GEOLOGY AND LATE CRETACEOUS DEPOSITIONAL ENVIRONMENTS IN THE NORTHERN CORNER OF CAMP PENDLETON, SOUTHERN CALIFORNIA

A Thesis
Presented to the
Faculty of
San Diego State University

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

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by
Frank Johannes Groffie
Spring 1985

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Approved by:

Richard W Berry 4/19/85
Date

Michael J Walawender

Vincent J Landis

Wink at small faults; remember, thou hast great ones.

- Benjamin Franklin

Gradual school is where people go and gradually find out they don't want to go to school any more.

- From the film "The World
According to Garp"

ACKNOWLEDGEMENTS

I would like to acknowledge the help of several people who have contributed to this thesis.

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CHAPTER 1

INTRODUCTION

Purpose

The northern corner of Camp Pendleton contains an Upper Cretaceous sedimentary sequence which has not been studied closely since 1948. The primary purpose of this project is to describe the stratigraphy, and to bring the understanding of the depositional environments of the Upper Cretaceous section into step with modern geological concepts. Lithologic comparison of the units present here with the same formations further north in the Santa Ana Mountains, and with formations of similar age in southern San Diego County, will contribute to our understanding of Late Cretaceous paleogeography in Orange and San Diego Counties. In addition, this report will refine our knowledge of the general geology of the northern corner of Camp Pendleton, especially with regard to faults and contacts. This will help to further the Marine Corps' goal of obtaining a full understanding of the geology of their base.

Location, Access, and Exposures

The study area is located approximately 10 kilometers east of the city of San Clemente, and covers approximately 72 square kilometers. It lies within parts of the San Clemente, Sitton Peak, and Margarita Peak quadrangles (U.S.G.S. 7.5-minute topographic sheets; see Plate I). Most of the area lies within the northern corner of

Camp Pendleton, in San Diego County, but a small portion extends beyond into Orange County. The boundaries of the study area do not follow any geographic or political lines, but rather were simply tailored to provide for a maximum understanding of the Upper Cretaceous section and contacts while avoiding areas for which I lacked permission or were too hazardous to enter.

Permission was obtained to enter the Marine Base, as well as special clearance to enter those parts of the study area which lie inside impact areas. Parts of the impact areas have been swept, but other parts may yet contain unexploded ordnance of various calibers. In addition, firing, bombing, and strafing practice take place periodically in these areas, requiring coordination of geologic field work with the Impact Control people in order to avoid any potentially dangerous conflicts with such military activities.

Access onto the Marine Base from Interstate 5 is best made via either Christianitos or Basilone Roads (Fig. 1). Several dirt roads provide access into the canyons and the heart of the study area. Roblar Road offers an alternate route to the extreme eastern side of the area. These roads are of far more variable quality than the topographic sheets would suggest, and a 4-wheel-drive vehicle is advisable on many segments.

Travel to the outcrops is best done on foot along the numerous firebreaks, ridgecrests, and stream bottoms, features which themselves often provide the only exposures. In addition, the short access roads to the power line towers along the south side of Talega Canyon offer uncommonly good roadcut exposures. Except for these

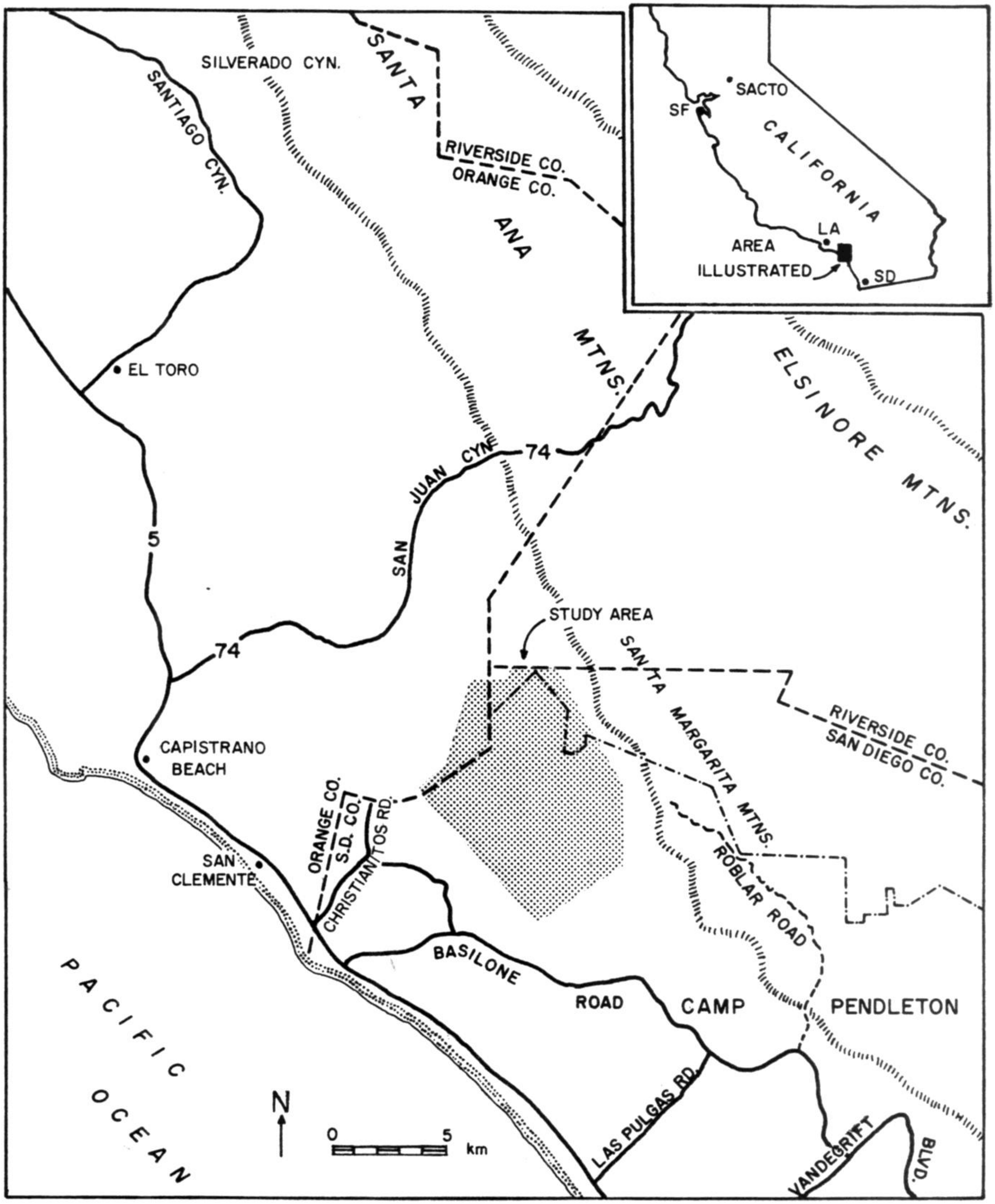


Figure 1. Map showing location of the study area and access roads.

alternatives, mapping is made difficult by dense chapparal, cactus, and rugged terrain. Overall, the quality of exposure is only fair, due to soil, oftentimes thick vegetation, and poor induration of most beds (Fig. 2).

Methods

Fieldwork

Mapping was conducted during August, September, and October of 1984 (a time when many heat records were broken throughout southern California). Geologic data was mapped directly onto 7.5-minute U.S.G.S. quadrangles. The geologic maps of Stevenson (1948), Moyle (1973), and Sowma (1982), and air photos (1:12000, available at the San Diego County administration building) aided in the placement of faults and contacts. Sections were measured using a Jacob's staff and Brunton compass. Thicknesses obtained were checked against those on the geologic map (Plate I).

Detailed Sedimentology

Representative sandstone samples were taken from the Trabuco, Ladd, and Williams Formations in Talega Canyon (sample localities 3, 5, 7, and 8; see Plate I), and analyzed by seiving at half-phi intervals from -2 to +4 phi. Grain-size parameters accompanying the histograms were obtained graphically from cumulative-percent curves (because of the "open tails"), using formulas prescribed by Folk (1980). The same samples were thin-sectioned and examined under the petrographic microscope. Paleocurrent indicators

Figure 2. Talega Canyon looking west (left) and east (right). Note generally poor exposure quality, rounded topography developed on the basement complex (background, right), and power transmission line towers (left).

(cross-stratification) were measured for the Holz Shale and Schulz Ranch Sandstone Members. (Rarely can such indicators be found in the Trabuco Formation or Pleasants Sandstone Member.) These measurements were taken from outcrops in Talega Canyon and areas north, since good outcrops are rare to the south. Outcrops with cross-stratification were either too well-indurated to excavate, or too poorly indurated to hold up under excavation. As a result, no three-dimensional data could be obtained. A high margin of error, perhaps as much as 30° to 40°, is therefore inherent in each measurement. The methods used in analyzing conglomerate clasts are detailed in the section on clast analysis in Chapter 2.

Paleontology

An unsuccessful search for microfossils was done by examining selected fine-grained samples under the binocular microscope.

Climate and Vegetation

The northern corner of Camp Pendleton lies in a transition between two climatic zones: steppe at lower elevations near the coast, and Mediterranean at higher elevations further into the back-country (Durrenberger and Johnson, 1976). Annual rainfall for the entire area averages approximately 35 centimeters (Durrenberger and Johnson, 1976), and summers are warm. However, this varies in that rainfall and termperature extremes are generally greater in the eastern, more mountainous part of the study area than in the coastal strip.

Vegetation varies in a similar way: grasses, sagebrush, and cactus of the coastal area gradually give way to dense chapparal and cactus inland. Slope orientation is a factor of equal importance to proximity to the ocean, with the northerly-facing slopes harboring thicker, brushier vegetation. In addition, the general pattern has been disrupted by fire in large areas south of Talega Canyon, where grasses now prevail. Bottoms of larger canyons throughout the area support shady groves of large oak and sycamore trees.

Geologic Setting

The Santa Ana Mountains are located at the northern end of the Peninsular Ranges physiographic province. The Upper Cretaceous sequence is wedged between Mesozoic batholithic and prebatholithic rocks on the east which form the backbone of the Peninsular Ranges, and a thick, Cenozoic clastic wedge on the west.

The oldest rocks in the area are the prebatholithic Bedford Canyon Formation. This is a Triassic (Larsen, 1948) to Jurassic (Imlay, 1963) sequence of terrigenous clastic sediments which has been subjected to variable but generally mild regional metamorphism by intrusion of plutonic bodies. The low-grade metamorphic products are largely quartzites and slates with poorly developed cleavage. Phyllites, schists, limestones, sandstones, shales, and conglomerates are also present (Larsen, 1948).

Unconformably deposited on the Bedford Canyon Formation are the Upper Jurassic (Fife and others, 1967; Schoellhamer and others, 1981) to Cretaceous (Colburn, 1973; Schoellhamer and others, 1981) Santiago Peak Volcanics, which consist chiefly of andesites, quartz latites, rhyolites, basalts (Larsen, 1948), and some sedimentary rocks of volcanic origin (Fife and others, 1967). As with the Bedford Canyon Formation, these rocks show evidence of low-grade metamorphism owing to intrusion by the Peninsular Ranges batholith (Larsen, 1948).

The Cretaceous Peninsular Ranges batholith, which extends from about the Santa Ana Mountains south into Baja California, is not one but a series of small, discreet plutonic bodies of variable composition and age (Larsen, 1948). These rocks are generally thought to be products of Mesozoic subduction and arc magmatism, and represent the ancestral Santa Ana Mountains.

Tectonically, the immediate area shows surprisingly little activity considering that the North American-Pacific plate boundary lies nearby to the east. This zone of right-lateral transform motion is several tens of kilometers wide, and includes the Elsinore, San Jacinto, and San Andreas Fault zones. The Christianitos and Newport-Inglewood Faults are the only known faults of consequence to the west. Large-scale folding of post-batholithic sedimentary rocks in the Santa Ana Mountains is minor. Dips, although increasing from south to north, generally indicate relatively low-angle tilting to the southwest, due largely, according to Ball (1961), to late Pliocene orogeny.

Previous Work

Relatively little previous work has been done on the Cretaceous sediments within Camp Pendleton, largely because of military restrictions. However, a great wealth of knowledge exists about the

Cretaceous formations of the Santa Ana Mountains in general, from which this study will borrow heavily. Previous work in the Santa Ana Mountains can be divided into three stages.

The first-level work to come out of this area consisted largely of reconnaissance geology. Besides a few early workers who alluded to an Upper Cretaceous section in the Santa Ana Mountains before the turn of the century, Packard (1916) was the first to examine these rocks critically. He named the Trabuco Formation, and assigned the overlying Cretaceous rocks to the Chico Group. Woodford (1925) included brief descriptions of these "Chico" beds within Camp Pendleton in his report on the Miocene San Onofre Breccia. Southwick (1928) mapped the geology of the southern Santa Ana Mountains. Moore (1930) mapped an area north of Camp Pendleton where he proposed four informal subdivisions of the Cretaceous section, and Levet (1940) mapped the San Juan Canyon area. Stevenson (1948) produced a large-scale map of the entire Upper Cretaceous exposure in the southern Santa Ana Mountains. His report includes the only previous map of the extent of Upper Cretaceous units within Camp Pendleton, which assisted greatly in the mapping aspect of this project.

The second-level work in the Santa Ana Mountains produced a great body of detailed lithostratigraphic and paleontologic information. W. P. Popenoe provided a solid biostratigraphic framework, and named the post-Trabuco formations and their subdivisions (Popenoe, 1936, 1937, 1941, 1942; Popenoe and others, 1960). Schoellhamer and others (1954) produced a comprehensive geologic map of the northern Santa Ana Mountains. Wheeler (1952) and Orr (1964) investigated the microfaunas. Boss and others (1958) undertook the earliest geologic investigation of Camp Pendleton, although focusing largely on post-Cretaceous geology. Roth (1958) and Ball (1961) mapped areas directly to the north and west of the study area in this report, respectively. Gray (1961) reported on the stratigraphy in the Santa Ana Narrows area. Morton (1972, 1974) studied various aspects of the Cretaceous stratigraphy in the San Juan Canyon area. Moyle (1973) produced a map of the western portion of Camp Pendleton, utilizing, in part, the report of Boss and others (1958), and likewise forgoing much pre-Tertiary detail. Elliot (1973, 1975) charted stratigraphic correlations between San Diego and Orange Counties. Davis (1978) studied paleocurrent indicators. Various aspects of Cretaceous paleontology have been treated by Totten (1974), Lang (1976, 1978), Almgren (1982), Saul (1982), and Bottjer and others (1982). Schoellhamer and others (1981) discussed the stratigraphy in the northern Santa Ana Mountains. Finally, Sowma (1983) and Craig (1984) produced reports on areas to the north and south, respectively, of the study area in this report, although focusing predominantly on post-Cretaceous stratigraphy.

A large volume of data is now available, and workers have begun to debate the depositional environments, paleogeography, and detailed geologic history of the Upper Cretaceous section. Although several of the reports cited above offer some discussion of the Late Cretaceous depositional environments, Colburn (1970) and Sundberg and Cooper (1978) were probably the first to address exclusively this problem. Recently, a large number of such studies have appeared, including reports by Sundberg (1980, 1982), Sundberg and Cooper (1982), Cooper and others (1982), Link and Bottjer (1982), Blake and Colburn (1982), and Buck (1983).

CHAPTER 2

STRATIGRAPHY

Basement Complex

The Mesozoic basement complex has been left lithologically undivided for mapping purposes since these rocks are beyond the scope of this report (consult Larsen, 1948). Nevertheless, it is important to describe briefly the nature of basement units east of the study area, as these will enter the discussions about clast provenance and paleogeography. The following four paragraphs are paraphrased after Larsen (1948), except where otherwise noted.

The oldest unit in the basement complex is the Triassic (Larsen, 1948) to Jurassic (Imlay, 1963) Bedford Canyon Formation. It consists of mildly metamorphosed sedimentary rocks, chiefly, black to dark gray argillites and slates grading into schists, with quartzites, conglomerates, and limestones. Metamorphic grade varies, and in places unmetamorphosed flysch sequences are found to consist of lithic sandstones and lithic graywackes, conglomerates, shales, pebbly shales, and limestones (Moscoso, 1967). Within these sequences, sedimentary structures characteristic of turbidites are common (Moscoso, 1967).

The next youngest unit in the area is the Upper Jurassic (Fife and others, 1967; Schoellhamer and others, 1981) to Cretaceous (Colburn, 1973; Schoellhamer and others, 1981) Santiago Peak

Volcanics. According to Larsen (1948; p. 24), "the rocks are predominantly andesites and quartz latites with some rhyolites and probably some basalts. They form a pile of alternating flows, tuffs, and breccias" representing the main part of the volcanic pile, but include interbedded slates, argillites, and graywackes. Dikes and larger intrusive bodies (old volcanic necks) are present, associated in time and space with the Santiago Peak Volcanics. One such body is a fine-grained granodiorite, about 17 kilometers long, which forms the spine of the Santa Margarita Mountains just east of the study area

The Santiago Peak Volcanics have undergone mild metamorphism, with the dominant metamorphic mineral being chlorite. With increasing proximity to intrusive bodies, metamorphic grade increases and the volcanic groundmass coarsens. In general, metamorphism has obscured or obliterated flow structures, glassy layers, and vesicles.

The youngest basement rocks are those comprising the Cretaceous Peninsular Ranges batholith. These are plutons of varying age and composition, the most common types being tonalite, granodiorite, gabbro, and granite.

Within the study area itself, basement rocks consist mostly of Santiago Peak Volcanics, with some small intrusions in Devil's Canyon which Larsen (1948) has lumped together as "miscellaneous tonalite". Outcrops are restricted to the eastern side of the study area, and are expressed topographically as relatively higher, rounded surfaces, with deep narrow canyons.

No exact ages have been determined for the plutons. However, extrapolation of K-Ar data produced by Krummenacher and others (1975;

Fig. 3) gives a time of about 105-110 m.y.b.p. for the cooling of biotite and hornblende in these plutons. This would place the age of the batholithic rocks inside the study area within the Early Cretaceous Epoch.

Upper Cretaceous Sequence

Preface

The Upper Cretaceous section within the study area consists of marine and non-marine conglomerates, sandstones, and mudstones, which nonconformably overlie the basement complex and are overlapped locally by Tertiary rocks. The section develops a total thickness of approximately 1000 meters, and has been subdivided into the Trabuco, Ladd, and Williams Formations. The type section of the Trabuco Formation is in Harding Canyon (approximately 3 kilometers south of Silverado Canyon; Packard, 1916). The type localities of the Ladd and Williams Formations and their subdivisions are located in the vicinity of Silverado Canyon (Popenoe, 1942).

The Orange County nomenclature is used here rather than San Diego area nomenclature, for several reasons. Stevenson (1948) (working under W. P. Popenoe who subdivided the post-Trabuco Upper Cretaceous section in Orange County) has previously carried the Upper Cretaceous nomenclature down into central Camp Pendleton. This usage would tend to be supported by the lateral continuity and stratigraphic similarity between the Upper Cretaceous sequence in Camp Pendleton and that in Orange County, versus the lack thereof between the Camp Pendleton and southern San Diego County sequences. The

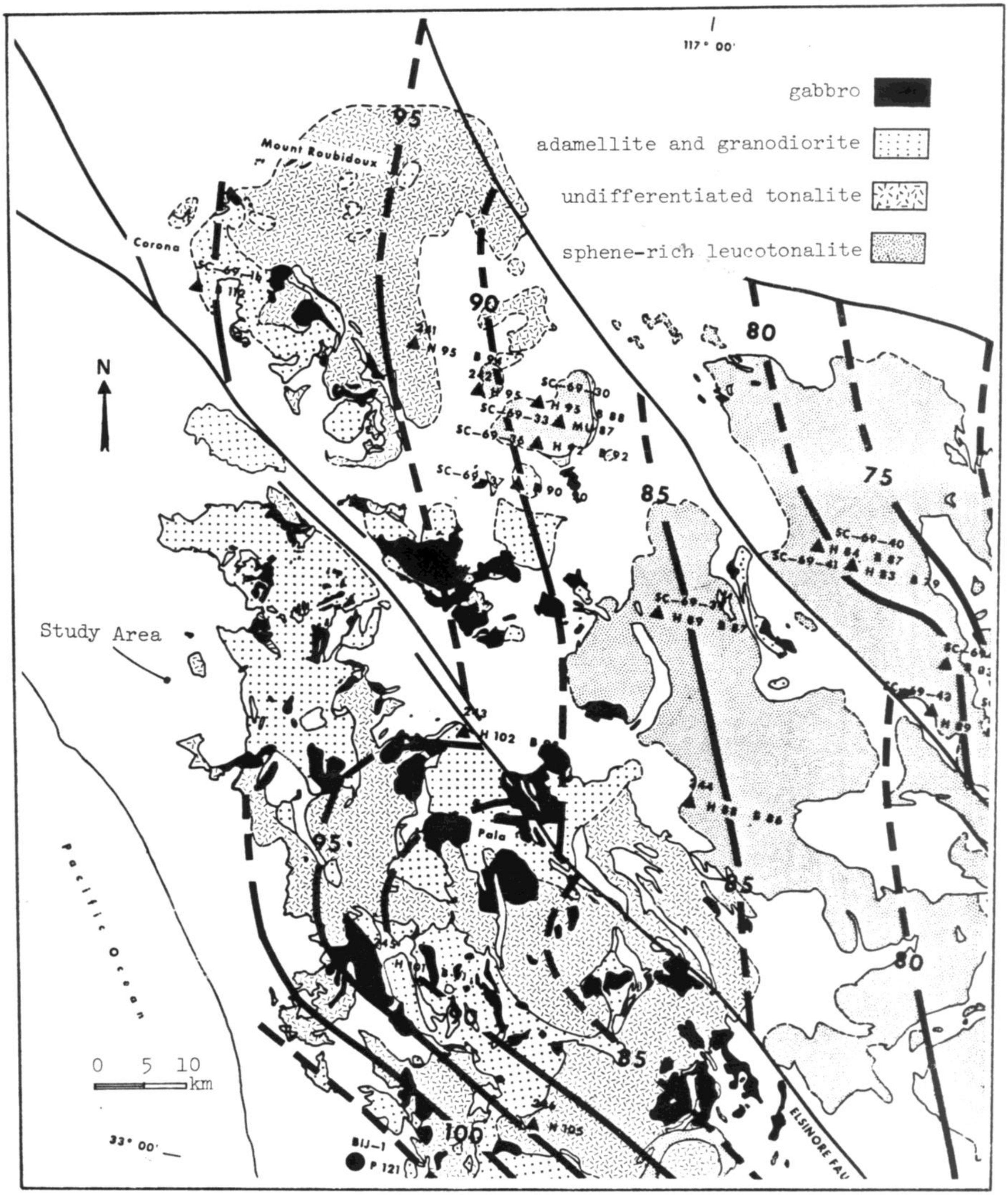


Figure 3. Biotite isochrons from rocks of the Peninsular Ranges batholith suggest an Early Cretaceous age for the small isolated tonalite plutons in the northern corner of Camp Pendleton. From Krummenacher and others (1975).

complete and up-to-date designations (as outlined in Schoellhamer and others, 1981) are used, except where shortened for the sake of brevity, even though the lithologies in Camp Pendleton may not match the descriptive parts of the names as they were established to the north. For example, the "Holz Shale Member" is occasionally shortened to "Holz", and is largely sandstone and conglomerate in Camp Pendleton. (In my opinion, the textural designations should be dropped as being unwieldy, and innapropriate in light of the diverse lithologies present within the units.)

Differences between the Camp Pendleton and northern Santa Ana Mountains stratigraphy are outlined briefly here. Coloration of the Trabuco Formation is generally lighter in Camp Pendleton. The Baker Canyon Conglomerate Member is absent between the Holz Shale Member and the Trabuco Formation. The Holz Shale Member coarsens considerably to the south and ultimately pinches out (Plate III). Lastly, the section in Camp Pendleton appears to be unfossiliferous except for trace fossils, plant fragments, and leaf impressions.

The relative abundance of facies components and sedimentary features in the Upper Cretaceous section is depicted in Fig. 4.

Trabuco Formation

The Trabuco Formation is a soft, reddish gray, disorganized, coarse conglomerate which nonconformably overlies the basement complex, forming the lowest unit in the post-batholithic succession. It is deeply weathered, massive, and unfossiliferous, hence it is believed to represent an apron of alluvial fans deposited by ephemeral

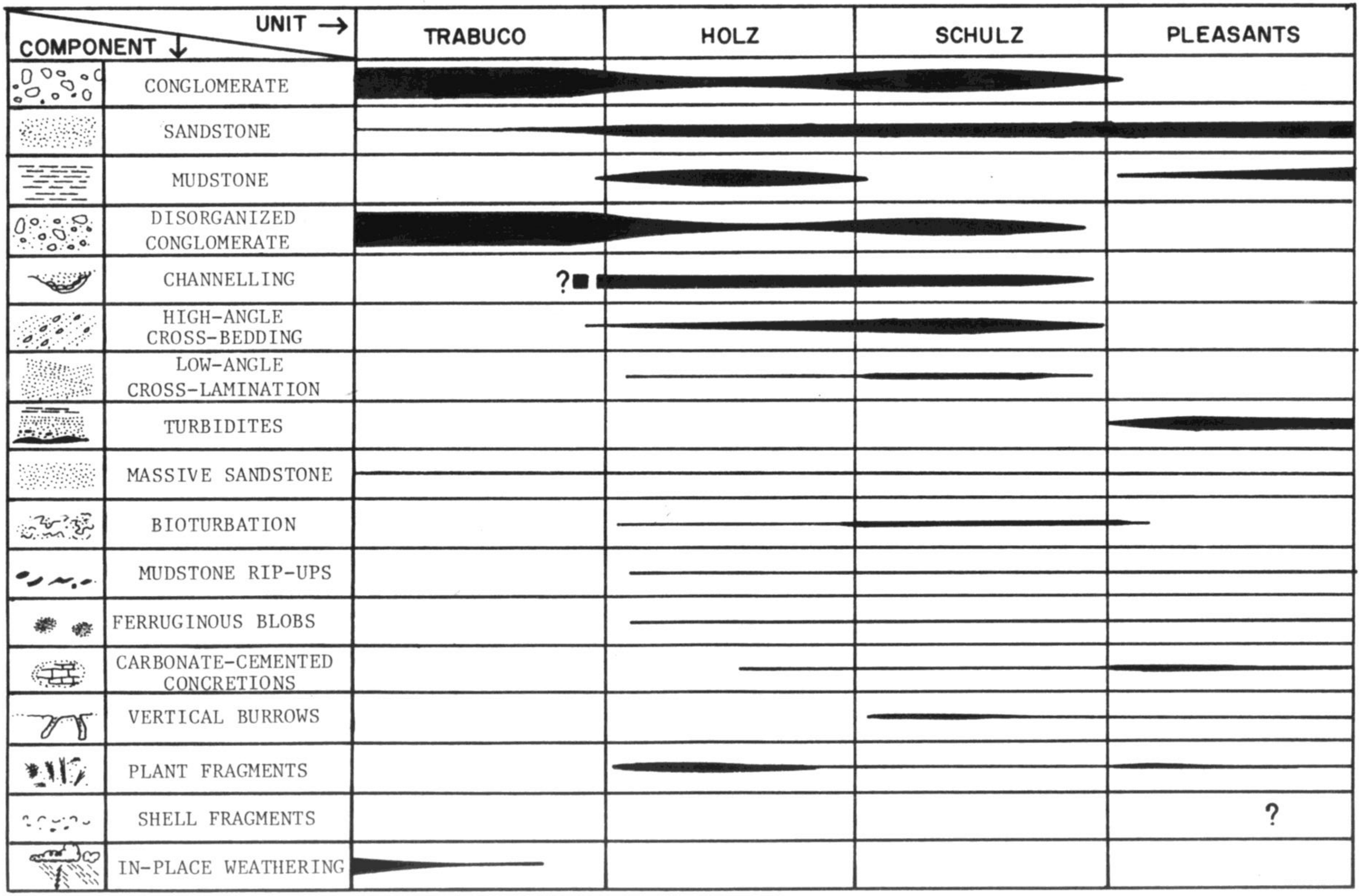


Figure 4. Relative abundance of facies components and sedimentary features in the Upper Cretaceous section in Camp Pendleton.

streams originating in the ancestral Santa Ana Mountains. It is continuous in outcrop throughout the study area, although quite variable in thickness along strike, and also probably along dip. Due to its poorly consolidated nature, the Trabuco Formation is easily eroded and never crops out well except on very fresh roadcuts. Surfaces underlain by it are highly incised. Small rockslides are common in the steep upper reaches of ravines. Contact with the underlying basement can be determined from air photos with reasonable certainty by these characteristics, and by sudden broadening and braiding of streambeds upon crossing onto outcrops of the Trabuco Formation.

The Trabuco Formation is very poorly sorted throughout. Clasts range in size up to 1 meter, the modal size being in the range of cobbles to small boulders. Most clasts are angular to subrounded (Fig. 26). Angularity and clast size decrease slightly upsection. The matrix generally is composed of muddy sand which commonly forms clods, but muddiness becomes less prevalent upsection, yielding a sandier matrix.

Sandy lenses (Fig. 5) occur sporadically throughout the unit, typically being ½ meter thick and several meters long. They are moderately indurated, and may exhibit crude bedding, but are usually massive. Petrographic and grain-size analyses show a sample from one such lens at sample locality 3 to be a medium-grained, moderately sorted, iron-oxide-cemented, immature, biotitic, feldspathic litharenite. These lenses are not associated vertically or laterally with any other notable sedimentary structures, and are the only source of attitudes in the Trabuco Formation. Exceedingly rare, faint layering and imbrication of clasts are the only other expressions of bedding, but these are too indistinct to provide attitudes.

The Trabuco Formation is a light rusty gray in most places, due to a thin coating of iron oxides deposited on the grains and clasts. In this respect, it resembles the light-colored upper part of the type Trabuco Formation. Coloration near the base is variable, however. At the base of the unit just to the southeast of Indian Potrero Truck Trail, an 8-meter-thick section is stained a bright maroon color, whereas in other places the base is stained the same faint brick-gray as further up in the section. No correlation was detected between such variations and either clast or basement composition. Thus, these variations probably are caused by different degrees of weathering. Evidence of deep, in-place weathering is seen in the clasts themselves (Fig. 6). Many plutonic clasts are stained through to their centers, and often crumble at the touch. Some of the darker fine-grained clasts exhibit spheroidal weathering.

Ladd Formation, Baker Canyon Conglomerate Member

The Upper Cretaceous Baker Canyon Conglomerate Member of the Ladd Formation is absent in Camp Pendleton. Its well-indurated, organized, and highly fossiliferous characteristics are not observed in any interval near the Holz-Trabuco contact in Camp Pendleton. This agrees with the findings of Stevenson (1948) and Roth (1958), who both show the Baker Canyon Conglomerate Member wedging out near the three-way intersection of Orange, Riverside, and San Diego

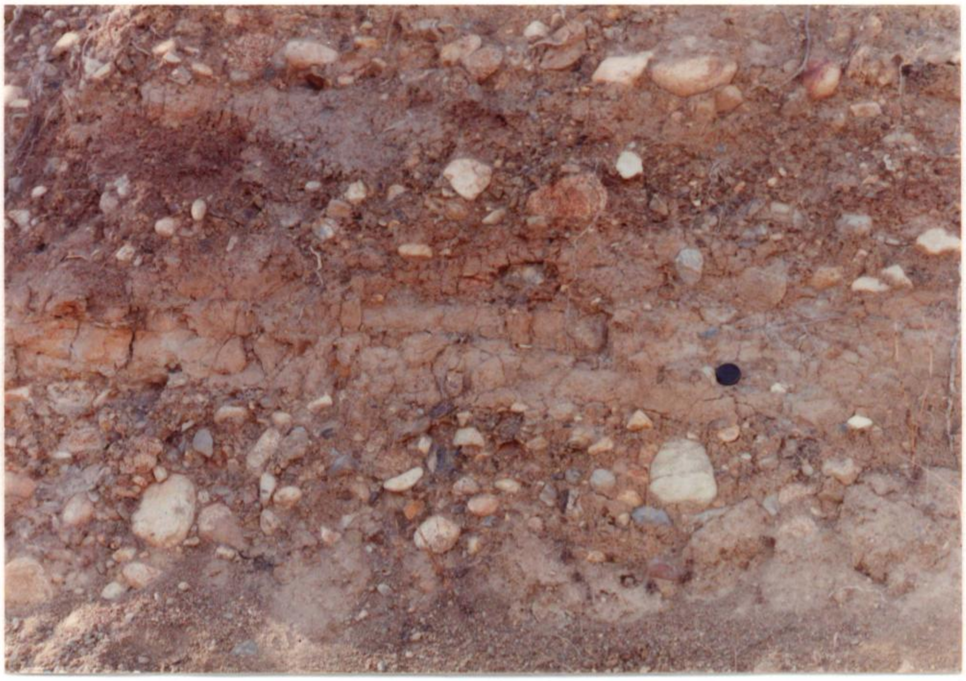


Figure 5. Sandstone lens in the Trabuco Formation at sample locality 3. Note lens cap for scale.

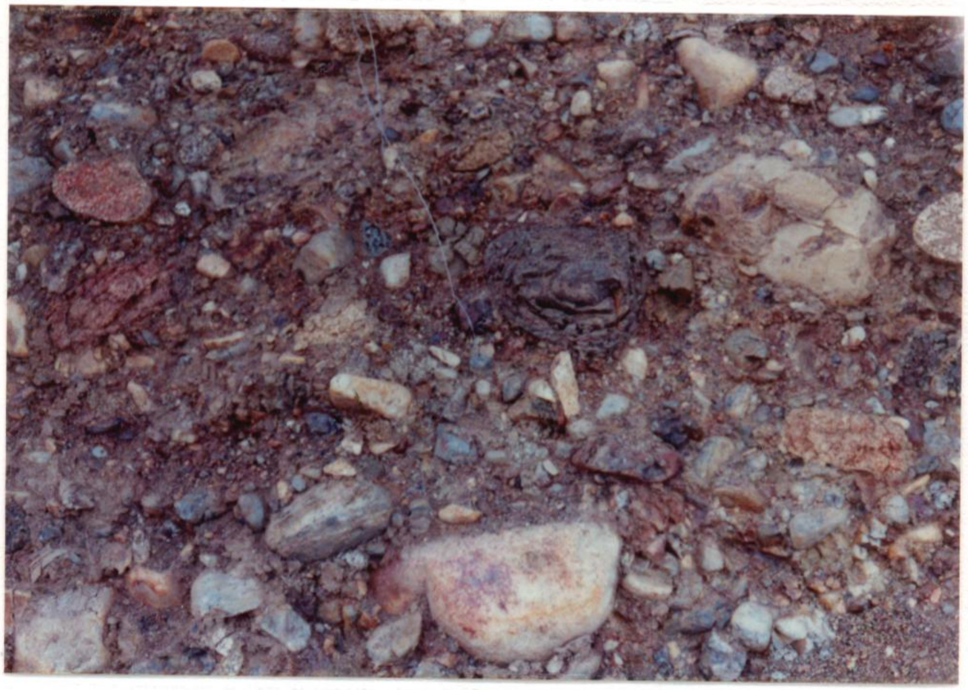


Figure 6. Typical exposure of the Trabuco Formation along a roadcut. Note spheroidal weathering of dark clast in center, and deep weathering of pinkish clasts at left. Large clast at bottom is approximately 30 cm across.

Counties.

Ladd Formation, Holz Shale Member

The Holz Shale Member of the Ladd Formation, throughout its extent in the study area, lies conformably on the Trabuco Formation. The contact between them is gradational, as can clearly be seen in Talega Canyon, precluding the possibility that the Baker Canyon Conglomerate Member is lost due to overlap. During mapping, the contact was placed at the first appearance of well-bedded mudstone or sandstone. The Holz Shale Member coarsens markedly to the south, with its characteristic mudstones gradually giving way to an increasing proportion of conglomerate and sandstone. From San Mateo Canyon on south, the unit cannot be distinguished or mapped. This conclusion agrees with that of Stevenson (1948). Though the presence of the Holz Shale Member there has not been positively excluded (good exposures are rare, and much of the area is inaccessible in impact areas), the map (Plate I) and cross section B-B' (Plate III) both show the unit pinching out in the vicinity of San Mateo Canyon. The Holz Shale Member crops out only slightly better than the Trabuco Formation, and forms the same type of low, jagged, brushy ridges. However, thick beds of moderately well-indurated, cliff-forming sandstones create good outcrops in some canyons. Otherwise, it is exposed only along roadcuts.

Mudstone, sandstone, and conglomerate comprise, repectively, about 20-25%, 35-40%, and 35-40% of the unit. These lithofacies may be interbedded in a chaotic manner, showing little repetition or pattern (Fig. 8), or as relatively laterally extensive beds (Fig. 7). Bedding is generally thick, and cross-cutting relationships and channelling (Fig. 9) abound. Intervals of mudstone may be from a few centimeters to several meters thick, but cannot be traced laterally for very great distances. Load structures are seen at a few sandstone/mudstone boundaries, but distinct structures with potential paleocurrent information, such as scours or flames, were not observed. The sandstones also occur as thick (up to 2 or 3 meters) beds which may be discontinuous lenses or laterally traceable beds, and show no evidence of penecontemporaneous deformation. The conglomerate lithofacies occurs as stringers and relatively thick, short lenses. This lithofacies, along with the sandstones, is often seen cross-cutting beds of mudstone.

The mudstone lithofacies consists of soft, gray, massive (probably bioturbated) or thinly laminated and fissile, silty mud (Fig. 10). Sand-sized, carbonized plant fragments are locally abundant. Twig and leaf impressions (Fig. 11), up to 8 centimeters across, are abundant in one outcrop of mudstone. The leaf impressions were made by angiosperms, and represent one of only a few known occurences of such leaves in Upper Cretaceous rocks in California (Jeff Myers, pers. comm., 1985).

The sandstone lithofacies typically consists of light buff to gray, moderately indurated sand, which may include granules and pebbles in small amounts. Petrographic and grain-size analyses show the sample from locality 5 to be a fine-grained, moderately sorted, limonite-cemented, submature, biotitic, lithic arenite. The

Figure 7. Typical exposure of the Holz Shale Member along a roadcut.

Figure 8. Typical exposure of the Holz Shale Member in a streamcut.

Figure 9. Disorganized conglomerate filling a channel incised into mudstone of the Holz Shale Member.

Figure 10. Close-up of mudstone of the Holz Shale Member.

sandstones commonly show steep foreset bedding with sets up to 2 meters thick. They may also exhibit low-angle cross-lamination (Fig. 12), and ripple cross-lamination, or may be massive (probably due to bioturbation). Fining-upward sequences are seen in two outcrops (Figs. 13 and 14). Light-gray, carbonate-cemented concretions, and brown blobs, up to 1 meter in diameter, are present but rare. The brown blobs consist of sandstone with a brownish-black interstitial component which is probably reduced iron. When tested for total organic content they yielded only a trace amount.

The conglomerate lithofacies consists chiefly of cobbles with a modal diameter of about 10 centimeters, although a few rare boulders may have diameters up to about 30 centimeters. Clasts are mostly subangular to subrounded (Fig. 26). The conglomerate may be disorganized, steeply but crudely cross-bedded, crudely horizontally bedded, or may occur as clast-supported lags (Fig. 14). The matrix is a poorly sorted sandstone which is generally mud-free, in contrast to the notably muddy conglomerates of the Trabuco Formation.

Williams Formation, Schulz Ranch Sandstone Member

The Schulz Ranch Sandstone Member is the lower of the two members of the Williams Formation, and consists of interbedded buff-colored sandstones and coarse conglomerates. It is one of the more persistent members in the study area, though in places small portions may be overlapped by Tertiary sandstones. Its cliff-forming sandstones also make it perhaps the most distinctive in terms of topographic expression.

Figure 11. Angiosperm leaf impressions in mudstone of the Holz Shale Member. Approximately ½ actual size.

Figure 12. Well-developed stratification in sandstone of the Holz Shale Member.

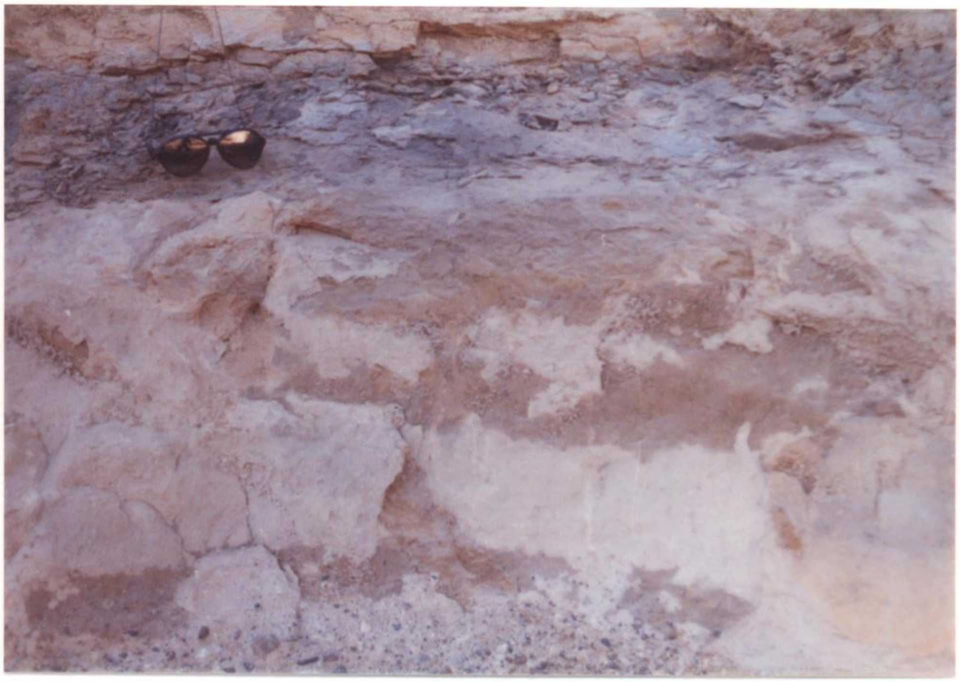


Figure 13. Fining upward in the Holz Shale Member.

Figure 14. Fining upward in structureless, conglomeratic sandstone of the Holz Shale Member.

The contact with the underlying Holz Shale Member of the Ladd Formation, and with the Trabuco Formation where the Holz Shale Member is absent (in the southern portion of the study area), appears to be gradational and conformable everywhere. In mapping, the Holz-Schulz contact was placed where thick, cliff-forming sandstones of the Schulz Ranch Sandstone Member become evident and the mudstones of the Holz Shale Member become absent. This placement was necessarily subjective and inexact, due to poor outcrops, similarity in lithologies, and gradational nature of the contact. Distinguishing the Schulz-Trabuco contact was even more difficult. Here in the southern part of the study area, outcrops are rare, impact areas become an obstacle, and the conglomerates of the two units are very similar, especially with regard to topographic expression. Hence, the contact was placed below the first well-bedded, cliff-forming sandstones. Since the Schulz-Trabuco contact is obviously hard to locate, and good attitudes are rare in the Trabuco Formation, the conformable nature of the contact is not supported by direct evidence. Nevertheless, the contact is probably conformable, owing to a lack of any evidence for an unconformity, and to the conformable and gradational natures of the Holz-Trabuco and Schulz-Holz contacts to the north.

The conformable nature of the Schulz-Holz contact, along with the southward coarsening seen in the Holz Shale Member, would indicate that the unit is not overlapped by the Schulz Ranch Sandstone Member in the southern part of the study area. Rather, facies change probably causes a lithologic merger with the Trabuco Formation and(?) the Schulz Ranch Sandstone Member. Stevenson (1948, p. 12) stated that some of the lower Schulz Ranch Sandstone Member is therefore probably contemporaneous with the Holz Shale Member in this location, since he also noted no abrupt lithologic change or unconformity between them.

The conglomerates of the Schulz Ranch Sandstone Member crop out as the same type of low, angular ridges developed on the underlying Holz Shale Member and Trabuco Formation. The sandstones, however, provide a welcome contrast, and allow for easy recognition of the unit from afar and in aerial photos. These well-indurated, thick sandstones create resistant cliffs and ridges, and even scattered overhangs along streambanks. These features are best expressed where canyons parallel the strike of the unit, for example, in La Paz Canyon. The cliff-forming sandstones do not, however, persist throughout the thickness of the entire unit, and thus are not of much help in delineating contacts.

As with the Holz Shale Member, there is a complete gradation between the sandstones and conglomerates in the Schulz Ranch Sandstone Member, due to the intimate intermixing between the two lithofacies. Sandstones and conglomerates may grade into one another laterally or vertically. Channelling is a dominant theme. The sandstones may contain variable amounts of gravel, from granule to boulder size, though boulders rarely exceed 30 centimeters in diameter. Boulders have even been observed as solitary individuals set within thick sandstone beds, though this is rare. Nevertheless, a majority of intervals in the unit approach one of the two lithologic endmembers.

The sandstones themselves are generally comprised of fine- to coarse-grained, moderately indurated, gravelly sand. Petrographic and grain-size analyses show the sample from locality 7 to be a coarse-grained, moderately/poorly sorted, limonite-cemented, submature, biotitic, lithic arenite. When fresh they are generally light orange (caused by recent limonite staining) to light gray. Weathered surfaces are a uniform dull gray. Beds may be less than a centimeter to over 3 meters thick. The thinnest beds usually alternate with siltstone, which comprises a very small fraction of the Schulz Ranch Sandstone Member in the study area. The most common sedimentary structures are steeply dipping, large-scale, planar foresets (Fig. 15); sets can be up to 2 meters thick. Thick, structureless beds are also present but rarer. Bioturbation is probably present in these beds. In a few instances, solitary cobbles or boulders, and large mudstone rip-ups, will be set within the massive beds (Fig. 16). Low-angle planar and hummocky cross-lamination and ripple cross-lamination are well-developed in one distinctive outcrop in Talega Canyon. Bedding, where present in such outcrops, is manifested either by subtle textural differences, or by limonite staining. These types of bedforms are associated with Ophiomorpha and Ophiomorpha nodosa, which are generally common in the unit (Fig. 17). Carbonate-cemented concretions, and ferruginous blobs, concretions, and haloes (Fig. 18), up to 1 meter in diameter, are present but uncommon. Body fossils are lacking. Finely divided carbonized plant debris, including rare, whole twigs, are locally concentrated in some sandstone beds.

Figure 15. Steep, planar cross-bedding in conglomeratic sandstone of the Schulz Ranch Sandstone Member.

Figure 16. Massive, thick-bedded sandstone of the Schulz Ranch Sandstone Member, containing large mudstone rip-ups and "floating" boulders.

Figure 17. Sandstone of the Schulz Ranch Sandstone Member containing vertical burrows (Ophiomorpha) and low-angle planar cross-lamination accentuated by limonite staining.

Figure 18. Ferruginous halo and Ophiomorpha in cross-laminated sandstone of the Schulz Ranch Sandstone Member. Note V-in-V structures near top, center, which represent collapsed burrows.

The conglomeratic lithofacies consists of pebbles, cobbles, and boulders with a soft, gray-colored matrix composed of poorly sorted sandstone. This is the same generally mud-free matrix seen in conglomerates of the Holz Shale Member, which contrasts with the muddy conglomerate matrix seen in the Trabuco Formation. Conglomeratic bodies range in size from stringers no thicker than the clasts themselves up to lenses well over 3 meters thick. The clasts themselves achieve a maximum size of about ½ meter, few exceed 30 centimeters in diameter, and the modal size is approximately 10 centimeters. Some have a reddish-brown iron coating, but none are of the fragile, deeply weathered variety found in the Trabuco Formation. Conglomerate may occur as beds with steep, faint, planar cross-bedding, as disorganized conglomerate lenses, or as clast-supported lags. Clast imbrication is exceedingly rare and indistinct. Clasts are mostly subangular to rounded (Fig. 26).

Williams Formation, Pleasants Sandstone Member

The Pleasants Sandstone Member is the upper member of the Williams Formation, and consists predominantly of rhythmically bedded sandstone and silty mudstone (Fig. 19). It crops out only in the western corner of the study area and is overlapped by the Tertiary Santiago Formation elsewhere. The contact with the underlying Schulz Ranch Sandstone Member is gradational, yet it is probably the easiest contact to locate of those in the Upper Cretaceous section. Surfaces underlain by the Schulz Ranch Sandstone Member are bouldery, while those soils developed on the Pleasants Sandstone Member are characterized by fractured bits of mudstone resembling dog kibble, and by soft micaceous sand. In addition, exposures of the Pleasants Sandstone Member tend to produce gentle, rounded slopes, often mantled by grass and relatively thick soil.

The sandstones are buff to gray, and moderately indurated. Petrographic and grain-size analyses show the sample from locality 8 to be a fine-grained, moderately sorted, limonite-cemented, submature, biotitic, lithic arenite. The sandstones may be thin, on the order of less than a centimeter, to a meter or more thick (Fig. 20). They are usually quite regular and traceable for tens of meters laterally, with parallel bedding planes. The same generally holds true for the mudstones, which may be less than a centimeter to several meters thick where massive. Where sandstones and mudstones are relatively thin and rhythmically bedded, they show many of the characteristics of turbidites. T_{abe} Bouma (1962) sequences with erosional bases and mudstone intraclasts (Fig. 20) are seen, but T_{ab} (Fig. 21), T_{be}, and T_{ae} sequences are observed also. Cross-stratification is not present.

Also present are thick intervals of mostly sandstone or mudstone where the Bouma sequence is not applicable. Near the base of the unit, amalgamated sandstones are thick (approximately 1 meter), contain bouldery stringers, and show evidence of sedimentary processes of considerable erosive force (i.e. channelling). The boulders may be up to ½ meter in diameter and may be matrix- or clast-supported. Further up in the unit, amalgamated sandstones are thin (on the order of approximately 1 centimeter) and horizontally laminated. Thick, muddy intervals are composed of thinly laminated silty mudstone with

Figure 19. Typical outcrop of the Pleasants Sandstone Member.

Figure 20. Turbidite(?) in the Pleasants Sandstone Member. Pocket knife for scale. Contains Ophiomorpha (obscured in this photo). Note erosional nature of base.

scattered thin layers of sandstone. They probably represent periods of time dominated by pelagic fallout with occasional pulses of low-density turbidity currents.

Other minor features characterize the Pleasants Sandstone Member. Ferruginous blobs and carbonate-cemented concretions, up to 1 meter in diameter, are common in the sandstones (Fig. 22), as are small mudstone rip-ups up to a few centimeters in diameter. Many carbonate-cemented concretions were broken open; none revealed any fossils. Burrows of *Ophiomorpha* and *Ophiomorpha nodosa* are rare to common. Finely divided carbonized plant fragments, up to a few centimeters in size, are locally abundant, especially in purplish-colored sandstone beds. Soft-sediment deformation in the form of convolute lamination in the sandstones (Fig. 23) is present but not common. Fractures filled with ½-centimeter-thick veins of selenite (the clear form of gypsum) are common in outcrops of this unit in the study area.

Ages

The entire Upper Cretaceous section in Camp Pendleton is unfossiliferous, except for *Ophiomorpha* and plant debris and impressions in the Ladd and Williams Formations, and some possible molds of thin-shelled bivalve debris in one outcrop of the Pleasants Sandstone Member. Macrofossils, either whole, macerated, or within concretions, are apparently lacking, and a search for microfossils within the mudstones was fruitless. This confirms the findings of Stevenson (1948), that the sequence, though richly fossiliferous to the north, is barren here. This may indicate that conditions in Camp Pendleton

Figure 21. Turbidite in the Pleasants Sandstone Member. Note vertical burrow and mudstone intraclasts.

Figure 22. Typical carbonate-cemented concretion in the Pleasants Sandstone Member.

Figure 23. Convolute lamination in the Pleasants Sandstone Member.

Figure 24. Mudstone rip-up flap in the Pleasants Sandstone Member.

during the Late Cretaceous were not suitable for the proliferation of a benthic fauna, perhaps due to a high rate of sedimentation or anoxic conditions. Yet, planktic and nektic groups are also lacking, while at the same time burrows are common. These facts would lend weight to the other explanation for the lack of fossils, namely, that groundwater leaching has obliterated their remains in this particular area (Almgren, pers. comm., 1984).

In any case, for the present we have to rely on the ages gotten by those working on the same units to the north, in San Juan and Silverado Canyons. The Trabuco Formation is unfossiliferous everywhere, but its age is bracketed by the underlying Lower Cretaceous rocks of the Peninsular Ranges batholith and the overlying Upper Cretaceous sediments of the Ladd Formation, and it is therefore invariably assigned a Turonian age (Popenoe and others, 1960; Morton, 1972; Almgren, 1973; Bottjer and others, 1982; Sundberg and Cooper, 1978). The Holz Shale Member is now generally assigned a Turonian through early Campanian age (Popenoe and others, 1960; Morton, 1972; Lang, 1976, 1978; Sundberg, 1982; Cooper and others, 1982; Saul, 1982). The middle Campanian age for the sparsely fossiliferous Schulz Ranch Sandstone Member is inferred from the time range represented by fossils in underlying and overlying units (Morton, 1972) and by a meager molluscan fauna (Cooper and others, 1982; Schoellhamer and others, 1981). The Pleasants Sandstone Member is late Campanian (Schoellhamer and others, 1981; Saul, 1982) to possibly Maastrichtian in age in thicker sections (Morton, 1972).

Clast Analysis

Procedures. Conglomerate clasts were studied from three units: the Trabuco Formation, the Holz Shale Member of the Ladd Formation, and the Schulz Ranch Sandstone Member of the Williams Formation. (Conglomerates in the Pleasants Sandstone Member of the Williams Formation are scarce.) The clasts were analyzed for composition and roundness, for the purpose of drawing conclusions about their provenance and environments of deposition. The procedures used followed along lines set forth by Popenoe (1941) and Colburn and Blake (1982). For each unit in this study, a representative outcrop was chosen and contiguous clasts were removed from one small area until they totalled 100. This was done for two widely separated outcrops of the Trabuco Formation to see how composition varied as a function of location. Unfortunately, the same could not be done for the other units, due to a lack of roads and outcrops in the necessary areas. The roundness of each clast was determined by comparison with the roundness scale of Powers (1953). Composition was determined in hand sample. Each sample was then placed in one of three broad categories (sedimentary, plutonic, volcanic) according to rock type, or if metamorphosed, according to pre-metamorphic protolith.

Results. Clasts in the Upper Cretaceous conglomerates were all derived from units present in the basement complex (see Fig. 24). Quartzites and argillites match descriptions of similar sedimentary and metasedimentary rocks from the Bedford Canyon Formation. A small number of sandstones tallied also probably were derived from this

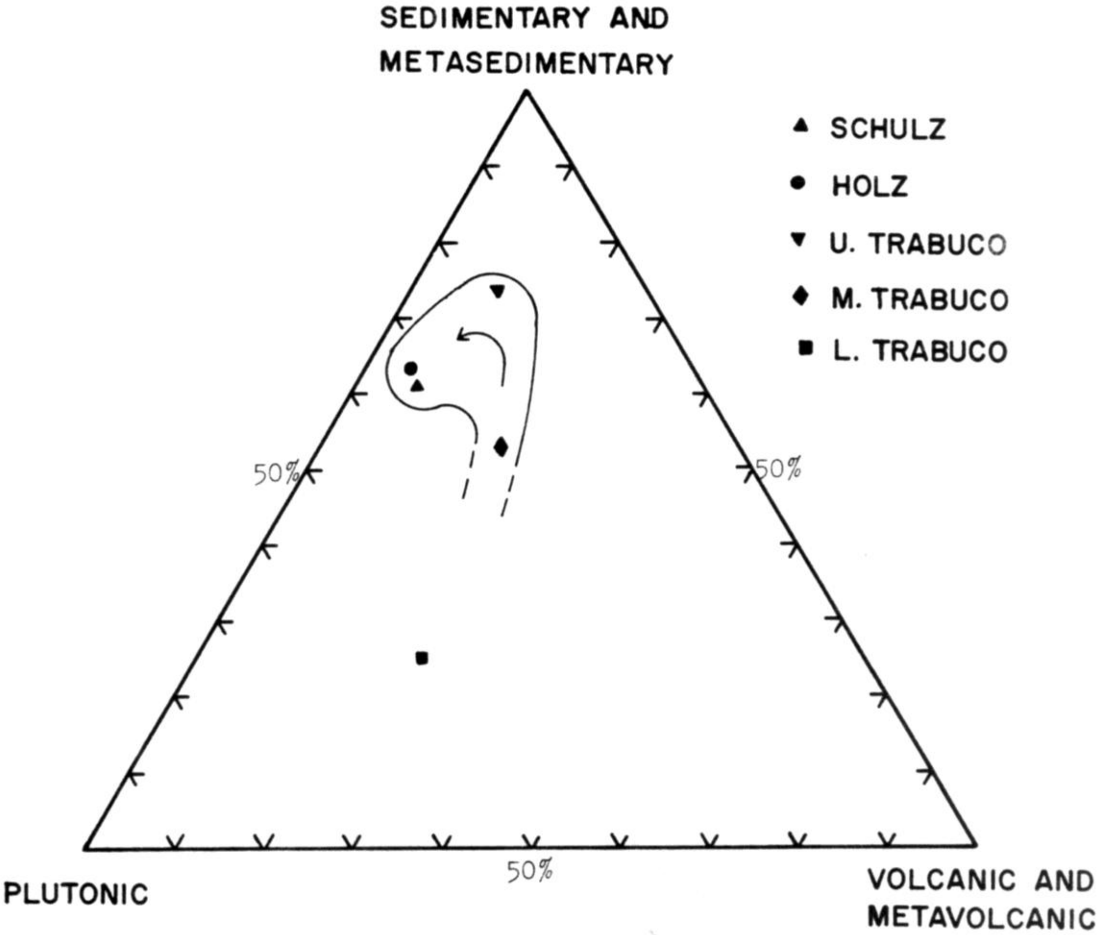


Figure 25. Clast compositions for Upper Cretaceous units in Camp Pendleton. Arrow suggests one possible interpretation of how composition might have changed slightly through time.

unit. Greenish andesites and other volcanic and metavolcanic clasts match descriptions of rocks of the Santiago Peak Volcanics. Various types of plutonic clasts match descriptions of rocks of the Peninsular Ranges batholith. None match descriptions of the distinctively red, pink, and purple Poway clasts (see Peterson, 1970), and none are likely to have come from any exotic terrane. This indicates that the conglomerates were derived from the nearby, freshly unroofed basement complex, and hence probably were delivered to the Trabuco fanglomerates by short streams originating not far inland.

However, the relative proportions of these clast lithologies in the Trabuco Formation show little correlation to that of the basement complex units _in the study area_. The underlying basement throughout the study area is comprised predominantly of the Santiago Peak Volcanics. Yet 50%, 80%, and 91% of the clasts in the Trabuco Formation at sample localities 1, 2, and 4, respectively, are plutonic or sedimentary. This, however, probably can be explained by erosion of the basement complex, which has undoubtedly altered the relative amounts of area underlain by the different basement lithologies since the Trabuco Formation was deposited in the Late Cretaceous.

Figure 25 shows that the clast compositions throughout the section in Talega Canyon (sample localities 2, 4, 6, and 7) remain fairly uniform, mostly sedimentary clasts with lesser amounts of plutonic and volcanic clasts, whereas the Trabuco Formation at locality 1 is comprised largely of plutonic clasts. This may imply that clast composition varies largely as a function of strike. Popenoe's (1941) findings for the Trabuco Formation in the northern Santa Ana

Mountains illustrate this same relationship. The resulting conclusion is that at a given locality along strike, the conglomerates throughout the section were probably derived from the same source area, which was probably one of a number of small drainage basins in the Late Cretaceous ancestral Santa Ana Mountains, and that little mixing occurred between source areas.

The results of the clast roundness study (Fig. 26) show that roundness increases upsection both moderately and continuously. In other words, there is no appreciable decrease in roundness at any point. Qualitative visual inspection revealed no correlation between roundness and composition. The roundness trend, therefore, is probably due to an increasing distance from the source area. The resulting conclusion is that clasts moved through several different, laterally contiguous and progressively more distal depositional environments, corresponding to the vertical stacking of the Trabuco Formation, Holz Shale Member, and Schulz Ranch Sandstone Member.

Sandstone Petrography

Preface. The same four sandstone samples used in the grain-size analyses, one from each unit, were analyzed in thin section. Three-hundred points were counted in each section. Maturity was determined as outlined by Folk (1980). Results are summarized in Fig. 27 and Table 1.

Relative percentages of quartz and feldspar are similar in the four sandstones. Compositionally, they differ mainly in the amounts of lithic fragments, biotite, matrix, and pore space. Sandstones

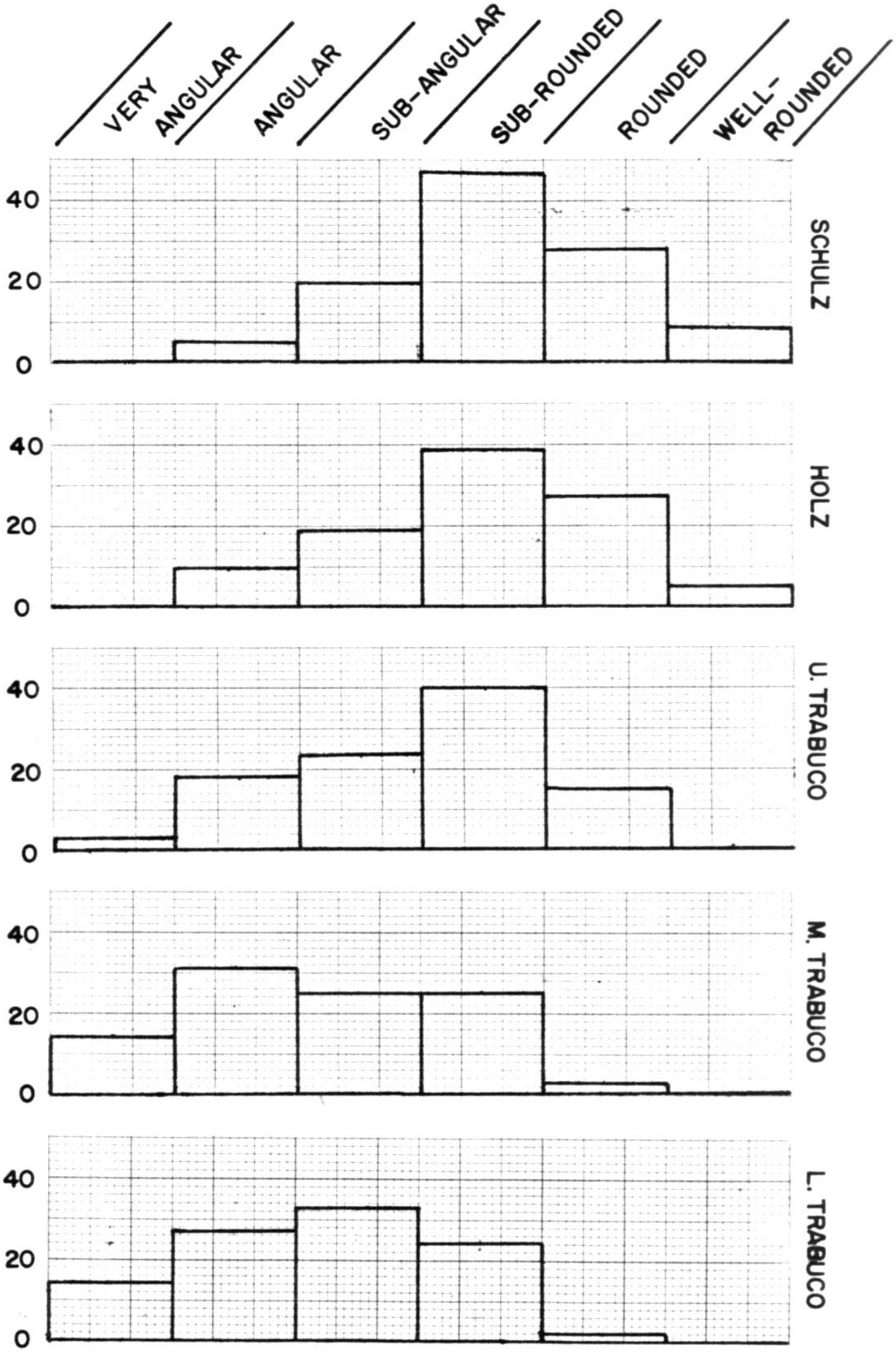


Figure 26. Results of the clast roundness study.

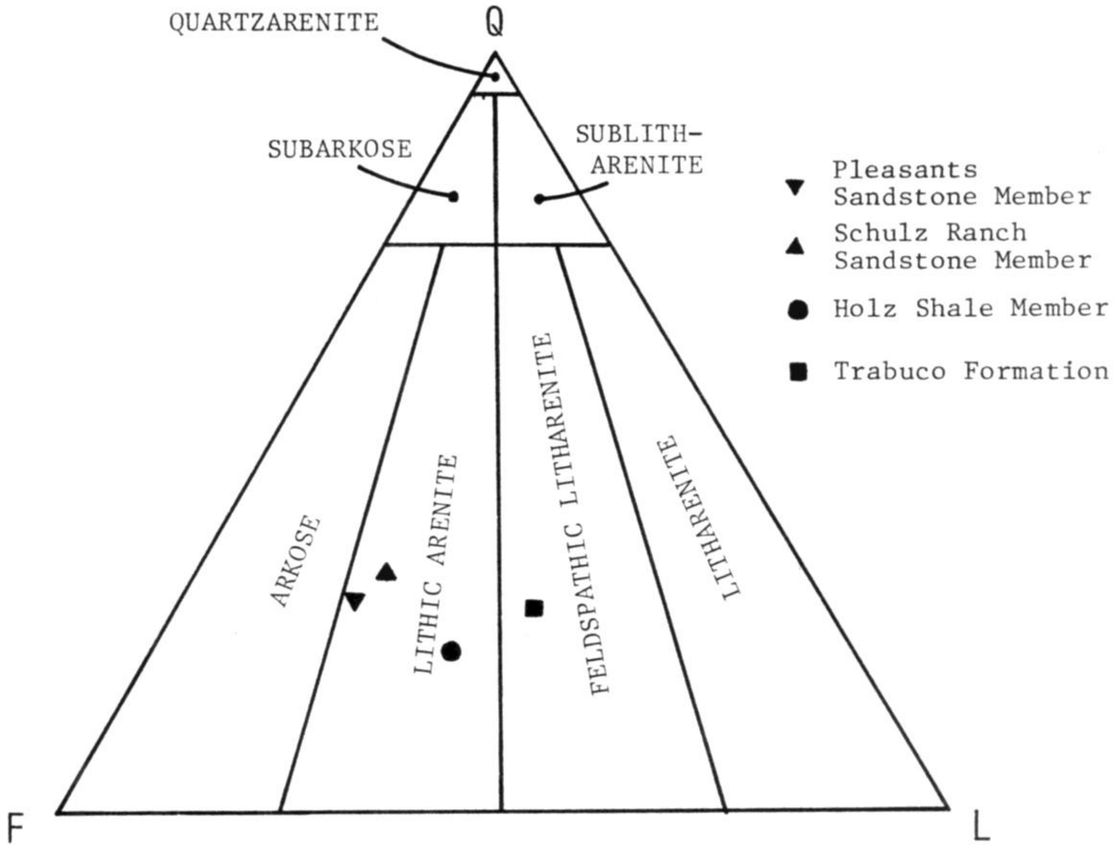


Figure 27. Compositions of Upper Cretaceous sandstone samples from Talega Canyon. Classification scheme is that of Folk (1980).

Table 1. Results of the petrographic analysis of Upper Cretaceous sandstone samples from Talega Canyon.

	essentials			Q	K	P	lithics			accessories				interstitial		
	quartz	feldspar	lithics	quartz	k spar	plag.	metased.	metavolc.	plut.	biotite	chlorite	zircon	opaque	matrix	pores	cement
Pleasants	28	53	19	16	30	1	~0	10	1	18	~0	0	0	14	8	2
Schulz	32	47	21	15	17	5	3	4	3	7	~0	~0	2	2	37	5
Holz	21	45	34	15	26	6	2	20	2	8	~0	0	1	7	11	2
Trabuco	27	33	44	20	20	4	4	20	5	2	~0	0	1	21	3	~0

from the Holz Shale, Schulz Ranch Sandstone, and Pleasants Sandstone Members are more like each other in terms of these characteristics than either of them are to sandstones from the Trabuco Formation.

Trabuco Formation. The sandstone sample from the Trabuco Formation at sample locality 3, is an iron-oxide-cemented, immature, biotitic, feldspathic litharenite. It has very little pore space compared to the other sandstones in the section, and has a very large percentage of matrix, which is in part silt and biotitic hash. A significant though unknown fraction of the matrix in this sample may be crushed rock fragments. Due to their fine-grained nature they can be very difficult to distinguish from matrix except when outlines are visible. Quartz may give straight or undulose extinction, and polycrystalline quartz is common. Feldspars are mostly orthoclase with lesser amounts of plagioclase and microcline; some are weathered, some are fresh. Subequant biotite grains appear somewhat weathered. Framework grains are generally angular.

Holz Shale Member. The sample from a sandy lens in the Holz Shale Member at sample locality 5, is a limonite-cemented, submature, biotitic, lithic arenite. Porosity is higher and matrix content significantly lower than in the Trabuco Formation sandstone. Quartz may give straight or undulose extinctions, and polycrystalline quartz is common. Feldspars are mostly orthoclase with lesser amounts of plagioclase and microcline; some are weathered, some are fresh. Subequant biotite grains are common and do not show a preferred orientation. Framework grains are generally angular. Some organic matter is visible in thin section.

Schulz Ranch Sandstone Member. The sample from the Schulz Ranch Sandstone Member at sample locality 7, is a limonite-cemented, submature, biotitic, lithic arenite. Porosity is high and matrix content is low. The quartz may give straight or undulose extinction, and polycrystalline quartz is common. Feldspars are mostly orthoclase with lesser amounts of plagioclase and microcline; some are weathered, some are fresh. Biotite flakes are somewhat elongate but show no preferred orientation. Framework grains are generally angular.

Pleasants Sandstone Member. The sample from the Pleasants Sandstone Member at sample locality 8, is a limonite-cemented, submature, biotitic, lithic arenite. Quartz may give straight or undulose extinction, and polycrystalline quartz is common. Feldspars are mostly orthoclase with lesser amounts of plagioclase and microcline; some are weathered, the majority appear fresh. Framework grains, as in the other sandstones, are generally angular. Elongate, fresh biotite flakes are noticeably abundant in this sandstone. They are commonly bent and molded around framework grains and show a preferred orientation. Some organic matter is visible in thin section.

Lithic fraction and provenance. The lithic fraction in these samples is comprised predominantly of low-grade metavolcanic rock fragments, with lesser amounts of metasedimentary and plutonic fragments. A few grains are composed of stretched, polycrystalline quartz, indicating a small contribution from a higher-grade metamorphic source. The indicated source for these sandstones is the immediately adjacent basement complex: argillites and schists in the Bedford Canyon Formation supplied the low- and high-grade metamorphic fragments, while the plutonic and metavolcanic fractions were supplied by the Peninsular Ranges batholith and Santiago Peak Volcanics, respectively.

Grain-size Analysis

The same samples used in the sandstone petrography were analyzed by seiving at half-phi intervals from -2 to +4 phi. The results are presented in Figs. 28 through 31. Figure 32 shows the probability cumulative curves which were obtained graphically (because of the "open tails") from cumulative percent curves (not shown). Visher (1969) attributes the two grain-size populations in such curves to two separate transport mechanisms. The coarser segments of the graphs represent saltation load whereas the finer segments represent suspension load.

Post-Cretaceous Units

Paleocene Oxisol

Small outcrops of a lateritic paleosol are found unconformably atop the Pleasants Sandstone Member in Talega Canyon. It has been placed in the Paleocene Silverado Formation by Sowma (1983) in her report on the clay deposits of this area. The paleosol is composed of gravelly, sandy clay, the sand consisting of coarse, poorly sorted

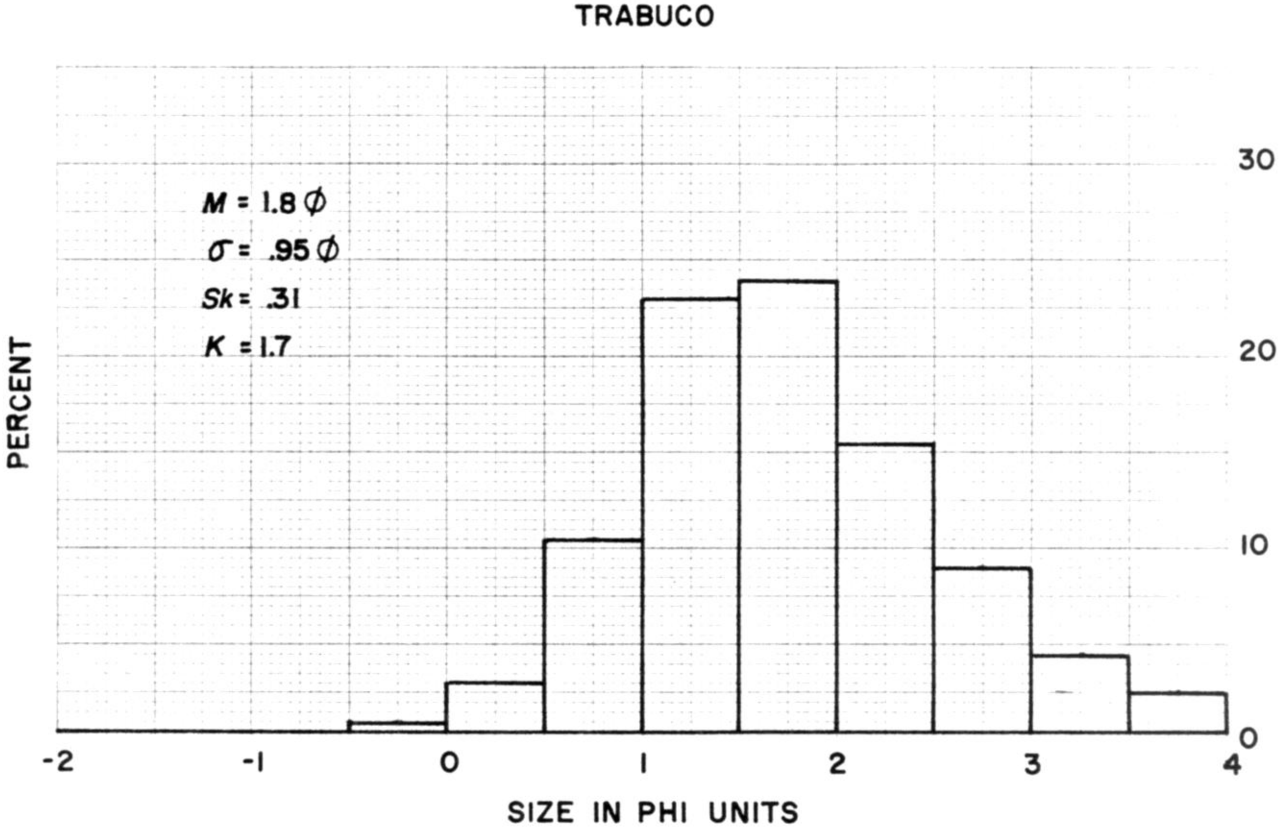


Figure 28. Results of the grain-size analysis of sandstone from sample locality 3 in the Trabuco Formation. This is a medium-grained, moderately sorted sandstone.

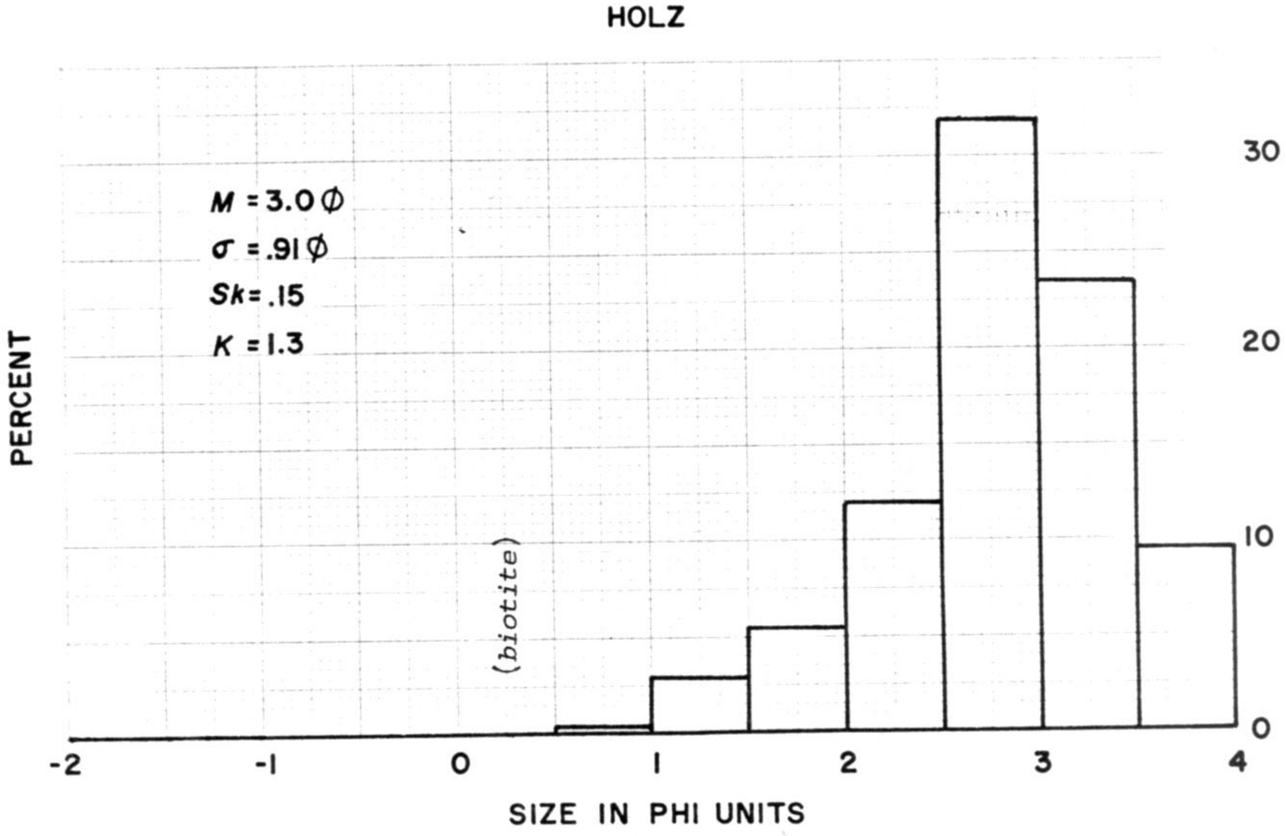


Figure 29. Results of the grain-size analysis of sandstone from sample locality 5 in the Holz Shale Member. High concentrations of biotite flakes are noted in the coarsest fraction. This is a fine-grained, moderately sorted sandstone.

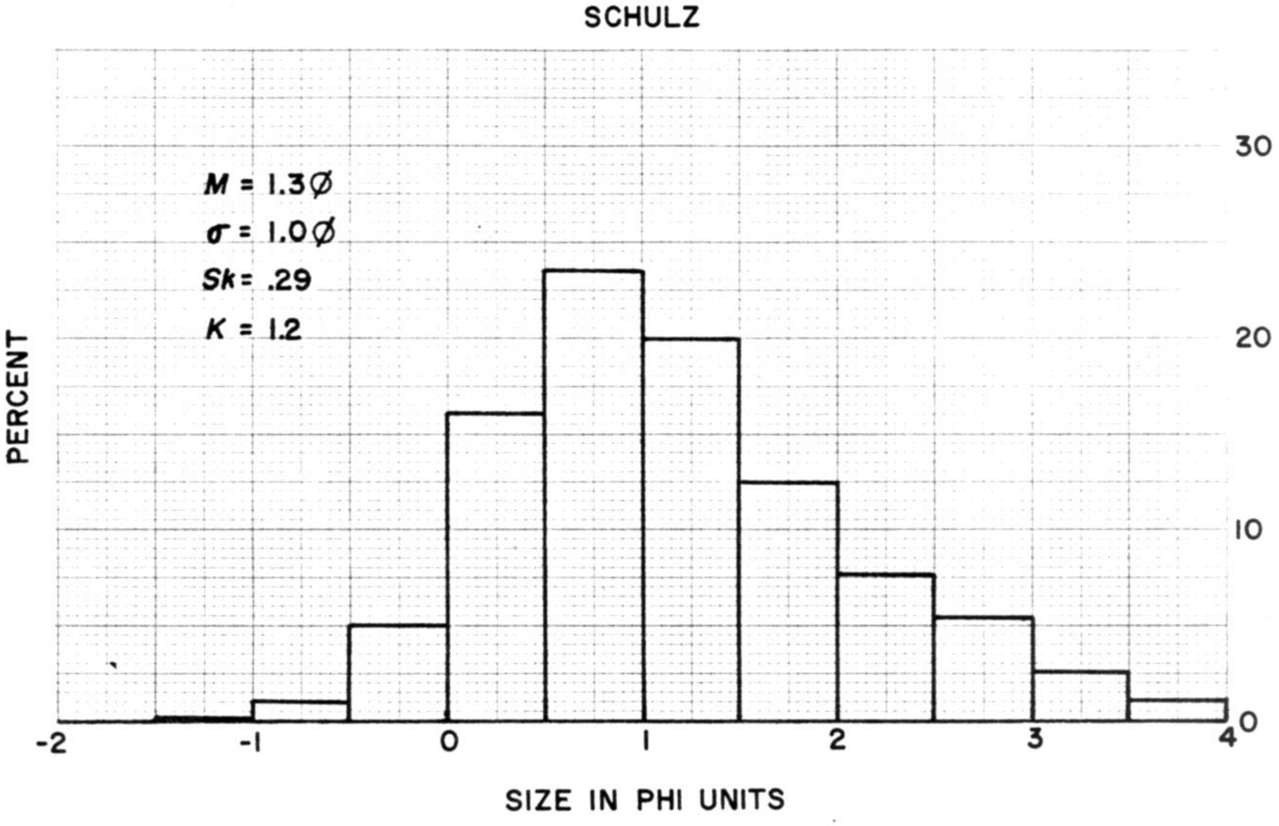


Figure 30. Results of the grain-size analysis of sandstone from sample locality 7 in the Schulz Ranch Sandstone Member. This is a coarse-grained, moderately/poorly sorted sandstone.

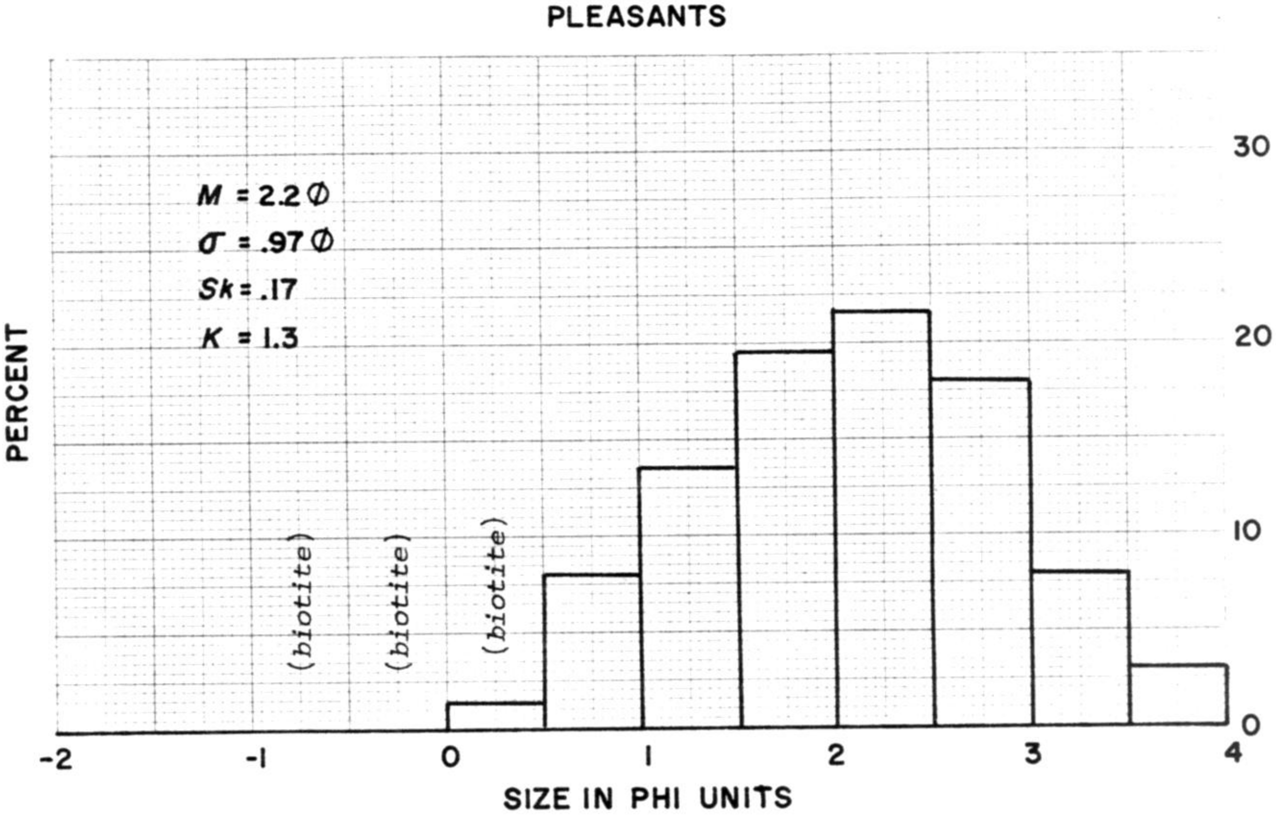


Figure 31. Results of the grain-size analysis of sandstone from sample locality 8 in the Pleasants Sandstone Member. High concentrations of biotite flakes are noted in the coarsest fractions. This is a fine-grained, moderately sorted sandstone.

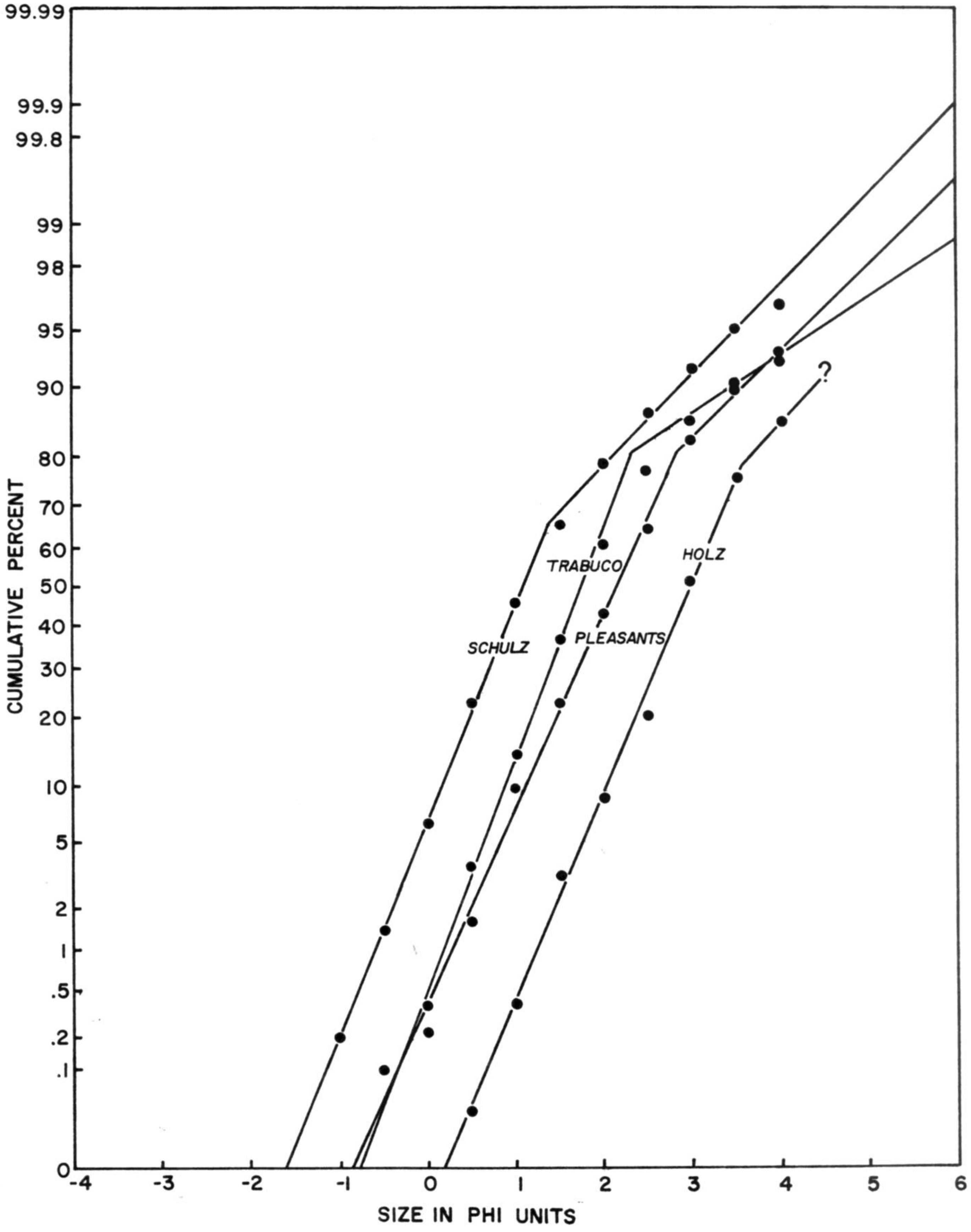


Figure 32. Probability cumulative curves for samples from the Upper Cretaceous section in Camp Pendleton. Note two grain-size populations in each sample.

angular quartz. The clay itself generally approaches kaolinite in composition with variable amounts of iron (Ball, 1961; Sowma, 1983). Where freshly exposed in prospects on the north side of Talega Canyon (Fig. 33), and at a landslide scarp on the south side of the canyon (Fig. 34), the clay horizon is distinctively bright purple, red, pink, and white.

The paleosol was exhumed in most places before Eocene time, such that remaining outcrops are few and discontinuous. The maximum thickness developed in the study area probably does not exceed 8 meters, though just northwest of the study area on Mission Ranch Viejo land, thicknesses of 20 meters have been noted (Sowma, 1983). These best-preserved and thickest sections, including the ones in Camp Pendleton, probably represent deposition in valleys in the Paleocene and latest Cretaceous topography (Sowma, 1983).

The paleosol is, more precisely, an oxisol formed by translocation of clay by intense leaching in a tropical environment. Oxisols of the same age have been found developed upon various rock formations throughout southern and Baja California, and have been used to make paleoclimatic interpretations for this period (see Peterson and Abbott, 1975). They also have significant economic importance (Chapter 6). The age of the oxisol is bracketed by the underlying Late Cretaceous and overlying Eocene units, and as such it has been assigned a Paleocene age (Peterson and Abbott, 1975).

Santiago Formation

The Eocene Santiago Formation lies with slight angular

Figure 33. Clay prospect in the paleosol on the north side of Talega Canyon.

Figure 34. Exposure of the paleosol developed on the Pleasants Sandstone Member at a landslide scarp on the south side of Talega Canyon.

unconformity upon the underlying Paleocene and Upper Cretaceous units. It is continuous in outcrop along the southeastern border of the study area, and is readily distinguished in the field from Upper Cretaceous sandstones by being bright white and by its cliff-forming tendencies (Fig. 35). It also, in some places where freshly exposed, develops almost a badlands topography, along with a knobby appearance from concretion-like masses.

It consists of fine- to coarse-grained, massive and cross-bedded sandstone, interbedded with thin (a few centimeters) to thick (approximately 2 meters) intervals of massive or thinly laminated mudstone. Sandstones may contain pebbles and small mudstone intraclasts, and the sand grains are characteristically angular and moderately well-sorted. Also present are rare, discontinuous, thin (a few centimeters), brownish peaty seams.

The Sangiago Formation beds described here are probably equivalent to the lowest of three lithofacies mapped by Craig (1984) and Furu (1982) in areas in the southern part of Camp Pendleton. The inferred depositional environment is one of sandy tidal flats, possibly transitional to estuarine fluvial facies and subtidal sand bars (Craig, 1984; Furu, 1982). The age is middle Eocene (Craig, 1984; Furu, 1982).

Older Alluvium

Terraced stream deposits occur at lower elevations in the study area. They are composed of rust-colored, bouldery conglomerate (Fig. 35), and in many respects closely resemble the Trabuco Formation, but are generally not more than a few meters thick. These deposits underlie the distinctively subdued topographic surfaces (Fig. 36), which reflect a geomorphic equilibrium established before base level changes placed them above the current level of stream activity. Their weathered appearance and association with the major trunk streams indicate that they are fluvial in origin. Several different levels can be discerned. In the future it might prove interesting to correlate these with the marine terraces in Camp Pendleton.

Figure 35. The Santiago Formation, capped by older alluvium, in San Mateo Canyon. Cliff is approximately 10 m high.

Figure 36. Older erosion surface in Talega Canyon. Note clay prospects and T.R.W. facility.

CHAPTER 3

LATE CRETACEOUS DEPOSITIONAL ENVIRONMENTS

Historical Overview

The depositional environments of the Upper Cretaceous exposure belt in the Santa Ana Mountains have generated considerable controversy during the last decade. Most of the discussion has centered on the Holz Shale Member of the Ladd Formation. Depositional models concerning this unit can be divided into two schools of thought.

Adherents of the "bathyal model" conclude that the middle (specifically) of the Holz Shale Member was deposited below wave base in an outer shelf to slope setting (Almgren, 1973, 1982; Lee, 1979; Blake and Colburn, 1982; Link and Bottjer, 1982; Buck, 1983). Others have argued that the entire Holz Shale Member was deposited in a shallow marine, possibly restricted estuarine environment (Stevenson, 1948; Wheeler, 1952; Orr, 1964; Morton, 1972; Lang, 1976, 1978; Sundberg, 1980; Sundberg and Cooper, 1978, 1982; Saul, 1982). Some have modified their views: Sundberg (1982) states that the Holz Shale Member varied between bathyal and neritic depths, and Cooper (pers. comm., 1984) has expressed less attraction to the neritic interpretation of the unit. The controversy clearly has not yet been resolved.

Paleoenvironmental interpretations for the remainder of the Upper Cretaceous sequence historically have encountered greater agreement. The Trabuco Formation generally has been labelled non-marine. The first writer to address this issue was Moore (1930), who concluded that the Trabuco Formation is marine and distinct from the Baker Canyon Conglomerate Member of the Ladd Formation because it, and not the Baker, was altered by iron-bearing meteoric waters. Moore's idea, however, was discredited by Popenoe (1941), and the Trabuco Formation is now invariably considered to be an alluvial-fan conglomerate. The Baker Canyon Conglomerate Member (not present in Camp Pendleton) represents shoreface reworking of coarse clastic sediments dumped at the end of fan-delta lobes (Roth, 1958; Morton, 1972; Sundberg and Cooper, 1978; Saul, 1982; Blake and Colburn, 1982; Bottjer and others, 1982; Cooper and others, 1982; Sundberg, 1982). The Schulz Ranch Sandstone Member of the Williams Formation was produced by interaction between fluvial and nearshore influences, in much the same way as the Baker Canyon Conglomerate Member (Sundberg and Cooper, 1978; Bottjer and others, 1982; Cooper and others, 1982; Saul, 1982). The Pleasants Sandstone Member of the Williams Formation is interpreted as having been deposited in an open-marine, shallow shelf setting (Sundberg and Cooper, 1978).

Paleoenvironmental interpretations for the post-Trabuco units diverge concerning events at the Ladd-Williams boundary. When the units were originally set up, the Ladd and Williams Formations were both subdivided into a coarse-grained lower and fine-grained upper member, suggesting to most workers a repetition of sedimentary environments. Some workers place a disconformity between the two formations (Popenoe, 1941, 1942; Stevenson, 1948, strat. column; Roth, 1958; Morton, 1972). Others propose a gradual shoaling of the basin towards the end of "Holz time", based largely on paleontologic bathymetry (Sundberg, 1982; Saul, 1982; Almgren, pers. comm., 1984). Either way, two transgressive sequences, one after the other, are implied. Alternately, in the highly detailed model of Sundberg and Cooper (1978), no major event separates the Holz Shale and Schulz Ranch Sandstone Members: the spits and peninsulas recorded in the Schulz Ranch Sandstone Member were contemporaneous with the Holz Shale Member, and thus helped create the restricted circulation conditions necessary for deposition of the Holz mudstones.

The Sequence in the Northern Corner of Camp Pendleton

Preface

The interpretation proposed herein for the Upper Cretaceous sequence in Camp Pendleton is most closely allied with the Sundberg and Cooper (1978) model. In the proposed model (Fig. 37) the Trabuco Formation was deposited by alluvial fans which toed directly into a marine setting. The Holz Shale Member represents marginal marine embayments. The Schulz Ranch Sandstone Member records a complex interaction between fluvial and nearshore processes on a fan-delta fringe, which helped produce quiet-water conditions for the Holz embayments. The Pleasants Sandstone Member is comprised of turbidites and other rhythmically bedded sandstones which were deposited below wave base on a delta front. The main theme in this depositional system is one of large amounts of extremely coarse clastic sediments being transported down steep slopes directly into a marine environment. The main contributions of this study lie in

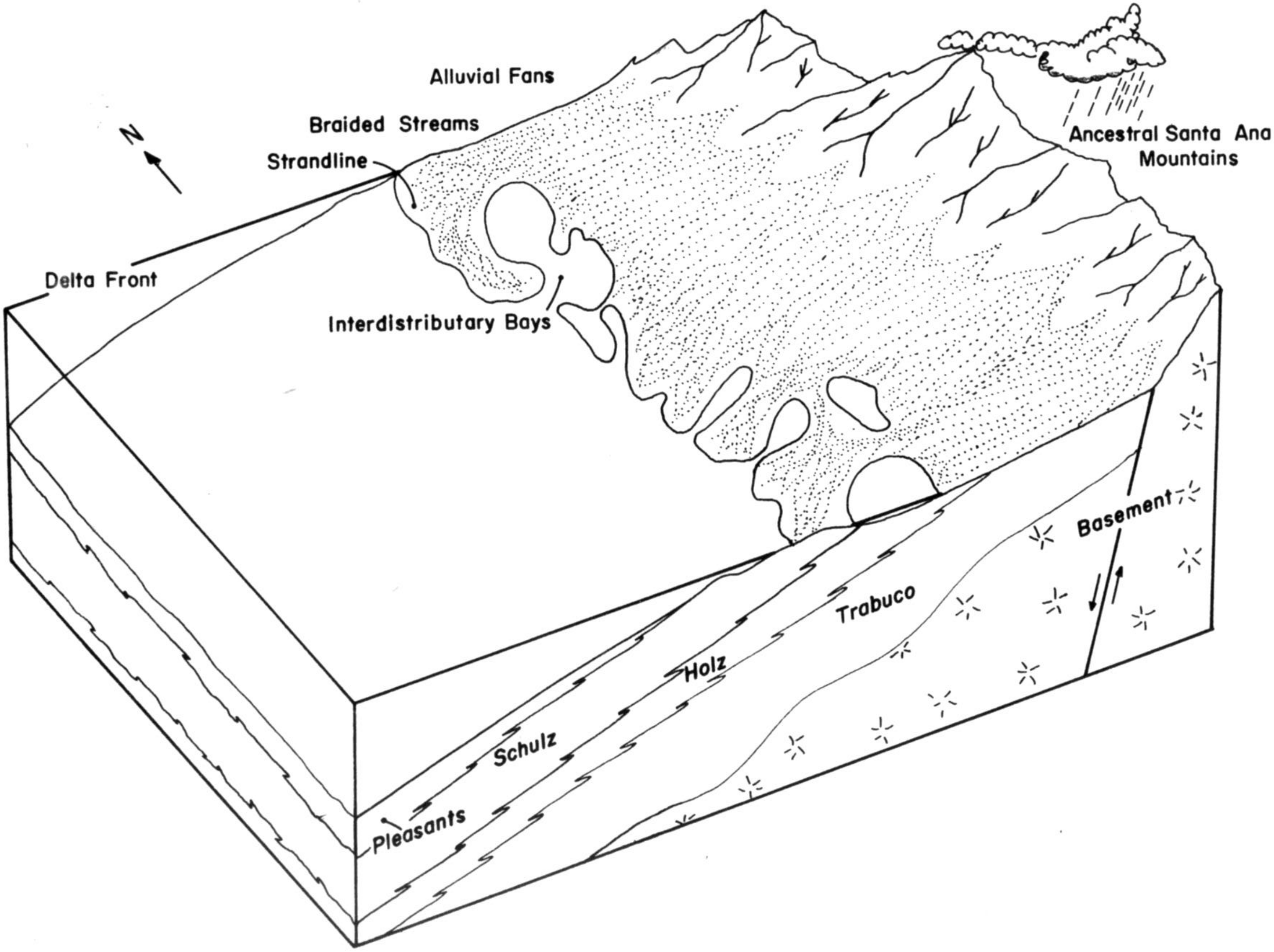


Figure 37. Block diagram illustrating the fan-delta model for the Talega Canyon Upper Cretaceous section.

the recognition of turbidites in the Pleasants Sandstone Member, and in the proposed tectonic setting which was responsible for producing a thick, transgressive, largely marginal-marine sequence.

Several problems arise in the paleoenvironmental study of the Upper Cretaceous section. None of the classic depositional models in the geologic literature fit the section. No completely satisfactory modern analogs are known, and no examples from the rock record match the proposed model (see, however, McGowen, 1970, and Flores, 1975). Wescott and Ethridge (1980) argue that many ancient fan deltas have been overlooked or have received only cursory mention. Few truly diagnostic indicators are encountered in the Camp Pendleton section, and several aberrations are noted. In addition, the interpretations are hampered by the limited number of outcrops available, which represent only a few percent of the total land area in the study area. Nevertheless, the proposed fan-delta model appears to be well-supported by a suite of sedimentary criteria, and by their observed stratigraphic relations.

Trabuco Formation

The Trabuco Formation within the study area, in agreement with interpretations for the unit in other places, exhibits many characteristics of a fanglomerate. The large size and poor rounding of the clasts, lack of bedding, and support by a muddy, sandy matrix, evince deposition by debris flows (see Fig. 38) on a steep slope. Lack of fossils, reddish coloration, and decomposition and spheroidal weathering of many clasts after deposition, indicate non-marine

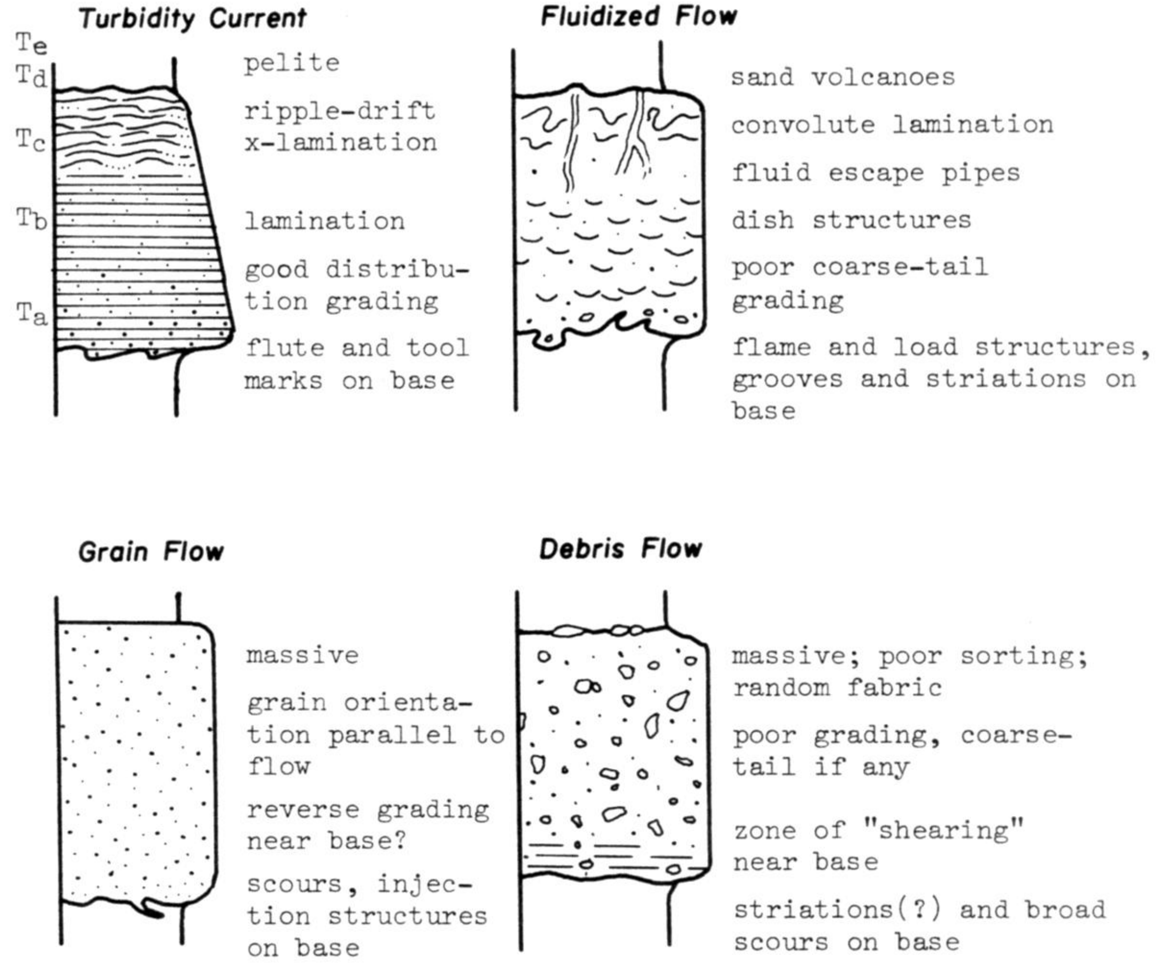


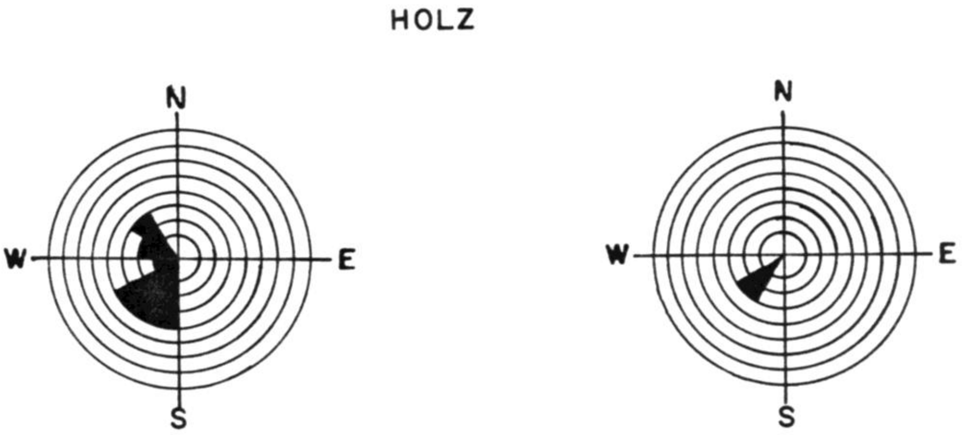
Figure 38. Comparison between idealized associations of sedimentary structures produced by the four main end-member types of mass flow mechanisms. Debris-flow deposits occur in the Trabuco Formation and Holz Shale and Schulz Ranch Sandstone Members. Turbidites occur in the Pleasants Sandstone Member. After Middleton and Hampton (1973).

conditions. Hence, the Trabuco Formation clearly represents an apron of coalescing alluvial fans deposited at the base of the ancestral Santa Ana Mountains by short, ephemeral streams.

Holz Shale Member

The Holz Shale Member in Camp Pendleton shows evidence of having been deposited close to shore in a predominantly low-energy, subaqueous setting. The unit's stratigraphic position between the high-energy fluvio-foreshore Schulz Ranch Sandstone Member and the non-marine Trabuco Formation, along with a high concentration of plant fragments, place the inferred paleoenvironment of the Holz Shale Member close to shore. Large leaf impressions and abundant mudstone both indicate low-energy conditions. The unit contains no unequivocal marine or non-marine indicators--it is barren of body fossils in Camp Pendleton. However, a gross similarity between the abundance of plant fragments and brownish-black blobs in the Holz Shale Member and their abundance in the marine Schulz Ranch Sandstone and Pleasants Sandstone Members, along with a complete lack of such features in the non-marine Trabuco Formation, suggest that similar geochemical conditions prevailed in the three post-Trabuco paleoenvironments. In addition, bioturbation is probably present in the Holz Shale Member. Hence, a marine setting for the unit is probably indicated.

The inferred depositional environment, therefore, is one of a protected embayment or embayments, perhaps in the form of interdistributary bays between fan-delta lobes. Braided streams periodically injected large quantities of coarse clastic sediments into this environment, as indicated by the disorganized conglomerates and steeply cross-bedded sandstones and conglomerates. Paleocurrents in these streams were predominantly toward the southwest (Fig. 39A). If the sediments in this setting were reworked by marine currents, evidence has largely been obliterated by bioturbation. The principle inconsistencies in this interpretation are the lack of fossils, which ought to be abundant in such an environment, and the rarity of tidal current features. The latter could be explained by bioturbation, yet such effective bioturbation arguably should have left behind some other evidence of animal life. A slope paleoenvironment for the middle of the Holz Shale Member in the northern Santa Ana Mountains has been argued by several workers (Almgren, 1973, 1982; Lee, 1979; Blake and Colburn, 1982; Link and Bottjer, 1982; Buck, 1983), based on microfaunal assemblages and turbidite-filled channels incised into Holz mudstones (the Mustang Springs conglomerate lens). Such a conclusions is not warranted for the Holz Shale Member in Camp Pendleton. Slope sediments tend to show indications of slumping, which are lacking in Holz mudstones in the study area. Some coarse sediments interbedded with the Holz Shale Member in the study area could have been deposited by sediment gravity flows, but current-produced features in the sandstones are far too abundant to have been produced in submarine canyons. In addition, the southward coarsening and eventual wedging out of the unit is likely the result of increasing proximity to a fan-delta lobe.



A) 14 MEASUREMENTS

LARGE-SCALE CROSS-STRATIFICATION

B) 3 MEASUREMENTS

SMALL-SCALE CROSS-STRATIFICATION

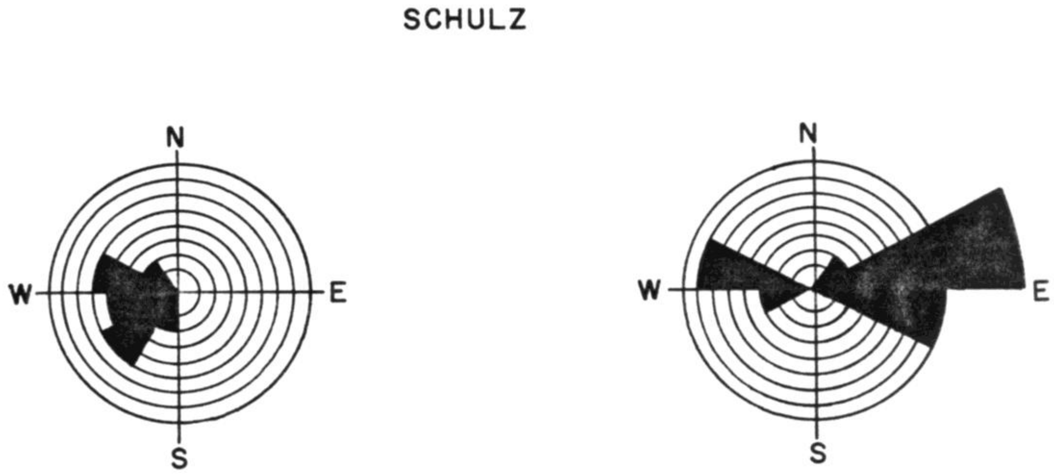
Figure 39. Paleocurrent directions in the Holz Shale Member. Two different processes may be responsible for producing different patterns (see Fig. 40).

Schulz Ranch Sandstone Member

The Schulz Ranch Sandstone Member records the complex interplay between well-developed fluvial processes and a more poorly represented foreshore environment. In only one outcrop of the unit was the foreshore facies well-developed, although this may be a function of poor exposure quality in the study area.

Disorganized, extremely coarse clastic sediments in the conglomeratic lithofacies, and large mudstone rip-ups, indicate deposition by large events of considerable energy. Steeply cross-bedded and crudely imbricated conglomerates suggest foresets produced by bar migration. These features evince deposition by heavily-laden braided streams. The steep, large-scale foresets observed in pebbly sandstones are also best explained in terms of a fluvial setting, and are evocative of Gilbert-type delta foresets. It is conceivable that some of these sediments were debouched into standing water. Paleocurrent indicators in the steeply cross-bedded sandstones and conglomerates are unimodal and to the west and southwest (Fig. 40A).

Intervals characterized by ripple cross-lamination and low-angle planar and hummocky cross-lamination are associated with Ophiomorpha burrows, indicating a marine origin for these beds of the Schulz Ranch Sandstone Member. The sedimentary structures, good sorting, and bipolar paleocurrents (Fig. 40B) all point toward a nearshore marine environment. Their close association with fluvial deposits, along with a lack of shelf mud, support this interpretation. (Ophiomorpha are not used as a diagnostic indicator of a neritic environment in this discussion. Although they may be more abundant



A) 18 MEASUREMENTS

LARGE-SCALE CROSS-STRATIFICATION

B) 33 MEASUREMENTS

SMALL-SCALE CROSS-STRATIFICATION

Figure 40. Paleocurrent directions in the Schulz Ranch Sandstone Member. Results were separated into two groups since two different processes appear to be responsible for producing two different patterns.

in the neritic zone (Frey and others, 1978), they have also been found in deep-water submarine fan deposits (Kern and Warme, 1974), and appear to occur more as a function of substrate and current energy than depth (Frey and others, 1978).) The Schulz Ranch Sandstone Member is devoid of body fossils in Camp Pendleton, which is somewhat peculiar for a high-energy foreshore deposit. Sundberg and Cooper (1978), however, report finding a sparse, low-diversity, high-energy molluscan assemblage in the unit in Silverado Canyon.

Pleasants Sandstone Member

The sedimentology of the Pleasants Sandstone Member supports a deeper-water interpretation. Rhythmically bedded and laterally extensive sandstones and mudstones show many characteristics of turbidites (see Fig. 38), and can be described adequately by the Bouma (1962) sequence in some instances. Ophiomorpha, plant fragments, and mudstone chips are also present, but these are indicative of neither deep nor shallow water. However, bedding planes are parallel, and the tops of beds show no evidence of being reworked by wave- or tide-induced currents. Hummocky cross-bedding is absent, and bioturbation is not indicated.

The inferred paleoenvironment for this unit, therefore, is a low-energy setting below wave base. The generating mechanisms for these turbidites and other rhythmically bedded sandstones were probably storm surges originating close to shore, and/or exceptionally high runoff on the alluvial fans. The resulting clouds of sediment would have moved down the subaqueous delta and deposited sand in a normally low-energy environment. Reineck and Singh (1972) found that such deposits indicate water depths of 15 to 40 meters. Slumped sediments and mudstone rip-up flaps (Fig. 24) in the Pleasants Sandstone Member suggest a slope of some sort, hence the inferred delta-front setting. An intra-shelf basin or outer shelf setting cannot be ruled out completely, however.

Sundberg and Cooper (1978) envision a shallow-shelf setting for the unit, based on macrofaunal assemblages and sedimentary textures. No previous work has been published on the sedimentary structures in the Pleasants Sandstone Member. The sedimentary structures of this unit in the north should be studied in relation to the paleontologic data to determine if shallow-water fossils could have been transported into relatively deep water by the processes described above.

The Sequence in its Entirity

The paleoenvironmental interpretations for the four Upper Cretaceous units are assembled to provide additional support for the fan-delta model. Contacts between the units appear to be gradational and conformable. Fluvial deposits of the Trabuco Formation, Holz Shale Member, and Schulz Ranch Sandstone Member all show a high degree of similarity to one another. This similarity demonstrates that similar fluvial processes were operating in all three units, albeit in different proportions to other processes. Moreover, the clast-roundness study also suggests that the three units were laterally contiguous, with sediments being transported progressively further from their source as they moved through the paleoenvironments of the Trabuco Formation, Holz Shale Member, and Schulz Ranch Sandstone Member. Hence, Walther's Law (Walther, 1894) is applicable, and the four Upper Cretaceous units were laterally contiguous in the manner shown in Fig. 37. In addition, rapid facies changes, such as the southward coarsening and pinching out of the Holz Shale Member, are commonly observed in marginal marine strata.

Alternate Model--A Submarine Fan

Since much of the Upper Cretaceous System in California is made up of submarine fan deposits, and turbidites have been reported within the Holz Shale Member in the northern Santa Ana Mountains (Blake and Colburn, 1982; Link and Bottjer, 1982; Cooper and others, 1982; Buck, 1983), a submarine-fan model for the Upper Cretaceous sequence in Camp Pendleton was also considered (Fig. 41). In this model, the Schulz Ranch Sandstone and Pleasants Sandstone Members would represent proximal and distal areas, respectively, of a submarine fan built at the base of a submarine slope, represented by the Holz Shale Member. An overall transgression would explain the Trabuco-Holz-Schulz-Pleasants succession. The Pleasants turbidites obviously would fit in well with such a model. The disorganized conglomerates in the Holz Shale and Schulz Ranch Sandstone Members could be explained in terms of debris flows of the type discussed by Lewis (1976) and Embley (1976), operating in inner submarine fans. The model would neatly explain what became of the sediments which were transported downslope within channels of the middle Holz Shale Member in the northern Santa Ana Mountains. This problem has perplexed

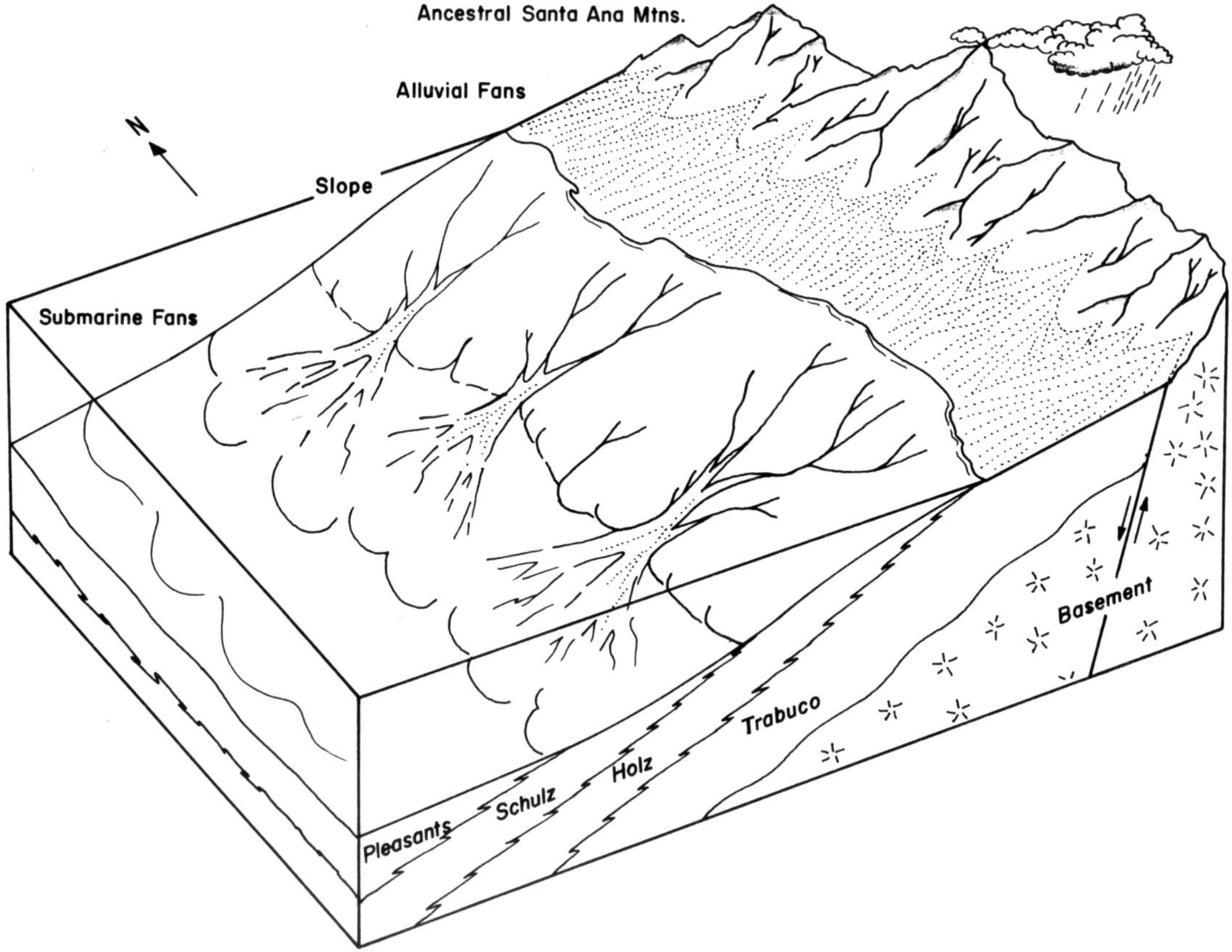


Figure 41. A submarine-fan model for the Talega Canyon Upper Cretaceous section. Rejected in favor of the fan-delta model of Fig. 37.

those workers who infer a slope paleoenvironment for the middle Holz Shale Member there (e.g. see Buck, 1983). Shallow-water body fossils, abundant in the northern Santa Ana Mountains section, would have simply been transported into deeper water by the same processes moving sediments down-slope.

However, cross-stratification in sandstones and conglomerates in the Holz Shale and Schulz Ranch Sandstone Members are far too abundant to have been produced in a submarine fan system. Bioturbation and large leaf impressions also argue against a deep-water setting. Until and unless these shortcomings can be remedied, the fan-delta model should be favored over a submarine-fan model.

Coastal Paleogeography

The shallow-marine facies is uncommon compared to the fluvial and delta-front facies, hence a fluvial-dominated, lobate delta which toed directly into relatively deep water is inferred. Steep slopes both on the alluvial fan and on the submarine delta front are also inferred, based on the characteristics of the Trabuco Formation and Pleasants Sandstone Member. A fan delta in Jamaica studied by Wescott and Ethridge (1980) toes directly onto a relatively steep submarine slope (Fig. 42). This fan delta is indeed fan-shaped and lacks well-developed foreshore deposits along much of its fringe. As such, it may provide a modern analog for the Trabuco-Schulz-Pleasants succession (southern part of the study area). Wedging out of the Holz Shale Member in the southern portion of the study area suggests the complete absence of the protected embayment paleoenvironment in favor

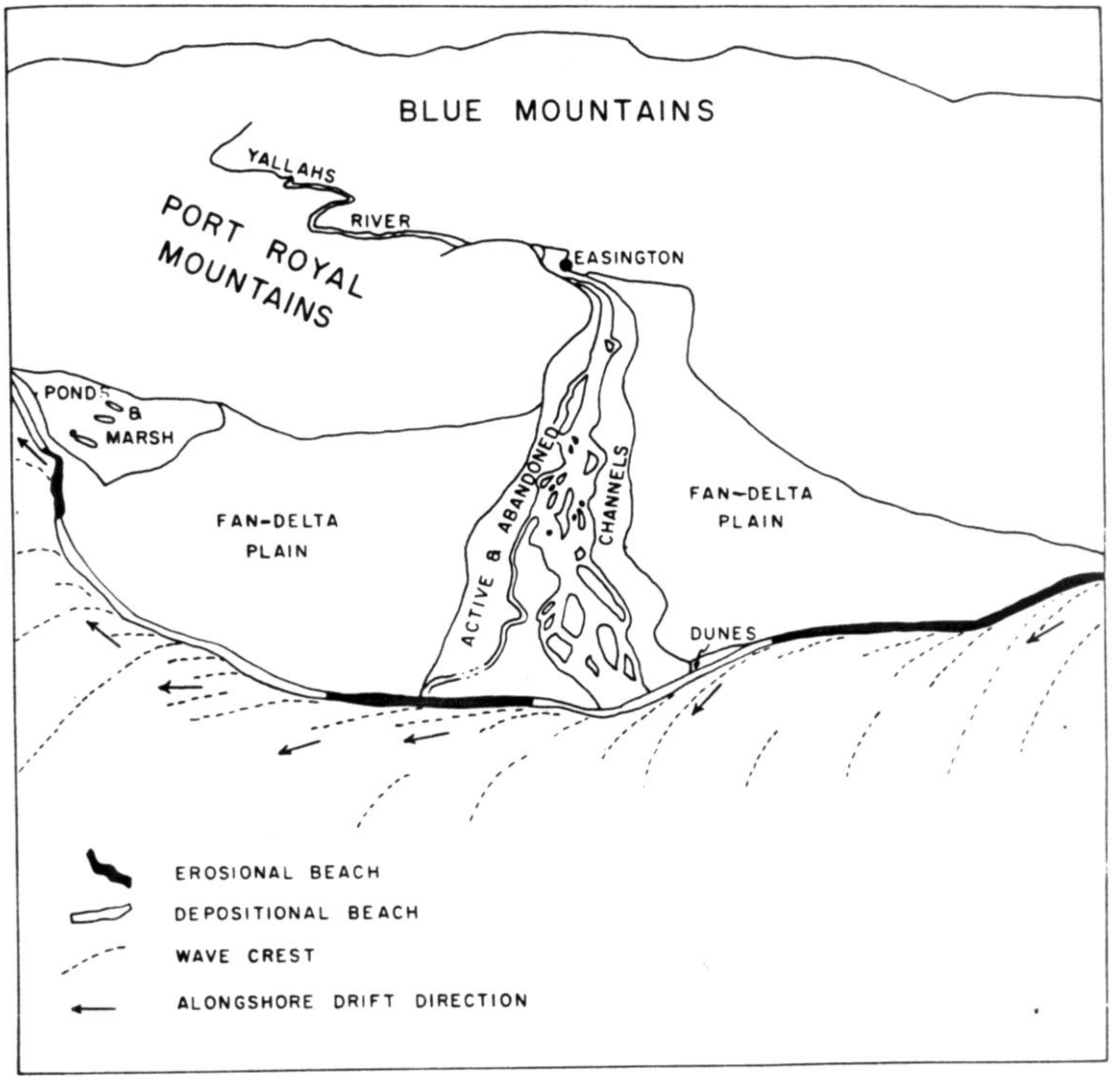


Figure 42. The Yallahs fan delta in Jamaica. From Wescott and Ethridge (1980).

of a particularly well-developed fluvial paleoenvironment in that region.

Angiosperm leaf impressions and abundant plant fragments demonstrate that the landward areas supported lush, rain-forest-type vegetation (Jeff Myers, pers. comm., 1985).

Greater amounts of marginal- and shallow-marine sediments in the Camp Pendleton section compared to the Upper Cretaceous southern San Diego County section, may indicate that such areas were more extensive in the Camp Pendleton district than in the southern district during Late Cretaceous time.

Tectonic Setting

Coarseness of sediments and the thickness of the Upper Cretaceous section imply that relatively large amounts of material were being shed off the basement terrane during Late Cretaceous time. This might be expected to produce a regressive sequence, yet the opposite is seen. Rapid downfaulting of the sedimentary basin is suggested to account for transgression. A large contribution by a plutonic and metamorphic source was discovered in the Upper Cretaceous sediments during the sandstone and conglomerate-clast analyses. The eastern source terrane must therefore have been lifted high above sea level during Late Cretaceous time. This event is reflected in the sandstone petrography (Fig. 43; see also Fig. 44). Moreover, we know that alluvial fans tend to form in basins that are being rapidly downfaulted. The Trabuco Formation is such a deposit which, along with its equivalents, is present for hundreds of kilometers along strike.

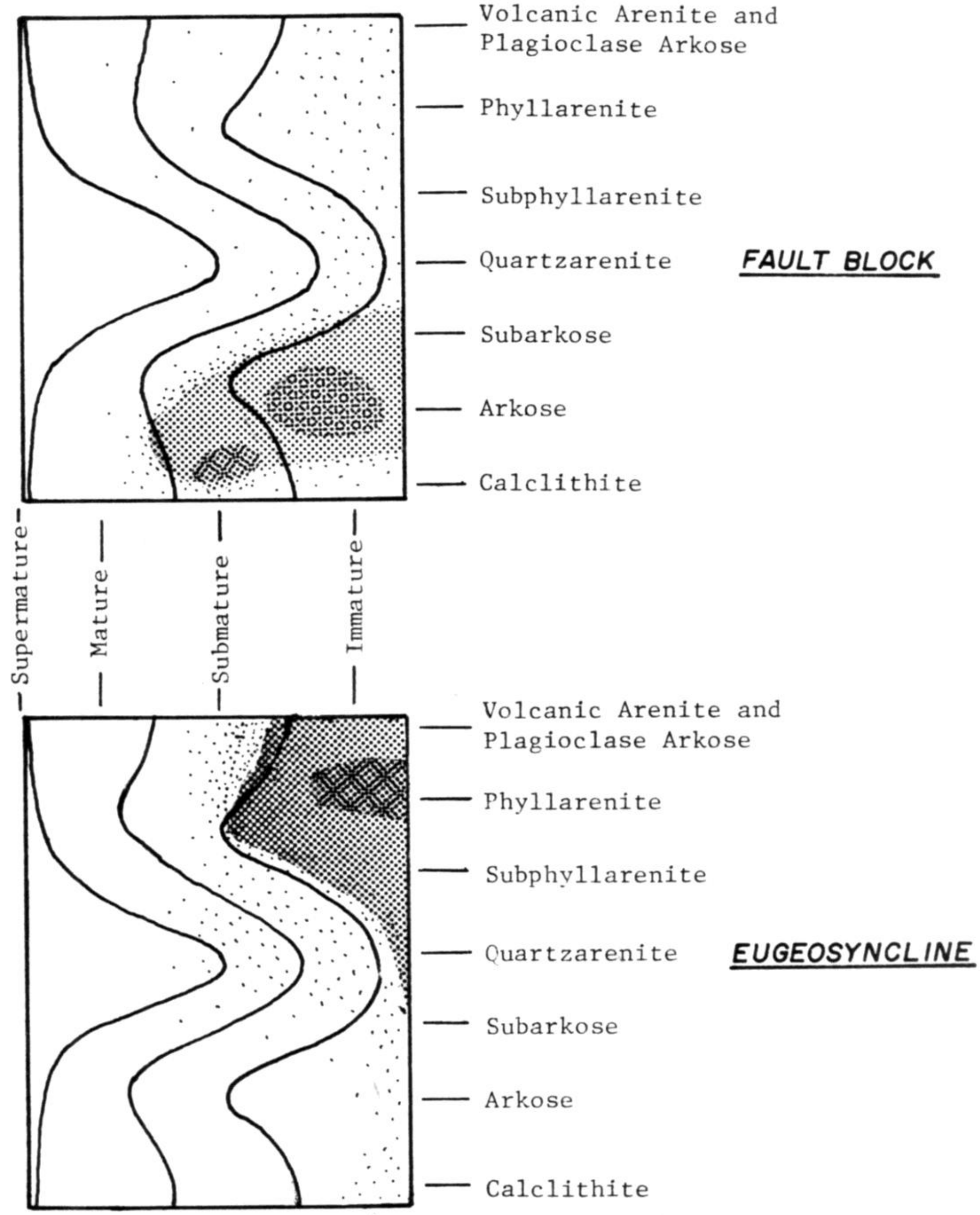


Figure 43. Relative abundance of sandstone maturity/rock-clan combinations in two tectonic environments, as depicted by shading (after Folk, 1980). Sandstones from the study area are immature to submature lithic arenites and feldspathic litharenites. The above illustrations suggest that these sandstones record an overprinting of eugeosynclinal and fault-block tectonics.

Gastil and Allison (1966) first suggested some kind of fault control for the Late Cretaceous southern California and northern Baja California coast, based on the fact that the eastern edge of the Upper Cretaceous outcrops can be plotted with a ruler. Gastil (pers. comm., 1985) confirmed that the normal faulting as shown in Fig. 37 is consistent with his ideas on coastline paleotectonics.

Two potential problems are inherent in this proposal, however. 1) Major normal faulting of the type described above appears in none of the models for island-arc subductions zones (see following section). 2) A transgressive sequence in Camp Pendleton may be inconsistent with the Upper Cretaceous marine section in southern San Diego County, the Point Loma and Cabrillo Formation, which display overall regression (Nilsen and Abbott, 1979, 1981; Fig. 45).

Differential amounts of subsidence versus sedimentation between the two districts could account for the difference. Such a variation in tectonic movement may also be recorded in the Silverado Canyon section. Several workers believe they see a rapid deepening of the basin in the middle of "Holz time" there, followed by rapid shallowing near the Holz-Schulz transition (Sundberg, 1982; Almgren, pers. comm., 1984). Perhaps the sedimentary trough(s) hinged in a manner to allow different types of sequences to be preserved in the three areas, the northern Santa Ana Mountains, Camp Pendleton, and southern San Diego County. Gary Girty (pers. comm., 1985) suggests that this region may have been in the midst of a broad band of strike-slip deformation, in much the same way as southern California is now. Pull-apart basins would thereby be downdropped, perhaps at differing rates. Obviously, the foregoing paragraph is mostly speculation.

Thus, the proposed normal faulting is important to the fan-delta model for the Upper Cretaceous section, but evidence for it is circumstancial.

Plate-tectonic Setting

The plate-tectonic setting for the Upper Cretaceous sediments is that of a forearc basin. The Santiago Peak Volcanics and Peninsular Ranges batholith represent a magmatic arc which shed the Late Cretaceous detritus in a westerly direction; the trench lay some unknown distance to the west. Immature, coarse, and poorly organized sediments, and the lack of a well-developed shelf facies are consistent with this. In addition, the sandstone petrography is indicative of a magmatic arc setting (Fig. 44; see also Fig. 43). Strata of the same age to the north (the Great Valley Sequence) and to the south (the Rosario Group) are also interpreted as having been deposited in such a tectonic setting and with an eastern source area (Nilsen and Abbott, 1979, 1981).

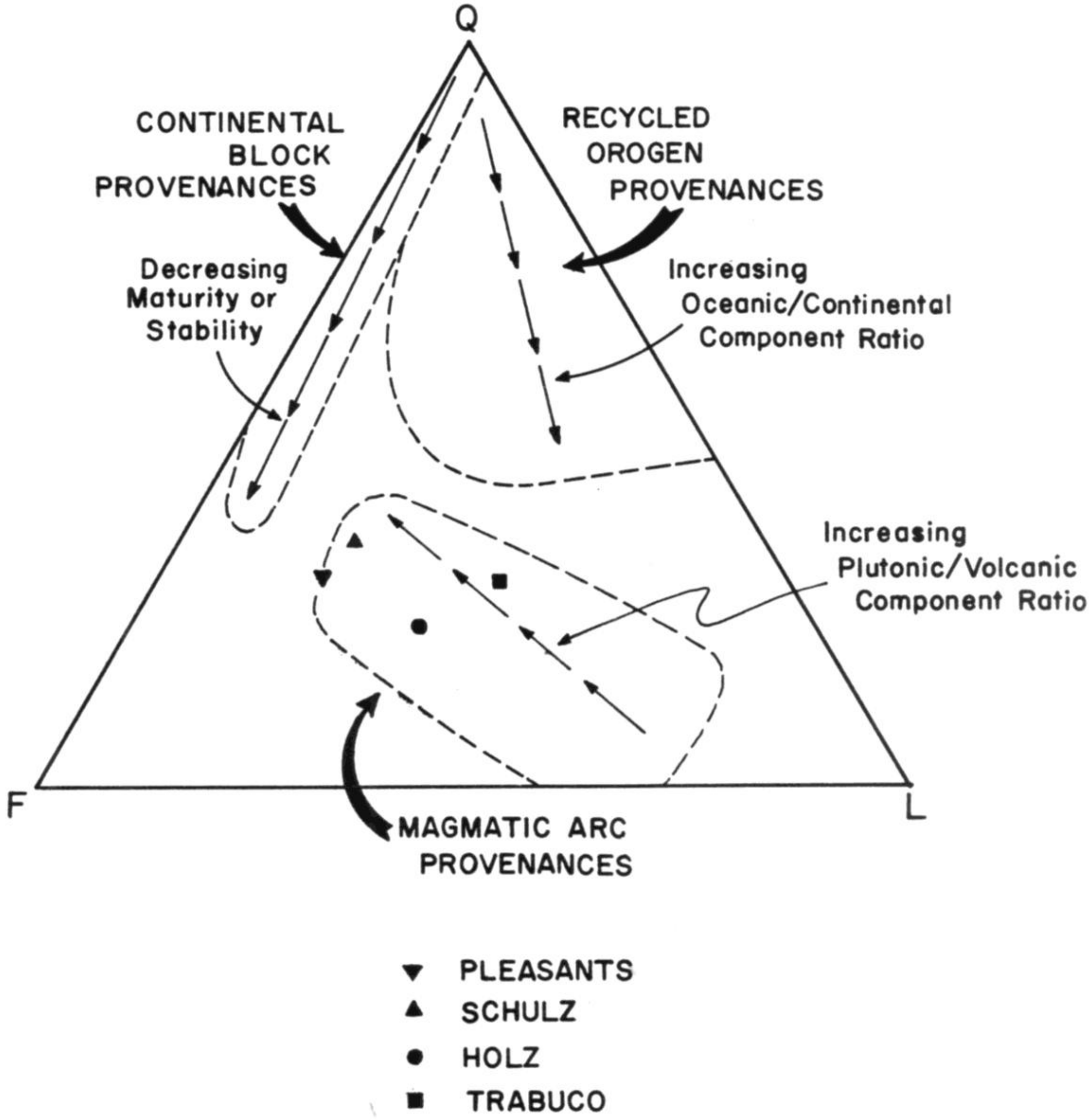


Figure 44. Sandstone sample compositions from Talega Canyon, plotted on the ternary diagram of Dickinson and Suczek (1979).

CHAPTER 4

CORRELATION WITH THE ROSARIO GROUP

The Upper Cretaceous sequence in the Santa Ana Mountains and Camp Pendleton appears to be partly correlative with that in southern San Diego County. The Trabuco Formation probably correlates with the Lusardi Formation, as suggested by Nordstrom (1970) and Kennedy and Moore (1971). The Lusardi Formation, however, contains much larger clasts than the Trabuco Formation, has different percentages of rock types, may be slightly younger in age, and exposures of the two are separated by large distances (Nordstrom, 1970). Nevertheless, inasmuch as the two formations are of nearly the same age and reflect nearly identical depositional conditions, they could be considered equivalent. Correlation of the Lusardi Formation with "an unnamed fanglomerate near the base of the Williams Formation" in San Juan Canyon (Kennedy and Moore, 1971, p. 73), is less certain.

No lithologic correlation is attempted herein between the Ladd and Williams Formations, and the Upper Cretaceous marine sequence in southern San Diego County, the Point Loma and Cabrillo Formations. Important differences exist between the two districts. Most notably, the Point Loma and Cabrillo Formations are younger, Campanian and Maastrichtian in age, display overall progradation, may be floored by an unconformity, and were deposited by submarine fans (Nilsen and Abbott, 1979, 1981; Fig. 45). This makes it difficult to pick out lithologic equivalents or draw tie-lines between the two sections.

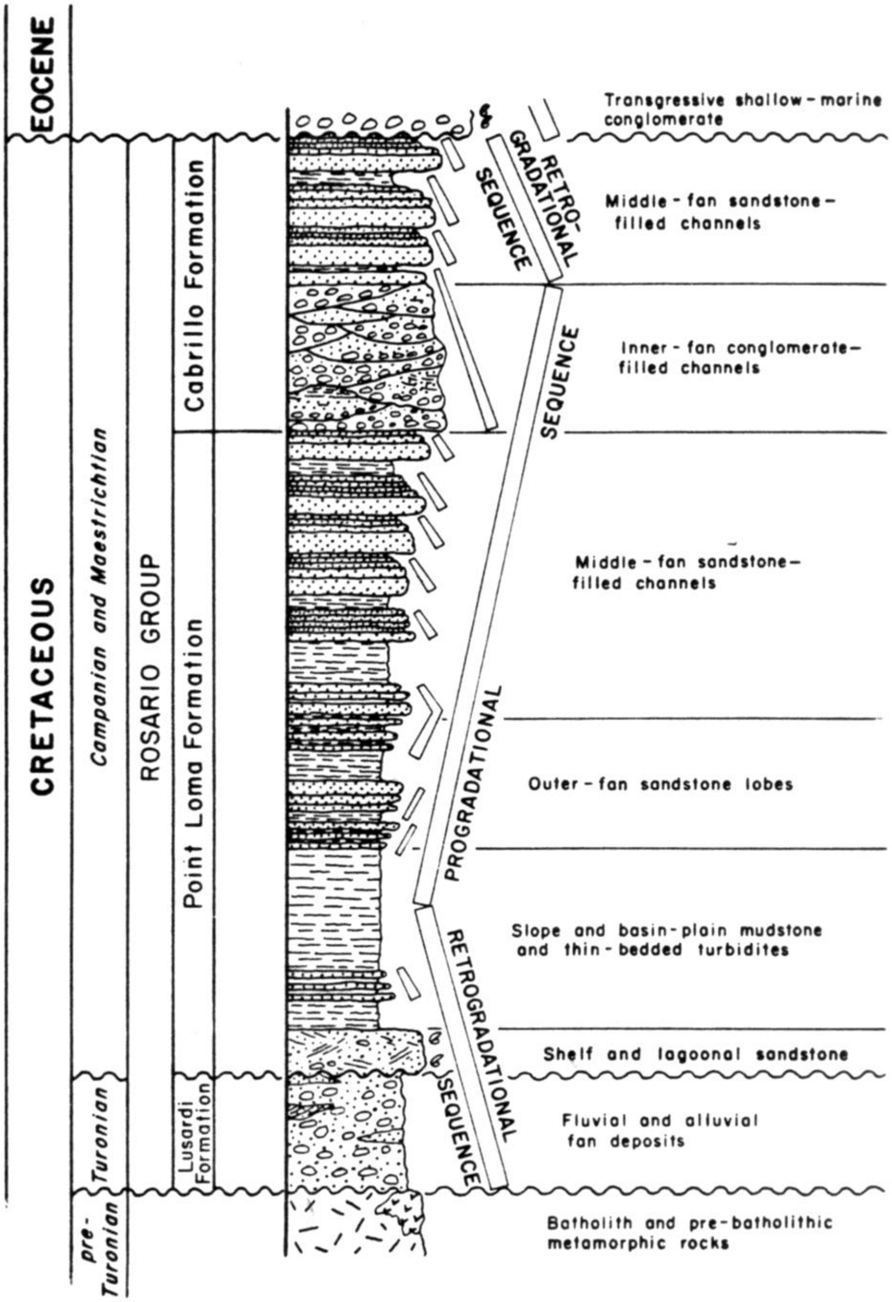


Figure 45. Composite stratigraphic column of the Rosario Group in the San Diego area, showing pro- and retrogradational cycles and paleoenvironmental interpretations. From Nilsen and Abbott (1982).

The small Upper Cretaceous exposures at Carlsbad and Olivenhain show affinity to the southern section (Zlotnik, 1981). Hence the switch in nomenclature between Carlsbad and Camp Pendleton, as has been customary in most of the literature, seems justified.

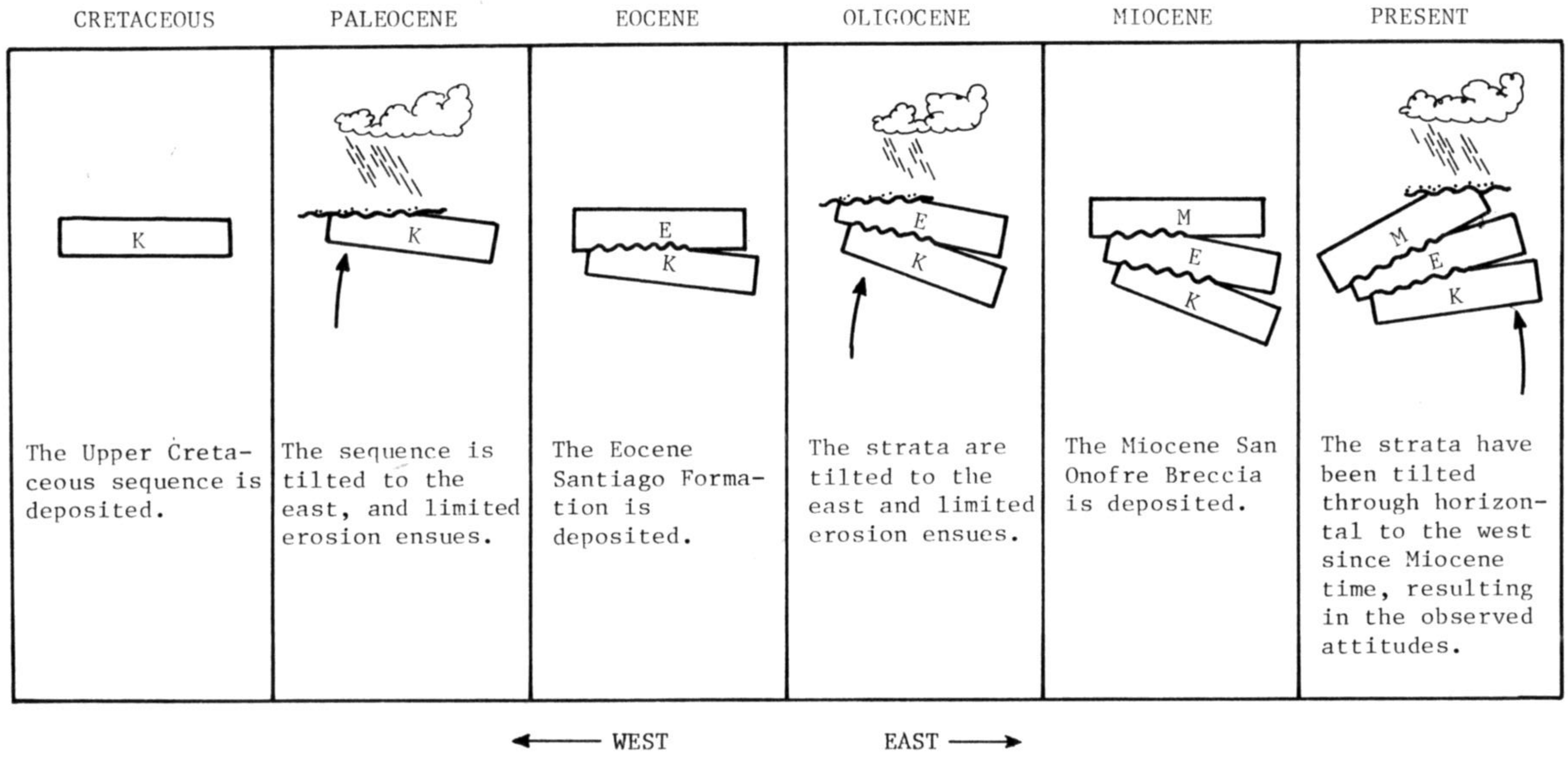
CHAPTER 5

STRUCTURE

Structural geology in the northern corner of Camp Pendleton is relatively simple considering that areas of complex faulting and folding are present both to the east along the San Andreas Fault system, and offshore in the California borderlands. Tectonically, the study area has remained isolated from most types of major deformation since inception of post-batholithic deposition. The resulting structural style is that of a seaward-dipping homocline (attitudes averaging around N40°W, 10°SW) with relatively little faulting, and no discernable folding.

A significant though unknown component of that dip is due to tilting. Attitudes of Upper Cretaceous and Eocene beds in the study area, and of the San Onofre Breccia in central Camp Pendleton (Moyle, 1973), along with unconformable relationships between those rock units, show that easterly and westerly tilting have both occurred since the Late Cretaceous Epoch (Fig. 46; Camilleri, pers. comm., 1984). Any perceived similarities between present-day dips and inferred depositional dips in the Upper Cretaceous strata, are therefore only fortuitous. No explanation is offered herein for the proposed tilting.

Some extensional(?) faulting has been discovered within the study area. The most significant feature is a NW-SE-trending fault paralleling the southwest boundary of the study area (Plate I). A



The Upper Cretaceous sequence is deposited.

The sequence is tilted to the east, and limited erosion ensues.

The Eocene Santiago Formation is deposited.

The strata are tilted to the east and limited erosion ensues.

The Miocene San Onofre Breccia is deposited.

The strata have been tilted through horizontal to the west since Miocene time, resulting in the observed attitudes.

Figure 46. Diagram illustrating how the Upper Cretaceous and Eocene strata were tilted to the east before being tilted to the west sometime after Miocene time, as inferred from present-day attitudes and unconformable relationships. Original dips, as would be inferred from transport directions, are neglected, but would enhance the effects depicted above. Cross sections are drawn looking north. Data on the San Onofre Breccia (not present in the study area) is from Woodford (1925), Moyle (1973), and Stuart (1975). From a concept by P. Camilleri.

2-meter-thick, well-indurated sandstone near the base of, but within, the Santiago Formation is offset by this fault in the San Mateo Canyon area (Fig. 47). The sense of displacement here is NE-down, SW-up. Near the T.R.W. facility in Talega Canyon, the fault is suspected of being responsible for a bench-like feature. Sowma (1983) shows what may be the same fault continuing into her area north of here, striking in the same direction but with a sense of displacement opposite to that seen in San Mateo Canyon, namely NE-up, SW-down. Hence the fault may scissor, or may represent one of several anastomosing strands. It also may be related to relatively large-scale faulting in Firing Range 214 (Fig. 48) which also strikes in a northwesterly direction. Air photos and field investigation reveal no other recent perturbations in the topography, and because of the paucity of outcrops, no other unequivocal offsets in the stratigraphy can be found. In all, the sandstone marker bed suggests some kind of large-scale vertical offset which may connect with other similar offsets, but those connections are speculative. The possibility of such extensive faulting may warrant further investigation because of the area's proximity to the nuclear generating facility at San Onofre, located a few kilometers from the fault trace, just below the lower margin of Plate I.

A normal(?) fault is located on the extreme eastern side of the study area. This fault can be observed on a roadcut near the head of Jardine Canyon. The fault plane trends approximately N10°E, 40°W. A 20-centimeter-thick brecciated gouge zone can be observed, and vertical displacement can be bracketed at a minimum of 6 meters.

Figure 47. A sandstone marker bed (arrows) near the base of the Santiago Formation, offset by a fault in San Mateo Canyon.

Figure 48. A fault in Firing Range 214 which may be related to the large fault in the study area. Fault trends N59°W, dips 67°SW, and contains an 8-centimeter-thick clayey gouge zone. Cretaceous rocks at left are juxtaposed against the Santiago Formation at right, indicating a NE-up SW-down, 8-meters-plus offset. Striations indicate a purely dip-slip motion.

Although the fault could not be observed elsewhere, owing to the amount of offset it probably extends further than is indicated on Plate I.

A few other minor normal(?) faults exist in Talega Canyon (for example see Fig. 49). These faults are observable along roadcuts or streamcuts and generally show vertical offsets of under 1 meter. Work by San Diego State University undergraduates immediately south of the study area, where outcrops and faults are more numerous, suggests that there probably are many other small faults in the study area which cannot be located owing to lack of good outcrops, and homogeneity of much of the geology. Another possible fault of unknown offset or sense of displacement is located in the northeastern portion of the study area. This fault is inferred from the alignment of White Oak Springs, and from a faint lineament which is visible in the field and in air photos.

Figure 49. A small horst near sample locality 8.

CHAPTER 6

ECONOMIC GEOLOGY

Petroleum and clay are the two principal mineral commodities present in the area. Neither have been developed within the boundaries of Camp Pendleton, but clay and minor quantities of oil have been produced in areas directly north and west of the study area. Since they concern units present in the study area, they deserve some discussion.

Production of oil in this area represents the southernmost productive area in California, and the producing zones occur within the Schulz Ranch Sandstone Member. The two producing fields, now abandoned, are the San Clemente and Christianitos fields, situated in southern Orange County (Fig. 50). Shell Oil Company initiated activity in the area by drilling the first hole in the San Clemente field in 1952 (Ball, 1961). Two producing wells were drilled there by Texaco in 1954 (Fig. 50), one producing oil at a rate of 14 barrels per day, and the other at 3 b/d. The field produced a total of 1425 barrels of oil before abandonment in 1955 (Goodban, 1958). The Christianitos Creek field was discovered in 1954 (Ball, 1961). Its sole producer, drilled by Humble Oil in 1959(?), pumped at the rate of 52 b/d, and produced 3079 barrels of oil before abandonment in 1960 (Colburn and Tucker, 1973). In both the San Clemente and Christianitos Creek fields the oil occurs in sporadic, thin sandstones within the upper half of the Schulz Ranch Sandstone Member. The

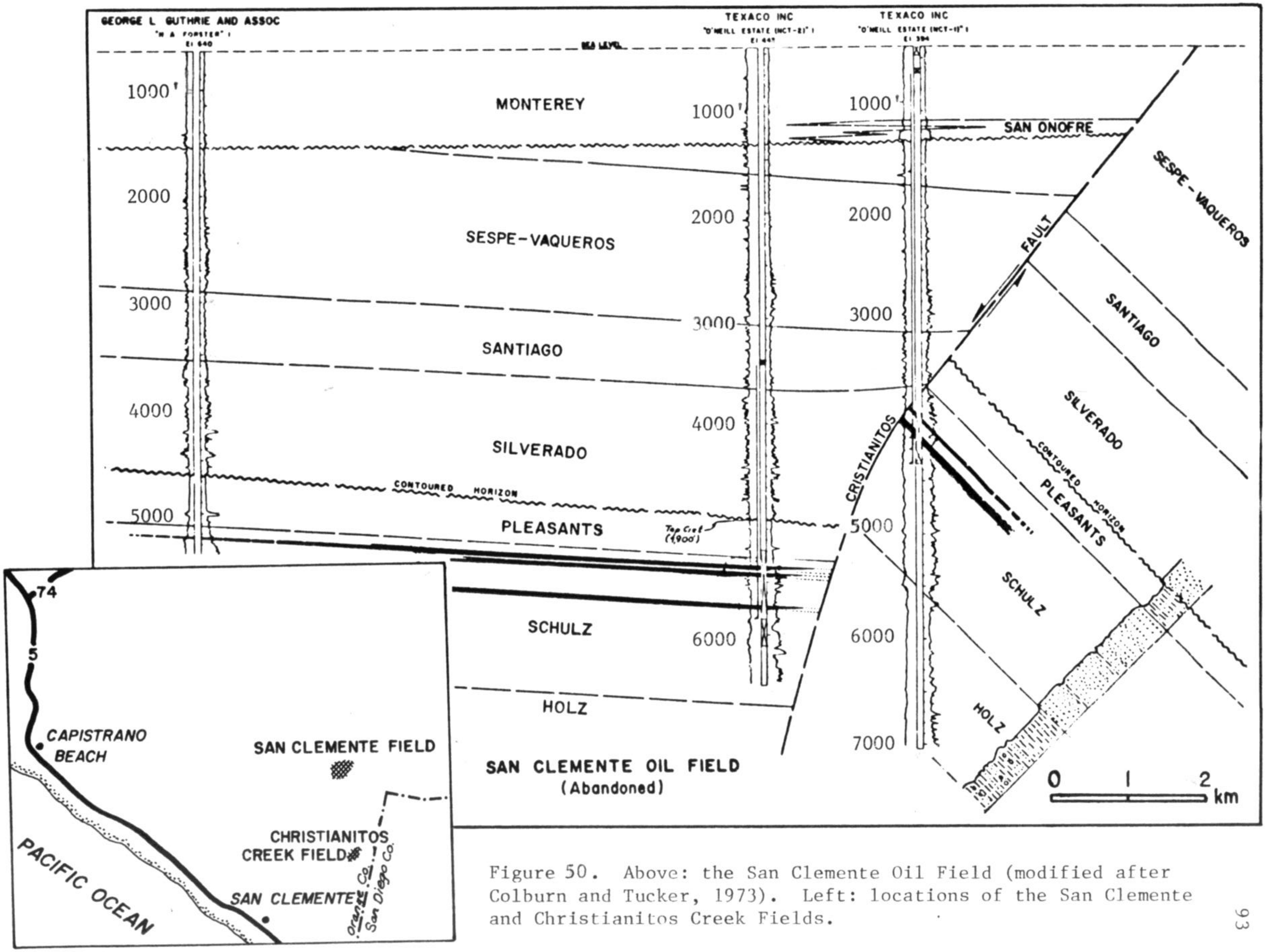


Figure 50. Above: the San Clemente Oil Field (modified after Colburn and Tucker, 1973). Left: locations of the San Clemente and Christianitos Creek Fields.

limiting factor of production in these fields was primarily the low permeabilities and porosities of the sandstones, resulting from calcite cementation (Colburn and Tucker, 1973). Colburn and Tucker (1973) feel that this might be an attractive area for future exploration, owing to the high-gravity oil and lack of urban development.

Clay is mined from the Paleocene paleosol throughout Orange and San Diego Counties. Ball (1961) and Sowma (1983) provide excellent descriptions of the geology and mining aspects of these deposits for the area directly north of Talega Canyon, otherwise known as Rancho Mission Viejo. Clay is mined from several pits in that area to be used in the production of fire brick (Ball, 1961). Within the study area itself but just north of Camp Pendleton's boundary in Talega Canyon near the T.R.W. facility, small prospects appear to have been dug in subeconomic outcrops of the clay (Figs. 33 and 36). An outcrop created by a landslide scarp on the south side of Talega Canyon (Fig. 34) has also been explored for economic potential, according to Weber (1963). Other outcrops of clay can be found on Camp Pendleton, but none are known to have been worked.

Gravel pits exist on the marine base; two can be seen on Plate I in San Mateo Canyon west of the study area. In addition, the stream gravels in the larger canyons including Talega, San Mateo, and Jardine, were tapped for groundwater to supply cattle watering troughs when the land was used for ranching prior to its conversion to a military base in 1942. However, domesticated cattle no longer roam the base, and the wells and windmills have fallen into disrepair.

CHAPTER 7

CONCLUSIONS

Though the Upper Cretaceous sequence in Camp Pendleton is closely related to the Upper Cretaceous Santa Ana Mountains sequence, differences do exist. These include absence in Camp Pendleton of body fossils and of the Baker Canyon Conglomerate Member, along with the southward coarsening and ultimate disappearance of the Holz Shale Member. In addition, turbidites have been recognized in the Pleasants Sandstone Member. Nevertheless, far greater differences exist between the Upper Cretaceous Camp Pendleton and San Diego County sequences, and as a result, the Camp Pendleton section cannot be considered as transitional between the Upper Cretaceous Orange County and San Diego County sections. These north-south facies changes and stratigraphic discontinuities may have been one result of major Late Cretaceous normal faulting paralleling the coast, which is proposed in this report.

Clasts in the Upper Cretaceous conglomerates were all derived from adjacent basement complex units. The sandstones underscore this relationship, and display characteristics typical of immature forearc basin sediments. Paleocurrents are bipolar (east-west) in marine sandstones, and unipolar (west to southwest) in fluvial sandstones and conglomerates. No unconformities were discovered in the Upper Cretaceous section, contradicting Stevenson's (1948) findings. This provides one of the more important pieces of evidence supporting a transgressive fan-delta model for these rocks, very similar to Sundberg and Cooper's (1978) model, which has, in part, encountered some disfavor by those working on the northern Santa Ana Mountains section. The Upper Cretaceous section is unfossiliferous, aside from plant fragments, common *Ophiomorpha*, and large leaf impressions. The discovery of angiosperm leaf impressions in the Holz Shale Member in Camp Pendleton constitutes the only known occurrence of such fossils in this unit, and represents a rare find in rocks of Cretaceous age in California. It also shows that the land areas supported lush, rain-forest-type vegetation (Jeff Myers, pers. comm., 1985).

Positive evidence has been found for a fault which was previously mapped with some uncertainty by Moyle (1973). This fault may be related to tectonic features present to the south in Firing Range 214, and with a fault mapped by Sowma (1983) to the north. As such, it may warrant further investigation as a potential hazard to the San Onofre Nuclear Generating Facility.

It is my hope that the conclusions presented herein will stimulate further research, especially with regard to the depositional environments of the Upper Cretaceous exposure belt in Orange County.

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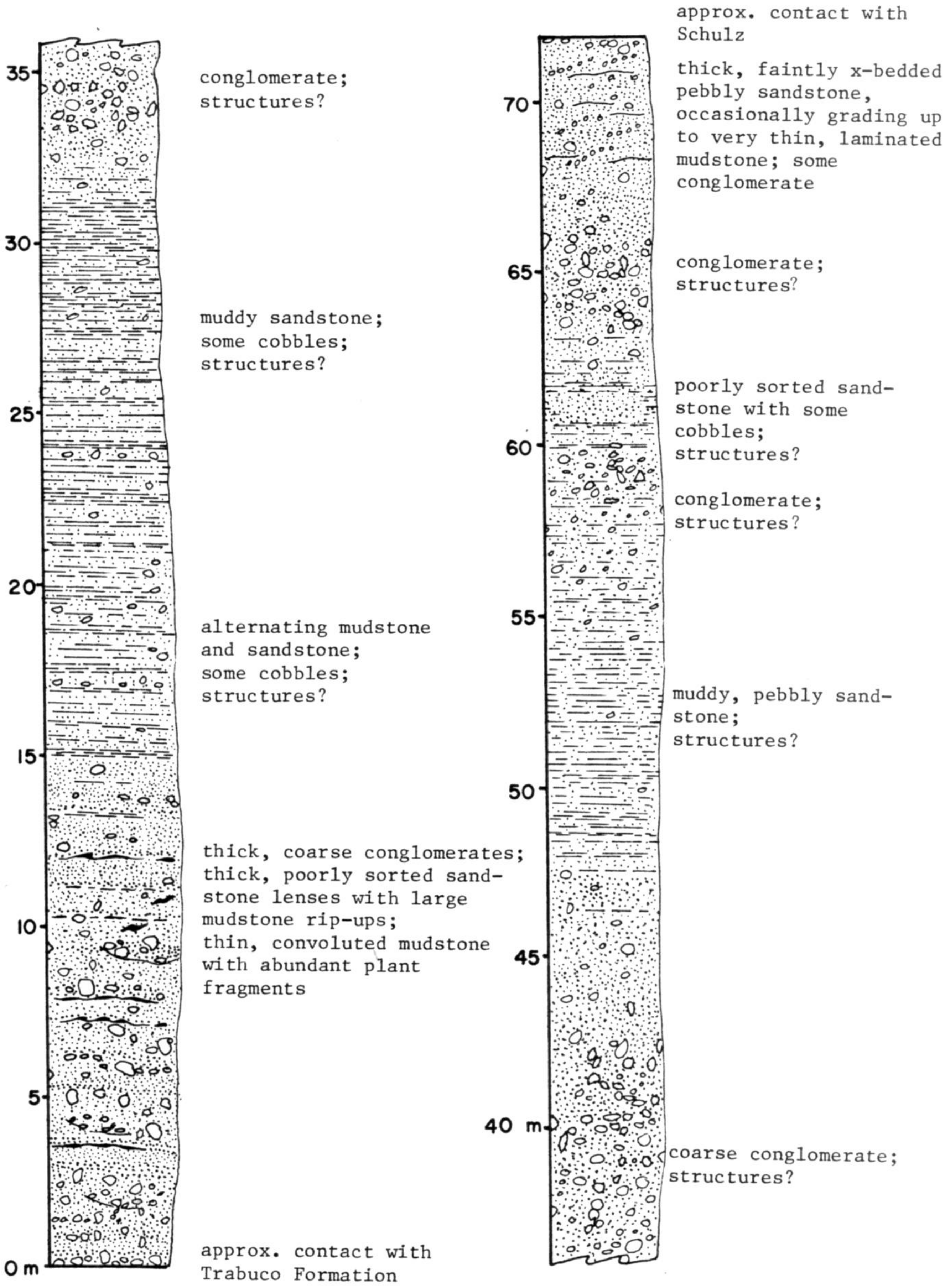
APPENDICES

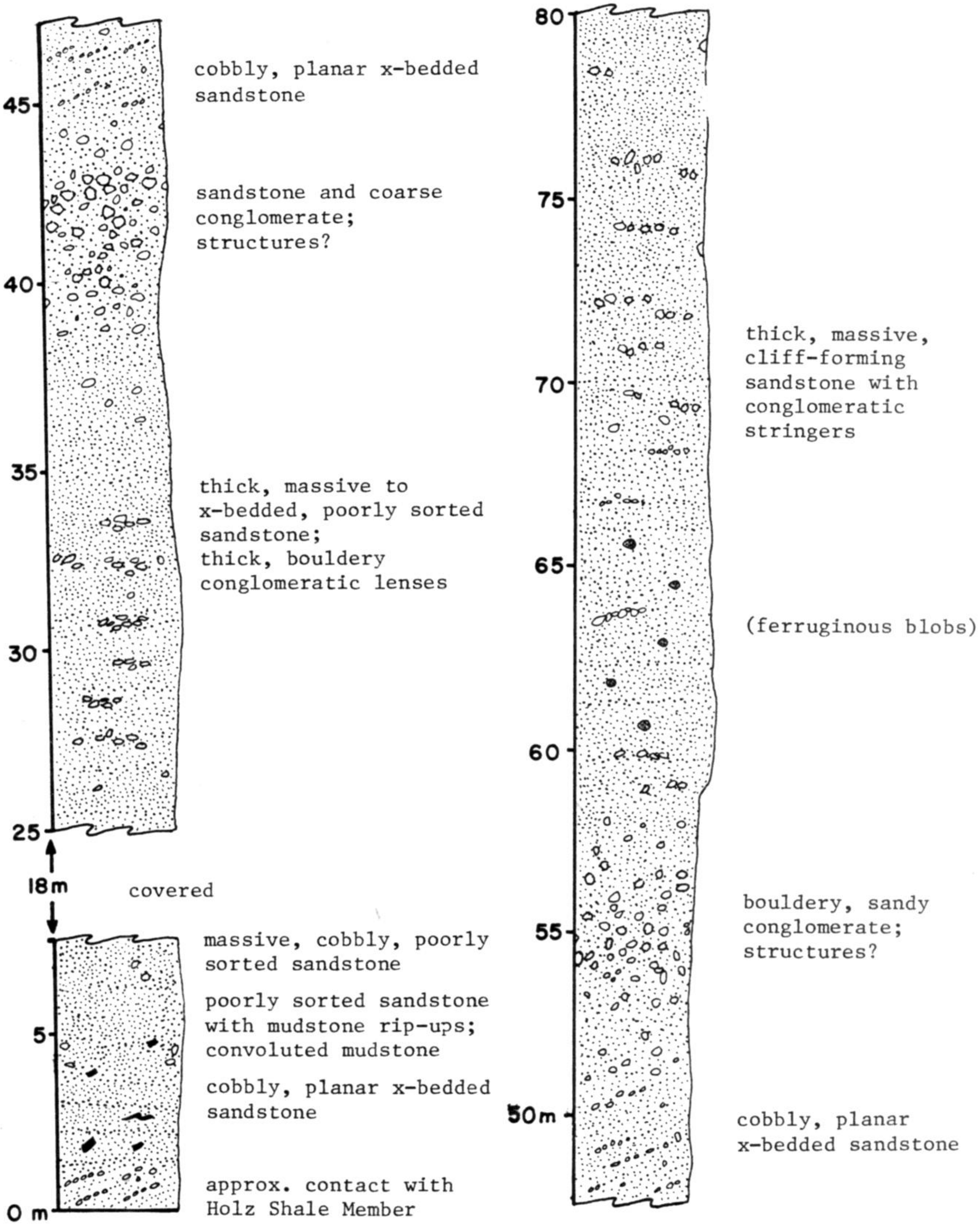
APPENDIX A

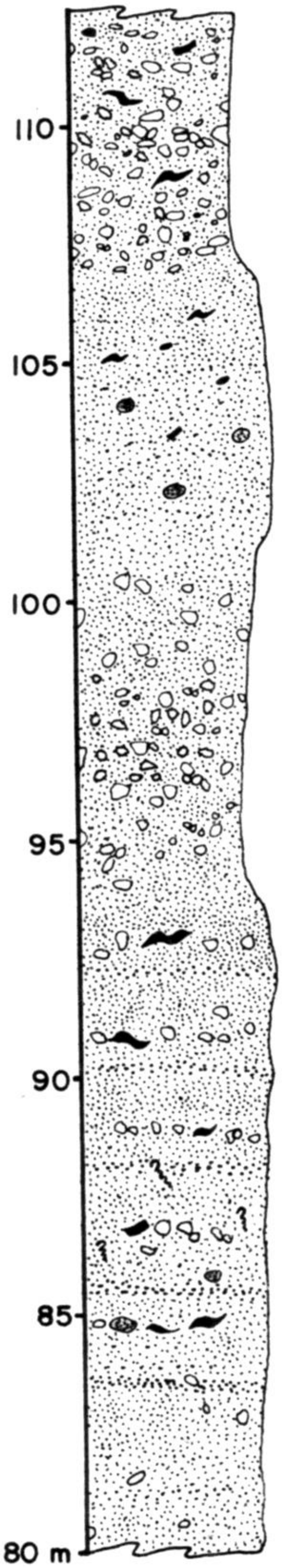
Measured section through the Holz Shale Member. Sedimentary structures are described where possible, but are obscured in places. Column is intended mainly to show facies distributions.


35
30
25
20
15
10
5
0 m
conglomerate; structures?
muddy sandstone; some cobbles; structures?
alternating mudstone and sandstone; some cobbles; structures?
thick, coarse conglomerates; thick, poorly sorted sandstone lenses with large mudstone rip-ups; thin, convoluted mudstone with abundant plant fragments
approx. contact with Trabuco Formation
70
65
60
55
50
45
40 m
approx. contact with Schulz
thick, faintly x-bedded pebbly sandstone, occasionally grading up to very thin, laminated mudstone; some conglomerate
conglomerate; structures?
poorly sorted sandstone with some cobbles; structures?
conglomerate; structures?
muddy, pebbly sandstone; structures?
coarse conglomerate; structures?

APPENDIX B

Measured section through the Schulz Ranch Sandstone Member. Sedimentary structures are described where possible, but are obscured in places. Column is intended mainly to show facies distributions.


45
40
35
30
25
18m
covered
5
0 m
cobbly, planar x-bedded sandstone
sandstone and coarse conglomerate; structures?
thick, massive to x-bedded, poorly sorted sandstone; thick, bouldery conglomeratic lenses
massive, cobbly, poorly sorted sandstone
poorly sorted sandstone with mudstone rip-ups; convoluted mudstone
cobbly, planar x-bedded sandstone
approx. contact with Holz Shale Member
80
75
70
65
60
55
50m
thick, massive, cliff-forming sandstone with conglomeratic stringers
(ferruginous blobs)
bouldery, sandy conglomerate; structures?
cobbly, planar x-bedded sandstone



poorly sorted conglomeratic lenses with mudstone rip-ups

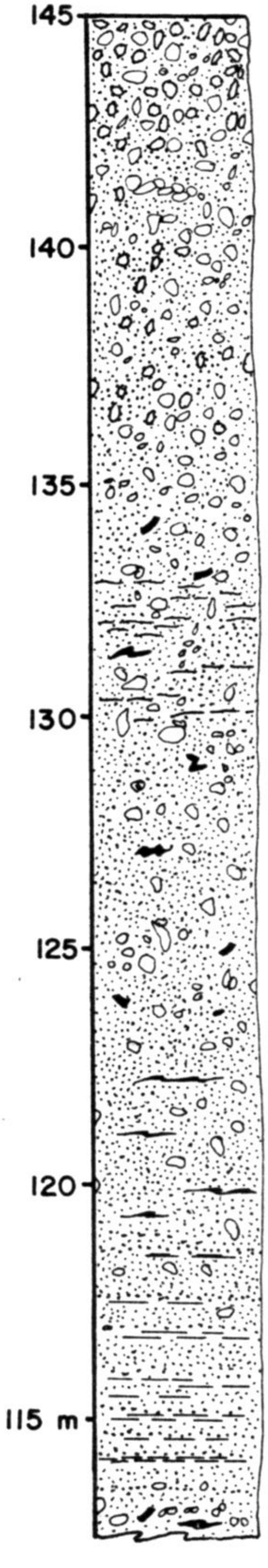
poorly sorted, cliff-forming sandstone with small mudstone rip-ups; ferruginous blobs

bouldery interval; structures?

cliff-forming, thick, amalgamated, poorly sorted sandstone with large mudstone rip-ups and "floating" boulders (see Fig. 16)

(*Ophiomorpha*)

(ferruginous blobs)



approx. contact with Pleasants

bouldery conglomerate; structures?

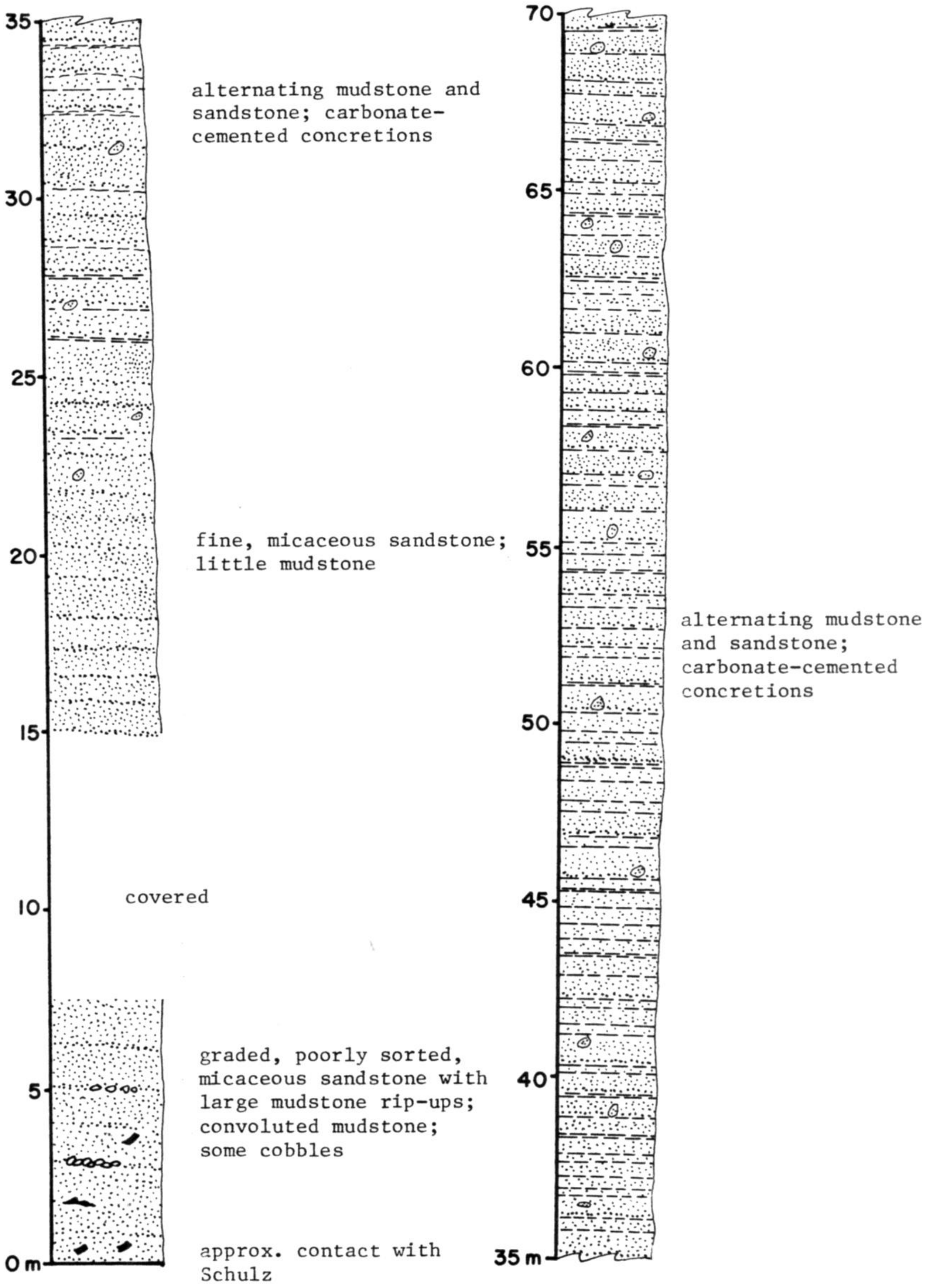
bouldery conglomerate; sandstone; mudstone; mudstone rip-ups; soft-sediment deformation

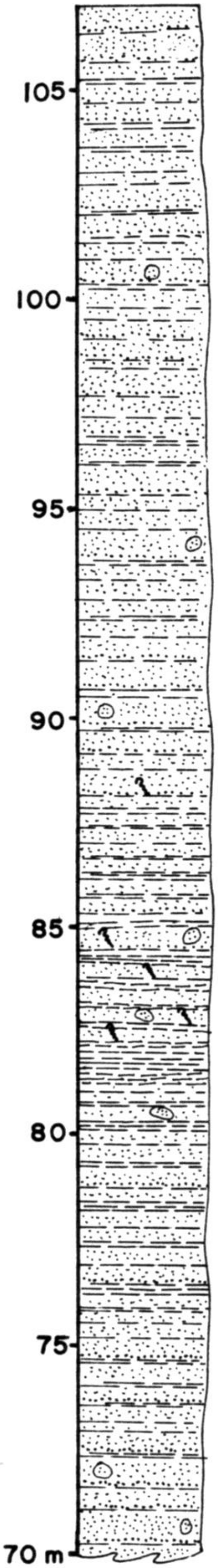
alternating thin sandstone and mudstone

poorly sorted conglomerate lenses with mudstone rip-ups

APPENDIX C

Measured section through the Pleasants Sandstone Member. Sedimentary structures are described where possible, but are obscured in places. Column is intended mainly to show facies distributions.


35
30
25
20
15
10
5
0 m
alternating mudstone and sandstone; carbonate-cemented concretions
fine, micaceous sandstone; little mudstone
covered
graded, poorly sorted, micaceous sandstone with large mudstone rip-ups; convoluted mudstone; some cobbles
approx. contact with Schulz
70
65
60
55
50
45
40
35 m
alternating mudstone and sandstone; carbonate-cemented concretions



end of measured section

3:1 sand:mud ratio

alternating mudstone and
graded, micaceous sandstone;
plant fragments;
soft-sediment deformation;
carbonate-cemented
concretions

(<u>Ophiomorpha</u>)

(T_{abe} sequences)

(1:3 sand:mud ratio)

alternating mudstone and
calcareous, micaceous sandstone;
carbonate-cemented concretions

ABSTRACT

ABSTRACT

The main contributions of this thesis include 1) a detailed geologic map of the general geology of the northern corner of Camp Pendleton, 2) a depositional model for the Upper Cretaceous units, and 3) a better understanding of the Late Cretaceous paleogeography and relationships between Upper Cretaceous units in Orange and San Diego Counties.

Methods used included geologic field mapping, section measuring, paleocurrent and conglomerate clast analysis, and sandstone thin-sectioning and grain-size analysis.

The study area contains a homoclinal and structurally intact sequence of Upper Cretaceous and Tertiary strata deposited on a Mesozoic basement complex. The Upper Cretaceous section has been subdivided into the Trabuco Formation, Holz Shale Member of the Ladd Formation, and Schulz Ranch Sandstone and Pleasants Sandstone Members of the Williams Formation. A Paleocene oxisol and the Eocene Santiago Formation overlie the Upper Cretaceous rocks. Extensional faulting is present in the study area. Sediments in the Upper Cretaceous units were derived from adjacent basement complex units, and display characteristics typical of immature forearc basin sediments. Paleocurrents are bipolar (east-west) in Upper Cretaceous marine sandstones, and unipolar (west to southwest) in fluvial sandstones and conglomerates. The Upper Cretaceous section is largely unfossiliferous, aside from plant fragments, common *Ophiomorpha*, and large,

angiosperm leaf impressions.

A transgressive fan-delta model is indicated for the Upper Cretaceous section. In this model, the fanglomerates of the Trabuco Formation toe directly into a marine environment. The Holz Shale and Schulz Ranch Sandstone Members record a complex interplay between braided stream, interdistributary bay, and beach foreshore environments. The Pleasants Sandstone Member represents turbidites and other rhythmically bedded sandstones deposited below wave base on a delta front. The presence of fanglomerates, plutonic and metamorphic sediments, and a transgressive sequence, all imply a rapid downfaulting of the Late Cretaceous forearc basin in which these sediments were deposited. Significant differences distinguish the Upper Cretaceous Camp Pendleton sequence from strata of the same age in southern San Diego County. As a result, the Camp Pendleton section cannot be considered as transitional between the Upper Cretaceous Santa Ana Mountains and San Diego County sections, and few lithologic correlations can be made between the two districts.