon Tierra Blanca Mountains frontal zone cut the Palm Spring Formation, the upper Pleistocene and Holocene Mesa Conglomerate (unit Qm)(the broad alluvial fan of Carrizo Valley), and, locally, Holocene deposits. The flat-lying Mesa Conglomerate (Woodard, 1974) overlies the folded Palm Spring Formation with angular unconformity. The frontal faults of the Vallecito Mountains cut the Palm Spring Formation and the Mesa Conglomerate, and in one place may also cut Holocene deposits.

The frontal faults of the Vallecito Mountains (fig. 2) cut the Late Cretaceous anticline described in the preceding section. The net result of this faulting was uplift of the Vallecito Mountains block, but one fault in the north wall of Mason Valley (north of Campbell Grade) may also show about 0.5 to 1.5 km apparent right-lateral displacement of a contact between prebatholithic metasedimentary rocks and the tonalite of La Posta. Uplift of the Vallecito Mountains block produced one or more landslides along the southern flank of the block (Hart, 1991). The large landslide in the northeast corner of the Mount Laguna quadrangle that is composed exclusively of the tonalite of La Posta lies below a steep fault-bounded headwall underlain by the same unit. An even more complex Neogene structure for this part of the Elsinore fault zone is indicated by the presence of discontinuous high-angle fault-bounded exposures of low-angle faults or slides that carried crystalline rocks over the Palm Spring Formation (unit QTp); one of these is exposed in the area north of Campbell Grade.

DESCRIPTION OF ROCK UNITS

METAMORPHOSED PREBATHOLITHIC ROCKS

Metamorphosed prebatholithic rocks (unit JTrm) consist of interlayered fine-grained quartzo-feldspathic schist and semischistose rocks; micaceous, feldspathic quartzite, commonly with calc-silicate minerals; andalusite- and sillimanite-bearing pelitic schist; and metamorphosed calcareous grit, pebble, and small-cobble conglomerate (in part grading to tuff-breccia and (or) reworked tuff-breccia)(Todd, 1978a, 1979; Todd and Shaw, 1979; Germinario, 1982; Detterman, 1984; Grove, 1987a). The quartzo-feldspathic semischistose rocks grade into the feldspathic quartzites and pelitic schists. These rocks are similar to, and are here assigned to, the Julian Schist of Hudson (1922), a unit composed of flyschlike, predominately metasedimentary rocks that crops out in a north-northwest-trending belt in central-eastern San Diego County (figs. 1, 2). The type locality of the Julian Schist is in the Julian 7.5-minute quadrangle northwest of the Mount Laguna quadrangle (fig. 2). With the exception of massive quartzite beds, all of the rocks are thin-layered and probably originated as fine-grained argillaceous sandstones and siltstones, and silty shales. Calcareous cement or bioclastic material is represented locally by interstitial calc-silicate minerals. Crossbedding and graded beds are preserved locally. Interlayered with these rock types are minor amounts of amphibolite (metavolcanic rocks). Metacarbonate and relatively pure quartz-clastic rocks are present locally in the desert ranges of the Mount Laguna quadrangle, which suggests that the screens in the map area preserve remnants of a continental-margin assemblage composed of deep water turbidites interlayered with minor volcanic and shelf admixtures.

The maximum metamorphic grade attained in screens in the Mount Laguna quadrangle is upper amphibolite facies (low pressure-high temperature type) of regional dynamothermal metamorphism. Primary structures are best preserved in the largest screens.

PLUTONIC ROCKS

Pre- to syntectonic intrusive sequence

Jurassic (S-type) granitoids

Migmatitic schist and gneiss of Stephenson Peak

The migmatitic schist and gneiss of Stephenson Peak (unit Jsp)(Todd, 1978a) consists of migmatitic pelitic schist, granodiorite gneiss resembling the granodiorite of Harper Creek (unit Jhc), and discrete layers, lenses, and boudins of calc-silicate-bearing feldspathic metaquartzite and amphibolite. Outcrops of these rocks in the Cuyamaca Peak 7.5-minute quadrangle to the west (fig. 2) were too small to show at that scale and were included with prebatholithic rocks or with the granodiorite of Harper Creek (Todd, 1977b). In the Mount Laguna quadrangle, these migmatitic and gneissic rocks underlie large areas between relatively homogeneous granodiorite plutons and prebatholithic screens. The migmatitic schist and gneiss of Stephenson Peak forms a partial envelope around the large pluton of the granodiorite of Harper Creek in the northwest part of the quadrangle.

The prebatholithic rocks and the granodiorite of Harper Creek (unit Jhc) appear to represent two end-members between which the composition of the Stephenson Peak unit ranges. Over zones from 0.1 km to 1 km wide, prebatholithic schist becomes increasingly segregated into biotitic and quartzo-feldspathic layers and the more refractory metaquartzite and amphibolite occur as increasingly isolated screens, lenses, and boudins as the Harper Creek unit is approached. This transitional rock gives way to rocks in which large migmatitic schist inclusions are embedded or suspended in the granodiorite of Harper Creek, then to granodiorite with smaller schist inclusions, and finally, to relatively homogeneous granodiorite with micaceous lenses. Elsewhere, prebatholithic schist and granodiorite alternate over distances of only a few meters, and because these areas strike into the gradational rocks described above, they have also been mapped as the migmatitic schist and gneiss of Stephenson Peak. The mineralogy, geochemistry, and isotopic characteristics of the granitoid component of the migmatitic schist and gneiss of Stephenson Peak appear to be identical to those of the granodiorite of Harper Creek described below. However, thin section views of the Stephenson Peak unit show that its microtextures commonly have aspects of both metasedimentary rocks and extremely deformed granitoid rocks.

The mantles consisting of the migmatitic schist and gneiss of Stephenson Peak around Harper Creek-type plutons may have been dragged upward from the zone of melting by rising Harper Creek diapirs. The granitoid component of the Stephenson Peak unit may represent "puddles" of Harper Creek-type granodiorite magma in a framework of partially melted metasedimentary restite. Syn- and post-intrusive deformation has altered the shapes of the Harper Creek diapirs and blurred the contacts between granodiorite magma and restite.

Granodiorite of Harper Creek

The granodiorite of Harper Creek (unit Jhc)(Todd, 1977b) consists of red-brown and yellow-weathering, gneissic granodiorite and lesser tonalite, locally sillimanite- and (or) muscovite-bearing. In the Mount Laguna quadrangle, the unit occurs in north-northwest- elongate plutons that typically are intersheeted with plutons of the granodiorite of Cuyamaca Reservoir (unit Jcr) and with large metasedimentary screens (unit JTrm). Harper Creek plutons increase in number and size toward the east in San Diego County. The granodiorite of Harper Creek contains abundant metasedimentary inclusions as much as several meters in length as well as closely spaced biotite-rich lenses several centimeters in length that grade to ghostly, partly assimilated pelitic schist inclusions The orientation of these inclusions and lenses parallel to a strong mineral foliation imparted a gneissic texture to the Harper Creek rocks.

Study of thin sections indicates that the granodiorite of Harper Creek underwent nearly complete recrystallization while being strained (synkinematic metamorphic texture). A few plagioclase grains retain euhedral oscillatory zoning and locally, potassium feldspar grains enclose small, early subhedral plagioclase phenocrysts, but igneous textures are typically lacking. Plagioclase of the unit ranges from oligoclase to andesine and less commonly, to sodic labradorite. Quartz is abundant, as is pale-orange to reddish-orange biotite. Muscovite in the Harper Creek unit ranges from a trace to 13 percent. Where scarce, muscovite is fine-grained, is sited in plagioclase and potassium feldspar, and appears to be secondary. Where muscovite is abundant, it is coarse-grained and apparently grew at the expense of biotite, plagioclase, and potassium feldspar. Scarce ragged, equant grains as large as 4 mm may be igneous relics. Sillimanite, chiefly as fibrolite, grew locally in biotite and plagioclase. More ubiquitous accessory minerals are tourmaline, apatite, and graphite; ilmenite, garnet, and cordierite are rare.

The granodiorite of Harper Creek has many of the mineralogic and geochemical characteristics of S-type granitoids--biotite as the only mafic mineral, ilmenite as the chief opaque oxide, presence of muscovite and one or more aluminosilicate minerals, initial $^{87}Sr/^{86}Sr$ ratios ranging from 0.711 to 0.713 and $\delta^{18}O$ values from 14.8 to 19.8, and relatively high K_2O/Na_2O ratios (Todd and Shaw, 1985; Todd and others, 1991). These characteristics indicate that the Harper Creek magma resulted from partial melting of metasedimentary source materials. The geochemical and isotopic characteristics of the Julian Schist make it, or rocks very like it, a probable source (S.E. Shaw, unpublished data, 1994).

Contacts between the granodiorite of Harper Creek and the granodiorite of Cuyamaca Reservoir (unit Jcr) are both gradational and sharp. Where contacts are gradational, the Cuyamaca Reservoir unit is either (1) fine-grained, highly sheared, and contains abundant partly assimilated metasedimentary inclusions, or (2) coarse-grained, pegmatitic, leucocratic, and full of metasedimentary inclusions and biotitic lenses. These relations may suggest that the Cuyamaca Reservoir unit intruded the Harper Creek plutons at which time residual fluids of the Cuyamaca

Reservoir magma ponded against the Harper Creek plutons or against thin wallrock screens that lay between them. In other places, the granodiorite of Cuyamaca Reservoir is interlayered with the granodiorite of Harper Creek with relatively sharp contacts. Lenticular or sill-like bodies of Cuyamaca Reservoir-type rocks occur locally within Harper Creek plutons. In one place, the Harper Creek unit carries inclusions of an adjacent Cretaceous(?) I-type granitoid pluton and in another, a Harper Creek host pluton has back-intruded I-type quartz diorite dikes synplutonically. These relations indicate that the Harper Creek unit was remobilized during Cretaceous intrusion. Uranium-lead zircon isotopic ages determined for plutons of the Harper Creek unit are chiefly Middle and Late Jurassic (Leeson and others, 1989; Todd and others, 1991; Thomson and others, 1994). Dikes of Harper Creek-type rocks too small to show at the map scale are indicated on the geologic map by open diamonds.

Grain size in the granodiorite of Harper Creek and the degree of migmatization of wallrock inclusions increase rather abruptly east of a line that coincides approximately with an abrupt eastward increase in metamorphic pressures as indicated by geobarometry of pelitic mineral assemblages in the Julian Schist (Grove, 1994). Grove interpreted this apparent eastward increase in structural depth (~5 km) as the result of Late Cretaceous westward thrusting. The migmatitic schist and gneiss of Stephenson Peak (unit Jsp) occurs in appreciable volumes only east of this line. Likewise, metasedimentary rocks east of this line contain fewer relict sedimentary structures and are noticeably more migmatitic than rocks located west of the line (Grove, 1994). The screens east of the line have undergone extensive partial melting and polyphase folding.

Granodiorite of Cuyamaca Reservoir

The granodiorite of Cuyamaca Reservoir (unit Jcr)(Todd, 1977b) consists of distinctive reddish- and orange-brown-weathering, fine- to medium-grained orthopyroxene-bearing biotite granodiorite and lesser tonalite. The unit crops out in the west half of the Mount Laguna quadrangle where it is typically associated with plutons of the granodiorite of Harper Creek (unit Jhc) and metasedimentary screens (unit JTrm). The granodiorite of Cuyamaca Reservoir is light to dark gray on fresh surfaces depending upon the mafic content, which ranges from about 16 to 30 percent. Where the unit is in contact with gabbro and (or) contains abundant mafic dikes, it is contaminated to a relatively mafic tonalite and contains abundant, fine-grained mafic inclusions that are flattened and elongate parallel to foliation. The Cuyamaca Reservoir unit is strongly foliated and, on the average, more deformed than the Cretaceous I-type plutonic units adjacent to it. In thin section, the granodiorite of Cuyamaca Reservoir shows highly strained and recrystallized igneous textures. The unit is locally porphyroclastic and mylonitic next to large metasedimentary screens, where it contains metasedimentary inclusions over a distance of several meters away from the contact.

The granodiorite of Cuyamaca Reservoir contains plagioclase (ranging from sodic labradorite to oligoclase but typically andesine) greatly modified by recrystallization, and pale straw-colored to "foxy" red-brown (reduced) biotite. Both granodiorite and tonalite of the unit may contain orthopyroxene and rare hornblende relics within biotite aggregates; intergrowths of actinolite and epidote that have replaced hornblende and pyroxene are common. The chief accessory minerals are ilmenite, allanite, sphene, and apatite.

The Cuyamaca Reservoir unit's mineralogic characteristics (reduced biotite, ilmenite as the dominant opaque oxide) and isotopic characteristics ($^{87}Sr/^{86}Sr$ initial ratios from 0.706 to 0.708, $\delta^{18}O$ from 11.8 to 13.8) indicate that the parental magma originated from a source that contained both primitive mafic and metasedimentary components (I-S transitional granitoid)(Todd and Shaw, 1985).

Plutons of the granodiorite of Cuyamaca Reservoir are intersheeted with those of the granodiorite of Harper Creek (unit Jhc) as described above. The volume of Cuyamaca Reservoir rocks decreases eastward in San Diego County. The granodiorite of Cuyamaca Reservoir locally has fine-grained margins against, and sends dikes into, the Cuyamaca Gabbro (unit Kc). Contact relations between the Cuyamaca Reservoir unit and adjacent I-type granitoid units observed over a wide area suggest that the granodiorite of Cuyamaca Reservoir was in part coeval with some I-type units. Locally, the Cuyamaca Reservoir unit appears to have been partly melted or remobilized next to I-type tonalite plutons. Contacts in the Mount Laguna quadrangle between the large pluton of hypersthene tonalite (tonalite of Las Bancas, unit Klb) located immediately south of the town of Mount Laguna and the Cuyamaca Reservoir unit are summarized below:

1. Contact pseudo-gradational and interfingering; rocks are texturally and compositionally similar, but granodiorite is brown- to orange-weathering and marginal tonalite phase of hypersthene tonalite pluton is pinkish-gray-weathering.
2. The Cuyamaca Reservoir unit tends to be finer-grained (fine to medium), more leucocratic, and sheared (porphyroclastic) next to marginal tonalite; marginal tonalite texturally unchanged right up to contact.
3. Neither rock type shows textural change; they are separated by thin (locally less than 1 m) screens of the Cuyamaca Gabbro or metasedimentary wallrocks.
4. The granodiorite of Cuyamaca Reservoir occurs as schlieren-like inclusions in hypersthene tonalite.
5. Dark-gray-weathering, fine-grained dikes of hypersthene tonalite occur locally in granodiorite along the contact.

The granodiorite of Cuyamaca Reservoir has been dated by U-Pb zircon method as probably Late Jurassic in age (Thomson and others, 1994). The field evidence for local overlapping intrusive ages for the Cuyamaca Reservoir unit and adjacent, presumably Cretaceous, I-type granitoid plutons may be explained by remobilization of Jurassic granodiorite during Cretaceous intrusion and (or) by the existence of undated Jurassic I-type granitoids.

Gabbroic rocks

Cuyamaca Gabbro

The Cuyamaca Gabbro (unit Kc) consists chiefly of peridotite, olivine gabbro, hornblende gabbro, and norite (Everhart, 1951; Nishimori, 1976; Walawender and Smith, 1980). The unit was named for gabbroic rocks in the Cuyamaca Mountains by Creasey (1946). Everhart (1951) assumed that all of the large gabbro plutons in southern San Diego County are coeval, and the data of the present study support this interpretation. At first glance, gabbro appears to be the oldest plutonic rock because most granitoid units form dikes in gabbro and locally have fine-grained margins against it. Discontinuous gabbro screens, locally as thin as one meter, occur between plutons of the granodiorite of Cuyamaca Reservoir (unit Jcr) and the tonalite of Las Bancas (unit Klb) in the Mount Laguna quadrangle. However, most of the large gabbro plutons have broad, fine-grained porphyritic margins against surrounding granitoid plutons. Thin sections of the marginal gabbro show relict chilled or quenched (hypabyssal) igneous textures modified by recrystallization. Concentrically zoned sheeted complexes of gabbroic and granitoid rocks are common. Zones of intrusion breccia between gabbro plutons and surrounding granitoid plutons consist of rounded blocks of fine-grained porphyritic gabbro in a matrix of chilled, contaminated granitoid rocks. These zones of intrusion breccia are deformed parallel to the regional foliation and grade into contaminated margins of granitic plutons, margins that contain abundant fine-grained mafic inclusions. These relations suggest that gabbro emplacement was broadly contemporaneous with intrusion of granitoid magma, that is, gabbro plutons contained some liquid after surrounding granitoid plutons had solidified. This inference is supported by preliminary U-Pb isotopic dating of plutons in western San Diego County that yielded similar Early Cretaceous ages for tonalite and gabbro plutons (Todd and others, 1994).

Fine-grained, locally porphyritic mafic and intermediate dikes, in part continuous with gabbroic plutons, cut gabbro and granitoid units. Some of the mafic and intermediate dikes may be late differentiates of the parent magma of the Cuyamaca Gabbro. Swarms of dikes too small to show at the map scale are shown on the map by the symbol x.

The gabbro plutons that crop out in Cottonwood Valley in the southwestern part of the Mount Laguna quadrangle may have originally belonged to a single pluton that was intruded by granitoid plutons and deformed in a ductile shear zone. The three northernmost bodies are composed of fine- to medium-grained clinopyroxene-hornblende gabbro, whereas the "frayed" southern body consists of fine-grained hornblende gabbro and diorite. The western and southern parts of the inferred original pluton have extremely complex, mutually intrusive relations with the surrounding granitoid units. The south end gives way to a network of north-northwest-trending mafic dikes that cut all of the surrounding plutons. A similar relation exists in the two lensoid gabbro plutons that crop out near the rim of the Laguna Mountains escarpment near Garnet Peak (fig. 2). The widest part of the larger of these two plutons consists of medium- to coarse-grained gabbro. The northern "tails" of the plutons give way along strike to swarms of fine-grained quartz diorite dikes (not shown on map).

Cretaceous (I-type) granitoids

Tonalite of Las Bancas

Two formal names, the Green Valley Tonalite (Miller, 1937) and the Bonsall Tonalite (Hurlbut, 1935), were previously applied to tonalitic rocks in San Diego County (see Everhart, 1951). In the type localities of these units in northern San Diego County, the Green Valley Tonalite consists of dark-colored inclusion-free tonalite, whereas the Bonsall Tonalite is a lighter-colored tonalite with abundant mafic inclusions. This study has used new, local names for tonalitic rocks mapped in southern San Diego County because on older maps, both Green Valley- and

Bonsall-type tonalites (as well as other rock types) were found in areas designated by one or the other of the two established names.

The informal name tonalite of Las Bancas (unit Klb) was given to the unit that underlies the Las Bancas erosion surface in the Descanso 7.5-minute quadrangle, adjacent to the southwest part of the Mount Laguna quadrangle (fig. 2) (Hoggatt and Todd, 1977). The tonalite of Las Bancas consists of dark-gray hypersthene-biotite tonalite and lesser quartz diorite, quartz gabbro, and granodiorite. The rock that composes the large hypersthene-biotite tonalite pluton in the southwestern part of the Mount Laguna quadrangle is lithologically similar to the Las Bancas unit in the Descanso quadrangle but is probably about 5 m.y. younger. The pluton at Las Bancas has a U-Pb zircon age of 109±2 Ma (Todd and others, 1994) whereas a sample from the Mount Laguna pluton collected in Crouch Valley yielded an age of 104 Ma (Silver and others, 1979; L.T. Silver, oral commun., 1979). The small concordant tonalite plutons that crop out in a northwest train along the Laguna Mountains escarpment are similar to the marginal phase of the Mount Laguna pluton and are probably apophyses of the larger pluton.

The tonalite of Las Bancas is dark gray on fresh surfaces, weathers reddish or buff-gray, and typically forms bouldery outcrops. The unit is homogeneous and generally inclusion free. Scattered 0.5- to 2.5-cm poikilitic biotite grains are common. The tonalite of Las Bancas is a medium-grained, approximately equigranular, moderately foliated rock with partially recrystallized aggregates of mafic minerals. The rock contains 12 to 24 percent quartz; up to 15 percent potassium feldspar, locally as large poikilitic crystals; oscillatory-zoned grains of labradorite to andesine; and has a color index ranging from 20 to 32. Next to bodies of gabbro, the unit is more mafic, contains less than 10 percent quartz, and has plagioclase with anorthite content as high as bytownite. Thus, some of the Las Bancas rock is quartz gabbro according to the classification of Streckeisen (1973); the more mafic Las Bancas rocks are petrographically similar to the tonalite and there is a complete gradation between the two. The Las Bancas unit contains biotite and lesser hypersthene, with minor hornblende occurring as sparse, narrow rims on corroded pyroxene cores; both pyroxene and hornblende are poikilitically enclosed by biotite. The magmatic reaction sequence of the mafic assemblage was orthopyroxene-to-clinopyroxene-to-pale olive green hornblende-to-dark yellowish-brown biotite. These igneous reaction textures have been variably modified by recrystallization.

The large pluton that underlies the southwestern part of the Mount Laguna quadrangle consists of Las Bancas-type rock with a marginal facies of coarser grained, less mafic, more strongly foliated tonalite. The marginal facies has medium to coarse lenticular mafic grains and aggregates and contains subequal hornblende and biotite, locally with scattered larger biotite and (or) hornblende grains giving it a seriate-porphyritic texture. Rusty-weathering spots (metasedimentary relics?) are common. Sparse inclusions in the marginal facies consist of large (about 30 cm) rounded blocks of interior Las Bancas-type rock. Along the southeast margin of the pluton, the marginal facies interfingers with the granodiorite of Cuyamaca Reservoir, which it greatly resembles at the contact. Away from the contact, the two rock types can be distinguished readily.

Outcrops of the tonalite of Las Bancas in the Mount Laguna quadrangle commonly display two foliations at large angles to one another, both of which appear to have involved some recrystallization. Locally, an east-trending foliation is seen to be reoriented by the north-trending foliation, and the latter is associated with thin seams of black mylonitic rock grading to gneissic tonalite with slabby jointing. The north-trending foliation may have re-oriented an earlier, largely magmatic fabric.

Initial $^{87}Sr/^{86}Sr$ ratios and $\delta^{18}O$ values of the tonalite of Las Bancas range from about 0.704 to 0.705, and from 7.0 to 8.2, respectively (Shaw and others, 1986). Geochemical studies suggest that the hypersthene tonalite plutons are products of an unique parental magma that was not related by differentiation to that of the tonalite of Japatul Valley (unit Kjv) or the latter unit's close relative in the western part of San Diego County, the tonalite of Alpine (Todd, 1980).

The tonalite of Las Bancas locally has a fine-grained (chilled?) margin against the Cuyamaca Gabbro in the Mount Laguna quadrangle. In the western part of San Diego County, the Las Bancas unit is locally fine-grained against, and intersheeted with, gabbro in what appears to be a mingling complex (Hoggatt and Todd, 1977). There, the monzogranite of Chiquito Peak (unit Kcp) forms dikes in the Las Bancas unit and the latter has back-intruded these dikes synplutonically in some places. The Mount Laguna pluton shows both concordant and discordant relations to the surrounding Jurassic plutons. The lobe of hypersthene tonalite west of Kitchen Creek appears to crosscut the granodiorites of Cuyacama Reservoir and Harper Creek (units Jcr and Jhc, respectively). As described in an earlier section, plutons of the Cuyamaca Reservoir unit may have contained some liquid at the time of intrusion of the Mount Laguna pluton, most likely as the result of melting and (or) metamorphic remobilization of solid granodiorite by younger, high-temperature tonalite magma.

Quartz diorite of East Mesa

The quartz diorite of East Mesa (unit Kem) consists of small plutons and large sills composed of heterogeneous quartz diorite and tonalite in about equal volumes, and lesser quartz monzodiorite, diorite and gabbro. The unit occurs only in the ductile shear zone that lies east of the I-S line (fig. 1). Plutons of the quartz diorite of East Mesa are strongly foliated, especially near their margins, and in places consist of mylonite gneiss and mylonite. In the Mount Laguna quadrangle, the unit comprises a series of narrow elongate plutons near the southwest border.

The quartz diorite of East Mesa can be divided into two textural facies, both of which include quartz diorite and tonalite compositions. These are 1) a dark, fine- to medium-grained, near-porphyritic facies and 2) a lighter-colored, medium-grained gneissic facies with abundant mafic inclusions. Plutons of the East Mesa unit generally consist of these two textural types in lenticular bodies and mixed zones that are oriented parallel to regional foliation.

The fine- to medium-grained facies of the East Mesa unit is dark gray in color and in places seriate-porphyritic with relict subhedral phenocrysts of plagioclase and hornblende. A common variety has a spotted appearance due to poikilocrysts of biotite in a fine-grained groundmass. In some rocks, hornblende and biotite have been altered to actinolite, chlorite, epidote, and sphene. The fine- to medium-grained facies grades locally into fine-grained dikes with scattered to abundant relict euhedral plagioclase phenocrysts. The medium-grained facies of the East Mesa unit is lighter colored and 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 blocky or irregular in shape. Typically, these inclusions are only slightly darker than the host rock and therefore have a ghostlike appearance. Contacts within East Mesa-type plutons suggest that some of these inclusions may be remnants of an early auto-injected marginal phase.

Color index of the quartz diorite of East Mesa ranges from 23 to 52, decreasing as modal quartz increases. Pale-brown to green hornblende is either the dominant mafic mineral or is about equal in abundance to reddish-brown biotite. Rocks whose hornblende crystals enclose pyroxene cores (hypersthene surrounded by clinopyroxene) grade into hypersthene tonalite and quartz gabbro in the centers of the largest East Mesa-type plutons. Recrystallized plagioclase grains (labradorite to andesine) show relict oscillatory zoning with strongly calcic cores.

Plutons of the quartz diorite of East Mesa contain inclusions of fine- to medium-grained gabbro in a wide range of sizes; the unit is notably darker and contaminated near these inclusions. The distribution of quartz diorite, tonalite, and gabbro within plutons shows no regular pattern.

Preliminary geochemical data indicate that the quartz diorite of East Mesa is similar in composition to the tonalite of Las Bancas (unit Klb). The two units are almost mutually exclusive in their areas of outcrop--the Las Bancas unit crops out mainly to the west and east of the ductile shear zone and the East Mesa unit is exposed chiefly within it. In the Mount Laguna quadrangle, the quartz diorite of East Mesa grades and (or) interfingers with the tonalite of Las Bancas. These relations, together with the fine grain size and strong deformation of the East Mesa-type plutons, suggest that they crystallized from Las Bancas-type magma that was emplaced into a ductile shear zone (deep fault zone?) located approximately between two different prebatholithic crustal blocks. The finer-grained facies of the East Mesa unit probably represents bodies of magma that crystallized rapidly in evanescent fractures within a fault zone.

The quartz diorite of East Mesa intrudes, and locally grades into, the Cuyamaca Gabbro. The East Mesa unit forms dikes in, and has fine-grained (chilled?) margins against, the granodiorite of Cuyamaca Reservoir (unit Jcr), the tonalite of Japatul Valley (unit Kjv), and the monzogranites of Chiquito Peak and Pine Valley (units Kcp and Kpv, respectively). These age relations commonly are reversed along the strike of contacts as the more silicic granitoid plutons synplutonically intrude the East Mesa rocks. In this case, the units are interlayered, have been mutually contaminated, and their contacts have been deformed, leading to very complex outcrop patterns

Tonalite of Japatul Valley

The tonalite of Japatul Valley (unit Kjv)(Todd, 1987b) occurs mainly west of the I-S line (fig. 1), but a few small, sheetlike plutons occur as far east as the southwest part of the Mount Laguna quadrangle. The tonalite of Japatul Valley consists of medium- to coarse-grained, moderately to strongly foliated hornblende-biotite tonalite and lesser granodiorite. Color index ranges from 12 to 32 and the rocks carry abundant mafic inclusions. The mafic inclusions, which typically weather out in relief on outcrop surfaces, may be large and irregular in shape, or flattened parallel to foliation, both shapes occurring within a single outcrop. Their compositions are mostly intermediate but include fine-grained diorite and (or) gabbro; some inclusions are peppered with subhedral plagioclase grains (porphyritic texture). Large inclusions resembling the tonalite of Las Bancas are seen locally. In addition to the ubiquitous mafic inclusions, stained slabs reveal fragments of granitic rocks whose lithologies and textures differ from the host tonalite of Japatul Valley. The tonalite of Japatul Valley is distinctly equigranular and its subhedral plagioclase and hornblende grains locally give the unit a more igneous-appearing texture than that of the other tonalite units. Plagioclase of the unit ranges from labradorite to oligoclase, but is typically andesine. Biotite and hornblende grains commonly occur in recrystallized aggregates. Scarce pyroxene is present as corroded cores within hornblende grains. Accessory minerals include epidote, allanite, apatite, sphene, zircon, and magnetite.

The abundance of hornblende and magnetite in the tonalite of Japatul Valley and the igneous nature of its inclusions suggest that it is an I-type granitoid, that is, one that originated by partial melting of igneous or metaigneous source rocks (Chappell and White, 1974). This is confirmed by the unit's relatively Na_2O-rich, diopside-normative geochemical character and by its low initial $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values (0.7035 to 0.7046 and 6.4 to 8.7, respectively)(S.E. Shaw, unpublished data, 1994).

The tonalite of Japatul Valley exhibits complex compositional and textural variations where it is in contact with metavolcanic wallrock screens (Todd, 1978b). Zones of intrusion breccia as much as 2 km wide in the tonalite consist of metavolcanic inclusions that were variably injected, assimilated, and partly melted in a matrix consisting of quenched, contaminated, and locally pegmatitic tonalite of Japatul Valley. Stained slabs show small (centimeter-size) silicic metavolcanic inclusions. The prevalence of these hybrid zones suggests that the presently exposed level of the batholith west of the I-S line was relatively close to the roof in Cretaceous time.

The age of the tonalite of Japatul Valley relative to the other plutonic units in the Mount Laguna quadrangle is based largely on field observations made outside the quadrangle. Plutons of the Japatul Valley unit locally appear to grade to, intrude, and be intruded by, the granodiorite of Cuyamaca Reservoir (unit Jcr) (Todd, 1982). Locally, neither rock type shows any textural change up to a sharp contact between them, or else the two rock types may be separated by a thin screen of gabbro and (or) prebatholithic rocks. Although these relations suggest the simultaneous intrusion of two different magma types, the recent determination of Jurassic ages for the Cuyamaca Reservoir unit indicates that the Jurassic rock was remobilized locally along contacts with the Cretaceous intrusion. As mentioned above, the tonalite of Japatul Valley contains scarce inclusions of hypersthene tonalite that resemble the tonalite of Las Bancas (unit Klb). However, the tonalite of Alpine (unit Ka), a unit that appears to be a more mafic variant of the tonalite of Japatul Valley and is present only west of the I-S line, is intruded by the tonalite of Las Bancas, which suggests that the Japatul Valley and Las Bancas magmas are probably approximately coeval (Todd, 1983). This inference is supported by a U-Pb zircon age of 108±2 Ma for the tonalite of Alpine (Todd and others, 1994). Granodiorite of the Japatul Valley unit grades into, and is intruded by, the monzogranite of Chiquito Peak (unit Kcp)(Todd, 1983). These two units are typically found in association with metavolcanic wallrock screens and with the intrusion breccia zones described above. In the Mount Laguna quadrangle, the tonalite of Japatul Valley is cut by dikes of the monzogranite of Pine Valley (unit Kpv) and was intruded by the tonalite of Granite Mountain (unit Kgm).

Monzogranite of Chiquito Peak

The monzogranite of Chiquito Peak (unit Kcp)(Todd, 1977b) consists of medium-grained, strongly foliated, grayish-white-weathering monzogranite, granodiorite, and minor tonalite. The unit has a color index of 2 to 16 and commonly carries mafic inclusions. It occurs in a series of steeply dipping, partly interconnected sheets and small lensoid plutons in the east-central part of San Diego County and in larger northwest-elongate diapirs in the western part. The two bodies in the southwestern part of the Mount Laguna quadrangle mark the most easterly occurrence of the Chiquito Peak unit in San Diego County. The larger body appears to be part of a sheeted gabbro-monzogranite complex (Todd, unpublished mapping). The interconnected sheet-like plutons of the Chiquito Peak unit in the east-central part of the county can be viewed as large sill complexes in which monzogranite intruded metasedimentary wallrocks, gabbro, and older granitoid plutons and was in turn contaminated by partial assimilation of stoped inclusions of these rocks. Syn- and post-intrusive deformation of these contaminated zones in the Chiquito Peak unit has given rise to complex hybrid zones between it and surrounding prebatholithic screens and older plutons.

A textural variant of the monzogranite of Chiquito Peak is a fine- to medium-grained, slightly porphyritic (1-cm subhedral white potassium feldspar grains) rock bearing abundant mafic inclusions. This rock type occurs near wallrocks and appears to be a chilled or quenched facies of the typical monzogranite and granodiorite. A rock type with color index ranging from 2 to 3 that is nearly devoid of hornblende and contains slightly more quartz than the average monzogranite grades into and intrudes monzogranite of the Chiquito Peak unit. This leucocratic monzogranite locally carries abundant 1- to 2.5-cm-long subhedral potassium feldspar grains and is associated with dikes of pegmatite, alaskite, and aplite.

The plagioclase feldspar of the Chiquito Peak unit is andesine and oligoclase with relict euhedral oscillatory zoning. Mafic minerals include 1) dark greenish-brown biotite that appears to be derived by magmatic reaction from 2) dark greenish-brown hornblende. Both biotite and hornblende are recrystallized, but igneous relics are present. Prominent accessory minerals are sphene, epidote, apatite, magnetite, and allanite.

Field and petrographic relations between the monzogranite of Chiquito Peak and the tonalite of Japatul Valley (unit Kjv) suggest that these units may be parts of a single magmatic sequence. Strontium and oxygen isotopic ratios for the Chiquito Peak unit (initial $^{87}Sr/^{86}Sr$=0.704; $\delta^{18}O$= 8 to 9) are comparable to those of the Japatul Valley unit, while most major and trace element geochemical trends for the two units are similar (S.E. Shaw, unpublished data, 1994). Granodiorite of the Japatul Valley unit is lithologically similar to mafic inclusion-rich granodiorite of the Chiquito Peak unit. The inclusion-rich granodiorite of the Chiquito Peak unit grades into, and locally is intruded by, "clean" monzogranite in both small, discrete pods and large partly gradational dikes. The zones of hybrid metamorphic rocks associated with both the Chiquito Peak and Japatul Valley units may represent remnants of prebatholithic screens that once separated differentiated pockets of magma.

Based largely on field observations outside the Mount Laguna quadrangle, the monzogranite of Chiquito Peak has mutually intrusive contacts with the Cuyamaca Gabbro (unit Kc), the tonalite of Las Bancas (unit Klb), and the quartz diorite of East Mesa (unit Kem).

Monzogranite of Pine Valley

The monzogranite of Pine Valley consists of coarse-grained, strongly foliated monzogranite and granodiorite with color index ranging from 4 to 10. The pluton of Pine Valley type that underlies Rattlesnake Valley in the Cuyamaca Peak 7.5-minute quadrangle ranges from tonalite to monzogranite (Cameron, 1980). The Pine Valley unit occurs exclusively east of the I-S line where it forms discrete northwest- and north-northwest-elongate plutons that are generally inclusion-free and uncontaminated in contrast to those of the monzogranite of Chiquito Peak (unit Kcp). In the Mount Laguna quadrangle, the Pine Valley unit was emplaced as a series of steeply dipping sills. The rock is white weathering and forms highlands except where it is faulted.

Mafic minerals of the monzogranite of Pine Valley are dark yellowish-brown biotite and scarce, small, skeletal relics of dark bluish-green hornblende. Many samples contain no hornblende. The plagioclase feldspar is andesine and oligoclase occurring as recrystallized grains with relict euhedral oscillatory zoning. Prominent accessory minerals are sphene, allanite, schorl, and epidote. Pine Valley rocks that contain abundant white, subhedral potassium feldspar grains as long as 2 cm have subporphyritic texture. Lenticular gray, 2- to 4-cm-long recrystallized quartz grains, probably relics of large igneous grains, are characteristic of the unit.

The monzogranite of Pine Valley locally has fine-grained (chilled?) margins against, and occurs as dikes in, the Cuyamaca Gabbro (unit Kc), the granodiorites of Harper Creek and Cuyamaca Reservoir (units Jhc and Jcr), the monzogranite of Chiquito Peak (unit Kcp)(west of the Mount Laguna quadrangle), the tonalite of Las Bancas (unit Klb), and the quartz diorite of East Mesa (unit Kem). The Pine Valley unit intrudes the same plutonic units as those intruded by the monzogranite of Corte Madera (unit Kcm), a unit that is present outside the map area and west of the I-S line (fig. 1). The chief difference between the two units is that the Pine Valley unit has higher normative corundum and its leucocratic phases contain primary muscovite and accessory garnet. Both units intrude, and locally appear to grade to, the monzogranite of Chiquito Peak (unit Kcp). The petrogenetic relations among these three monzogranite units are unclear, but it seems likely that the Pine Valley magma was modified by assimilation of metasedimentary and (or) Jurassic S-type granitoid rocks. Uranium-lead zircon dating of the monzogranite-granodiorite pluton that underlies the town of Pine Valley (fig. 2) yielded an age of about 118 ±2 Ma (Todd and others, 1994).

Leucocratic dikes

Dikes composed of leucogranite, pegmatite, alaskite, and aplite (unit Kl) occur in all crystalline units and generally share the fabric of the host plutonic rocks. In areas where the dikes can be traced into a parent pluton, chiefly the monzogranites of Chiquito Peak (unit Kcp) or Pine Valley (unit Kpv), or the tonalite of La Posta (unit Klp), it is assumed that they represent late differentiates of the parent magmas of those units. Where no association with such plutons was established, and the dikes are large enough to show at map scale, they have been mapped simply as leucocratic dikes. A solid diamond pattern indicates swarms of dikes too small to show at the map scale. Although the age of most of the leucocratic dikes is assumed to be Cretaceous, some dikes that intruded the Jurassic granitoids may be Jurassic in age (G.H. Girty, oral commun., 1992).

Late- to posttectonic intrusive sequence

Tonalite of Granite Mountain

The tonalite of Granite Mountain consists of white-weathering, biotite-hornblende tonalite with prominent euhedral to subhedral plagioclase and hornblende crystals. Color index of the unit ranges from 6 to 27. The Granite Mountain unit occurs as two north-trending "prongs" into the pre- to syntectonic intrusive sequence in the southwestern part of the Mount Laguna quadrangle. These bodies are part of a series of plutons of the tonalite of Granite Mountain that lies between plutons of the pre- to syntectonic intrusive sequence and the tonalite of La Posta (unit Klp)(fig. 1). The Granite Mountain unit reappears in the foothills of the Laguna Mountains as a northward-widening zone of tonalite between the pre- to syntectonic plutons and the tonalite of La Posta. Not shown on the map are small lenses of the tonalite of Granite Mountain that occur in the marginal facies of the Mount Laguna pluton between Storm Canyon and the Sawtooth Mountains (fig. 2).

The tonalite of Granite Mountain is characterized by abundant hornblende prisms from 0.5 to 2 cm long, the grains tending to be blocky (1x2 cm) rather than acicular. Sparse biotite is fine-grained and recrystallized, but in rocks where the mineral is subequal in amount to hornblende, biotite occurs as large rectangular grains surrounding hornblende. Small euhedral biotite books are seen locally. In areas where the Granite Mountain rocks are deformed and recrystallized, the texture is similar to that of the tonalite of Japatul Valley. The part of the Granite Mountain unit that has retained igneous texture is well foliated due to the alignment of subhedral hornblende grains and mafic aggregates. This foliation is parallel to that of the surrounding, more deformed tonalite units. Quartz in the Granite Mountain unit is medium-grained, but 1-cm lenticular recrystallized grains or multi-grain aggregates occur locally. Flattened and aligned mafic inclusions and inclusions of tonalite more mafic than the Granite Mountain unit are also seen. Some outcrops contain scattered, 5-cm, colorless poikilitic potassium feldspars, which are more diagnostic of the tonalite of La Posta (unit Klp). Sphene is typically recrystallized; rarely are grains large enough to be obvious in outcrop.

In thin section, the tonalite of Granite Mountain shows magmatic textures with a wide degree of modification by strain and recrystallization. The rocks consist of plagioclase (andesine), blocky rectangular pale-brown and greenish-tan hornblende, dark reddish-brown biotite, and fine-grained, recrystallized sphene replacing biotite and hornblende. In some samples, hornblende contains large hypersthene cores with relict euhedral shapes and is jacketed by biotite. Biotite-after-pyroxene pairs are also seen.

Like the tonalite of La Posta (unit Klp), the tonalite of Granite Mountain has higher strontium concentrations that those of the plutonic units of the pre- to syntectonic intrusive sequence (S.E. Shaw, unpublished data, 1994). The Granite Mountain unit is transitional between the tonalite of La Posta and pre- to syntectonic units in strontium values as well as in other geochemical values. Initial $^{87}Sr/^{86}Sr$ ratios of the Granite Mountain unit average 0.704, while its $\delta^{18}O$ values range from 6.5 to 8.0.

The tonalite of Granite Mountain occurs as a discontinuous envelope of variable thickness around posttectonic plutons of the tonalite of La Posta (unit Klp), separating the latter from plutons of the tonalite of Japatul Valley (unit Kjv). The contact between the tonalite of La Posta and the more mafic, hornblende-rich tonalite of Granite Mountain may be gradational or abrupt; at abrupt contacts, the two rock-types are interlayered over a distance of a few meters and contacts between these layers are sharp to indistinct. Dikes of the La Posta unit are seen in the tonalite of Granite Mountain in these zones. In the western part of San Diego County, where the rocks are deeply weathered, the contact appears as a change from broad, flat white outcrops (tonalite of La Posta) to pale grayish-white, oblong residual boulders whose longest dimensions are nearly vertical (tonalite of Granite Mountain). The contact between the tonalite of Granite Mountain and the tonalite of Japatul Valley is sharp or pseudogradational. The chief difference between the two units across the contact is the degree of modification of igneous texture by strain and recrystallization. The tonalite of Japatul Valley is one of the least deformed of the pre- to syntectonic plutonic units. These relations suggest a spatial and temporal progression from deformed hornblende tonalite (tonalite of Japatul Valley, unit Kjv, older than 105 Ma?), to less deformed, locally idiomorphic hornblende tonalite (tonalite of Granite Mountain, approximately 100 Ma, L. T. Silver, oral commun., 1979), to weakly deformed or massive trondhjemite (tonalite of La Posta, unit Klp, 95±3 Ma, Clinkenbeard and others, 1986). The tonalites of Granite Mountain and La Posta apparently were emplaced as deformation waned.

Tonalite of Granite Mountain contact breccia

The tonalite of Granite Mountain contact breccia (unit Kgmc) is composed of approximately equal volumes of the tonalite of Granite Mountain (unit Kgm), high-grade metasedimentary rocks (unit JTrm), and leucocratic dikes with lesser amounts of gabbro (unit Kc) and quartz diorite (unit Kem). Field relations suggest that intrusion of the Granite Mountain unit into metasedimentary wallrocks in lit-par-lit fashion was nearly contemporaneous with the intrusion of dikes and pods of fine-grained gabbro and quartz diorite. Following relatively closely was the emplacement of abundant leucogranite and pegmatite-aplite dikes that are probably genetically related to both the tonalite of Granite Mountain (unit Kgm) and the tonalite of La Posta (unit Klp). In areas where the resulting outcrop pattern is too complex to show at the map scale (that is, in the walls of the large canyon north of Vallecito Stage Station County Park and in the middle of three low-angle fault plates at the north end of the Tierra Blanca Mountains), the unit designation Kgmc is used. Similar contact breccia in the Campbell Grade area has been mapped in some detail.

Tonalite of La Posta

The tonalite of La Posta (unit Klp) consists of homogeneous, coarse-grained, idiomorphic white-weathering tonalite and granodiorite with color index 1 to 20. The unit as exposed in the Mount Laguna quadrangle comprises part of a large pluton in the southeastern part of San Diego County and northern Baja California (part of which is equivalent to the La Posta Quartz Diorite of Miller, 1935). A number of smaller satellitic plutons enclosed by older, pre- to syntectonic plutons lie to the west of this large pluton. Most tonalite of La Posta appears weakly foliated to massive. Foliated tonalite occurs near the margins of the pluton where the rock is finer grained and darker because of moderate strain and recrystallization of biotite. This marginal foliation is oriented parallel to the pluton's walls and to foliation in the surrounding older plutons and country rock screens. Elsewhere, within the interior of the La Posta pluton, foliation trends are generally consistent only over areas of several square kilometers. In thin section, the foliated rock shows textures indicating minor strain and recrystallization of quartz, feldspar, and biotite that was similar to, but much less intense than, these effects in older plutonic rocks.

The large north-trending metasedimentary screen in the south-central part of the Mount Laguna quadrangle was intruded on the east side by a series of large pods and dikes of two-mica leucogranite that appears to represent a highly fractionated facies of the tonalite of La Posta. Through detailed mapping of this screen, Detterman (1984) recognized several muscovite- and (or) garnet-bearing phases of the La Posta pluton that he considered to have formed by reaction of La Posta magma with metasedimentary rocks. In the present study, these pods and dikes are mapped as leucocratic dikes (unit Kl).

Quartz, which makes up 28 to 38 percent of the rock, occurs as 0.5- to 1-cm bipyramidal grains in unfoliated rocks and as ovoid, recrystallized grains in foliated marginal rocks. Potassium feldspar is present as poikilitic grains as much as 5 cm across that are visible as widely spaced reflective cleavage surfaces on rock faces. Plagioclase of oligoclase to andesine composition has retained hypidiomorphic texture with delicate euhedral oscillatory zoning and synneusis aggregates and minor grain-margin recrystallization. Biotite occurs as euhedral, 0.5- to 1-cm barrel-shaped books in relatively unfoliated rocks, and as more abundant-appearing, finer, scaly recrystallized aggregates in foliated rocks. Tonalite in the Tierra Blanca Mountains contains sparse acicular to subhedral hornblende grains 0.5 to 1 cm long. Accessory minerals are sphene, allanite, epidote, apatite, zircon, and ilmenite. Tonalite south and west of the Mount Laguna quadrangle locally contains subequal amounts of hornblende and biotite; the more hornblende-rich rocks tend to carry medium-grained quartz rather than the large quartz phenocrysts of the more biotitic rocks. The hornblendic variety locally grades into the tonalite of Granite Mountain. In these areas, both lithologies may have large poikilitic potassium feldspars.

The tonalite of La Posta has unique geochemical characteristics (high strontium, low yttrium) that distinguish it from plutons of the pre- to syntectonic intrusive sequence with the same silica contents. Initial $^{87}Sr/^{86}Sr$ ratios and $\delta^{18}O$ values of La Posta samples west of the I-S line (fig. 1) are 0.704 and 7 to 8, respectively, while those samples collected east of the I-S line have values of 0.705 to 0.706 and 10 to 11, respectively. Thus, the chemistry of the rocks shows subtle changes across this older crustal boundary.

Two outcrops outside of the Mount Laguna quadrangle indicate that the posttectonic tonalite of La Posta is younger than the pre- to syntectonic tonalite of Japatul Valley (unit Kjv). In one outcrop, idiomorphic tonalite of La Posta has a chilled margin against the tonalite of Japatul Valley; a discontinuous train of metavolcanic inclusions partly separates the two plutons. In the second outcrop, large leucocratic dikes of the La Posta unit cut across foliation and deformed mafic inclusions in the tonalite of Japatul Valley. This field evidence is supported by

U-Pb zircon ages of 95±3 Ma for the tonalite of La Posta (Clinkenbeard and others, 1986) and a probab'e Early Cretaceous age for the tonalite of Japatul Valley (see above).

POST-BATHOLITHIC SEDIMENTARY ROCKS AND DEPOSITS

Palm Spring Formation

The Palm Spring Formation (unit QTp) is present in the northern part of the Mount Laguna quadrangle. The formation consists of poorly indurated sandstone, siltstone, conglomeratic sandstone, and conglomerate. It is of Pliocene to early middle Pleistocene age in the Arroyo Tapiado 7.5-minute quadrangle to the east (Woodard, 1963, 1974), where the formation is interpreted to represent alluvial floodplain deposits with minor intercalated marine beds that were laid down adjacent to the most recent northward transgression of the Gulf of California into the western Colorado Desert. Woodard considered the Palm Spring beds to be marginal deposits whose accumulation accompanied the gradual retreat of the gulf. In Carrizo Valley (fig. 2), approaching the Vallecito and Tierra Blanca Mountains, the Palm Spring Formation grades downward and laterally into the Canebrake Conglomerate, described by Woodard as coarse, marginal pediment boulder to cobble fanglomerate and lesser pebbly arenite. The Canebrake Conglomerate is the marginal equivalent of both the Palm Spring Formation and the underlying, older marine Imperial Formation of Pliocene age (Woodard, 1974). In this report, the Canebrake Conglomerate is mapped as part of the Palm Spring Formation.

The Palm Spring Formation consists chiefly of poorly indurated, pale-gray-weathering sands with abundant pebble and cobble interbeds marked by fluvial crossbedding, cut and fill structures, and gravel lenses. The sediments were deposited upon a surface whose relief was similar to that of the arroyos and hills of the present mountain pediments. In most places in the Mount Laguna quadrangle, the depositional contact between the Palm Spring Formation and crystalline rocks has been obscured by normal faulting or by overlying deposits of lag gravel. Clasts in the conglomerate beds range from cobble to small boulder size, commonly are rounded to well-rounded, and consist of the lithologies found in nearby mountain ranges. The same granitoid and metamorphic lithologies occur in coarse clastic sandstone interbeds. The source area for the Palm Spring Formation thus appears to be local.

The present distribution of outcrops of the Palm Spring Formation in the Mount Laguna quadrangle suggests a narrow wedge that thins to the west-northwest. The distribution of coarse- and fine-grained facies and the preservation of onlap relations on both sides of Carrizo Valley suggest that the original basin of deposition occupied approximately the same position as present-day Carrizo Valley.

Mesa Conglomerate

The Mesa Conglomerate (unit Qm)(Woodard, 1963, 1974) consists of poorly stratified to unstratified deposits that include a basal conglomerate overlain by unconsolidated, massive and cross-laminated, coarse-grained, poorly sorted well-rounded sand and gravel. The unit includes some massive conglomerate interbeds. Clasts in the conglomerate beds include granitoid and metamorphic lithologies of local origin, some of boulder size. Woodard

(1963, 1974) considered the Mesa deposits to be late Pleistocene and Holocene in age. The formation represents pediment fan and sheet-flood deposits that accumulated during and after uplift and erosion of the older Pliocene and Pleistocene rocks.

In Carrizo Valley, deposits correlated with Woodard's Mesa Conglomerate include massive fan-head deposits; broad, flat terrace-capping conglomerate or fanglomerate; and sandy deposits in areas along relatively inactive parts of the range-bounding faults and inner valleys. Steep, massive fan-head deposits occur on the western part of the Vallecito Mountains fan and on the northeast front of the Tierra Blanca Mountains northwest of the mouth of Canebrake Canyon (fig. 2). These deposits consist of well-indurated, very poorly sorted mixtures of pebbles, cobbles, and boulders (including car-sized boulders on the Vallecito fan) set in a sparse granitic sand-silt-clay matrix. The deposits closely resemble the coarse talus and colluvial material now forming at faulted mountain fronts in the study area. Typically, the subrounded to subangular clasts consist of the tonalite of La Posta (unit Klp) with minor components derived from the tonalite of Granite Mountain (unit Kgm) and metamorphic rocks. The matrix of these coarse deposits ranges in color from pale greenish-gray or tan to red depending upon the development of oxidized coatings on grains. Locally, the unit is cemented by calcium carbonate. Washes cutting the deposits expose 1) indistinct bedding, 2) local poorly developed size grading, and 3) small channel deposits of well-bedded pebbly and cobbly sand within the fanglomerate. Northwest of the mouth of Canebrake Canyon, this fanglomerate grades northwest along the mountain front into well-bedded conglomeratic sands that dip off the tonalite of La Posta (unit Klp) at about 23°. Locally, the coarse fanglomerate deposits seem to grade imperceptibly through an interval of sedimentary breccia or talus into highly fractured tonalite of the frontal fault zone.

On both sides of Carrizo Valley, the fanglomerate facies of the Mesa Conglomerate grades into old alluvial fans that are essentially intact on the south flank of the Vallecito Mountains but largely eroded from the Tierra Blanca Mountains. The surface of the fan south of the Vallecito Mountains is a lag gravel of large, desert-varnished rounded boulders derived from the tonalite of La Posta (unit Klp) and sparse metasedimentary clasts. The size of the old fan material is larger than that found in the present washes. Bedded sands and gravel of the fan lie nonconformably on weathered tonalite of La Posta along the front of the Tierra Blanca Mountains and extend southwestward into the range as disconnected, eroded stream terrace deposits marginal to major drainages and mantled by colluvium. The Vallecito fan deposits grade southeastward into the relatively thin (up to 4 to 5 m) terrace deposits that cap erosional remnants of the Palm Spring Formation. The terrace deposits consist of horizontally bedded, poorly rounded sand and gravel that lie in angular unconformity upon a Palm Spring surface of gentle relief. Bedding in the terrace deposits is typically indistinct, but graded beds, crossbedding, and horizontally-oriented planar clasts occur locally.

The finer grained facies of the Mesa Conglomerate occurs in Inner Pasture, a large interior valley in the Tierra Blanca Mountains (fig. 2), and probably also in Agua Caliente Springs County Park and the area immediately to the south. In Inner Pasture, remnants of poorly indurated, yellowish-tan, crossbedded, pebbly granitoid sands with scattered subangular cobbles and boulders and intercalated gravel lenses lie nonconformably on the tonalite of La Posta (unit Klp). Locally, the sand deposits are at least 30 m thick. Bedding in the sands is planar and horizontal, and the gravel-size clasts are composed mainly of the tonalite of La Posta with lesser rounded (often broken) small cobbles and pebbles of metasedimentary rocks, other plutonic rocks, and rare porphyritic volcanic rocks.

Older alluvium

Older alluvium (unit Qoa) consists of dissected alluvium that underlies much of Vallecito and Mason Valleys in the desert areas of the Mount Laguna quadrangle (fig. 2). Unconsolidated to poorly indurated, flat-bedded, bouldery alluvial fan deposits consisting of metasedimentary rocks, the tonalite of Granite Mountain (unit Kgm), the granodiorite of Harper Creek (unit Jhc), the Cuyamaca Gabbro (unit Kc), and leucogranite dike rocks (unit Kl) occur in the upper reaches of the large canyons that trend northeastward into the desert from the rim of the Laguna Mountains escarpment. Some of this material shows the same degree of dissection as, and is probably equivalent in age to, the upper Pleistocene and Holocene Mesa Conglomerate. However, some older alluvium in the northeast-trending canyons of the Laguna and Tierra Blanca Mountains appears to be only slightly older than the material on the active parts of the alluvial fans, and some grades to younger alluvium (unit Qya).

Colluvium

Colluvium consists of veneers of poorly sorted sand, silt, and gravel on steep hillslopes in the Laguna and In-ko-pah Mountains (fig. 2). Locally, colluvium grades into the younger alluvium (unit Qya) of broad valleys.

Younger alluvium

Younger alluvium (unit Qya) in the Colorado Desert consists of sand, silt, and gravel derived from the older alluvium (unit Qoa), Mesa Conglomerate (unit Qm), and Palm Spring Formation (unit QTp). It is present in active washes incised into the older alluvium and as a thin veneer on older units. In the Laguna and In-ko-pah Mountains (fig. 2), the younger alluvium consists of sand, silt, and gravel deposits typically less than 6 m thick in broad valleys and narrow streambeds.

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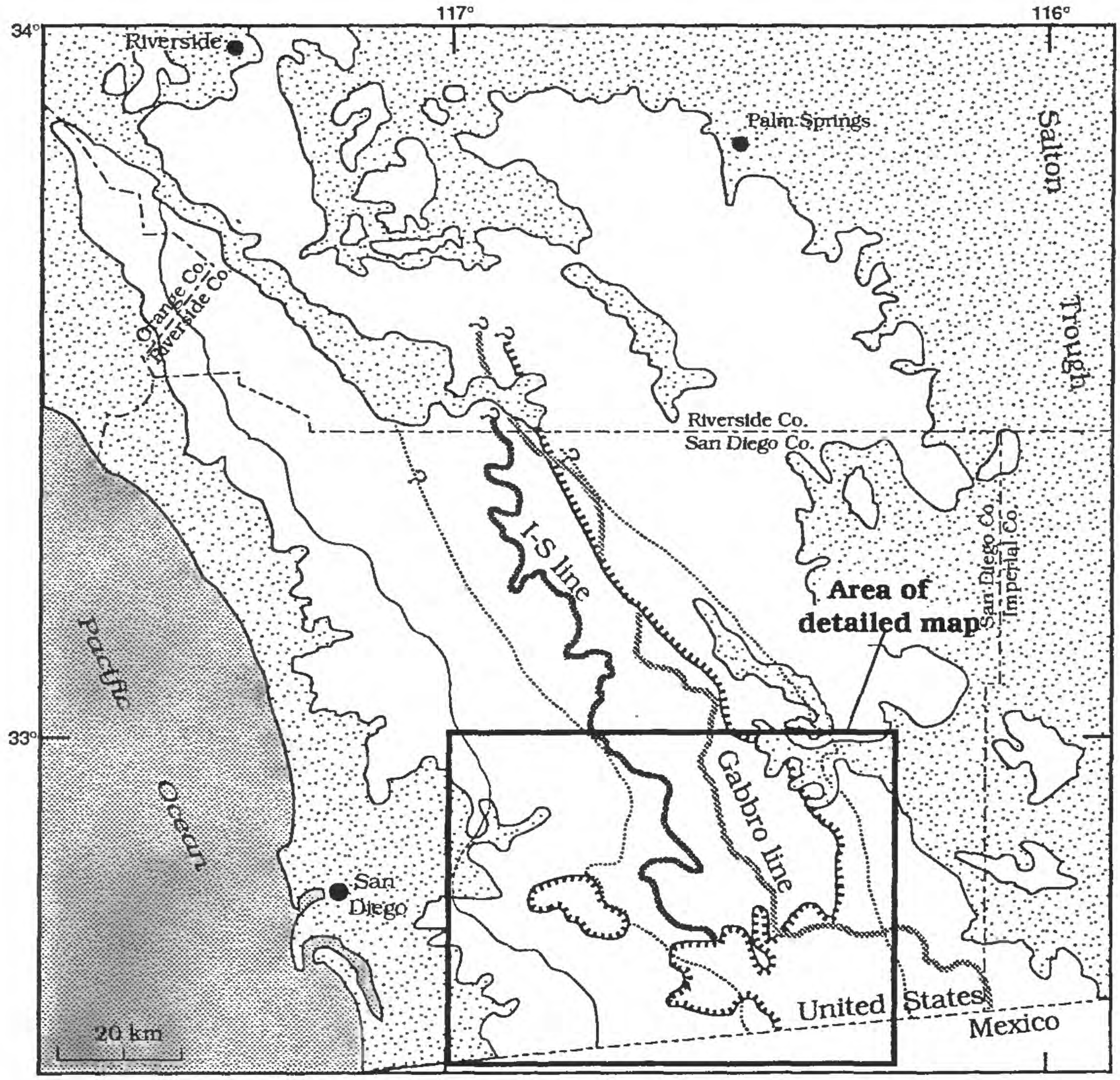


Figure 1.

A. Generalized geologic map of the Peninsular Ranges batholith in southern California showing area of detailed map of B (from Todd and others, 1988). Unpatterned area comprises Mesozoic batholithic and Mesozoic and Paleozoic prebatholithic crystalline rocks, stippled pattern indicates Cenozoic and Mesozoic post-batholithic deposits. North-northwest-striking lines mark major lithologic boundaries: light solid line is eastern boundary of Early Cretaceous Santiago Peak Volcanics of Larsen (1948); dotted lines divide prebatholithic rocks into: 1) western zone consisting of Cretaceous and Jurassic metavolcanic rocks, 2) central zone of Jurassic and Triassic metamorphosed flysch (including the Julian Schist of Hudson, 1922), and 3) eastern zone of metamorphosed Mesozoic and Paleozoic miogeoclinal rocks; heavy solid line is western boundary of Jurassic metagranitoids (I-S line); stippled line is eastern limit of large gabbro plutons (gabbro line); hachured line is western boundary of late- to post-tectonic plutons.

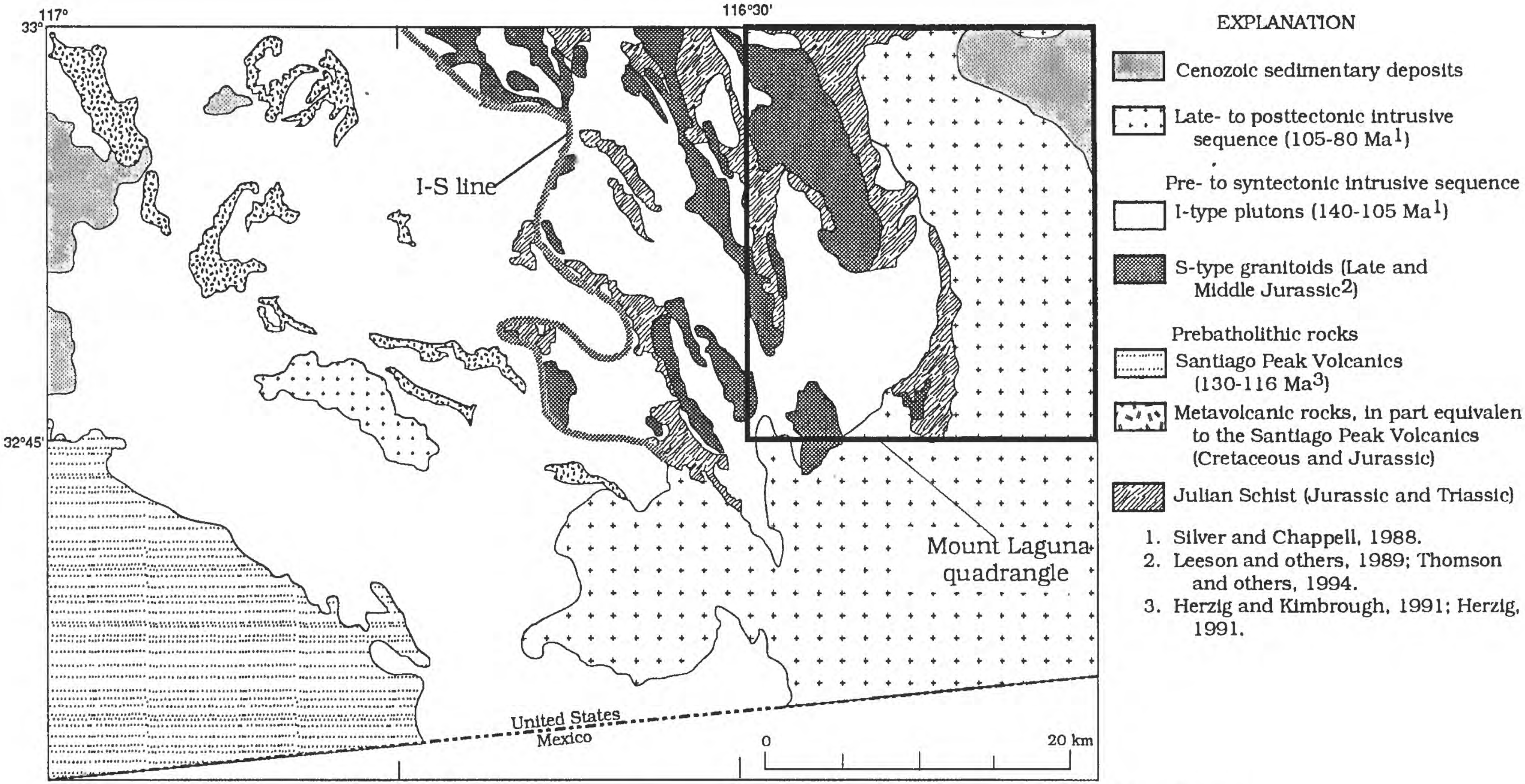
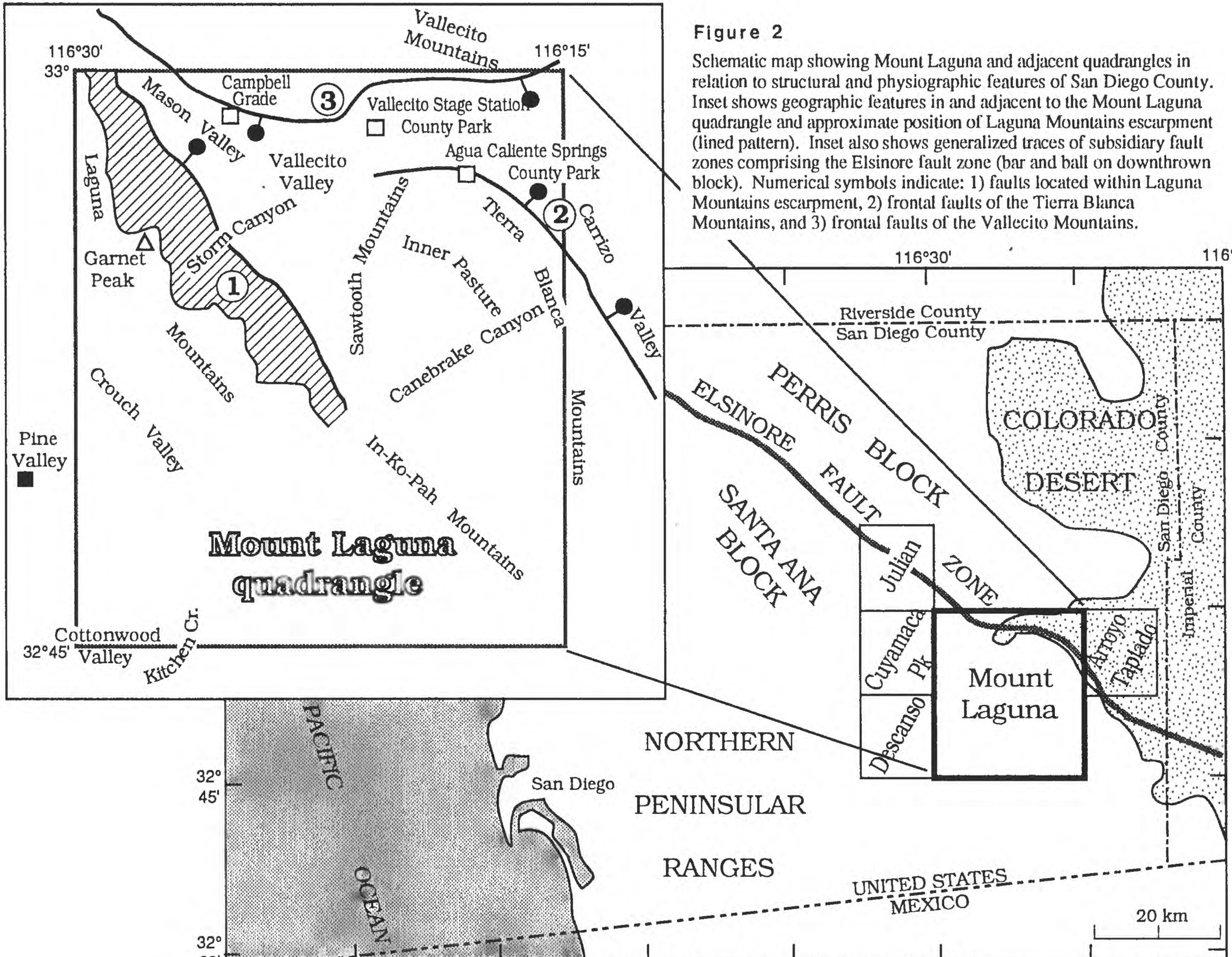


Figure 1. B. Generalized geologic map of southern part of San Diego County showing Mount Laguna quadrangle in relation to major post-batholithic, batholithic, and prebatholithic rock units.

Figure 2

Schematic map showing Mount Laguna and adjacent quadrangles in relation to structural and physiographic features of San Diego County. Inset shows geographic features in and adjacent to the Mount Laguna quadrangle and approximate position of Laguna Mountains escarpment (lined pattern). Inset also shows generalized traces of subsidiary fault zones comprising the Elsinore fault zone (bar and ball on downthrown block). Numerical symbols indicate: 1) faults located within Laguna Mountains escarpment, 2) frontal faults of the Tierra Blanca Mountains, and 3) frontal faults of the Vallecito Mountains.



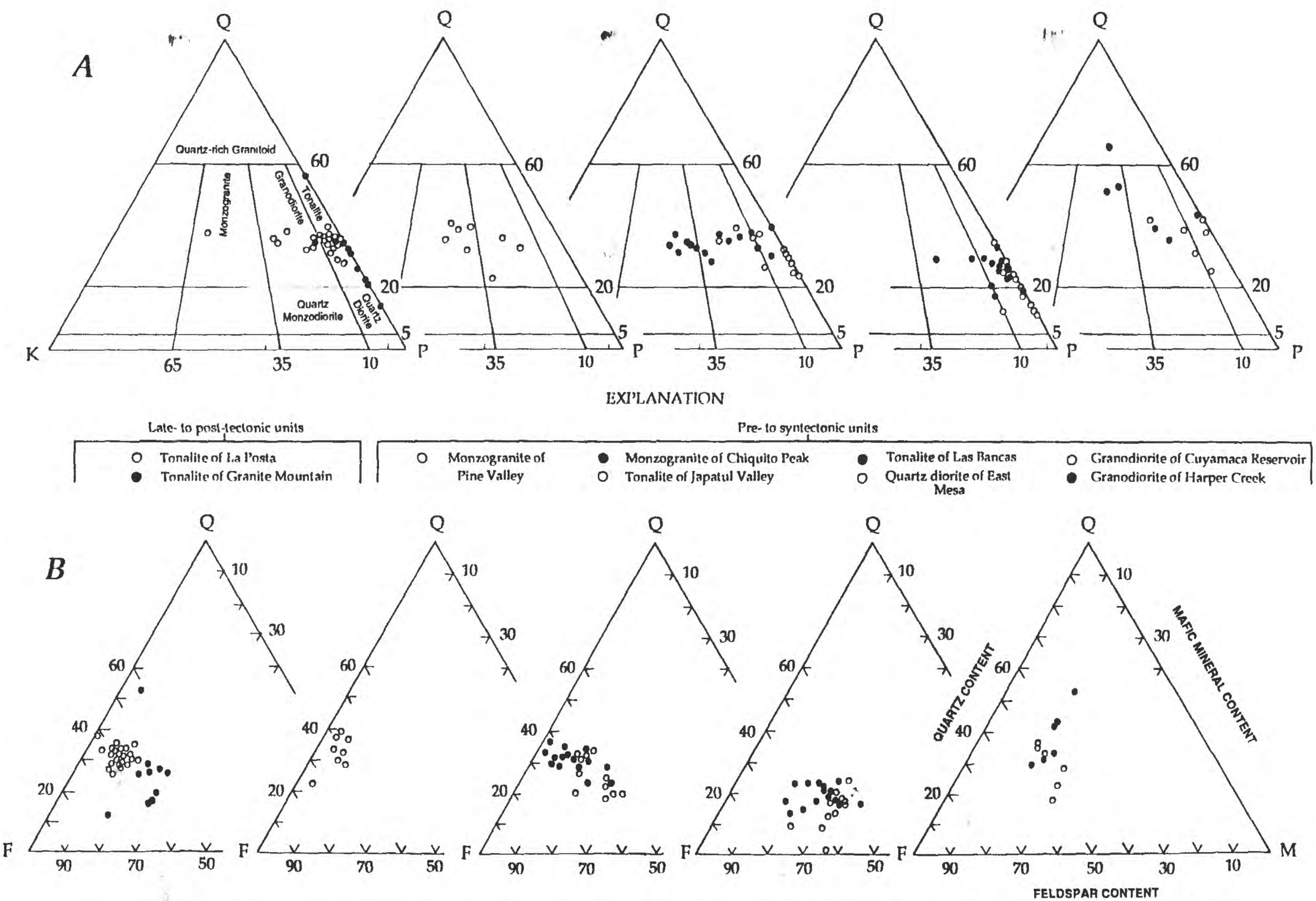


Figure 3. Ternary diagrams displaying modal analyses of plutonic rock units of the Mount Laguna and surrounding quadrangles; rock classification after Streckeisen (1973). A. Quartz (Q), potassium feldspar (K), plagioclase feldspar (P). B. Quartz (Q), feldspar (F), mafic minerals (M).

Table 1. Subsidiary fault zones of the Elsinore fault zone, Mount Laguna 15-minute quadrangle, California

Fault Zone	**Predominant type of movement**	**Age of youngest unit cut by faults**
Faults of Laguna Mountains escarpment	Dip-slip?, normal?	Late Pleistocene and Holocene
Frontal faults of Tierra Blanca Mountains	Dip-slip, normal	Holocene
Frontal faults of Vallecito Mountains	Dip-slip, normal; local right-lateral slip as much as 0.5 to 1.5 km?	Late Pleistocene and Holocene; Holocene?