INTRUSIVE RELATIONS OF THE BATHOLITH OF SOUTHERN CALIFORNIA NEAR BONSALL, CALIFORNIA

by

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Professor of Geology

January 16, 1959

Date
TABLE OF CONTENTS

Introduction --------------1
Setting and Objectives --------------1
Acknowledgements --------------2
Basement and Plutonic Rocks --------------3
General Statement --------------3
Metamorphic Rocks --------------4
Volcanic Rocks --------------6
Intrusive Rocks --------------7
Structural Features of the Metamorphic Rocks --------------13
Original Structures --------------13
Imposed Structures --------------14
Cleavage --------------14
Joints --------------15
Contact Features --------------15
Structural Features of the Granitic Rocks --------------16
Oldest Structures --------------16
General Statement --------------16
Inclusions --------------16
Linear Flow Structures --------------17
Platy Flow Structures --------------18
Transition Structures --------------19
General Statement --------------19
Shear Zones --------------19
Gneissic Borders --------------19
Fracture Structures --------------22
General Statement --------------22
"Feather" Fractures --------------22
Cross Joints --------------23
Flat Lying Normal Faults --------------23
Regional Structural Pattern --------------24
Resumé of Pre-Cretaceous Structures --------------24
Cretaceous Intrusive Structures --------------24
San Marcos Gabbro --------------24
Bonsall Tonalite --------------25
Green Valley Tonalite --------------27
Woodson Mountain Granodiorite (Central Body) --------------27
Woodson Mountain Granodiorite (Eastern Body) --------------28
Regional Structures --------------28
Steep Primary Fractures --------------29
General --------------29
Local Curving of Joints --------------30
Regional Joint Pattern --------------30
Relative Age of Joints -----------------------------------32
Movement ---------------------------------------------------41
Upward Motion ---------------------------------------------41
Horizontal Shift -------------------------------------------41
On Northwest Structures -----------------------------------41
On North-Northeast Structures -----------------------------42
On North-Northwest and East-Northeast Structures ---------42
Problem of Intrusion --------------------------------------43
Background -------------------------------------------------43
Mechanics of Emplacement and Space Problem ---------------44
Magmatic Stopping -----------------------------------------44
Forceful Injection -----------------------------------------45
Tectonic History ------------------------------------------46
Magma Source ---------------------------------------------51
Summary and Conclusions ----------------------------------52
Bibliography ---------------------------------------------55
TABLE OF PLATES

<table>
<thead>
<tr>
<th>Plate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Index map</td>
<td>Frontispiece</td>
</tr>
<tr>
<td>2. Structural features of Bonsall tonalite</td>
<td>11</td>
</tr>
<tr>
<td>3. General outcrop view and arrangement of inclusions in Bonsall tonalite</td>
<td>21</td>
</tr>
<tr>
<td>4. Transition structures in tonalite screen</td>
<td>22.2</td>
</tr>
<tr>
<td>5. Contour Diagram of Jointing in Central Body of Woodson Mountain granodiorite</td>
<td>34</td>
</tr>
<tr>
<td>6. Contour Diagram of Jointing in Eastern Body of Woodson Mountain granodiorite</td>
<td>36</td>
</tr>
<tr>
<td>7. Contour Diagram of Jointing in Bonsall tonalite along Moosa Canyon</td>
<td>38</td>
</tr>
<tr>
<td>8. Contour Diagram of Jointing in Bonsall tonalite screen</td>
<td>40</td>
</tr>
<tr>
<td>9. Sections A-A' and B-B'</td>
<td>56</td>
</tr>
<tr>
<td>10. Sections C-C' and D-D'</td>
<td>57</td>
</tr>
<tr>
<td>11. Tectonic map</td>
<td>pocket</td>
</tr>
</tbody>
</table>

TABLES

1. Summary of Igneous and Metamorphic Rocks | 4
Intrusive Relations of the Batholith of Southern California near Bonsall, California

INTRODUCTION

Setting and Objectives.

Various structural studies have been made in the Sierra Nevada of California within the past twenty to thirty years by several investigators. No detailed ones however, as can best be determined, have been made in the Batholith of Southern California. Therefore, it is the intention of this paper to present the results of a structural study of a restricted area in this batholith.

Specifically, the area (Pl. 1) encompasses approximately seven square miles of the Peninsular Range Province immediately southeast of Bonsall, California in T10S, R3W and T11S, R3W (Pl. 11). It is limited on the west by the San Luis Rey River, on the north and south by Moosa Canyon and Gopher Canyon and to the east by the South Fork of Moosa Canyon.

The conclusions arrived at for the emplacement of the intrusive masses in the Sierra Nevada have favored either a forceful emplacement or one that has been a "permissive" intrusion, tectonically controlled\(^1\). In contrast, in this portion of the Southern Batholith, it has been determined that forceful emplacement together with magmatic stoping have been

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the important methods of plutonic entry into the crust. Such differences however, do not preclude there being certain inherent elements or forces common and necessary to both areas.

The area in question is underlain by Triassic and Jurassic metamorphics and volcanics which have been repeatedly intruded by Cretaceous intrusives. As the area is predominantly made up of these latter intrusions, the system originated by Cloos for studying granite tectonics and outlined by Balk\(^2\) has been followed. Using the data accumulated the objectives of this paper are: (1) to define the intrusive structures of the Cretaceous crystalline rocks; (2) to outline the superimposed regional fracture pattern; (3) to interpret the influence of regional structures on localizing these intrusions; and (4) to discuss, as far as the data permits, the problem of emplacement.

In order to arrive at these objectives the crystalline rocks will be described in brief and the structural patterns will be treated in some detail. After the presentation of these facts the general picture will be developed and discussed. The general presentation and development will be patterned after a paper published by Mayo\(^3\).

Acknowledgements.

The author wishes to express his grateful appreciation to Dr. W. C. Lacy of the University of Arizona for the time and assistance he has cheerfully afforded on various occasions in the preparation of this manuscript. In addition I would like also to express my appreciation to all those members of the faculty of the Department of Geology who have aided me by supplying needed material or advice.

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BASEMENT AND PLUTONIC ROCKS

General Statement:

The Batholith of Southern California has been mapped and studied petrographically in some detail by Larsen. Megascopic examinations of these rocks in the field have encountered no reason to question this work and in large part the following descriptions of the rock types are based on those descriptions noted by Larsen.

The batholithic and basement rocks mapped in the area of investigation are composed of metamorphic, volcanic and intrusive types. The metamorphics are considered to be Triassic in age on the basis of fossil evidence. The volcanics are Jurassic in age and have undergone some mild metamorphic effects but their general nature is clear. The intrusive rocks are mostly Cretaceous in age with the exception of one small Jurassic plug.

The Triassic and Jurassic metamorphics, volcanics and intrusives formed the host complex for the later Cretaceous intrusions and are now encountered only as irregular remnant bodies. The metamorphics are however, frequently seen elsewhere in the Peninsular Range Province as drawn out screens or ribs separating intrusive bodies or included within them. The Cretaceous intrusive bodies have been emplaced in order of ascending acidity and are seen as the normal products of a differentiating magma.

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4. Esper S. Larsen, Jr., Batholith and Associated Rocks of Corona, Elsinore and San Luis Rey Quadrangles Southern California, Geol. Soc. Am., Mem. 29 (1948)
### Table 1. Summary of Igneous and Metamorphic Rocks

<table>
<thead>
<tr>
<th>Age</th>
<th>Name</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cretaceous</td>
<td>Woodson Mountain granodiorite</td>
<td>coarse-grained granodiorite</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Green Valley tonalite</td>
<td>medium-grained tonalite</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Bonsall tonalite</td>
<td>medium-grained tonalite containing numerous oriented inclusions</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>San Marcos gabbro</td>
<td>generally a medium-grained, hornblende rich gabbro.</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Santiago Peak intrusives</td>
<td>fine-grained granodiorites associated with the volcanics, mildly metamorphosed</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Santiago Peak volcanics</td>
<td>primarily andesites and quartz latites, metamorphosed.</td>
</tr>
<tr>
<td>Triassic</td>
<td>Bedford Canyon formation</td>
<td>medium-grained quartz-mica or mica schists</td>
</tr>
</tbody>
</table>

**Metamorphic Rocks.**

The metamorphic rocks exposed in this area have been assigned to the Bedford Canyon formation of Triassic age. Where exposed in this area they appear generally as medium-grained, quartz-mica or mica schists. Elsewhere in the nearby region however, this formation has been observed to be made up of slate grading to phyllite, argillites or quartzites. Limestones are also reportedly encountered in the formation but have not been personally observed. Within the area studied the rock is made up primarily of quartz, plagioclase and orthoclase feldspar.
plus biotite and muscovite. Original sediments appear to have been predominantly shales and pure to impure sandstones.

The grade of metamorphism present is variable. To the north in the Santa Ana Mountains where the formation was named and dated the metamorphism is low grade. To the east and southeast the grade of metamorphism increases. South of the Santa Ana Mountains, i.e., here, within the comparatively small bodies existing as screens or ribs, the metamorphism is sometimes quite intense. In some cases these rocks appear as coarse-grained, highly injected gneisses.

The Bedford Canyon formation in this area, as compared to the majority of these smaller southern bodies, does not follow the usual pattern. Instead it appears in two, small, irregularly-truncated bodies in sections 2, 3 and 4 T11S, R3W and sections 33 and 34 T10S, R3W (Pl. 11). These two bodies are separated by a northeast trending pluton of San Marcos gabbro.

The western remnant in sections 33 and 34 has been fairly strongly jointed and locally carries thin pegmatites or aplites along the joint planes. To the east it has been intruded by west-northwesterly and northeasterly dikes of granodiorite, which locally pinch and swell but average about 15' in thickness. Toward their limits of penetration they taper out. In a restricted halo around these dikes recrystallization effects have changed the texture of the quartz-mica schists into that of a granitic appearing rock. The eastern body of metamorphics is concealed.

Volcanic Rocks.

The volcanic rocks exposed in the area are part of the Santiago Peak volcanics, named from their exposure on Santiago Peak in the Santa Ana Mountains. According to Larsen their age is Jurassic as based on their unconformable relationship to the underlying Triassic sediments. However, a similar unconformity between Triassic metasediments and later andesites was studied by Knopf in 1918 in the Inyo Range. Evidence collected by Knopf points rather conclusively to a Middle or Late Triassic age for those volcanics. Likewise, there are indications that the metasediments and volcanics of the southern Sierra Nevada may be correlative to similar units encountered in the northern portion of the southern batholith. Consequently, it would appear that present day age concepts for the Batholith of Southern California may be subject to revision. Such revisions would make the whole age picture clearer and more reasonable.

These volcanic rocks where exposed in this area are generally quartz latites or andesites, although minor amounts of rhyolitic material have been encountered. The groundmass is characteristically aphanitic and the rocks are usually dark gray to greenish gray. These volcanics are believed to represent former extensive and thick deposits of flows, tuffs and breccias.

Within the area studied there are two bodies of the volcanics left. They occur in sections 29, 30, 31 and 32 and are separated from each other by a narrow screen of tonalite.

Contact metamorphism of the volcanics is noticeable, particularly around the smaller of the two remnants. Around this body, which outcrops poorly, there are occasional occurrences of a light-colored, coarse-grained granitic appearing rock believed to represent recrystallization of the volcanics. Petrographic work to support this has not been done. The width of this zone of contact effects, if such is the case, is indeterminable due to the lack of good outcrops.

**Intrusive Rocks.**

The various types of intrusive rocks present in the area will be discussed briefly commencing with the oldest. Since there is a question as to the age of these rocks, they will be referred to as Jurassic or Cretaceous but may well be somewhat older i.e., more closely conforming with the age of the material in the Sierra Nevada.

The oldest intrusive body is a small granodiorite plug located in section 34. This body is Jurassic in age, being associated with the volcanics previously described. Where encountered these bodies are known as the Santiago Peak intrusives. They are fine-grained in texture, gray colored and frequently carry "peculiar long, irregular prisms of amphibole". Where mapped here the body has intruded the Bedford Canyon formation and later been truncated slightly on the north by the Woodson Mountain granodiorite.

The San Marcos gabbro according to Larsen "appears to be the oldest rock of the Cretaceous (?) batholith". It was intruded early into the metamorphic complex and has since been affected adversely by all

9. Esper S. Larsen, Jr., op. cit., p. 28
subsequent intrusions. Miller describes the gabbro as follows:

"The gabbros are divided primarily into three groups—olivine rocks, norites, and quartz-biotite norites—but each type is subject to local or widespread enrichment in hornblende. The result is a complex group of hornblende gabbros. The distribution of the hornblende-rich rocks in relation to the hornblende-poor types is highly irregular. The hornblende gabbros range from light-gray rocks speckled with large hornblende grains or clusters of smaller hornblende grains to very dark rocks which appear to be made up mostly of coarse-grained hornblende."

Where seen in this area the gabbro is generally hornblende rich.

Two gabbro bodies in the area are located in sections 28 and 34, T10S, R3W and section 3, T11S, R3W (Pl. II). The body in section 28 is an elongated remnant oriented west-northwest while the other one to the south is oriented northeast. In addition there are large blocks of gabbro surrounded by tonalite located in the NW1/4, NE1/4, SE1/4 of section 29 (Fig. 1, Pl. 2).

The actual contact between the gabbro and the older metamorphics in sections 3 and 34 is hidden but can be predicted with certainty from outcrops of the respective material on either side. To the north the gabbro is truncated by the Woodson Mountain granodiorite body. Contacts between the gabbro and the tonalite in section 28 however, are not so sharp or clear cut, instead, they are frequently gradational with the actual division an arbitrary one.

The Bonsall tonalite followed the gabbro in the Cretaceous intrusive sequence. Evidences of its younger age are everywhere apparent as

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inclusions of gabbro in the tonalite and intruding relationships. At the time of its emplacement it would appear that it occupied quite large areas. However, subsequent movements and intrusions have reduced its extent until it is now present only as large northwest oriented remnants. In appearance the tonalite is a light to dark gray, medium-grained, inequigranular rock. Larsen has described the mineral percentage as follows:

"Plagioclase makes up from 55 to 60 per cent of the rock rock... averaging about An10. Orthoclase makes up only a few per cent of the tonalite. Quartz averages about 20 to 25 per cent. Hornblende averages about 10 per cent. Biotite makes up from 5 to 15 per cent."

One other very distinguishing characteristic of this rock is the abundance of inclusions of gabbro, schist or other material nearly always present.

Contacts between the tonalite and the gabbro or Green Valley tonalite are frequently gradational and difficult or impossible to define precisely. Likewise, the contact with the volcanics may range from sharp, well-defined contacts to gradational, as in the case of the recrystallized contacts. Contacts with the metamorphics or granodiorite are sharp and well defined.

The Green Valley tonalite outcrops as a small plug in section 29 expressed topographically as a small, rounded knob. Contacts of this body with the surrounding Bonsall tonalite are gradational attesting to their nearness of intrusion. The material is clearly later, as the flow lines of the Bonsall tonalite are sharply truncated by the plug (Pl. 11).

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Figure 1: Stoping and assimilation of San Marcos gabbro by Bonsall tonalite (light colored material). Fragments in lower right have been removed from larger block above and settled into the tonalite. Subparallel tonalite filled joints are also shown in upper center and upper left. Such joints symbolize in part at least, the breaking up of larger blocks to fragments to start the assimilation sequence.

Figure 2: Gneissic banding in the Bonsall tonalite screen near the Woodson Mountain granodiorite contact. This contact is approximately 30 feet to the right (north) as viewed.
PLATE 2.

Fig. 1. Stoping of San Marcos gabbro by Bonsall tonalite

Fig. 2. Gneissic banding in Bonsall tonalite
This small plug is the only known occurrence of the Green Valley
tonalite in the immediate region and heretofore has not been mapped. The
principal area of occurrence for this tonalite is further to the south.
Identification is necessarily tentative as it has been by megascopic
means and comparison with published descriptions by Larsen.\footnote{13}

The rock itself is light-gray to gray in color, medium-grained
containing inclusions. The inclusions are light to dark-colored and
fine-grained. They are partially assimilated and rounded but are not
drawn out as compared to those of the Bonsall tonalite. In origin they
appear to be reworked fragments of the earlier gabbro and metamorphic
material.

The youngest intrusive rock within the area is the Woodson Moun­
tain granodiorite - also of Cretaceous age. This rock occurs in two
separate plutons which areally underlie approximately one-third of the
area. One of these bodies is located in the extreme eastern portion and
the other is in the central portion of the area. Structurally, both
bodies have been influenced during emplacement by west-northwest and
northeast structural directions.

Contact relations between the granodiorite and the other rocks
of the area are always clearly defined with chilled effects and frequently
banded or gneissoid zones immediately adjacent to the contact. The grano­
diorite during its intrusion has truncated structural elements of the
other intrusive or metamorphic bodies present and has also extended,
in a few cases, dikes into the older material.

\footnote{13. Op. cit., p. 54-55}
The rock itself is a coarse-grained, light-colored, equigranular granodiorite. Inclusions are sparse and generally lacking completely. Larsen has described the average mineral percentages as follows:

- Quartz: 33%
- Microperthite: 20%
- Plagioclase: 14%
- Anorthite content: 25%
- Biotite: 5%
- Hornblende: 1%

Although the granodiorite is the youngest intrusive in the area studied there are other younger, more granitic intrusives elsewhere in the batholithic complex. The granodiorite, however, occupied major portions of the complex and even today still exists over widespread areas.

In addition to the younger intrusives which are not seen in this area, there are present innumerable thin to thick dikes of quartz, aplite or pegmatite which are structurally controlled in the majority of cases. There is also one lamprophyre mapped in section 35 (Pl. 11). In section 27 (Pl. 11) however, there is one discordant body of pegmatite which appears as a small pipe with dikes extending radially from it. Along these dikes the pegmatite grades to aplite. In general the pegmatites are simple varieties, although in some cases they carry black tourmaline or biotite.

**STRUCTURAL FEATURES OF THE METAMORPHIC ROCKS**

**Original Structures.**

Original structures in the metasediments within the area appear to have been fairly well obliterated. For this reason, it was not considered worthwhile to try to determine the few remnant features.

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Within the volcanics however compositional differences in the flows seem to have effected a bedding of sorts which can occasionally be recognized, though, in general it is hard to distinguish and not everywhere apparent.

Imposed Structures.

Cleavage: This is the most prominent imposed feature noticed in either the metavolcanics or the metasediments. Within the metasediments a northwest cleavage is noticeable in the orientation of the biotite and frequent separation of the biotite into bands. In the metavolcanics, the cleavage is noticeable in mildly alternating bands of different color, as a segregation banding.

Within the metasediments the cleavage is believed to be flow cleavage and has also been identified as such by Larsen\(^\text{15}\). Likewise, within the areas there are suggestions of flow cleavage. In one instance drag folds were noticed in a remnant of metavolcanic material included with the metasediments in the northwest-quarter of section 33. These drag folds seemingly were formed by folding of the segregation banding previously mentioned, although they could well be due to some unknown movement of the old flows. Cleavage in the nearby metasediments is oriented generally parallel to the axial plane of the drag folds thus suggesting flow cleavage.

Orientation of the cleavage is constant throughout the area in all remnant bodies in strike and generally in dip also. One instance was noted in the metasediments however, where the dip was reversed giving a synclinal appearance in the cleavage. Such a reversal however is not an

\(^{15}\) Op. cit., p. 19
unusual occurrence in a metamorphic sequence.

Joints: Various joint sets are present in the metamorphics but there are four prominent ones which are always noticeable. These four, in addition to others which locally are present, are always in the same relation to each other and quite consistent.

The first of these parallels the northwest cleavage of the metamorphics both in strike and dip, with only local variances. Normal, or nearly so, to this set is another set which strikes approximately north-northeast. There is some tendency of this set to maintain an attitude normal to the cleavage but it persists generally in the north-northeast attitude and dips steeply.

Diagonal with respect to the cleavage are two other sets. One of these sets strikes about north-northwest and the other northeast to east-northeast. These sets both dip steeply.

Thin pegmatite dikes have been encountered only along the north-northwest set. The others might well carry dikes however, since much of the area underlain by the metamorphics is covered or partially so. Also these same joint directions are all known to carry aplite and pegmatite dikes elsewhere.

Contact Features: Contacts between the metamorphics and younger intrusives are generally steeply dipping to vertical, although milder dips are indicated locally. Between the intrusives and the metasediments the contacts are generally sharp and well defined. Recrystallization of the metasediments is occasionally noticed however, along with intensification of flow structures in the intrusives.

Between the metavolcanics and intrusives however, the contacts
range from sharp to gradational. Recrystallization of the metavolcanics frequently has formed a halo of medium to coarse-grained granodioritic rock rich in hornblende, grading from the intrusive material to the metavolcanics. Around the smaller metavolcanic body in section 29 recrystallization is most intense but even around the larger body in sections 29 to 32 such effects are noticeable.

**STRUCTURAL FEATURES OF THE GRANITIC ROCKS**

**Oldest Structures.**

General Statement: The oldest structures revealed in the intrusive rocks of the area are either linear or planar. Such structures have been described by Balk as "linear flow structures" or "platy flow structures". In this paper they will be referred to as flow lines or flow layers, and are revealed in the area by the arrangement of the biotite, quartz, feldspars or the inclusions (autoliths and xenoliths).

Inclusions: Inclusions are paramount in revealing the flow lines within the Bonsall tonalite and are abundant (Pl. 3, Fig. 2). In contrast, the granodiorite and gabbro are almost completely devoid of inclusions. Inclusions are abundant almost everywhere in the tonalite, but there are definite increases, percentage-wise, near the gabbro and metamorphic contacts. However, there are locally areas nearly devoid of inclusions.

The inclusions range from small, tear-drop, spindle or elongated, flattened discs up to angular blocks several feet in diameter. Except near contacts, which they parallel, or in crowded source areas, the inclusions are well oriented parallel to the regional structural pattern.

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and the faint schistosity of the tonalite. The various shapes of the inclusions are undoubtedly due to resorption and reaction with elongation resulting from the viscous state attained. The larger blocks are often broken by subparallel veinlets of the younger material (Pl. 2, Fig. 1).

Larsen states:

"In most places the flat inclusions appear to be disclike, but in some they are more or less elongated in or near the dip" 17.

He also refers to work done by Hurlbut and makes the statement:

"In both the inclusions and the tonalite, the plagioclase has the flat face (010) parallel to the streaking and the long dimension (crystal axis a) nearly parallel to the dip. The hornblendes likewise have their c crystal axis nearly parallel to the dip but are not oriented in the prism zone" 18.

Primarily the inclusions are finer-grained than the tonalite and quite high in hornblende. Otherwise the mineral makeup is about the same as the tonalite but in different proportions. In color they are almost without exception much darker than the tonalite.

**Linear Flow Structures:** Flow lines, excepting the inclusions of the tonalite, are encountered in all the intrusive bodies but are more noticeable in the granodiorite. Quite often they are the only manifestation of flow in the central areas of the granodiorite intrusions.

Those flow lines recognized are termed by Balk as "linear parallelism of clots" and "linear parallelism of equigranular rocks" 19. The clots are formed by small masses of biotite whose individual crystals may or may not be in alignment. Such clots are arranged in stringers through

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17. Esper S. Larsen, Jr., op. cit., p. 64
18. Ibid.
the granodiorite.

The other flow line structure recognized is formed by the quartz and occasionally the feldspars being recognizably elongated in the flow direction. Such a feature noted above by Balk as "linear parallelism of equigranular rocks" has also been referred to by him as a linear "fiber" within the rock. Locally in the central portions of the granodiorite intrusions this "fiber" is quite evident. Such a "fiber" is also seen in the orientation of the hornblende and plagioclase crystals in the Bonsall tonalite.

Platy Flow Structures: These structures are prominent features around the outer portions of the younger intrusions and are everywhere in evidence. They are generally less pronounced in the Bonsall tonalite than in the granodiorite, but they are present. In the central portions of the intrusions these flow layers give way to flow lines in importance. These layers are composed of biotite oriented in thin, parallel bands encircling the central areas of the intrusives much like husks of corn encircling the cob. The biotite leaves in these thin bands are oriented with the 001 faces approximately parallel to the plane of lamellar flow. Frequently however, these flow layers are also made up of near vertical or vertically oriented, linear structures formed on the foliation planes.

With increasing distance from the centers of the intrusives the bands noticeably increase in thickness and also continuity. Near the contacts these bands frequently are strongly developed grading into younger transition structures.

20. Esper S. Larsen, Jr., op. cit., p. 64
Transition Structures.

General Statement: Transition structures according to Mayo are named for their time of occurrence in the tectonic history of a region where they bridge the time interval between motion in the plastic state and in the fracture state. Such structures, though present, are not frequent. In this particular area motion during the transition period was recorded principally by gneissic borders and shear zones.

Shear Zones: Shear zones while not common throughout the area are prominent in the tonalite screen where they are as much as several feet in thickness. Such zones are oriented parallel to each other and strike in the northwest direction. Replacement and recrystallization commensurate with the shearing have commonly healed the shears giving the appearance as shown in Pl. 4, Fig. 2. In addition such zones also appear as strong gneissic zones (Pl. 4, Fig. 1.). The attitude of these structures where observed is steeply dipping to vertical.

Gneissic Borders: Strongly foliated or gneissic contact zones are especially noticeable between the tonalite and granodiorite. In some places these gneissic bands appear like clay varves with their alternating light and dark bands as much as half an inch or more in thickness. Such foliated or gneissic zones extend in places up to fifty or more feet into the tonalite and likewise the granodiorite before disappearing. The most intense gneissic banding has been seen in the tonalite, with the foliation in the granodiorite increasing in intensity towards this contact. Such a contact is illustrated in Pl. 2, Fig. 2.

Figure 1: General view of Woodson Mountain granodiorite outcropping in central body. View looking northeast. Bonsall tonalite screen contact covered in this particular area but runs between shed and base of hill, paralleling the base of the hill.

Figure 2: Inclusions in Bonsall tonalite. View looking east showing rounded to angular inclusions pitching gently towards the observer.
Fig. 1. General view of Woodson Mountain granodiorite outcropping in central body

Fig. 2. Inclusions in Bonsall tonalite
Fracture Structures.

General Statement: With the continuing solidification of the intrusives in this area, there came a time when near surface adjustments to deep-seated surges could no longer be made by plastic release. Instead, fracturing replaced plastic flow to provide the necessary release mechanism. Fractures resulting from such later surges are not abundantly present, but those that are, are clearly recognizable as such. Such fractures as these that are evidenced are "feather" fractures and cross joints. "Feather" fractures are tensional in nature and were formed in this area by the shearing action of the upsurg ing intrusive past the solidified walls. In attitude they dip steeply from the wall rock into the intrusion.

"Feather" Fractures: Fractures of this type are present in the Santiago Peak intrusives, the Bonsall tonalite and the San Marcos gabbro. In the Santiago Peak intrusives such a fracture exists in the northern portion of the body immediately south of the contact with the Woodson Mountain granodiorite in section 34 (Pl. 11). This marginal fracture is thought to be the result of drag from the consolidating material along the contact.

Along the Woodson Mountain granodiorite contact in the tonalite in section 29 (Pl. 11) such fractures strike west-northwest and dip steeply towards the granodiorite. The dip is about 70° but cannot be measured with complete certainty. Two such structures are present here and are occupied by pegmatites ranging from a few feet up to 10 feet in thickness. Along the strike to east and west they appear to taper out.

Figure 1: Gneissic zones within Bonsall tonalite screen looking west. Such zones, shown in extreme left and to right of pick handle, are characterized by flattening and stretching of inclusions and tonalite material forming a banded appearance. Unaltered tonalite is shown to left of pick handle with normally shaped inclusions, which in the screen pitch to the east towards the observer.

Figure 2: Shearing and recrystallization in Bonsall tonalite screen. During plastic deformation the structure has been healed by quartz filling the fractures and flooding the near by walls. View looking west.
Fig. 1. Gneissic zones within Bonsall tonalite screen

Fig. 2. Shearing and recrystallization in Bonsall tonalite screen
In the gabbro body located in section 28 (Pl. 11) are two other strong dike structures which appear to intersect each other although the point of intersection is concealed. The northwesterly structure has a measurable dip of 55° to the southwest while the dip of the west-northwest one is concealed. This latter dike is known more from a strong float zone than from actual outcrop examination. Both dikes appear to range up to over 15 feet or more in thickness locally and are filled with pegmatite vein matter. Locally however, they appear completely filled with quartz.

The "feather" fractures observed in the area are all comparable. All dip steeply towards the associated intrusions and parallel them in strike. Likewise the intrusive contacts are near vertical or steeply dipping towards the fractures. In all cases they have resulted from fracturing of the solidified walls and near surface intrusive material due to late upsurges of the still active magma chamber.

Cross Joints: Joints of this type appear to be present throughout the area but their exact nature cannot be depicted due to their rather erratic occurrence. Also, there is frequent confusion in trying to decide whether the structure being examined is actually a cross joint or a similar structure formed by erosional unloading. In any case, these joints do exist and are nearly horizontal with variable strikes. They are known to carry thin pegmatites or aplites.

Flat Lying Normal Faults: These joints are locally present in the area but appear to be of little importance. Where best seen in the eastern granodiorite body they usually strike northwest and dip about 30° to the northeast. Occasionally, nominal normal displacements are seen in the
offsets of other joints. This seemingly would indicate some lateral expansion of this granodiorite body to the northeast. In the other intrusive bodies, there are various flat lying joints which seem to occur erratically with no absolute displacements observable. It could well be that many of these would also qualify as flat-lying normal faults, but extensive work would be required to definitely establish their character.

**REGIONAL STRUCTURAL PATTERN**

**Resumé of Pre-Cretaceous Structures.**

The original structural pattern of the pre-Cretaceous metasediments and metavolcanics can only be interpreted from small remnant bodies in the area. As is shown on Plate 11 the cleavage in both the metasediments and metavolcanics strikes west-northwest to northwest and dips steeply to the northeast, with only local reversals.

The metasediments represent asymmetrical and possibly isoclinal folding of the original sediments resulting in a northwesterly structural orientation. The metavolcanics deposited unconformably on the metasediments have likewise undergone continued folding and their structural orientation has necessarily been made to conform approximately to the older. Resultant flow cleavage commensurate with metamorphism has outlined the structure as we see it today; a series of northwesterly striking beds with steep northeasterly dips generally, cut and disrupted by later intrusions.

**Cretaceous Intrusive Structures.**

*San Marcos Gabbro:* An ideal picture of the intrusive structure
of this rock is virtually impossible due to its early stage of intrusion with resultant truncation and assimilation by all subsequent intrusions. In the one body exposed to study the platy flow structures are oriented to northwesterly strikes with conflicting dips. The strikes are also somewhat divergent.

In general these structures are suggestive of a former northwesterly oriented intrusive body which has been truncated and deformed by the later intrusions. The diverging platy flow layers are probably representative of some local change of direction rather than any major structural change. Likewise the attitude of the contacts can only be inferred in comparison to other intrusive contacts of the area. They appear to be steep but are confused by the gradational relationship of the tonalite to the gabbro in many areas.

It would, however, be a reasonable assumption that the original gabbro bodies were generally elongated along the northwesterly structural trend of the metamorphics. Such structures would have tended to channelize the early intrusions in much the same manner as the majority of the later ones have been controlled. Likewise the contacts would have been steep to vertical.

**Bonsall tonalite:** The principal tonalite body present in the area is but a portion of a much larger body. The smaller tonalite screen is likewise a remnant of this larger body being separated from it by the granodiorite intrusion. Consequently, original contacts and outlines in this area of the tonalite have been obliterated in most instances. Nevertheless, excellent linear flow structures are preserved in the arrangement of the inclusions. Moreover, these inclusions are
oriented along the same structural directions as that followed by the later intrusions. As a result in large part the flow structures of all intrusions roughly parallel each other. An exception to this is in the eastern portion of the principal tonalite body in sections 27 and 34 where the flow lines are obliquely truncated by the granodiorite (Pl. 11).

Where the tonalite is in contact with the older metasediments, outcrops are not good, and in one instance due to insufficient exposures flow lines near the contact appear truncated by the metasediments (Pl. 11, Section 33). This however, is not the case as the linear elements are in fact conforming to the contact with the metasediments. In two other instances however, the flow lines are truncated sharply by small intrusions of Woodson Mountain granodiorite and Green Valley tonalite (Pl. 11, Section 29). Where the Green Valley tonalite truncates the flow pattern, this pattern is in its usual west-northwest orientation. In the case of the granodiorite truncation the flow lines are oriented anomalously for some, as yet, unknown reason.

The flow lines within the principal body of Bonsall tonalite pitch gently N67W at an average of approximately 18°. Locally however, attitudes are horizontal or steeper. In the same manner the trend will vary.

Flow lines within the narrow, elongated screen of tonalite south of the principal body are in striking contrast to the general trend however. Within this body the flow lines pitch S60E at about 60°. The angle of pitch is variable however. Flow layers within
screen are also well developed and strike about NW-SE dipping steeply to the northeast.

**Green Valley Tonalite:** Flow structures within this body have not been mapped or studied since the size of the body and few outcrops precluded the acquisition of reliable information.

**Woodson Mountain Granodiorite (Central Body):** Flow structures within this body are uniform and consistent throughout, except where diverted locally by contact relations. Flow layers and flow lines are both present and clearly defined. Flow layers are most prominent nearer the contacts with flow lines more in evidence on turns and in the central portions of the intrusions.

The general strike of the flow layers swings from N25W to N59W in agreement with the change in orientation of the granodiorite intrusion. Near termini of the lobes of the intrusion in section 29 and 32 (Pl. 11) the flow layers are not prominent but flow lines define the movement with clarity. In section 32 the actual turning zone is concealed with only one nearby outcrop showing the flow line trend. In section 29 the turn is nicely defined by the flow lines. In section 33 the flow lines bend around the nose of tonalite which extends well into the granodiorite. Regrettably, only the edges of this turn are known positively, as the flow layers in the area are concealed by mantle deposits.

The attitudes revealed by the flow layers and flow lines indicate an elongate body inclined steeply to the northeast. Vertical flow layers encountered in the northwestern portion of the intrusion, together with local widening in area, define minor domal enlargement
of the body to the northeast in this area (Plates 9 and 11). Domal enlargement is also indicated by the structures in the southeast portion of the body. That this enlargement was in part forceful is shown by the associated "feather" fractures in the tonalite north of the contact.

Woodson Mountain Granodiorite (Eastern Body): Structural relations within this body are quite similar to that of the central body. Flow layers are characteristically better developed nearer the contacts with flow lines encountered in the central portions. Near contacts the flow lines bend to conformity.

In areal outline the intrusion is a large, irregular body with extensions and protrusions. To the northwest a long, tapering finger extends along the metasediment - tonalite contact. To north and south rather bulbous protrusions extend out of the area.

The general flow pattern within the body is oriented N72W. attitudes of the flow layers and flow lines show the body to have expanded upwards and outwards in all directions (Plates 10 and 11). This expansion may have been principally to the northeast as in the central body, but the relation is not quite so clear. In the long, tapering finger to the northwest the attitude is comparable to that of the central body - somewhat sill-like and inclined steeply to the northeast.

Regional Structures.

The pattern of the regional framework in this area is clearly defined and predominant throughout. This is a west-northwest structure in contrast to the northwest trend generally prevalent throughout
the Southern California Batholith and the Sierra Nevada. It is everywhere apparent in the area, with all structures basically complying to this direction. Such a deviation from the general northwest trend is thought to have possibly resulted from the formation of the Texas Lineament structure encountered to the north. One subordinate direction to this trend is present but weakly developed. This is a north-northeast to northeast trend noticed in the protrusions from the eastern granodiorite body, in the body of Jurassic granodiorite in section 34 and in the ill-exposed body of gabbro in sections 34 and 3 (Pl. 11).

Whether or not these are the only two directions of note in the Peninsular Range Province of the batholith cannot be said. There may well be other subordinate ones, which would be disclosed with detailed studies in other portions of the batholith or province.

**Steep Primary Fractures.**

**General:** The definition of the various joint patterns has been reached through collection of numerous readings in the area. Fortunately, as regards the mapping, the usual impenetrable brush covered slopes had been bared by a brush fire in the Fall of 1957 and were readily accessible. The readings collected in the field were plotted on work sheets and also on point diagrams which were then contoured (Plates 5-8). With the completion of these sheets and the field work, final identification of the different patterns was made.

The general patterns and relations are consistent throughout the area. Within the different intrusions as the flow patterns change, so likewise to a certain extent do the various joints as they attempt
to maintain their normal relationship. This local changing to satisfy the requirements of normal relationship is illustrated by and also accounts for the shifting foci of intensity shown on the joint contour diagrams (Plates 5-8). In addition to the principal directions, there are locally various, weak sets scattered across the area. As such they have been disregarded except for recognition and plotting where seen.

Within the area studied the steep joints are all occupied in one locality or other by pegmatites or aplites. These are as a rule no more than one or two inches in thickness. In addition, there is one rather extensive lamprophyre present within the granodiorite in section 35 (Pl. 11). This dike has known thicknesses of two to three feet and possibly more. The fact that these steep structures are so occupied would point out that they were formed near the surface, shortly after the cooling of the intrusion and before the complete solidification of the interior portions.

**Local Curving Of Joints:** This feature is noticeable in the steep, west-northwest trending joints which parallel the principal structural direction of the region. As a rule only the major changes of direction are paralleled by the curving of the joints. Visible exposures illustrating these curves are occasionally present and show them to be broad in nature. However, in many instances, the curves are noticed only by small changes in strike in the measurement of several joints within a restricted area.

**Regional Joint Pattern:** Field studies have revealed four principal joint directions. Three of these joint directions parallel known regional structures within the area. Whether the fourth joint direction
is also parallel to such a structure is unknown from this area. By analogy however, it would seem likely that such exists within the batholith.

The northwest to west-northwest joint set, which parallels the regional structure throughout the area and elsewhere, is considered to be a longitudinal set as defined by Balk\(^{24}\). This set is steeply dipping to vertical in all instances and consistent in its relation to the regional flow structure. In relation to one another the spacing is variable, from closely spaced almost sheeted zones to widely spaced. The joint surfaces generally are fairly smooth having been made so by weathering processes, but where protected they occasionally exhibit indications of movement.

Located at approximately right angles to the west-northwest set is the north-northeast set. This set is referred to as the tension set and is traceable all through the area. Attitudes of this set are vertical or near vertical in all cases. Within the Bonsall tonalite these joints might well be called cross joints from their relation to the flow lines. However, since they are so continuous and not confined within one body, they are more appropriately known as tension jointing. This set is also consistent in its relation to the flow structures and longitudinal jointing. The joint planes again may be smooth or contain evidences of movement, depending on the protection they have received from weathering. One tendency of this set appears to be that of slight refraction from one intrusive or metamorphic to another. Actual examples

\(^{24}\) Robert Balk, op. cit., p. 34-36
have not been seen of this but strike measurements from opposite sides of contacts suggest this variation.

The last two sets of prominence are complementary sets considered to be diagonals. One of these strikes north-northwest to northwest and the other northeast to east-northeast. Attitudes of both sets are near vertical to vertical. Frequently both sets are in evidence and where not, at least one or the other will be. The joints are usually spaced several feet apart but occasionally closely sheeted zones are encountered. Where fresh surfaces are exposed the joint planes show some indications of movement.

Relative Age Of Joints: Determination of the relative age of the joints within the area is difficult, due to the weathering processes which in many cases have destroyed all vestiges of movement along the joint planes. However, there are occasions where such structures have been preserved. Likewise there are occasional areas where offsets of one joint set by another are recognizable. From such meager information a tentative assignment of relative ages has been accomplished.

The diagonal joints appear to have been the first to form. They were in turn followed by the tension joints and the longitudinal joints in that order, although the last two have conflicting evidence and may have formed at or about the same time.
PLATE 5

Explanation Of Diagrams: The contour diagrams represent points plotted for each joint reading measured in the field, and are the contoured value of the concentrations of all the joints measured in the particular body. Each joint is plotted as if it were a plane passing through the center of a sphere. From the center a perpendicular is constructed normal to the dip which intersects the sphere at a point termed the pole position in each hemisphere. For our purposes only the upper hemisphere is used. These poles are then projected to the plane of the paper (equatorial section represented by the circle on the paper) and marked. After all poles are plotted, contours are drawn. Dips plotted on the edges represent vertical attitudes and range to flat lying dips in the center.

The values shown for each percentage range mean that, that percentage of the total number of joints measured lie within an area equal to one percent of the total area of the diagram.

Within the central body of the Woodson Mountain granodiorite a total number of 146 joints have been plotted. The concentrations to the NNE and SSW represent the near vertical attitude of the WWW trending longitudinal joints. The concentrations to NWW and ESE represent the near vertical NNE tension joints. Concentrations to NWW and SSE are diagnostic of the vertical ENE diagonal set. The steeply dipping NWW diagonal set is represented by the somewhat shifting concentration to the NNE. The central concentration is representative of the near horizontal cross jointing and/or erosional unloading. Other minor concentrations represent minor joint attitudes along less important sets.
PLATE 5. Contour Diagram of Joints in Woodson Mountain Granodiorite — Central Body
A total number of 122 joints were plotted in the construction of this diagram representing the eastern body of Woodson Mountain granodiorite. The concentrations to NNE and SSE reveal the steeply NE dipping longitudinal joint set. Broad concentrations to NW and ESE represent the generally vertical attitude of the NNE tension set. The steep N to NW diagonal set is revealed in the concentrations to the W and NE. The ENE diagonal set is disclosed by the vertical and near vertical concentrations to the NNW and SSE. The diagonal sets in this body, while holding to a general direction are inclined to shift somewhat in both strike and dip, as evidenced by their broad transitory concentrations. Again cross jointing and/or erosional unloading is seen in the near horizontal set evidenced by the central concentration. Other minor joint directions are evidenced by local concentrations.
PLATE 6. Contour Diagram of Joints in Woodson Mountain Granodiorite — Eastern Body
In this body of the Bonsall tonalite a total of 85 joints were plotted in the construction of the contour diagram. The regional tension pattern is disclosed by the shifting concentrations in the WNW which indicate dips ranging from steeply WNW to ESE. The longitudinal pattern is shown, but somewhat weakly by the vertical concentration to NNE and SSW. The ENE diagonal set is revealed by vertical but strike shifting concentrations to NW and SE. The NNW diagonal set is shown by the concentrations to NE and SW. Other minor concentrations are noted as small concentrations scattered about and represent local and weakly developed joint sets. Some of these are no doubt of a regional nature while others were probably local in origin. As was noted in the granodiorite bodies a near horizontal set is noticeably present and represents cross jointing and/or erosional unloading.
PLATE 7. Contour Diagram of Joints in Bonsai Tonalite — Moos Canyon
A total number of only 48 joints have been plotted in the construction of this diagram. This is due to the limited area of the Bonsall tonalite screen and also to a sizeable portion being partially or completely covered by mantle. The major directions are revealed however, plus other local ones of regional and local origin. The tension direction is revealed by the vertical set in the NW to WNW and SE to ESE. The vertical longitudinal set is disclosed by the concentrations to NNE and SSW. NNW diagonal jointing is revealed by steeply dipping attitudes to the NE and ENE, while ENE diagonals are disclosed by vertical concentrations to NNW and SSE. Again a horizontal set is indicated by the centrally located concentration. In this case it is believed that in the majority of instances this pattern is due to unloading.
PLATE 8. Contour Diagram of Joints in Bonsall Tonalite Screen
Upward Motion.

Upward motion in the batholith is primarily recorded in the orientation of the linear flow elements of the intrusive bodies. Steeply pitching linear elements to the northeast or vertically pitching elements are distinct evidences of motion from these directions. Supporting evidence for this upward movement are the "feather" fractures which open steeply downwards into the intrusions from the wall rocks.

Further evidence of this somewhat forceful upward movement is found in the thin, elongated screen of Bonsall tonalite lying between the metavolcanics and the granodiorite. Flow structures within this body are in direct contrast to the regional pattern of the tonalite, strong gneissic banding is evidenced on the margins and the body itself is split by northwesterly, near vertical shear zones. All are indicative of thrusting movements.

Horizontal Shift.

On Northwest Structures: Lateral displacements along the longitudinal jointing are not uncommon, especially where the criteria to recognize such have not been destroyed. In those cases where displacements are recognizeable by offsets, the amount of offset is never more than a few inches. In all cases, with one exception, the southwest wall has moved to the northwest in relation to the northeast wall. This one exception, located in the western end of the central granodiorite body, showed just the reverse relations.
On North-Northeast Structures: Lateral movements along these tension joints are not prominent and in most cases appear completely lacking. On occasion however, minor offsets are noticed. These offsets, where present, are contradictory. Where the southeast wall on one may have moved to the northeast, a neighboring joint will exhibit the opposite relation.

On North-Northwest and East-Northeast Structures: Movements along these complementary joints (diagonals) are locally evident in the eastern granodiorite body. Where evidenced, the northeast wall of the north-northwest joints has moved to the northwest and the northwest wall of the east-northeast joints has moved to the northeast.

The movements on these joints within this eastern body are not completely understood in connection with the regional tectonics as yet. Such displacements as they portray, would tend to elongate the eastern body against the principal compressive stress, while the body has been affected by this stress and elongated in part along the west-northwest direction. It may be that these movements are the latest movements recorded on the joints and reflect the north-northeast protrusion. These joints, within the west-northwest elongation, do not reveal this type of movement noted above, which is shown in the central portion of the eastern body.

Within the central granodiorite body movements along these joints are not evidenced. From the general elongation of the body however, it would seem that the movements would necessarily have had to be the reverse of those seen in the eastern body.
Prior to the Cretaceous intrusions, lateral compressive movements had strongly folded and compressed the metavolcanics and metasediments along the Pacific Coast line into a deformed belt extending roughly parallel to the coast line. The orientation of this deformed belt ranged from northwest to west-northwest. Accompanying this deformation, deep-seated faults were formed plus others of lesser magnitude commensurate with the resolution of the compressive stresses. With the formation of these structures, the way was prepared for the intrusions to follow.

The methods of emplacement for these intrusions have been discussed in various papers, with various methods being advocated. Mayo, working in the Sierra Nevada, has made the suggestion that the emplacement of that massif was controlled by buckling of the tightly-folded, metamorphic rocks due to north-south compression. This buckling provided space for the intrusions. On the other hand, Larsen concluded that stoping played a major role in the emplacement of the Batholith of Southern California. The question here is not to resolve which of these is correct, but to decide which process or processes were important, whether one of the above, another or a combination of processes.

One other problem which arises in a study of this type is the origin of the intrusive material. Was it formed in situ or has it

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25. Evans B. Mayo, op. cit., p. 1073-1076
26. Esper S. Larsen, Jr., op. cit., p. 167-170
migrated from a magma source deep in the crust? This question will be treated separately utilizing the evidence pertaining to this problem which has been encountered in the area.

Mechanics Of Emplacement And Space Problem.

**Magmatic Stopping:** This process appears to have played a major role in the emplacement of the Bonsall tonalite and may have likewise been instrumental in the emplacement of the gabbro. Intrusive features regarding this oldest Cretaceous intrusive however, are clouded by the reworking it has undergone by all subsequent intrusions.

Evidences of stopping by the tonalite are manifold wherever the rock is examined. Primarily of interest are the abundance of inclusions of gabbro, metasediments or metavolcanics distributed throughout the rock. These inclusions are present in all stages of assimilation.

That stopping was an important process in the tonalite emplacement can be seen by an examination of the inclusions. They are present in all stages of assimilation from recently foundered, angular blocks (Pl. 2, Fig. 1) to streaks. Upward arching of the magma, in part due to lateral stress, undoubtedly caused shattering of the overlying metamorphics or igneous rock. Such shattering greatly facilitated removal by the intruding magma, with the stoped blocks sinking into the intruding magma.

Mayo has argued against stopping in the Sierra Nevada on the grounds that the magma viscosity was too high to permit such sinking in a strongly upward intruding body. In contrast to this however,

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27. Evans B. Mayo, _op. cit._, p. 1069-1070
Larsen in the southern batholith has stated:

"At the time of emplacement to approximately its present position, compared with the late stages of solidification it had a higher temperature, lower viscosity, and fewer crystals and hence a lower density. It could, of itself, develop little energy, and it could transmit hydrostatically any forces slowly imposed upon it... At times when the magma was actively moving they (inclusions) would tend to be dissipated in the magma, partly by solution, partly by mechanical disintegration. At times of quiet they would tend to settle by gravity." 28

Consequently, with the believed magmatic elements of low viscosity and density coupled with the necessary lateral stresses, it is hard to discount the presence of stoping as a method of emplacement. Especially so with evidence so indelibly preserved.

**Forceful Injection:** Evidences of forceful emplacement are pronounced in relation to the granodiorite bodies. The western nose of the central body has related "feather" fractures extending from the tonalite into the intrusion. In addition, parallel shear zones indicative of thrusting are located parallel to this elongated nose on the south in the tonalite screen. Also evidenced in relation to the elongated nose of granodiorite are an arch of flow layers (Plates 9-11) and gneissic banding (Pl. 4, Fig. 1) on the contacts - all indicative of strong upward movements.

The eastern body of granodiorite has not revealed any "feather" fractures, except in one instance, or thrust zones around its contacts, but its flow layers reveal a definite expansion upwards. This expansion has manifested itself to the northeast and south with protrusions along the north-northeast and south-southwest tension directions. Such

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28. Esper S. Larsen, Jr., op. cit., p. 168, 169
protrusions are not shown as they extend out of the area mapped.

Other indications of forceful movement in the area are noticed in the pegmatite dikes in the northern gabbro body. These dikes appear to occupy marginal fissures or "feather" fractures formed by the tonalite emplacement.

**Tectonic History:** The processes of magmatic stoping and forceful injection have been recognized and described as the important methods employed in the emplacement of the intrusive bodies present. The remaining factor which is necessary to complete the picture is the force — how was it active and from whence was it derived?

We know that compressive movements commencing in Mesozoic times caused the formation of a chain of isoclinal and asymmetrical folding, extending the length of California and beyond, roughly paralleling the coastline. Extensive faulting commenced also in this pre-Cretaceous time. Foremost among the zones formed was the San Andreas fault together with subordinate, parallel faults such as the San Jacinto and Elsinore faults in southern California. Such faults as these are all steeply dipping to vertical. It would appear however, that forces to form these faults would have had to come from some new direction because the old forces would seemingly have been blocked after the folding of the metamorphics.

Mayo recognized this in the Sierra Nevada structures and postulated a new force acting in a north-south direction. Such a force

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29. Evans B. Mayo, op. cit., p. 1073
was indicated as being necessary to supply the horizontal shift and buckling required for the formation of certain relations in the Sierra Nevada. In 1938 Bailey Willis, working with joints in the Logan granite, concluded that this force was oriented N15\(^\circ\)E. \(^{30}\) Studies of joints in this area indicate this stress to be oriented approximately N24\(^\circ\)E. In any event, allowing for small changes of direction from one area to another, this force seems to definitely have existed in a north to northeast direction. Within this area such a direction is recognized in the orientation of the tension, diagonal and longitudinal joint sets.

This new north to north-northeasterly force caused the development of horizontal shifting along the San Andreas fault direction and north to north-northeasterly tension fracturing. Such horizontal shifting is reflected in the longitudinal joints of this area. Such a fault structure as this has been defined and described by DeSitter as a wrench-fault. \(^{31}\) The San Andreas fault is one of several large fault zones he lists and describes as examples of this type faulting. In corroboration, experimenters Hans Cloos in 1929-30 and Riedel in 1929 proved the existence of such a structure. This was accomplished by successfully duplicating the formation of the tension cracks in an oblique relationship to the vertical shear-plane from lateral compression. \(^{32,33}\)


\(^{31}\) L. U. DeSitter, op. cit., p. 159-160, 162-165


With the formation of such fracturing, channelways from depth were provided for the intrusions to follow. The emplacement of the oldest Cretaceous intrusion, the San Marcos gabbro, is mostly cloaked in obscurity due to effects of subsequent intrusions. However, there does seem to have been in part at least, a tendency for this early material to be controlled along the north-northeast and northwest directions.

The intrusion of Bonsall tonalite which followed, before the complete solidification of the gabbro, appears to have been controlled in large part by the lateral compression and the northwest structure direction. Northwest wrench-fault structures provided the accessways with stoping of the overlying material providing the space. Continuing compressive stresses, during the time of intrusion, aided the stoping process by creating hydrostatic pressures within the intrusion. These were directed upwards and outwards, causing arching and shattering of the overlying material. Such material, as it was removed and submerged in the intruding magma, was immediately acted upon by processes of assimilation and oriented structurally to the least stress direction. The flattening of the inclusions was probably, in part at least, due to this continuing lateral pressure. Currents within the intruding magma were responsible for the subhorizontal attitudes and stretching out of the inclusions.

Continuing differentiation of the underlying magma created the intrusion of the granodiorite. In contrast to the tonalite intrusion, this one appears to have gained its emplacement and space more by forcing aside its walls and doming the roof, than by stoping.
Evidences of stoping in this body are few and inconclusive. Only occasional inclusions are noticed and fewer ghosts.

The original injections of granodiorite were likewise controlled by the northwest wrench-fault direction. These injections were no doubt aided by the lateral stresses being resolved upwards and outwards through the intrusions. The roof over the material likewise appears to have been stronger than that over the tonalite injection, offering more resistance. The roof in this case would have been the recently emplaced tonalite in large part, rather than the metamorphics. In any case, doming of the roof is evidenced in the preserved flow layers and vertical or near vertical linear elements.

Within the elongated nose of the central granodiorite body, these flow features indicate that the upward motion came steeply from the northeast, abutting against the metavolcanics with only a thin screen of tonalite as a cushion. Continuing upward motion developed strong banding along the tonalite contact. With arrival of the transition period, and partial crystallization, continuing upward movements were compensated for by shearing in the tonalite screen acting as a lubricant between the granodiorite and the metavolcanics. This shearing has been responsible for the anomalous structural attitudes in the tonalite. Lateral expansion to the west during the transition and later crystalline stage was compensated for in part by the "feather" fractures. Likewise, the diagonals and tension jointing have also aided in this expansion.

Within the eastern granodiorite body, the principal structural
feature is the doming effect. North-northeast and southerly protrusions, believed to be controlled by the tension direction, would no doubt reflect the same upward expansion. This body to the northwest has sent out an elongated, tapering nose shaped like a thin wedge. It might well be that this tapering wedge is symbolic of how the first entries are made along the structural directions i.e., forced in by hydrostatic pressures, wedging aside of the walls, with strong upward movements and roof expansion following.

Upon completion of the emplacement, and before complete crystallization of the individual intrusions, continuing lateral pressure superimposed the pattern of regional jointing. The longitudinals were formed parallel to the regional structure and reflected the horizontal shifting. The tensions are parallel to the direction of compressive stress and signify the release of pressure to the west-northwest and east-southeast. The diagonals are indicative also of this continuing compression plus the confined nature of the intrusions as they cooled and crystallized. That these were formed before complete cooling of the interior portions of the magma is evidenced by the presence of thin aplites and pegmatites along the joint planes.

Flow layers at all times within the intrusive bodies were oriented parallel to the plane of least and median stress. Such are approximately parallel to the principal direction of wrench-faulting along the San Andreas system.

Such a system as interpreted for this area is but slightly at variance with the findings of Larsen in his reconnaissance of the
southern batholith. Larsen felt that stoping was the prime factor in the batholithic emplacement, with forcing aside of the walls important possibly in a few elongate bodies\textsuperscript{34}. It could well be that this area would qualify as one of his elongate areas.

Likewise, Mayo arrived at the same structural directions in developing his theory of "permissive" intrusion, tectonically controlled, for the emplacement of the Sierra Nevada portion in which he worked\textsuperscript{35}. The prime differences between here and the Sierra Nevada, are not in stress directions, but in the structures undergoing deformation. In the Sierra Nevada, strong isoclinally folded metamorphics were buckled by horizontal shifting (wrench-faulting) along the northwest or Pacific Coast direction, due to north to north-northeasterly directed compressive stresses. In this area the intense isoclinal folding was not evidenced but the stress directions are the same.

**Magma Source.**

The question of whether the magma has formed in situ or whether it has been formed elsewhere and migrated to its present position, is rather conclusively answered in favor of the latter, within the area of study. One of the prime requisites of the granitization school is the continuity of structure, no matter how discordant the contact, from the granitic material into the wall rock. Such is not the case within this area.

\textsuperscript{34} Esper S. Larsen, op. cit., p. 170
\textsuperscript{35} Evans. B. Mayo, op. cit., p. 1073-1076
Instead, there is general prevalence of sharp, continuous contacts through the area truncating structures. Such contacts, in addition, exhibit slight chilled effects or banding. Moreover, the plutons themselves exhibit domal structures. Inclusions within some of the igneous material are elongated and stretched out, also indicating movement. Other evidences of migration past the walls are gneissic banding on some of the contacts, shearing and "feather" fractures.

Further evidence in favor of a magmatic source is found in the well defined pattern of magmatic differentiation seen in the batholith. In summation, the evidence seems overwhelming in favor of a magmatic source rather than granitization in situ.

**SUMMARY AND CONCLUSIONS**

The intrusive structures observed within this area of the Southern Batholith of California are elongated approximately parallel to the northwest or Pacific Coast tectonic belt. Flow structures within the intrusions are likewise approximately parallel to this direction and steeply dipping to vertical. Elements of flow within these intrusions are indicative of near vertical movements with, in the case of the Bonsall tonalite, subhorizontal components. Domal structures are characteristic in the near vertically intruded granodiorites.

The regional fracture pattern is the result of northwest wrench-faulting with compressive stresses oriented about N24'E. Such compressive movements have been active throughout the period of
intrusion and are existent even today. Horizontal shift of the southwestern block to the northwest, along this wrench-fault structure, is evidenced in offsets along the longitudinal joints within the area. Other prominent joints developed by the wrench-fault structure are tensions oriented parallel to the stress direction and oblique to the northwest structure. Diagonal jointing is also imposed at approximately 45° to the tension direction. Such jointing has been superimposed upon each intrusive body upon cooling.

Localization of the intrusions along these regional directions has certainly been effected. The northwest to west-northwest direction however, is the principal direction in the area. Minor control and emplacement has also been effected along the north-northeast or tension direction.

Emplacement of the plutonic bodies has been accomplished by the processes of magmatic stoping and forceful injection. Evidences of both are outstanding in the area with the earlier intrusions emplaced by stoping. Evidences of stoping include abundantly distributed inclusions in all stages of assimilation, coupled with an intruding magma of low viscosity and density. Evidences of forceful injection are seen in gneissic contacts, shearing, "feather" fractures and domal structures within the plutons.

The origin of the magma as seen from relations in the area is a strictly magmatic one. Among other evidence to support this statement is the prevalence of sharp, continuous contacts throughout the area between the different rock units, coupled with truncation of structures.
It can only be concluded that the basic features in the Sierra Nevada and the Southern Batholith appear to be essentially the same. Direct comparisons between the two are present in pre-intrusive metasediments and metavolcanics, stress directions and age. The differences are minor and easily explained. Differences in method of emplacement are certain to occur with different crustal conditions from one area to another along a tectonic belt as complex as the coast of California. Differences in composition of the intrusions are likely those of differences in differentiation from one portion of the magma reservoir to another.
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GEOLOGIC SECTIONS
(Looking west)
Scale 1"=600'

Kwm: Woodson Mountain granodiorite
KB: Bonsall tonalite
Km: San Marcos gabbro
Jsp: Santiago Peak volcanics

- Inclusions pitching towards, shallow, level, steep
- Inclusions pitching away, shallow, level, steep

Flow lines and Flow layers
GEOLOGIC SECTIONS
(Looking west)
Scale 1' = 600'

- Kwm (concealed)
- Bonsall tonalite
- San Marcos gabbro
- Santiago Peak intrusives
- Bedford Canyon formation

Inclusions: pitching away, shallow
Flow lines
Flow layers