PETROLOGY AND EMPLOYMENT OF THE
LONG POTRERO PLUTON: A TAIL OF ONE TONALITE

A Thesis
Presented to the
Faculty of
San Diego State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Geology

by
Harl Hoppler
Spring 1983
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Approved by:

[Signatures]
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CHAPTER I

INTRODUCTION

The Peninsular Ranges batholith is a complex igneous and metamorphic terrane covering approximately 35,000 square miles. It extends in a belt, which averages 60 miles in width, from the Transverse Ranges in southern California to approximately the 28th parallel in Baja California, Mexico. Lithologic variations in the igneous suite of rocks range from peridotite to granite, but tonalite and granodiorite are the principal rock types. Prebatholithic rocks consist of metavolcanic and metasedimentary units.

Many previous studies (Miller, 1937; Larsen, 1948; Everhart, 1951; Gastil and others, 1974; Silver and others, 1979; Todd and Shaw, 1979) have shown that the lithologies, geochemistry, and geochronology of these rocks vary consistently and systematically across the short axis of the batholith. In the paper by Gastil and others (1974) three sub-belts are recognized based on these variations. The western sub-belt consists principally of tonalite and granodiorite, but is characterized by the presence of gabbro plutons. The central sub-belt is defined by the absence of gabbroic rocks and the
presence of large zoned tonalite and granodiorite plutons. Also characteristic of this sub-belt is the presence of small muscovite- and garnet-bearing granitoid bodies which locally form the cores of the large zoned plutons (Walawender and others, 1983). The eastern sub-belt, which outcrops only in Mexico, is characterized by granodiorite and subsidiary amounts of granite. These suites of igneous rocks were intruded into volcanic and volcaniclastic rocks (Santiago Peak formation, Larsen, 1948) along the western margin of the batholith. Further inland the batholith intruded pelitic and quartz-rich sediments (Julian Schist, Hudson, 1922). The eastern slope of the batholith contains roof pendants of pelitic as well as carbonate rocks that may be as old as Ordovician (Gastil and Miller, 1981). The intrusion occurred during late Jurassic to mid-Cretaceous times.

The Long Potrero pluton is a circular zoned feature composed of a gradational sequence of tonalites and leucomylonites. It crops out approximately 35 miles east of San Diego (Fig. 1). The area studied covers about 40 square miles. Elevations in the study area vary between 1800' and 3200', but are in the upper half of the range in most places. Vegetation in the rolling bouldery terrain is dominated by mesquite and associated flora which thrive in the thin grussy soil of this semi-arid environment.
Figure 1
Location Map

San Diego
Tijuana
Ensenada
Mexicali
San Luis
Rattlesnakes, biting flies, ticks and the odd deer form the bulk of the native fauna. Man's contributions include cattle and a variable transient population of illegal aliens and pursuing Federal agents.

Other lithologies in the study area include gabbroic and associated rocks, granodiorite, and granitic dikes. Field relationships indicate that the gabbroic rocks are the oldest and have been intruded by the Long Potrero tonalites. The tonalite has in turn been intruded by the granodiorites whereas the granitic dikes intrude all units.

A gradational sequence of mineralogically and texturally related tonalites make up the Long Potrero pluton. The mineralogical variations include biotite-hornblende, hornblende-biotite, biotite, and muscovite-biotite (or two-mica) tonalites. An aplitic facies with a mineral assemblage identical to the two-mica facies is also present.

Previous geologic studies of the intermediate igneous rocks in the Peninsular Ranges batholith are limited. The classics (Miller, 1937; Larsen, 1948; Everhart, 1951) address the group in a regional sense, as does the mapping by Todd and Hoggatt (summarized in Todd and Shaw, 1979). More specific studies include zoned plutons described by Merriam (1941), Duffield (1968), Murray (1979), and Heaton
(1981). These features, however, do not have the unique combination of characteristics exhibited by the Long Potrero pluton. The tonalites described by Merriam are circular in outcrop pattern but are not comagmatic. Duffield's pluton shows less mineralogic variation and does not show the progressive concentric sequence seen at Long Potrero. The tonalites described by Murray also lack the variations in mineralogy whereas Heaton's pluton lacks a concentric pattern, and has mineral variations which are different from those observed at Long Potrero.

The purpose of this study was to determine the origin and emplacement history of the Long Potrero pluton and to help delineate the role of tonalitic plutons in the Peninsular Ranges batholith. Field mapping was carried out in 1977-78 and early 1983 using portions of the following U.S.G.S. 7 1/2' topographic maps; Morena Reservoir, Potrero, Barrett Lake, and Tecate. Aerial photographs were also used for additional control. 110 thin sections were prepared and analyzed using standard flat stage petrographic techniques. The I.U.G.S. system of igneous rock classification (Streckeisen, 1973) was used for all rock nomenclature.
CHAPTER II

PETROGRAPHY

COUNTRY ROCKS

The lithologies which are intruded by, or intrude into, the Long Potrero pluton range from basic to felsic in composition. The oldest units are the quartz norite and gabbronorites of Potrero Peak. This is intruded by the Long Potrero sequence, which is in turn intruded by granodiorites. Aplitic and pegmatitic dikes intrude all the older lithologies. No metamorphic prebatholithic rocks were mapped in the area.

The quartz norite-gabbronorite sequence is similar in part to rocks described by Lillis (1978) and Lillis and others (1979). The older quartz-bearing facies is thought to be the product of an early gabbro melt contaminated with siliceous country rock. Walawender and others (1979) document a similar unit in the northern Peninsular Ranges.

The quartz norite and gabbronorite are similar petrographically. A sodic bytownite (An\textsubscript{72-76}) forms the dominant mineral species. It is normally zoned, complexly twinned and generally euhedral. In the gabbronorite, prismatic pyroxenes are mantled in a thin rim of amphibole. Optical properties suggest that the species are
hypersthene and common hornblende, respectively. The quartz norite is similar but has quartz and biotite as additional interstitial phases. The quartz is present as small anhedral crystals (0.3 cm) and the biotite forms large poikilitic crystals that exceed 2.0 cm in most places.

The younger granodiorite crops out west of the Round Potrero. Similar to the Woodson Mountain granodiorite (Everhart, 1951) or Corte Madera granodiorite (Hoggatt and Todd, 1977), it is a coarse-grained biotite granodiorite to leucogranodiorite. Orthoclase and plagioclase are both present as large more or less euhedral crystals. Trails of anhedral quartz and biotite crystals define a weak foliation. Several roof pendants of tonalite and quartz norite are scattered along the contact.

The granodiorite grades into pegmatite and aplite dikes which intrude all other units. One small dike of nearly pure rose quartz crops out in McAlmond Canyon.

LONG POTRERO TONALITE

General

The tonalites of the Long Potrero pluton are divided into five mappable groups based on mineralogy and texture. The distribution of these units is shown on Plate I
(back pocket). The biotite-hornblende facies (biotite<
hornblende) forms the outermost ring of the pluton. It
consists of the two mafic minerals with plagioclase,
quartz and minor accessory and opaque minerals. The
hornblende-biotite facies is similar in gross aspect to
this outer facies, but biotite forms the dominant mafic
phase. This unit forms an inner ring within the pluton.
The biotite facies shows an increase in modal plagioclase
and particularly quartz and the disappearance of
hornblende. It crops out as an arcuate band within the
hornblende-biotite facies and is concave to the north-
northwest. The innermost facies is the two-mica rock
type. Its distinguishing feature is the presence of
primary muscovite and traces of interstitial and
myrmekitic orthoclase. It is more or less circular in map
view and forms the core of the pluton. The aplite facies
is mineralogically similar to the two-mica facies but is
finer grained and, based on field relationships, younger.
These mineralogical variations are summarized in Figure 2.

Based on mineralogical, textural, and structural rela-
tionships these rocks can be divided into two synplu-
tonic groups. The biotite-hornblende and hornblende-
biotite facies are gradational and form the older group.
The biotite and both subdivisions of the two-mica rock
type are also gradational and form the internal and
Figure 2
Minerologic Variation, Long Potrero Pluton
younger group. Both groups, however, while mineralogically somewhat different, are thought to be comagmatic and therefore gradational. Modal abundances are listed in Appendix A.

**Biotite-hornblende Facies**

The biotite-hornblende facies of the Long Potrero pluton is a biotite-hornblende tonalite which also contains minor amounts of epidote, opaques, and, locally, pyroxene. The rock is hypidiomorphic granular and coarse-grained.

The least abundant mafic mineral is biotite, which is present as two phases. The most obvious phase in hand sample is the large (to 0.6 cm) subhedral to anhedral crystals which help define foliation. Viewed under the microscope, the mica exhibits normal tan to brown pleochroism without evidence of zircon and the associated halos. Small prismatic crystals of plagioclase are commonly poikilitically included. Extinction is normal for this mineral species and shows no distortion. Cleavage is likewise undisturbed. Some resorption may be indicated by corroded crystal faces and edges. The smaller phase of the biotite occurs as anhedral interstitial blebs (to about 0.2 cm) which are also foliation defining. Neither phase forms as coronas or reaction rims on other mafic phases.
Common hornblende is slightly more abundant than biotite and is also present in two modes with a size distribution similar to the mica phase. Larger (to 0.7 cm) subhedral to rarely euhedral crystals are weakly aligned in the rock. The amphibole has optical properties consistent with common hornblende (high 2V, optically negative, and pleochroism in tan to dark green). Plagioclase crystals are also poikilitically enclosed by the amphibole. Compositional zoning is indicated by color zonation that is also reflected in the pleochroism. The largest crystals often exhibit sieve-like textures and have scarce relict orthopyroxene cores. Those mineralogical and textural relationships are confined to samples taken from the outer margins of the pluton. The smaller interstitial phase exhibits optical properties similar to the rims of the larger crystals. They are anhedral and range to about 0.1 cm in maximum dimension.

The quartz in the rock exists as an interstitial phase. In general it forms subequant anhedral blebs whose long axes are parallel to the plane of foliation. Locally, the blebs form optically continuous masses which poikilitically enclose the other minerals. The individual crystals vary to 0.3 cm whereas the large poikilitic bodies usually exceed 1.0 cm in length. Extinction shows the typical slight waviness normal to quartz.
Plagioclase is the dominant mineral constituent of the rock. Crystals vary to 0.5 cm in maximum dimension. Larger crystals are typically subhedral to euhedral, with smaller crystals forming an anhedral interstitial phase. The crystals exhibit weak normal zoning with a slightly oscillatory character. The rim of the crystal is typically about 0.05 cm in width, is markedly more sodic, and shows no compositional zoning. Composition ranges from An_{42-44} in the core to An_{28-32} on the rims (as determined by the Michel-Levy technique). The cores of the crystals and, to a limited extent, the more calcic zones in the phenocrysts show moderate to slight resorption. This is evidenced by embayment in the cores and in areas where the zoning is relatively calcic. These corroded areas are commonly the site of late-stage mafic mineral crystallization. Epidote may also be present. Trace amounts of opaques and epidote are present throughout the rock.

The texture of this facies is consistent over the area of its outcrop. Composition varies from the outer boundary of this facies to its gradational contact with the hornblende-biotite facies. An overall increase in the silica content is indicated by the disappearance of pyroxene, a decrease in overall mafic minerals, and an increase in quartz.
Hornblende-biotite Facies

The hornblende-biotite facies of the Long Potrero pluton is a tonalite which grades to a leucotonalite at its interior margin. Mineralogy is similar to the biotite-hornblende facies except that biotite exceeds hornblende in modal abundance and there are trace amounts of sericite.

Hornblende, as the subordinate mafic phase, is virtually identical in its properties to the amphibole in the biotite-hornblende facies. Significantly, the modal abundance of this species drops to zero, which defines the inner contact of the facies. This progressive modal decrease is also marked by a progressive size decrease in the amphibole phenocryst toward the inner contact. The interstitial phase of the mineral also disappears, although this occurs away from the inner contact. The compositional zoning becomes less marked and no pyroxene relicts or sieve textures are present.

The biotite present in this facies is also virtually identical to that in the outer facies. No change in texture or optical properties was noted, only the increase in modal abundances.

Quartz also increases progressively through this facies. In general the phenocryst size also increases slightly. No evidence of optical or crystallographic
continuity between the blebs was noted. One additional optical quality noted was the degree of post-crystallization strain, as evidenced by the extinction pattern of individual grains. Marked waviness in the extinction, including something resembling the hourglass extinction common to some pyroxenes (Kerr, 1959), is present.

Plagioclase abundance remains about the same through this facies. Optically it is similar to the feldspar found in the biotite-hornblende facies. Phenocryst size and composition are also similar. Resorption phenomena are present although they appear slightly less pronounced. Also different is the slight thinning of the outer-most sodic compositional rim. Trace amounts of sericite are also locally present, usually at the resorption sites.

**Biotite Facies**

This facies is characterized by the presence of biotite as the only mafic mineral. The exposure of this rock type is limited to a slightly arcuate band trending west-northwest across the pluton (Plate I, back pocket). Compositionally it is a leucotonalite and the texture is hypidiomorphic granular.

The biotite is optically similar to that previously described. It has better crystal habit, being subhedral to euhedral, and has the same size distribution. Inclu-
sions of prismatic plagioclase are still common. Trace amounts of zircon are now found, as well as the pleochroic halo common to the association. Locally the biotite grades to chlorite and exhibits minor kinking or strain of cleavage planes.

The occurrence of quartz is also similar to that previously described. Interstitial subequent blebs to one-half centimeter are the norm. The extinction shows increasing post-crystallization strain with fairly sharp bands of extinction which sweep across the mineral.

More than half the rock is still composed of plagioclase. Subhedral to euhedral crystals range to 0.4 cm in length. Albite, carlsbad, and pericline twinning is present. Weak normal to slightly oscillatory zoning and noticably more sodic rims are also present. Composition of the crystals ranges from An$_{30-32}$ in the cores to An$_{18-20}$ on the rims. Resorbtion of the more calcic zones and the core is evidenced by corrosion and embayment in these areas. Traces of epidote and, more rarely, sericite are found at these sites.

Two-mica Facies

This facies is texturally similar to the biotite facies and varies mineralogically only with the addition of primary muscovite.
The muscovite is present as anhedral to subhedral booklets with a maximum length of 0.2 cm. Sericite is also present although slightly less abundant.

Strain in the quartz of this facies reaches its maximum. The separation of distinct optical domains within the quartz gives a protoclastic texture to the rock. This protoclasis is also exhibited by the plagioclase to a limited extent. Minor fracturing and albite twin plane deformation is present. Otherwise, the plagioclase is similar in optical properties to those in the biotite facies.

A late-stage textural variation of this lithology is an aplitic two-mica leucotonalite. It crops out entirely within the main body of the two-mica leucotonalite. Plagioclase and biotite are porphyritic in a fine-grained sugary groundmass composed mostly of plagioclase and quartz. Traces of muscovite, biotite and alkali feldspar are also present as groundmass constituents.

**Inclusions**

Inclusions in the igneous rocks of the Peninsular Ranges batholith are virtually ubiquitous and something of a puzzle. Two specific studies (Hurlbut, 1935; Howard, 1978) address them and their origin. Due to their
similarly and dispersion through all units except the aplitic facies, their petrography is covered in one heading.

The texture of the inclusions is similar in all facies. Phenocrysts of plagioclase and biotite are distributed through a fine grained recrystallized groundmass. The mineralogy of the groundmass includes plagioclase, biotite, quartz, + hornblende, + pyroxene, and + muscovite. The latter phases occur in the inclusions' groundmass only if present in the host facies.

Distribution and morphology of the inclusions is covered in the next section.
CHAPTER III

STRUCTURE

The development and expression of structure in igneous rocks may relate to several processes. The composition, emplacement, cooling history and subsequent deformation of a given pluton can all affect its structure. This structure can be defined by the presence of mineral layering, foliation, or lineation, the morphology of the body and its relation to the surrounding country rocks, and the joint pattern which can be related to its cooling and/or post-solidification history.

The outline of the Long Potrero tonalite is roughly circular. The southwestern margin and concentrically zoned lithologic variations show a slight flattening along a N70W trend giving the circularity a slightly lopsided aspect. Mineral foliation, lineation, and zonation, in part define this structural pattern. The distribution and orientation of the inclusions within the various facies of the tonalite also reflect this circularity, as do the joint patterns and general topographic expression of the pluton.

All of the mineral phases in the pluton show some degree of orientation. The degree to which the minerals
are oriented is related to their crystal habit. Foliation is well defined by the platy phenocrysts of biotite. Lineation, and to a lesser extent, foliation are defined by prismatic hornblende and plagioclase. These minerals all existed as early crystallization products in the melt. The minerals which crystallized as interstitial phases (notably quartz) only weakly define the foliation.

These fabrics are the result of orientation of minerals during the emplacement of the Long Potrero pluton. Figure 3 shows diagrammatic representations of the types of intrusive flow patterns (after Mackin, 1947) which would orient the minerals.

Convergent flow (Fig. 3A) is characterized by a decrease in cross-sectional area through which a flow proceeds. As the area decreases (or the constriction increases) the velocity of the flowing material increases. This creates the flow gradient which orients the platy or tabular minerals.

Somewhat analogous is differential lamellar flow (Fig. 3B). A fluid moving along a stationary interface (in this case magma along a wall rock) will be slowed by friction. This slowing decreases away from the interface again causing a velocity gradient. A similar orientation of minerals results.
Figure 3
Intrusive Flow Patterns
Duffield (1968) further describes a process which offers an explanation for the production of the lineation noted in the tabular minerals. Tabular particles subjected to a medium undergoing differential lamellar flow tumble during the flow. The rotation of the particles is fastest when their long axes are perpendicular to the flow. Thus at any given time a majority of particles will have their long axes parallel to the direction of flow, producing a lineation. This process also reinforces foliation in platy minerals.

Measurements taken on the foliation near the outer margins of the biotite-hornblende and two-mica facies and those in the biotite facies tend to be better developed, that is, the degree of alignment of the biotite crystals tends to be better. The hornblende-biotite facies' foliation is less well-defined. As one goes toward the center of the outcrop of the two-mica facies, the degree of foliation drops significantly. In most places the foliation is only weakly defined and may be absent. If present, it may lack the concentric pattern developed in the other facies.

Hornblende crystals also define foliation, although not as clearly. The tabular habit of the amphibole is less strongly affected by the flow regimes. Sections of hornblende parallel to the b-axis more frequently define a
near vertical or steeply plunging lineation. It is also developed best near the outer margin of the pluton. This is partially due to the distribution of the largest crystals in these areas.

Plagioclase is also a mineral with a tabular crystal habit. It is less evident in outcrop and therefore less likely to be observed for measurement. And, as it is relatively equant normal to the b-axis, it tends to define only lineations. The attitudes taken on plagioclase crystals are consistent with those taken on other species.

As noted in the petrography section, the contacts between the various facies of the tonalite define a circularity coincident with the pattern of foliation. Such a pattern indicates slow inward migration of the solidus surface without any major disruptive movement oblique to the contents.

Inclusions in the tonalite are also parallel to the foliation. Lineation may also be measured if the outcrop face containing the inclusions is parallel to the foliation plane. The inclusions in the tonalite are variably distributed and have a range of morphologies. The mineralogy also varies, but is limited by the host facies as previously described.

The greatest concentrations of inclusions occur near the outer contact of the biotite-hornblende facies and
generally constitute only a few percent of the rock. The concentration of inclusions decreases toward the center of the pluton, becoming rare in the two-mica phase (<1%). Inclusions do not occur in the aplite facies.

The shape of the inclusions seems to reflect a degree of deformation which decreases toward the core of the pluton. The inclusions found in the two-mica and biotite facies are typically shaped like slightly flattened ellipses. The long axis is typically 30 cm or less in length and is parallel to lineation. The intermediate axis is usually within the foliation plane. The inclusions becomes increasingly discoid toward the edge of the margin although the length to width ratio in the foliation plane does not change substantially.

The joint pattern in the pluton shows a marked circularity, again paralleling the general concentric patterns previously described. Topographically, an expression of circularity is also present. Long Potrero is a valley coincident with the center of the pluton. Arcuate ridges concave toward the valley flank the topographic low. The expression of those ridges is subtle but persistent, particularly going to the east. Hauser Mountain is a series of these low relief features, all concave to the west. Both the jointing and related topographic pattern would
suggest the development of cooling joints parallel to the pluton margins.
The interpretation of the emplacement history of a given igneous body is, for obvious reasons, based on empirical data. These data and their interpretation may be supported by observations of systems whose processes are similar. Experimental data (Grout, 1945; Ramberg, 1970) simulate intrusive processes in the laboratory. The study of salt domes and their environs (Braunstein and O'Brien, 1968; Sorgenfrei, 1971; Talbot, 1978) document analogous emplacement processes in nature. By analyzing the petrography and structure of the Long Potrero pluton and comparing the observed phenomena with the types of models just mentioned and other field studies as well, an emplacement history can be derived.

The petrography and structure of the Long Potrero pluton indicate that a relatively simple sequence of events led to its formation. This sequence includes differentiation at depth and subsequent diapiric upwelling and emplacement at the observed erosional level.

Without geochemical data, statements about the source of the parental melt can only be made by analogy. Silver and others (1979) have compiled significant data about a
portion of the Peninsular Ranges batholith that includes the study area. The data includes substantial geochemical information and its interpretation. Based on various aspects of this data two igneous terranes are delineated. A western group characterized by older isotopic emplacement ages, diverse lithologies, and low initial strontium ratios, to mention some of the characteristics. This is in contrast to the eastern group's younger ages, limited lithologic range, and higher initial strontium ratios. These groups correspond approximately to the western and central sub-belts of Gastil and others (1974). As mapped, the Long Potrero tonalites are near the eastern margin of the western group. Characteristics of this group indicate that the source material for the parental melt was the mantle wedge overlying a subducting oceanic crustal fragment (Silver and others, 1979).

Mineral phases present at the time of emplacement include plagioclase, hornblende, and biotite. Subhedral to euhedral crystals, depending on the facies, are distributed throughout the pluton. These phases began crystallizing at some depth greater than the current erosional level as evidenced by their fabric. The textures and relict features exhibited by the hornblende and plagioclase support an even earlier crystallization episode. Relict pyroxenes at the cores of hornblende in
the marginal portions of the pluton support this hypothesis, as do the prismatic plagioclase inclusions in the hornblende and biotite phases. Other manifestations of early crystallization are supported by their optical properties as well. Compositional zoning is evident in both the hornblende and plagioclase. Early crystallization and subsequent differentiation of the magma, as well as changing pressure and temperature conditions during upwelling, would be responsible for the zoning and/or resorption features.

Applying the crystallization sequence observed to experimental data compiled by Naney (1978), limitations on the water content of the magma and pressure regime at the level of emplacement can be derived. The data was originally derived for melts whose compositions were granodioritic. At a pressure of 2 kb the range of water saturations for the Long Potrero magma would be 3.5 to 5.0 percent. The range increases to 3.5 to 11.0 percent with a pressure increase to 8 kb. These represent maximums, as no evidence for a vaporous water phase (e.g. pegmatites) is found in the field. Other work in the area indicates that the pressures involved are probably in the 2 to 5 kb range (Berggreen and Walawender, 1978; Hagen, 1979; Walawender and Smith, 1980).
The upwelling and subsequent emplacement of this magma can best be modeled after tailed or tadpole intrusions (see Pitcher, 1979, for a comprehensive discussion on the emplacement processes of granitic plutons) analogous to the diapirism of salt domes. Figure 4 diagrammatically represents this sequence. No scale is implied in the diagram in that the outer margins of the pluton have not been mapped. The tonalites of Long Potrero extend well beyond the mapped area to the north and southeast. More recent intrusions mask the extent in other directions. The exposed two-mica and biotite facies of the pluton form the core (and probably central portion) of the original intrusion whose volume was substantially greater than the current outcrop indicates. This central portion of the pluton, as mapped, would be where the tail of the tadpole, formed during initial upwelling, catches up with and intrudes the main body of the pluton.

The structural elements of the Long Potrero pluton support this diapiric intrusion hypothesis. The passage of the diapir through the country rock would tend to produce the flow regimes as presented in Figure 3. Near the head of the tadpole convergent flow would tend to align the inclusions and various mineral phases. This fabric would be reinforced and added to as the more or
Figure 4
Emplacement Sequence, Long Potrero Pluton
less cylindrical body of the pluton flowed through the area breached by the intrusion.

As the magma rose to its current, and now exposed level, it would have been undergoing cooling due to the temperature differential between the magma and country rock. This cooling could be manifested in several ways. Cooled margins, porphyritic in texture and relatively dark (i.e. less-differentiated) would form around the pluton. These margins would tend to form preferentially at the top of the intrusion since there the temperature difference would be the greatest. The change in flow regime from convergent to lamellar with the progress of the magma toward the surface could then reincorporate portions of the chilled margins to form the inclusions seen throughout the tonalite. The resultant magma would tend to become somewhat vertically stratified mineralogically and cause a chemical gradient to be established. The volatiles and more felsic elements in the magma would tend to migrate toward the center of the intrusion and down toward its tail.

This process would help explain several observed phenomena within the body of the tonalite. The high concentrations of inclusions in the marginal facies would be the result of their almost in situ formation. Their ability to move back into the magma chamber would be
limited by the velocity gradient increase away from the margins of the intrusion. It would also tend to explain the mineral species present in the inclusions relative to their host as they are essentially cogenetic. The change in mineralogy across the now exposed tonalites would also result from the flow patterns and mineral distributions resulting from diapiric upwelling. As the magma goes through the initial stages of differentiation at the top of the chamber the volatiles would be concentrated inward. This inner magma would become increasingly felsic as the magma progressed upward because of this differentiation. Central portions of the chamber would also tend to catch up with the early crystallized phases not only due to the established velocity gradient but also due to the ultimate cessation of upwelling. These factors together would result in the intrusion of the silicic more-differentiated tadpole tail into its own less-differentiated head.

When vertical motion of the pluton had stopped the inward migration of solidus surface would be the dominant process acting on the magma (Fig. 4C). The less-differentiated marginal facies would crystallize zoned plagioclase and hornblende and, in limited space, subhedral biotite. Inward progression of the solidus would crystallize increasingly euhedral biotites, the small hornblendes related to the rims of the zoned
marginal phase, and increasing amounts of quartz. Volatiles would continued to be concentrated inward.

As the solidus migrated inward, the volume of the chamber would be reduced in a non-linear fashion. This change in the volume of the magma could be manifested as the strain phenomena seen to increase toward the core of the pluton. This strain might also be the result of, or concurrent with, the last magmatic event, the intrusion of the aplitic facies. The volume of rocks involved in this last phase of magmatism is small and crosscuts the poorly defined foliation of the two-mica tonalite. The texture of an aplite can be produced by pressure quenching and could be the result of venting of this magma fraction, if not to the surface, at least through the tonalite to a higher level.

Conclusions

The sequence of tonalites observed at Long Potrero appear to be the result of a complete intrusive event. The upwelling, emplacement, and cooling of the magma is represented by the changes in mineralogy and texture across the outcrop of the body. Interpretation of the processes involved in the generation of these changes may place some limits on the evolution of the Peninsular Ranges batholith.
The differentiation processes involved in the emplacement of this pluton indicate that a distinctly leucoocratic rock can be generated from a relatively mafic magma. However, the virtual absence of potassium feldspars with this degree of differentiation is surprising. Although the volume of the original magma and its full lateral extent are unknown, they are substantially greater than the study area. This large volume of material has produced only trace amounts of orthoclase. If this magma type is consistent throughout the batholith, the inability of these tonalitic magmas to produce rocks with substantial k-spar fractions suggests that a separate parent melt is necessary for the production of orthoclase-bearing (granodioritic) rocks. Many authors, from as early as Larsen (1948) to much more recent works (Nishimori, 1976), have argued that the large-scale differentiation of all the rock compositions of the Peninsular Ranges batholith arose from one vast parent melt. Based on the limited potash enrichment in the Long Potrero pluton, this would not seem to be the case.

Limits on post-emplacement deformation of the Peninsular Ranges batholith can also be derived. Regional deformation of the batholith as a whole has been postulated by Todd and her co-workers (Todd and Shaw, 1979).
The area mapped for this study is south of the main thrust of the aforementioned mapping by about five miles. However, no evidence for the disruption of this circular zoned pluton can be seen. Deformation on a small scale (cleavage disruption and extinction phenomena) can be related to synplutonic processes. Unless the deformation predates the emplacement of this pluton, its effects are not present in the study area.
REFERENCES CITED
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Hagen, R.A., 1979, Depth of emplacement and fractionation models for the aplitic rocks of the Woodson Mountain granodiorite [Undergraduate research report]: San Diego, California, San Diego State University, 38 p.


APPENDIX
### APPENDIX A

### MODAL DATA

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ABSTRACT
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The Long Potrero pluton is a zoned circular feature whose composition grades inward from pyroxene-bearing biotite-hornblende tonalite to biotite-muscovite leucotonalite. It is part of a much larger composite tonalite body whose margins are not fully defined. Textural and structural data indicate that the pluton was emplaced by diapiric upwelling. This diapirism was accompanied by differentiation involving plagioclase, hornblende, and to a limited extent biotite. This produced a more basic (i.e. less-differentiated) head on the diapir and more felsic tail. As the magma intruded to the present erosional level, the differentiated tail of the diapir caught up with, and intruded, its own head forming the zoned structure. No evidence for post plutonic deformation of the pluton could be found. This tonalitic magma did not differentiate to form granodioritic rocks and suggests that a separate parent melt is necessary for the production of these more silicic plutons in the Peninsular Ranges batholith.
Plate 1
GEOLOGY OF THE LONG POTRERO PLUTON
H. HOPPLER
1983

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H. HOPPLER
1983

Harl Hoppler
Petrology and emplacement of the Long Potreró pluton - a tail of one tonalite