CLASTIC INTRUSIONS IN THE MORENO SHALE,
EAST FLANK-PANOCHIE HILLS, 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
Norman B. Smyers
June 1970
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Approved by:

[Signatures]

Date
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CHAPTER I

INTRODUCTION

Clastic intrusions, particularly sandstone dikes and sills, are secondary sedimentary structures commonly and widely distributed in California, especially along the western border of the Great Valley Province (Peterson, 1968b). Of the many localities that have been noted in the literature, the intrusions in the Moreno Shale of the Panoche Hills appear especially large and well-exposed and have not received detailed study. The main purpose of this thesis is to describe in detail the distribution and origin of the sandstone dike and sill complex which occurs along the east flank of the Panoche Hills in western Fresno County, California.

The Panoche Hills lie approximately forty-five miles west of Fresno, California, and may be reached easily from that city by driving west upon State Highway 180 (Figure 1). At Mendota, Fresno County Road J1 may be taken directly to the northern extent of the Panoche Hills. Another approach to Mendota would be from Los Banos traveling south upon State Highway 33, or north from Coalinga upon the same route.

The field area is traversed by a number of dirt
Figure I. Index map to the Panoche Hills, Fresno Co., California.
roads, many of which lead directly to outcrops of the sandstone intrusions. The area has a light vegetation cover and fences are absent.

Field work was accomplished during the latter part of December 1969, and much of January 1970. It involved mapping approximately seven miles of exposure along the strike of the Moreno Shale and bounding units. Sandstone dikes and sills were incorporated on the geologic map. Attitudes and widths of the intrusions were recorded for structural analysis and samples were collected for petrographic examination.
CHAPTER II

GEOLOGY OF THE PANOCHE HILLS

REGIONAL SETTING

The Panoche Hills lie on the border between the Great Valley and Coast Ranges Provinces and contain sedimentary and structural affinities common to both. They are among several east-flanking hills of the Coast Ranges Province in which are exposed many thousands of feet of Upper Jurassic, Cretaceous and Cenozoic sedimentary rocks of shelf and slope facies. The exposed section dips homoclinal toward the Great Valley and extends almost continually from the northern end of the Sacramento Valley to the southern San Joaquin Valley. These shelf and slope sediments are separated from the eugeosynclinal Franciscan rocks to the west by a major fault zone (Page, 1966, p. 268).

Great Valley Province

The late Mesozoic succession of sedimentary rocks of the Great Valley include conglomerates, sandstones and shales which were derived from the ancestral Sierra Nevada to the east. This succession of strata is wedge-shaped and increases in thickness to the west. It is
interpreted as a shelf-slope (miogeosynclinal) sequence that bordered a deeper eugeosynclinal type trough that was found to the west (Bailey et al., 1964, p. 123).

The distribution of early Tertiary sedimentary rocks is less continuous along the west side of the Great Valley. This distribution is in part due to post-depositional deformation and erosion, and in part to tectonic deformation during sedimentation which continually changed the position and configuration of the basins of deposition. Thus, it is difficult to trace many Tertiary units long distances along their strike. Some of the Cretaceous units, however, can be easily traced for several hundred miles (Hackel, 1966, p. 219).

Tertiary tectonism not only created an array of sedimentary traps, but likewise produced positive regions which contributed sediments to the basins of the Coast Ranges Province and the trough of the Great Valley Province. As these basins became filled with more and more sediment the environment of deposition was more near-shore and continental. By the end of Miocene time, the Great Valley basin had a structural configuration similar to that of the present (Hackel, 1966).

Pliocene uplift of the Great Valley and Coast Ranges Province resulted in more extensive continental sedimentation. Volcanism contributed igneous debris to
the clastic materials being shed by surrounding mountain ranges.

Pleistocene and Recent rocks are continental and grade downward into similar Pliocene units (Hackel, 1966, p. 234).

Coast Ranges Province

Franciscan rocks are found throughout much of the Coast Ranges. At least 20,000 feet, and probably more, of graywacke, shale, metavolcanic rocks, chert, some limestone and low-grade metamorphic rocks are representative of this sequence of strata. The Franciscan rocks of Late Jurassic and Cretaceous age are thought to represent a deep-water, eugeosynclinal equivalent of the contemporary miogeosynclinal succession to the east in the Great Valley Province. These two great sequences of Late Mesozoic sedimentary rocks have been brought into close proximity by large scale Tertiary thrust faulting. To the north in the Great Valley this structure is designated the Stoney Creek fault (Page, 1966). In the Panoche Hills region the Ortigalita thrust fault forms the contact between the two sequences (Payne, 1962, p. 171).

The early Tertiary tectonism probably initiated numerous individual sedimentary basins. These traps were filled with shallow-water marine and continental
sediments. Abrupt lateral changes in facies and thickness reflect intermittent localized faulting, folding, and volcanism.

Axial trends of folds generally lie parallel to the major northwest trend of this province, but individual fold axes are difficult to trace for more than a few miles (Bailey et al., 1964, p. 151).

Volcanic rocks, chert, and siliceous shales characterize the Miocene record. Volcanism continued but with diminished intensity during the Pliocene time. Uplift and intense tectonism resulted in local accumulations of coarse sandstone and conglomerate during Pleistocene and Recent time (Page, 1966).

PREVIOUS WORK

The first detailed report concerning the Panoche Hills was by Anderson and Pack in 1915. This early United States Geological Survey Bulletin was a survey of the geology and oil resources of the west border of the San Joaquin Valley. In this report the Panoche Hills were designated the type locality of both the Panoche Formation and the Moreno Shale. Much of the mapping, structural analysis, and geologic interpretations set forth in this bulletin are still the most comprehensive for this area.
The next repeated mention of the Panoche Hills in the literature was during the late 1930's. Several reports were published describing the reptilian fauna of the Moreno Shale, one by Chester Stock (1939). During the mid-forties, Stewart et al. (1944) and Davies (1946) published charts and articles describing the stratigraphy and mineralogy of several formations found in the hills bordering the western San Joaquin Valley in the Los Banos region.

The most detailed stratigraphic work directly concerned with the Panoche Hills was by Max B. Payne (1951 and 1962). His earlier paper is a detailed description of the Moreno Shale and some of the early Tertiary units overlying it. His more recent paper is a study of the Panoche Formation (equals Panoche Group of some writers), its sedimentary rocks, fauna, and structural setting.

The Panoche Formation, as noted by Payne (1962), has been the subject of another report, a Stanford University thesis by Don W. Sutton (1952) which was unavailable to the writer.

A lack of economic deposits of any significance is no doubt an explanation for the lack of published material concerning the Panoche Hills. Early petroleum efforts yielded nothing of economic value. Mercury
deposits do occur several miles to the west. The area is primarily used as grazing land for cattle and sheep.

**STRATIGRAPHY**

The units involved in this report include sandstone and shales of Late Cretaceous and early Tertiary age (Figure 2). The Upper Cretaceous units, the Panoche Formation and the Moreno Shale are well defined and the stratigraphic nomenclature is non-controversial. However, a decided disagreement exists among geologists regarding the nomenclature of the early Tertiary strata of this area. It is not the purpose of this report to enter into any lengthy discussion of stratigraphic propriety. For this reason, the following descriptions will be limited to the general sequence of strata encountered and their mappable characteristics.

**Panoche Formation**

The type section for this formation occurs in the Panoche Hills between Panoche and Little Panoche Valleys (Anderson and Pack, 1915, p. 38). The formation is approximately 22,000 feet thick, but this report is concerned with the upper few hundred feet or the Uhalde Member (equals the Uhalde Formation of Payne, 1962).

Payne (1962, p. 171) estimated the Uhalde Member as consisting of 50 percent shale and 50 percent
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<td>CENOZOIC</td>
<td>TERTIARY</td>
<td>EOCENE</td>
<td>&quot;TEM-&quot;</td>
<td>INCLUDES-Kreyenhagen Shale</td>
<td>50-100'</td>
<td>Non-marine white, yellow, blue, red clays with minor amounts of sandstone</td>
<td>Light-brown to dark-brown shaly sand, in places hard and platy</td>
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<td></td>
<td>&quot;BLOR&quot;</td>
<td>Laguna Seco Sand</td>
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<td>Dos Palos Shale - dark-brown, soft shale</td>
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<td>Dos</td>
<td>300'</td>
<td></td>
<td>Cima Sandstone - fine-grained, light-brown sand</td>
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<td></td>
<td></td>
<td>DANIAN</td>
<td></td>
<td>Dos Palos</td>
<td></td>
<td></td>
<td>Hard, white, platy, diatomaceous shale</td>
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<td></td>
<td></td>
<td>Cima Sandstone</td>
<td>0 - 350'</td>
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<td>Mano, often hard and platy shale; contains fossilized wood</td>
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<tr>
<td>MESOZOIC</td>
<td>CRETAEOUS</td>
<td>MIOcene</td>
<td></td>
<td>Dos Palos Shale</td>
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<td>Light-brown, fine-grained sand interbedded with maroon shales</td>
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<td></td>
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<td>Uhalde Sandstone and Shale</td>
<td>50'</td>
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**Figure 2.** Generalized stratigraphic column for the east flank of the Panoche Hills. Adapted from Payne, 1951, and 1960.
concretionary sandstone in alternating beds. In general, this member is a light-brown, shaly sandstone, with some concretionary sandstone layers. In the past (Anderson and Pack, 1915; Payne, 1951, p. 9), it was one of these dark-gray concretionary sandstone layers which was used as the mappable boundary between the Panoche Formation and the Moreno Shale. This boundary was employed by the writer in separating the two units.

The division between the two units where the concretionary sandstone is not exposed is still apparent as Payne (1962, p. 171) has noted, due to an "... abrupt physiographic change from the rounded, low lying Moreno Shale topography to the steeper ridges of the Uhalde sandstone and shale."

Moreno Shale

The Moreno Shale (equals Moreno Formation of some writers) is an Upper Cretaceous rock unit originally named and described by Anderson and Pack (1915). It has more recently been divided into four distinct lithologic members by Payne (1951). In ascending order, his divisions include the Dosados Sandstone and Shale, Tierra Loma Shale, Marca Shale, and the Dos Palos Shale Member. These members represent a maximum cumulative stratigraphic thickness of 3,200 feet along the eastern flank
of the Panoche Hills (Payne, 1962, p. 166).

Dosados Sandstone and Shale Member. The basal unit of the Moreno Shale and a probable source of the sand for the clastic intrusions is the Dosados Sandstone and Shale. It consists of two or three sandstone beds, each of which are twenty to thirty feet thick and are separated by similar thicknesses of maroon shales.

Tierra Loma Shale Member. The Tierra Loma Shale is the thickest member, about 1,200 feet. These maroon shales are usually hard and platy, and contain fossilized wood. Most of the reptilian remains of the Moreno Shale are to be found within this unit (Stock, 1939).

Marca Shale Member. The Marca Shale Member, like the two members below it, is Maestrichtian in age. It is a hard, white, platy, diatomaceous shale, and in places contains numerous calcareous concretions.

Dos Palos Shale Member. The Dos Palos Shale, or upper member of the Moreno, is a soft, dark-brown shale. It contains the Cima Sandstone Lentil which increases in thickness from south to north in the mapped area. Payne (1951, p. 11) noted that this sandstone lentil is not continuous and, as a result, the Dos Palos Shale is in places directly overlain by the hard and platy sandstones
of the early Tertiary units. The Cima Sandstone is fine-grained, and light-brown. This member is Danian in age.

**Tertiary Units**

The stratigraphic nomenclature for the units overlying the Moreno Shale is in question. Originally, sandstones and shales of Eocene and Miocene age were described as members of the Martinez and Tejon Formations (Anderson and Pack, 1915). This nomenclature is no longer in favor as indicated by a more recent paper by Payne (1951). In this report the Tertiary units are included together as undifferentiated Tertiary rocks for mapping convenience. The rock units which are incorporated within this map unit include the Kreyenhagen Shale, Laguna Seca Sandstone, and the "Temblor" Formation.

The Tertiary formations in the Panoche Hills are an onlapping sequence of light- to dark-brown shaly sandstones. In places they are hard and platy and are generally an abrupt change from the soft underlying shales of the Moreno. As a general rule, the boundary between these lower Tertiary units and the Moreno Shale was drawn at a hard platy, brown, dirty looking sandstone. These relatively hard rocks form a slight ridge along the east flank of the Panoche Hills where they are in contact with the easily erodable Moreno Shales.
GEOLOGIC HISTORY

The earliest and most discernible record of events in the geologic history of the Panoche Hills, as related by Payne (1962), begins in the early Late Cretaceous. Sand, shale, and gravel were deposited across a wide stable shelf and in a near-shore trough at depths of 1,000-2,000 meters. Faunal evidence indicates that subtropical to tropical climate prevailed for much of Late Cretaceous time.

An abundance of volcanic debris within the lower Panoche Formation indicates active volcanism. This volcanism continued into the beginning of Maestrichtian time.

The Uhalde Member of the Panoche Formation was deposited under variable conditions caused by a fluctuating shoreline. For this reason, the sandstones and shales were deposited alternately at depths ranging from 500-2,000 meters. The upper portions of the Uhalde were deposited under shallower conditions at depths somewhat less than 1,000 meters and in temperate waters (Payne, 1962, p. 173).

A large variety of life forms indicate a prolific and varied environment of deposition. These life forms include foraminifers, diatoms, radiolarians, and even large marine reptiles.
Glauconite within the Dos Palos Shale may mean that it was deposited at depths less than 300 meters where sedimentation was slow and under weakly oxidizing conditions. Corals within the Cima Sandstone indicate a maximum depth of ninety meters, water temperatures of 18.5°C to 25°C, and a clear neritic environment.

With the beginning of the Tertiary Period the sediment source shifted somewhat from the more distant ancestral Sierra Nevada to the close emerging Coast Ranges. Included within this latter province, the Panoche Hills region became one of many tectonically produced basins collecting shallow water marine and continental deposits. By mid-Eocene time, more stable and widespread marine conditions prevailed.

Prior to the Miocene epoch, a major phase of folding and faulting took place (Payne, 1962, p. 174). Another phase of folding and faulting occurred in the Pliocene and Plio-Pleistocene. It may be during this latter episode of deformation that the fracturing necessary for the formation of the dikes and sills within the Moreno Shale of the Panoche Hills occurred. For the remaining Tertiary and to the present, continental conditions persisted.
STRUCTURE

The Panoche Hills were described by Anderson and Pack (1915, p. 109) as being a broadly folded dome. The strata along the eastern flank of this dome, and in the mapped area, dip consistently east at an angle of 40°-45°. At the southern end of the mapped area the beds strike north-south. Toward the northern end of the Panoche Hills the strike is N35°W. This change in strike of the beds may be related to the origin of the sandstone dikes and sills within the Moreno Shale. This matter will be discussed more fully in a following section.

No evidence of large scale faulting was observed in the mapped area. A few feet of displacement along several small fractures was noted. Payne (1962) showed a few small, insignificant faults at either end of the hills, but nowhere else.

If the Panoche Hills are viewed as a small unit of a much larger feature, the Diablo Range, they appear to be a parasitic fold upon the flank of that range. The Diablo Range extends from Clear Lake, north of San Francisco, to the Orchard Peak area just east of Paso Robles, a length of approximately 250 miles (Marsh, 1959, p. 3; Bailey et al., 1964, p. 154).

The Diablo Range, and other ranges bordering the
western Great Valley, contain rocks of the Great Valley sequence lying in tectonic contact with rocks of the Franciscan sequence. In the Diablo Range the Tesla-Ortigalita thrust fault forms this tectonic boundary. Page (1966, p. 272) stated that most of the displacement along this fault occurred in the Paleocene or Early Eocene. Other lines of evidence presented by Blake et al. (1969) indicate that the thrusting may have began in the Late Mesozoic.

The folding which created the Diablo antiform and the other folded features bordering the western Great Valley affected the thrust boundaries as well. Therefore, the folding is somewhat more recent than the thrusting. Page (1966, p. 272) has suggested, as have many other geologists, that this folding occurred during the Pliocene and Plio-Pleistocene. Marsh (1959, p. 39) interpreted these folds as being a response to shearing along the San Andreas Fault.

Complicating this folding has been the emplacement or intrusion of Franciscan rocks into the cores of many anticlinal folds so as to create diapirs or piercement structures (Bailey et al., 1964, p. 155). The result is many broadly folded domes with axes that are irregular and hard to define.

Unconformities between the Upper Cretaceous,
Lower Eocene, Eocene and Miocene units of the Panoche Hills indicate separate episodes of tectonism (Payne, 1951). However, even the youngest unit within the Panoche Hills, the Miocene "Temblor" Formation, has been strongly folded. Therefore, the folding of the Panoche Hills appears related to the Pliocene and Plio-Pleistocene phase of deformation which affected most of the west bordering hills of the Great Valley.
CHAPTER III

CLASTIC INTRUSIONS OF THE PANOCE HILLS

INTRODUCTION AND PREVIOUS WORK

Clastic intrusions are similar to those of igneous origin. They are usually tabular bodies of rock which represent infillings of cracks or fissures. The main difference is that the intrusive material is mobil sediment rather than an igneous melt. The infilling of sediment may be the result of forceful injection from any direction, or from normal sedimentary deposition from above.

J. S. Diller (1890) in his study of clastic dikes in the northern Great Valley of California noted that Charles Darwin was probably the first to describe such intrusions from a locality in Patagonia in 1833.

More recent papers describe the occurrence of sandstone dikes within a wide range of rock types (Kelsey and Denton, 1932; Vitanage, 1954; Peterson, 1968b; Powell, 1969) and in association with a variety of structural situations (Smith, 1952; Duncan, 1964; Harms, 1965; Peterson, 1966). Discussions concerned with internal structures of clastic dikes have also been offered by Jenkins (1925), Walton and O'Sullivan (1950),
and Peterson (1968a), to mention but a few. If the reader wishes a more complete summary of the literature concerning clastic intrusions, he should consult either Peterson (1968a) or Powell (1969).

Many interpretations have been suggested for the origin of sandstone dikes. In those cases where the fractures were not filled from above by normal depositional processes, most agree that the intrusions were formed when fractures tapped unconsolidated water-charged sands under high hydrostatic pressures. The sands were released as a mobil fluid and were forcefully injected into the available fractures (Diller, 1890; Meek, 1928; Kelsey and Denton, 1932; Shrock, 1948; Duncan, 1964). This process could be aided by the liquefaction and mobilization of water and sand by earthquake shock waves (Diller, 1890; Jenkins, 1925; Meek, 1928; Shrock, 1948; Marschalko, 1965). This latter idea receives support from Reimnitz and Marshall (1965), who reported that during the Alaskan earthquake of March 27, 1964, sand issued from cracks and fissures in certain areas of tidal flats. Subsequent studies showed that these cracks and fissures were filled with sand which originated from some sand bed of unknown depth.

Although reported from a wide range of areas throughout California, such as those at Santa Cruz
(Newsom, 1903) or at Newport Beach in Orange County (Meek, 1928), the greatest concentration of sandstone intrusions occurs along the western border of the Great Valley. Clastic dikes are known to crop out in the Ono area (near Redding), near Crows Landing, near Coalinga, at several localities in the Temblor Range, and at one locality, the topic of this thesis, in the Panoche Hills (Peterson, 1968b).

Anderson and Pack (1915) were the first to comment on the large and extensive set of sandstone intrusions in the Panoche Hills area. In their description of the Moreno Shale they wrote, "Large sandstone dikes traversing the shale are very conspicuous, a zone of several such dikes being traceable for most of the distance across the strike of the formation" (p. 46-47).

The next reference to these dikes was by Jenkins (1930) in a paper discussing the possibility of sandstone dikes being conduits for oil migration through shales.

In a description of the reptilian fauna of the Moreno Shale in the Panoche Hills, Stock (1939) noted the presence of the dikes and cited one instance in which a series of vertebrae of a marine reptile were displaced by one of the dikes.

Stewart et al. (1944) first mentioned the existence of sandstone sills as well as dikes within the
Moreno Shale. Also, their correlation charts showed the presence of dikes within the Kreyenhagen Shale of the Panoche Hills. None of these latter intrusions were observed by the author.

Payne (1951, p. 11) commented that the only lithologic change within the Tierra Loma Shale are the "... numerous sandstone dikes."

This thesis, therefore, is the first detailed descriptive work concerning these sandstone dikes and sills. The purpose of the investigation was to map these intrusions, to describe them, to interpret their structural setting, and to determine the origin of the intruding sands.

FIELD WORK

The field work was conducted during the latter parts of the months of December 1969, and January 1970. Field work consisted of mapping the upper and lower boundaries of the Moreno Shale, and position of dikes and sills within the shale. Orientation and width data was recorded for all mapped intrusions. Samples were collected for petrographic examination.

The 7.5 minute Chounet Ranch, California quadrangle was used for the purpose of mapping. Enlarged aerial photographs published by the United States
Department of Agriculture were used as a supplement to the 7.5 minute quadrangle map.

The map (Plate I, back pocket) included in this report is a simplification of the Chounet Ranch quadrangle; topography and cultural features were eliminated to simplify the geologic map. The main drainage lines and two section corners were included on the geologic map as control for correlation with the topographic map.

The field work was initiated at the southern extremity of the mapped area. As the work proceeded northward, it was evident that the intrusions varied in their density of distribution or frequency, extent, and width. During later structural analysis, the total map area was subdivided into three nearly equal smaller areas in order to investigate the possibility that the structural picture might be different in any one of these smaller areas. It should be emphasized that these subdivisions were made solely on a geographic basis and not upon any preconceived notion of structural relationships.

The geographic subdivisions and their boundaries are: (1) the Capita area, which includes all those intrusions mapped from the southern extent of the area to, and including, those of Capita Canyon and its branches; (2) the Marca area, which includes all those intrusions within and north of Chaney Ranch Canyon and
south of Moreno Gulch; and (3) the Moreno area, which includes all those intrusions found within and north of Moreno Gulch, including about twenty intrusions located north of the Chounet Ranch quadrangle. Intrusions north of the mapped area are not on the geologic map which accompanies this report, however, they are included on the various charts, graphs, and structural diagrams that accompany the text.

GENERAL FIELD RELATIONSHIPS

The dikes and sills of the Panoche Hills are tabular bodies of sandstone cutting across the steeply inclined strata of the Moreno Shale (Figures 3 and 4). Some of the intrusions divide into a number of branches (Figures 5 and 6). Intersections between intrusions are very common (Figure 4). These intersections are remarkably free of deformation, and in most instances make it impossible to determine cross-cutting relationships.

Dikes are readily identified as such because they are markedly discordant to the bedding of the Moreno Shale. On the other hand, it was often difficult to separate a sill from a sandstone bed or lense. Sills were recognized and separated from sandstone beds if they truncated the stratification of the shale and terminated against a dike (Figure 7). In addition, some
Figure 3. Large intrusion complex in north branch of Marca Canyon. Note that some dikes form dividing ridges between adjacent hillside drainages.

Figure 4. Intersecting dikes in canyon south of Marca Canyon. Note conspicuous slope wash of several highly weathered intrusions.
Figure 5. Bifurcation of a dike in Capita Canyon.

Figure 6. Bifurcation of a large dike in Moreno Gulch.
Figure 7. Termination of a sill against a dike, in north branch of Marca Canyon.
sills climb the section, this discordancy facilitating their recognition.

**Frequency and Extent of the Intrusions**

The frequency and linear extents of the intrusions are misleading when their distribution is viewed on the map (Plate I, see back pocket). Exposures were better on south-facing slopes and in south-draining tributaries. Soil and grass cover made it difficult to trace an intrusion from south- to north-facing hillsides. The Moreno Shale is highly susceptible to slumping. This slumping compounded the problem of exposure, especially on north-facing slopes.

Slumping may account for some of the irregularities in attitude of various intrusions. Some intrusions appear sinuous with minor divergences in dip along their length. These variations might reflect inhomogeneities in the strata with certain areas being more favorable to fracturing and intrusion than others. Slumping also made it difficult to find reliable bedding attitudes.

The intrusions are found in every member of the Moreno Shale, with the greatest frequency of occurrence in the Tierra Loma and Marca Shale Members. At times, the intrusions are too numerous to map at the scale chosen. Therefore, only the most prominent or typical intrusion of these clusters was mapped and recorded. The
author mapped and recorded data for 350 to 400 intrusions. This may represent only half of all dikes and sills observed in the field.

The greatest concentrations of intrusions are in Marca and Capita Canyons and their branches. Here, the most extensive dikes were found, some of which were nearly one-half mile in length. Toward the northern or southern limits of the mapped area the intrusions were less numerous and more limited in extent and width.

**Width of the Intrusions**

As noted above, in situations where there were so many intrusions that it was impossible to map them all, the most prominent or typical was mapped. The most prominent intrusion was generally the widest. In situations where few intrusions were encountered, even some of the intrusions less than six inches wide were mapped. Therefore, the histograms of Figure 8 are misleading in that they represent only those intrusions mapped.

The width of most intrusions mapped ranges from one to two feet. Dikes six to fifteen feet are not uncommon, and one dike in the Capita area was over twenty-three feet wide.

In general, dikes of the Marca area are wider than those of the Capita and Moreno areas. Because the
Figure 8. Dike width histograms.
intrusions of the Marca area are presumably more extensive as well, one could be tempted to equate width with length. In other words, a long dike is correspondingly wider than another dike which is not so long. But this does not appear to be a valid relationship, for in fact, most intrusions pinch and swell and vary in width along their length.

**Internal Characteristics**

The dikes and sills for the most part are massive and have few internal structures. Many of the dikes have been extensively fractured. The fracturing may have destroyed any internal structures that might have been present. Only in the Moreno area was there a well-defined example of an internal structure somewhat resembling a set of ripple marks (Figure 9).

Peterson (1968a) described the presence of internal structures (i.e., "ripple marks," preferred orientation of tabular grains, layering) in the dikes of the Ono area. He interpreted them as flow structures formed as a result of variations in the viscosity and/or velocity rates of the intruding sediment-water mixture. Structureless intrusions were interpreted to indicate either a high velocity of intrusion or a low viscosity for the intruding sediment, perhaps owing to a high water
Figure 9. "Ripple-marks" within a dike in the vicinity of Moreno Gulch.
Most dikes are badly weathered and their debris forms conspicuous slope wash (Figure 4, page 25). However, some dikes are well indurated and stand out in relief (Figure 10), in places forming the dividing crests between adjacent hillside drainages (Figure 3, page 25).

The majority of intrusions are white. A considerable number are a rust-red. Using a method of laboratory analysis described by Mehlia and Jackson (1959) this rust-red color was found to be an iron-oxide grain coating and not a difference in mineralogy of the sandstones. Such processes as leaching of iron from overlying or enclosing beds, iron rich solutions selectively following certain intrusions, or differences in ground water levels could explain the color variation.

Mineralogy

The intruding sand is mostly quartz with some potassium feldspar, and deficient in heavy minerals. The sandstone is weakly cemented by gypsum, and in the case of those intrusions which are rust-red, gypsum and iron-oxide. This, perhaps explains in part why the rust-red intrusions are somewhat better indurated than their white counterparts. The iron-oxide is undoubtly a better cementing agent.
Figure 10. A well indurated dike.

Figure 11. Contact between the Dosados Sandstone and Shale Member (light colored unit) and the Tierra Loma Shale Member. Intrusions can be seen originating from the Dosados unit. Also visible are minor faults cutting the contact.
Gypsum is also associated with the intrusions in another manner. Thick, one-to two-inch sheets of gypsum (var. selenite) in many places border the contact between the intrusions and their surrounding shales. Gypsum also fills minor fractures in the shales that have not been filled with sand. Evidently, gypsum rich solutions percolated through the sandstone dikes and sills which were avenues of high porosity in otherwise impermeable shale. Gypsum was precipitated out of solution at this boundary owing to equilibrium conditions or to loss of water at the sandstone-shale interface.

The minor fractures in the shale likewise constituted more permeable channels for fluids to follow. So again, precipitation of gypsum took place in these fractures. Duncan (1964) reported an analogous situation in his study of some sandstone dikes in the Santa Monica Mountains. In this case, gypsum occupied fractures that were formed after an earlier set had been filled with sand, and the hydrostatic state of the sand precluded its injection into this newer set of fractures. Therefore, they were available to be filled with gypsum. The dikes of the Panoche Hills are cut by gypsum veins as well as the surrounding shales. This indicates that the region must have been affected by a post-intrusion deformation that resulted in another set of fractures.
ORIGIN OF THE SANDS

In an attempt to determine the source of the intruding sands, a bromoform-heavy mineral separation was performed. Sands analyzed using this method included the intruding sands, the sands from those of the Dosados Sandstone and Shale Member, and the Uhalde Member of the Panoche Formation. It was hoped that the heavy mineral suites would permit a source to be recognized. A similar approach was used with success by Meek (1928), and Kelsey and Denton (1932).

The results proved inconclusive. This is not surprising, since it is known that the sandstones of the Upper Cretaceous, in particular the Panoche Formation and the Moreno Shale, differ little in mineralogical content (Davies, 1946). These sandstones are dominated by quartz and alkali-feldspar, and the heavy mineral suites generally comprise less than one percent of the total. Of the heavy minerals which are present, biotite, hornblende, chlorite, and black opaques (chiefly ilmenite and magnetite) are the most common. A few exotic minerals such as zircon, tourmaline, and garnet are present in minor amounts.

The intruding sandstones most closely resemble those of the Dosados Sandstone and Shale Member. More
intrusions are found toward the base of the Moreno indicating the sand probably originated in this region. Also, many intrusions emerge from the Dosados Sandstone and Shale Member and extend both upward and downward into the section (Figure 11, page 34).

A few intrusions (dikes) originate in the overlying Tertiary beds and extend downward into the Moreno Shale. These were limited both in extent and width. However, they do indicate that sands can be intruded from above as well as from below.

Few dikes or sills emerged from the Uhalde Member of the Panoche Formation. Therefore, upon these lines of evidence it is concluded that the principle source for the intruding sandstones is the Dosados Sandstone and Shale Member of the Moreno Shale, but that sands in the underlying and overlying formations contributed a minor amount.

**STRUCTURAL INTERPRETATION OF THE INTRUSIONS**

**Methods Used**

Most fracture systems, whether filled with sand or not, owe their pattern and distribution to some structural cause. This structural cause can be identified by using methods commonly employed in structural analysis.
In this case, a Wulff meridional stereonet and a Lambert-equal area net were used. Pole points that represent normals to the dike and sill planes were plotted on these projections. In addition, the density of pole points on the Lambert-equal area net were contoured on a percentage basis (Dennison, 1968). The pole points to the dominant joint sets were obtained from the contoured diagrams.

Finally, the planes of the dominant joint sets were reconstructed in their present orientation upon a Wulff meridional stereonet.

**Total Area**

When all the pole points for all the intrusions of the mapped area were plotted on a Wulff stereonet, a somewhat diffuse pattern was produced (Figure 12). The same poles plotted and contoured on a percentage basis using the Lambert-equal area net revealed strongly developed concentrations (Figure 13). From this latter method the best fit pole points to three dominant joint sets were obtained by visual inspection (Figure 14). The plane striking approximately N27°W and dipping 44°E is representative of the sills. Representing dikes are two vertical joint planes, one with a strike of N58°E, the other striking N8°W.
Figure 12. Stereonet diagram of pole points to dike and sill planes - Total Area.
Figure 13. Equal area diagram of contoured pole points - Total Area.
Figure 14. Stereonet diagram reconstruction of principle intrusion planes in their present orientation—Total Area.
According to proper notation, the set trending N58°E appears to be the primary set, the other two joint sets are secondary sets (Price, 1966, p. 112). This distinction is based upon frequency rather than width or extent of the fractures. Investigations into the possibility that one or another of the sets might be wider or more extensive than another proved inconclusive.

Only minor variations are encountered when considering a similar analysis of the joints sets within the three smaller areas. Price (1966, p. 116) found that "... joints, which develop in the competent units in the limbs, remote from the crest or trough of the fold, are usually strongly influenced by the orientation of the rock unit." With the fold axis of the Panoche Hills approximately seven miles west of the mapped area, it appears that the orientation of the joint sets, from area to area, has been influenced by a change in strike of the host formation. For in fact, the beds of the Moreno Shale, as previously discussed, are known to change their strike direction from a north-south orientation at the southern end of the mapped area to approximately N36°W at the northern end of the Panoche Hills.

Capita Area

In the southern end, or the Capita area, of the mapped area the primary joint (dike) set strikes N76°E
and dips approximately $82^\circ$NW (Figures 15, 16, and 17). The secondary set of dikes strikes N$4^\circ$W and is vertical. The sills strike N$24^\circ$W and dip $42^\circ$E.

According to Payne's (1962) map, the strike of the regional bedding just below the Capita area is approximately north-south. In the Capita area an average value for the strike is N$10^\circ$W, the dip is $39^\circ$E.

**Marca Area**

Within the Marca area only two joint sets are well developed (Figures 18, 19 and 20). The primary joint set strikes N$58^\circ$E and dips $85^\circ$NW. The sills represent the other joint set present; they strike N$25^\circ$W and dip $40^\circ$E. No suggestion of a secondary dike set exists on either the stereonet diagram of pole points or the Lambert-equal area net.

The strike of the Moreno Shale in the Marca area is approximately N$23^\circ$W. The dip is $40^\circ$E or essentially the same as that of the Capita area.

**Moreno Area**

In the Moreno area three joint sets are again present (Figures 21, 22 and 23). The primary set of joints (dikes) are vertical and strike N$68^\circ$E. The secondary set of joints (dikes) strike N$14^\circ$W and dip $83^\circ$SW. The sills strike N$31^\circ$W and dip $48^\circ$E.
Figure 15. Stereonet diagram of pole points to dike and sill planes - Capita Area.
Figure 16. Equal area diagram of contoured pole points—Capita Area.
Figure 17. Stereonet diagram reconstruction of principle intrusion planes in their present orientation—Capita Area.
Figure 18. Stereonet diagram of pole points to dike and sill planes—Marca Area.
Figure 19. Equal area diagram of contoured pole points - Marca Area.
Figure 20. Stereonet diagram reconstruction of principle intrusion planes in their present orientation—Marca Area.
Figure 21. Stereonet diagram of pole points to dike and sill planes - Moreno Area.
Figure 22. Equal area diagram of contoured pole points—Moreno Area.
Figure 23. Stereonet diagram reconstruction of principle intrusion planes in their present orientation - Moreno Area.
The regional strike of the Moreno Shale in this area is more to the northwest (N36°W), but an average dip of 43°E is not very different from that in the other two areas.

Relation of Intrusions to Regional Structure

The angle between the primary and secondary set of dikes is approximately 60°. The angle between a set of conjugate shear fractures would be approximately 60°. And the angle between a longitudinal joint set and a set of shear fractures on a fold would also be approximately 60° (Badgley, 1965, p. 99; Price, 1966, p. 114).

However, there is no satisfactory means by which these two dike sets can be related to the fold of the Panoche Hills. The dike sets appear identical. Any differences in width, length, or structure are not apparent. Perhaps then, the dike sets were formed in the same manner. If one set of dikes were longitudinal joints, which are tensional features, and the other shear joints, one would expect observable differences in the appearance of the dike sets. The best possible explanation for their similarity would be that they are a set of conjugate shear joints. But once again, it is difficult to relate their attitude to the fold of the Panoche Hills.
The San Andreas Fault zone is approximately twenty-eight miles west of the Panoche Hills. The San Andreas Fault in this area strikes N50°W. If a diagram by Badgley (1959, p. 247) were aligned so that one of the first order shears corresponded to the strike of the San Andreas Fault, then vertical second order shear features would have the following orientations: (1) N6°W; and (2) N54°E (Figure 24). These two strike directions are very similar to the orientation of the two dike sets within the mapped area (N8°W and N58°E). This suggests the possibility that the two dike sets within the Moreno Shale of the Panoche Hills are fillings of second order shear fractures related to movements along the San Andreas Fault.

These second order shear planes must have been late in the folding phase of the Panoche Hills, for they are vertical as would be expected for conjugate shear fractures related to a vertical strike slip fault. The attitude of the regional bedding could account for minor differences in the orientation of the fracture planes in any one of the three smaller areas.

Most of the sills represent intrusion accompanying flexural-slip folding in the initial phases of deformation. Flexural-slip folding is the most convenient means for rock strata to yield to stress during
Figure 24. Theoretical pattern for conjugate shearing in a homogeneous medium under homogeneous stress. The first order shear in this case is aligned N50°W or the orientation of the San Andreas Fault west of the Panoche Hills. After Badgley, 1959, p. 247, fig. 314.
the early phases of folding. Such folding would not produce stresses favorable to vertical fracturing. Therefore, intrusion of water-charged sands under high hydrostatic conditions would occur as a matter of consequence along the planar weaknesses, and at this stage be confined to an area immediately adjacent to the sand source, in this case the Dosados Sandstone and Shale Member. In fact, this appears to be the case, for more sills are found toward the base of the Moreno, or in the vicinity of the Dosados Sandstone unit rather than higher in the formation. Subsequent fracturing, if vertical, would by necessity favor the formation of dikes and not sills. Under these conditions, the water-charged sands found a ready route to the upper portions of the Moreno Shale, but were unable to intrude parallel to the bedding surfaces except in a few instances.

Objections raised against the infilling of shear joints and flexural-slip planes with sand so as to cause dialations up to fifteen feet are refuted by Secor (1965). His studies have shown that even a normal hydrostatic fluid pressure distribution will permit the development of tension fractures to a depth of several thousand feet, and as the ratio of fluid pressure to overburden approaches one, the maximum depth for tension fracturing and fluid injections becomes very great (Secor, 1965,
The Dosados Sandstones, interbedded as they are between impervious shale layers, could have possessed a high water to sand ratio. Normal burial of these sands beneath several thousand feet of overburden would produce the fluid pressure values Secor (1965) has set for moderate fracturing. Add compression due to folding to these existing overburden pressures and the injection of water-charged sands between shale layers at depth becomes less of a problem.

Fluid pressures could dialate shear fractures and flexural-slip planes in order to create sandstone dikes and sills. On the other hand, a clastic dike study by Smith (1952) has demonstrated shear joints to be in some situations extensional features capable of being filled from above by aeolian deposition.

It may be asked why the intrusions occur to such an extent in this particular locality of the Panoche Hills. Perhaps the area was the region of maximum stress relief for the folding which created the Panoche Hills anticline. In other words, conditions favoring the type of fracturing observed were to be found in an area where the beds experienced their greatest change in strike. Complicating this interpretation is the possible relationship the fractures might have with the San Andreas
Fault.

Subsequent deformation since the creation of the dikes must be slight, for they appear little rotated from their expected vertical position (Badgley, 1959).
CHAPTER IV

SUGGESTIONS FOR FURTHER STUDY

The writer made several reconnaissance trips to other localities where the Moreno Shale is known to outcrop. These trips were made to see if the Moreno in these other localities possessed intrusions similar to those observed along the east flank of the Panoche Hills.

No intrusions were observed within the outcrops of the Moreno Shale in the Laguna Seca Hills which lie to the northwest of the mapped area (Figure 1, page 2). Briggs (1953, p. 34) noted several small dikes in the Ortigalita Peak area farther north, but he commented that they were not as common there as elsewhere within the Diablo Range.

During a casual inspection of the area immediately south of the mapped area no intrusions were observed. However, intrusions were encountered in and adjacent to Panoche Creek at the southern end of the Panoche Hills. Due to access problems, the extent, size, and complexity of these intrusions could not be fully determined. Payne (1962) showed several faults to exist in this area, therefore, these intrusions may be associated with faulting. At any rate, these intrusions
warrant further study to discover what relationship their existence may bear to the intrusions mapped by the author farther north.

William Travers (personal communication) of Princeton University has reported clastic intrusions within the Moreno Shale in the Pine Mountain area, approximately fifteen miles southwest of the Panoche Hills. He did not know, however, their size, extent, or structural relationship.
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ABSTRACT
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During a phase of Plio-Pleistocene deformation in the Panoche Hills region of Fresno County, California, Upper Cretaceous rocks of the Great Valley sequence were deformed into a broadly folded dome. Fractures within the Moreno Shale were filled with sand from one of that formation's lower members, the Dosados Sandstone and Shale Member. Some of the sandstone dikes and sills are nearly one-half mile in length. Most of the intrusions mapped were one to two feet in width, but dikes six to fifteen feet wide were not uncommon, and one dike was over twenty-three wide.

A contoured Lambert-equal area plot of poles to dike and sill planes established the existence of three dominant joint planes or sets: (1) a primary dike set, striking N58°E and vertical; (2) a secondary dike set, striking N80°W and also vertical; and (3) a secondary joint set representing sills striking N27°W and dipping 44°E.

Comparing the orientation of the dike sets with diagrams drawn by Badgley (1959) suggests the possibility that the dike sets represent infillings of second order shear fractures. It is the opinion of the writer that the sills represent sand intrusion along flexural-slip joints.