UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

STRATIGRAPHY AND PALEOENVIRONMENT OF MIOCENE PHOSPHATIC ROCKS IN THE EAST SAN FRANCISCO BAY REGION, CALIFORNIA

by

James M. Hill

Open-file report 79-1570

1979

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

A stratigraphic study of the Monterey Group in the East San Francisco Bay Region, California, indicates that a depositional basin began to subside in early to middle Miocene time. The Miocene sea transgressed from the west or southwest, and the area subsided to a possible water depth of 500 to 2,500 m.

The Monterey Group within the study area is a time-transgressive sequence of six sandstone and shale formations. Stratigraphic cycles of interbedded sandstone and shale formations are related to the amount of terrigenous sediment input into the basin as well as the depositional environment. During periods of low terrigenous sedimentation, biogenetic sedimentation in the form of diatomite layers were interbedded with hemipelagic muds and thin turbidite sands. These diatom-rich sediments were probably deposited within the upper bathyal zone (180 to 500 m) and, during lithification, diagenetically altered to form siliceous shales and cherts. As terrigenous sedimentation increased, probably due to periodic uplift east of the study area, biogenetic sedimentation was masked until finer grained sediment at a lower rate of deposition reoccurred. As the basin filled and a higher energy environment prevailed, coarse-grained sediment was again deposited until a lower energy environment resumed.

Three types of inorganic phosphate are present within the study area: nodular, pelletal, and pebbles of sandy phosphatic mudstone. The nodular phosphate is associated with the siliceous shale formations and formed within diatomite layers before compaction and lithification. The other two types of phosphate are found within the sandstone formations and probably originated in a shallower, higher energy environment than the siliceous shales.

Faulting was active during middle to late Miocene time. The change in stratigraphic thickness across the Mission fault is 350 m which may approximate the vertical (?) displacement along this fault. This displacement took place in middle to upper Miocene time and apparently caused erosion of the upper formations of the

Monterey Group on the west side of the Mission fault before the Briones Formation was deposited in late Miocene time. Depositional thinning of the Monterey Group in the southern portion of the study area may imply that the Hayward and Calaveras faults were also active at this time.

INTRODUCTION

This investigation was conducted as a part of the U.S. Geological Survey's California Phosphorite Program. The investigation was concentrated on the Monterey Group in the study area because it contains variable amounts of phosphatic material and is the northernmost known extension of the middle Miocene phosphatic facies in California (Dickert, 1966). Rock units stratigraphically above and below were examined only to determine age and contact relationships with the Monterey Group.

The major objectives of this study were: (1) to define stratigraphic relationships between the formations of the Monterey Group, (2) to describe the environment of deposition of the phosphatic members of the Monterey Group, and (3) to determine the distribution and mode of origin of the phosphatic material within the Monterey Group.

The study area consists of 3,740 km^2 (1,440 mi^2) in the East San Francisco Bay Region, hereafter referred to as the East Bay Region. It is within the Diablo Range and is approximately 22 km (14 mi) wide and 170 km (106 mi) long, located between 38°06'00" and 37°24'00" N., and is approximately bounded by the Hayward and Calaveras faults (fig. 1).

The Monterey Group within the study area consists of six interbedded sandstone and shale formations (in ascending stratigraphic order): (1) Sobrante Sandstone, (2) Claremont Shale, (3) Oursan Sandstone, (4) Tice Shale, (5) Hambre Sandstone, and (6) Rodeo Shale. The formations have been folded into a series of northwest-trending anticlines and synclines, many of which are overturned and faulted (pl. 1). The dips of the Monterey strata are rarely less than 40°, and overturned layers are common. The study

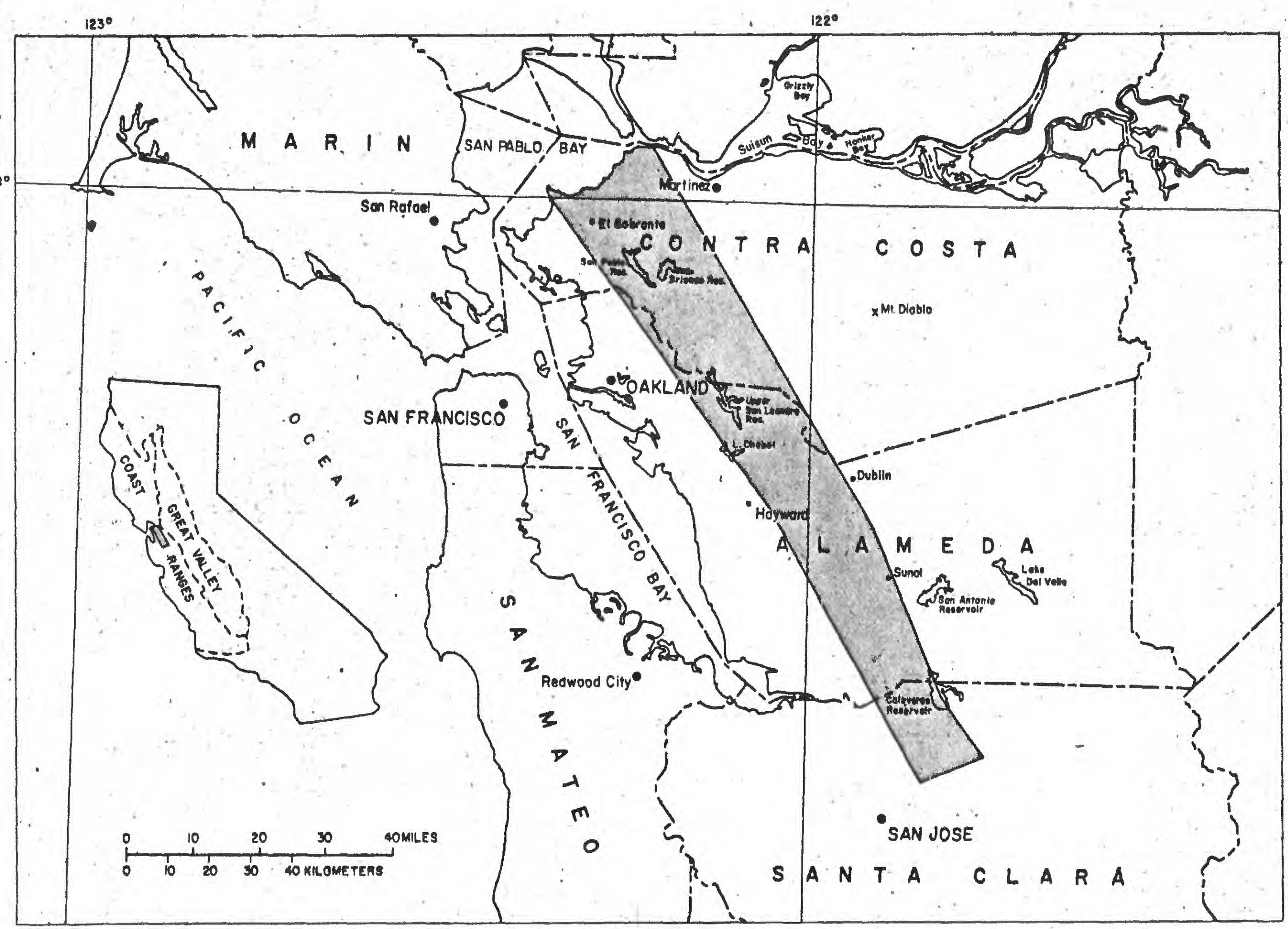

Figure I. Location of study area in the East San Francisco Bay Region (shaded) area has low to moderate relief and a thick (8 m or more) weathered profile. Exposures of these formations are very poor. Stratigraphic sections were measured and sampled in the larger canyons, highway cuts, and fire trails where bedrock was exposed normal to the strike of the formations. For covered areas between sections of the formations and for weathered portions of the measured sections, a trailer-mounted 10 HP auger was used to obtain unaltered samples containing identifiable foraminifera.

Eleven stratigraphic sections were measured within the Monterey Group (pls. 1 and 2), and two stratigraphic sections were taken from the literature (Bramlette, 1946). The stage names of Kleinpell (1938) and the the time scale of Arnal (1976, fig. 2) were used for correlation between measured sections.

ACKNOWLEDGMENTS

I thank A. E. Roberts for his invaluable technical assistance and guidance throughout this study. I am also grateful for the assistance of W. O. Addicott, R. E. Arnal, J. D. Buckry, D. L. Jones, K. A. McDougall, C. A. Repenning, and P. B. Smith for fossil identifications. Special thanks is given to D. H. Radburch for the use of her lithologic sample data in this report, to E. E. Brabb for use of unpublished geologic maps, and to R. L. Oscarson for technical assistance with the SEM-EDAX equipment. The writer has benefited from discussions about stratigraphic problems or paleontologic interpretations as well as critical manuscript reviews with R. E. Arnal, K. A. Bailey, T. W. Dibblee, Jr., A. E. Roberts, and R. L. Rose.

Acknowledgments are also due to the officials of the East Bay Municipal District, the San Francisco Water District, and the owners in the area for the permission granted for access to their property.

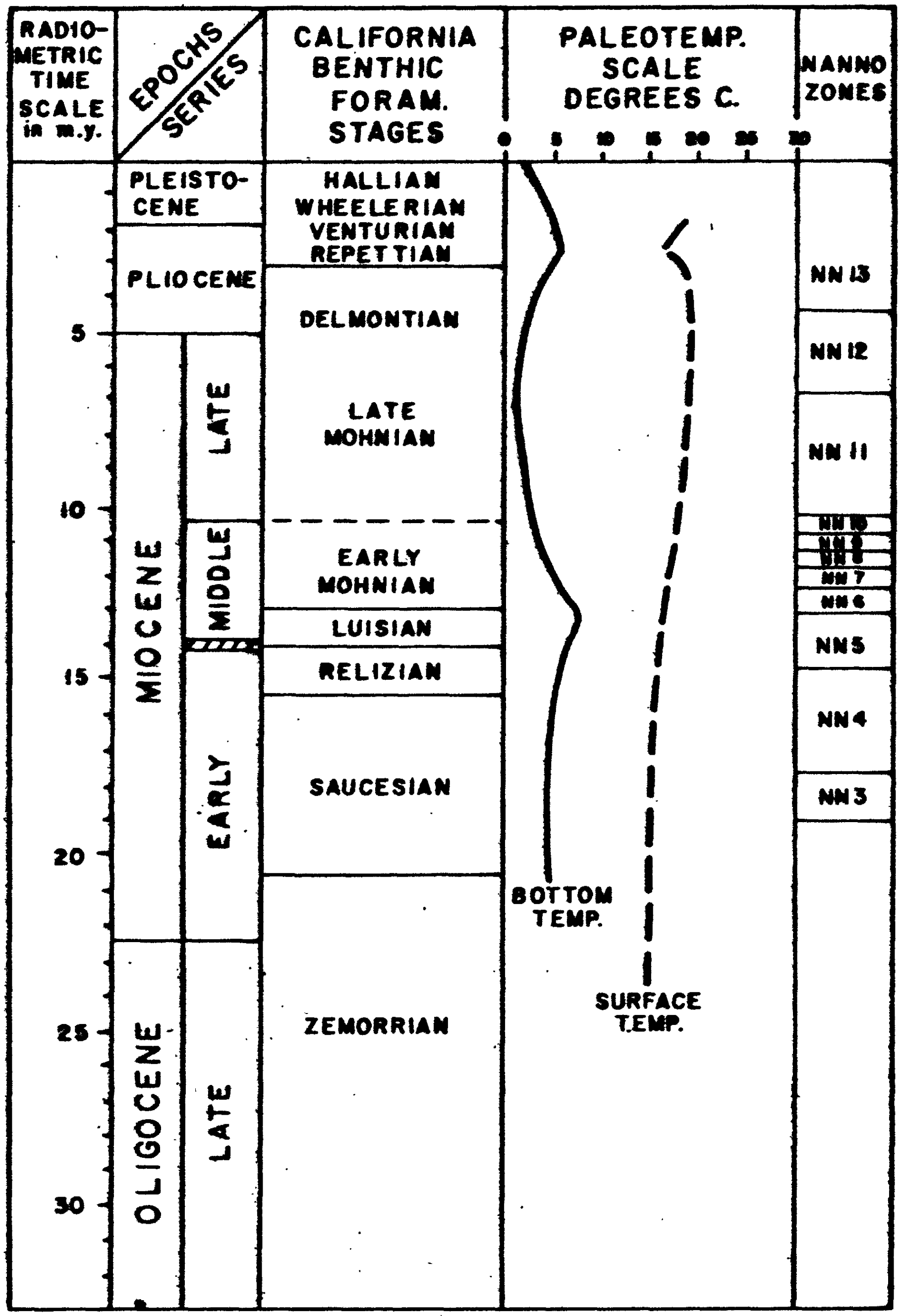

Figure 2. Time scale after Arnal (1976)

PRE-MONTEREY GROUP ROCKS

The Pre-Monterey Group rocks in the East Bay Region consist of three distinct units: (1) Franciscan rocks, (2) Cretaceous rocks, and (3) lower Tertiary rocks. The depositional contact between the Monterey Group and older rocks is a distinct angular unconformity and is best exposed on the north side of Calaveras Road in the quarry where section 3 was measured (Plate 1). The angular discordance between the Monterey Group and the underlying Cretaceous rocks at this locality is 27 degrees.

Franciscan rocks consist of a tectonic mixture of graywacke, pillow basalt, radiolarian chert, and serpentinite that may have originated in an ocean trench (Hamilton, 1969). Within the study area, the Monterey Group does not rest depositionally upon Franciscan rocks; however, it is in depositional contact with Franciscan rocks outside the study area, east of the Calaveras fault and north of Calaveras Reservoir (Dibblee, 1972). Inasmuch as no new information about Franciscan rocks is presented in this paper, the reader is directed to the publications by Irwin (1957), Durham (1962), and Bailey and others (1964) for detailed studies of the Franciscan rocks.

Cretaceous rocks exposed within the study area were first studied by Lawson (1914). Later workers related these rocks to the Late Jurassic to Late Cretaceous Great Valley Sequence (Bailey and others, 1964). The Great Valley Sequence within the study area consists of 7,575 to 9,091 meters (25,000 to 30,000 ft) of interbedded sandstone, mudstone, and conglomerate (Perkins, 1975) which structurally overlies the coeval Franciscan rocks along a complex regional thrust fault (Barbat, 1971; Dickinson and Rich, 1972); the Great Valley Sequence within the study area is considered to be a klippe of this thrust.

Of the three fossil localities found within rocks older than Miocene age, only two were age diagnostic. In section 1 (pls. 1 and 2), in Alum Rock Canyon, rocks mapped as the Berryessa Formation (Crittenden, 1951) yielded coccoliths of Cenomanian or Turonian (Upper Cretaceous) age (J. D. Buckry, written commun., 1976). In section 7, just north of the town of Niles, a siltstone stratigraphically above (?) the Oakland conglomerate as mapped by Hall (1958) yielded Buchia piochii (Gabb) or B. Unicitoides (Pavlow) of Late Jurassic or Early Cretaceous age (D. L. Jones, written commun., 1976).

Rocks of Oligocene age underlie the Monterey Group in the vicinity of Oursan Ridge (Lutz, 1951). The name Concord Formation was first used by Clark (1918) for these rocks. In section 12 on Oursan Ridge (pl. 1), the Concord Formation is completely covered or was not recognized.

MONTEREY GROUP

Lawson (1914) designated the middle Miocene rocks in the study area the Monterey Group and divided it into seven formations (in ascending stratigraphic order): (1) Sobrante Sandstone, (2) Claremont Shale, (3) Oursan Sandstone, (4) Tice Shale, (5) Hambre Sandstone, (6) Rodeo Shale, and (7) Briones Formation. Subsequent workers have noted a faunal similarity between the Briones Formation and the San Pablo Group (Clark, 1921; Trask, 1922; Weaver, and others, 1944). These workers include the Briones Formation into the San Pablo Group. Throughout most of the study area, the Briones Formation rests conformably upon the Hambre Sandstone or Rodeo Shale formations of the Monterey Group. In section 7 (pls. 1 and 2), the Briones Formation rests unconformably upon the Claremont Shale. The contact between these formations is erosional with no apparent angular discordance. This relationship is also present in sections 1 and 2 (pls. 1 and 2). On the basis of the faunal evidence and the unconformable relationship between the Briones Formation and the Claremont Shale in certain portions of the study area, the Briones Formation, for this investigation, will be included into the San Pablo Group and not investigated in detail. The generalized stratigraphic sequence of the Monterey Group is presented in figure 3.

Monterey rocks throughout California are typified by siliceous shales and cherts (Bramlette, 1946). In the East Bay Region, however, these siliceous shales and cherts are interbedded with sandstone units of formational rank. This is why the Monterey is

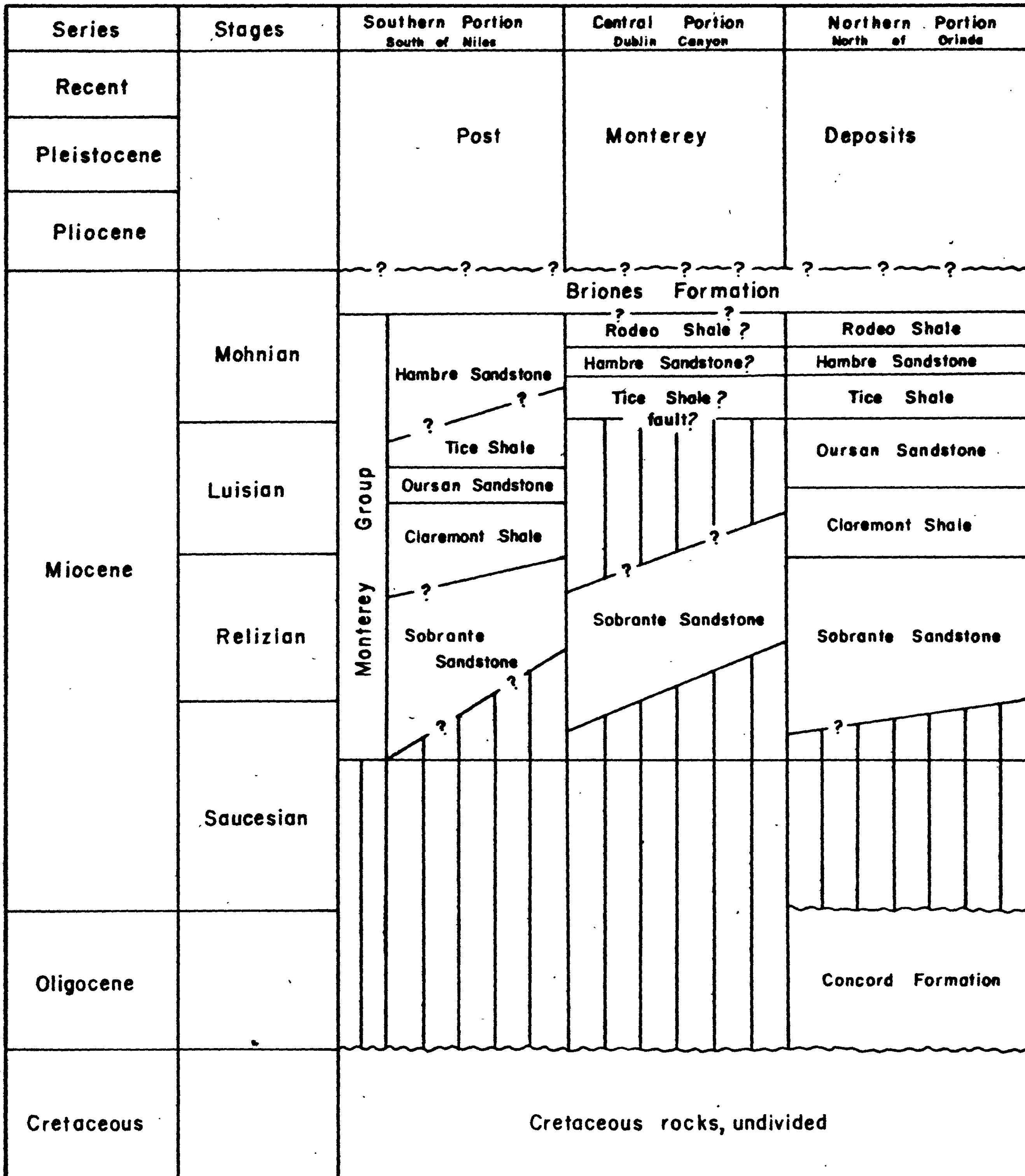

Figure 3. Correlation of stratigraphic units of the East San Francisco Bay Region

classified as a group in the East Bay Region instead of a formation as it is elsewhere in California.

Sobrante Sandstone

The term Sobrante Sandstone was first used by Lawson (1914, p. 10) for the basal formation of the Monterey Group. He designated the type area of the formation to be Sobrante Ridge, Contra Costa County.

Clark (1915, p. 12), recognizing an unconformity within the Sobrante Sandstone in the type area, found the rocks below the unconformity to be Oligocene in age and named those above the unconformity the "Sobrante Sandstone." In 1918, he further divided the Oligocene into the San Ramon Formation, the Kirker Tuff, and the Concord Formation. All references to the Sobrante Sandstone in this paper will be understood to follow Clark's terminology.

Lutz (1951) found no Sobrante Sandstone exposed on Sobrante Ridge. He proposed the section along Bear Creek Road, near Oursan Ridge in Contra Costa County, as the type locality. Here the Sobrante Sandstone is conformably overlain by the Claremont Shale and uncornformably underlain by the Concord Formation of Oligocene age. The thickness of the Sobrante Sandstone in the type section exceeds 36 m (117 ft).

Distribution and thickness. The thickness of the Sobrante Sandstone varies considerably throughout the study area (pl. 2). The thickest section is in Dublin Canyon, where 112 m (370 ft) are exposed; here the lower 30 m (100 ft) may be equivalent to the San Ramon Formation of Oligocene age, on the basis of one poorly preserved megafossil (W. O. Addicott, oral commun., 1976). North of Dublin Canyon, the Sobrante Sandstone decreases in thickness from 59 m (191 ft) in Claremont Canyon to 36 m (117 ft) (Lutz, 1951) along Bear Creek Road, on the south side of Lawson Hill. No fossils were found in the Claremont Canyon section. The lithology of these rocks is very similar to that of the Sobrante Sandstone exposed elsewhere within the study area (see Appendix A). These rocks are included in the Sobrante Sandstone on this basis. Older rocks of lithology similar to that of the Monterey Group may be included in the section.

South of Dublin Canyon, the Sobrante Sandstone also thins and is 30 m (100 ft) thick at the quarry on Calaveras Road (pl. 2, col. 3) and 9 m (30 ft) thick at Alum Rock Park (pl. 2, col. 1). At three other measured sections (pl. 2, secs. 4, 5, and 7), the sandstone unit is not recognized.

Lithology. In outcrop, the Sobrante Sandstone is typically a massive, jointed, hard to friable, very fine- to fine-grained rarely medium to coarse-grained arkosic, lithic sandstone which is light gray on a fresh surface to rust brown on a weathered surface. It is easily distinguished from the underlying Cretaceous rocks by its lighter color, lack of bedding, and the absence of wrinkled biotite. The abundant dark lithic fragments give the sandstone a salt and pepper appearance.

The contact between the Sobrante Sandstone and older rocks is best exposed in a quarry on the north side of Calaveras Road where section 3 (pls. 1 and 2) was measured. The Sobrante Sandstone overlies the Cretaceous Berryessa Formation with a distinct angular unconformity of 27 degrees. Pholads have burrowed extensively perpendicular to the erosional surface between the Berryessa Formation and the Sobrante Sandstone. The pholads are too poorly preserved to identify but range in size from 2 to 5 cm in diameter. The burrows, filled with sand from the overlying Sobrante Sandstone, appear to be as much as 0.6 m (2 ft) long. No basal conglomerate or beds of conglomerate were observed within the Sobrante Sandstone. Well-rounded pebbles of brown chert and white quartzite up to 1 cm in diameter are scattered throughout the upper 30 m (100 ft) of the Sobrante Sandstone of Dublin Canyon, along with carbonized wood fragments, fish scales, and occasional bone fragments.

Beds of conglomerate 2.7 to 4.6 m thick (9 to 15 ft) are present within the Sobrante Sandstone in the eastern portion of the study area southeast of Martinez in the Pacheco Syncline (Lutz, 1951), and in the vicinity of Castle Hill west of Walnut Creek (Ham, 1952). The conglomeratic beds contain acid plutonic rocks, white quartzite, pale green chert, plagioclase, andesite, purple chert, gray marble, dark gray-green quartzite, red chert veined by quartz, red slate, and buff sandstone (Cretaceous?); some of these may have been in part derived from Franciscan material (Ham, 1952).

The Sobrante Sandstone, at the contact in section 3 (pl. 1 and 2), is a fine- to medium-grained sandstone that contains tabular clasts of bluish-gray Berryessa siltstone up to 2 cm long. These clasts are abundant in the lower 10 cm of the bed and display a distinct imbrication indicating a current once flowed from the southwest to the northeast. Pecten haywardensis calaverasensis (Lutz, 1951) was found approximately 6 m (20 ft) above the contact between the Berryessa Formation and the Sobrante Sandstone. The fossil was not in life position, and only one valve was present.

Sedimentary structures are uncommon in the Sobrante Sandstone. Small-scale cross beds and parallel laminations are the only structures present in section 3.

In the Hayward quadrangle, just south of Dublin Canyon, an expsoure of Sobrante Sandstone was found that contained carbonate concretions. These concretions are light to dark gray and range from 14 to 50 cm in diameter.

The contact between the Sobrante Sandstone and the overlying Claremont Shale is gradational. Fine- to very fine-grained sandstone grades into and becomes interbedded with friable, brownish-gray, sandy shale or light- to medium-gray mudstones, which vary in size from thin stringers to beds up to 3 m thick. The contact between the Sobrante Sandstone and the Claremont Shale is drawn where siltstones and mudstones predominate over fine-grained sandstones. These siltstones and mudstones grade upward into interbedded opaline chert and siliceous shale of the Claremont Shale.

Six thin sections of the Sobrante Sandstone were examined, and point counts were done on two. Results of the point counts are presented in Appendix D. Stratigraphic locations are found on plate 2. Microsopic examination indicates that 24 to 35 percent of unstable grains have altered to sericite or clay. The remaining grains are angular to subangular, sometimes subrounded, and are composed predominately of volcanic rock fragments, plagioclase, chert and quartz, with minor amounts of orthoclase, microcline, and silt. The volcanic rock fragments make up almost 30 percent of the rock and are of two types: 1) Franciscan spilite (Ham, 1952), and 2) volcanic grains with textures similar to those of Mesozoic dacites and rhyolites presently found in the Sierra Nevada (R. L. Rose, oral commun., 1976). No distinction between these two types was made in the point counts. Some of the volcanic grains stain for potassium feldspar, possibly due to their alteration to potassium-bearing clays. Plagioclase grains make up approximately 20 percent of the rock; they are angular to subangular, predominantly andesine, rarely oligoclase or labradorite, and are usually unzoned. Some grains are fractured, and alteration to sericite or clay is conmmon. Subrounded chert grains usually constitute five to ten percent of the unaltered grains. They are similar in size and texture to chert grains found in the Cretaceous rocks within the study area. Quartzite grains are present in trace amounts and were counted as chert. Angular to subangular grains of quartz usually make up less than 10 percent of the rock. These grains are sometimes fractured, and less competent volcanic grains are deformed against them. Quartz grains are stained and display a 2V of five to ten degrees. Alteration of quartz to sericite is very rare, occurring only at the edge of grains.

Accessory minerals that usually make up less than one percent of the rock are glauconite, green and brown hornblende, opaque minerals, biotite, and zircon. Notable exceptions are: 1) In a sample from a carbonate concretion found within the Sobrante Sandstone in Crow Canyon (pls. 1 and 2, sec. 9), green and brown hornblende make up almost two percent of the detrital grains. Carbonate matrix in this sample makes up 46 percent of the rock. Within carbonate concretions, hornblende and other unstable minerals are somewhat protected from alteration effects of solutions within sedimentary layers (Bramlette, 1941). Therefore, the amount of hornblende in this sample is probably near to that at the time of deposition. 2) Near the top of the Sobrante Sandstone in section 3 (pls. 1 and 2), glauconite composes more than 75 percent of several beds that are .3 to 1.25 m thick. Well-rounded pebbles of phosphate rock up to 2 cm in diameter constitute almost two percent of these beds; fine sand, silt, and clay make up the approximately 20 percent remaining.

The Sobrante Sandstone is a very immature sandstone. It is very compact and grain-supported with voids between grains filled by sericite or clay. In some cases, the boundaries of grains replaced by phyllosilicates can still be distinguished. The compaction of the Sobrante Sandstone is probably partly tectonic in nature. Plagioclase and quartz grains are some times fractured, and less competent volcanic grains are deformed around quartz grains into a type of pseudomatrix (Dickenson, 1970).

Age and correlation. Lutz (1951, p. 383) using megafossils collected from the type section just south of Lawson Hill, correlated the faunas of the Sobrante Sandstone with the Temblor Formation of California and the Astoria Formation of Oregon and Washington. The foraminifera he found indicated that the Sobrante Sandstone is not older than Relizian nor younger than Luisian in age.

Megafossils collected throughout the study area within the Sobrante Sandstone show it to be equivalent to the Temblor stage of the Pacific Coast chronology (W. O. Addicott, written commun., 1976). Foraminifera of the Sobrante Sandstone indicate a Relizian age in the Oursan Ridge area (P.B. Smith, written commun., 1966) and a Luisian age in the Dublin Canyon area (K. A. McDougall, written commun., 1976). In the southern portion of the study area, in Alum Rock Canyon, nannofossils from a mudstone lying 4.6 m stratigraphically above the top of the Sobrante Sandstone are of Oligocene or early Miocene age (J. O. Buckry, written commun., 1976). The age of the Sobrante Sandstone and its relationship to other formations of the Monterey Group is summarized in figure 3.

Claremont Shale

The Claremont Shale, first described by Lawson (1914), was named for exposures in Claremont Creek in the Concord quadrangle east of Berkeley, California. The type section for the Claremont Shale is designated for this study to be in Claremont Creek, east of Berkeley, California; the measured section appears in plate 2 (sec. 10) and lithologic descriptions can be found in appendix A. Contact relationships between the Claremont Shale and the formations that lie conformably above and below it are not exposed in Claremont Canyon, but are well exposed in Morrison Canyon in the Niles Quadrangle. The stratigraphic section in Morrison Canyon is here defined as a Reference Section; the measured sections appears in plate 2 (sec. 6) and lithologic descriptions are in Appendix B.

Distribution and thickness. The siliceous nature of the Claremont Shale makes it the most distinctive and widespread unit of the Monterey Group. The thickness of the Claremont Shale varies throughout the study area. In the Reference Section in Morrison Canyon (sec. 6), it is 116 m (384 ft) thick, and in the type section in Claremont Canyon, it attains its maximum thickness of 300 m (989 ft). The lithologic character of the Claremont Shale in both areas is almost identical. However, the top of the Claremont Shale in Claremont Canyon has been removed by post-Monterey erosion, and the total thickness at the time of deposition cannot be estimated. This post-Monterey erosion affects the Monterey Group for 1.6 km (1 mi) north and 11.2 km (7 mi) south of Claremont Canyon and also affects the areas around sections 1 and 7.

The thinnest non-eroded section (40 m thick) of the Claremont Shale is located in the northern portion of the study area on Oursan Ridge (sec. 12). The formation consists of porcellanites interbedded with siliceous shales similar to those in the Tice Shale in Morrison Canyon. Its stratigraphic position above the Sobrante Sandstone defines this unit as the Claremont Shale.

Lithology. Throughout the study area, the Claremont Shale is characterized by interbedded opaline cherts and siliceous shales with, in most localities, minor amounts of interbedded porcellanite, siltstone, and mudstone. The abundance of each lithologic type appears to be related to stratigraphic position and topographic location.

The siliceous shales, porcellanites, and cherts which characterize the Monterey Group are thought to originate from diatomaceous deposits (Lawson, 1914; Taliaferro, 1933, 1941; Bramlette, 1946; Murata and Larson, 1975). After burial, diatomite layers diagenetically alter to form chert, porcellanites, and siliceous shales. The complete diagenetic sequence is exposed in Chico-Martinez Creek and was investigated by Murata and Larson (1975). They defined three distinct depth-controlled zones characterized by different forms of silica. These zones are, in descending stratigraphic order: (1) biogenic opal zone, with remains of diatoms and other siliceous organisms; (2) diagenic cristobalite zone; and (3) diagenetic quartz zone. The general relation, in the Monterey, of diagenetic alteration to depth of burial suggests that moderate load and dynamic metamorphism tends to produce porcellaneous shale and that greater metamorphism tends to produce denser cherty rocks (Bramlette, 1946). This relationship of depth of burial to lithologic type is probably represented in sections 6 and 7. In section 5, in Morrison Canyon, the Monterey Group is 479 m (1,580 ft)(pl. 2) thick with the Briones Formation conformably overlying it. The Claremont Shale in section 5 is composed of interbedded chert and siliceous shale. In section 7, the Claremont Shale is the only Monterey unit present, and it is unconformably overlain by the Briones Formation. The Claremont Shale in section 7 is 130 m (425 ft) thick and is composed of interbedded porcellanites and siliceous shales. The difference in thickness of the total Monterey Group in these localities indicates that in section 7 possibly as much as 335 m (1,110 ft) of Monterey was eroded above the Claremont Shale before deposition of the Briones Formation. This difference in overlying thickness was apparently enough to cause the difference in lithology present in sections 6 and 7.

The cherts within the Claremont Shale are well bedded, the beds ranging from 1 to more than 85 cm thick. They are hard, jointed or fractured, black to pale brown when fresh, light gray to white when weathered, and are usually stained with limonite. Foraminifera within chert layers are rare, and pyrite is usually present in trace amounts. Fractures or partings within the chert and siliceous shales are often filled with secondary gypsum. Other less abundant secondary minerals found within the Claremont Shale are jarosite and vivianite. These minerals were identified by x-ray diffraction methods. The chert has a smooth surface, an even to conchoidal fracture, and vitreous to dull luster. While the chert layers are slightly silty or clayey, no gradations from chert to siliceous shale were seen within any one bed.

The chert beds sometimes contain lozenge-shaped phosphate nodules that range in width from less than 1 mm to several centimeters and are less than 1 cm thick. The light and dark laminations found within many of the chert beds are parallel to the bedding and are composed of organic debris of various densities (Bramlette, 1946). This organic debris gives the Claremont cherts and shales their dark color. Laminations within the chert horizons are laterally continuous and are probably depositional features. Deformation occasionally is seen in these laminations. Such deformation must have been produced prior to lithification. Two types of deformational structures are defined by the laminations: (1) minor slump-folds, usually overturned, with amplitudes less than 4 cm, and (2) inclined laminations that look very much like ripple crossbeds, with amplitudes less than 2 cm.

The distribution of laminations within the chert does not seem to follow a stratigraphic pattern. Laminated cherts are often interbedded with nonlaminated chert layers. These nonlaminated cherts are similar in thickness to the laminated variety, but they are not as abundant and are homogeneous in color. The occurrence of phosphate nodules does not seem to be related to the presence or absence of laminations.

The chert of the Claremont Shale is interbedded with shale that is well bedded, brittle to friable, black to brown to light gray, and forms beds averaging 1 to 5 cm thick. These shale interbeds can be as thick as 3.8 m, as found in Claremont Canyon (sec. 10). These thick shale horizons usually occur at the top or bottom of the Claremont Shale. The clay fraction consists of montmorillonite and chlorite with smaller amounts of koalinite (C. E. Gutmacher, written commun., 1976). The shale contains small amounts of foraminifera that are usually extensively weathered. In many cases, only siliceous internal molds or limonite-stained casts remain. The amount of siliceous cement within the shales is variable and is probably related to the hardness of the shales. Porcellanite is a silica-cemented rock that is less hard, dense, and vitreous than chert. Such rock has minute pore spaces which usually give it a dull or matte luster resembling that of unglazed porcelain (Murata and Larson, 1975). Porcellanites within the study area are well bedded, in layers 1 to 10 cm thick, are hard, slightly porous, and gray to light brown with a dull luster. They break with a smooth to conchoidal fracture and are sometimes slightly sandy. Light gray to white chert layers .5 to 5 mm thick are occasionally found within porcellanite layers. The porcellanite layers are interbedded with chert layers, elsewhere within the study area.

Siltstone and mudstone are not as abundant as the other rock types in the Claremont Shale. Siltstones are moderately well bedded, in beds from .3 to 7.6 m thick, hard, light brown to gray, noncalcareous, and slightly sandy with very fine-grained sand.

Mudstones are usually well bedded, light gray to medium gray, blocky, and slightly shaley and sandy with locally abundant, medium sand-sized, glauconite grains. They are noncalcareous and contain scattered fish scales and bones. Mudstones are usually found in the contact between the Sobrante Sandstone and Claremont Shale. Sandstones grade upward into mudstones, and the mudstones grade into chert and siliceous shales. The thickness of the mudstones varies throughout the study area. They are usually not recognized, except in section 3, where the mudstone member is approximately 6 m (20 ft) thick. This member thickens south of section 3 and is over 60 m (200 ft) thick in section 1 in Alum Rock Canyon.

Sandstone beds are rare within the Claremont Shale and usually are not more than 0.8 m (2.6 ft) thick. The sandstones are hard, jointed, light gray to rust brown, fine- to medium-grained, and well sorted with subangular grains of quartz, feldspar, scattered dark grains, and, in one case, brown, well-rounded phosphate pellets. These sandstone beds contain no visible internal structures, are noncalcareous, and are usually stained by limonite. These sandstone beds occur randomly through the Claremont Shale.

Sandstone dikes. Sandstone dikes cut the bedding planes of the Claremont Shale at angles ranging from perpendicular to almost parallel to bedding. These clastic dikes were found in sections 2, 3, and 10 but are most abundant in section 3. They range from 1 cm wide and 5 cm long to over 5 m (16.5 ft) wide with unknown length. The dikes often bifurcate to form a dendritic pattern.

The contacts between the sandstone dikes and the surrounding siliceous shales are strongly sheared with sand injected into the shear planes. Clastic dikes contain angular, laminated chert and siliceous shale fragments. These fragments range from 0.5 cm to more than 1 m in length.

The presence of these angular chert fragments indicates that the sandstone dikes probably intruded the Claremont Shale after it was lithified. The formation of sandstone dikes may be related to strike-slip faulting of underlying competent basement rocks (Peterson, 1966).

Mineralogy of the sandstone dikes is very similar to that of the sandstone beds found within the Claremont Shale and of other sandstone formations within the Monterey Group. The dikes consist of sandstone that is light gray to white, fine- to medium-grained, with well-sorted angular to subangular grains of quartz, feldspar, dark lithic fragments, and rare mica. In section 3 (pl. 2), dark lithic fragments within a large sandstone dike were concentrated into flow bands 0.5 cm thick.

Carbonate concretions. Carbonate concretions and a few carbonate beds are distributed throughout the siliceous shale formations of the Monterey Group (i.e., the Claremont Shale, Tice Shale, and Rodeo Shale) in the study area. The carbonate concretions in these formations are similar in size, shape, and composition. They are generally oblate ellipsoids that have their long direction parallel to the bedding. They range from several centimeters to over 3 m (9.9 ft) in length and up to 0.6 m (2 ft) in thickness. The concretions are sometimes interbedded with beds of carbonate rock that pinch and swell along strike, probably because of compaction and lithification of the surrounding sediment. The carbonate beds are also similar in color and composition to the concretions and were probably formed under the same conditions.

Both the beds and concretions occur in distinct calcareous horizons that vary from less than 1 m (3.3 ft) to over 9 m (29.7 ft) thick. The stratigraphic position of these horizons cannot be correlated from one locality to another. Most of the concretions and beds of carbonate are composed of dolomite; some are composed of calcite. All weather a distinctive yellow-orange, which contrasts sharply with surrounding dark siliceous shales. The concretions are highly resistant to weathering and often are the only exposed rocks in the grassy hills.

Bramlette (1946, p. 21) suggested that the concretions are diagenetic, formed during the early stages of compaction and lithification. According to Murata and others (1969), calcite from foraminifera and other fossils was dissolved and redeposited along certain favorable zones to form carbonate concretions.

The contact relationships between the concretions and the surrounding siliceous deposits indicate that the concretions formed beneath the surface of the sediment, prior to lithification. In most cases, this took place at a depth below that reached by burrowing organisms. However, in one example from section 3, a carbonate concretion had been intensively burrowed by organisms. These burrows range from 10 to 12 mm in diameter and are filled with very fine-grained sandstone.

Age and correlation. The age of the Claremont Shale and its relationship to the other formations of the Monterey Group is summarized in figure 3. In Alum Rock Canyon (pl. 2, sec. 1), nannofossils from a mudstone 4.6 m stratigraphically above the top of the Sobrante Sandstone are of Oligocene or early Miocene age (J. O. Buckry, written commun., 1976). This mudstone is exposed south of Alum Rock Canyon, and based on foraminifera, has been assigned a Saucesian age (R. L. Rose, oral commun., 1976). The majority of age calls (Appendix C) indicates that the strongly siliceous portion of the Claremont Shale probably began within the Relizian or Luisian.

In Dublin Canyon, a sample taken at the base of the lowest shale unit (pl. 2, sec. 8) contained foraminifera of lower upper Mohnian age (R. E. Arnal, written commun., 1977). In Crow Canyon, foraminifera of late Saucesian to early Luisian age were found at the base of the Claremont Shale. This difference in age indicates that there is probably a fault in Dublin Canyon at the top of Sobrante Sandstone which may cut out the Claremont Shale (pl. 2) as suggested by the mapping of Hall (1958). The limited sequence (pl. 2, col. 8) between microfossil localities Mf 3334 (Luisian) and Mf 3272 (lower upper Mohnian) also suggests that the Claremont Shale is faulted out of the Dublin Canyon Section. Therefore the name Tice Shale may be a more correct name for the shale unit above the Sobrante Sandstone in Dublin Canyon.

Oursan Sandstone

The name Oursan Sandstone was first proposed by Lawson (1914) for the fine-grained sandstone exposed between the Claremont Shale and the Tice Shale along Oursan Ridge, northwest of Briones Valley in the Berkeley Hills.

Distribution and thickness. The Oursan Sandstone is present in most of the study area except in sections 1, 7, and 10, where it has been removed by post-Monterey erosion. The thickest section of Oursan Sandstone is in the northern portion of the study area in section 11, where it measures 152 m (500 ft) (Bramlette, 1946). The thinnest non-eroded section is the southern area, in section 4, where it is 44 m (146 ft) thick.

Thinning and thickening of the Oursan Sandstone is common. In the southwest portion of the study area, the Oursan Sandstone forms channel-like bodies that appear to thin very rapidly along strike to the north of section 3 (pl. 1). Distinct flute casts or sole marks that indicate a transport direction of N70°E are present near the base of the formation and indicate that it is of probable turbidite origin.

Lithology. The lithology of the Oursan Sandstone is remarkably uniform throughout most of the study area. In outcrop, the Oursan Sandstone is usually composed of massive sandstone that is light gray on a fresh surface and light to rust brown on weathered surfaces. It is hard to friable, usually noncalcareous, slightly silty, and is composed of very fine- to fine-grained, rarely medium-grained, subangular to subrounded grains of quartz, feldspar, dark lithic fragments, and rare mica. In sections 4, 5, and 6, the Oursan Sandstone becomes very silty and is interbedded with yellowish-brown siltstones that are friable, very sandy, and weather spheroidally. The siltstones are found in layers up to 3 m thick.

Although sedimentary structures are rarely found within the Oursan Sandstone, on Oursan Ridge it has parallel laminations composed of light and dark grains. The laminations, 1 to 3 mm thick, sometimes define symmetrical ripple marks .8 cm in amplitude and 11 cm in wavelength; these yield a questionable flow direction of N20°E and indicate a possible turbidite origin for this portion of the Oursan sandstone. In section 3, the contact between the Oursan Sandstone and the underlying Claremont Shale is sharp with fine- to medium-grained sandstones in contact with chert and siliceous shales. In Morrison Canyon, this contact is also sharp, with silty sandstones directly overlying chert and siliceous shales.

Five thin sections were made of the Oursan Sandstone. Four of these sections (pl. 2) were point counted, and the results are detailed in Appendix D. Lithologically, the Oursan Sandstone is almost identical to the Sobrante Sandstone. The Oursan Sandstone is very compact, possibly partly because of tectonic compression. Unstable feldspars and volcanic fragments are partly altered to form a matrix of sericite or clay. This matrix makes up between 5 and 54 percent of the rock (Appendix D). Plagioclase is predominately andesine, with occasional labradorite. Potassium feldspars are predominantly orthoclase with very minor amounts of microcline. Green and brown hornblende usually are present in trace amounts except in a sample from a carbonate concretion in Crow Canyon, in which hornblende makes up 1 percent of the rock. Other accessory minerals found within the Oursan Sandstone in trace amounts include zircon, glauconite, pyrite, sphene, and staurolite. Well-rounded phosphate pellets were found within the Orusan Sandstone in Dublin Canyon (pl. 2). These pellets make up less than 1 percent of the rock (see phosphate occurrences). A chemical analysis of a sample from the Oursan Sandstone in Dublin Canyon indicates that it contains 3 percent phosphorus (Appendix E).

Age and correlation. The age of the Oursan Sandstone and its relationship to the other formations of the Monterey Group is summarized in figure 3.

Microfossils are rare and poorly preserved within the Oursan Sandstone. Foraminifera found within the Oursan Sandstone in the southern portion of the study area indicate a Luisian to late Relizian age (K. A. McDougall, written commun., 1976). Megafossils collected from Dublin Canyon (M 6610) are (W. O. Addicott, written commun., 1976):

Nassarius sp.

Protothaca Tenerrima (Carpenter?)

Solen sp.

Spisula sp.

Tellina aff. T. Emacerata (Conrad)

These megafossils indicate an age of middle Miocene or younger and an environment within the Neritic Zone (between low tide and 92 m (600 ft) in depth) (W. O. Addicott, written commun., 1976). The Oursan Sandstone in the Dublin area was probably faulted out with the Claremont Shale. In the northern portion of the study area, the Oursan Sandstone is Luisian in age (Bramlette, 1946).

Tice Shale

The Tice Shale was named by Lawson (1914) for the bituminous, sometimes chalky shale that crops out in Tice Creek, in the Concord quadrangle.

Distribution and thickness. The thickest section of the Tice Shale was measured in Morrison Canyon (sec. 6) and is 155 m (510 ft) thick; the thinnest non-eroded section was measured in section 3 (pls. 1 and 2) and is 44 m (146 ft) thick. Average thickness of the Tice Shale within the study area is 86 m (283 ft). The Tice Shale is present throughout most of the study area, except where it has been removed by post-Monterey erosion.

Lithology. The best exposures of the Tice Shale are located in Morrison Canyon in the Niles quadrangle (sec. 6). Top and bottom of the formation in section 6 are well exposed and conformable. The contact between the Tice Shale and the underlying Oursan Sandstone is gradational as deposition gradually changed from the coarse-grained Oursan to the fine-grained Tice. The Tice sedimentary sequence indicates a gradual change in deposition of the basal sandy siltstones upward to silty, siliceous shales, porcellanites, and scattered chert beds. Sandy siltstone found at the contact between the Oursan Sandstone and the Tice Shale in section 6 is massive, spheroidally weathered, brittle to friable, brownish-gray, very sandy, clayey, and has scattered carbonaceous fragments, fish scales, and abundant weathered foraminifera. The abundance of poorly preserved foraminifera continues throughout the formation. These sandy siltstones grade into finer grained silty shales that are friable, brownish-gray, slightly sandy, and are interbedded with hard, light gray to gray, strongly siliceous shales in layers up to 8 cm thick. The siliceous shales grade into porcellanites and cherts similar to those found within the Claremont Shale. The chert is well bedded in layers from 1 to 5 cm thick, is hard, dense, and has a smooth to conchoidal fracture. It is light to dark gray, laminated, and interbedded with brittle to friable, silty, siliceous shales that contain abundant foraminifera. Nodules of phosphate 2 mm in diameter are rare and are only found within the chert layers in the Tice Shale. Carbonate concretions are present within the more siliceous portions of the Tice Shale and are similar to those found within the Claremont Shale.

Age and correlation. The age of the Tice Shale and its relationship to the other formations of the Monterey Group is summarized in figure 3. The Tice Shale ranges in age from Luisian (K. A. McDougall, written commun., 1976) in the southern portion to Mohnian (Bramlette, 1946) in the northern and central portions of the study area. Kleinpell (1938, fig. 14) has correlated the foraminiferal fauna of the Tice Shale with that of the lower Mohnian Modelo Formation in the Los Angeles Basin.

Hambre Sandstone

Lawson (1914) first used the name Hambre Sandstone for the sandstone which crops out in Arroyo del Hambre, in the Concord quadrangle.

Distribution and thickness. The Hambre Sandstone is present throughout the study area except where it has been removed by post-Monterey erosion. The thickest measured section of Hambre Sandstone is present in Crow Canyon (sec. 9) and is 183 m (605 ft) thick. However, the Hambre Sandstone apparently thickens north of Crow Canyon; and in the Briones Valley quadrangle, the thickness from mapped contacts is 485 m (1,600 ft). A minimum thickness of 55 m (180 ft) was measured in the southern portion of the study area in section 3 (pls. 1 and 2). The average overall thickness of this formation is 176 m (580 ft).

Lithology. The gradational conformable contact between the Hambre Sandstone and the underlying Tice Shale is best exposed in Morrison Canyon (sec. 6). The ourctop at this locality is stained with jarosite. Porcellanite, chert, and interbedded siliceous shale of the Tice Shale grade into brownish-gray to light gray, silty mudstone and sandy siltstone, which in turn grade into spheriodally weathered, light gray, fine-grained, silty sandstone. The contact between the Tice Shale and Hambre Sandstone is drawn where sandstone predominates over siltstones and mudstones.

The lithology of the Hambre Sandstone is fairly uniform throughout the study area. The formation is typically a massive, jointed sandstone, which has a spheroidal weathering surface that is sometimes stained by jarosite or limonite. The sandstone is light gray to brown, very fine- to medium-grained, and slightly silty. It is usually non-calcareous, with predominantly subangular grains of quartz and feldspar and well-rounded, dark, lithic fragments. In section 6 (pls. 1 and 2) near the top of the Hambre Sandstone, the sandstone is interbedded with yellowish-brown, friable, sandy siltstone in beds .15 m (.5 ft) to .30 m (1 ft) thick.

Five thin sections of the Hambre Sandstone were examined. Three were point counted; the results are presented in Appendix D, and the stratigraphic locations are displayed on plate 2. The microscopic texture and mineralogy of the samples of Hambre Sandstone are very similar to those of the other sandstone formations of the Monterey Group. The sandstone is very compact, probably in part due to tectonic compression. Some feldspar and quartz grains are fractured. Less competent volcanic grains are deformed about quartz grains, forming a type of pseudomatrix. Ten to about 40 percent of the rock is matrix composed of unstable feldspar and lithic fragments that have altered to sericite or clay. Silt makes up almost 22 percent of the rock in section 4. The sandstone is made up of very fine- to medium-grained, angular to subrounded grains of volcanic rock fragments identical to those found in the Sobrante Sandstone, plagioclase that is predominantly andesine, and quartz that displays a 2V of up to 10 degrees. Potassium feldspar, usually orthoclase, and chert grains compose up to 8 percent of the rock.

The heavy minerals from the Hambre Sandstone were examined by Bramlette (1941) who found that the percentage of heavy minerals present within the Hambre Sandstone from the San Pablo area ranged from 2.2 percent within a carbonate concretion, to 0.7 percent in the sand just outside the concretion. The difference is due to the corrosive action of solutions within buried strata, which destroy unstable minerals not protected within carbonate concretions (Bramlette, 1941). Bramlette (1941) identified green and brown hornblende, epidote, ziosite, zircon, garnet, tourmaline, glaucophane, rutile, titanite, andalusite, and opaque minerals from heavy mineral fractions of the Hambre Sandstone.

The sandstone formations of the Monterey Group may have more than one source area. Rock fragments of Franciscan spilite basalt (Ham, 1952) and minerals characteristic of the Franciscan blue schist facies like glaucophane, epidote, actinolite, and sphene indicate that the Franciscan rocks were an important source. Minor amounts of metamorphic minerals like andalusite, staurolite, and garnet indicate that metamorphic terraines in the Sierra Nevadas may have also contributed to the sediment. The abundance of andesine and trace amounts of basaltic hornblende are probably derived from andesitic volcanic rocks. Andesites are exposed in the foothills of the Sierra Nevadas (Dalrymple, 1964).

Age and correlation. Kleinpell (1938, fig. 14) assigns an early Mohnian age to the Tice Shale and a middle Mohnian age to the Rodeo Shale. The Hambre Sandstone lies stratigraphically between these two formations and, thus, is Mohnian in age. No foraminifera were found within the Hambre Sandstone, and the megafossils that were found were either non-diagnostic of age or were too poorly preserved to identify. Its age and stratigraphic relationships to the other formations of the Monterey Group are summarized in figure 3.

Rodeo Shale

Lawson (1914) named the Rodeo Shale for the bituminous, chalky, and locally cherty shale that crops out in Rodeo Creek, Concord quadrangle.

The Rodeo Shale is recognized mainly by its stratigraphic position between the Hambre Sandstone and the Briones Formation. Exposures of the Rodeo Shale are almost nonexistent, and slumping is common on slopes underlain by it.

Distribution and thickness. The Rodeo Shale attains its maximum thickness of 109 m (360 ft) in the San Pablo Bay area (pl. 2, sec. 13). Southward it thins to 48 m (160 ft) in Crow Canyon. The Rodeo Shale is not present south of Dublin Canyon. In Morrison Canyon (pl. 2, sec. 6), several silty shale horizons at the top of the Hambre Sandstone probably are equivalent to the Rodeo Shale in this area. North of Dublin Canyon, the Rodeo Shale is very poorly exposed, and only two sections containing it are presented (pl. 2, secs. 9 and 13).

Lithology. The Rodeo Shale is composed of poorly bedded, brittle to friable, brownish-gray to brown, silty, sandy shale; it is usually calcareous because of the abundance of foraminifera. Calcareous concretions are a distinctive feature of this formation as they are in the other shale members of the Montery Group. Although the Rodeo Shale is described as being very siliceous by Bramlette (1946) (pl. 2, sec. 13), no strongly siliceous beds within the Rodeo Shale were observed.

Age and correltion. In all the samples collected within the Rodeo Shale in this study, foraminifera were too severely weathered to be identified; however, Kleinpell (1938, pl. 14) assigned the Rodeo Shale to the Mohnian stage on the basis of foraminifera.

SAN PABLO GROUP

Briones Formation

The Briones Formation was originally defined and described by Lawson (1914, p. 7) as the "light colored to whitish well-washed sandstone" exposed in the Briones Hills of Alameda County. He considered this sandstone unit to be part of the Monterey Group. Trask (1922) made a detailed study of the fauna and lithology of the Briones Formation and decided that it belonged to the San Pablo Group.

Locally, the Briones Formation can be divided into three members (Hall, 1958): (1) upper, fine-grained sandstone member; (2) middle, lithic wacke, and bioclastic member; and (3) lower, fine-grained sandstone, and interbedded, silty claystone member. Only the lower member will be described in this report.

Lithology. The lower member of the Briones Formation, where it conformably overlies the Monterey Group, is typically a well-bedded, massive, fairly hard to friable, light-brown to brownish-gray sandstone. It usually is calcareous, poorly sorted to moderately well sorted, and is composed mainly of fine- to medium-grained, subangular to subrounded grains of feldspar, dark lithic fragments, and quartz. The quartz, feldspar, and dark lithic fragments give the sandstone its typical "salt and pepper" texture. Accessory minerals include glauconite, biotite, and hornblende. This sandstone is usually interbedded with beds 0.6 to 3.0 m (2 to 10 ft) thick, of brownish-gray, slightly sandy siltstone and claystone. Minor amounts of pyroclastic material is present in the lower sandstone member in Sunol Regional Park (pl. 1).

In localities where the Briones Formation rests unconformably upon the Monterey Group, as in section 7 (pl. 2), the Briones is typically a massive sandstone that is hard, light gray on a fresh surface, and weathers yellowish brown. It is very calcareous and is composed of medium to very coarse, subrounded to subangular grains of quartz, chert, shell debris, and some feldspar.

The contact between the Briones Formation and the underlying Claremont Shale in section 7 is an erosional unconformity or disconformity with no apparent angular discordance. The Briones Formation contains subangular pebbles, cobbles, and boulders of laminated Claremont chert that are up to 0.7 m (2.3 ft) in diameter; these are found for over 2 m above the contact with the Claremont Shale in section 7 (pl. 2).

Age and correlation. No fossils diagnostic of age were collected from the Briones Formation in this study. Trask (1922) determined that the Briones Formation is late Miocene in age. Kleinpell (1938, p. 130), using foraminifera, concluded the Briones Formation is late Mohnian in age.

CONTRA COSTA GROUP

Orinda Formation

The Orinda Formation is the basal unit of the Contra Costa Group (Lawson, 1914) and was first mapped by Lawson and Palache (1902). They interpreted the rocks as being of continental and fluvial origin, and of lower Pliocene age. Richey (1943) discovered marine fossils near the base of the formation and suggested that it ranges in age from late Miocene to early Pliocene.

Lithology. The Orinda Formation is composed of conglomerates, medium- to coarse-grained sandstone, and red, gray, and green siltstone. Pebbles in the lenticular conglomerates consist mainly of Franciscan graywacke, chert, basalt, greenstone, Cretaceous sandstone, and Monterey chert (Case, 1968).

The Orinda Formation was observed in only two localities--in Claremont Canyon and near the Upper San Leandro Reservoir. In both of these localities, the contact between the Orinda Formation and the underlying Claremont Shale was obscured by soil or landslide debris. Case (1968) mapped the contact between the Claremont Shale and the Orinda Formation as a erosional contact with possible angular discordance. Considerable erosion of the Monterey Group must have taken place before deposition of the Orinda Formation.

DEPOSITIONAL ENVIRONMENT OF THE MONTEREY GROUP

Sobrante Sandstone

The Sobrante Sandstone is the basal formation of the Monterey Group and a marine transgressive sequence. Good exposures of the Sobrante Sandstone are present in the southern portion of the study area in section 3, where the formation is 29 m (95 ft) thick. At the base of the Sobrante Sandstone at this locality, tabular clasts of Berryessa siltstone display a distinct imbrication indicating that a current flowed from southwest to northeast. Small-scale crossbeds and parallel laminations within the lower 10 m (33 ft) of the Sobrante Sandstone in section 3 were probably produced by currents or shoaling waves. Average waves can produce ripples in sediment in water depths of 50 to 100 m (165 to 330 ft)(Komar and others, 1972). Absence of sedimentary structures in the upper 19 m (63 ft) of the formation in section 3 may indicate that, at the time of deposition, water depth had increased over 100 m (330 ft). Sandstones of the Sobrante Sandstone grade into mudstones of the overlying Claremont Shale. This transition indicates a lower energy environment, probably found in water depths greater than 100 m.

Environmental factors inferred from benthonic foraminifera found within the Sobrante Sandstone north of Dublin Canyon (pl. 1) are shown in plate 3. Species for foraminifera are grouped into depth-controlled biofacies (Table 1), based on the work of Arnal (1976). Due to the limited number of foraminifera, only very general environmental interpretations can be made. The graph in plate 3 indicates that the Sobrante Sandstone may have been deposited within the middle to lower bathyal biofacies (between 500 and 2,500 m). Lutz (1951, p. 378) used megafossils to hypothesize the deposition of the Sobrante Sandstone in the San Leandro Hills took place principally in waters below the littoral zone (deeper than 200 m).

Table 1. -- Biofacies zones from Arnal (1976).

Biofacies zones	Water depth in meters
Inner Sublittoral biofacies	0-60
Outer Sublittoral biofacies	60-180
Upper bathyal biofacies	180-500
Middle bathyal biofacies	500-1,000
Lower bathyal biofacies	1,000-2,500
Abyssal biofacies	2,500

Claremont Shale

Environmental conditions in the study area during deposition of the diatomites that later altered to form the Claremont Shale are assumed to have been similar to the conditions controlling the formation of recent diatomaceous deposits.

The main conditions controlling the formation of diatomaceous deposits are (Riedel, 1959): (1) the rate of production of siliceous organisms in the overlying waters; (2) the degree of dilution of siliceous remains by terrigenous, volcanic, and calcareous organic contributions; and (3) the extent of the solution of siliceous skeletons.

Massive diatom blooms and a low rate of terrigenous sedimentation are necessary conditions for accumulation of the amount of diatomite needed to produce the Claremont Shale and other siliceous shale formations within the study area. The source of silica needed for massive diatom blooms is a topic of controversy. Silica from volcanic sources has been suggested (Taliaferro, 1933; Bramlette, 1946); however, in studies of recent diatomaceous deposits, upwelling of nutrient-rich, deep ocean water has been found to contain sufficient silica for the accumulation of large quantities of biogeneous silica in the sediments of the Gulf of California (Calvert, 1966).

Volcanic deposits within the study area do not appear large enough to be a significant source of silica. Therefore, upwelling of nutrient-rich, deep ocean water is the probable source of silica and other nutirents.

Diatomite is composed of diatoms, microscopic plants that secrete siliceous frustules. Because of their small size, diatoms probably accumulate in very low energy environments, below wave base.

Environmental factors inferred from foraminifera found within the Claremont Shale throughout the study area are shown in plate 3. The limited number of foraminifera obtained imply that the Claremont Shale was probably deposited within the upper bathyal biofacies (180 to 500 m). Modern diatomite layers have been found accumulating in water 224 to 632 m (672 to 1,896 ft) deep (Burnett, 1974).

Also within the Claremont Shale, a large number of specimens, but a comparatively low number of species, indicate deposition in the outer sublittoral zone (60 to 180 m). Deposition of parts of the Claremont Shale could have taken place within this zone.

Some diatomites that formed the Claremont Shale were probably deposited on gentle slopes. Minor gravity slumps, typified by low amplitude, overturned folds defined by laminations are visible within some chert layers. Such folds are commonly turncated at the top by undisturbed parallel laminations, which implies that the folds formed during deposition, before lithification. These deformational features also indicate that the laminations present within chert layers are a depositional feature. The preservation of these laminations implies an absence of burrowing organisms, which is probably due to the lack of oxygen within the water mass at the sediment surface. The occasional occurrence of pyrite within the siliceous shales also indicates a reducing environment.

Oursan Sandstone

In most localities where the contact between the Oursan Sandstone and the underlying Claremont Shale is visible, it is usually sharp and conformable. Hall (1958), from an analysis of megafossils, concluded that the Oursan Sandstone was deposited in a sandy to muddy bay environment. This interpretration is probably correct for the southeast portion of the study area. However, it does not reflect the conditions of deposition to the west in section 3 (pls. 1 and 2), where the Oursan Sandstone is a turbidite sand with distinct flute casts. These flute casts indicate a flow coming from N70^{o}E. This influx of terrigenous sediment was probably caused by uplift and subsequent erosion of a land mass northeast of the basin. In other localities, parallel laminations, current ripples 0.8 cm in height and 11 cm in wavelength, and ripple crossbeds indicating a possible flow direction of N20^{o}E, suggest that currents or wave action affected the sediment surface.

Within the Oursan Sandstone, the largest number of species and specimens are found in the upper bathyal biofacies (180 to 500 m). Not enough data is available to make any estimation of the depth zone in which this formation originated.

Tice Shale

The paleobathymetric data derived from foraminifera from the Tice Shale is plotted in plate 3. Not enough specimens were obtained to determine the exact conditions of deposition for the Tice Shale. However, enough indentifiable foraminifera were obtained to make generalizations about the paleobathymetry of a few specific localities. Three samples of the Tice Shale were collected at the southwest end of the

San Pablo Dam in the northern portion of the study area by D. H. Radburch in 1966. All three samples (Mf 874, 5, 6) contained foraminifera characteristic of water depths less than 100 m and probably less than 50 m (P. B. Smith, written commun., 1966). Foraminifera from the Tice Shale in section 3 (pl. 2, Mf 3339), in the southern portion of the study area, indicate deposition in the upper bathyal biofacies (180 to 500 m) (K. A. McDougall, written commun., 1976).

Hambre Sandstone.

The exact conditions of deposition of the Hambre Sandstone cannot be determined because of the absence of diagnostic fossils and the rarity of sedimentary structures. Crossbeds and parallel laminations found in this formation in the northern portion of the study area suggest that the Hambre Sandstone was deposited above wave base. Average waves can produce ripples in sediment in water depths of 50 to 100 m (Komar and others, 1972).

Rodeo Shale

The conditions of deposition of the Rodeo Shale cannot be determined because no diagnostic fossils were obtained and no sedimentry structures were seen. The fine-grained lithology of the Rodeo Shale implies that it was deposited in a deeper environment than the Hambre Sandstone.

PHOSPHATE OCCURRENCES IN THE EAST SAN FRANCISCO BAY REGION

Introduction

Deposition of phosphatic sediments in present and ancient oceans is generally thought to be related to upwelling of cold phosphate-rich waters off the west coast of continents (Kazakov 1937; McKelvey and others, 1953), and in the trade-wind belt in relatively warm climates at latitudes between 40°N and 40°S (Sheldon, 1964). For a current review of the literature on the formation of marine phosphorites, the reader is referred to McKelvey (1967) and Gulbrandsen (1969).

The marine phosphatic facies of the Monterey Group and its stratigraphic equivalents are best developed in central and southern California (Gower and Madsen, 1964). The largest known deposits of these phosphate-bearing rocks are in Kern, San Luis Obispo, and Santa Barbara Counties (A. E. Roberts, oral commun., 1976). The Coast Ranges east of San Francisco Bay form the northernmost extension of this facies (Dickert, 1966).

Three principal types of phosphate rock represent differing modes of occurrence in the Coast Ranges in California (Gower and Madsen, 1964, p. D79): nodular, pelletal, and argillaceous laminar. Of these, only pelletal and nodular types were recognized in the study area. Phosphatic sandy mudstone pebbles are found only locally; these may be equivalent to the argillaceous laminar type of phosphate rock.

Twenty samples of phosphate taken from within the study area and one sample collected by A. E. Roberts from Indian Creek at Wilson Corner, San Luis Obispo County, California, were examined petrographically and by using a Cambridge Steroscan 180 Scanning Electron Microscope (SEM) equipped with an Energy Dispersive Analysis of X-rays (EDAX) system. The EDAX system identifies major elements by analyzing x-rays generated when the SEM bombards the sample with electrons.

The P_2O_5 content of samples was estimated by the method of Shapiro (1952) with modifications and calibrations by R. A. Gulbrandsen (oral commun., 1976). In addition, these rock samples that contained nodular, pelletal or pebbles of phosphate were analysed by the U.S. Geological Survey's branch of analytical laboratories by Karen Duvall. A semiquantitative, six-step spectrographic analysis was done on each sample. The results of the analyses are presented in appendix E.

Phosphate nodules. Phosphate nodules, composed of carbonate apatite, are disseminated throughout laminated chert and siliceous shales of the Claremont Shale and, very rarely, in the siliceous portions of the Tice Shale. The nodules are white to very pale orange, and range in size from 0.01 mm in diameter to large, lozenge-shaped nodules averaging 0.5 cm in thickness and 1 cm in length. They occur in apparently continuous horizons several centimeters to over 5 m (17 ft) thick. One laminated, dark-gray chert bed 0.45 m (1.5 ft) thick, found 27 m (92 ft) stratigraphically below the Briones-Claremont contact in Alum Rock Canyon, contains abundant, coarse sand-sized phosphate grains. This bed was traced 7.5 m (25 ft) laterally with no apparent variation in the number of phosphatic grains.

The nodules display compressional features. Thinning and thickening is common in nodules longer than 2 cm. Laminations within chert beds curve around and conform to the shale of the nodules. Such features indicate that the nodules formed directly after deposition, before compaction and lithification of the sediment.

In thin sections, nodules are cryptocrystalline to very fine crystalline. They are very weakly birefringent when crystals are visible. No terrigenous or biogenic particles were identified within the nodules. Contacts between nodules and the surrounding chert are sharp.

SEM studies at 1500 magnification were conducted on a nodule from the Claremont Shale collected near the Upper San Leandro Reservoir. The nodule is composed of globular masses that have a mean diameter of 1.8 microns. EDAX analysis indicates oxygen, aluminum, silicon, phosphorus, and calcium to be present.

SEM studies of three other nodules from different localities from within the study area indicate similar globular masses. The mean diameters of these masses range from 0.9 to 1.8 microns. These nodules have elemental compositions similar to that of the sample discussed above, except that iron is present in small amounts. They also contain 29 to 33 percent P_2O_5, the highest concentration found within the study area. A sample of the Claremont Shale from Morrison Canyon that contained these nodules contains one percent phosphorus (Appendix E).

The origin of the nodules must be related to the origin of the cherts containing them. The chert and siliceous shales of the Monterey Group in the study area were originally diatomites. Inorganic precipitation of carbonate apatite takes place around a nucleation site such as the surface of siliceous, skeletal debris. The time required is on the order of a few thousand years (Burnett, 1974). The phosphate nodules within the study area are probably originated in a similar fashon.

Phosphate pellets. Pellets of phosphate are found within the Claremont Shale in Alum Rock Canyon and Oursan Ridge (pl. 1). Pellets are also found in the lower portion of the Oursan Sandstone off Pinole Valley Road (Dickert, 1966) and in the Hambre Sandstone in Dublin Canyon (pl. 2).

The pellets are light brownish-gray to brown, and are spherical, elliptical, or tabular. Pellets from Dublin Canyon and Oursan Ridge have a mean diameter of 0.2 mm but may be as large as 0.5 mm in length; those from Alum Rock Canyon are larger, with a mean diameter of 0.42 mm and a maximum of 1.0 mm in length.

The pellets have cores of very fine sand-sized, angular quartz, or feldspar, surrounded by layers of brown phosphate. The pellets are isotropic and contain abundant silt-sized inclusions. Pellets from Dublin Canyon are predominately isolated within the sand matrix, in groups of three or more. The pellets are deformed about one another as though they had once been plastic. The Claremont Shale on Oursan Ridge has most pellets; two beds 25 and 75 cm thick consist of 50 and 90 percent pellets, respectively (Dickert, 1966). In all other localities examined, pellets make up less than one percent by volume of the rock.

Analysis of phosphate pellets found within the Claremont Shale from Oursan Ridge yield 18 percent P_2O_5. In other localities, pellets were lacking in sufficient quantity for analysis. A sample of the pellet-bearing Oursan Sandstone in Dublin Canyon contains 3 percent phosphorus (Appendix E).

Environmental and paleoenvironmental studies suggest that the most favorable conditions for the formation of pelletal phosphorite are in water depths of 100 m (330 ft) and probably less than 50 m (165 ft)(D'Anglejan, 1967; Smith, 1968). Ocean currents, which doubtless were important in the shaping of the pellets, would probably not have permitted accumulation of the diatomite that altered to form the chert and siliceous shale of the Claremont Shale, in which the pellets were found. Therefore, the pellets within the Claremont Shale in Alum Rock Canyon were probably transported from a shallower water environment where waves or currents were present.

The surface texture of the phosphate pellets from the Claremont Shale in Alum Rock Canyon were compared with the surface texture of pelletal phosphate from Indian Creek in San Luis Obispo County, California. The sample from Indian Creek was collected from the locality where Smith (1968), using foraminifera, estimated a paleobathymetric depth of 60 m (190 ft) or less. The samples were examined with the SEM. The surface texture of the pellets from Indian Creek, at 460 magnification, is fairly smooth with only scattered pitting. The surfaces of the pellets from Alum Rock Canyon, at 110 magnification, are badly pitted and abraded; visible scratches appear at 332 magnification. Such features indicate that the pellets from Alum Rock Canyon have been transported.

Phosphatic sandy mudstone pebbles. Pebbles of phosphatic sandy mudstone are present in the upper Hambre (?) Sandstone between Hollis Canyon and Devany Canyon (pl. 1). These pebbles were not found in Crow Canyon 4 km (2.5 mi) to the north, indicating the limited areal extent of the phosphatic pebbles.

A well-exposed stratigraphic section of the Monterey Group was measured in road cuts along Interstate 580 in Dublin Canyon (sec. 8). Phosphatic pebbles were first encountered 376 m (1,240 ft) stratigraphically above the contact between Cretaceous and Monterey rocks (pl. 2). These phosphatic pebbles are not the first occurrence of phosphate in this section; at 276 m (910 ft)(pl.2) above this contact, oolitic pellets of phosphorite were found, which constituted less than one percent of the rock. The phosphate pebble zone in Dublin Canyon (sec. 8) is not well exposed, and detailed stratigraphic relationships could not be determined. Good exposures of the pebble zones were found in both Hollis and Devany Canyons, where detailed sections were measured (pls. 1 and 4, secs. 8a and 8b). In Hollis Canyon (sec. 8a), a stratigraphic section 16.4 m (54 ft) thick was measured within the phosphatic pebble zone. The heaviest concentration of pebbles occurs in the middle sandstone bed (pl. 4). Well-rounded phosphatic mudstone pebbles are concentrated in a fine- to medium-sized sand matrix in the lower 20 cm of this bed to form a conglomeratic layer. The pebble zones contain 3 percent phosphorus (Appendix E). The pebbles contain 16 to 18 percent P_2O_5 and range from 0.3 to 1.5 cm in diameter. A decrease in the number of pebbles occurs above this conglomeratic horizon, and pebbles are not found in the upper 0.91 m of the bed. The pebbles contain 5 to 10 percent very fine, angular quartz and feldspar grains in a brownish-gray, silty, cryptocrystalline matrix. SEM examination indicates that the pebbles are composed of sand and other terrigenous debris in a phosphatic matrix. At high magnification, authigenic quartz crystals are visible. EDAX analysis indicates aluminum, silicon, calcium, phosphorus, and iron as the major elements in this material.

In Devany Canyon (sec. 8b) a stratigraphic section 26.1 m (86 ft) thick was measured. The beds exposed are very similar to those found in Hollis Canyon. Sandy, phosphatic mudstone pebbles are found in sandstone beds interbedded with siltstones and shales. The pebbles are concentrated in zones 11 to 15 cm thick at the base of the beds, and decrease in number toward the top of the bed. The pebbles contain 17 percent P_2O_5.

Poor exposures and complex structural relations prohibited any tracing of the pebble beds from Hollis Canyon south to Devany Canyon. The pebble beds in both canyons seem to occur at the same stratigraphic horizon and are possibly related.

The origin of the phosphatic pebbles is unclear. The distinct, normal grading and sharp contact with underlying shales and siltstones indicate a mass-flow origin. No directional features were seen. These pebbles probably originated from a sandy, phosphatic mud deposit that was later disrupted, possibly by a storm, and transported to deeper water in mass flows. Poor sorting of the pebble-bearing horizons possibly means that these sediments were not transported very far from their point of origin.

Organic phosphatic material. Phosphatic fish bones and scales are common within the Monterey Group and are most often found in the shale and siliceous shale beds. However, no phosphatic shell material was found in the study area.

Phosphatic rocks of the Monterey Group in the East Bay Region are not commercial by present economic values for phosphate for the following reasons: (1) the stratigraphic zones consist of a few individual phosphatic beds that are generally less than a meter thick; and (2) the beds contain much less than the 30 percent P_2O_5 required for the manufacture of phosphatic products.

MIOCENE TECTONICS AND ITS RELATIONS TO SEDIMENTATION

Near the end of Oligocene time (24 m.y. ago), the subduction of the Farallon Plate beneath central California was complete (Atwater, 1970); the major changes that this caused in plate configuration and motion may have affected structural forces within California. Blake, and others (1978) suggest that changes in relative motion between the Pacific and American plates produced extensional strain along the continental margin of California. This strain was manifested in middle Miocene time (10 to 14 m.y. ago) in the formation of basins along the continental margin west of the San Andreas fault, the present plate boundary (Blake and others, 1978).

In the study area of this paper, the basin in which the Monterey Group was deposited began to subside in early to middle Miocene time. Its formation may have been generated or influenced by the tectonic forces discussed previously, even though it lies east of the San Andreas fault. The Monterey Group is a marine transgressive sequence. The Sobrante Sandstone was deposited in a shallow water, high energy environment present during the early stages of a transgressing sea. As the basin subsided and a low energy environment took place, diatomite deposition together with a low rate of terrigenous sedimentation deposited the Claremont Shale. Uplift, probably to the east of the study area, caused an influx of turbidite-deposited sandstones of the Oursan Sandstone. When turbidite deposition ceased, deposition of the Tice Shale began with the influx of fine-grained, terrigenous, locally diatomaceous sediment. In the southern portion of the study area, this deposition began in Luisian ,and in the northern portion, it began in the Mohnian. As the basin of deposition filled with sediment, a shallower, higher energy environment prevailed during deposition of the Hambre Sandstone. These conditions prevailed in the southern portion until the deposition of the Briones Formation. In the northern portion, a lower energy environment was again present during deposition of the Rodeo Shale before deposition of the overlying Briones Formation.

Case (1968) stated that the depositional basin of the Monterey Group was outlined by the Hayward and Calaveras faults (pl. 1). Across these faults, the Monterey Group undergoes drastic changes in thickness. These changes in thickness are probably due to post-Monterey erosion and strike-slip displacements along these faults. Depositional features found within the Monterey Group seem to indicate that the boundaries of the depositional basin extended beyond these faults. Thickness of the Claremont Shale increases in the northwest portion of the study area, and the maximum measured thickness is found in Claremont Creek (pls. 1 and 2, sec. 10), near the Hayward fault. Flute casts within the Oursan Sandstone, in section 3, very close to the Hayward Fault, indicate this area to have been a relatively deep portion of the basin. Also, the flute casts indicate a flow direction of N70^{o}E flowing toward the Hayward Fault, not away from it. Sandstones and siliceous shales of middle Miocene age, similar to those found within the study area, are present to the west, in the Palo Alto quadrangle (T.W. Dibblee, oral commun. 1976).

The Calaveras fault is the eastern boundary of the study area. The strandline of the middle Miocene Sea apparently was close to and east of this fault, just south of Mount Diablo (Repenning, 1960, fig. 9). The changes in thickness across the Calaveras fault are probably best explained by strike-slip motion on the fault; Prowell (1974) has estimated 11 to 27 km of right lateral strike-slip displacement along the Calaveras fault in the past 3.5 m.y.

The thinning of the Monterey Group rocks in the southern portion of the study area, where the Hayward and Calaveras faults begin to converge, indicates that the area between the faults was rising during deposition. When right lateral strike-slip faults converge, the block between the faults is elevated (Crowell, 1974). The elevation of this block may be an indication that the Hayward and Calaveras faults were active strike-slip faults as early as middle Miocene (Luisian) time. Hall (1958) suggested that the Calaveras fault system originated from ancestral faults in Eocene or Oligocene time.

The Mission Fault was active in middle Miocene time. Stratigraphic sections 4 km (2.5 mi) apart were measured on each side of the Mission Fault. Section 6, in Morrison Canyon, is east of the fault and section 7 is to the west. The approximate thickness of the Monterey Group in Morrison Canyon is 479 m (1,580 ft)(pl. 2). All the formations of the Monterey Group, except the Rodeo Shale, are present in Morrison Canyon. The contact between the overlying Briones Formation and the underlying Monterey Group appears to be conformable and gradational. In section 7, where the total thickness of the Monterey Group is 130 m (429 ft), the Claremont Shale is the only formation of the Monterey Group present, and the Briones Formation rests disconformably upon it.

Since large angular blocks of Claremont chert and siliceous shale are found within the Briones Formation in section 7, the diagenetic conversion of diatomite to siliceous shale, porcellanite, and chert which presently compose the Claremont Shale must have been complete before erosion took place and deposition of the Briones Formation began. This diagenetic reaction, as discussed earlier in this paper, was caused by heat and pressure of burial, probably by the same formations as those found above the Claremont Shale in section 6. These formations were elevated by dip-slip movement on the Mission fault and, subsequently, eroded before deposition of the Briones Formation in late Miocene time. Thus, the 350 m (1,155 ft) difference in the stratigraphic thickness between the Monterey Groups in section 6 and in section 7 may approximate the dip-slip displacement of the Mission fault.

REFERENCES CITED

Arnal, R. C., 1976, Miocene paleobathymetric changes of the Santa Rosa-Cortes Ridge area, California Continental Borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication no. 24, p. 60-79.

Atwater, T. M., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, no. 12, p. 3513-3536.

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Barbat, W. F., 1971, Megatectonics of the Coast Ranges, California: Geological Society of America Bulletin, v. 82, no. 6, p. 1541-1562.

Blake, M. C., Jr., Campbell, R. H., Dibblee, T. W., Jr., Howell, D. G., Nilsen, T. H., Normark, W. R., Vedder, J. C., and Silver, E. A., 1978, Neogene basin formation in reltion to plate-tectonic evolution of San Andreas fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, no. 3, p. 344-372.

Bramlette, M. N., 1941, The stability of minerals in sandstone: Journal of Sedimentary Petrology, v. 11, no. 1, p. 32-36.

______1946, The Monterey Formation of California and the origin of its siliceous rocks: U.S. Geological Survey Professional Paper 212, 57 p.

Burnett, W. C., 1974, Phosphorite deposits from the sea floor off Peru and Chile--radiochemical investigtions concerning their origin: Hawaii Institute of Geophysics Report HIG-74-3, 164 p.

Calvert, S. E., 1966, Accumulation of diatomaceous silica in the sediments of the Gulf of California: Geological Society of America Bulletin, v. 77, no. 6, p. 569-596.

Case, J. E., 1968, Upper Cretaceous and Lower Tertiary rocks, Berkeley and San Leandro Hills, California: U. S. Geological Survey Bulletin, 1251-J, 29 p.

Clark, B. L., 1915, Fauna of the San Pablo Group of middle California: California University Publications, Geological Science Bulletin, v. 8, no. 22, p. 385-572.

________1918, The San Lorenzo series of middle California: California University Publications, Geological Science Bulletin, v. 11, no. 2, p. 45-234.

______1921, The Marine Tertiary of the west coast of the United States--its sequence, paleogeography, and the problems of correlation: Journal of Geology, v. 29, no. 7, p. 583-614.

Crittenden, M. D., Jr., 1951, Geology of the San Jose-Mount Hamilton area, California: California Division of Mines Bulletin, 157, 74 p.

Crowell, J. C., 1974, Origin of Late Cenozoic basins in southern California: Society of Economic Paleontologists and Mineralogists Special Publication, no. 22, p. 190-204.

D'Angeljan, B. F., 1967, Origin of marine phosphorite off Baja California, Mexico: Marine Geology, v. 5, no. 1, p. 15-44.

Dalrymple, G. B., 1964, Cenozoic chronology of the Sierra Nevada, California: California University Publications, Geological Science Bulletin, v. 47, 41 p.

Dibblee, T. W., Jr., 1972, Preliminary geologic map of the Calaveras Reservoir Quadrangle, Alameda and Santa Clara Counties, California: U. S. Geological Survey Open File Map.

Dickert, P. F., 1966, Tertiary phosphatic facies of the Coast Ranges, in Bailey, E. H., ed., Geology of northern California: California Division of Mines and Geology Bulletin, 190, p. 289-304.

Dickinson, W. R., 1970, Relations of andesites, granites, and derivative sandstones to arc-trench tectonics: Reviews of Geophysics Space Physics, v. 8, p. 813-860.

Dickinson, W. R., and Rich, E. I., 1972, Petrologic intervals and petrofacies in the Great Valley Sequence, Sacramento Valley, California: Geological Society of America Bulletin, v. 83, no. 12, p. 3007-3024.

Durham, J. W., 1962, The late Mesozoic of central California: California Division of Mines and Geology Bulletin, 181, p. 31-38.

Emigh, G. D., 1967, Petrology and origin of phosphorites, in Anatomy of the western phosphate field—Intermountain Association of Geologists, p. 103-114.

Gower, H. D., and Madsen, B. M., 1964, The occurrence of phosphate rock in California, in Short papers in geology and hydrology: U. S. Geological Survey Professional Paper 501-D, p. 79-85.

Gulbrandsen, R. A., 1969, Physical and chemical factors in the formation of marine apatite: Economic Geology, v. 64, no. 4, p. 365-382.

Hall, C. A., Jr., 1958, Geology and paleontology of the Pleasanton area, Alameda and Contra Costa Counties, California: California University Publications Geological Science Bulletin, v. 34, no. 1, p. 1-89.

Ham, C. K., 1952, Geology of Las Trampas Ridge, Berkeley Hills: California Division of Mines Special Report 22, 26 p.

Hamilton, W. B., 1969, Mesozoic California and the underflow of Pacific mantel: Geological Society of America Bulletin, v. 80, no. 12, p. 2409-2430.

Irwin, W. P., 1957, Franciscan Group in Coast Ranges and its equivalents in Sacramento Valley, California: American Association of Petroleum Geologists Bulletin, v. 41, no. 10, p. 2284-2297.

Kazakov, A. V., 1937, The phosphorite facies and the genesis of phosphorites, in Geological investigations of agricultural ores U.S.S.R.: Science Institute Fertilizers and Insectofungicides Translations (USSR), no. 142, p. 95-113. (Special issue in English published for 17th International Geological Congress).

Kleinpell, R. M., 1938, Miocene stratigraphy of California: Tulsa, Oklahoma, American Association of Petroleum Geologists, 450 p.

Komar, P. D., Neudeck, R. H., and Kulm, L. D., 1972, Observations and significance of deep water oscillatory ripple marks on the Oregon continental shelf, in Shelf sediment transport processes and patterns, edited by Swift, D. J. P., Duane, D. B., and Pilkey, O. H.: Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Penn., 656 p.

Lawson, A. C., 1914, Description of the San Francisco district--Tamalpias, San Francisco, Concord, San Mateo and Hayward quadrangles: U. S. Geololgical Survey Geologic Atlas, Folio 193, 24 p.

Lawson, A. C., and Palache, C., 1902, The Berkeley Hills, a detail of Coast Range geology: California University Publications, Geological Science Bulletin, v. 2, p. 349-450.

Lutz, G. C., 1951, The Sobrante Sandstone: California University Publications, Geological Science Bulletin, v. 28, no. 13, p. 367-406

Murata, K. J., Friedman, Irving, and Madsen, B. M., 1969, Isotopic composition of diagenetic carbonates in marine Miocene formations of California and Oregon: U. S. Geological Survey Professional Paper 614-B, 24 p.

Murata, K. J., and Larson, R. R., 1975, Diagenesis of Miocene siliceous shales, Temblor Range, California: Journal of Research, U. S. Geological Survey, v. 3, no. 5, p. 553-566.

McKelvey, V. E., 1967, Phosphate deposits: U. S. Geological Survey Bulletin, 1252, 21 p.

McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953, The Permian phosphate deposits of western United States: 19th International Geological Congress, Comptes rendus, section 11, part 11, p. 45-64.

Perkins, M. E., 1975, Geology and petrology of the East Bay outlier of the late Mesozoic Great Valley sequence, Alameda County, California: University of California, Berkeley, unpublished M.S. thesis, 120 p.

Peterson, G. L., 1966, Structural interpretation of sandstone dikes, northwest Sacramento Valley, California: Geological Society of America Bulletin, v. 77, no. 9, p. 833-842.

Prowell, D. C., 1974, Geology of selected Tertiary volcanics in the Central Coast Range Mountains of California and their bearing on the Calaveras and Hayward fault problem: University of California, Santa Cruz, Ph.D. thesis, 182 p.

Repenning, C. A., 1960, Geologic summary of the Central Valley of California with reference to the disposal of liquid radioactive waste: U. S. Geological Survey TEI-769, 69 p.

Richey, K. A., 1943, A marine invertebrate fauna from the Orinda Formtion, California: California University Publications, Geological Science Bulletin, v. 27, p. 25-36.

Riedel, W. R., 1959, Siliceous organic remains in pelagic: Society of Economic Paleontologists and Mineralogists Special Publication 7, p. 80-91.

Shapiro, Leonard, 1952, Simple field method for determination of phosphate in phosphate rocks: American Mineralogist, v. 37, nos. 3 and 4, p. 341-342.

Sheldon, R. P., 1964, Paleolatitudinal and paleogeographic distribution of phosphorite, in Short papers in geology and hydrology: U. S. Geological Survey Professional Paper 501-C. p. 106-113.

Smith, P. B., 1968, Phosphate-bearing Monterey Shale, Salinas Valley, California: American Association of Petroleum Geologists Bulletin, v. 52, no. 9, p. 1785-1791.

Taliaferro, N. L., 1933, The relation of volcanism to diatomaceous and associated siliceous sediments: California University Publications, Geological Science Bulletin, v. 23, no. 1, 55 p.

_______1941, Geologic history of the Central Coast Ranges of California: California Division of Mines and Geology Bulletin, part 2, p. 119-163.

Trask, P. D., 1922, The Briones Formation of middle California: California University Publications, Geological Science Bulletin, v. 13, no. 5, p. 133-174.

Weaver, C. E., and others, 1944, Correlation of the marine Cenozoic formations of Western North America: Geological Society of America Bulletin, v. 5, no. 1, p. 243-269.

APPENDIX A

Lithologic description of the type section of the Claremont Shale in Claremont Canyon (pl. 2, col. 10)

(Measured by J. M. Hill and G. A. Younse, 1976)

Contact between Cretaceous rocks and Monterey covered

Sobrante Sandstone	Meters	Feet
Sandstone, massive, jointed, hard, light greenish-gray, fine- to medium-grained, predominantly subrounded grains of quartz, feldspar, dark lithic fragments, and rare biotite.	13.8	45.4
Sandstone, massive, jointed, sheared in places, light brown, noncalcareous, fine- to medium-grained, predominantly quartz, feldspar, dark lithic fragments, and rare biotite.	16.9	55.8
Sandstone, massive, hard, light brown to light gray, fine-grained, well sorted, noncalcareous, predominantly subangular grains of quartz, feldspar, and dark fragments, some thin shale stringers.	19.7	65.1
Shale, friable, brownish-gray, silty, sandy with very fine sand.	3.03	10.0
Sandstone, hard, light brown, glauconitic, fine- to medium-grained, predominantly subangular quartz and feldspar.	4.55	15.0
Total measured thickness of Sobrante Sandstone.	57.98	191.3
Claremont Shale		
Fault zone--sheared, angular fragments of shale, siltstone, and siliceous shale.	3.76	12.4

	Meters	Feet
Porcellanite, hard, very silty, interbedded with shale, friable, brownish-gray, slightly sandy. Dolomite concretion, hard, 1.7 ft in thickness, weathering ocherous brown.	1.39	4.6
Chert, hard, well bedded in layers 5 to 20 cm thick, laminated with laminae from .5 to 1.0 mm thick dark gray, interbedded with shale, brittle to friable, well bedded in layers .5 to 2.0 cm thick, siliceous, silty.	1.36	4.5
Shale, brittle to friable, medium gray, slightly silty, some horizons siliceous scattered white grains.	1.82	6.0
Deformed zone--strongly folded varied lithology, dark gray laminated cherts interbedded with light gray, friable shale and scattered ocherous weathering dolomite concretions.	8.55	28.2
Chert, deformed, laminated, interbedded with thin bedded shale.	3.33	11.0
Sandstone, massive, jointed, light gray, calcareous medium-grained, predominantly subrounded quartz, lithic fragments and feldspar with rare biotite. Grades upward into sandy siltstone.	4.30	14.2
Sheared zone--angular fragments of laminated chert and siliceous shale.	.45	1.5
Chert, hard, well bedded in layers from 1 to 3 cm thick, weathered, rust brown to light gray, laminated, with scattered medium-grained nodules of phosphorite, interbedded with shale, friable, medium gray, slightly sandy in layer 2.0 to 5.0 cm thick.	3.52	11.6

	Meters	Feet
Small fault.	.06	.2
Chert, hard, well bedded in layers 10 to 13 cm thick, laminated and unlaminated, interbedded with shale, brittle to friable, well bedded in layers 1 to 2 cm thick, brownish-gray, slightly sandy, siliceous in part.	6.55	21.6
Siltstone, friable, rust brown, sandy.	.39	1.3
Sandstone, hard, well bedded, jointed noncalcareous, light gray to rust brown, medium-grained, predominantly subangular grains of quartz, feldspar, and dark lithic fragments.	.79	2.6
Dolomite concretion, hard, light gray on fresh surface to ocher on weathered surface, scattered medium dark grains.	.55	1.8
Chert, hard, in layers 1 to 8 cm thick, light gray to medium gray, laminated with laminae .5 mm thick, interbedded with shale, friable, in layers 1 to 7 cm thick, slightly sandy with scattered white grains. Layers cut by a sandstone dike 17 cm thick.	2.61	8.6
Limestone, hard, laminated, ocherous weathering.	.21	.7
Chert, hard, laminated, interbedded with thin, friable shale.	2.39	7.9
Shale, sheared, friable, medium gray, slightly silty with scattered white sand grains.	1.00	3.3
Chert, hard, in layers 2 to 6 cm thick, light gray to white, massive and laminated, interbedded with shale, friable, in layers .5 to 1 cm thick, gray, slightly sandy.	6.76	22.3

	Meters	Feet
Shale, brittle to friable, well bedded in layers 1 to 14 cm thick, brownish-gray, slightly sandy with dark grains.	3.58	11.8
Covered.	53.82	177.6
Porcellanite, hard, well bedded in layers 1 to 3 cm thick, light brownish-gray, silty, sandy.	1.48	4.9
Volcanic tuff?, brittle, white, very fine-grained glass shards?	.21	.7
Porcellanite, hard, light gray, interbedded with medium-gray shale.	.52	1.7
Mudstone, blocky, brittle, medium gray, slightly shaly and sandy.	1.09	3.6
Siltstone, hard, moderately well bedded, light brown to light gray, siliceous in part, slightly sandy with very fine- to fine-grained sand, jarosite staining.	7.67	25.3
Porcellanite, well bedded, 1.5 to 3.0 cm, slightly sandy, interbedded with shale, .5 to 1.0 cm thick, light brown, fish scales.	5.88	19.4
Siltstone, brittle, well bedded in layers 4 to 20 cm thick, slightly shaly, sandy with dark grains and carbonaceous fragments interbedded with porcellanite, hard, well bedded in layers 2 to 4 cm thick.	2.67	8.8
Porcellanite, hard, well bedded in layers 1 to 5 cm thick, weathers rust brown, weakly laminated, interbedded with shaly siltstone, brittle, slightly sandy with fine-grained sand, carbonaceous fragments and rare oval nodules of phosphorite.	2.12	7.0

	Meters	Feet
Limestone, hard, orange, silty, slightly sandy.	.06	.2
Porcellanite, hard, light gray, with scattered sand-sized white blebs.	.18	.6
Covered.	13.58	44.8
Siltstone, brittle, well bedded in beds 1 to 5 cm thick, light gray, sandy with scattered fish scales and bones.	5.24	17.3
Siltstone, hard, well bedded in beds .5 to 18 cm thick, very sandy with fine-grained sand, scattered fish scales.	2.24	7.4
Limestone, hard, well bedded, orange, silty and sandy.	.61	2.0
Chert, hard, well bedded in layers 1 to 15 cm thick, brownish-gray, laminated, interbedded with shaly siltstone, brittle, well bedded in layers 1 to 5 cm thick.	4.33	14.3
Siltstone, brittle to friable, light gray, spheroidal weathering interbedded with porcellanite and ocherous weathering limestone.	6.55	21.6
Covered.	16.61	54.8
Chert, poorly exposed, hard, nonlaminated, interbedded with shale, friable, light gray, slightly sandy.	2.55	8.4
Siltstone, poorly exposed, brittle, medium gray, sandy with fine-grained sand.	3.21	10.6

	Meters	Feet
Chert, hard, well bedded in beds 1 to 3 cm thick, laminated to massive, interbedded with shale, well bedded in layers 2 to 6 cm thick, light brownish-gray, sandy and silty.	16.27	53.7
Sandstone, hard, well bedded, light gray to white, noncalcareous, fine- to medium-grained rare biotite and lithic fragments.	.67	2.2
Chert, hard, well bedded in beds 2 to 8 cm thick, rust brown, interbedded with shale, friable, brownish-gray, slightly silty.	1.58	5.2
Dolomite concretion, hard, light gray on fresh surface, ocher on weathered surface, very sandy with medium-grained sand.	.27	.9
Chert, hard, well bedded in layers 1.5 to 11 cm thick, light gray to white, slightly sandy, interbedded with shale, friable, light gray, and argillaceous sandstone, friable, gray, fine- to medium-grained poorly sorted predominantly subangular quartz, feldspar, and dark fragments.	4.12	13.6
Limestone, hard, ocher on weathered surface.	.15	.5
Chert, hard, well bedded in layers 1 to 20 cm thick, layers thicken and thin and pinch out in some cases, medium gray to light gray, laminated with laminae about .5 to 1 mm thick, truncated, similar to small scale cross-beds, interbedded with shaly siltstone, brittle to friable, light gray, slightly sandy with carbonaceous fragments and fish scales.	8.52	28.1

	Meters	Feet
Chert, hard, well bedded in layers 1 to 10 cm thick, medium gray to light gray, laminated with laminae truncated and folded, some completely overturned, interbedded with silty shales, brittle to friable, (well bedded in layers 1 to 6 cm thick), dark gray, slightly sandy.	7.64	25.2
Siltstone, brittle to friable, dark gray, slightly sandy, stained with jarosite, no chert or porcellanite interbeds.	2.12	7.0
Dolomite, hard, light gray when fresh, ocherous weathering, slightly sandy with fine-grained brown grains.	.64	2.1
Chert, hard, well bedded in layers 3 to 14 cm thick, medium to light gray, laminated with some truncation, interbedded with shaly siltstones, friable, dark gray, slightly sandy.	3.64	12.0
Dolomite concretion, hard, ocherous weathering, laminated.	.30	1.0
Chert, hard, well bedded in layers 2 to 7 cm thick, medium gray, massive, interbedded with shale, friable, well bedded in layers 1 to 8 cm thick, light gray, silty, slightly sandy, becoming more shaly at the top.	2.76	9.1
Porcellanite, hard to brittle, light gray, interbedded with shale, brittle light gray, very silty, slightly sandy.	3.30	10.9
Shale, medium gray, brittle, silty, slightly sandy, noncalcareous, a few thin porcellanite beds near the bottom of the bed.	3.15	10.4

	Meters	Feet
Porcellanite, hard, well bedded in layers 1 to 3 cm thick, interbedded with shale, friable, light gray, sandy.	2.73	9.0
Shale, friable to brittle, light gray, sandy, silty, slightly siliceous, interbedded with sandstone, hard, in layers up to 8 cm thick, yellowish-gray, fine-grained, outcrop stained with jarosite.	3.88	12.8
Sandstone, hard, massive, coarse-grained, predominantly subangular quartz, feldspar, and dark grains.	.82	2.7
Covered.	53.03	175
Total thickness of Claremont Shale	299.58	988.6

Orinda Formation
sandstones and conglomerates

APPENDIX B

Lithologic description of reference section of the Claremont Shale in Morrison Canyon (pl. 2, col. 6)

(Measured by J. M. Hill and S. M. Lankford, 1976)

<u>Sobrante Sandstone</u>

Covered in part, predominantly massive, brittle, gray, sandy siltstone, first calcareous concretions appear at the top of the formation.

Claremont Shale	Meters	Feet
Covered in part, shale, brittle to friable, siliceous, silty, slightly sandy, interbedded with porcellanites, hard, dark gray, very silty.	13	43
Covered, siliceous shale and laminated chert in float, fault?	19	61
Chert, hard, fractured, well bedded in beds 1 to 8 cm thick, dark gray to black, laminated, rare phosphate nodules up to .7 cm in diameter, interbedded with shale, brittle to friable, brownish-gray, silty, some limonite staining, rare badly weathered foraminifera, fish scales and wood fragments?	8	27
Deformed slightly, chert, hard fractured, dark gray, laminated, slightly silty, interbedded with shale, brittle to friable, brownish-gray, siliceous with scattered, badly weathered foraminifera.	9	30
Deformed zone, predominantly chert and siliceous shale, thickness estimated.	2.4	8

	Meters	Feet
Chert, hard, well bedded in beds 5 to 20 cm thick, laminated with scattered phosphate nodules up to 1 cm in diameter, interbedded with shale, brittle to friable, siliceous.	11	37
Chert, hard, well bedded, as above, scattered ocherous weathering, carbonate concretions, interbedded with shale as above.	17	55
Covered, laminated chert in float, fault?	10	33
Chert, hard, well bedded in beds 1 to 4 cm thick, dark gray to black, rare phosphate nodules, interbedded with shale, brittle, in layers to 2 cm thick, silty, with rare weathered forams, several carbonate concretions scattered throughout.	27	90
Total thickness of Claremont Shale	116.4	384

Oursan Sandstone

The contact is sharp between the Oursan Sandstone and the Claremont Shale. The Oursan Sandstone is hard, brownish-gray, spheroidal weathering, very fine- to fine-grained, very rare, coarse grains, silty, noncalcareous, tuffaceous? rare phosphatic grains.

APPENDIX C

Fossil localities

Fossil localities are listed by 7½' quadrangles in alphabetical order. Fossils are grouped into three categories, M - megafossils, Mf - microfossils, N - nannofossils. The number following these designations represents the U. S. Geological Survey's locality number or the field locality number.

Briones Reservoir quadrangle

M 6617 Collector, J. Hill. Tice Shale; fire road 258 m (850 ft) E. of junction with Hampton Road in T. 1 N., R. 3 W. Identified by W. O. Addicott. Age: middle or late Miocene.

1N/3N-16CZ Collector, D. Radbruch, 1966. Sobrante Sandstone; E. side of Hampton Road, S. of road to Hampton's grave, approximately 182 m (600 ft) W. and 2,061 m (6,800 ft) S. of intersection of Hampton Road and Bear Creek Road. Identified by P. Smith, 1966. Age: middle Miocene, probably Relizian.

Mf 884 Collector, D. Radbruch, 1966. Oursan Sandstone; SW. side of Pinole Ridge; approximately 30 m (100 ft) N. of Wright Ave. Identified by P. Smith, 1966. Age: Luisian.

Mf 885 Collector, D. Radbruch, 1966. Oursan Sandstone; NE. side of Sobrante Ridge, on SE. side of NE-trending spur about 273 m (900 ft) W. of Castro Road and 348 m (1,150 ft) S. of Pinole Valley Road. Identified by P. Smith, 1966. Age: Luisian.

Mf 887 Collector, D. Radbruch, 1966. Claremont Shale; SE. end of Oursan Ridge, about 106 m (350 ft) NW. of intersection of Hampton Road and a fire road extending SW. from Hampton. Identified by P. Smith, 1966. Age: late Luisian.

Mf 1529 Collector, D. Radbruch, 1966. Claremont Shale; approximately 636 m (2,100 ft) S. and 152 m W. of Lookout on Grizzly Peak. Identified by P. Smith, 1966. Age: middle Miocene.

Calaveras Reservoir quadrangle

N 9-4-1 Collector, J. Hill. Berryessa Siltstone; sample taken 5 m (15 ft) below Berryessa-Monterey contact in Alum Rock Canyon. Identified by J. D. Buckry. Age: late Cretaceous, Cenomanian, or Turonian.

N 11-18-1 Collector, J. Hill. Claremont Shale (?); nannofossil sample collected 4.6 m (15 ft) above top of Sobrante Sandstone in Alum Rock Canyon. Identified by J. D. Buckry. Age: Oligocene or early Miocene.

Mf 3339 Collector, J. Hill. Tice Shale; 121 m (400 ft) N., 848 m (2,800 ft) W. of SE. corner of Sec. 33, T. 5 S., R. 1 E. Identified by K. McDougall and Mary Ann Breeden. Age: Luisian.

Mf 3341 Collector, J. Hill. Claremont Shale; 424 m (1,400 ft) S., 394 m (1,300 ft) W. of NE. corner of Sec. 3, T. 6 S., R. 1 E. Identified by K. McDougall and Mary Ann Breeden. Age: Miocene, probably Luisian.

Mf 3263 Collector, J. Hill. Claremont Shale; sample collected in Alum Rock Canyon 58 m (190 ft) below Briones-Monterey contact. Identified by K. McDougall and R. Poore. Age: middle to late Miocene.

Dublin quadrangle

M 6608 Collector, J. Hill. Oursan Sandstone; 379 m (1,250 ft) N., 924 m (3,050 ft) E. of SW. corner of Sec. 4, T. 2 S., R. 1 W. Identified by W. O. Addicott. Age: probably middle Miocene.

M 6610 Collector, J. Hill. Oursan Sandstone; 606 m (2,000 ft) N., 76 m (250 ft) E. of SW. corner of Sec. 4, T. 2 S., R. 1 W. Identified by W. O. Addicott. Age: probably middle Miocene or younger.

M 6612 Collector, J. Hill. Sobrante Sandstone; 970 m (3,200 ft) N., 606 m (2,000 ft) W. of SE. corner of Sec. 5, T. 2 S., R. 1 W. Identified by W. O. Addicott. Age: early Miocene (?).

M 6614 Collector, J. Hill. Sobrante Sandstone; 939 m (3,100 ft) N., 864 m (2,850 ft) W. of SE. corner of Sec. 5, T. 2 S., R. 1 W. Identified by W. O. Addicott. Age: middle Miocene, Temblor.

Mf 3272 Collector, J. Hill. Tice Shale (?); 924 m (3,050 ft) N., 871 m (2,875 ft) W. of SE. corner of Sec. 5, T. 3 S., R. 1 W. Identified by R. Arnal. Age: Mohnian or Delmontian, probably late Mohnian or Delmontian.

Mf 3334 Collector, J. Hill. Sobrante Sandstone; 1,076 m (3,550 ft) N., 894 m (2,950 ft) W. of SE. corner of Sec. 5, T. 3 S., R. 1 W. Identified by K. McDougall. Age: Luisian.

Hayward quadrangle

Mf 3275 Collector, J. Hill. Claremont Shale; sample taken in Crow Creek, 545 m (1,800 ft) SW. from junction of Crow Canyon Road and Norris Canyon Road. Identified by K. McDougall. Age: late Saucesian to early Luisian.

Mf 3276 Collector, J. Hill. Tice Shale; sample taken from Crow Creek 283 m (935 ft) from the Briones-Monterey contact. Identified by K. McDougall. Age: Miocene.

La Costa Valley quadrangle

Mf 3356 Collector, J. Hill. Oursan Sandstone; 576 m (1,900 ft) S., 470 m (1,550 ft) W. of NE. corner of Sec. 4, T. 5 S., R. 1 E. Identified by K. McDougall and Mary Ann Breeden. Age: Miocene.

Mf 3270 Collector, J. Hill. Oursan Sandstone; 61 m (200 ft) N., 273 m (900 ft) E. of SW. corner of Sec. 3, T. 5 S., R. 1 E. Identified by K. McDougall. Age: late Relizian to early Luisian.

Los Trampas Ridge quadrangle

Mf 702 Collector, D. Radbruch, 1966. Claremont Shale; W. side of Skyline Blvd. approximately 455 m (1,500 ft) NW. of junction of Skyline Blvd. and Grizzly Peak Blvd. Identified by P. Smith. Age: Luisian.

Mare Island quadrangle

Mf 920 Collector, D. Radbruch, 1966. Tice Shale; W. side of Pinole Creek 273 m (900 ft) W. of Pinole Valley Road, 455 m (1,500 ft) N. of Interstate 80, 606 m (2,000 ft) S. of San Pablo Ave. Identified by P. Smith, 1966. Age: Mohnian.

Niles quadrangle

M 6562 Collector, J. Hill. Cretaceous rocks; 273 m (900 ft) N., 424 m (1,400 ft) W. of SE. corner of Sec. 17, T. 4 S., R. 1 W. Identified by D. L. Jones and J. W. Miller. Age: early Cretaceous or late Jurassic.

M 6621 Collector, J. Hill. Oursan Sandstone; 712 m (2,350 ft) N., 470 m (1,550 ft) E. of SW. corner of Sec. 23, T. 4 S., R. 1 W. Identified by W. O. Addicott. Age: probably middle Miocene.

Mf 3257 Collector, J. Hill. Oursan Sandstone; 545 m (1,800 ft) E., 727 m (2,400 ft) N. of SW. corner of Sec. 23, T. 4 S., R. 1 W. Identified by K. McDougall. Age: Luisian.

Mf 3258 Collector, J. Hill. Tice Shale; 712 m (2,350 ft) N., 424 m (1,400 ft) E. of SW. corner of Sec. 23, T. 4 S., R. 1 W. Identified by K. McDougall. Age: late Relizian to early Luisian.

Mf 3264 Collector, J. Hill. Claremont Shale; 848 m (2,800 ft) S., 242 m (800 ft) E. of NE. corner of Sec. 17, T. 4 S., R. 1 W. Identified by K. McDougall. Age: Miocene.

Oakland East quadrangle

1S/3W-16L1 Collector, D. Radbruch, 1966. Sobrante Sandstone; N. side of Thorndale, near Sobrante, approximately 712 m (2,350 ft) S. and 1,152 m (3,800 ft) W. of NE. corner of Sec. 16, T. 1 N., R. 3 W. Identified by P. Smith, 1966. Age: late Saucesian or Relizian.

Mf 555 Collector, D. Radbruch, 1966. Claremont Shale (?); 1,181 m (3,900 ft) E., 485 m (1,600 ft) S. of NW. corner of Sec. 25, T. 1 S., R. 3 W. Identified by P. Smith, 1966. Age: late Miocene - Mohnian.

Mf 806 Collector, D. Radbruch, 1966. Sobrante Sandstone; approximately 1,000 m (3,300 ft) S., 848 m (2,800 ft) W. of NE. corner of Sec. 16, T. 1 N., R. 3 W., Skyline Blvd. NW. of Snake Road. Identified by P. Smith, 1966. Age: early Relizian.

Mf 837 Collector, D. Radbruch, 1966. Sobrante Sandstone; end of Balsam Way, approximately 303 m (1,000 ft) S. of Oakland city boundary marker at elev. 1,431 ft. Identified by P. Smith, 1966. Age: middle Miocene - late Saucesian or Relizian.

Mf 882 Collector, D. Radbruch, 1966. Sobrante Sandstone; street between Snake Road and Oakwood Drive. Sample from NE. side of unnamed street, about 45 m (150 ft) SE. of intersection with Oakwood Drive. Identified by P. Smith, 1966. Age: middle Miocene, Relizian.

Richmond quadrangle

Mf 874 Collector, D. Radbruch, 1966. Tice Shale; SW. end of San Pablo Dam, in a drainage ditch on SW. side of old San Pablo Dam Road, NW. of reservoir intake structure. Identified by P. Smith, 1966. Age: early Mohnian.

Mf 875 Collector, D. Radbruch, 1966. Tice Shale; roadcut on NW. side of new San Pablo Dam Road, SW. of San Pablo Dam. Identified by P. Smith, 1966. Age: early Mohnian.

Mf 876 Collector, D. Radbruch, 1966. Tice Shale; SW. end of San Pablo Dam, roadcut on SW. side of old San Pablo Dam Road, SE. end of reservoir structure. Identified by P. Smith, 1966. Age: early Mohnian.

Mf 888 Collector, D. Radbruch, 1966. Claremont Shale; east side Appian Way, approximately 121 m (400 ft) E. and 455 m (1,500 ft) N. of intersection of Appian Way and Eastshore Freeway. Identified by P. Smith, 1966. Age: middle Miocene.

Mf 889 Collector, D. Radbruch, 1966. Claremont Shale (?); approximately 61 m (200 ft) E. and 515 m (1,700 ft) N. of intersection of Appian Way and Eastshore Freeway. Identified by P. Smith, 1966. Age: middle Miocene - Luisian.

Mf 890 Collector, D. Radbruch, 1966. Claremont Shale; 455 m (1,500 ft) N. and 894 m (2,950 ft) E. of SW. corner of Sec. 27, T. 2 N., R. 4 W. Identified by P. Smith, 1966. Age: middle Miocene - Luisian.

Mf 891 Collector, D. Radbruch, 1966. Claremont Shale; approximately 364 m (1,200 ft) N. and 636 m (2,100 ft) E. of SW. corner of Sec. 21, T. 2 N., R. 4 W. Identified by P. Smith, 1966. Age: middle Miocene - Luisian.

Mf 892 Collector, D. Radbruch, 1966. Claremont Shale (?); west side of Appian Way, approximately 121 m (400 ft) E. and 697 m (2,300 ft) N. of intersection of Appian Way and Eastshore Freeway. Identified by P. Smith, 1966. Age: middle Miocene.

Mf 904 Collector, D. Radbruch, 1966. Oursan Sandstone; NE. side of ravine extending NE. from end of Paloma Street, Pinole, approximately 182 m (600 ft) from end of street. Identified by P. Smith, 1966. Age: middle Miocene.

Mf 905 Collector, D. Radbruch, 1966. Oursan Sandstone; NE. side of ravine extending NE. from end of Paloma Street, Pinole, approximately 136 m (450 ft) from end of street. Identified by P. Smith, 1966. Age: middle Miocene.

Mf 907 Collector, D. Radbruch, 1966. Tice Shale; on Pinole Creek, 76 m (250 ft) N. of intersection of Collins Ave. and Tomar Court. Identified by P. Smith, 1966. Age: Mohnian.

Mf 907a Collector, D. Radbruch, 1966. Tice Shale; on Pinole Creek, 136 m (450 ft) N. of intersection of Collins Ave. and Pinole Valley Road. Identified by P. Smith, 1966. Age: Mohnian.

APPENDIX D

Point Count Results

	Quartz	Plagioclase	K-Feldspar	Rock Fragments	Silt	Hornblende	Matrix
Sobrante Sandstone							
Section 3, smp. T 10-2-2	9%	22%	3%	39%	3%	--	24%
Section 9, smp. T 7-9-3	1%	18%	3%	30%	--	2%	46%
Oursan Sandstone							
Section 3, smp. T 11-18-6	8%	15%	2%	25%	7%	--	43%
Section 4, smp. T 10-22-3	5%	23%	11%	21%	27%	--	13%
Section 9, smp. T 7-10-3	6%	16%	0%	20%	3%	1%	54%
Section 12, smp. T 9-17-6	15%	29%	8%	35%	8%	--	5%
Hambre Sandstone							
Section 3, smp. T 11-12-4	18%	17%	5%	32%	1%	--	27%
Section 4, smp. T 10-21-1	7%	12%	6%	14%	22%	--	39%
Section 9, smp. T 8-27-10	12%	37%	2%	29%	6%	4%	10%

APPENDIX E

Chemical Analysis localities

A5-3-1, nodular phosphate in chert, Claremont Shale, Morrison Canyon, 818 m (2,700 ft) S., 970 m (3,200 ft) W. of NE. corner of section 23, T. 4 S., R. 1 W., Niles quadrangle.

A12-17-7, phosphatic mudstone pebbles in sandstone, Hambre Sandstone, Hollis Canyon, 45 m N., 1,076 m W. of SE. corner of section 32, T. 2 S., R. 1 W., Dublin quadrangle.

A1-14-3, phosphate pellets in sandstone, Hambre Sandstone, Dublin Canyon, 1,167 m S., 939 m W. of NE. corner of section 4, T. 3 S., R. 1 W., Dublin quadrangle.

APPENDIX E

Semiquantitative 6-step spectrographic analyses

(Analyses by Karen Duval, 1977)

Element	Smp. A5-3-1	A12-17-7	A1-14-3
Fe%	1.0	2.0	2.0
Mg%	0.1	0.3	0.3
Ca%	1.0	3.0	3.0
Ti%	0.10	0.20	0.15
Si%	10.0	10.0	10.0
Al%	2.0	5.0	5.0
Na%	0.18	1.5	1.5
K%	0.3	1.8	1.5
P%	1.0	3.0	3.0
Mn ppm	50	70	200
Ag "	1.0	0.7	0.7
B "	100	50	70
Ba "	200	500	500
Be "	1.5	1.0	1.5
Co "	2.0	1.5	5.0
Cr "	50	100	100
Cu "	15	10	10
La "	15	50	50
Mo "	10	7	7
Nb "	7	0	5
Ni "	30	15	30

APPENDIX E

Semiquantitative 6-step spectrographic analyses

(Analyses by Karen Duval, 1977)

(continued)

Element	Smp. A5-3-1	A12-17-7	A1-14-3
Pb ppm	15	30	30
Sb "	70	0	70
Sc "	10	10	10
Sr "	200	300	500
V "	100	50	50
Y "	15	30	50
Zn "	100	100	100
Zr "	70	150	150
Ga "	7	15	15
Yb "	3	5	5