GEOLOGY OF A PORTION OF THE ENSENADA QUADRANGLE
BAJA CALIFORNIA, MEXICO

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
James Edward Schroeder
July 1967
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Approved by:
[Signatures]
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CHAPTER I

INTRODUCTION

This thesis is a detailed geologic study of a sequence of slightly metamorphosed pre-batholithic volcanic rocks, the plutonic which intrudes them, and the unconsolidated sedimentary deposits derived from them. The area is important since no detailed work has been published on the Mesozoic pre-batholithic rocks between Santo Tomás Valley, Baja California, and San Diego County, California.

I. LOCATION AND ACCESSIBILITY

The area of investigation is located just south of Ensenada in northwestern Baja California, Mexico. It is geographically bounded by 31° 52' 24" and 31° 45' 32" north latitude and 116° 37' 36" and 116° 29' 36" west longitude (Figure 1).

The region covers approximately 90 square kilometers, extending 2,000 meters north of Arroyo el Gallo in the north to Valle de Maneadero in the south. Mexican Highway from Tijuana through Ensenada crosses the area. Dirt roads in Arroyo el Gallo and Valle de Maneadero give access to the eastern margin of the region.
FIGURE 1
INDEX MAP
This area is characterized by a nearly flat coastal plain on the west with prominent elevations to the east, underlain by a series of metavolcanic and plutonic rocks. The mountainous terrain reaches elevations of 500 to 750 meters above sea level. Individual peaks are separated by narrow incised ravines, which are small in extent. Elevations decrease gradually westward where deep, rugged canyons become broader, open valleys with gentle slopes. Cliffs of 125 to 150 meters are common along the western margin, although locally they seldom exceed 200 meters.

The coastal plain ranges in width from less than 2 kilometers in the north to about 4.8 kilometers in the south. This plain is dissected by intermittent creeks and streams which flow westward out of the numerous canyons along the mountainous front. Cliffs along Valle de Maneadero produced by subsequent stream drainage attain elevations of 15 to 25 meters.

The streams are dry during most of the summer months with exceptions found in the middle and upper reaches of both the Arroyo el Gallo and Valle de Maneadero.

The climate is semiarid with temperatures ranging from 65°F to 90°F during the summer months, with occasional higher recordings toward the east where sea breezes are
interrupted by mountain peaks. Winter temperatures range from 45°F to 75°F. The average annual precipitation is 283.3 mm, occurring chiefly between the months of January and April.

The area supports a vegetation dominated by California sagebrush, chaparral, manzanita, and cactus. There are pasture and cultivated lands on the terrace. Near streams and ponds, cottonwood trees and reeds are found. In the higher elevations to the east, oak trees separated by a thick growth of manzanita dot the horizon.

III. METHOD OF STUDY

The geology of the area was mapped directly on aerial photographs at a scale of 1:40,000. Aerial photographs were obtained from Compania Mexicana Aerofoto, S.A. by San Diego State College. The geology was then transferred to a topographic base map with a scale of 1:18,000, and contour interval of 50 meters. This base map was an enlargement of a portion of map sheet 11 R-11-b3-I Ensenada published by the Consejo de Recursos Naturales No Renovables, Mexico.

A total of nine weeks was spent in the field during the summer months of 1966, and January 1967. Because of poor outcrops and density of brush, few rock unit contacts were located with greater accuracy than ± 4 meters, and
some on the order of \( \pm 9 \) meters.

A petrographic analysis of the rocks was determined necessary when it became evident early in the report that much of the history would have to be obtained from such a study. Approximately forty thin sections of plutonic and metavolcanic rocks were observed. X-ray fluorescence was also used for mineral identification when petrographic work was uncertain.

Plutonic and metamorphic rocks were classified as specified by Williams, Turner, and Gilbert (1954). Sedimentary names were based on classifications by Pettijohn (1957) and Fisher (1961).

IV. PREVIOUS WORK.

Santillán and Barrera (1930) regionally mapped the peninsula of Baja California, Mexico from latitudes 30° to 32°N. as part of a study in determining oil possibilities. They named the pre-batholithic rocks in the lower Santo Tomás Valley the Alisitos Formation, and assigned an Early Cretaceous age based on fossils collected from the vicinity of Rancho Alisitos (approximately 21 kilometers to the south of the area of study).
Beal (1948) conducted a geologic reconnaissance of the entire Baja Peninsula and published a geologic sketch giving a regional summation.
CHAPTER II

REGIONAL GEOLOGY

The Baja California Peninsula is 1,300 kilometers in length and 50 to 250 kilometers wide. The dominant physiographic feature is the high north-south trending mountain range, which is an extension of the Peninsular Ranges of southern California. This mountainous terrain is underlain by the crystalline rocks of the batholith of southern California and Baja California. The batholith extends 1,613 kilometers from Riverside, California down the axis of the peninsula to its southern tip, covered in places by younger rocks (Wisser, 1954). The major rock type of the batholith is quartz diorite, although the batholith was emplaced by many injections and ranges in composition from gabbro to granite (Larsen, 1948).

The batholith forms the Sierra de Juarez and the Sierra San Pedro Matir (Woodford, and Harriss, 1938). These mountains have a long western slope to the Pacific Ocean and a steep eastern face, much like the Sierra Nevada of California.

The foothills which lie between the mountain summits and the Pacific Coast are underlain by pre-batholithic volcanic rocks, which have been locally
intruded and metamorphosed by small plutons. Post-batholithic sedimentary and volcanic units overlie these rocks in a narrow strip along the Pacific Coast.

I. PRE-BATHOLITHIC ROCKS

Pre-batholithic rocks of the northwestern coastal region of Baja California typically include a thick section of interbedded flow, pyroclastic, and metasedimentary rocks. The most common rock types are basic to intermediate tuffs, breccias, and flows. Many units are characterized by sorting, channeling, graded bedding, and cross-bedding. The effect of metamorphism on these rocks varies from intense near the intrusion to almost negligible near the coast. Most units have a regional strike to the northwest with a steep dip component.

In the coastal region between Ensenada and Colonia Guerrero, Silver et al. (1963) found amydaloidal andesite and basalt flows intercalated in the clastic units to be the most common rock type. Although rhyolite debris was found in some clastic deposits, no rhyolite flows have been observed (Silver et al., 1963).

The repetitious nature of the volcanic lithology and the unknown structure have prevented reliable estimates of the thickness of the section. A minimum of 5,000 meters has been estimated by Allison (1964). No widespread
unconformities have been noted in the pre-batholithic rocks, nor have the top or bottom of the section been determined (Silver et al., 1963).

II. BATHOLITHIC ROCKS

The pre-batholithic rocks of northwestern Baja California have been intruded by plutons as well as numerous small igneous bodies. These rocks are part of the Peninsular Range Batholith and are similar in part to the batholithic mass described by Larsen (1948) in areas north of the International Border. Quartz diorite comprises more than 80 per cent of the plutonic rocks studied by Silver et al. (1963), with granodiorite the second most prevalent composition. Diorite and gabbro have been noted more commonly as smaller sills and dikes.

Many large plutonic bodies adjoin one another along the north-south axis of the peninsula, but are increasingly separated by metamorphic sequences to the west until along the coast the rocks are predominantly metamorphic (Allen et al., 1960). The known eastern extent of the batholith borders the Gulf of California.

Geochronological studies on these intrusives are presented by Silver et al. (1963). By use of an isotope dilution analysis of a monzonite from the La Grulla Granodiorite (Woodford and Harriss, 1938) an absolute age
of 115 million years was established. In later studies, Silver (personal communication, January 1967) used the mass spectograph on a number of samples from the intrusives of San José, San Telmo, San Vicente, Punta Cabros, Sierra San Pedro Martir, and from the Agua Blanca pluton and concluded that these intrusives were nearly the same age ranging from 110 to 115 million years.

III. POST-BATHOLITHIC ROCKS

Post-batholithic rocks exposed in northern Baja California are represented by marine and continental sedimentary rocks of the Upper Cretaceous Rosario Formation (Beal, 1948) which crop out as a narrow band essentially parallel to the present coast line; Cenozoic volcanic and associated nonmarine sedimentary rocks that form erosional remnants capping the Sierra Juarez and the coastal hills north of Ensenada; and Quaternary terrace deposits, fan gravels, and alluvium.

Terraces, many of which are overlain by strata with Quaternary invertebrates, occur in many places along the west coast of the peninsula. Invertebrate Pleistocene fossils have been reported from many of the lower terraces with elevations ranging from 6 to 30 meters. Recent invertebrates are reported to be scattered over wide areas of the coastal region to a maximum elevation of 545 meters
and are thought to represent kitchen midden material (Beal, 1948).

Lindgren (1888) noted "old shore lines" at Bahía Todos Santos near Ensenada, and well-marked wave built terraces at Punta Bunda as low as 9 to 12 meters above sea level. Many of the terraces occurring along the coastal region from the southernmost portion of San Diego County to a point some 20 kilometers south of the International Border were named and described by Ellis (1919). Beal (1948) observed two terraces for a distance of nearly 40 kilometers along the coast south of Tijuana, one at an elevation of 15 meters above sea level and the other at 30 meters above sea level. South of Punta China, a series of terraces (some attaining elevations of 180 meters) were reported by Emerson (1956). A Late Pleistocene age was assigned to the lowermost terrace on the basis of fossil content.

Comprehensive information concerning the distribution, composition, and geologic history of the terraces occurring in northwestern Baja California is limited, making correlations difficult.
CHAPTER III

PRE-BATHOLITHIC ROCKS

The pre-batholithic rock sequence in the Ensenada region is a series of mildly metamorphosed, fine-grained, pyroclastic beds, volcanic flows, and volcanic breccias with compositions ranging from dacite to andesite (see columnar section, Figure 2). The colors vary from white in some tuffaceous strata to dark red in the volcanic breccias. Light gray, green, purple, and dark gray colors are also common. Metamorphism, deuteric alteration, weathering, and localized silicification has affected nearly all of the rock units so that original textures are poorly preserved. These pre-batholithic rocks constitute a section of approximately 1,575 meters, and have an east-west strike with a northwest dip except where deformation is represented.

Assigning an age and formational name to the pre-batholithic rocks in the Ensenada region is difficult. North of the International Border, Hanna (1926) applied the name Black Mountain Volcanics to mildly metamorphosed pre-batholithic volcanic rocks with inliers of slates, argillites, and meta-graywackes. This sequence is exposed as a discontinuous north-northwest trending belt that lies
Qal, Qb, Qt - RECENT SEDIMENTS and TERRACE DEPOSITS.

Mvf - MEMBER F: dacite lithic and crystal tuff.

Mve - MEMBER E: andesite breccia.

Mvd - MEMBER D: interbedded tuffaceous andesite breccia and volcanic sandstone.

Mvc - MEMBER C: tuffaceous andesite breccia, welded lithic tuff, and andesite.

Mvb - MEMBER B: dacite breccia and welded tuff, dacite porphyry, and tuffaceous andesite breccia.

Mva - MEMBER A: interbedded dacite breccia, tuffaceous andesite breccia, andesite, and andesite breccia.

Kg, Kgd - INTRUSIVES: granodiorite and quartz diorite.

FIGURE 2

COLUMNAR SECTION
within a few kilometers of the coast. These volcanic rocks were later renamed the Santiago Peak Volcanics by Larsen (1948) because the name Black Mountain had been used for a basalt of Plio-Pleistocene age in northern California. The volcanic rocks of the San Diego region have been tentatively correlated by Milow (1961) with the pre-batholithic rocks in Baja California. However, information is lacking as to the stratigraphic and structural continuity of these units to the area of study. Fossils found within the Santiago Peak Volcanics are of a Late Jurassic (Portlandian) age (Fife et al., 1967).

To complicate the problem, the lithology of the volcanic rock exposures in western San Diego County is also similar to the Early Cretaceous (Aptian-Albian) Alisitos Formation (Santillán and Barrera, 1930; Allison, 1955, 1964), which is exposed to the south of Ensenada. Volcanic flows and tuffaceous sedimentary rocks of the Alisitos Formation are lithologically similar to those in the area of study. There are also almost continuous exposures from the area of interest to the type section of the Alisitos Formation, located 21 kilometers to the south in the vicinity of Rancho Alisitos, Santo Tomás Valley. However, the Agua Blanca Fault separates these two regions, and as yet there is incomplete information as to the function of the fault in the distribution of the
pre-batholithic rocks.

Inasmuch as fossil evidence has not been reported in the area of study, nor the top or bottom of the section recognized, no equivalence of these rock units has been demonstrated. Therefore, the name Mesozoic volcanic rocks will be applied to these rocks until further information can assure a definite formational correlation.

I. MEMBER A

The lowermost pre-batholithic volcanic rock unit in the Ensenada section is a sequence of undifferentiated andesite and dacite breccias, and andesite flow rocks. This unit is exposed continuously from near the month of Valle de Maneadero to the eastern border of the mapped area. It is approximately 455 meters thick, and is conformably overlain by a dacite flow of Member B. The most prominent exposures occur along Valle de Maneadero where it forms smooth debris-covered cliffs towering 400 meters above the valley floor. To the south and southeast, mafic hornfels and slightly schistose rocks crop out near the batholithic intrusion. These rocks grade into the volcanic sequence and are thought to be lateral equivalents.

Andesite breccia. The southern and lowermost exposures along Valle de Maneadero are characterized by an
andesite breccia. This unit consists of angular to sub-angular clasts of andesitic and dacitic composition, ranging in size from a few millimeters to 13 cm, and cemented in an tuffaceous andesite matrix. Where fresh, the rocks are dark red to purplish-brown. Reddish-brown to dark brown colors are characteristic of the weathered surface. Many outcrops are heavily stained with iron oxide giving the rock surface a light orange coloration. In some areas the weathered outcrops have a nodular appearance produced by differential weathering of the fragments and matrix. Fragments of pumice commonly produce a pitted surface because of their more rapid weathering.

The clasts and matrix of the breccia generally have a similar composition. However, the clasts tend to contain less iron oxide than the matrix. Tuff fragments consist of devitrified glass, plagioclase, quartz, and epidote. Often the tuff is outlined by particles of clay and iron oxide, which exemplify their shape. The common plagioclase of the fragments is An_{22} to An_{25}. Cristobalite-plagioclase fibers are the products of devitrification.

The matrix of the breccia has a hyalopilitic texture containing devitrified glass, plagioclase, quartz, and magnetite. Phenocrysts of quartz and plagioclase range
in size from 0.5 mm to 2.0 mm. Both have been resorbed and filled with matrix material. The plagioclase is normally zoned and ranges in composition from An$_{24}$ to An$_{32}$, slightly more calcic than in the clasts. Accessory minerals are hematite, magnetite and apatite. Secondary minerals usually include chlorite, epidote, and sericite.

**Andesite.** Dark green andesite is a common volcanic rock in this lower sequence. Outcrops are characteristically light to reddish-green.

The andesite shows a porphyritic texture with plagioclase phenocrysts attaining lengths of 0.5 mm to 1.5 mm. The matrix is hyalophitic containing microcrystalline plagioclase and quartz with interstitial glass. Five to 10 per cent of the rock consists of angular to subangular fragments of andesite, dacite, and minor pumice, ranging in size from 0.25 mm to 6.0 mm.

Euhedral to subhedral plagioclase phenocrysts range in composition from An$_{26}$ to An$_{40}$. They frequently exhibit broken crystal borders with resorption along the margins and core, filled with more sodic plagioclase and quartz. Fractured margins are altered to sericite. The plagioclase crystals are usually more calcic than the matrix plagioclase. The matrix has a green coloration in hand sample due to the abundance of secondary epidote derived
by metamorphism from the calcium-aluminum minerals.

The minor andesite and dacite fragments have a matrix composed of a microlitic intergrowth of plagioclase with intersertal devitrified glass and quartz. Many of these fragments contain an abundance of finely dispersed iron oxide so as to give them a definite red cast in thin section. Accessory minerals include apatite, hematite and magnetite with secondary chlorite, sericite, and epidote.

**Tuffaceous andesite breccia.** The tuffaceous andesite breccia is a dark red to purple rock, weathering brownish-red to dark brown. It is porphyritic with plagioclase phenocrysts ranging in size from 0.50 mm to 2.0 mm. It has a general mineralogic similarity with the andesite breccia, except that glass shards are more prevalent. The lithic fragments are angular to subangular, and consist of andesite flow rock, tuff, and pumice. Andesite fragments contain more iron oxides than the matrix yielding a characteristic red color. These andesitic fragments consist of plagioclase microlites in matrices of devitrified glass particles, microcrystalline plagioclase, quartz, and magnetite. Andesine (An$_{30}$ to An$_{35}$) is the common feldspar. Pumice is the abundant lithic fragments. They range in size from 0.25 mm to
5.0 mm and show little alteration, with minor devitrification. Cristobalite-plagioclase (?) devitrified glass particles are present in both the breccia matrix and the fragments.

The matrix of the breccia has a hyalophitic texture containing devitrified glass particles, microcrystalline feldspar, quartz, and magnetite. The plagioclase composition is generally more calcic than the clast plagioclase. Composition ranges from An$_{30}$ to An$_{42}$. Secondary epidote and clay minerals are found in the ground mass.

**Dacite breccia.** Dacite breccia is a dark gray to light purple rock weathering to a light gray. Locally it has been highly polished by erosion to a very smooth surface. The clasts are dacitic and andesitic in composition and range from 0.2 mm to 15 cm. In some areas differential weathering has left a pebbly surface with clast protruding 3 mm to 1 cm from the matrix.

This rock has an intersertal matrix of plagioclase, quartz, epidote, and minor glass. The commonly exhibited texture is hyalopilitic. Size of the matrix crystals are usually smaller than 0.05 mm.

Phenocrysts can be either euhedral oligoclase (An$_{26}$) and (An$_{40}$) or euhedral quartz. Sizes of the phenocrysts vary from 0.25 mm to 2.0 mm. Quartz commonly occurs with
rounded, corroded edges filled by matrix. The plagioclase has resorbed edges and fractures altering to sericite.

The subangular to subrounded clasts contain more iron oxide than the matrix making their outlines evident in both hand sample and thin section.

Accessory minerals found in the dacite breccia are magnetite and apatite. Secondary minerals present include sericite, epidote, and iron oxides.

II. MEMBER B

Above Member A is a sequence of interbedded volcanic flows, volcanic breccias and welded tuffs. It rests conformably on the underlying unit and comprises a total thickness of 409 meters. The section is exposed in an east-west trending belt from the middle portion of the area of study extending to the eastern border. The separate units of this member are easily differentiated because of the excellent exposures on the canyon walls of deeply incised streams.

Volcanic breccia with clasts of volcanic flow rock, breccias, and tuff clasts are interbedded with dacite porphyry and welded tuff. These units are easily differentiated because of texture and color variations. Fragments in the breccias are angular to subangular with mineral compositions nearly identical with the matrices,
although color variations do exist between matrices and clasts. The breccias vary in thickness and in coloration. Excellent exposures are located in the west, but become covered with debris and vegetation to the east so that individual units become undiscernable.

Member B differs from Member A in that the individual units in Member B are quite easily differentiated in the field. The units in Member A are interlayered and grade into one another along strike. The dacite porphyry flow rock is also quite diagnostic of Member B for it does not crop out in any other portion of the field area.

**Dacite porphyry.** Dacite porphyry is observed in two separate flows. The lowest unit is exposed along the lower portions of an east-west trending valley to the north of Valle de Maneadero. This section is 91 meters thick, and commonly develops a columnar joint pattern (map reference point 5). These columnar joints are approximately 12 meters high with pinch and swell structures along the vertical faces.

A second dacite porphyry exist further up in the section and is separated by a tuffaceous breccia. This unit is 76 meters thick, and is easily identified for it is bordered by two darker volcanic units and is covered by little talus and debris on the canyon wall. The dacite
is light gray and weathers to a characteristic gray-green to orange-gray depending on the amount of iron oxide staining.

The dacite porphyry has a seriate porphyritic texture with phenocrysts of quartz and plagioclase. Phenocrysts range in size from 0.25 mm to 3.5 mm. The matrices are composed primarily of pilotaxitic plagioclase, devitrified glass, and epidote.

Plagioclase (An$_{35}$ to An$_{42}$) is most commonly oscillatory zoned although normal zoning is present. Epidotization of more calcic cores and seritization of fractured and corroded margins is common in most of the euhedral to subhedral phenocrysts. Resorbed areas are filled with quartz and more sodic plagioclase. Quartz phenocrysts range in size from 0.25 mm to 1.0 mm. Many crystals have corroded borders with irregular tongues of matrix material projecting into them. Most quartz, however, is found in the matrix as interstitial anhedral crystals. The matrix plagioclase (An$_{32}$) is more sodic than the phenocrysts. Secondary minerals include chlorite, sericite, and hematite.

**Tuffaceous andesite breccia.** Separating the two dacite porphyry units is a dark red to purple tuffaceous andesite breccia. This unit weathers typically brownish-
red and is commonly pitted where clasts have been weathered out. The breccia is 83 meters thick, and thickens slightly to the east. Clast size ranges from 1.0 mm to 5 cm.

The clasts and matrices of the breccia are mineralogically similar with the exception that most clasts have a higher content of iron oxide giving them a dark red color. The matrix of the breccia has a hyalophitic texture containing devitrified glass particles, microcrystalline plagioclase, hematite, magnetite, and quartz. Epidotization of the plagioclase is irregularly dispersed throughout the matrix. Plagioclase (An$_{30}$ to An$_{35}$) is twinned according to the Albite and Carlsbad laws. The devitrified glass is commonly altered to cristobalite-plagioclase. Fractured edges and margins of the matrix plagioclase is altered to sericite.

The tuffaceous clasts are angular to subangular with plagioclase crystals in a matrix of microcrystalline feldspar, quartz, and hematite. These fragments constitute 10 per cent of the total volume of the rock. The larger plagioclase crystals in these fragments have a composition of An$_{27}$. Most euhedral feldspar crystals are from 0.2 mm to 0.5 mm in length and partially altered to clay. Quartz is restricted to the groundmass where it occurs with plagioclase as small anhedral crystals.
Pumice fragments (ranging from 0.5 mm to 5.0 mm) are common in this rock. These fragments have a long slender dimension with minor alteration to the colorless vesicular glass. Cristobalite-plagioclase fibers are the product of the devitrified glass.

**Dacite welded tuff.** Conformably overlying the second dacite porphyry unit is a dark red dacite welded tuff. This unit is 98 meters thick, weathers brownish-purple, and pitted where lithic fragments have been weathered. The clasts are difficult to observe on weathered surfaces. However, on less weathered exposures these fragments are dark gray to black due to iron oxides.

This rock is foliated (eutaxitic) due to parallel arrangement of flattened glass shards and pumice fragments. The matrix is composed of glass, microcrystalline plagioclase, quartz, and magnetite. The glass is commonly devitrified to cristobalite-plagioclase.

Pumice fragments (ranging from 0.25 mm to 5.0 mm) normally are associated with the shard material. These fragments have elongate tubular pore spaces which give the specimen a fibrous structure. Many pumice clasts have been devitrified, destroying the original fibrous structure. The devitrified areas have a coarse-grained intergrowth of cristobalite-plagioclase. Many of the
glass shards and pumice fragments have been thoroughly bent and distorted around other foreign fragments.

Andesite clasts are subrounded to subangular with matrices of devitrified glass, plagioclase, quartz, and magnetite in a hyalopilitic textured groundmass. Euhedral to subhedral andesine (An\textsubscript{24}) is the most common plagioclase in these fragments. Many of the clasts are embayed with glass and microcrystalline matrix material.

Phenocrysts constitute 40 per cent of the total volume. The most abundant phenocrysts are euhedral to subhedral plagioclase (An\textsubscript{32} to An\textsubscript{40}) ranging from 0.5 mm to 2.0 mm in diameter. Many of these phenocrysts have been intricately fractured so that the crystals are sharply angular in outline. Many have been resorbed and filled with quartz, while others have been altered by chlorite and sericite. Quartz phenocrysts are minor with most of the quartz restricted to the groundmass.

Accessory minerals include apatite, hematite, and magnetite. The secondary mineral of calcite constitutes 5 to 10 per cent of the total volume.

Dacite breccia. The dacite breccia is a light-gray to pinkish-gray unit, which conformably overlies the welded tuff. This rock unit is 61 meters thick. Clast size within the breccia ranges from 0.5 mm to 21 mm,
increasing from west to east.

The clasts range from andesite to dacite. These subangular to subrounded fragments contain dispersed iron oxide giving them a dark gray color. Andesine (An$_{32}$) phenocrysts are distributed in a hyalopilitic matrix with felted plagioclase microlites, microcrystalline quartz, and magnetite. The andesine is twinned according to the Albite and Carlsbad laws, and commonly is epidotized. Lithic fragments constitute 10 to 15 per cent of the total volume of the rock.

The matrix of the breccia again has a hyalopilitic texture with microlites of plagioclase dispersed in a felted texture of quartz. Magnetite is found throughout with minor epidotization of the plagioclase. The composition of the plagioclase varies from An$_{23}$ to An$_{32}$.

Euhedral to subhedral plagioclase phenocrysts attain dimensions of 0.5 mm to 2.0 mm with a slightly more calcic composition than the matrix of An$_{26}$ to An$_{40}$. Normal zoning is prevalent with epidotization of the calcic cores. Many of these crystals have resorbed and fractured areas with quartz and more sodic plagioclase filling the embayed portions.

Quartz phenocrysts range from 0.75 mm to 1.2 mm in diameter. These crystals often have been rounded and embayed by the matrix material.
III. MEMBER C

Member C is an east-west trending sequence of interbedded welded lithic tuff, andesite, and andesite breccia. This unit is exposed in the middle portion of the area of study and extends to the eastern margin. It is 303 meters thick, and conformably overlies Member B. The welded lithic tuff and andesite breccia are interlayered and grade into one another. The andesite is underlying these upper units and grades vertically into them.

Andesite. The andesite is 15 meters thick. Fresh exposures are light gray-green, weathering to a light brownish-green and in many areas covered by an iron oxide stain. Lithic fragments ranging in size from 0.25 mm to 15 mm are distributed throughout the rock, and consist of dark red andesite and dacite as well as light brown pumice. On many weathered surfaces these clasts have been plucked out or completely altered so as to produce a pitted texture.

The matrix is a felted groundmass of devitrified glass particles, plagioclase, and quartz. Plagioclase in both the matrix and phenocrysts has been epidotized giving the rock a green coloration.

The plagioclase phenocrysts (An$_{26}$ to An$_{40}$) are
0.25 mm to 2.5 mm in size, euhedral to subhedral, commonly fractured, and sericitized. They have minor zoning (normal), and are partially resorbed by quartz and more sodic plagioclase.

The andesite and dacite clasts tend to contain more iron oxide than the surrounding matrix. Compositionally, the clasts are very similar to the matrix, however the plagioclase of the fragments is slightly more sodic (An$_{22}$ to An$_{32}$). The groundmass is hypocrystalline containing feldspar microliths and devitrified glass in a hyalopilitic texture.

Accessory minerals include apatite, chlorite, hematite, and magnetite.

**Welded lithic tuff.** The welded lithic tuff is a red porphyritic rock with light gray streaks of compressed pumice fragments up to 2 cm long and 10 mm wide. This unit is 129 meters thick, and weathers to a light red with a rough pitted surface texture. The welded tuff is characterized by euhedral to subhedral plagioclase phenocrysts with fragments of andesite and tuff ranging from 0.5 mm to several centimeters.

This tuff has a foliate structure (eutaxitic) due to a parallel arrangement of compacted and flattened glass shards and pumice fragments. The planar arrangement
imps one a foliation which has the appearance of flow banding. Though thorough welding and strong compression against embayed plagioclase and lithic fragments is evident, there is only slight distortion of the shards. Much of the glassy matrix has been devitrified after welding with the formation of a fine grained intergrowth of cristobalite-plagioclase.

The pumice fragments commonly are devitrified with the original fibrous structure destroyed by the recrystallization to cristobalite-plagioclase. Apparently, pumice fragments are more acceptable to devitrification for in many areas the pumice is completely devitrified, while the glass shards remain unaltered. The long axis of the pumice fibers is elongate to the parallel arrangement of the glass shards.

The plagioclase (An$_{28}$ to An$_{32}$) phenocrysts are sharply euhedral, ranging in size from 0.1 mm to 1.0 mm. Many of the feldspar crystals are fractured and altered to sericite and epidote. The alteration generally is limited to microlites in the glassy groundmass.

The andesite clasts contain plagioclase phenocrysts in a holocrystalline matrix of plagioclase, quartz, and glass particles. Epidote, sericite, and chlorite are scattered sporadically throughout the matrix. The tuff clasts consist of devitrified glass, plagioclase, and
quartz in a vitrophyric groundmass. Plagioclase compositions in both the andesite and tuff clasts are more sodic than those of the matrix phenocrysts. Andesite fragments have more iron oxide than the groundmass causing them to stand out in both hand sample and thin section. Accessory minerals include apatite, hematite, and magnetite.

**Tuffaceous andesite breccia.** The upper unit of this member is a light gray andesite breccia, which has an irregular gradational contact with the underlying welded tuff. This unit is approximately 159 meters thick. Excellent exposures are on the northern face of a long narrow canyon directly east of San Jorge. Bedding is nearly undistorted with the base covered by talus and thick vegetation.

The breccia has a vitrophyric textured matrix containing spherulitic devitrified glass particles, microcrystalline plagioclase (An$_{28}$ to An$_{38}$), quartz, and minor magnetite. These euhedral to subhedral crystals attain lengths of 2.0 mm so as to give the groundmass a porphyritic character. Calcite is found as clusters around larger plagioclase phenocrysts and scattered through the matrix, as a result of the alteration of the plagioclase.

Clast sizes range from 0.5 mm to 15 cm. The
andesite clasts are subangular, and have a porphyritic texture with plagioclase crystals ranging in size from 0.25 mm to 1.0 mm. The groundmass is hypocrystalline, containing plagioclase microlites and devitrified glass particles in a felted texture. The plagioclase (An$_{24}$ to An$_{30}$) is slightly more sodic than the breccia matrix.

The tuff clasts consist of devitrified spherulitic glass particles, quartz, plagioclase, and magnetite in a vitrophyric groundmass. Andesine (An$_{24}$) is the common feldspar, and usually is altered to calcite and clay minerals. The size of the andesine crystals range from 0.25 mm to 1.5 mm, and are polysynthetically twinned. Hematite and magnetite occur only in small traces.

IV. MEMBER D

One of the most extensive members in the area of study, underlying approximately 18 square kilometers, is a sequence of tuffaceous breccias and volcanic sandstones. These units are interlayered and grade into one another along strike. This member strikes predominantly northwest although local variations exist. On the north, these rocks are warped and repeated across an east-west trending syncline, where they grade laterally into a series of contact metamorphic rocks. The most prominent exposures are along the gorge walls northeast of San Jorge where
maximum thicknesses are in the order of 91 meters. To the east landslides and slope wash have covered most of this member so that outcrops are hard to find.

**Tuffaceous andesite breccia.** Tuffaceous andesite breccia constitutes most of this member. This unit is composed of angular to subangular pumice, andesite, and tuff clasts, ranging in size from 0.25 mm to 60 cm. Clastic material decreases in size and quantity to the east with the rock characteristically becoming more tuffaceous. These rocks are dark purple to dark brown, and weather to a greenish-brown.

The breccia has a hypocrystalline matrix of devitrified glass, plagioclase, quartz, and hematite. The common texture is hyalopilitic. Glass shards range in size from 0.25 mm to 1.25 mm. Crystals range from 0.25 mm to 0.75 mm in length. Iron oxide dispersed throughout the matrix gives the rock a purplish-red color.

Euhedral to subhedral plagioclase (An$_{25}$ to An$_{35}$) phenocrysts are twinned by the Albite and Carlsbad laws. Many of these crystals are highly fractured, and have been resorbed by more sodic plagioclase and quartz. Minor epidote is found along the margins of the feldspar.

The pumice fragments are the most prevalent foreign clast. These fragments have elongate tubular pore spaces,
giving the specimen a fibrous structure. There are also fragments in which the cell structure has collapsed, due to load pressure. The fragments show minor affects by devitrification. However, most have been altered to paragonite.

Light colored tuffaceous clasts ranging up to 60 cm in diameter are subrounded, and sparsely segregated. These clasts are composed of spherulitic, devitrified glass particles, plagioclase, quartz, and minor magnetite in a vitrophyric groundmass. The plagioclase (An$_{20}$ to An$_{28}$) is altered to clay minerals along the margins and fractured areas.

**Volcanic sandstone.** Volcanic sandstone is interbedded with the breccia. A light grayish-green color characterizes the weathered surfaces, whereas fresh exposures are dark green. These sandstones are well indurated, poorly sorted, with angular and subangular volcanic lithic fragments of dacite and andesite. The fragments range in size from 0.25 mm to 2.0 mm and constitute 20 to 25 per cent of the rock.

Angular grains of quartz and plagioclase plus the fragmented material are set in a matrix of glass and microcrystalline quartz. Clay minerals are scattered throughout the matrix along the margins and fractures of
larger crystals. The matrix quartz is interstitial between the larger grains and acts as a bonding agent. Much of the plagioclase has distinct Carlsbad and Albite twinning. Minor minerals include magnetite, hematite, and apatite.

V. MEMBER E

Underlying approximately 16 square kilometers in the northwestern portion of the field area is a thick section of andesite breccia. This member is exposed on both limbs of the east-west trending syncline to the north, and also is exposed as isolated patches to the west within the syncline. This breccia ranges in thickness from 23 meters to 189 meters as it thins rapidly to the north. The thicker sections are exposed in the gorges east of El Naranjo. This member is composed of angular andesite, dacite, and tuff clasts ranging in size from 0.5 mm to 10 cm, and cemented in a volcanic matrix of tuffaceous andesite. The clast size decreases to the east, and the matrix becomes exceedingly silicified to the northeast. The rocks vary from greenish-gray to purplish-brown where fresh, and weather to a greenish-brown or dark redish-brown. In many areas the weathered outcrops have a nodular appearance produced by differential weathering of the clasts and matrix.
The clasts are commonly decomposed so as to produce a pitted, weathered surface. These rocks have a dull white chalky coating on the weathered exposures, which is thought to be SiO\(_2\) remaining after the removal of more soluble calcium and MgO. Slight metamorphism is evident throughout the unit. However, metamorphism increases to the east with recrystallization producing a dark gray to black amorphous rock.

Conformity between Members E and F well is displayed on the gorge just east of El Naranjo. To the north this contact is faulted.

The unit has a hyalophitic textured matrix containing devitrified glass particles, microcrystalline plagioclase, (An\(_{24}\) to An\(_{38}\)), quartz, and magnetite. Much of the plagioclase has been altered to epidote, chlorite, and clay minerals. However, many larger euhedral plagioclase crystals have been altered completely by epidote so as to leave only the original crystal boundaries. This rock is composed of 15 to 20 per cent epidote, causing the green coloration.

The plagioclase crystals show at least one period of resorption with the corroded regions being filled by more sodic plagioclase. The quartz has been completely confined to the finer matrix material. Cristobalite and plagioclase fibers are the alteration products of the
devitrified glass.

The tuff clasts have a similar lithology and texture as the enclosing breccia matrix. These fragments are composed of spherulitic, devitrified glass particles with minor plagioclase, quartz, epidote, and magnetite in a vitrophyric groundmass. Plagioclase crystals (An$_{32}$) range from 0.25 mm to 1.0 mm in length. Again epidote, chlorite, and clay minerals have been formed from the polysynthetically twinned plagioclase crystals. The epidote commonly occurs in clusters along the margins of these tuff clasts giving definite outline in plane light.

The andesite fragments exhibit a porphyritic texture, with andesine (An$_{32}$) ranging in size from 0.25 mm to slightly less than 1.0 mm. The groundmass is hypocrystalline with microlites of plagioclase and devitrified glass particles, in a pilatoxitic texture. The iron content in these fragments is much higher than that of the surrounding matrix giving them a dark red coloration. These fragments have been altered to epidote and chlorite, but not as completely as the surrounding matrix. Minor minerals include hematite and sericite.

VI. MEMBER F

Overlying the andesite breccia is a sequence of dacite lithic and crystal tuffs. This is the youngest
volcanic unit in the field area, and is exposed to the northwest along the axis of the east-west trending syncline. Like the underlying andesite tuff breccia this member also thins to the north (126 meters to 20 meters).

The upper strata of this sequence are characterized by a porous dacite crystal tuff. Nearly white in fresh exposures, iron oxide causes widespread orange-red coloration on weathered surfaces. The composition, degree of consolidation, silicification, and therefore the specific gravity increases with depth as crystal tuff grades vertically downward into lithic tuff. Lithic tuff is confined to the lower 68 meters of this member. It is composed of subrounded to subangular tuff, pumice, and clasts of andesite, and dacite ranging in size from 0.25 mm to 20 mm. Where fresh, the rocks are light pink, Weathered surfaces are dark pink to purple. Graded bedding is well preserved in both units. Excellent exposures are found along river channels to the northeast of El Naranjo. The lower portions of the crystal tuff and the lithic tuff are more silicified, while in general the upper portion of the member is soft and forms comparatively gentle slopes.

The tuffs consist of matrices rich in devitrified spherulitic glass shards and particles composed of cristobalite-plagioclase fibers commonly showing perfect
axiolithic structure, with quartz, plagioclase, epidote, magnetite, and hematite. The devitrified glass particles constitute 50 to 60 per cent of the tuffs, with crystals totaling 15 to 20 per cent, and lithic fragments, 10 to 15 per cent. Cusp-shaped, elongated Y-shaped, and U-shaped glass shards range in size from 0.5 mm to 1.5 mm. Small, well-formed crystals of plagioclase and quartz are common in most specimens. Plagioclase (An$_{28}$ to An$_{45}$) has been altered to clay minerals along fractured areas with epidote and chlorite forming along the edges. Plagioclase crystals are commonly found in clusters giving a glomero-porphyritic texture. Quartz is second in abundance only to plagioclase, occurring either as anhedral or subhedral detrital fragments. Quartz shows rounding and embayment by matrix material.

Pumice fragments contain elongated tubular pore spaces, but occasionally have nearly equidimensional, roughly spherical bubbles. The pumice fragments are subject to devitrification as are the glass shards with the same resulting aggregate of feldspar and cristobalite. However, the devitrification product is much coarser and has not gone to completion as in the case with most glass shards.

In general, the andesite and dacite fragments are seemingly fresh and unaltered. Most consist of plagioclase
microlites and microcrystalline quartz in a glassy vitrophyric matrix colored by ferritic particles.

The lower extremities of this member have been cut by a dark green diabase dike (map reference point 1). This intrusive rock is not traceable on the surface because of accumulated talus and rock debris. The dike is 2 meters wide and causes no apparent alteration to the surrounding tuffaceous material.

The diabase has a hypocrystalline matrix of glass, plagioclase microliths and minor quartz and augite. The commonly exhibited texture is hyalopilitic. The phenocrysts are composed wholly of labradorite (An$_{52}$) laths which are twinned according to the Albite and Carlsbad laws. Zoning of the plagioclase is limited to normal zoning with the more calcic cores epidotized. Quartz is a minor constituent (5 to 8 per cent) and occurs as interstitial, interprecipitate grains, between the plagioclase laths and augite grains.

VII. CONTACT METAMORPHIC ROCKS

Quartzo-feldspathic hornfels, biotite-hornblende schists, and quartzo-feldspathic schists are distributed near plutonic rocks found both to the north and south in the area of study. The largest exposed body of moderately metamorphosed rocks extends eastward from a point just
east of Todas Santos to the border of the area. This mass is crudely wedge-shaped and broken to the northeast by the quartz diorite intrusive rocks.

The biotite-hornblende schists are found only in the northern part of the area (map reference point 2). Good exposures are seen in the Arroyo el Gallo near Granjo San Joaquin. These rocks are light brown to dark gray, fine-grained, and exhibiting visible foliation. The foliation has a northeast trend with a variable dip to either the northwest or southeast.

The quartzo-feldspathic schist is restricted to small discontinuous lensoidal, bodies to the south. This unit is difficult to distinguish from the granitic rocks because of the similarity in weathering.

The quartzo-feldspathic hornfels is the most common contact metamorphic rock. These rocks are well exposed along the southern portion of the Arroyo el Gallo and also near the intrusive rocks in Valle de Maneadero. In hand sample the textures of these rocks are directionless, showing no lineation. However, in thin section, well-defined mineral orientation is exhibited. The hornfels is continuous with the undifferentiated volcanic sequence to the south and with the tuffaceous breccia unit to the north, and is thought to be the metamorphosed equivalent of these volcanic rocks.
Hornblende-biotite schists. The hornblende-biotite schists are compact, fine grained, thinly-laminated rocks with alternating dark and light bands. Each band ranges from a few millimeters to several centimeters in thickness. The lighter bands consist of quartz and feldspar in about equal proportions.

The schist consists predominantly of equigranular quartz, orthoclase, plagioclase, biotite, and hornblende. The schistosity is well exhibited by the parallel alignment of biotite and hornblende, which range in size from 0.25 mm to 3.0 mm. Essential minerals are quartz, orthoclase and plagioclase, which range in size from 0.25 mm to 1.5 mm. Occasionally, the schists exhibit a porphyroblastic texture with prophyroblasts of quartz ranging in size to 1.5 cm.

Biotite, hornblende, and chlorite form nearly continuous parallel trains, which alternate with granular quartz-feldspar layers. Anhedral quartz is elongated and usually shows undulatory extinction. Anhedral andesine is poikiloblastic with quartz inclusions, and has lamellae twinned on either the Albite or pericline law. Accessory minerals include zircon, magnetite, apatite, and secondary chlorite and sericite.

Quartz-feldspathic schists. Light gray to brown
quartzo-feldspathic schists are found near the intrusive contact in the southern part of the field area. They are lensoidal bodies of limited extent and intergrade with the hornfelsic rocks.

These rocks exhibit a weak schistose texture with a tendency toward porphyroblastic texture. The schist consists primarily of quartz, orthoclase, and andesite (An$_{27}$). Quartz is the most abundant constituent and is found as anhedral, slightly stained, elongate porphyroblasts, in segregated interlocking equigranular bands, and as interstitial material between plagioclase and orthoclase. Anhedral to subhedral andesite also forms porphyroblasts which range in size to 4.0 mm. The feldspars are often altered to sericite and kaolinite. Minor minerals include biotite, hornblende, magnetite, apatite, sphere, and zircon.

**Quartz-feldspathic hornfels.** The quartz-feldspathic hornfels is typically dark gray to black, however, light brown varieties occur. The predominant mineralogy is quartz and feldspar with minor accessory minerals.

The hornfels exhibits a fine-grained, epigranular, granoblastic texture. Grain sizes range from 0.25 mm to 1.0 mm. Segregation banding is common. Occasionally,
these rocks have blastoporphyritic textures, marked by persistent subsequent recrystallized relict phenocrysts of quartz and feldspar.

The feldspars are orthoclase, albite (An$_9$) and microcline. Typically the albite is complexly twinned. Considerable sericite and kaolinite alteration is exhibited by the feldspars.

Clear anhedral crystals of quartz are the most abundant mineral in the hornfels. These crystals have sutured borders and are unstrained. Minor minerals present in the hornfels include biotite (oriented in a decussate fashion), garnet, zircon, sphere, and magnetite, with secondary crystals of chlorite, sericite, and kaolinite.

VIII. CONCLUSION

As seen from the volcanic rock description, the vertical lithologic variation of the section is not great, but rather a repetitious sequence of volcanic and volcaniclastic rocks of similar composition.

In most of the pre-batholithic rocks, rank of metamorphism is very low. Volcanic glass has been devitrified with axiolitic intergrowth of cristobalite-plagioclase, along with the development of interstitial chlorite, epidote, and calcite. However, near the
intrusive contact a distinct metamorphic facies is developed with the formation of quartzo-feldspathic hornfels, hornblende-biotite schist, and quartzo-feldspathic schist.

The volcanic section appears to have had a terrestrial origin since it is nonfossiliferous and sedimentary structures are preserved only locally.

The graded bedding in Member F may be due to deposition in an aqueous environment. However, if this rock represents air-fall tuff deposited into water, the glass shards would have settled more slowly than the crystals. Hence, plagioclase, magnetite, and lithic clasts would be vertically separated from the shards. This contradicts observation for the crystals and shards appear to be intermixed, and therefore suggest that the rock was not water-laid. The ragged fragments also indicate that there was no reworking upon deposition.

The origin of the volcanic material is not completely understood. The angularity of the clasts and the poorly sorted nature of the clastic rocks suggest that the transportation distance was not great. The rapid change from fine to coarse pyroclastic material may indicate an unstable source area, undergoing repeated uplifts and subsidences. It may also be noted, that since the composition of the clasts and matrices of the
pyroclastic and flow rocks is very similar the origin of both may be one and the same.

The extreme thinning of a number of the units to the north may indicate a southerly source. However, this is not true of the entire volcanic sequence. Therefore, it would seem that the volcanic material was not derived from one area but perhaps several, and deposited into a central low.
CHAPTER IV

BATHOLITHIC ROCKS

Batholithic rocks occupy roughly 23 square kilometers in the northern and southern portions of the field area. The plutons are irregular in outline, forming bold hills and mountains, with somewhat smooth brush covered slopes. Where soil is formed it is a dark brown. These plutonic rocks are mapped as two separate bodies, one granodiorite and the other quartz diorite. Emplacement is believed to have been in Late Cretaceous time as correlated with geochronological studies conducted by Silver et al. (1963) to the south.

I. QUARTZ DIORITE

Quartz diorite is the most extensive granitic rock. It is remarkably uniform with only slight and local variations in texture and composition. Exposed to the north, it continues southeastward along the eastern slope of the mountainous terrain.

The quartz diorite is light-to medium-gray, with a medium grained hypautomorphic-granular texture. Composition as tabulated by point count from thin sections is as follows:
quartz, 20 per cent; plagioclase (An$_{26}$ to An$_{52}$), 61 per cent; biotite-chlorite, 8 per cent; hornblende, 3 per cent; orthoclase, 7 per cent; magnetite, 1 per cent; augite, 1 per cent. Accessory minerals include zircon, sphene, and apatite; with secondary sericite and kaolinite (?). A calculation of chemical composition is given in Table I (see Appendix).

Crystal size ranges from 1.0 mm to 2.5 mm. Euhedral to subhedral plagioclase exhibits oscillatory zoning, with compositions ranging from An$_{26}$ to An$_{32}$, and more calcic cores ranging from An$_{41}$ to An$_{52}$. Twinning is according to the Albite and Carlsbad laws. The plagioclase crystals show at least one period of resorption with more sodic plagioclase, quartz, and orthoclase filling the corroded areas. Anhedral quartz often shows wavy extinction, and commonly occurs as individual crystals growing interstitially between the plagioclase, or as poikilitic intergrowths with biotite and orthoclase. Sparse myrmekitic intergrowths occur as small patches between feldspar grains. Augite is always surrounded by and grades into a rim of pleochroic hornblende. Textures suggest that pyroxene reacted with the melt to form the encircling hornblende. Both brown biotite and green hornblende show alteration to chlorite.

One of the few variations within the quartz diorite
is along the eastern contact zone, where a distinctive border facies containing darker colored xenolithic inclusions is observed. These inclusions range from less than 3 cm to 31 cm or more across, and give an irregular surface due to differential weathering between the host and rock fragments. These inclusions are characteristically much richer than their host in the dark minerals, especially in hornblende. Their mineral composition indicates that they represent a concentration of the minerals of earlier crystallization from the quartz diorite.

Cutting the quartz diorite are several small aplitic dikes (map reference points 3 and 4). These light pink, saccharoidal rocks are irregular in extent, ranging from 30 to 90 cm thick. Their general trend is northwest. These rocks consist of 35 to 40 per cent quartz, 25 to 30 per cent plagioclase (An$_{18}$ to An$_{35}$), 20 to 25 per cent orthoclase, 2 to 4 per cent microcline, 1 to 2 per cent biotite, with accessory minerals of magnetite, epidote, and zircon, and clay minerals. The texture is equigranular allotriomorphic-granular with grain size rarely exceeding 1.0 mm.

The three mutually perpendicular jointing planes commonly developed in the quartz diorite, are similar to those observed in most of the metavolcanic rocks. At
Casa Blanca, one set is nearly horizontal, and the two nearly vertical planes strike N 20°W and N 85°E. In other areas, for example, southeast of Rancho Bonito, the numerous joints cannot be correlated.

II. GRANODIORITE

Granodiorite forms much of the mountainous terrain in the south. On the west it is overlain by Quaternary terrace sediments, while to the east it intrudes an undifferentiated zone of metavolcanic rocks, developing pronounced contact metamorphism. These rocks are somewhat lighter than the quartz diorite, although they possess a similar yellow-brown iron stain on the weathered surface.

The granodiorite is composed of plagioclase (An_{48} to An_{35}), 42 per cent; quartz, 31 per cent; biotite 6 per cent; hornblende, 8 per cent; orthoclase, 11 per cent; magnetite, 2 per cent. Accessory minerals include zircon, sphene, and apatite, with secondary chlorite and clay.

Medium-grained, hypidiomorphic-granular texture is characteristic of this rock. Crystal size varies from 0.5 mm to 3.0 mm. The euhedral to subhedral plagioclase has normal oscillatory zoning with central zones of andesine (An_{48}) and marginal zones of oligoclase (An_{27}). The cores are locally porous and inclusion-filled, and in areas the marginal zones are myrmekitic. Twinning
according to the Albite and Carlsbad laws is also common with minor seritization of the more olacic plagioclase. The biotite shows pleochroism from light brown to dark brown, and hornblende from light yellow-green to dark green. Both biotite and hornblende have been hydrothermally altered to chlorite, in many areas alteration is extensive. Anhedral quartz and orthoclase are arranged interstitially between the plagioclase crystals. The calculated chemical composition of the granodiorite is given in Table II (see Appendix).

Many dark-colored xenolithic inclusions occur near the margin of these plutonic rocks. These fragments appear to be recrystallized clasts of the older metavolcanic sequence. The average composition consists of 45 to 60 per cent plagioclase, 20 to 30 per cent hornblende, 10 to 12 per cent quartz, and minor magnetite and orthoclase.
CHAPTER V

POST-BATHOLITHIC ROCKS

I. TERRACE DEPOSITS

North of Valle de Maneadero a terrace extends at an elevation of 7 to 60 meters above sea level along the coast line to the northwestern boundary of the mapped area as a nearly uninterrupted topographic feature. The terrace deposits unconformably overlie the Mesozoic volcanic and intrusive rocks. Excellent exposures of this deposit are found along the northern extent of Valle de Maneadero, where it forms steep cliffs of 8 to 15 meters high. Lithologically, the terrace consists of poorly sorted sandstones and conglomerates overlain by approximately one meter of gravel and reddish-brown soil. The conglomerate clasts are subrounded to rounded, pebbles to cobbles, ranging in size from 20 mm to 150 mm with a median of 50 mm. Clast composition is predominantly of volcanic derivation although plutonic rocks are quite common (Table III, Appendix).

Sedimentary analyses were made of ten sandstone samples randomly collected from the terrace. These samples were disaggregated and sieved through a tier of
Tylor screens, spaced at 0.5Φ intervals. The data were plotted on arithmetic probability paper, the results of which are summarized on Table IV (see Appendix). The grain size of the sandstone ranges from -0.75Φ (very coarse sand) to +4.00Φ (very fine sand) with an average of +1.23Φ (medium sand). An average Median Diameter ($M_\Phi$) of +1.55Φ was found for all ten samples, with a Mean Diameter ($M_\Phi$) of +1.45Φ, and a Standard Deviation of +1.17Φ. Parameters were calculated using the method of Inman (1952). Sorting, computed from the value of the Phi Deviation Measure as established by Folk (1966), indicates that all the samples are poorly sorted except two, which are moderately sorted.

The +2.00Φ fraction was used in the study of the mineralogy of the sandstone. Ten heavy mineral separations were prepared by the separatory and bromo-form methods. Identification and mineral percentages were then calculated (Tables V and VI, Appendix).

The average "light mineral" fraction consisted of 80 per cent of the total volume. The principal "light minerals" consisted of quartz, 27 per cent; plagioclase, 42 per cent; potassium feldspar, 9 per cent; and other rock fragments, 2 per cent. The "heavy minerals" are predominantly micas (almost completely biotite), 9 per cent; hornblende, 4.0 per cent; and magnetite, 7 per cent.
A number of quartz grains contain small inclusions. These are commonly scattered at random within the grain, although there is a tendency for some to be arranged. Gas bubbles are also noted in some of the clearer varieties. Irregular inclusions are characteristic of granitic quartz, whereas the regularly oriented inclusions suggest a metamorphic origin (Pettijohn, 1957). Many of these grains have worn overgrowths, which are indicative of reworked sediments.

The sandstone contains a high percentage of feldspars. These grains are angular to subangular and show minor weathering. The percentage of plagioclase feldspars (42 per cent) far exceeds that of the potash varieties (9 per cent). Igneous feldspars include both the potash-bearing species and the plagioclase feldspars. However, the potash varieties are indicative of the more acid igneous rocks, whereas the plagioclase feldspars are characteristic of igneous rocks of intermediate composition (Pettijohn, 1957). Numerous metamorphic feldspar grains are also noted by the abundance of many inclusions and common alterations. Therefore, from the criteria, the provenance appears to be a nearby area of high relief consisting of both metamorphic and igneous rocks of intermediate composition.

Cross bedding is found commonly throughout the
terrace. It is not confined to any particular grain size, however, better preservation was noted in the finer sediments. Most graded from a coarse sandstone at the base to a fine sand at the top, with a paralleling increase of biotite upward. These crossbeds are tabular shaped with erosional basal contacts. Thicknesses of the individual crossbedded layers vary from 15 to 200 cm.

The reddish-brown soil formed by the terrace cover contains locally abundant recent invertebrates which are thought to have originated from aboriginal kitchen midden. The midden interpretation is based upon the unnatural association of species.

The author found no evidence either paleontological or stratigraphic during the course of this investigation which can be used to assign a definite age to the terrace material. With reference only to similar terrace deposits described by Beal (1948) in areas to the north of Ensenada, and by Emerson (1956) in an area near Punta China, this material is thought to be of Late Pleistocene age.

II. RECENT SEDIMENTS

Recent sediments include both beach sand, dune deposits, and stream alluvium.

Stream deposits consist of subangular to sub-rounded, poorly sorted gravels, sand and silt deposited
along incised streams and major valleys. The well-defined channels divide into rilles near mountain slopes and broaden downstream. The characteristic high feldspar content and relatively low quartz content indicate the material has not traveled far from its source area. Alluvium in many small stream bottoms was not generally of sufficient areal extent to warrant attention on the field map (Pl. 1).

Several small eolian sand dune deposits are evident between Valle de Maneadero and Arroyo el Gallo. Dunes are less than 2.0 meters thick and overlie the reddish-brown soil cover of the terrace deposit. This material is extremely well sorted with a high quartz content. These sands move from the beaches to dunes and from dunes to beaches. Each grain has probably been deposited many times by water and as many times by wind.
CHAPTER VI

STRUCTURE

The principal structural features of the area are associated with the Mesozoic volcanic rock sequence. Bedding in the Mesozoic rocks strikes approximately east-west. Local variations are common, but the regional trends are perpendicular to the length of the mountainous terrain. Most attitudes represent a homoclinal dip to the northwest and vary from 14 to 25 degrees, but there is a westward plunging syncline in the northern portion of the area and minor flexures to the south.

The syncline located just east of Balneario Playa Hermosa has a nearly east-west axis, plunging 9 to 12 degrees to the west. Members D, E, and F are involved in this warping, with Member E and F thinning extensively to the north. Metamorphism has eliminated evidence of this structure just south of Rancho Bonito. Other small flexures of synclinal or anticlinal nature can be seen on the south flank of the major syncline and just north of El Calido in the Valle de Maneadero.

The discordant igneous contacts suggest that the volcanic rocks are not related to the intrusion and probably represents an earlier stage of deformation prior
Schistose structures are common in the contact metamorphic rocks along intrusive contacts in the northern portion of the field area (map reference point 2). This schistose marginal zone is discontinuous with the schistosity trending in a northeast direction, essentially parallel to the intrusive contact of the quartz diorite. Folds within the schistose rocks strike parallel to the schistosity with dips of 60 to 70 degrees to the northwest and southeast. The folding is thought to be related to the intrusion because it is concordant with the intrusive contact and strikes almost perpendicular to the east-west regional fold axis. Therefore, this folding would be younger than the regional plan.

Faulting in the Ensenada region is exemplified by a number of northwest and northeast trending normal faults. These faults cut the regional east-west trend obliquely by 20 to 40 degrees with dips of 70 to 90 degrees to the northwest or southeast. Normal vertical displacements are on a small scale. Many displacements can not be calculated in the field, however, in the vicinity of Cementos California normal faulting has lowered the hanging wall approximately 23 meters relative to the foot-wall as indicated by the offset beds. In other areas offset is less than 10 meters. Many minor
faults in the area are on the order of joint slippage due to removal of material on the down dip side. Most of these minor fractures were beyond the scope of this report and are not shown on the map (Pl. 1). Normal faulting in this region is thought to have been a resultant of tension release of the north-south compressive forces, which caused folding in the metavolcanic sequence. Probable minor shearing along the northeast and northwest axis occurred as a result of compression. The shear movement would have occurred concurrently with the folding, while normal movement took place during a time after the initial compression acted on the region. Normal faulting probably continued intermittently from the initial compression relaxation in Late Cretaceous or Early Tertiary to Recent time.

Jointing is well developed in both the volcanic rocks and intrusive rocks. It is particularly well displayed in the rectangular weathering blocks of granodiorite and quartz diorite. No single joint system seems to prevail over the entire area. However, two systems appear to be more consistent than any others. One joint set strikes approximately N 60°E with dips of 25 to 60 degrees, while the other strikes approximately N 35°W with dips of 30 to 80 degrees. The jointing is either due to random rupture planes or a compound
structural history, possibly both.

Along the eastern margin of the quartz diorite and volcanic rock contact zone (map reference point 3 and 4) are a number of small aplitic dikes. These light-colored rocks developed from residual solutions of the magmas that produced the intrusive mass, and probably represent injections into primary northwest-southeast trending joints developed along the margins of the consolidating magma.
The oldest rocks in the area are volcanic. These were laid down during Mesozoic time by outpouring of viscous and explosive eruptions. During this period several hundred meters of material was violently discharged or flowed out onto the surface. The volcanic accumulations include tuffs, breccias, and flow rocks. The volcanic material appears to have accumulated on land since the section is void of fossils, and only localized sedimentary structures are noted. The deposition of volcanic debris was continuous; there is no evidence of a significant depositional break within the sequence.

A period of deformation followed and effusion sedimentation. Tectonic deformation or orogeny apparently did not take place until the volcanic material was completely deposited since individual layers are not locally deformed. Deformation resulted in gentle folding and regional tilting.

Following the fold deformation, and probably while the uplift accompanying it was still active, the volcanic sequence was intruded by granodiorite and quartz diorite. These rocks represent a portion of the Peninsular Range.
Batholith which was emplaced during Cretaceous time. Intrusion was accompanied locally by contact metamorphism. Many roof pendants hanging in the molten mass are now represented by schistose outliers along the marginal contact of the granodiorite.

Profound and widespread erosion followed in Late Cretaceous time. A sedimentary change in provenance and lithologic type took place in the Late Pleistocene. The process of sedimentation yielded a fine-to coarse-grained, feldspar-quartz rich sandstone interrupted occasionally by thin conglomeritic streaks. The provenance for this material was the Mesozoic basement complex to the east. Short transportion accounts for the poor sorting and unstable mineral suite.

A lack of evidence for significant post-Cretaceous submersion of the coastal segments suggests that the present width of the terrace may be a result of pedimentation acting on a feature initially cut at sea level.

Subsequent uplift followed terrace depositions. The land emerged abruptly, as evidenced by the rather horizontal development of the terrace. Recent alluvium is actively filling in stream valleys with sand being deposited by shore currents and in part by wind action along the coastal margin.
BIBLIOGRAPHY


Wisser, E. H., 1954, Geology and ore deposits of Baja California: Econ. Geol., vol. 49, p. 44-76.

APPENDIX
<table>
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<th>Mineral</th>
<th>Volume %</th>
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TABLE II
CALCULATED CHEMICAL COMPOSITION BY USE OF MODE, SPECIFIC GRAVITIES, AND COMPOSITIONS: GRANODIORITE

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TABLE III

SUMMARY OF CLAST COUNT
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Summary of Statistical Parameters, Terrace Sandstone

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Parameters were computed using Phi ($\phi$) units (Inman, 1952).

Sorting: PS, poorly sorted; MS, moderately sorted.

Sorting based on Phi Deviation Measure ($\phi$) as outlined by Folk, 1966.

$\text{Md}_\phi$ = Phi Median Diameter;
$\text{M}_\phi$ = Phi Mean;
$\phi$ = Phi Deviation Measure.
### TABLE V

**PER CENT OF "LIGHT" AND "HEAVY" MINERALS TERRACE SANDSTONE**

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<tr>
<td>G</td>
<td>81.1</td>
<td>18.9</td>
</tr>
<tr>
<td>H</td>
<td>79.7</td>
<td>20.3</td>
</tr>
<tr>
<td>I</td>
<td>79.4</td>
<td>20.6</td>
</tr>
<tr>
<td>J</td>
<td>83.2</td>
<td>16.8</td>
</tr>
</tbody>
</table>

**Average** 81.1 19.9

Percentage by weight.
TABLE VI

PER CENT OF COMMON MINERALS
TERRACE SANDSTONE

<table>
<thead>
<tr>
<th>Mineral</th>
<th>A</th>
<th>B</th>
<th>D</th>
<th>E</th>
<th>G</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>25.2</td>
<td>21.8</td>
<td>30.9</td>
<td>28.9</td>
<td>23.3</td>
<td>27.1</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>42.4</td>
<td>41.1</td>
<td>42.2</td>
<td>43.6</td>
<td>39.7</td>
<td>41.8</td>
</tr>
<tr>
<td>K-spar</td>
<td>10.1</td>
<td>9.5</td>
<td>6.8</td>
<td>8.5</td>
<td>10.6</td>
<td>9.3</td>
</tr>
<tr>
<td>Micas</td>
<td>7.3</td>
<td>9.2</td>
<td>5.3</td>
<td>9.1</td>
<td>10.3</td>
<td>8.6</td>
</tr>
<tr>
<td>Hornblende</td>
<td>2.6</td>
<td>4.4</td>
<td>4.7</td>
<td>3.2</td>
<td>4.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Magnetite</td>
<td>9.3</td>
<td>2.5</td>
<td>7.4</td>
<td>4.4</td>
<td>9.7</td>
<td>6.7</td>
</tr>
<tr>
<td>Others</td>
<td>0.9</td>
<td>0.2</td>
<td>0.8</td>
<td>0.5</td>
<td>1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Rock</td>
<td>2.4</td>
<td>1.3</td>
<td>1.7</td>
<td>1.8</td>
<td>1.2</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Percentage calculated by point count.
ABSTRACT
ABSTRACT

The portion of the Ensenada Quadrangle studied is located approximately 60 miles south of the United States-Mexico International Border, along the Pacific Coast of Baja California, Mexico. Three major rock units are distinguished: pre-batholithic volcanic and volcanic derived rocks; intrusive rocks; and post-batholithic sedimentary deposits.

Pre-batholithic rocks comprise approximately 1,575 meters of volcanic flows and nonfossiliferous sediments. This section has been subdivided into six members ranging in thickness from 91 to 455 meters. Since Cretaceous and Jurassic volcanic and volcanioclastic strata have been found both to the north and south of the Ensenada region, a Mesozoic age has been assigned to these rocks.

The Mesozoic section has been intruded by granodiorite and quartz diorite, which are part of the Peninsular Range Batholith, and assigned a Cretaceous age. Metamorphism preceded the intrusion, and only locally is there appreciable metamorphism.

The structure of the basement rocks is a persistent homoclinal dip, which has locally been warped and faulted.

The batholithic and volcanic rocks have undergone
extensive erosion since Late Cretaceous time and are now partially overlain by younger sediments. The post-batholithic strata of the coastal plain are nonfossiliferous terrace deposits. These deposits are thought to be of Late Pleistocene age, because of correlations with terraces found both to the north and south. Mineralogical characteristics of sedimentary samples, and the abundance of Mesozoic volcanic and granitic rock types as conglomerate clasts in the terrace suggest the basement complex to the east as the source area. Beach sands and stream deposits of Recent age occur along the coastal front and in incised stream beds dissecting the terrace deposits.