COAXIAL REFOLDING IN SOUTHEAST
SAN DIEGO COUNTY, CALIFORNIA

A Thesis
Presented to the
Faculty of
San Diego State College

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

by
Edward Hayden Phillips
June 1964
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Approved by:

[Signatures]

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PART I

INTRODUCTION

The pre-batholithic metamorphic rocks were studied in an area almost entirely within the southern half of the Earthquake Valley (7°5') quadrangle (Fig. 1). Geologic mapping was plotted partly on enlargements of aerial photographs (1" to 220"), and partly on enlarged portions of the topographic map (1" to 675").

The primary objective of the investigation was to study the geometry of surfaces, lineations, and grain fabrics in the

Figure 1. Index map. Arrow indicates the southern half of the Earthquake Valley quadrangle.
metamorphic rocks as a guide to their deformational history.

Exposures are excellent over most of the mapped area. Differences in elevation are extreme, and slope angles of 30° are not uncommon.
PART II

GEOLOGIC SETTING

GENERAL GEOLOGY

The metamorphic rocks of the Oriflamme Mountains have been, for purposes of this investigation, divided into two mappable units; (1) the schist series, and (2) rock of gneissic or migmatitic fabric.

The granitic rocks include a tonalite and numerous pegmatite dikes. Similar tonalite collected at Bonsall, California, has been dated by the Larsen Method as 120 million years (Bushee, et al., 1963, p. 804). The pegmatites are equally abundant in both the tonalite and gneiss, establishing their age as clearly younger than both.

STRUCTURE

The structure of the southern Oriflamme Mountains may be generalized as a series of isoclinal or closely appressed parasitic folds on a larger synclinorium terminating north and south. The north and south closures of the larger structure closely follow the limits of the schists (see geologic map in pocket). Both
mesoscopic\(^1\) and megascopic\(^2\) folds have axes trending north-northwest and plunging about 25°. The axial planes of megascopic folds dip steeply to the northeast.

The strike of several steeply dipping faults intersect the axial planes of large folds at angles of 45 to 50°. The area is bounded on the west by the Elsinore fault zone (Jahns, 1954, p. 45), and on the east by the Earthquake Valley fault (Dibblee, 1954, p. 26).

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\(^1\)Mesoscopic – bodies that can be effectively studied in three dimensions by direct observation (with or without a low power hand lens; Turner and Weiss, 1963, p. 15).

\(^2\)Megascopic – bodies too large or too poorly exposed to be examined in their entirety (the "macroscopic" scale of Turner and Weiss, 1963, p. 16).
PART III

PETROLOGY OF THE PRE-GRA NITIC ROCKS

SCHIST SERIES

The schist series consists essentially of three metamorphic rock types, (a) quartzo-feldspathic schists (biotite and muscovite-biotite schists), (b) quartzite and (c) amphibolites. The mica schists are by far the most abundant, constituting an estimated 97 per cent by volume of the schist series.

The schist series of the Oriflamme Mountains shares structural and compositional characteristics with metamorphic rocks of adjacent areas which have been mapped as Julian Schist (Hudson, 1922; Donnelly, 1934; Merriam, 1946; and Miller, 1946). No attempt was made to trace the series into areas of previous work, so for purposes of this investigation the body will be called simply the "schist series."

The quartzo-feldspathic mica schists are predominantly medium grained. Coarser-grained, more quartzose varieties tend to form ribs that lend expression to the areal structure.

The petrography of the schists is extremely variable; however, muscovite rarely exceeds biotite in abundance, and plagioclase (An_{8-32})^{1} occurs widely in both clear well defined laths

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^{1}All plagioclase determinations based on Slemmons' (1962) suggested procedures.
and as extremely altered grains with poorly defined outlines (presumably detrital grains). Common accessory minerals occurring in the schist are garnet, zircon, apatite and magnetite in that order.

All rock identified as quartzite contains more than 95% quartz. The quartzites are gray to pink and white and are locally interbedded with the schists in the form of thin (less than ten feet in thickness) discontinuous layers usually less than one hundred feet in length. In some instances the quartzites paralleling foliation are tectonically "pinched out." Other lateral discontinuities of the quartzites are probably of primary origin.

The subtlety of changes in grain size and composition, and the discontinuity of competent units necessitated mapping of the schist series as a single unit.

AMPHIBOLITES

Amphibolites occur widely scattered as discontinuous, small outcrops usually less than fifteen feet thick and averaging less than several tens of feet in length. The composition is commonly blue-green amphibole 55-65%, plagioclase (An_{20-40}) 30-35%, clear quartz 1-2%, and minor amounts of the accessory minerals zircon, magnetite, apatite and sphene. These units are in part calcareous and may be metamorphosed calcareous argillaceous rock. The amphibolites commonly display lineation parallel to the regional fold axis. This lineation consists of axes of small folds in calcareous layers, and alignment of amphiboles crystals.
GNEISS

The rocks grouped in this unit grade from quartzofeldspathic mica schists with subsidiary amounts of granitic material to coarsely granular gneiss. Several of the rock types recognized and discussed by other authors as parts of either the Julian Schist or Stonewall (?) quartz diorite have been called gneiss for purposes of this investigation. Included are the gneissic phases of quartz diorite described by Hudson (1922, p. 86), and the injection gneiss of Merriam (1946, p. 227).

The appearance of the rock is variable, some portions being coarse grained and granitic; it changes abruptly to medium grained schist at the contact with the schist series. In the gneissic rock, biotite schist and coarse grained quartzofeldspathic material alternate in bands of less than an inch to several inches in width, and commonly displays intricate folding and contortion.

The mineralogic composition of the gneiss varies widely. Generally, however, quartz constitutes as much as 40% of the rock, plagioclase (An_{10-40}) about 20-25%, potassium feldspar 10%, with biotite and muscovite occurring in nearly equal amounts up to 15% each. The accessory minerals zircon, apatite and magnetite make up the remainder.
PART IV

PETROLOGY OF THE GRANITIC ROCKS

BONSAI TONALITE

The Bonsall tonalite was first described in Hurlbut’s (1935, p. 611) investigations of the rocks around Bonsall, California, in the northern half of the San Luis Rey quadrangle. Merrim (1946) later traced the tonalite eastward into the Ramona quadrangle. Everhart (1951, p. 28) extended the name to a similar tonalite in the Cuyamaca Peak quadrangle between the Ramona area and Earthquake Valley. Castil (1961, map 5), following Merriam (1958), mapped a tonalite in Earthquake Valley as the Bonsall tonalite.

The outstanding feature of the Bonsall tonalite is the abundance of streaked-out inclusions or schlieren which, in this particular instance, are inclusions of the schist series. The tonalite is resistant to erosion and forms topographic prominences.

The composition is not uniform, but commonly consists of: andesine, 50-70%; potassium feldspar, 10-15%; quartz, 15-25%; hornblende, 5-15%; biotite, 8-12%; and less than 1% each of apatite, sphene, zircon, and limonite after magnetite.

It is not uncommon to find parallel alignment of biotite flakes in the Bonsall tonalite in this area. This alignment could have been caused by involvement in deformation.
The dikes of this district are mineralogically simple and consist of quartz, perthite and albite with subordinate muscovite and some accessory garnet and schorl. Many of the dikes consist of three zones: a border zone which is invariably fine grained and discontinuous; a wall zone which is coarsely crystalline; and a simple or segmented core composed largely of graphic granite and albite. Some dikes are fine grained and of quartz diorite composition; others are gradational from the fine-grained to the three-zoned variety. The thickness of individual dikes varies from that of stringers several inches thick, to bulges of one hundred feet or more; however, individual dikes may average 15 feet in thickness. Because of their large numbers and variability in thickness, no attempt was made to map them all to scale. They are included simply to demonstrate their relationship to the structural trends of the area.

One of the more striking features of the dikes is their persistence in strike and dip. They tend to dip with low to moderate angles to the southwest, trend in a northwest direction, and are parallel to subparallel.

The pegmatites are systematically related to bedding and foliation in the gneiss in that the pegmatites, although parallel in strike, dip in opposite directions at high angles. Jahns (1954) believes that the pegmatites of the Pala and Rincon districts of
northern San Diego County, which are similar in many respects to those in this area, were emplaced along a single set of well developed fractures. A set of fractures conforming to the dike pattern in the area under consideration would be the \textit{horizontal} (longitudinal) joints of Turner and Verhoogen (1951, p. 531). These joints form parallel to the fold axis, but may vary their position to a plane normal to the flanks of the fold. Probably these joints formed normal to the bedding on all parts of the fold in a fan-like pattern, thus establishing the high angle relationship of the dikes to bedding. The dikes may have been involved in megascopic folding as they conform closely to the structural trends of the area (see south central portion of map). Further possible evidence for involvement in folding is that several of the quartz dioritic dikes trending east-west around the southern nose of the mega-structure display mesoscopic folding ranging from gently undulating and open folds to chevron folding with amplitudes of 5 to 6 inches.

No consistent relationship could be ascertained between the tonalite or dikes and the surrounding rocks to determine their relative position in terms of the deformational history of the area.
PART V

DESCRIPTION OF STRUCTURAL ELEMENTS

GENERAL STATEMENT

The use of the term s-surface is essentially that of Sander (1930, p. 38): any planar surface of a tectonite either inherited (e.g., bedding) or secondary (e.g., schistosity, cleavage, axial planes of folds). S-surfaces are identified by an S followed by a subscript used to designate chronologic sequence: e.g., bedding = S\(_1\); transposed bedding = S\(_2\), etc.

The letter \( \beta \) is used for statistically defined axes of intersection of a group of surfaces and has the significance of a fold axis in some cases (Weiss, 1959, p. 92).

All projections of structural data are lower hemisphere, equal-area, and were prepared by use of a 20 centimeter printed net.

BEDDING

Bedding (S\(_1\)) is generally well preserved as small discontinuous quartzose lenses (several inches to several feet in thickness), and as subtle lithologic differences on the scale of several feet or more in the schists. Criteria which suggest that lithologic layering is bedding are: (1) small layers of schist in massive quartzite paralleling proposed bedding; (2) continuity of
lithology in the plane of the layer; and (3) presence of the sedimentary structure graded bedding (rare).

FOLIATION (SCHISTOSITY)

The term foliation is used here to designate only secondary foliation and, more specifically, any tectonically produced surface. In most places this foliation is a surface of slip as evidenced by boudin and microscopic off-sets in the plane of the foliation. The sense of slip, however, is not constant, and small passive folds in bedding are present locally.¹

Two distinct foliations ($S_2$ and $S_4$) are locally present and they intersect to define a regional lineation which is coincident with the trend of the axis of folding. $S_2$, probably transposed bedding (primary lithologic layering that has been rotated into parallelism with slip surfaces; Knopf and Ingerson, 1938, p. 189-190), is distinguishable from a slip cleavage, $S_4$, (subparallel to the axial planes of megafoolds). $S_4$ is a surface of slip and microscopic off-sets of bedding layers that transgress it are widespread. $S_4$, common to the schists, is present but difficultly measurable in the gneiss. This surface is poorly developed in the gneiss and is visible as individual planes of muscovite flakes.

¹A passive fold is one in which the folded layer behaved as a passive indicator layer during folding (the shear or slip fold of Turner and Verhoogen, 1960, p. 607).
On the microscopic scale $S_4$ appears as large isolated muscovite flakes which have a preferred orientation oblique to well developed $S_1-S_2$ surfaces (Pl. II, diagram III).

**LINEATIONS**

Intersections of s-surfaces, boudins and axes of small folds ("meso-folds" of Turner and Weiss, 1963) are collectively designated L. Axes of lineations are generally divided into "groups" sharing unique orientation and designated $B$, $B'$, etc. Parker, 1961, p. 1794). However, in this particular region the lineations are essentially uniform in orientation so their separation into groups is not necessary. The letter $B$ will be restricted to use of designating the regional fold axis, and any surfaces folded about that axis will be shown as $BS_1$, $BS_2$, and if both are folded about the same axis, $B_{S_1}S_2$, etc.

Two types of folds are observable on the mesoscopic scale; (1) isoclinal folds with broad hinges (Fig. 2a), and (2) closely

![Figure 2. Diagrams showing two styles of folds. a. Isoclinal fold with broad hinge; b. Closely appressed fold with simple hinge.](image-url)
appressed folds with simple hinges (Fig. 2b) which are far more common.

AXIAL PLANES

A plot of poles to the axial planes of mesoscopic folds \( (S_3) \) yields a fan-like dispersion about the megascopic fold axis indicating that they too have been folded about the same axis as \( S_1 \) and \( S_2 \) \( (=B_{S_1S_2} \) and represents passive folding, Fig. 5c).

The mean orientation of \( S_1-S_2 \) was determined graphically for six subfields (a subfield is a three-dimensional subdivision with approximate structural homogeneity; Turner and Weiss, 1963, p. 147-151) by plotting traces of \( S_1 \) and \( S_2 \) on an equal area net, and contouring the resulting points of intersection of the projected planes (Fig. 3). Lineations are plotted as points on the \( \beta S_1-S_2 \) diagrams (Pl. I). The significance of the weak maxima in some diagrams may be indicated by comparing the orientation of \( \beta S_1-S_2 \) in subfields II and III with that in subfield IV. In subfields II and III \( S_1 \) and \( S_2 \) are nearly parallel throughout. Nevertheless, the \( \beta S_1-S_2 \) maxima are nearly coincident in all diagrams. From this agreement in orientation (approx. N. 18° W. 30° NW.) it is concluded that the \( \beta S_1-S_2 \) axes have the significance of a fold axis in the sense of Clark and McIntyre (1951, p. 94), who state that "The axis of a fold is defined as the nearest approximation to the line, which, moved parallel to itself in space, generates the fold."
PLATE I. DIAGRAMS SHOWING THE GEOMETRY OF PENETRATIVE SURFACES AND LINEATIONS IN SIX SUBFIELDS

diagrams showing the geometry of $S_{1-2}$, $S_4$, and L. Diagrams are contoured at 3-5-7-9 per cent per one per cent area. Tick marks represent true north. All projections are lower hemisphere, equal area plots. Number of data are as follows:

<table>
<thead>
<tr>
<th>Subfield</th>
<th>$S_{1-2}$</th>
<th>$S_4$</th>
<th>L</th>
<th>Subfield</th>
<th>$S_{1-2}$</th>
<th>$S_4$</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>19</td>
<td>9</td>
<td>23</td>
<td>IV</td>
<td>15</td>
<td>24</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>22</td>
<td>12</td>
<td>22</td>
<td>V</td>
<td>23</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>III</td>
<td>24</td>
<td>4</td>
<td>12</td>
<td>VI</td>
<td>16</td>
<td>3</td>
<td>13</td>
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For location of subfields see Figure 3.
The $\beta S_4$ diagrams were prepared in the same way as the
$S_1-S_2$ diagrams and serve to illustrate the parallelism of $S_4$
throughout the entire area. In subfields I, III, and IV, $S_4$ is
inclined at high angles to $S_1-S_2$, while being nearly parallel to
$S_1-S_2$ in subfields II, V, and VI.

**JOINTS**

A dominant joint set of simple unfilled fractures strikes

![sketch map showing location of subfields. Schist series is stippled.](image)

Figure 3. Sketch map showing location of subfields. Schist series is stippled.

almost east-west, and varies only a few degrees from the vertical.
These joints are nearly perpendicular to the megascopic fold axis
and are called "cross-joints" (the ac joints of Turner and
Verhoogen, 1951, p. 524).
PART VI

MICROFABRIC

Fabric diagrams are usually prepared from two or three mutually perpendicular thin sections cut normal to the three fabric axes a, b, and c (Fig. 4). Intersections of s-surfaces, boudins, axes of folding, etc., are chosen provisionally as the b fabric axis; and normal to b in the plane of a conspicuous foliation is a, thus fixing the position of c (Cloos, 1946; Turner and Verhoogen, 1951, p. 518). The ab plane also coincides with the axial planes of folds. Following the example of Turner and Weiss (1963, p. 87-90) these axes are purely descriptive, non-genetic axial directions free of kinematic or dynamic implications.
The microfabric of several specimens was examined by standard universal stage methods to investigate the relationship of grain fabric to larger scale structural elements. The rocks are well suited to petrographic study because of their large grain size and high percentages of quartz and mica. Three mutually perpendicular thin sections were used in the preparation of the quartz diagrams.

The orientation of quartz c-axes was measured in four specimens, supplemented by poles to biotite cleavage (Plate II). Specimens 6 and 10 were collected from subfield IV. Specimen 12 was collected from subfield V, and specimens 715 and 131 from subfields I and VI respectively. Specimen 8 was collected from subfield IV. Specimens 6 and 131 display folding in the hand sample, 12 is singly foliated, 10 has S4 poorly developed, and specimen 8 displays well-developed S1-S2 and S4.

**QUARTZ SUBFABRIC**

The most obvious feature of the quartz diagrams is their triclinicity (excepting that for specimen 12 which is nearly monoclinic; Plate II, IVa). Rarely in tectonites with well-developed foliation, lineation and mica subfabrics do quartz diagrams show weak or random preferred orientation (Turner and Weiss, 1963, p. 432). Also characteristic of these tectonites are clear, unstrained quartz crystals. The lack of preferred orientation of quartz in tectonites with clear unstrained crystals has been
I

II

III

IV

V

VI

PLATE II. DIAGRAMS SHOWING EQUAL AREA PLOTS OF QUARTZ AND MICA SURFABRIC OF SIX ORIENTATED SPECIMENS

Ia. 112 quartz c-axes from specimen 6 contoured at 0-3 per cent per one per cent area; b. 200 poles to biotite cleavage from specimen 6 contoured at 1-3-5-8 per cent per one per cent area.

IIa. 135 quartz c-axes from specimen 10 contoured at 0-3 per cent per one percent area; b. 100 poles to biotite cleavage from specimen 10 contoured at 1-3-6-9 per cent per one per cent area.

IIIA. 164 poles to biotite cleavage from specimen 8 contoured at 1-2-4-6-9 per cent per one per cent area.

IIVa. 143 quartz c-axes from specimen 12 contoured at 1-2-4-6 per cent per one per cent area; b. 160 poles to biotite cleavage from specimen 12 contoured at 1-2-4-6-9 per cent per one per cent area.

IVa. 135 quartz c-axes from specimen 715 contoured at 0-3 per cent per one per cent area; b. 100 poles to biotite cleavage from specimen 715 contoured at 2-4-8-10 per cent per one per cent area.

V a. 163 quartz c-axes from specimen 131 contoured at 0-3 per cent per one per cent area.
explained as recrystallization under hydrostatic stress either by annealing or under the influence of pore fluids (Turner and Weiss, 1963, p. 432). The exception to the triclinic symmetry, specimen 12, has crystals of quartz which are broken and crushed; as opposed to the clear, unstrained crystals of the other specimens.

MICA SUBFABRIC

Perhaps the most conspicuous feature of the mica diagrams is a marked tendency for \(\{001\}\) to lie parallel to \(b\), the axis of microfolding, and to display maxima coincident (or nearly so) with the poles of visible \(s\)-surfaces. This, however, is not always true (Plate II, IIb). Two possible interpretations are indicated; 1) the mica lies in a slip surface not otherwise visible, or 2) the micas have been rotated into limiting orientation by slip parallel to the visible foliation (Parker, 1961, p. 1798).

It has been suggested that since micas are largely a product of post-tectonic crystallization, and because of the markedly tabular habit, crystal orientation is a function of crystal dimensions rather than lattice structure (Turner and Weiss, 1963, p. 442). For this reason mica diagrams reflect the presence and symmetry of observable mesoscopic foliations and lineations; however, they add little to the movement picture of the total fabric.

The symmetry displayed in the mica diagrams varies from monoclinic (Plate II, Ib) to orthorhombic in specimens containing \(S_1-S_2\) and \(S_3\) (Plate II, IVb). Diagram Vb is rendered triclinic.
because the maximums of poles to {001} are located oblique to the poles of visible s-surfaces. The total mica subfabric thus becomes triclinic.
Collective $S_1-S_2$, $S_3$, and $L$ are shown in Figure 5. The girdle of poles to $S_1-S_2$, the normal to which is the $S_1-S_2$ axis,

![Figure 5. Synoptic equal area plots of field data.](image)

is consistent with a $\beta S_1-S_2$ axis ($=\omega S_1^{S_2}$) axis parallel to those defined in several subfields. The girdle of poles to $S_3$ (Fig. 5c) is also consistent with a regional fold axis ($=\omega S_1^{S_2} S_3$) and homogeneous orientation of lineations it is concluded that the region has undergone superposed coaxial refolding similar to that discussed by Ramsay, and others (1957). Similar to Ramsay's discoveries in the Loch Fannich area of the Scottish Highlands is the monotony of trend and plunge of lineations, but with great circle
dispersion of certain s-surfaces. It should be made clear that the term refolding as used here does not necessarily imply that stresses were imposed, released, then superimposed. Coaxial refolding in the Crilamme Mountains may be recognized by the fact that lineation, principally the axes of meso-folds, is nearly uniform in orientation, but that the poles to the axial planes of these same folds are spread on a great circle about the megascopic fold axis.

![Diagram](image)

Figure 6. Diagrammatic interpretation of the statistical geometry of surfaces and lineations. a. initial folding resulting in open folds. Presumably transposition of $S_1$ into $S_2$ was important during this stage of deformation; b. later coaxial refolding with slip on $S_1 - S_2$ no longer possible followed by development of $S_3$ and statistically affine slip on $S_4$ resulting in folds with axial planes sub-parallel to the surface of slip and becoming tightly appressed to isoclinal in form.

A dispersion of these elements indicates involvement in deformation beyond that which formed them. It is not known if the emplacement of the granitic rocks occurred contemporaneously with passive folding or is a post passive folding feature.

Considering the above, megascopic folds in $S_1$ are closely appressed or isoclinal with axial planes inclined to the northeast (Fig. 6b). During the first stage of folding slip on $S_1$ was
statistically affine,\(^1\) and presumably transposition of \(S_1\) into \(S_2\) was important (since both define coincident \(\beta\) axes). Coaxial re-folding followed (after or contemporaneous with intrusion of the granitic rocks) to which point slip on \(S_1-S_2\) was no longer possible. Development of, and slip on \(S_4\) occurred with this later folding of \(S_1-S_2\) accompanied by rotation of \(S_3\) (passive folding stage; Fig. 6b).

The total symmetry of a tectonite fabric can be no higher, or lower, than the symmetries of the subfabric end members (Oertel, 1962, p. 336). The total symmetry of the fabric considered in this investigation thus becomes monoclinic, \(C_{1h}^2\) (triclinicity of the quartz subfabric lowers the "slightly" orthorhombic mica subfabric to monoclinic. The symmetry of the surfaces \(S_1-S_2\), \(S_3\) and \(S_4\) is also monoclinic. The symmetry displayed by the lineations is nearly axial.

\(^1\)Affine (homogeneous) deformation—initially similar figures remain similar and similarly situated throughout deformation; Turner, 1946).

PART VIII

INTERPRETATION

MOVEMENT PLAN AND STRAIN

The symmetry of the movement plan may in many, if not all cases, be assumed to be reflected in the symmetry of the fabric (Turner, 1957, p. 2-4). Applying this symmetry principle, the movement may be described as rotation of $S_1$ about $B_{S_1}$ in the early stages of the deformational history. Transposition of $S_1$ into $S_2$ was followed by development of $S_3$. Further folding of $S_1$-$S_2$ and $S_3$ by slip on $S_4$ was probably important after development of $S_4$ (passive folding). Shortening normal to the axial planes of megascopic folds resulted in flattening normal to the foliation as boudined dikes and quartzite stringers occur in the plane of $S_4$. This stretching parallel to the $B$ axis would be the $b$ extension as related to the slip along $S_4$. 
A layered succession of sedimentary rocks was intensely deformed and metamorphosed into a series of tightly folded tectonites of high grade amphibolite facies. The evidence indicates deformation was accomplished in the early stages by flexural folding (small passive folds are flexural slip folds). Following renewed or continued coaxial deformation, slip could no longer be accommodated on bedding and transposed bedding surfaces ($S_1$-$S_2$). Due to this inability of the early surfaces to accommodate further slip, a new surface of strain slip cleavage ($S_3$) developed subparallel to the axial planes of the subsequent megascopic folds. Slip on this later surface is evidenced by microcrenulations of earlier surfaces parallel to the later one, and by boudin of small pegmatite dikes and quartzites in the plane of the Strain slip cleavage.
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ABSTRACT

The rocks of the Oriflamme Mountains of southeastern San Diego County are metamorphosed quartz sandstones, siltstones, and calcareous argillaceous rock (?) intruded by the Bonsall tonalite (mid-Cretaceous) and pegmatite of presumed mid-Cretaceous age. Mineral assemblages indicate metamorphism of high grade amphibolite facies.

The metamorphic rocks exhibit appressed cylindroidal folds with monoclinic symmetry in bedding ($S_1$) and transposed bedding surfaces ($S_2$). The axes of these folds trend north-northwest with an average plunge of 25°. The poles to the axial planes ($S_3$) of the mesoscopic folds are spread on a great circle arc, the normal to which coincides with the regional megascopic fold axis $B_{S_1 S_2}$. A slip cleavage ($S_4$) is developed subparallel to the axial planes of the megascopic folds. $S_4$, which strikes north-northwest with an average dip of 80° east, parallels $S_1 S_2$ in some subfields. The symmetry of both field and microscopic structures is monoclinic ($C_{1b}$).

Deformation was probably accomplished by early flexural slip folding of $S_1$ and $S_2$ about an axis parallel to $B_{S_1 S_2}$ with development of $S_3$ (kinematically active folding stage). Coaxial refolding followed and as slip could no longer be accommodated on $S_1 - S_2$, $S_4$ was developed accompanied by rotation of $S_3$ about $B_{S_1 S_2 S_3}$ (passive folding stage). Slip on $S_4$ is thought to have been normal to the axis $S_4$. 