PREBATHOLITHIC GEOLOGY OF THE BAHIA CALAMAJUE
AREA, BAJA CALIFORNIA, MEXICO

A Thesis
Presented to the
Faculty of
San Diego State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Geological Sciences

by
James R. Crocker
Spring 1987
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Approved by:

[Signatures]

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Date
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CHAPTER 1

INTRODUCTION

Purpose and Scope

The purpose of this study is to describe the prebatholithic geology of the northeastern Sierra Calamajue, Baja California, Mexico. The goals are to understand the: (1) premetamorphic stratigraphy and its depositional environment, (2) relationship to the regional geology, and (3) relationship to coeval continental margin and basin deposits in western United States and Mexico.

This work, the first detailed study of the Bahia Calamajue area, encompasses most aspects of the prebatholithic rock, and is thus somewhat generalized. It is left to future workers to determine in greater detail the structure and deformational history.

The study was conducted in conjunction with the ongoing work of Gordon Gastil and many fellow graduate students at San Diego State University who are investigating the prebatholithic history of Baja California.

Location

The study area is located in southeastern Baja California, Mexico, 640 km south of San Diego, California (Figure 1). To get there, take Mexico Highway 1, 580 km
south of San Diego, turn left (east) onto a graded dirt road 1 km north of the Rancho Chapala cafe. Take this road 60 km to its terminus at Bahia Calamajue. Road conditions vary considerably along the dirt road, but it is generally passable with a sturdy two-wheel drive truck.

A small fishing village is located at Bahia Calamajue, where a school and shortwave radio are also present. A dirt airstrip is located just behind the berm of the bay, but becomes rather soggy with either rain or exceptionally high tides.

The mapped area includes the northeasternmost 38 square km of the Sierra Calamajue, bounded on the east by the Sea of Cortez and on the west by Valle Calamajue. The topographic sheet series published by the Mexican government and used in this study can be somewhat confusing in terms of geographic nomenclature. Thus, although the map indicates the study area is part of the Sierra Calamajue, it is completely detached from the main body of the range to the southwest, and is closer and more closely aligned with the Sierra La Asamblea to the southeast.

**Geologic Setting**

The immediate region of the study area is characterized by metasediments and metavolcanics intruded
Figure 1. Location map of the Bahia Calamajue area.
by Cretaceous plutonic rocks, Tertiary volcanics and volcaniclastics, and by development of Holocene alluvial fans.

A relatively small leuco-tonalite body has intruded the metasediments in the southern part of the map area. It is a hornblende-biotite-sphene tonalite with very large euhedral crystals of biotite and hornblende, and very strongly resembles the hornblende-biotite facies of the La Posta tonalite in the eastern peninsular ranges (Gordon Gastil, 1983, oral communication). The geometry of the intrusion is elongate in a west-northwest direction, and has clearly exposed contacts against the metasedimentary rocks (Figure 2).

Mafic rocks which intrude the metasediments are gabbro and basalt. The gabbro is exposed only locally in the central part of the study area. Basalt occurs in dikes and small bodies, and generally intrudes structurally weakened areas, especially fault zones.

The post-batholithic volcanic and volcaniclastic rocks are included in the mid-Cenozoic San Borja-Punta Animas subprovince of the Gulf of California volcanic province, and are part of the Miocene volcanic rocks and Pliocene andesite-rhyolite sequences (Gastil et al., 1975).

The post-batholithic rocks of the northeastern Sierra
Figure 2. Well-exposed contact between the tonalite pluton which separates the northern and southern areas on the right, and the southern area metasediments on the left. Photo taken from the Gulf of California looking west.
Calamajue are not important to the emphasis of this thesis; therefore they have not been dealt with in detail. However, there are several very interesting problems associated with these rocks, such as their age and structure, which should be the focus of future study in this area.

Unconformably overlying the metasediments and the tonalite pluton are white to light brownish grey lahar deposits. Overlying the white lahar are tan-colored lahar beds which are lithologically identical to the underlying beds. The beds are internally massive and matrix supported, indicating a debris flow mechanism of deposition. There are generally very coarse grained, consisting of pebble-sized clasts of pumice, with individual crystals of biotite, quartz, and feldspar floating in the matrix. The beds are very poorly indurated, and the matrix appears to be mostly clay minerals, probably alteration products of volcanic glass and feldspar. The lahar deposits attain a maximum observed thickness of about 100 meters.

Overlying the lahar beds and, locally, the basement rocks, are very coarse-grained fanglomerates which contain abundant well-rounded vesicular volcanic and leuco-gabbro boulders. Only very limited gabbro outcrops are present in the map area, thus the source for the boulders remains problematic.
The fanglomerate formed well developed fans, which have been subsequently dissected by the present system of stream channels and alluvial fans.

The study area comprises its own discrete geomorphic block, separated from the Gonzaga block to the west and Remedios block to the south by grabens filled with Tertiary volcanics, volcaniclastics, and Recent alluvium (Gastil et al., 1975).

**Previous Work**

Some reconnaissance sampling and aerial photo interpretation was done by R. G. Gastil and students prior to publication of GSA Memoir 140 (Gastil et al., 1975). This work resulted in the observation that "Along the coast south of Arroyo Calamajue are carbonate rocks, quartzite, and bedded chert" (p. 24). Since then, the area has been mentioned by Gastil and Miller (1984), and included in the "Ballenas Terrane," which includes the Paleozoic metasedimentary rocks of basinal affinity from Southern California south to the Bahia de Los Angeles area, by Gastil (1985). Campbell and Crocker (1984) presented some of the preliminary general aspects of both the northeastern Sierra Calamajue and the northern Sierra la Asemblea, about 3 km south of this study area.

**Methods**

Aerial photographs were used extensively for the
mapping portion of the project, especially in the areas which were inaccessible by foot. Maps used in the field and for Plate 1 are 1:12,500 enlargements of the 1:50,000 scale topographic sheet series produced by the Mexican government.

Detailed field mapping was completed in order to determine the stratigraphy and spatial relationships of the various units. The nature of the structural problems was derived from this information. Combined field and microscope study was used to determine the lateral variations of the individual units. Thin sections were used to determine the mineral content and microscopic textures, as well as for microfacies analysis of the carbonate rocks.

Environment

Winter climate is very hospitable, January lows being in the low 40s (°F). Summers, however, are extremely uncomfortable, as temperatures can remain over 100 °F for most of the day, and dip only rarely below 80 °F, even at night (personal measurements). Late in the summer the humidity can be very high, and frequent thunder showers pose the hazard of flash flooding.

Vegetation is sparse, but rare rains in the winter cause many short-lived plants to grow and bloom, and increase the foliage of the perennial plants. Elephant
trees are abundant, and grow quite large in the deeper ravines of the area. Cirios cactus and many low-lying plants also grow and bloom with the advent of rain, irrespective of the season.
CHAPTER 2

STRATIGRAPHY

Introduction

The stratigraphy of the Bahia Calamajue area is characterized by fine-grained siliceous and carbonate metasediments. A small tonalite intrusion divides the study area into two distinct, yet related, stratigraphic areas. North of the tonalite the lithologies range from chert to quartzarenite, and from lime mudstone to carbonate conglomerate. South of the tonalite is predominantly carbonate flysch, with some large chaotic conglomerate deposits in addition to minor chert and phyllite.

Because of the great tectonic overprint, most original small-scale sedimentary structures have been obscured or destroyed. Thus, the descriptive textural term applied to each lithology is a function of the degree deformation has changed the appearance. For example, the metamorphosed shales and siltstones generally contain no original textures and are termed phyllites, whereas the carbonate rocks generally have many similarities to undeformed equivalent rocks, and are termed lime mudstones, wackestones, etc.

The carbonate textural terminology is primarily that
of Dunham (1962), and the siliceous rocks that of Folk (1974).

**Southern Area**

**Overview**

The southern area is exposed in a generally west-northwest trending ridge, bounded to the north by the tonalite pluton, to the south by Tertiary volcanics and Quaternary alluvium, and to the east by the Gulf of California. The metamorphic rocks of this area rocks generally dip steeply to the southeast, and are pervasively sheared and locally show tight isoclinal folding. The best exposures of this section are along the coastal cliffs just beyond the northern point of Ensenada Blanca where the full range of lithologies is exposed (Figure 3).

The southern area consists of the greenschist facies equivalents of limestone, chert, shale, and conglomerate, with additional contact metamorphism increasing with proximity to the tonalite. The pervasive structural deformation does not allow an accurate stratigraphic section to be constructed, although apparent graded beds (Figure 4) and a 6 m thick thinning upwards sequence (Figure 5) indicate the area is generally rightside.

The maximum exposed thickness of the southern area is about 1 km. However, the structural complications are
Figure 3. View looking southwest toward the carbonate flysch exposures along the coast of southern area.
Figure 4. Apparent graded bedding in carbonate flysch. Note the tendency for the layers to become increasingly clayey to the left, indicating the up direction is to the left.
Figure 5. Upward thinning cycle in the carbonate flysch. Beds thin and fine to the left.
so great that some of the stratigraphic and structural relationships remain problematic.

**Bedded Limestones**

Well-bedded and laminated limestone is the dominant rock type of the southern area, constituting about 60 percent of the section. Structural deformation has disrupted but not destroyed bedding in the limestones.

The color of the layers is a function of the amounts of detrital quartz, metamorphic micas, and carbonaceous material within the rock. The quartz-poor layers tend to have a greater amount of carbon, and are thus dark grey on both fresh and weathered surfaces. The more quartz-rich layers weather reddish brown, and may be dark grey if low in mica content, or medium light grey with greater mica content. The darker layers tend to be very fine grained and massive, whereas the more micaceous layers normally have thin internal laminations and express poorly developed shaly partings.

Most bedding ranges from 1 to 7 cm thick, although some beds up to 15 cm thick are present. Individual beds are very regular and continuous where structural deformation does not obliterate them. These rocks are texturally termed carbonate flysch (Wilson, 1975) for the consistency and regularity of the bedding.

The carbonate flysch rocks are generally very fine grained lime mudstones. Subangular quartz silt grains
are ubiquitous in the flysch, and represent 1 to 15 percent of each layer. The pervasive structural shearing and low-grade metamorphism has destroyed the original grain-to-grain relationships as well as any fossils.

Micas present are almost exclusively muscovite. Chlorite and biotite are also present, but only in trace amounts. The slatey cleavage in the light grey layers is a result of the alignment of the micas which define the foliation. Mica content varies from 0 to 10 percent. Tremolite is present in trace amounts.

Coarse-grained Beds

Interbedded with the fine grained carbonate flysch beds are granule to boulder conglomerate layers (Figure 6). These coarse-grained layers make up an estimated 15 percent of the total section. Bedding thickness is directly related to grain size of the debris.

The most common coarse grained layer is granule conglomerate which varies in thickness from 3 to 15 cm. The debris is largely carbonate rock, presumably intraclastic since the grains are equivalent to the surrounding fine grained flysch rocks. Sand and granule sized chert grains constitute up to 30 percent of the granule and pebble conglomerates. Some layers contain abundant bioclastic debris, especially plates, columnals,
Figure 6. "Megaclast" near top of thick olistostrome. The clast's exposed dimensions are approximately 3 m by 5 m.
and spines of echinoderms, brachiopod shell fragments, bryozoans, and conodonts (Figure 7).

Rare, but distinctive clasts in the granule and pebble conglomerates are yellowish, unevenly laminated, and sometimes partially silicified (Figure 8), and they closely resemble the microfenestral fabric of a pelleted and burrowed algae (Flügel, 1982). These clasts are also found in the conglomerates of Units D and F of the northern area.

Ubiquitous in the pebble and granule conglomerates are medium- and coarse-grained quartz sand which is generally dispersed throughout each layer. The grains are monocrystalline and well to very well rounded.

The granule and pebble conglomerates are generally moderately to moderately-well sorted. The degree to which they are grain supported or matrix supported is generally difficult to ascertain due to the tectonic overprint; however, some layers are obviously matrix supported (Figure 9) and some were at least partially grain-supported. The matrix is fine-grained carbonate.

The most spectacular stratigraphic aspect of the southern area is the cobble and boulder conglomerates which are well exposed along the coastal cliffs (Figure 6). Beds vary from 1 to 30 m in thickness.

Clast lithologies are predominantly the black and grey lime mudstone of the surrounding flysch. The clasts
Figure 7. Contact between lime mudstone (below) and granule conglomerate. The conglomerate contains clasts of chert, crinoid debris, lime mudstone, and silt- and sand-sized quartz. Note the rounded texture of the quartz grains. Average quartz diameter 0.5 mm.
Figure 8. Algal clast in carbonate conglomerate. Texture, called micro-fenestral fabric, caused by tiny boring animals in a shallow, warm-water environment. Clast is 1.25 mm wide.
Figure 9. Stretched chert pebble conglomerate. Apparent grading to the right.
show varying degrees of flattening and stretching, but many retain the thin internal laminations characteristic of some of the flysch. As the laminations are parallel to the long axis of those clasts, it is apparent the clasts were somewhat tabular when deposited (Figure 10). Some limestone clasts have been selectively bleached and recrystallized, possibly as a result of hydrothermal alteration from the nearby tonalite intrusion.

The rare quartzite pebbles and cobbles are reddish brown and consist of rounded fine sand-sized quartz grains in a sparry calcite matrix (Figure 11). The quartzite clasts are well-rounded (Figure 12), in contrast to the tabular limestone clasts.

Black chert clasts are present in varying amounts, making up 5 to 15 percent of the cobble and boulder conglomerates, and up to 30 percent of the granule and pebble conglomerates. Because of the abundance of bedded chert in close proximity, the chert clasts are interpreted to have been locally derived. Chert is the only clast type in one observed layer (Figure 9), where it is generally angular.

By far the largest clast (Figure 6) has exposed dimensions of 5 m long and 3 m wide and is composed of extremely fine grained tremolite, quartz, and hematite. This lithology is distinctive for two reasons. First, there are no layers in the study area made up of this
Figure 10. Black, tabular lime mudstone clasts in a thick olistostrome deposit.
Figure 11. Photomicrograph of quartzite clast in olistostrome deposit. Large quartz grain in the center is 0.425 mm long.
Figure 12. Brown, rounded quartzite cobble just left of the pencil.
lithology, indicating derivation from outside the local area. Second, small clasts of the same lithology are found in thin section within many of the granule and pebble conglomerates of the southern area and, importantly, in the conglomerates of Unit F in the northern area.

Mesoscopic biogenic material is rare in the coarsest conglomerates. There is a single occurrence of silicified oncolites found as a clast. Medium grey bioclastic wackestone clasts containing an unusually well preserved normal salinity, open marine biota (Wilson, 1975) of bryozoan fronds, pelmatazoan debris, brachiopod fragments, and other unidentified fossils (Figure 13) were found.

Chert and Phyllite

Black chert beds constitute less than 10 percent of the overall section. Chert forms a section nearly 100 m thick in the southeasternmost part of the area. These rocks appear to have original bedding surfaces, as every 3 to 10 cm there are 0.25 to 1 cm thick phyllite layers. In thin section, microcrystalline quartz is the predominant mineral. Small crystals of chlorite and muscovite are oriented parallel to the foliation. Hematite occurs as tiny amorphous blobs and along thin veins.

Underlying the chert layer is approximately 30 m of reddish-brown, flakey, fine-grained quartz phyllite. The
Figure 13. Well preserved bioclastic debris in a southern area clast. The upper photograph shows fragments of bryozoans, crinoids, and several unidentified fragments in a dark lime mudstone matrix. The rectangular piece at the bottom is 0.5 mm long. The lower photograph contains several brachiopod fragments, as well as an echinoderm spine. The spine has a diameter of 0.5 mm.
rock contains equal amounts of medium silt to fine sand-sized quartz and fine-grained muscovite. Tiny prismatic actinolite is also present, as are trace amounts of angular to subrounded detrital zircons. Hematite, now mostly altered to limonite, occurs as amorphous patches and thin veins. This rock was originally a quartz-rich shale.

Northern Area

Overview

The northern area includes the approximately 2 km thickness of exposed metamorphic rocks between Punta Calamajue on the north and the tonalite intrusion on the south. The rocks are exposed along a northwest trending ridge which is generally parallel to the strike of the layers.

The predominant lithology is siliceous phyllite, but there are also significant occurrences of limestone and volcanic rocks.

The tectonic overprint has had a major effect on the area. The finer grained layers (phyllites especially) rarely retain original bedding structures and the more ductile layers (limestone and volcanic rocks) show dramatic thickness variations. Fortunately, the major lithologies are generally continuous throughout the area.

The northern area, unlike the southern area, is easily
divisible into lithostratigraphic units, I have defined six, which are distinctive packages and easily mapped.

Unit A

Unit A, the lowest exposed stratigraphic unit in the northern part of the map area, outcrops nearly continuously from Bahia Calamajue south to the tonalite intrusion, and in small hills just to the west of the main ridge. Unit A is predominantly thinly layered argillaceous and siliceous lime mudstone, black chert, and phyllite. The maximum continuously exposed thickness is approximately 620 m, with the lower contact covered by alluvium, and the upper contact with overlying Unit B.

The lower two-thirds of this unit consists of roughly equal amounts of interlayered chert and limestone with minor amounts of grey phyllite. The chert forms layers 2 to 10 cm thick and in places exists as a single layer between argillaceous marble or phyllite layers, although more commonly occurs with other chert layers up to 1 m thick. The chert is black to dark grey on fresh surfaces, is extremely fine grained, and commonly has a reddish-brown iron oxide coating on weathered surfaces.

Carbonate rock makes up the remainder of the lower portion of Unit A. Two forms of carbonate rock occur. The most common type is thinly interlayered, fine-grained, medium grey lime mudstone and light brown weathering, medium grey, silty, lime mudstone. These
rocks form a distinctive outcrop, as the silty limestone is relatively resistant to weathering. No fossils were recovered from this lithology. Locally, these carbonate layers are cherty and dark grey.

The other carbonate rock type present in Unit A is a light greenish-grey lime mudstone which forms resistant layers 5 to 15 cm thick and may range up to 75 cm thick. These carbonate rocks comprise less than 10 percent of Unit A and contain rare normally graded bioclastic layers (Figure 14), quartz sand-rich layers, and calcisiltites with local poorly preserved low angle cross laminations and isolated ripples (Figure 15). No age indicators have been recovered from the bioclastic layers, although the bioclastics are medium and fine sand-sized echinoderm fragments. Texturally, the bioclastic layers are mudstones and bioclastic wackestones. Normal grading and cross laminations are the only preserved small scale sedimentary structures in the northern area. The structures indicate that Unit A, at the least, and most probably the entire northern section, is right side up. The greenish-grey carbonates are always in contact with the more thinly layered brown and grey carbonates, although in places directly overlie chert.

Quartz phyllite makes up the remaining upper third of Unit A. These rocks have a well developed slatey
Figure 14. Graded bed in Unit A. Sand-sized crinoid debris grades up into pure lime mudstone. Note the reddish-brown silty lime mudstone overlaying the darker layer.
Figure 15. Carbonate turbidite. Note the ripple cross-lamination in the silty lime mudstone in the area of the pencil point grading up to the parallel laminations above.
cleavage, and more micaceous layers which are poorly resistant to weathering. Silica content ranges from 40 percent to about 90 percent. The phyllites are very fine grained and range in color from medium grey to dark grey on fresh surfaces. Weathered surfaces have a reddish brown iron oxide coating. Locally, the quartz phyllite grades into chert.

Unit B

Consisting of metavolcanic rocks, phyllites, and metalimestones, Unit B is the most distinctive unit in the study area. It is exposed along the entire length of the northern area except where the left-lateral separation of the Cerro Estrato fault has offset it to the west, where it is presumably buried by aluvium.

The exposed thickness of Unit B varies greatly from north to south. At Punta Calamajue, a minimum of 6 m is exposed. Three kilometers south of there, a maximum of 590 m is exposed.

Unit B is easily distinguished from the surrounding units at a distance and upon close inspection by its dark green color and massive texture. In the most northerly part of the area the contact between Unit B and the overlying Unit C is obscured; elsewhere the contact of Unit B and surrounding units is clearly observed (Figure 16).

No subdivision of volcanic lithology was made due to
the generally intense and pervasive recrystallization, foliation, and brecciation (Figure 17). Only in two places are relict phenocrysts preserved. One of these areas contains particularly well preserved crystals. Large, black euhedral phenocrysts of hornblende (up to 65 mm in maximum exposed dimension) constitute 15 percent of the rock, and are visible in hand sample (Figures 18 and 19). Relict subhedral plagioclase phenocrysts constitute 5 percent of the rock. Many of the hornblende crystals are rounded and slightly embayed, probably as a result of partial remelting. The plagioclase has been extensively recrystallized, although preserved relict albite twining was observed in some crystals (Figure 20). Plagioclase and hornblende are the only observed relict phenocrysts. The matrix has been recrystallized to a groundmass of fine-grained chlorite (chlinoclore) with minor quartz, actinolite, sphene, and pyrite. Since quartz appears only as a metamorphic mineral, the phenocryst assemblage of hornblende and plagioclase indicates a protolith of hornblende andesite porphyry.

The other locality in which relict crystals were observed is more typical of the rest of volcanics in terms of the degree of recrystallization; that is, absence of relict volcanic textures and complete recrystallization of the rock. The relicts are large, thoroughly albitized plagioclase phenocrysts. The
Figure 16. Contact between the dark metavolcanic rocks of Unit B, and the overlaying grey phyllite of Unit C.
Figure 17. Extremely brecciated portion of Unit B. This is the predominant texture of the unit in outcrop. The dark green is the volcanic rock, and the light brown is coarsely crystalline calcite.
Figure 18. Close-up of hand sample from well preserved section of Unit B. The large black crystals are porphyritic hornblende.
Figure 19. Euhedral hornblende crystal. The matrix is predominantly fine-grained chloroclore. The crystal is 0.4 mm in diameter. Photograph taken with crossed nicols.
Figure 20. 0.06 mm long plagioclase crystal. Note the preserved albite and Carlsbad twinning.
mineralogy of the matrix is predominantly chlorite and ferroactinolite. The actinolite has grown into large acicular poikiloblastic syntectonic crystals (Spry, 1969). The unit is interpreted as a volcanic sill injected into water-saturated sediments (see Chapter 3).

Where the metavolcanic rocks are brecciated, light brown, coarsely crystalline carbonate fills the interstices (Figure 17). This mineral is also present as 0.5 to 2.0 cm discontinuous layers scattered through the middle portions of Unit B. In a small outcrop 2 km south of Punta Calamajue, the medium grey color and crinoidal debris common to the limestone of other units is preserved within a layer of the light brown carbonate. It thus appears that these now discontinuous light brown carbonate layers are thoroughly recrystallized limestone, presumably incorporated into the sill as it injected into the country rock.

Phyllite makes up 10 to 20 percent of Unit B. It occurs most commonly with the light brown carbonate and forms thin, weakly resistant brown to dark green layers. No relict sedimentary structures were observed. Phyllite is also located at the contact with Unit A and locally at the contact with Unit C. The phyllites are, like the carbonate rocks, originally part of the sedimentary sequence and were incorporated into and thermally altered by the sill injection.
One sample from the least altered portion of Unit B was analyzed for trace element content and plotted on the discrimination diagrams of Pearce and Cann (1973). The diagrams are an attempt to characterize volcanic rocks from different tectonic settings using Nb, Y, Ti, and Zr. The sample plots very high in the Ti/Zr diagram, indicating ocean floor basalt affinity (Figure 21). Using Zr, Ti, and Y, the sample plots in the "within plate" basalt field, but very near the ocean floor basalt field (Figure 22).

Ocean floor basalts, as defined by Pearce and Cann (1973), are formed at oceanic spreading ridges, in large oceanic basins and small back-arc basins behind island arcs. "Within plate" basalt occur at ocean islands such as Hawaii, Tristan de Cunha, and the Canary Islands, or at continental rift zones such as the African Rift Valley.

No conclusive evidence can be presented here in terms of the tectonic setting of the Unit B volcanics on the basis of one sample. However, it may be significant that Unit B has characteristics of volcanics formed in rifted or extensional settings, similar to what is suggested by the depositional environment of the sedimentary rocks.

Unit C

Unit C, with a thickness variation of 145 to 390 m, consists of phyllite, metalimestone, and chert, each
Figure 22. Ti, Zr, and Y discrimination diagram. "Within-plate" basalts, i.e., ocean island or continental basalts, plot in field B, low potassium tholeiites in fields A and B, and calc-alkali basalts in fields C and B. Point is from the same sample in Figure 21. From Pearce and Cann (1973).
representing approximately a third of the unit. The contact with Unit B is easily discernible as the green volcanics and phyllites give way to the reddish-brown weathering medium grey quartz-mica phyllite which makes up the lower portion of Unit C.

Cleavage is well developed in this phyllite, the rock splitting into thin layers and forming slopes. Petrographically, the phyllite consists of about 50 percent very fine-grained phyllosilicate minerals, predominantly muscovite. The phyllosilicates define the foliations, although minor post-tectonic idiomorphic muscovite is present. Minor idiomorphic post-tectonic actinolite and hematite are also present. Silt-sized quartz makes up 40 percent of the rock, and generally shows granoblastic polygonal quartz-to-quartz grain boundaries. Also present are thin veins of limonite, small black whips and clots of carbonaceous material, and very rare rounded detrital zircons. This phyllite is a metamorphosed siltstone. The lower portion of Unit C also includes minor grey argillaceous limestone, lime mudstone, and black chert.

The middle portion of Unit C is gradational with the lower and is characterized by thinly bedded light olive grey lime mudstone and moderate reddish orange weathering medium grey silty lime mudstone. The silty lime mudstone contains up to 40 percent silt and very fine sand-sized
quartz grains in a very finely crystalline calcite matrix. The olive grey lime mudstone is about 95 percent finely crystalline calcite, with very small amounts of subangular silt-sized detrital quartz and very small idiomorphic post-tectonic muscovite.

The lime mudstone then becomes interlayered with the phyllite and chert of the upper third of Unit C. The phyllite is identical to that in the lowest third of the unit. Greyish red weathering dark grey chert constitutes approximately 50 percent of the upper third, argillaceous lime mudstone 10 percent, and the phyllite 40 percent.

Unit D

Unit D represents a significant change in the lithology of the northern area; it contains the thickest and most varied carbonate accumulation in that area. Unit D is also significant from a structural standpoint because of the great ductility contrast between it and the siliceous units which envelop it. Tectonic forces caused the siliceous units to shear, and caused intensive folding and local megaboudins in Unit D. Thus, Unit D outcrops discontinuously along the entire length of the northern area, yet varies from 0 to 285 m thick. The thickest area is close to the tonalite pluton just below the summit of Cerro Calamajue where folding is greatest. As Unit D is relatively resistant to weathering, it is a ridge and cliff former.
In what appears to be the most completely preserved sections of Unit D (Figure 23), three subunits are present. The lower subunit is recognized by its contact with Unit C and the abrupt change from chert to limestone. The limestone is thinly interbedded, medium light grey weathering, medium dark grey lime mudstone and brownish-red weathering, laminated silty lime mudstone (Figure 24). Very minor amounts of thin-bedded crinoidal wackestone also occur in this subunit.

The carbonate layers thicken and coarsen gradationally upward to the middle subunit. This subunit consists predominantly of thick, massively bedded bioclastic wackestone with minor bioclastic packstone, pebble conglomerate, and lime mudstone. The bioclastic debris constitutes up to 40 percent of the rock in places, and metamorphic and diagenetic recrystallization may have destroyed evidence for more. The preserved bioclastics consist primarily of allochthonous medium sand to granule-sized echinoderm fragments, especially crinoid columnals, with ectoproct bryozoan fragments, brachiopod shell fragments, and coarse sand and granule-sized algal fragments (Figure 25). That the bioclastics are allochthonous is indicated by their fragmental nature and moderate to good sorting. The algal fragments generally show at least partial silicification to microcrystalline quartz; the best preserved fragments have
Figure 23. Representative exposure of Unit D. Below is the lower subunit consisting of thinly- and medium-bedded lime mudstone. The middle subunit is thick-bedded wackestone and packstone. The upper subunit is similar to the lowest subunit except with more bioclastic debris.
Figure 24. Typical outcrop of Unit D lower subunit.
Note the alternating colors of the lime mudstone which are a reflection of greater abundances of quartz silt in the brown layers.
pelleted and laminated features described by Flugel (1982). Possible burrowing structures and fenestral fabric are also observed. Despite dissolving several pounds of middle subunit carbonate, no conodonts were recovered.

Lithoclastic debris is present in these rocks as sand-sized or larger particles. Well-rounded, monocrystalline, medium sand-sized quartz is ubiquitous and is present up to 20 percent in thin sections. Subangular quartz silt is present in amounts up to 7 percent. Chert is also an important lithoclastic element, especially in the pebble conglomerates. The chert clasts and grains are very finely crystalline quartz, a small percentage of which also contain thin micaceous layers.

The conglomerates, although very rare and quite stretched, were observed along the length of the Unit D outcrop (Figure 26). They did not appear to delineate a horizon within the middle subunit. In a locality 0.5 km north from the tonalite an upwards fining sequence was found. At this locality, the conglomerate appears to grade from a chert pebble conglomerate containing clasts up to 8 cm long, 5 cm wide, and 2 cm thick, with little carbonate matrix to a polymictic pebble conglomerate containing clasts no larger than 3.5 cm long, 2 cm wide, and 0.5 cm thick, with 40 percent of the rock carbonate matrix. The clasts appear to have been moderately well
Figure 25. Wackestone with crinoid fragments (circular pieces with twinning), rounded quartz sand (extinct), and chert grains (granular grain at bottom). Nicols crossed. Crinoid spine at center 0.5 mm in diameter.
sorted at deposition but tectonic flattening has destroyed most evidence for rounding characteristics. The algal clasts were much less affected by tectonics, possibly because of silicification prior to deposition or compression caused them to be relatively more resistant to deformation. Thus, these clasts are generally well rounded, suggesting that the coeval, softer carbonate clasts were probably also similarly rounded.

The upper subunit is identical to the lower subunit in that they are both thinly bedded lime mustones and silty lime mudstones. However, the contact between the middle and upper subunits is gradational whereas the lower-middle contact is abrupt. Bioclastic layers are present only in the lower third of the upper subunit, but constitute a greater portion of the upper subunit than the lower.

Unit E

Unit E overlies Unit D, and the contact is identified by the abrupt change from the thin bedded limestone of the upper subunit of Unit D to the platy siliceous phyllite of Unit E.

Unit E is quartz-rich, consisting predominantly of phyllite, with lesser amounts of metachert, meta-limestone, metaquartz siltstone, and metaquartz arenite. Unit E is present along the entire length of the northern area and varies in thickness from 390 to 620 m.
Figure 26. Flattened pebble conglomerate. Pencil is 14 cm. Clasts are predominantly intraclastic lime mudstone.
The lowest portion of Unit E is medium grey, platy siliceous phyllite which appears to be identical to the lower subunit of Unit C. Overlying this is greyish olive weathering olive grey siliceous phyllite. No original bedding or other original sedimentary structures were identified. Very fine-grained quartz (less than 0.025 mm) makes up about 40 percent of the rock. An estimated 50 percent is fine-grained mica, with an equal proportion of biotite and chlorite. Carbonaceous matter makes up about 7 percent of the rock and exists in thin discontinuous layers.

Located from 50 to 250 m upsection from the contact with Unit D is the lower contact of a distinctive, yet very discontinuous horizon of metamorphosed quartz arenite boudin-shaped outcrops (Figure 27). These boudins are generally oval in outcrop, and elongate parallel to the foliation. The boudins range in maximum exposed dimension from 0.25 to 75 m. Outcrops have been observed nearly the entire length of the northern area. The boudins weather to moderate brown and are very resistant to weathering. On one thin section, 300 points counted showed that quartz made up 93 percent of the rock, calcite matrix 3 percent, metamorphic muscovite 2 percent, and possible pseudomatrix 2 percent (Figure 28). Since the calcite is probably not an originally transported grain and is present as matrix, and since muscovite probably is a product of metamorphosed
clay, the remaining quartz and framework lithic grains
(pseudomatrix) (Dickenson, 1970) indicate that the rock
was a quartz arenite, with 97.5 percent quartz and 2.5
percent "lithics" (Folk, 1974).

Individual quartz grains ranged from very fine sand
(minimum 0.1 mm diameter) to coarse sand (maximum 0.6 mm
diameter). Quartz appears to be moderately well sorted,
and averaged medium sand size. Rounded and well rounded
sand grains were observed (Figure 29). Although
deformation has had a significant impact on grain
boundaries and shapes, observed rounding and sorting
textures indicate a mature or supermature sand source for
this rock.

Mineralogically, only monocrystalline or plutonic
(Folk, 1974) quartz is present. Some degree of undulose
extinction is ubiquitous among the grains. Inclusions
observed in the quartz grains are apatite and rutile,
which are common, and biotite, plagioclase (Figure 30),
muscovite, and zircon, which are less common. The suite
of inclusions indicate a plutonic origin for the quartz.

The pseudomatrix probably represents intraformational
muddy rip-up clasts from the underlying mudstone
redeposited with the quartz arenite.

Above the quartzite horizon is more dark siliceous
phyllite similar to that which underlies it.

Fifty to 80 m upsection from the top of the quartzite
Figure 27. Typical quartz arenite outcrop. This horizon is discontinuous, and always stands out in relief.
Figure 28. Pseudomatrix in the quartz arenite. It is the large dark brown patch to the left, and is 0.625 mm long.
is a 0.5 to 3 m thick discontinuous dark grey, thin to medium bedded unfossiliferous lime mudstone. Above this is more of the dark phyllite, minor metachert, and minor metasiltstone. Quartz makes up approximately 60 percent of the siltstone, mostly in the coarse silt range, and 5 percent of the quartz is very fine sand. Calcite makes up 20 percent of the siltstone and is present as finely crystalline interstitial matrix. Rounded detrital zircon, apatite, and rare sphene constitute about 2 percent of the rock. Fine-grained muscovite and chlorite are also minor constituents, accounting for 7 percent of the siltstone. Hematite and limonite altered from pyrite make up the remaining 10 percent.

The greyish olive phyllite, the most significant volumetric lithology in Unit E, constitutes the remaining section of the unit. As the top of Unit E, the phyllite accounts for 80 percent of the cliff exposures along the coast in the northern area.

**Unit F**

Unlike the units previously discussed, Unit F is not present along the entire length of the northern area. This is for two reasons. First, as the uppermost unit, it is most affected by coastal erosion and, second, it is displaced by the fault which forms the southern contact of Units E and F.

The abrupt contact with Unit E is marked by the
Figure 29. Texture of the quartz arenite. Note the relict well-rounded grain shapes. Lobate sutured grain boundaries from metamorphism. Photograph taken adjacent to Figure 28, and the scale is the same.
Figure 30. Plutonic quartz sand grain. Inclusions are euhedral, albite twinned plagioclase, biotite, and rutile. Grain is 0.55 mm in diameter.
change in lithology between its dark colored, resistant phyllites, and Unit F's light colored, slope-forming phyllites. The light colored phyllites distinguish Unit F, and are easily recognised from a distance (Figure 31). In hand sample, this phyllite is very thinly layered, greyish pink and medium light grey (Figure 32). Quartz constitutes about 55 percent of the rock, and occurs mostly as silt-sized grains displaying straight grain boundaries. Very fine sand-sized quartz grains are about 10 percent of the quartz population. Very fine-grained flakes of muscovite delineate the foliation and form approximately 30 percent of the rock. Black, extremely fine-grained disseminated carbonaceous matter makes up about 10 percent of the phyllite. Hematite exists as large blobs and tiny disseminated cubes. A trace amount of rounded detrital zircons is also found in the phyllite, as well as trace amounts of tiny idioblastic ferroactinolite.

Thin to medium layers of dark grey and black metachert, and minor greyish green siliceous phyllite are interlayered with the light colored phyllite; the chert becomes predominant upsection.

Thin to medium bedded, dark grey lime mudstone which is very dense, organic rich, and finely laminated within each bed grades into the sequence at approximately 125 m upsection from the contact with Unit E. The rock
is approximately 90 percent very fine and finely crystalline calcite, with less than 2 percent observed transported carbonate and quartz grains. The remainder is extremely fine-grained black carbonaceous material in thin laminae (Figure 33). The presence of lime mudstone initiates a 65 m thickening and coarsening upwards sequence of carbonate beds. Chert gives way to layers of pure carbonate rock, and the thin and medium bedded lime mudstone grades up into medium and thickly bedded lime mudstone, fossiliferous wackestone and packstone, and rare fossiliferous pebble and granule conglomerate. Fossiliferous layers are generally thickly bedded, medium dark grey packstones and wackestones. The fossils are predominantly fine sand to granule-sized pelmatazoan fragments, with minor bryozoan and brachiopod fragments. Echinoderm fragments, largely crinoid columnals, are moderately well sorted in the very coarse sand range. The matrix is finely to medium crystalline calcite. A single silicified ooid was observed. Minor granule-sized chert and phyllite clasts are also present. Well rounded quartz sand and subangular quartz silt are a minor constituent. Very minor fine-grained idioblastic muscovite and biotite are the metamorphic minerals present.

Poorly preserved conodonts recovered from the fossiliferous layers were identified as being most like Mississippian and Devonian species (Miller, 1986,
Figure 31. View of Cerro Estrato. Contact between Unit E and overlying Unit F outlined by lower line. Between the lines is the light-colored phyllite. Top of the hill is capped by thick-bedded limestone. View is to the east, Gulf of California in the background.
Figure 32. Detail of the light phyllite of Unit F. The light layers are metamorphosed calcareous siltstone. The red layers are the same but with an abundance of hematite.
personal communication).

Interbedded with the thickly bedded fossiliferous layers towards the top of the carbonate cycle are very rare stretched granule and pebble conglomerates. Clasts are predominantly chert, phyllite, and lime mudstone. Rare, but microscopically distinctive, are tremolite-quartz-hematite pebbles which are also present in conglomerates in the southern area, and make up the megaclast described in the southern section. These clasts are metamorphosed claystones and were not observed in the conglomerates of Unit D. Also present are rare yellowish pelleted pebbles found in conglomerates in Unit D and in the southern area.

The top of Unit F, which is stratigraphically the highest exposed rock in the northern area, consists of variegated phyllite similar to the grey phyllite at the bottom of the unit, dark grey thinly bedded lime mudstone, and minor chert. The top of the unit is a stripped-dip slope descending to the Gulf of California. Unit F has a maximum exposed thickness of 290 m.
Figure 33. Photomicrograph of organic-rich lime mudstone. Plane light. The largest grain is 0.075 mm long. This rock is black in outcrop.
CHAPTER 3

DEPOSITIONAL SYSTEMS

Introduction

This chapter describes the depositional characteristics of each of the various lithologies, and contains a model which accounts for the entire system. It is proposed that the phyllites and cherts, which constitute an important part of the northern area, were deposited primarily by hemipelagic settling in a deep ocean basin. The origin of the quartz arenite, which forms only a thin horizon in the northern area, remains a mystery. Carbonate rock represents temporal encroachment of a passive, or extensional, carbonate platform margin. The volcanic rock appears to represent a sill injected into the water-saturated oceanic sediments. Thus the overall model, including deep ocean basin sediments, carbonate basin and base-of-slope deposits originating on an extensional continental margin, and basic volcanic rocks, introduces the likelihood that the study area developed at a rifting continental margin.

Favositid corals discovered in the southern area are branching forms, and thus are indicative of a low energy environment, below the shelf break (Flory, 1986, personal communication).
Phyllite and Chert

Phyllite is the metamorphosed equivalent of mudstone and shale. The lateral continuity and dark color of the beds indicates that the quiet water conditions required for their deposition was extensive and probably deep. This is also true for the cherts. In both cases, deposition was most likely by hemipelagic settling. No sedimentary structures other than bedding survived deformation.

Quartz Arenite

Because tectonic activity has deformed the quartz arenite into a series of boudins, it is not known whether more than one layer existed, or what the thickness might have been. In the present day the boudins form a somewhat erratic horizon in the lower portion of Unit E.

The presence of quartz arenite within dark basinal phyllite is enigmatic. Clearly, the source and mechanism which deposited this horizon was dramatically different than that which deposited the surrounding shales. No sedimentary structures remain which would be of help. In thin section, many original grain boundaries remain. They demonstrate that the grains were well rounded and the sandstone was moderately well sorted in the medium sand range. Quartz sand of these characteristics is known to originate in beach and aeolian environments. Inclusions in the quartz grains are commonly apatite and
rutile, with minor biotite, twinned plagioclase, muscovite, and zircon, all of which is evidence for a plutonic, or continental, source terrane (Folk, 1974).

What process deposited this horizon is not known. The Ordovician Valmy Formation of the northern Great Basin (Kettner, 1977) contains quartzarenite interbedded with deep water pelagic and hemipelagic sediments. Although much better preserved, details of the Valmy sandstone deposition are far from clear. Regardless of the mechanism, it is evident that a relatively proximal continental source provided the sediment.

**Siltstone**

Siltstone is a relatively minor constituent of the study area, and is only found in Units E and F. Silt-sized quartz is the primary constituent of these layers, but rounded heavy minerals such as zircon and sphene are also present. Although no sedimentary structures remain, the grain size constituents, and apparent poor sorting, of the siltstones indicate probable deposition as a result of turbidity currents.

**Carbonates**

The most illuminating lithology in terms of depositional environment are the carbonates. This is primarily due to their relatively good preservation, the presence of biogenic debris, and the range of lithologies
According to Cook (1983), pelagic sedimentation of carbonate rock was quite low up until 100 to 150 Ma. This was a result not of a lack of diversity among pelagic organisms, but rather a relative shortage of volume prior to the Cretaceous. Some pelagic carbonates are believed to exist in the study area. They are characterized by continuous, mm-thick laminations and dark grey to black color. Rocks with these characteristics are a minority of the carbonates, thus the majority of limestone present in the area is believed to be redepsoited, or allochthonous.

The following is a brief description of the various subaqueous depositional processes as defined by Middleton and Hampton (1976), in order of increasing internal disaggregation:

1. Rockfall, in which lithified, often large rock fragments move by free fall.

2. Sliding and slumping, in which a sediment mass, usually semi-consolidated, moves along a basal shear surface while retaining some internal structures (e.g., bedding).

3. Sediment gravity flow, a general term for a flow of mixtures of sediment and fluid in which bedding coherence is destroyed and the individual grains move in a fluid medium. Four types of sediment gravity flow can be distinguished, based on the mechanisms of grain support:

   (a) debris flow - clasts supported by matrix

   (b) grain flow - caused by grain-to-grain
interactions

(c) fluidized sediment flow - caused by escaping pore fluids

(d) turbidity flow - caused by fluid turbulence.

The presence of true rockfall deposits is highly debatable since the few layers which contain coarse, angular debris can more easily be explained as debris flows. This is primarily because the greater quantity of debris in the coarse layers is intraclastic.

Subaqueous sliding and slumping is a very common form of redeposition in deeper water carbonates in the base-of-slope and slope environments (Cook, 1983). It is not unlikely that this process was a factor in the southern area since the lithologies (carbonate flysch) and proposed depositional environment (base-of-slope) were the same as in areas in which this feature is common (e.g., the Upper Cambrian and lowermost Ordovician of central Nevada; Cook, 1979). Oversteepening of the slope by strong sediment accumulation is an important mechanism for generating slides and slumps in deeper water environments (Flugel, 1982). It was not possible to differentiate actual occurrences of slumping and sliding since the pervasive deformation would mask the evidence.

Sedimentary gravity flows are viewed here to be the primary process of carbonate deposition in both the northern and southern areas.
I have divided the carbonates into two groups based primarily on grain size. However, the difference in grain size also reflects differences in depositional mechanisms and environments.

**Fine-grained carbonates**

This group includes the well-bedded carbonate flysch, packstones, and wackestones. Cook (1983) said,

*A typical Paleozoic in situ slope or basin margin limestone is not a pelagic limestone but is normally a peri-platform carbonate. It consists dominantly of shoal-water, platform derived lime muds with minor amounts of pelagic microfossils and terrigenous clastics [pp. 5-11].*

Peri-platform sediments, or oozes, commonly are evenly bedded, grey lime mudstone with thin interbeds of argillaceous lime mudstone. Furthermore,

*... typical rock types are dark grey to black lime mudstones, calcisiltites, and wackestones. Variable amounts of insoluble residue are usually present as organic carbon, pyrite, silt-sized quartz grains, and clay minerals. Beds exhibit contacts ranging from planar and nearly parallel and continuous for tens of meters to more wavy and discontinuous. Slope sediment is further characterized by its thin bedding to millimeter-thick laminae. Preservation of laminae under quiet water conditions will depend mainly on whether the sediments formed in aerobic or anaerobic waters and the influence these conditions exerted on burrowing.*

Millimeter-thick laminae are present in several locations, but are not so abundant that the oxygenation level of the depositional site can be determined. However, the other characteristics noted for ancient deep water environments (i.e., lithologies and bedding planes)
support the possibility that the fine-grained carbonates of the study area were derived from a platform environment and deposited in a deep basin environment.

Microfacies analysis also indicates the basinal nature of these rocks. Representative samples from each of the lithologies were studied for microfacies textures. The non-bioclastic carbonate layers fall into Standard Microfacies (SMF) types 2 and 3 and Facies Zones (FZ) 1 and 3 (Wilson, 1975; Flugel, 1982), which is indicative of basin and deep shelf margin environments (Figure 34). The layers containing transported biota fall primarily into SMF type 4 and FZ 3 and 4, indicating deep shelf margin and foreslope environments. That these facies zones occur together indicates deposition at or near the base of slope. In addition to the micritic matrix of both bioclastic and non-bioclastic layers, other characteristics of slope and basin sediments are displayed (Flugel, 1982):

1. Flysch bedding
2. Mudflows with exotic blocks - debris flows
3. Bouma sequences
4. Resedimented clasts and retextured sediments
5. Current ripple mark or small scale cross lamination
6. Planar bedded lime-mudstone with even mm laminae.
Figure 34. Diagram relating Standard Microfacies Types (SMF) for carbonate rocks to the facies, lithologies, and organisms present in each. The carbonates in the Bahia Calamajue area range between SMF Types 1-4, though are predominately Types 1 and 3 (from Flugel, 1982).
Flysch bedding is seen throughout the area, but is especially preponderant in the southern area. Because of the micritic matrix, the fine-grained carbonates are interpreted as mudflows. Truly exotic blocks are discussed later, in the coarse-grained section. Whole Bouma sequences were not observed. Primarily in the southern area, the tendency of many of the flysch beds was a gradational change from massive texture to a more argillaceous, laminated texture. This is interpreted to be graded bedding resulting from a turbidity current (Middleton and Hampton, 1976). Resedimented clasts and retextured sediments are present primarily as the coarse-grained debris flows. Small scale cross laminations are present (Figure 15), but were only observed in Unit A. Planar-bedded lime mudstone with even mm laminations refers back to textures found within the flysch rocks.

The biota of echinoid and bryozoan fragments found in the packstones and wackestones indicates origination in a normal salinity, open marine environment (Wilson, 1975). It thus appears that a platform-type environment, although not preserved in the study area, was part of the depositional system and was the source for much of the debris.

**Coarse-grained carbonates**

These are pebble to boulder conglomerates which are rare in the northern area and significant in the southern
area. Clast lithologies are primarily intraformational black and dark grey laminated limestone, equivalent to the carbonate flysch that envelopes the conglomerate, and black chert, which is also part of the section. This evidence is indicative of two aspects of the depositional environment of the conglomerates. First, that the conglomerates are locally derived, and second, that the depositional mechanism responsible for emplacement of the coarse debris was active at depth. Minor amounts of shallow-water derived material is also present, especially as rounded, carbonate-cemented quartz arenite clasts, silicified oncolites, and pelleted laminated algal (?) granules and pebbles which commonly show a micro-fenestral fabric (Flugel, 1982).

The conglomerates are interpreted as debris flow deposits because of the random fabric, great variance in clast size, and the primarily intraformational character of the clasts (Nardin et al., 1979; Cook, 1983). Debris flows originating in deep water carbonate environments consist primarily of dark colored lime mudstone clasts (Cook, 1979).

The dark, laminated limestone clasts are generally tabular in shape (Figure 10). Cook (1979) recognized these in the late Cambrian and earliest Ordovician slope deposits of central Nevada, and suggested that these clasts are retextured slump deposits that were broken up
as the slump became internally folded and broken (Figure 35).

Tectonic modification has eliminated the matrix supported characteristic of most debris flows except in one instance.

Carbonate Summary

The two types of coarse-grained sediments are indicative of at least two different mechanisms of transport for these rocks. The granule conglomerates, containing mostly shoal water biota, rounded quartz sand grains, and lithoclasts such as algal clasts, have bypassed the shelf margin to be deposited at the base of the slope. This is generally accomplished by a network of channels originating on the shelf or platform which then cuts through the margin (Cook, 1979). This is also the vehicle most commonly attributed to the deposition of turbidites (Middleton and Hampton, 1976; Nardin et al., 1979).

The pebble to boulder conglomerates contain primarily intraformational clasts, and thus originated in and were deposited in the deep water, slope environment.

Carbonate flysch, common in both the northern and southern areas, represent redeposition of peri-platform sediments as turbidites, with a lesser component of pelagic deposition. A generalized model is presented in Figure 36.
Figure 35. Processes of mass gravity transport and their deposits. The primary mechanisms of carbonate deposition for the Bahia Calamajue carbonates were mass flow deposits and turbidites. From Jenkyns (1982).
Figure 36. Generalized depositional model. The Bahia Calamajue rocks were deposited in the slope and basin areas. The red deposits represent mass flows, and the green deposits represent turbidites. Adaptations of figures in Read (1982) and Cook (1983) by Mike Campbell.
**Volcanic Rocks**

The lack of any preserved pillow structures or volcanic detritus leads to the assertion that the volcanic unit found in the northern area was emplaced as a sill.

McBirney (1963) described the conditions required for sill emplacement as the result of the weight of the overlying rocks being less than that of the rising magma column. He then cited examples of where this can occur, namely bedding planes, joints and fractures in weak, water-saturated sediments. I propose that these were the circumstances of the emplacement of the volcanic rock in the northern area; i.e., that the phyllites and carbonates which surround the volcanics were water-saturated at the time of emplacement. The volcanic rocks are parallel to the other units, indicating emplacement parallel to bedding.

**Study Area Model**

The interbedding of slope and basin carbonate deposits and hemipelagic siliceous rocks reveal deposition in a deep basin proximal to a carbonate shelf. The clast lithologies of the debris flows indicate that the slope was itself deep. It is also apparent that debris from shallower depth was able to bypass the upper slope margin to end up in the basin. The abundance of well-
rounded quartz grains, although only locally concentrated, gives credence to the assertion that this depositional complex was adjacent to a continent. Further, the emplacement of the volcanic sill is indicative of tectonic activity.

Read (1982) discussed several general types of carbonate platform margin depositional environments along passive, or extensional, continental margins. The model he termed a "distally steepened ramp" fits the observed aspects of the south area conspicuously well. He defined carbonate ramps as,

1. gently sloping (generally less than 1°) platforms on which shallow wave-agitated facies of the near-shore zone pass downslope (without marked break in slope) into deeper-water, low energy deposits (Ahr, 1973). They differ from rimmed shelves in that continuous reef trends are absent, buildups are typically separate and discreet, and sediment gravity flow deposits containing clasts of cemented, shallow-water facies generally are absent from deeper water facies [p. 196].

He further divided ramps into "homoclinal ramps" and "distally steepened ramps" based on the slope. Cook (1983) noted:

The outer margin of a homoclinal or distally steepened ramp is an environment of low energy and is usually characterized by mud-supported facies rather than by high energy grain-supported textures [p. 5-3].

This is because the agitated shoal water to subwavebase facies transition occurs many kilometers back on the platform. These deep-ramp textures and lithologies are characteristic of the clasts in the south area.
conglomerates, indicating a slope environment outboard of the deeper ramp.

This information constitutes the diagnostic criteria for the distally steepened ramp model of Read (1982) in which the slope and basin margin facies consist of:

(a) even bedded, grey to black lime mudstone and lesser wackestone

(b) may be argillaceous or shaly

(c) laminated, unburrowed

(d) abundant intraformational truncation surfaces, slumps and breccias of slope facies (up to 10 m thick), lesser breccias with slope clasts and shoal water clasts (or lithified lime sand)

(e) breccias commonly channel-form or sheetlike

(f) some interbedded allochthonous lime sand beds (turbidites and contourites) [p. 200].

The facies are thought to reflect relatively high slopes into the basin.

Read (1982) suggested that development of this type of ramp could occur where a rimmed shelf environment is drowned by a relative sealevel rise, or where the distal ramp facies are developing over a zone of flexuring and rapid downwarping.

There is no way to determine whether or not eustatic sealevel changes were an important factor in the distribution of sediments in the study area. If the injection of the volcanic rocks is combined with the idea of downwarping or flexuring, however, a scenario involving possible continental rifting emerges. That is, where
rifting is taking place, both downwarping and volcanic activity would be expected as crustal thinning progresses.
CHAPTER 4

METAMORPHISM

In the same way that the carbonate rocks shed light on the depositional environment, the volcanic rocks are the key to understanding the metamorphism of the study area. This is due to the low grade of metamorphism and the shortage of distinctive mineral assemblages found in most lithologies.

Grade of metamorphism

Winkler (1979, p. 74) cited the mineral assemblage of:

chlorite + zoisite/clinozoisite ± actinolite ± quartz

as characteristic of low-grade metamorphism. These minerals are found together in various relative amounts within the metavolcanics, so rocks of the study area can be classified as low-grade metamorphics.

Turner and Verhoogen (1960) divided typical mineral assemblages characteristic of each metamorphic grade, or facies, into groupings based on AFC diagrams. These groupings, or subfacies, show increasing temperatures as reflected by changes in mineral content for various lithologies. The typical assemblage within the volcanic rocks of ferractinolite-zoisite-albite-chlorite-biotite indicates placement within the quartz-albite-epidote-
biotite subfacies, or medium temperature low grade. Piedmontite, the manganese epidote, was observed in one sample (Figure 37). Deer, Howie, and Zussman (1975) commented that piedmontite crystallization takes place at somewhat lower grade than the other epidote minerals. However, both epidote and clinozoisite occur within the same sample.

Another indication of medium temperature low-grade metamorphism is the formation of biotite in pelitic schists (Turner and Verhoogen, 1960). In a number of phyllites, small biotite crystals have been found, although muscovite is still the predominant mica in those rocks. In the phyllites in which no biotite was found, it is believed that chemical composition did not allow for its formation at the conditions the rocks were metamorphosed. According to Winkler (1979), the first introduction of biotite into pelitic rocks occurs when it coexists with phengite (muscovite), chlorite, and quartz defines a reaction-isograd at \( 450 \pm 20 \text{ C} \).

The high end of the temperature range for the rocks of the study area is indicated by the almandine garnet and hornblende-in-isograd for mafic rocks. This isograd is at \( 510 \pm 20 \text{ C} \), and since garnet and metamorphic hornblende are not present in the metavolcanics, a relatively narrow formation temperature range is observed, ranging from \( 430 \text{ C} \) to less than \( 490 \text{ C} \) at \( 2 \text{ Kb} \),
Figure 37. Piedmontite crystal from Unit B metavolcanics. Photograph shows the characteristic pink color and epidote fracture pattern. Plane light. Crystal is 0.03 mm long.
to 470°C to 520°C at 10 Kb (Figure 38). Unfortunately, reactions taking place at low-grade metamorphism are not useful for making pressure determinations.

Local contact metamorphism is present adjacent to the tonalite intrusion and the basalt dikes. The tonalite is primarily in contact with carbonate rock and thus the metamorphic expression is a significant increase in calcite grain size, the generally white color, and crystallization of diopside no further than 5 m from the contact. In fact, the mesoscopic metamorphic effects of the tonalite intrusion are not present in any place greater than 10 m from the contact.

The approximately twenty isolated Tertiary intrusions of basalt caused hornfelsic textures to be superimposed over the schistosity. This is expressed in both the phyllites and the metavolcanics as non-oriented biotite and chlorite crystals, in some cases replacing the post-tectonic ferroactinolite.

The primary foliation seen in thin section is parallel to the mesoscopic structure observed in the field. Thus, the forces which provided the area with its most significant deformation were also most likely responsible for the most significant metamorphism.

The syntectonic crystals are mostly the micas which generally define the foliation. Rare very thin trains of opaques are also parallel to the foliation within the
Figure 38. P/T diagram for mineralization of indicative low-grade metamorphism. Lines indicate major reaction-isograds. The temperature range for the metamorphism in the Bahia Calamajue area is confined between the biotite-in isograd and the hornblende-in isograd. From Winkler (1979).
metavolcanics. It is through these trains of opaques that the cores of the ferroactinolite crystals are also known to be syntectonic. This is due to the fact that where the trains of opaques are included by the cores of the ferroactinolite, they are generally at an angle of about 30° to the foliation. As the ferroactinolite was crystalizing, then, the shear stress of the deformation caused the crystals to rotate somewhat. After the rock stabilized, the P and T conditions remained favorable for ferroactinolite growth, allowing acicular poikiloblastic crystal development surrounding the cores.

The epidote-series minerals found--zoisite, clinozoisite, and piedmontite--are all post-tectonic and presumably formed at the same time as the poikiloblastic actinolite.

Intrafolial folds and interference folds are common in the finer-grained phyllites.

Thus, the regional metamorphism of the study area occurred during and after at least one major deformational period. No mineralogic pressure indicators were observed. A medium temperature range of low-grade metamorphism is indicated by the presence of biotite in the phyllites and the absence of metamorphic hornblende or garnet in the metavolcanics. Contact metamorphism is concentrated within 10 to 20 m of the tonalite intrusion, and to within 5 m of each basalt dike.
CHAPTER 5

AGE AND CORRELATIONS

Age

Two lines of evidence indicate a Medial to Late Devonian range for the sediments of the study area. Conodont fragments recovered include spathognathodiform elements, *Polygnathus* (?) sp., and an assemblage of miscellaneous bar, blade, and platform fragments (Figure 39, sample localities 119-27, 428-10). R. Miller (1986, written communication) examined these fossils and assigned an age range of Devonian to Early Carboniferous.

R. A. Flory of Chico State University examined silicified coral specimens from the southern area (sample locality 427-7) and was able to determine their favositid nature (Figure 40). A few specimens appear to have lunate coralite openings, which if not due to deformation, indicate they are alveolitids. However, in spite of the regional deformation, most bioclastic debris preserved in micritic matrix does not display noticeable stretching or flattening. The association of branching alveolitids and favositids in central Nevada is generally indicative of Middle to Upper Devonian tabulate assemblages (Flory, 1986, personal communication). Flory added that the overall appearance of the samples in terms
Figure 39. Conodonts recovered from the southern area. *Polygnathus* sp. fragments on the left (Square 16) and miscellaneous bar and blade fragments on the right.
Figure 40. Highly silicified, branching favositid corals with possible alveolitid corals in lime mudstone matrix. Specimens recovered in the south area.
of preservation and surrounding matrix tends to support this assumption.

**Correlations**

Middle Paleozoic slope and basin deposits are common around the western fringe of North America. Prior to the Late Devonian-Early Mississippian Antler orogeny, sediment accumulated along a stable, passive cratonic margin (Dickinson, 1977). Although an island arc is hypothesized for pre-Antler time to the west of the cratonic margin, it appears to have had little effect on the development of typical passive margin facies (Poole, Sandberg, and Boucot, 1977; Kettner, 1977). The depositional environment of the Bahia Calamajue area indicates development along an extensional continental margin, and thus shares many lithologic characteristics with presumably coeval deposits in the western United States and Mexico.

The purpose of this chapter is to incorporate my findings at Bahia Calamajue into a previously established regional framework of middle Paleozoic lithologies and depositional environments (e.g., Gastil and Miller, 1984; Campbell, 1985; Gastil, 1985). The lack of definitive age constraints for the Bahia Calamajue area limits the degree to which correlations can be made, but substantial lithologic similarities to other areas in western North
America provide abundant correlative evidence.

Mexico

A few localities exist in the states of Baja California, Sonora, and Sinaloa which contain age and/or lithologies possibly correlative to the Bahia Calamajue area. Discussed below are those areas which seem to have the greatest similarity to the study area.

Metasediments of the northeastern Sierra la Asamblea. Three kilometers to the south of the Bahia Calamajue area, and separated by a graben infilled with Tertiary volcanioclastics, is up to 4100 m of complexly folded and faulted, metamorphosed sedimentary and basaltic rocks (Campbell, 1985; Figure 41, Location 2). The sediments of this area are characterized by their fine-grained and thin-bedded nature. The lithologies of calc-silicate marble, metachert, phyllite, and minor metaquartzite are interbedded. The large volume of thin-bedded meta-lime mudstone resembles much of carbonate-flysch at the southern part of the Bahia Calamajue area, except that the Sierra la Asamblea rocks are more commonly interbedded with chert. Thick-bedded meta-lime mudstone, although uncommon, occurs towards the middle of the section. A single occurrence of a pebble and cobble intrabasinal debris flow was also found.

Pillowed alkaline metabasalt was discovered in two of
Figure 41. Location map for areas with possible correlations to the Bahia Calamajue area. Location 1: Bahia Calamajue. Location 2: Sierra la Arrambla. Location 3: Mission Calamajue. Location 4: Sierra las Pintas. Location 5: Isla Angel de la Guardia, Isla Tiburon, Isla Turner, Punta Onah. Location 6: Sierra de Cobachí. Location 7: Inyo Mountains. Location 8: Southern Nevada. Location 9: Central Nevada. Location 10: El Paso Mountains. Palinspastic reconstruction replaced 300 km of right lateral separation along the San Andreas Fault.
the mapped units, and though somewhat more basic in composition than the volcanics of Bahia Calamajue, still represents a possibly important genetic similarity. Pillow structures are abundant in the Sierra la Asamblea volcanics, and absent in those of Bahia Calamajue.

No age information was recovered from the Sierra la Asamblea, primarily due to the deformation and medium-grade metamorphism. The differences between the Bahia Calamajue rocks and Campbell's area may represent facies relationships, with Campbell's area being more basinal.

**Mision Calamajue.** Hoobs (1985) mapped a 6100 m section of Carboniferous metasediments and island-arc metavolcanics in an area approximately 30 km southwest of the Bahia Calamajue area (Figure 41, Location 3). Although probably not correlative with Bahia Calamajue, the Mision Calamajue rocks are mentioned here because a recent review of the conodont data from Bahia Calamajue (Miller, written communication, 1986) suggests a possible age range as young as Mississippian. The lower 1000 m contains thin-bedded to massive silty claystone interlayered with limestone, pebble conglomerate, and bedded chert. The remaining section is primarily island arc volcanic flow sand volcaniclastic sediments of Mesozoic age.
Sierra las Pintas. Located in northeastern Baja California, the prebatholitic metasediments of the Sierra las Pintas (Figure 41, Location 4) consist of interbedded chert and argillite, sandstone, siltstone and mudstone turbidites, and granule conglomerates, crinoidal packstone, and pillowed and flow basalts (Leier-Englehardt, 1986). *Polygnathus* fragments found in the chert indicate an age range of Middle Devonian to Early Mississippian for the area. The terrigenous sediments range in composition from arkose to feldspathic litharenite to sublitharenite, and indicate derivation from a mixed magmatic arc and rifted continental margin for two of the units, and a rifted continental margin for the two other terrigenous units. The carbonate rocks are generally sandy, and no fossils were preserved in life position. It is believed that the basalts were all deposited subaqueously, and interpretation of REE data indicate a transitional arc setting, involving rifting along a continental margin.

The lithologic similarities between the Sierra las Pintas and Bahia Calamajue are the interbedded chert and argillite (Unit A of this study), presence of bioclastic carbonates, and a continental source terrane for the terrigenous clastics (quartz arenite of Unit E, siltstone of Unit F). The volcanic rocks are also similar in their REE ratios, and close in composition, though the Sierra
las Pintas rocks were extruded rather than intruded. Additionally, the age of the Sierra las Pintas metasediments may be very close to that of the Bahia Calamajue rocks. A significant feature of the comparison between the two localities is the concurrent tectonic setting of rifted continental margins. This implication was determined using chemical analysis of the basalts and point counts of the clastics in the Sierra las Pintas, and carbonate sedimentology at Bahia Calamajue.

**Gulf of California.** Gastil and Miller (1984) cited occurrences of thin-bedded argillite, chert and minor carbonate on the southwest coast of Isla Angel de la Guardia, Isla Turner, at the southern tip of Isla Tiburon, and on the west coast of Sonora near Punta Onah (Figure 41, Location 5). Gastil (1985) felt that these rocks are similar to those of the Bahia Calamajue and Sierra la Asamblea areas in general lithology and basinal nature. No fossils have yet been recovered from any of these areas.

**Sierra de Cobaci.** Noll (1981) informally termed 288+ m of graptolitic shale, siliceous shale, bedded chert, stratiform barite, and associated terrigenous clastics and limestones exposed on Cerro Guayacan, the Guayacan group (Figure 41, Location 6).

Divided into three units, the Guayacan group has a
95 m Late Ordovician graptolitic shale sequence, an undated 24 m bedded black chert unit, and a 158 m Late Devonian unit of chert, barite, siliciclastics, and minor limestone. The siliciclastics are interesting because they were classified as subfeldspathic arenites and contain both plagioclase and K-spar grains, local volcanic grains, and large, rounded monocrystalline quartz grains. Noll (1981) determined that these sediments were derived from a mixed volcanic and granitic or sedimentary source terrane. Noll cited the similarity between these rocks and siliceous assemblage rocks of the Great Basin and the possibility of an offshore source (Kettner, 1977).

The uppermost unit of the Guayacan group is 10 m of interbedded peloidal sandy dark-grey limestone and silty tan lime mudstone. Conodonts ranging in age from late Frasnian to Osagean were recovered from eugeoclinal rocks of the Cobachi area (Noll, personal communication to Gastil, 1984), presumably at least in part from this unit.

The Guayacan group, then, is another sequence which contains rocks of similar lithologies and age to the Bahia Calamajue area, although there are also important differences.

**Western United States**

Middle Paleozoic deep basin and adjacent carbonate
slope deposits are well developed in the Great Basin of the western United States. Rocks with many similarities to the Bahia Calamajue area occur in a generally northeast trend from east-central California to south-central Idaho. These rocks, exposed over wide areas in tilted Cenozoic fault blocks, have been termed "transitional facies" (Poole et al., 1977) for their intermediary position between the deep water basin facies and the shallow continental shelf facies.

The basinal, or eugeoclinal, rocks are present in the Great Basin as part of the upper plate of the Roberts Mountain allochthon which now structurally overlies autochthonous or para-autochthonous Devonian and older continental slope and outer-shelf strata exposed in structural windows (Poole, 1974).

Stewart and Poole (1974) summarized the Devonian of the Great Basin and divided it into four facies. From east to west they are: (1) carbonate rock (primarily dolomite) and quartzite, (2) limestone and shale, (3) shale and chert, and (4) chert. There are many localities within the limestone and shale facies which bear lithologic and depositional relationships to the Bahia Calamajue area. These are: the Vaughn Gulch Limestone and Sunday Canyon Formation of east-central California (Figure 41, Location 7), the McGonnigal Limestone and Masket Shale of southern Nevada (Figure 41,
Location 8), the Wenban Limestone and Roberts Mountain Formation of central Nevada, and the Rabbit Hill Limestone of central Nevada (Figure 41, Location 9). The first-named stratigraphic unit of each of these couplets consists primarily of medium- to thick-bedded lime mudstone, wackestone, and packstone; the second-named unit is generally a platy-splitting pelagic carbonate. In the case of the Rabbit Hill Limestone, it also forms a couplet with the Roberts Mountain Formation. Because the differences in these units is primarily a function of locality, the Vaughn Gulch-Sunday Canyon association will serve as the generalized description.

**Vaughn Gulch Limestone and Sunday Canyon Formation.** Bender (1978) found that the Vaughn Gulch Limestone, which ranges in age from late Early Silurian through middle Early Devonian, consists of: autochthonous laminated limestone, allodapic limestone emplaced as turbidites and debris flows, autochthonous medium bedded to massive unfossiliferous limestone which displays many slump features, chert-bearing limestone, dolomitic siltstones, and autochthonous thin- to medium-bedded limestones. The depositional environment for these rocks is believed to be infilling of a local, possibly intracratonic basin (Bender, 1978) similar to the gently silled basins of the outer continental shelf inferred by
Matti and McKee (1977) for the Silurian and lower Devonian of central Nevada. The total thickness varies from 470 to 155 m as a result of the local paleogeography. The autochthonous laminated and bedded limestones probably represent pelagic and hemipelagic carbonate deposits, and locally are interstratified with the unfossiliferous slump deposits. Overlying these beds is a thick gradational cycle of allodapic limestones containing debris flows and proximal and distal turbidites. Bender (1978) divided these sediment gravity flows into two groups based on allochem composition and turbidite facies. Allochems of the first group are predominantly abraded macro- and microfossils and very minor detrital quartz. The second group includes mixed proportions of silicified and fragmented fossils, pebble-sized tabular limestone and dolostone intraclasts, detrital chert, and detrital quartz. Two thick (4 m) polymictic pebble and cobble debris flows are also present, and probably represent more proximal portions of the second group.

The Sunday Canyon Formation ranges in age from early Early Devonian to late Early Devonian, and in thickness from 81 to 211 m, and is a facies equivalent to the upper portion of the Vaughn Gulch (Miller, 1976). The Sunday Canyon contains finer-grained and thinner-bedded equivalents of the Vaughn Gulch rocks, but is up to
90 percent platy-splitting laminated limestone.

Although the Vaughn Gulch and Sunday Canyon rocks do not contain the range of lithologies observed in the Bahia Calamajue area, the types of carbonate deposits are strikingly similar to those found in the lower portion of Unit A, the lower portion of Unit C, all of Unit D, a small part of Unit E, and the upper portion of Unit F. Also, much of the southern area contains carbonates very similar to both the Sunday Canyon and Vaughn Gulch. The presence of the two types of coarse debris deposits based on allochon composition is similar to the same differentiation in the Bahia Calamajue area, except that the debris flows in the latter contain a much higher lithoclastic content, and can be much thicker.

The other cited stratigraphic units are, in almost every way, very similar to the Vaughn Gulch-Sunday Canyon association. For example, the Wenban limestone in the Cortez, Nevada area (Gilluly and Masursky, 1965) and Rabbit Hill Limestone at Copenhagen Canyon and Coal Canyon, also in central Nevada (Matti and McKee, 1977) are facies equivalents of the Roberts Mountain Formation wherein the Roberts Mountain Formation represents deep basinal pelagic and hemipelagic setting, and the other units are more proximal deposits from a shallower, more dynamic environment (Poole et al., 1977; Matti and McKee, 1977; Matti et al., 1974). More specifically, they
represent the slope and basin deposits of the middle Paleozoic North American continental margin.

There appears to be little in the middle Paleozoic section of the Great Basin which shares the variety of lithologies found in the Bahia Calamajue area. Although the types of carbonates and modes of deposition are considered to be the same, there is a general lack of intimately interbedded argillaceous rock, siltstone, chert, fine- and coarse-grained limestone, and volcanics. One exception to this case is the Milligen Formation of south-central Idaho (Figure 41, Location 10). Sandberg et al. (1975) determined that at its type locality, the Milligen consists of two members, a 900 m thick section of interbedded dark grey carbonaceous argillite and fine-grained quartzite, and an upper 300 m thick unit which is generally much less argillaceous and contains abundant medium-dark grey micritic sandy to silty limestone interbedded with quartzite, siltite, argillite, siltstone, dolomitic sandstone, and granule conglomerate. These rocks are interpreted to have been deposited in a relatively deep water, slope environment. The carbonates and sandstones were emplaced by turbidites and debris flow.

**Garlock Formation.** In the western Mojave Desert of southern California, Dibblee (1967) described the Garlock Formation, a Paleozoic formation which bears many
resmblances to the Bahia Calamajue area (Figure 41, Location 11).

Dibblee (1967) divided the Garlock into 22 units in the El Paso Mountains. Among these are units of greenstone, phyllite, quartzite, chert, polymictic conglomerate, andesite, and thick, massive limestone. Poole et al. (1977) reported unpublished work by Poole and A. G. Harris in which late Early Devonian to early Middle Devonian conodonts were collected from Unit 5 of the Garlock Formation. Unit 5 is a dark-greenish grey, sandy, thick-bedded limestone with interbedded chert and phyllite. Phyllite and chert units overlie Unit 5, a unit of phyllite and limestone underlie Unit 5, and chert conglomerate underlies that.

Overall, then, the most likely correlative in the United States appears to be the lower seven units of the Garlock Formation. This is based to a lesser degree on age similarities and to a greater degree on lithology. The Garlock Formation has the only middle Paleozoic stratigraphy found in my research of the United States which contains all of the lithologies (except the quartz arenite and the massive carbonate debris flows) found in the Bahia Calamajue area. That the conodonts of the Bahia Calamajue area may be as young as Mississippian does not pose a major problem with this correlation since the Garlock contains Permian fossils in Unit 12 and thus
may contain Carboniferous rocks between the two units.
CHAPTER 6

STRUCTURE

Field observations indicate that at least three periods of pre-Turonian deformation affected the study area. These three events predate intrusion of the tonalite pluton which, by comparison to granitic rocks in this part of the Peninsular Ranges batholith, is probably no younger than 90 m.y. (Krummenacher et al., 1975).

The earliest deformation (ε1) was a penetrative compressional event which created a regional axial planar cleavage subparallel to bedding surfaces. Each lithology responded to the deformation according to its own ductility potential and the contrast with the rocks surrounding it. The limestones are commonly folded into tight isoclinal folds (Figure 42), and the chert and argillaceous chert show rare small-scale open disharmonic folds. Phyllite shows no folding in hand sample, and rarely in thin section, so the deformation apparently took place along mica-rich shear planes via intragranular or intergranular flow (Turner and Weiss, 1963).

This form of large-scale differential deformation is common in bodies of stratally shortened interbedded carbonate and shale (e.g., the Helvitic nappes; Ramsey, 1981), and the actual geometry of the folds is in part determined by the relative amount of carbonate and shale
Figure 42. Tight isoclinal folding of Unit D limestones. Photograph taken in the hinge area of the large asymmetric fold. Hammer is 20 cm long.
(or other less competent lithology) present at a given site (Figure 43; Ramsey, 1981). Thus, within the carbonate units themselves (especially Unit D) the folding is harmonic because of a lack of ductility contrast, whereas the carbonate units as a whole are disharmonically folded relative to the surrounding rock.

The paucity of small-scale asymmetric folds prevented the detailed analysis offered by Hansen (1971) for movement direction. However, large-scale asymmetric folds of Unit D were observed in the southernmost parts of the northern area (Figure 44). The folds converge southeast, plunge subparallel to strike, and trend N15°E. The axial planes to these folds is parallel to the areal cleavage.

The foliation developed by S1 is displayed as slatey cleavage within the phyllites and thin-bedded carbonates. The shortage of micaceous minerals in the study area did not allow a pronounced schistocity to develop. The cleavage is parallel to bedding except where it passes through the hinges of S1 folds.

Boudinage attributed to this event is common in the northernmost area, especially where siliceous limestones are sandwiched between less competent, purer limestones.

The timing of the S1 event is not known for certain. Considering that the type of isoclinal folds and nappe-like structures found at Bahia Calamajue are absent at
Figure 43. Schematic diagram showing how fold style varies with stratigraphic thickness and facies. From Ramsey (1981).
Figure 44. Large asymmetric fold, looking northeast. Folded rock is primarily Unit D. Relief is approximately 200 m.
nearby Mission Calamajue (Hoobs, 1984, personal communication), it is possible that the S1 event was pre-Chesterian. If this is true, and one assumes that Bahia Calamajue was part of North America during deposition, one can speculate that the S1 event may have been at least coincident with the Antler Orogeny of the Great Basin (Smith and Kettner, 1968). Hoobs (1985) felt that the Mission Calamajue area may be a southern extension of the Carboniferous inner-arc basin postulated to have existed between the Antler Orogenic Highland and the Klamath-Northern Sierra Nevada island arc (Dickinson, 1977).

Poole and Christianson (1980) suggested Antler-correlative thrusting in the El Paso Mountains, and Noll (1981) and Peiffer-Rangin (1979) made the same observations in central to southern Sonora. Thus, a plausible guess at the age of the S1 deformation would be Late Devonian to Early Mississippian. An additional factor is the eastward component of vergence of the large asymmetric folds which, assuming little or no horizontal rotation, is what would be expected from that orogenic event (Dickinson, 1977).

The S1 event, because of its similarities to development of the Helvetic nappes in Switzerland (Ramsey, 1981), was probably developed as part of a larger, eastward-verging nappes structure.
The second pre-Turonian deformation (S2) formed a megascopic plunging synform, the hinge of which is partially exposed at Punta Calamajue. The fold plunges 40° NE in a N63°E trend. Great attenuation of the stratigraphic section is found in the hinge area. Unit B, 590 m at its thickest, is locally less than 6 m thick in the hinge area, and Unit D locally pinches out and is generally very thin.

Because the attenuation and large-scale discontinuity generally increase towards the hinge at this fold, it is felt that the S2 event superposed these features on the northernmost area which had already been thinned somewhat during S1. This is seen best in the limestones and quartz arenite, which acted as more competent bodies relative to the surrounding weaker phyllites.

The timing of the S2 event is also very speculative. Less than 50 km to the northeast, a large-scale steeply plunging syncline in which the more competent beds were highly boudined in the limbs was reported by Buch (1984) in the El Marmol area. These rocks are Upper Permian (?) to Lower Triassic, and overlie Lower Permian strata (Delattre, 1984) involved in the same folding. Whether or not the folding in the two areas is related is unknown.

The third period of pre-Turonian deformation (S3) resulted in the steeply-dipping east-west faulting
observed in the northern area. Most of these faults were
discovered through the use of aerial photographs, since
the actual fault traces are generally eroded. Associated
with the faults are gentle anticlines in which the hinges
are subhorizontal (Figure 45).

The faults have broken the northern area into five
major blocks. Each block is characterized by the manner
in which the units crop out. For example, the central
block exposes an attenuated, discontinuous section of
Unit D, whereas the blocks on either side reveal much
thicker exposures of that unit. The boundary between the
central block and the block directly to the north is the
only northeast-trending fault of importance, and is at an
angle of 75° to the east-west faults. Relative displace-
ment along these faults was not determined. However, the
Cerro Estrato Fault had sufficient left lateral
separation to expose Unit F. The lateral component of
this fault is then between 750 and 1000 m.

The age of the S3 deformation remains uncertain.
However, it is apparent that it is at least as old as the
tonalite intrusion because the intrusion is emplaced
parallel to the fault trend, probably along a fault.
Thus, the faulting may have occurred during emplacement,
or the tonalite may have risen through a zone of weakness
created by the faulting episode.
Figure 45. Fold resulting from S3 faulting. Responsible fault just out of picture to the right. Unit D is outlined.
CHAPTER 7

TECTONIC IMPLICATIONS

The lines of evidence indicating a North American origin for the Bahia Calamajue rocks are mostly drawn from the age and lithologic similarities to middle Paleozoic continent slope and basin deposits of the Great Basin and Mojave Desert (outlined in Chapter 5). However, several other metamorphosed, pre-batholitic terranes in Baja California have been identified which bear strong lithologic similarities to the age-correlative rocks on the North American plate. Gastil (1984) and Gastil and Miller (1984) have summarized these occurrences. The most notable areas are the Ordovician San Marcos allochthon in northern Baja (Lothringer, 1983), which has lithologic similarities to the Ordovician Valmy Formation of the central Great Basin; the miogeoclinal strata of the San Felipe area in east-central Baja which Anderson (1982) correlated with Cambrian and upper Precambrian strata in Sonora; and the Upper Permian (?) and lower Triassic miogeoclinal strata 50 km NW of Bahia Calamajue which Buch (1984) correlated to similar strata in the southwestern Great Basin.

Thus armed with only a few local data points in such a vast region, any attempt at tectonic reconstructions must be highly suspect. At the time of this
writing, the idea of "suspect terranes" (Coney et al., 1980) is frequently debated. It appears that this concept, whereby exotic blocks of crustal material have been accreted to western North America through subduction-related collisions, can account for many areas from northern California to Alaska which contain unique faunas and lithologies. Most of these terranes are thought to be pieces of oceanic basins and volcanic arcs, although some appear to be portions of unknown continental edges and are termed "quasi-continental" (Coney et al., 1980). The Bahia Calamajue area certainly has continental affinity and, since no direct evidence can prove a North American origin for the study area, it can be considered a "suspect terrane," or at least part of one.

Perhaps not until a distinctive faunal assemblage can be recovered will it be known with certainty whether or not the Bahia Calamajue rocks are domestic or imported. However, the age and lithology fit the trend of Paleozoic rocks in Baja established in the earlier cited works, i.e., ocean basin, probably adjacent to a rifted continental margin.

The great geographic distance between the southern Great Basin equivalents to the Bahia Calamajue area is made even greater when one replaces 300 km of late Cenozoic right lateral separation which resulted from the
opening of the Gulf of California (Gastil et al., 1975). This would indicate that the Cordilleran miogeocline extended far to the south, as indicated by Dickinson (1981) and Gastil and Miller (1984) (Figure 46).

The distance between the Bahia Calamajue area and the correlative Great Basin rocks is greatly reduced, however, for pre-Jurassic time if the Mojave-Sonora megashear of Silver and Anderson (1974) is accepted. The megashear was hypothesized to account for the disruption of ProCambrian tectonic belts in the southwest United States and northern Mexico, and is thought to extend in a S50 S trend from the southern Inyo Mountains in California into the Sierra Madre Occidental of Sonora, Mexico. Seven hundred to 800 km of left-lateral displacement is postulated for this transform fault, which is believed to have been active during the late Jurassic. Taking this movement into account places the Bahia Calamajue rocks directly in trend with the middle Paleozoic miogeocline-eugeocline boundary observed by Poole et al. (1977), Matti and McKee (1977), and Stewart and Poole (1975). This observation is also applicable to the Permian and Triassic rocks 50 km to the northwest (Buch, 1984b).

Another line of evidence suggesting a North American origin for the Bahia Calamajue rocks comes from the suggested timing of nappe development (Chapter 6). If the nappe structures are in fact coeval and genetically
Figure 46. Paleogeographic reconstruction of southwestern North America during Middle to Late Paleozoic. Figure palinspastically replaces 300 km right lateral separation along the San Andreas Fault. Modified from Dickenson (1981), Poole and others (1977), and Gastil and Miller (1984).
related to the Antler orogeny, then the North American connection appears even more likely.

No single line of evidence is adequate to unravel the actual place of origin of the Bahia Calamajue rocks. However, although the area qualifies as a "suspect terrane," the many indirect lines of evidence point to creation proximal to the North American continental margin.
REFERENCES CITED
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Buch, I. P., 1984b, Upper Permian (?) and Lower Triassic metasedimentary rocks, northeast Baja California, Mexico, in Geology of the Baja California Peninsula, J. A. Frizzel, ed., SEPM Pacific Section, pp. 31-36.

Campbell, M. J., 1985, Prebatholithic stratigraphy of the Northeastern Sierra La Asamblea, Baja California, Mexico, Unpublished M.S. Thesis, San Diego State University.

Campbell, M. J., and Crocker, J. R., 1984, Paleozoic metasediments of southeastern Baja California, Mexico, Program and abstracts, Annual meeting of Pacific Section of the AAPG, p. 49-50.


Delattre, M. C., Permian Miogeoclinal Strata at El Volcan, Baja California, Mexico, in Geology of the Baja California Peninsula, J. A. Frizzel, ed., SEPM Pacific Section, p. 23-30.


Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture, in Classification of carbonate rocks, a symposium, AAPG Memoir 1, p. 108-121.


Folk, R. L., 1974, Petrology of sedimentary rocks, University of Texas, Hemphill Publishing Co.


California, GSA Memoir 140.


Hoobs, J. H., 1985, Carboniferous island arc and associated rocks from the Mision Calamajue area, Baja California, Mexico, Unpublished M.S. Thesis, San Diego State University.


Miller, R. H., 1976, Revision of Upper Ordovician through Middle Devonian rocks in the Inyo Mountains: age and depositional environments, in Moore, J. M., et al., eds., Depositional environments of Lower Paleozoic rocks in the White-Inyo Mountains, Inyo County, California, SEPM Pacific Section, Pacific Coast Paleogeography Field Guide 1, p. 49-60.


McGraw-Hill.


Wilson, J. L., 1975, Carbonate Facies in Geologic History, Berlin: Springer-Verlag.

ABSTRACT

Adjacent to and south of the village of Puerto Calamajue, southeastern Baja California, Mexico, is approximately 40 square km of complexly deformed low-grade metamorphosed limestone, volcanic rocks, mudstone, siltstone, quartz arenite, marble, greenstone, slate, phyllite, quartzite and chert.

The stratigraphic section cannot be accurately measured because of the local attenuation and repetition. The exposed thickness in the northern part of the area averages 500 m. Premetamorphic lithologies of the northern part are thinly bedded lime mudstone, thin and thickly bedded coarse-grained bioclastic packstone, black chert, shale, quartz arenite, and hornblende andesite. Separated by a small tonalite pluton from the northern area, the southern area has an exposed thickness of nearly 1 km. Within this is predominately thinly layered metamorphosed lime mudstone, coarse-grained bioclastic packstone, and thick boulder and cobble conglomerates. Also present is minor chert and phyllite. Interpretation of the depositional environments indicates an anoxic slope-to-basin outboard of a distally steepened carbonate ramp. The coexistence of a hornblende andesite sill and abundant well-rounded quartz grains (especially in the
quartz arenite) indicates arc-type volcanics proximal to the continental edge.

Conodont fragments from both areas as well as favositid corals from the southern area indicate a medial Paleozoic age for the metasediments. Tentative age and lithologic correlations indicate relationships to the Sierra las Pintas in the Baja California, and areas in south-central Sonora, northeastern Sinaloa, and the western United States.

At least two periods of penetrative deformation have affected the area. The earliest event was a compression which created pervasive small-scale tight isoclinal folding and shearing, as well as large-scale recumbant folds. The axes of these folds dip gently to the north-northeast, and in the current position verge to the east and southeast. The second event resulted in a large synform of which only the western limb is preserved. The axis of this fold dips steeply to the east and caused attenuation of as much as 75% near the hinge.
Plate I: Geologic Map

Legend:
- Qd: Coarse grained alluvium
- T: Tuff and tephra deposits
- K1: Coarse grained hornblende-biotite leucotonalite
- Df: Thin bedded light grey and light red phyllite overlying dark grey thin- to thick-beded fossiliferous limestone
- Dc: Dark greenish-grey siliceous phyllite with minor limestone and a dispersed horizon of brown quartz arenite boudins
- Dd: Fossiliferous limestone, varies from thin and evenly bedded to thickly and massively bedded
- Dc: Light to medium grey quartz phyllite with minor thin bedded limestone
- Dc: Highly deformed massive dark green meta-andesite sills
- Dc: Thin bedded chert, phyllite and limestone. Limestone is locally fossiliferous and has rare, small-scale sedimentary structures

Symbols:
- Strike and dip of bedding
- Strike and dip of overturned bedding
- Fault; showing relative separation
- Approximate fault trend
- Trend and plunge of lineation
- Axial trend of antiformal

Scale: 1:12,500

Prebatholithic Geology of the Bahia Calamajue Area, Baja California, Mexico

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SOUTHERN AREA

Up to 1190 M exposed thickness. Predominately medium and dark grey carbonate flysch, with up to 10% silt and sand quartz grains. Granule through boulder conglomerate composed of tabular intraclastic carbonate and chert, quartzite, and shallower water bioclastics. Minor black chert and reddish quartz phyllite.

NORTHERN AREA

UNIT F
Light grey and greyish pink quartz–mica phyllite interbedded with thin and medium-bedded dark grey and black chert; chert increases upsection. Thickening and coarsening upwards sequence of thin to medium bedded micrite with thick bedded bioclastic wackestone and mudstone at the top of the sequence. Conodont fragments recovered from thick bedded packstone. Minor intraclastic granule and pebble conglomerate. Top of unit is light phyllite, dark grey thin bedded micrite, and minor chert.

UNIT E
Primarily resistant olive grey siliceous phyllite with minor medium grey quartz phyllite, boudining quartz arenite, dark grey unfossiliferous micrite, chert, and quartz-rich metasiltstone.

UNIT D
Some bryozoan, brachiopod, algal, and conodont fragments.

UNIT C
Lower portion: slope forming, medium grey quartz–mica phyllite, minor grey limestone, and minor black chert. Middle portion: thinly bedded light olive grey micrite and reddish orange weathering silty micrite. Upper portion: gradational with middle portion, mostly quartz phyllite interbedded with dark grey chert.

UNIT B
Dark green massive, locally brecciated metavolcanic silt; pervasively recrystallized except in one locality which shows large euhedral phenocrysts of hornblende; included in the silt injection are very discontinuous light brown coarsely crystalline marble layers and dark green phyllite.

UNIT A
Lower two-thirds: interbedded 2–10 cm thick black chert, thin bedded grey micrite and brown–weathering silty micrite and thin to medium bedded light greyish green micrite; local cross-laminations in silty micrite, and normal grading in greenish grey micrite. Upper third: grey slope forming quartz phyllite, locally grades into black chert.

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