UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGY OF THE MONTEREY BAY REGION

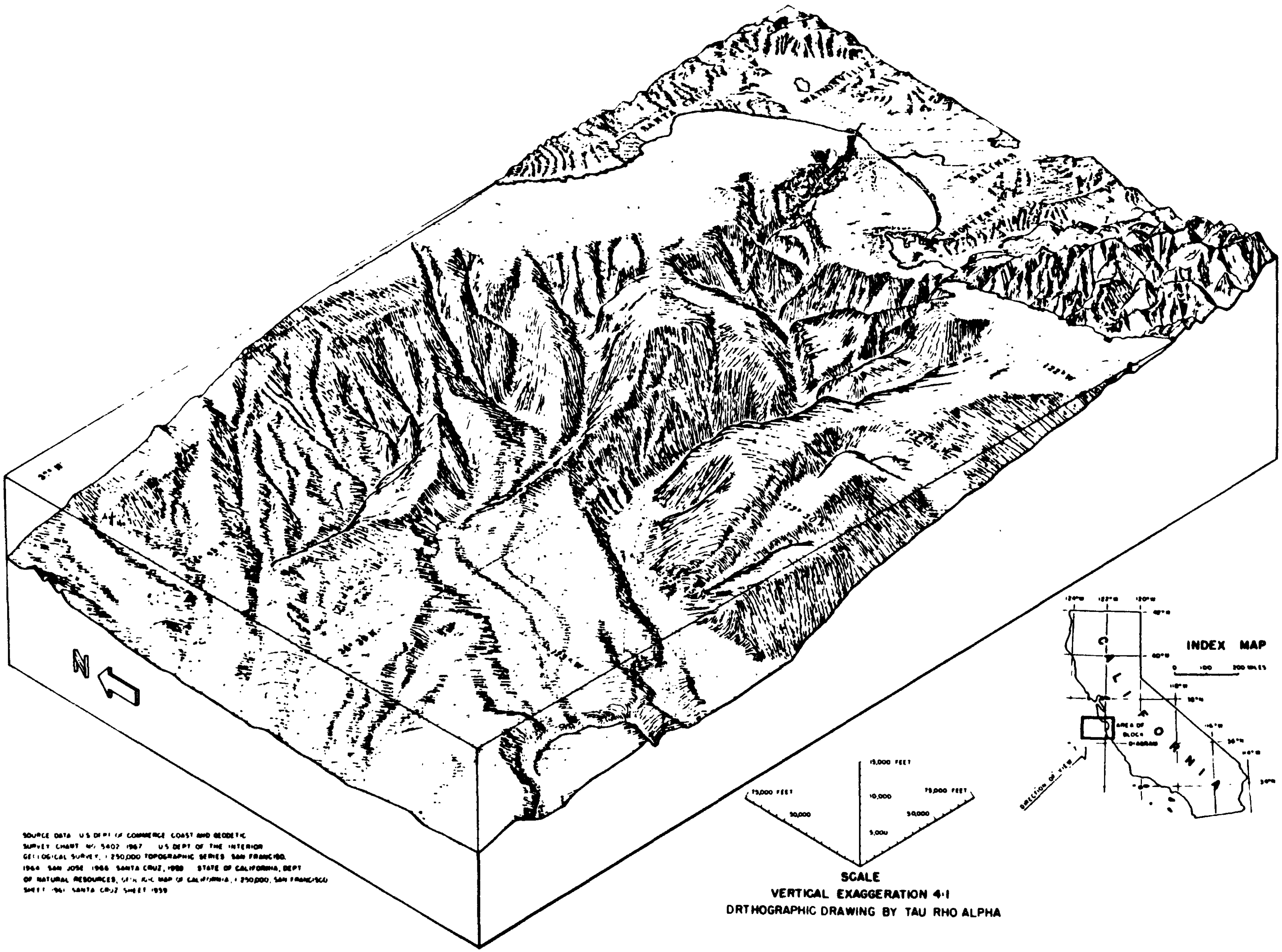
BY

H. Gary Greene

Open-file Report 77-718

1977

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



SOURCE DATA: U.S. DEPT OF COMMERCE COAST AND GEODETIC SURVEY CHART NO. 5402 1967. U.S. DEPT OF THE INTERIOR GEOLOGICAL SURVEY, 1:250,000 TOPOGRAPHIC SERIES SAN FRANCISCO, 1964 SAN JOSE 1966 SANTA CRUZ, [illegible]. STATE OF CALIFORNIA, DEPT OF NATURAL RESOURCES, GEOLOGIC MAP OF CALIFORNIA, 1:250,000, SAN FRANCISCO SHEET 1961 SANTA CRUZ SHEET 1959

MONTEREY CANYON

U S GEOLOGICAL SURVEY

Contents

Page

Page

Appendices

List of Illustrations

List of Illustrations

Figure		Page

Figure | Page

Tables

ABSTRACT

Geophysical data and sea floor samples collected from the continental shelf and slope between Año Nuevo Point and Point Sur, California indicate that the Monterey Bay region has had a complex late Cenozoic tectonic history. Uplift and depression have produced a succession of regressive and transgressive sedimentary units, while contemporaneous right-slip along faults of the San Andreas system have offset major structural and lithologic elements. This deformation produced three regional and several local unconformities within upper Tertiary rocks and initiated development of a canyon system that today includes the Monterey, Ascension, Carmel, and other large submarine canyons.

The Tertiary stratigraphy of the offshore Monterey Bay area is divided into two provinces by a major structural boundary, the north-trending Palo Colorado-San Gregorio fault zone. East of this zone in the offshore are four seismically distinct sequences that can be correlated with major sequences onshore. These sequences comprise (1) pre-Tertiary basement, and (2) middle Miocene, (3) upper Miocene to Pliocene, and (4) upper Pliocene to Holocene sedimentary intervals. Each of the latter three sequences is bounded by unconformities, as is its counterpart on land. Only Neogene sedimentary rocks are present offshore; Paleogene units, if originally present, have been removed completely by pre-middle Miocene erosion.

An extensive erosional surface was cut during Zemorrian time into the late Mesozoic granitic basement rocks. Incised into this surface are the ancestral Monterey Canyon and an unnamed canyon. Marine sedimentary rocks of upper Miocene and Pliocene age overlie this unconformity

and fill the unnamed canyon. Similar rocks also may have once filled Monterey Canyon. Near shore these strata are covered by terrestrial alluvial and eolian deposits, deltaic deposits, marine canyon fill, landslide and slump deposits, and unconsolidated sediments that range in age from upper Pliocene to Holocene. Monterey Canyon appears to have been filled and exhumed at least twice since its inception in Oligocene time, once in late Miocene and once in Pleistocene time.

Three major seismic stratigraphic units are apparent in continuous seismic reflection profiles from the offshore area west of the Palo Colorado-San Gregorio fault zone. These are (1) acoustical basement, and (2) middle Tertiary and (3) late Tertiary to Quaternary sedimentary intervals. Acoustical basement comprises Cretaceous to early Tertiary sedimentary rocks, Mesozoic or older metamorphic rocks, and Cretaceous or Jurassic rocks of the Franciscan assemblage. The middle Tertiary sequence consists of sedimentary rocks of questionable Miocene age. The late Tertiary to Quaternary sequence is composed of Pliocene sedimentary rocks and unconsolidated marine sediments, and submarine landslide and slump deposits.

Seismic reflection surveys indicate two major, intersecting, northwest-trending fault zones to be present in the offshore Monterey Bay area. The Palo Colorado-San Gregorio fault zone may be more than 200 km long; it is narrow (approximately 3 km wide) and is represented in most places by one or two faults. This zone appears to connect with faults mapped on land near Año Nuevo Point and Point Sur. The Monterey Bay fault zone, located in the area between Santa Cruz and Monterey, is a diffuse zone, approximately 10 to 15 km wide, of en echelon faults. Faults within this zone appear to connect with faults on land near Monterey, and the zone appears to be truncated by the Palo Colorado-San Gregorio fault zone west of Santa Cruz.

Locations of more than 110 earthquakes (1968-1976) show that the newly mapped fault zones in Monterey Bay are seismically active. Epicenters in the bay form two clusters, one at the intersection of the Monterey Bay and Palo Colorado-San Gregorio fault zones, and the other in a linear belt that trends northwest along the Palo Colorado-San Gregorio fault zone. Faults within the Monterey Bay fault zone parallel the San Andreas fault, and fault-plane solutions of two earthquakes in this fault zone indicate right-lateral, strike-slip displacement, similar in sense to the San Andreas fault. Fault-plane solutions of six earthquakes associated with the Palo Colorado-San Gregorio fault zone also indicate right-slip. The Palo Colorado-San Gregorio fault zone parallels the Hayward fault and resembles that fault in length, seismicity, and sense of movement. Moreover, both faults appear to intersect the San Andreas fault, at the same angle, the Hayward fault at its south end and the Palo Colorado-San Gregorio fault at its north end.

Recent earthquake activity on the Palo Colorado-San Gregorio and Monterey Bay fault zones probably reflects stress release along the San Andreas fault system, of which these zones are considered a part. Displacement along faults within these fault zones and along the newly named Ascension fault also may explain the apparent discrepancy in total offset along the San Andreas fault system in central and southern California. Right-slip within these fault zones has slivered the Salinian block, producing a serrated western margin for the block. This serrated margin was fragmented as the Salinian block was displaced northwestward along the San Andreas fault; tectonic slivers were pushed ahead of the block or were carried along at its seaward margin. A model for the tectonic slivering and elongation of the Salinian block is proposed on the basis of the sense of movement and patterns of faulting observed in the central part of the block, in the Monterey Bay region. Right-slip along the Palo Colorado-San Gregorio fault zone and older (pre-Pliocene) Ascension fault probably has offset the lower part of Monterey Canyon almost continuously for the past 20 m.y. The displaced segments of the lower canyon were exhumed during Pleistocene time, and are represented today by Pioneer and Ascension canyons. The present distance between Pioneer and Monterey canyons, 110 km, is a measure of offset along these faults since middle Miocene time. Strike-slip faulting also may explain the presence of submarine canyons elsewhere that head well offshore, on the outer shelf and inner slope.

CHAPTER I

INTRODUCTION

The Monterey Bay area of central California encompasses a geologically complex part of the continental margin of North America, the California Coast Ranges Province (Fig. 1). Interest and knowledge of the onshore geology of this area have increased significantly over the past decade due to detailed mapping and the recasting of the Tertiary tectonic history of the area in light of plate tectonic concepts (McKenzie and Parker, 1967; Morgan, 1968; Atwater, 1970; Atwater and Molnar, 1973). However, interpretation of margin history has been hampered by the lack of detailed knowledge of offshore geology and structure with most onshore geologic contacts ending abruptly at the strandline of Monterey Bay -- a characteristic common to most geologic maps of the world's coastlines. The principal aim of this study is to make a thorough marine geologic exploration of the Monterey Bay area using modern geophysical and geologic tools and methods, and to integrate the data gathered with evidence from onshore geologic studies, ultimately producing a synthesis of the Tertiary evolution of this portion of the Pacific margin with a special focus on faulting and tectonic history.

Geologic hazards related to structure, lithology and present tectonic environment have important consequences for development in the rapidly urbanizing region surrounding Monterey Bay. Consequently, these hazards are stressed in this report, particularly those in offshore areas that have previously received little attention.

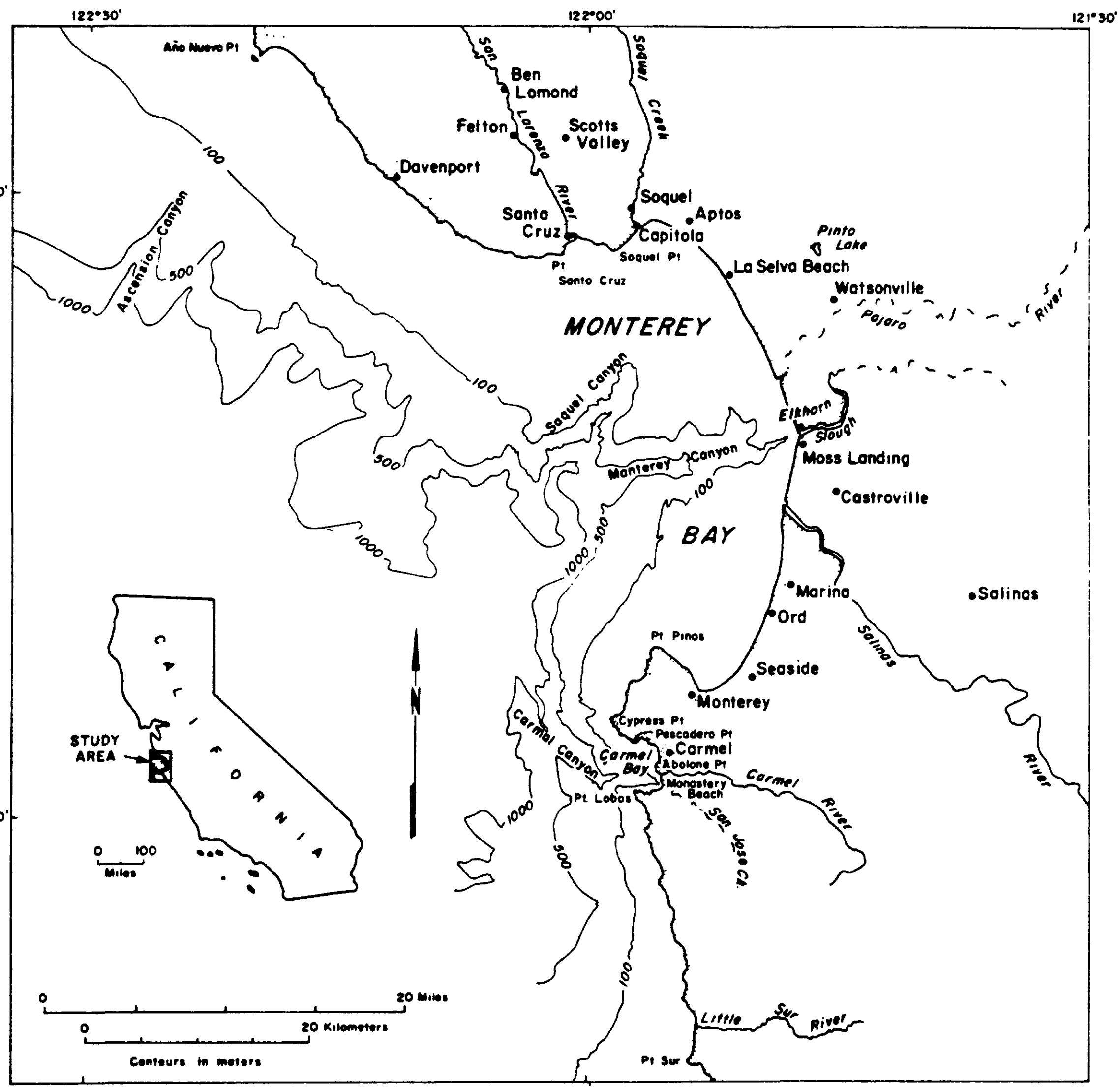


Figure 1. - Index map of California showing location of study area.

REGIONAL SETTING

The area of investigation is located within latitudes 36°15'N to 37°15'N and longitudes 121°15'W to 123°30'W, encompassing over 2,700 km^2. It extends from Año Nuevo Point southward along the central California coast to Point Sur, and from the shoreline seaward nearly to the base of the continental slope, an average distance of about 40 km (Fig. 1). Detailed marine geophysical surveys were focused in Monterey Bay, but studies in less detail were extended onto the adjoining shelf and slope (Fig. 2).

Monterey Bay is a nearly crescentic bay that lies along the central California coast approximately 115 km south of San Francisco (Fig. 1). It is a large embayment along an otherwise straight coastline, and its mouth measures 37 km in width between Point Santa Cruz and Point Pinos. The towns of Santa Cruz and Monterey are located on the bay's north and south shores, and Moss Landing is positioned approximately in the middle of the east shore (Fig. 1).

Topography is varied along the coast between Año Nuevo Point and Point Sur. Steep bluffs with flat-topped terraces interspersed with sandy pocket beaches are characteristic of the coastal region from Soquel Point northward to Año Nuevo Point. From Soquel Point southward almost to Moss Landing, cliffs fronted by sandy beaches are prevalent. Broad sandy beaches backed by large dune fields stretch southward in an unbroken line from Moss Landing to the rocky headland of the Monterey Peninsula, and from this point southward to Point Sur steep, rocky cliffs predominate.

Low to high relief mountain ranges and broad, flat-floored valleys are prevalent farther inland. The Santa Cruz and Gabilan mountain ranges dominate the topography in the northern and central half of the region. Two major rivers enter Monterey Bay from these highlands through well defined valleys. The San Lorenzo River enters Monterey Bay at the town of Santa Cruz, and the Pajaro River empties into the bay 6 km north of Moss Landing (Fig. 1). Elkhorn Slough, an old river estuary that today is represented only by tidal salt marshes, extends inland from Moss Landing for more than 10 km. The broad, extensive Salinas Valley and the northern Santa Lucia Range are the dominant topographic features in the southern half of the region. The Salinas River is the major drainage system in the region and empties into Monterey Bay 8 km south of Moss Landing. South of Monterey, the west flank of the Santa Lucia Range drops abruptly into the ocean. The valley of the Carmel River, which empties into the Pacific Ocean in Carmel Bay, and the Little Sur River, which enters the ocean 6.5 km north of Point Sur, are major topographic features in the southern part of the region (Fig. 1).

SUBMARINE PHYSIOGRAPHY

The undersea topography of the Monterey Bay region is as diverse and perhaps even more spectacular than that onshore. The submarine canyon system that comprises Monterey submarine canyon, sea valley, and fan dominates the submarine topography, exhibiting much greater relief than similar features onshore (Pl. 1). This canyon was first described by Davidson (1897, p. 75), who noted that "... at Monterey Bay there is a complete breaking down of the Coast Ranges for 25 miles, with the mountains receding well inland. Into this broad and deep bight heads the finest of submerged valleys."

Monterey Canyon cuts deeply into the flat shelf of Monterey Bay, heading less than 2 km seaward of the mouth of Elkhorn Slough and extending westward for over 90 km, bisecting the bay along its trend (Pl. 1). It is one of the world's largest submarine canyons with respect to width, depth, and length and its overall dimensions are comparable to those of the Grand Canyon of the Colorado River (Martin, 1964; Shepard and Dill, 1966). The walls of Monterey Canyon increase progressively in height with increasing water depth. Their greatest relief, nearly 1830 m, is at the intersection with Carmel Canyon approximately 10 km northwest of Point Pinos, where the axial depth is about 1920 m. At this point the distance between the opposing rims of the canyon is more than 20 km (Shepard and Dill, 1966).

Locally Monterey Canyon meanders, and two oxbow-type bends are incised in the shelf of Monterey Bay (Pl. 2). In addition, Monterey Canyon is joined by three major tributaries, Ascension, Soquel, and Carmel Canyons. Ascension Canyon is cut into the continental slope about 35 km northwest of Santa Cruz. Several of the nine branches composing its head cut the edge of the continental shelf; it intersects Monterey sea valley at a depth of 3290 m. Soquel Canyon is located on the northern shelf of Monterey Bay and joins Monterey Canyon about 18 km seaward of its head at a depth of 915 m. Carmel Canyon has its head only 30 m west of Monastery Beach at the mouth of San Jose Creek. It intersects Monterey Canyon approximately 30 km down-canyon at a depth of 335 m. Soquel and Carmel Canyons steepen in gradient as they approach Monterey Canyon, and appear to represent hanging valleys (Shepard and Dill, 1966, p. 84). Monterey Canyon and its tributaries are characterized by V-shaped cross sections with steep walls and narrow floors.

Elsewhere in this region the sea floor mostly comprises the flat continental shelf and gently dipping continental slope. In the southwest part of the study area a small, unnamed seaknoll projects approximately 320 m above the surface of the continental slope.

PREVIOUS WORK

Previous marine geological and geophysical investigations of the Monterey Bay region have been of a reconnaissance nature (e.g., Shepard and Emery, 1941; Shepard, 1948; Martin, 1964; Curray, 1965, 1966; Rusnak, 1966; Martin and Emery, 1967; Hoskins and Griffiths, 1971; and Silver and others, 1971). These reports discuss the geology of the Monterey Bay area as a part of more extensive investigations of the central California continental shelf, but do not describe the structure and stratigraphy of the Monterey Bay region in detail.

Martin (1964) compiled a geologic map of Monterey based on detailed bathymetry and geologic samples. Dohrenwend (1971) and Ellsworth (1971) used detailed bathymetry and seismic reflection profiles to describe the geology of the continental shelf between Point Sur and Cypress Point, and Frydenlund (1974) reports on the structural geology off Año Nuevo Point. Studies of Quaternary sediments in the bay have been made by Galliher (1932), Dorman (1968), Yancey (1968), Wolf (1970), Malone (1970), and Arnal and others (1974). Gravity studies are reported for the shelf areas between Año Nuevo Point and Point Sur by Souto (1973), Brooks (1973), Cronyn (1973), Spikes (1973), and Woodson (1973). Zardeskas (1971) and Simpson (1972) reported on bathymetric and geologic investigations of Carmel Bay. A bottom photographic survey of Monterey and Carmel canyons was made by Jensen (1976).

Published reports concerning the onshore geology of the Monterey Bay region are numerous. The first studies were done by Johnson (1855), Beal (1915), Trask (1926), Woodring (1938), and Allen (1946). Page (1966; 1970a, b), Compton (1966), Christensen (1966), Clark, J. C. (1966; 1970a, b,), Bowen (1969), Durham (1970; 1974), Clark and others (1974), Dupré (1975), and Tinsley (1975) contributed to the stratigraphic knowledge of the region. Geologic compilations for the region are by Jennings and Strand (1958), Jennings and Burnett (1961), California State Department of Water Resources (1970), and Brabb (1970). Studies focused on the geologic structures onshore have been made by Clark, B. L. (1930), Fairborn (1963), Sieck (1964), Durham (1965), Page (1970a, b), Burford (1971), Gilbert (1971), Griggs (1973), Ross and Brabb (1972), Clark and Rietman (1973), and Graham (1976). In contrast, little has been reported on geological hazards in this region. Exceptions include reports by Greene (1970) and Greene and others (1973) on subsea hazards such as seismicity, active faults, and submarine slumps and landslides, and by Tinsley (1975) and Hall and others (1974) on on-land hazards. A number of unpublished reports on environmental geology have been submitted to city and county governments.

METHODS AND PROCEDURES

Continuous seismic reflection profiling was the principal method used in this investigation of the offshore Monterey Bay region. Supplementary data were obtained from magnetic and bathymetric records and from sea floor bedrock and sediment samples collected during the course of this study.

Seismic Reflection

Four continuous seismic reflection systems were used for this study; these were a 160 and an 80 kj (kilojoule) low resolution-deep penetration "Sparker", a 26 kj, moderate resolution-intermediate penetration "Sparker", and a 0.6 kj high resolution-shallow penetration "mini-Sparker". Operational details and specifications of each of these systems are described in Appendix I. The 0.6 and 26 kj seismic reflection data were recorded simultaneously during cruises of the U.S. Geological Survey's research vessel POLARIS in 1969 and 1970. The 80 kj and 160 kj data were collected during 1969 and 1972 cruises, respectively, aboard the Navy Oceanographic Office's research vessel BARTLETT.

Magnetics

A marine proton precession magnetometer was used to measure the earth's total magnetic field in the Monterey Bay area. The raw analog data were reduced and digitized for computer processing and separation of the regional field. Details and specifications of equipment are given in Appendix I.

Bathymetry

Bathymetric data were collected continuously along all survey lines using a 3.5 kHz (kilohertz) fathometer profiling system. These data were used to construct bathymetric base maps and physiographic diagrams.

Bottom Samples

Bedrock and sediment samples were collected from canyon walls and slopes principally by dredging (Fig. 8). Several gravity cores of unconsolidated sediment were taken in Monterey Canyon, and three submersible dives were made to directly observe and collect data *in situ* from Monterey Canyon. In addition, several vibra-cores were taken from the shallow shelf areas of the bay. Details of these bottom sampling operations are given in Appendix I.

Except for samples obtained during the submersible dives, most geologic samples from Monterey Bay were collected during cruises of Stanford University's research vessel PROTEUS between 1969 and 1971. Some dredge samples from the continental slope were obtained during a 1969 cruise of the R/V BARTLETT, and the vibra-cores were collected by R. A. Andrews of the Naval Postgraduate School aboard the R/V OCEANEER in 1970.

Navigation

Geophysical data were collected along approximately 3,200 km of track line (Fig. 2). Several methods of navigation were used to locate the survey vessels during the collection of geophysical and geological data; these methods included high precision radar (both land based and shipboard), loran, satellite navigation, and visual sitings. The position accuracy and specifications of equipment used for positioning are described in Appendix I.

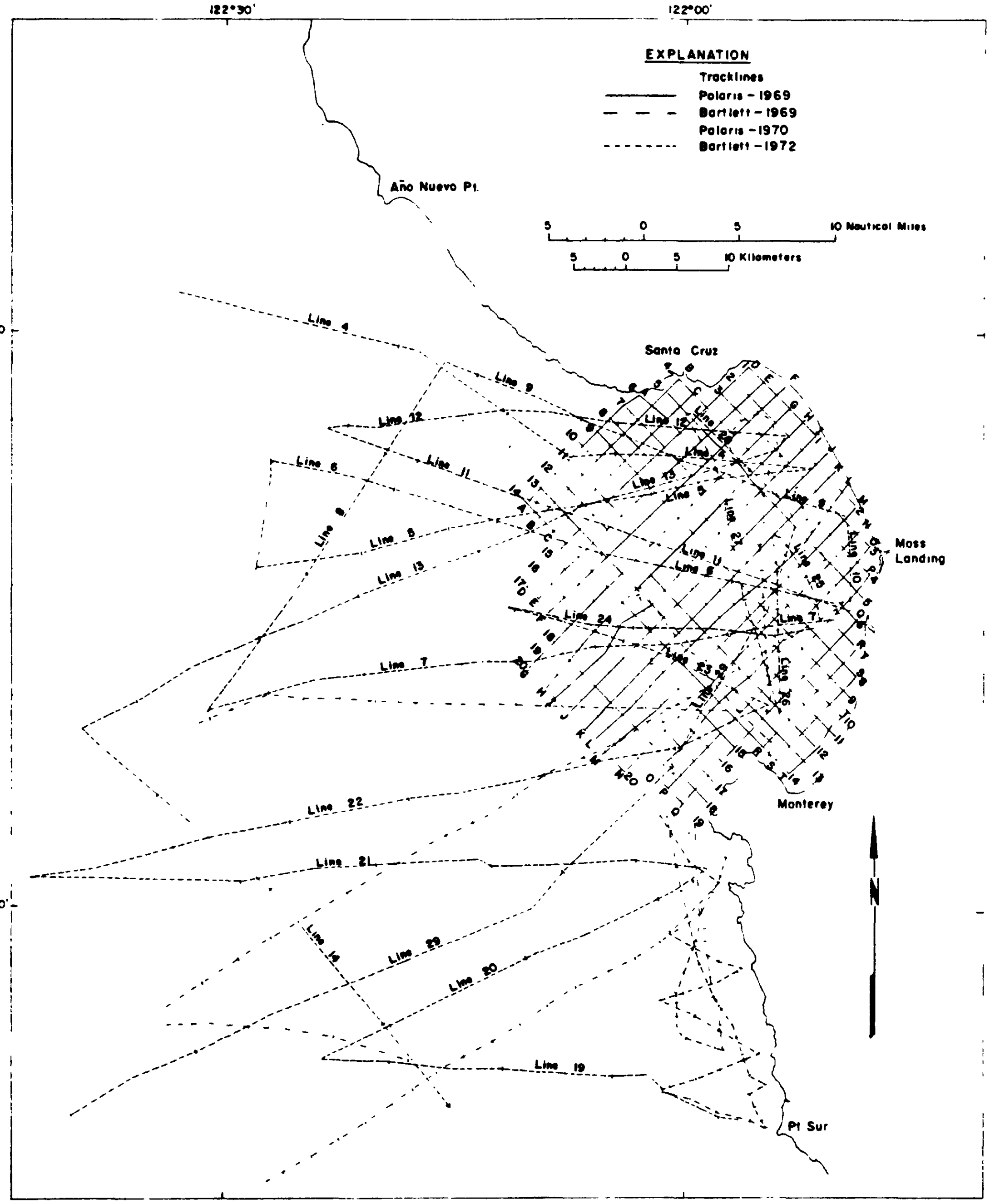


Figure 2. - Map showing tracklines across which geophysical data were collected.

GEOLOGIC STRUCTURE AND STRATIGRAPHY OF THE MONTEREY BAY REGION

Structure and stratigraphy of the Monterey Bay region are complex. The major structures trend northwest-southeast, and secondary structures are oriented east-west. Early Tertiary through Holocene sedimentary rocks with a composite thickness of more than 10,000 m overlie a granitic basement terrane in this region.

Tectonic Setting

The Monterey Bay region is located on a major structural element known as the Salinian block (Page, 1970a). The Salinian block consists of continental crust composed principally of Cretaceous granitic rocks and is flanked on either side by a heterogeneous aggregation of Jurassic and Cretaceous eugeosynclinal rocks assigned to the Franciscan assemblage. The northeast and southwest boundaries of this block are formed by the San Andreas and Sur-Nacimiento fault zones, and it extends from the Transverse Ranges northward almost 800 km to Cape Mendocino (Page, 1970a; Silver and others, 1971). The Salinian block is believed to be a mass of Sierran granitic basement displaced northward during Tertiary time by movement along the San Andreas fault, with the Sur-Nacimiento fault zone representing a displaced segment of the boundary between Sierran and Franciscan basement rocks (Hill and Dibblee, 1953; King, 1959; Page, 1970a).

Structure

Beginning with Lawson in 1914, many geologists have described the structure of the Coast Ranges in terms of tectonic blocks (Clark and Rietman, 1973). Likewise the Salinian block in the Monterey Bay region was described by Clark (1930) as comprising a series of smaller, elongate, northwest-trending, uplifted blocks and basins. The basins--Santa Cruz basin, Salinas graben, and Santa Lucia basin--are separated from each other by faults and by structural highs known as the Ben Lomond, Gabilan, and Toro Mountain blocks (Fig. 3). The most northerly basin delineated in this region by Clark (1930) is the Santa Cruz basin, a synclinorium in a thick sequence of Tertiary sedimentary rocks located between the central Santa Cruz Mountains and the northern Gabilan Range. This basin is separated from the Ben Lomond block to the southwest by the Ben Lomond fault. Recent evidence from gravity data tends to confirm Clark's (1930) belief that the Santa Cruz basin extended southeastward to the San Juan Bautista area during early Tertiary time (Clark and Rietman, 1973, p. 14). The largest structural depression of the region, variously termed the Salinas graben (Clark, 1930), Salinas trough (Starke and Howard, 1968), and King City flexure (Fairborn, 1963), extends from Monterey Bay down the Salinas Valley to King City, and is bounded on the northeast and southwest by the Gabilan and Toro Mountain blocks. Southwest of the Toro Mountain block is an irregular area named the Santa Lucia basin by Clark (1930).

Martin and Emery (1967) divided that part of the Salinian block underlying the Monterey Bay area into three tectonic blocks: the Gabilan stable area, the Monterey semi-stable area, and the Monterey graben (Fig. 3). The Gabilan stable area is bounded on the northeast by the San Andreas fault, and is separated from the Monterey graben and Monterey semi-stable area to the southwest by the Gabilan-King City fault of Martin and Emery (1967). The Monterey graben and Monterey semi-stable area, in turn, are separated from the central Franciscan area to the west by the

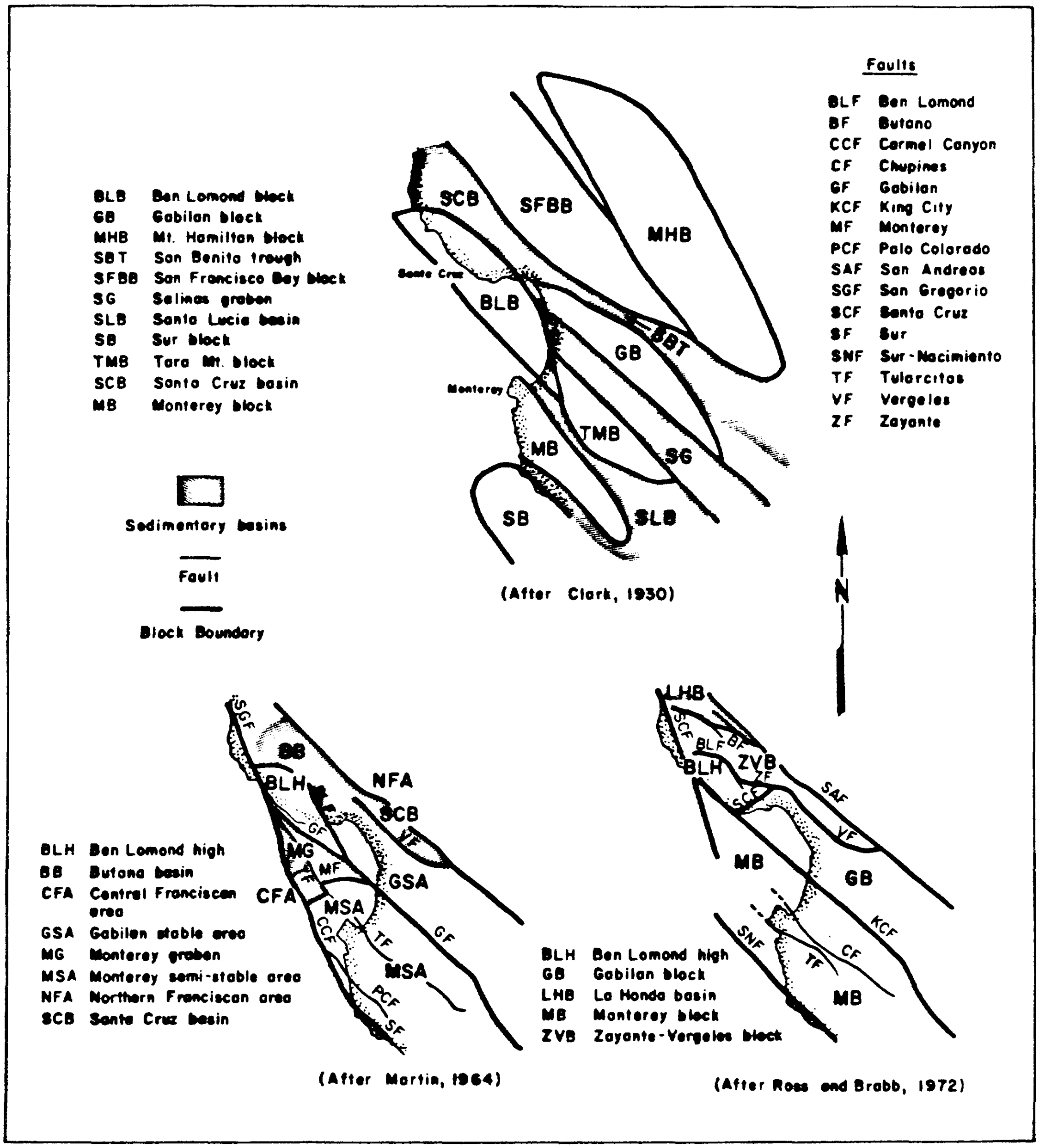


Figure 3 – Historical development of orographic blocks concepts

Carmel Canyon fault, later extended and named the Palo Colorado-San Gregorio fault by Greene and others (1973), and from each other by the so-called Monterey fault located in lower Monterey Canyon (Martin and Emery, 1967).

Based on their petrologic analysis of basement rocks, Ross and Brabb (1972) have divided the Salinian block in this region into four tectonic sub-blocks: the Zayante-Vergeles block, Ben Lomond block, Gabilan block, and the Monterey block (Fig. 3). The Zayante-Vergeles block is bounded on the northeast by the San Andreas fault, and is separated from the Ben Lomond and Gabilan blocks to the southwest by the Zayante-Vergeles fault. The Ben Lomond and Gabilan blocks, in turn, are separated from each other by the Santa Cruz fault of Ross and Brabb (1972). The Monterey block is bounded on the southwest by the seaward projection of the Sur-Nacimiento fault zone, and is separated from the Ben Lomond and Gabilan blocks to the northeast by the northwestward extension of the King City fault. Clark and Rietman (1973) consider the Ben Lomond and Gabilan blocks of Clark (1930) to be a single block, terming it the Ben Lomond-Gabilan block. This block separates the Santa Cruz basin of Clark (1930) from the San Lucia basin (Fig. 3).

Several basins and basement ridges have been identified in the submerged continental borderland of central California (Curray, 1965, 1966; Hoskins and Griffiths, 1971; Silver and others, 1971). Two individual basement ridges are delineated by Silver and others (1971, p. 1-3, Fig. 2). The outer ridge lies northwest of Monterey Bay and south of the Farallon Islands. This ridge is thought by Silver and others (1971) to be composed of rocks of the Franciscan assemblage, and has been mapped as three distinct segments that are believed to be continuous at depth. Shoreward of this ridge is one composed of granitic rocks that crop out as quartz diorite in the Farallon Islands (Silver and others, 1971, p. 103). In addition, two ridge-like features of middle Miocene or older sedimentary rocks are shown by Hoskins and Griffiths (1971, p. 217, Fig. 5), who named them the Santa Cruz and Pigeon Point highs.

The Cretaceous granitic basement rocks of the Salinian block and overlying Tertiary strata have been offset both horizontally and vertically by many faults that trend southeast from Monterey Bay through the Santa Lucia Range (Fig. 15). Some faults can be traced for more than 10 km and appear to have controlled the development of such major geomorphic features as the Salinas and Palo Colorado valleys, which are associated with the King City and Palo Colorado faults. The Sur-Nacimiento fault zone encompasses faults of various kinds and ages in a belt extending southeastward from Point Sur through the central and southern Coast Ranges of California (Page, 1970a).

North of Monterey Bay, faults in the Salinian block trend northwest and offset granitic basement rocks and the overlying Tertiary strata (Jennings and Burnett, 1961). Several faults, namely the Butano and Zayante faults, curve to a nearly east-west trend as they approach the San Gregorio fault zone (Pl. 3). The San Gregorio fault, which extends on land for nearly 30 km northwest of Año Nuevo Point, strikes N25°W and cuts across the regional structural grain.

Offshore, the granitic basement of the Salinian block "imparts a rigid block-faulting structural style to the overlying sediments" (Hoskins and Griffiths, 1971, p. 212). Although on-land faults, in most cases, have not been traced offshore with precision, their presence is well known; for example, Curray (1966, p. 342) has observed that sediments on the Monterey Bay shelf are displaced by many faults. Martin and Emery (1967) have described a fault trending northwestward across the upper axis of the submarine Monterey Canyon and two faults trending northwestward in Carmel Canyon that appear to join the San Gregorio and Sur faults.

Stratigraphy

The following stratigraphic summary is a synthesis of published studies by Beal (1915), Bowen (1969), California State Department of Water Resources (1970), Clark and Rietman (1973), and Clark and others (1974). Composite sections representing the stratigraphy of Tertiary rocks in the central Santa Cruz Mountains and the northern Gabilan Range, and of Cenozoic rocks in the upper Salinas Valley and northern Santa Lucia Range, are included as figures 4, 5, and 6. The areal distribution of these rocks is shown on the geologic map (Pl. 3). The Tertiary stratigraphy of the central Santa Cruz Mountains and the northern Santa Lucia Range is here described in terms of discrete stratigraphic sequences separated by unconformities, following the practice of Clark and Rietman (1973). Basement rocks in the Monterey Bay region include Paleozoic metasediments and Cretaceous granitic rocks of Ben Lomond Mountain, Paleozoic metamorphic rocks of the Sur Series of Trask (1926) in the Santa Lucia Range, and the Mesozoic Santa Lucia granodiorite in the northern Santa Lucia Range and Monterey Peninsula. Cenozoic rocks appear to overlie the basement complex with unconformity throughout the area extending from the Santa Cruz Mountains southward to the Santa Lucia Range, and from the San Andreas fault westward to the Palo Colorado-San Gregorio fault zone. Cenozoic rocks of the Monterey Bay region range in age from

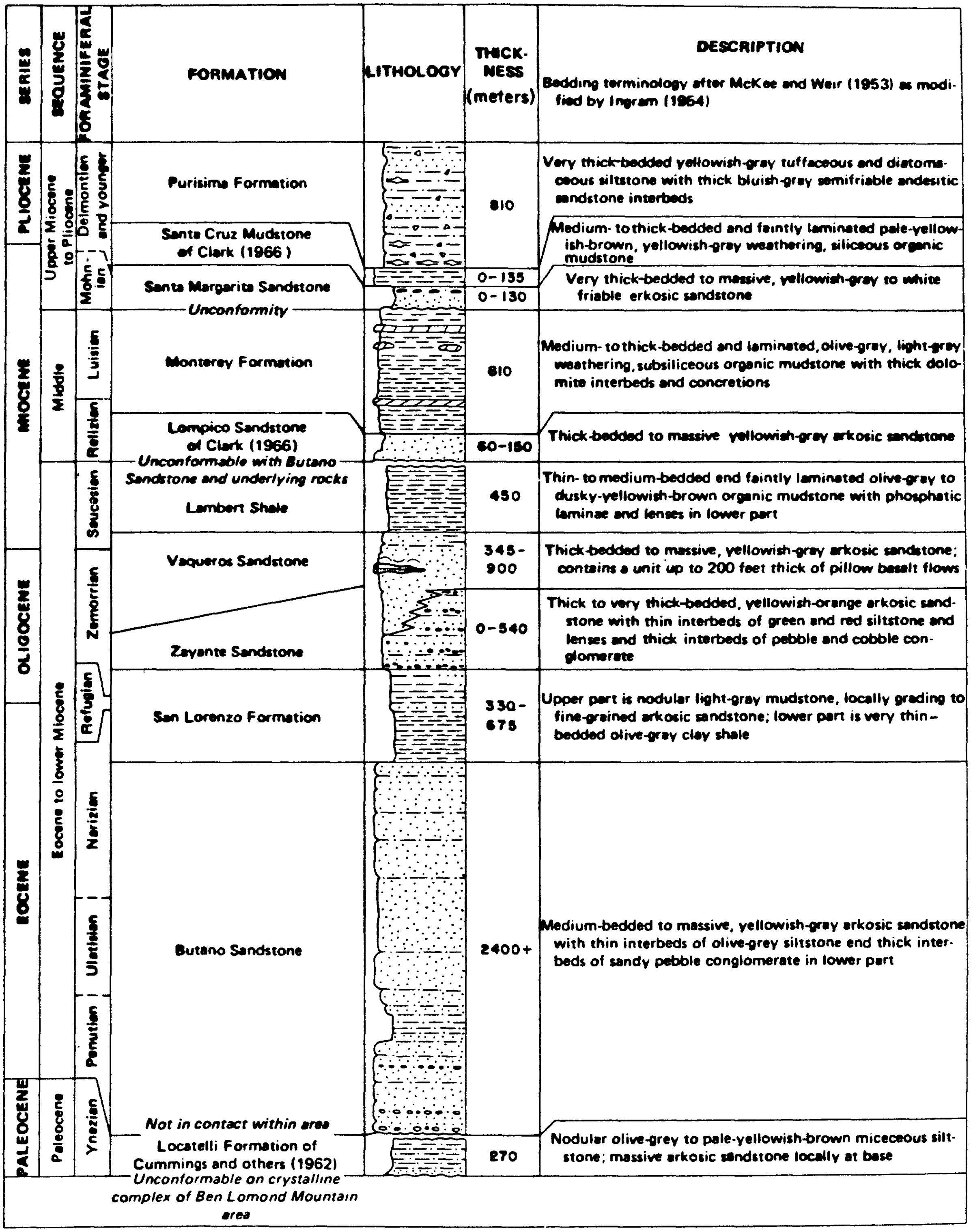


Figure 4.— Composite stratigraphic column of Tertiary rocks of central Santa Cruz Mountains southwest of San Andreas fault and northeast of San Gregorio fault. (After Clark and Rietman, 1973)

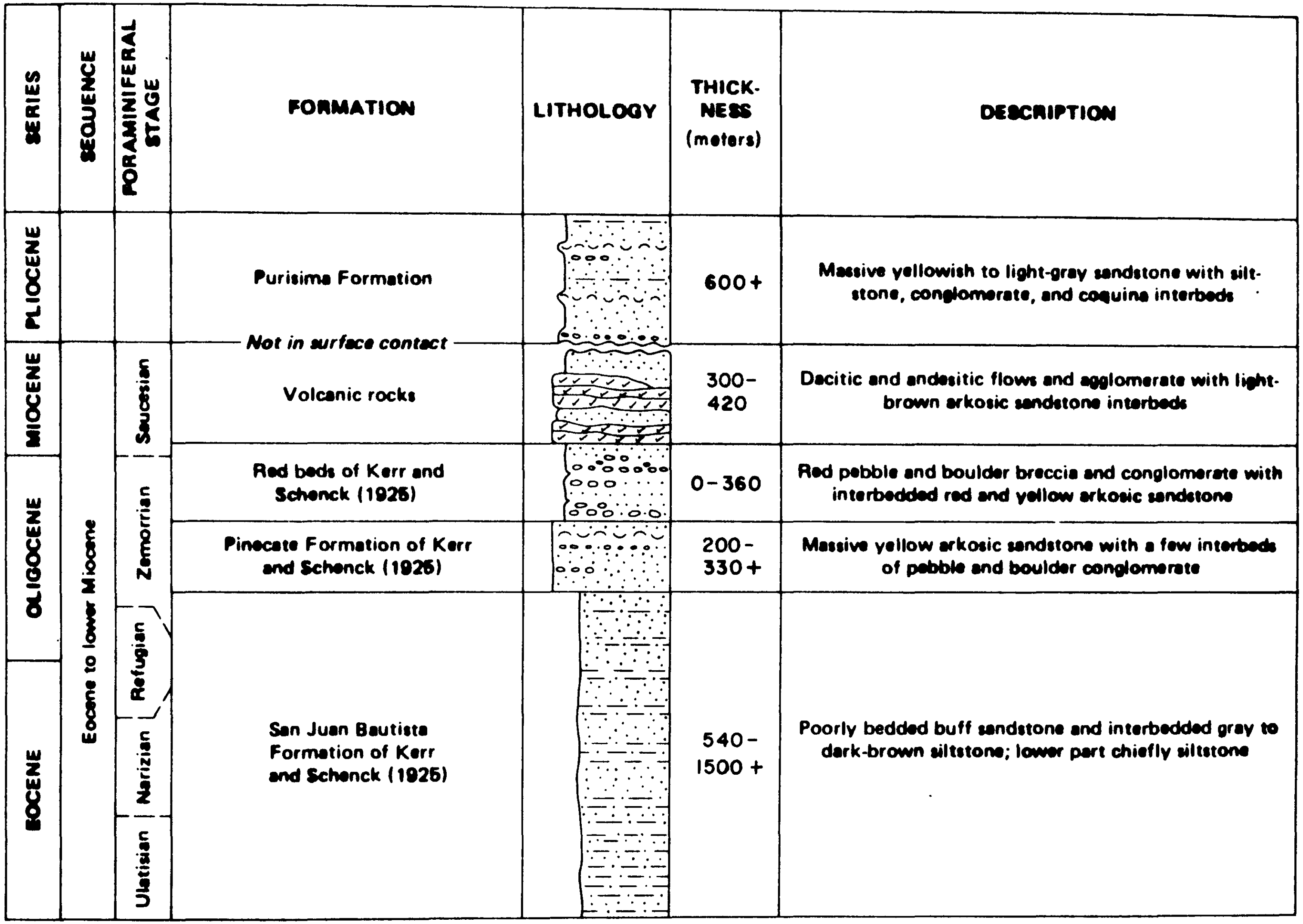


Figure 5 - Composite stratigraphic column of Tertiary rocks of Northern Gabilan Range southwest of San Andreas fault. (After Clark and Rietman, 1973).

AGE	SEQUENCE	FORMATION	LITHOLOGY	THICKNESS (meters)	DESCRIPTION
PLEISTOCENE	UPPER MIOCENE TO PLIOCENE	Aromas Sand		90	Reddish-orange cross bedded sand; non-marine
? PLIOCENE	?	Paso Robles Formation		150	Old alluvium deposited in a valley. Light colored sands and gravels; non-marine.
? MIOCENE		Santa Margarita Sandstone		480	White arkosic sand; minor gravel; marine and brackish marine, locally fossiliferous
		Monterey Formation		900	White diatomite in upper part; light brown siliceous shale in lower part
	MIDDLE MIOCENE	Marine sandstone (Temblor Formation of Trask, 1926)		250	Buff colored weathering arkosic sand and brown sandstone, gravel, minor shale - marine. Interbedded olivine basalt, vesicular or amygdaloidal.
		Red beds of Robinson Canyon		150(?)	Conglomerate, arkose, minor lake-bed clay; commonly red, maroon and green; non-marine
PALEOCENE		Carmelo Formation of Bowen (1965)		330	Buff to brown sandstone with much plant debris; thick conglomerate lenses made up of granitic rocks and strongly colored volcanic porphyries; marine
CRETACEOUS OR JURASSIC		Crystalline complex		?	Granites-granodiorites and quartz monzonites, locally porphyritic.
PALEOZOIC		Sur Series of Trask (1926)		?	Dark brown quartz-mica schist and gneiss; minor crystalline limestone.

Figure 6. - Composite stratigraphic column of upper Salinas Valley-northern Santa Lucia Range (modified after Beal, 1915; Bowen, 1965,1969; California State Department Water Resources, 1970; T. W. Dibblee, oral commun., 1974).

Paleocene to Holocene. The section is nearly 7,320 m thick in the central Santa Cruz Mountains, but thins southward to about 3,050 m in the northern Gabilan Range and about 2,745 m in the Monterey Bay area and northern Santa Lucia Range. The Cenozoic sediments in the upper Salinas Valley may be nearly 6,100 m thick. Cenozoic stratigraphic section in the latter areas is nowhere continuous and is interrupted by three major unconformities, one of which represents a lengthy hiatus.

Paleocene Sequence

Fine-grained Paleocene sedimentary rocks assigned to the Locatelli Formation of Cummings, Touring and Brabb (1962) are approximately 275 m thick in the central Santa Cruz Mountains, where they unconformably overlie crystalline basement rocks. In the northern Santa Lucia Range, the Paleocene Carmelo Formation consists of more than 365 m of sandstone and conglomerate that unconformably overlie granitic basement. Paleocene strata are missing in the northern Gabilan Range.

Eocene to Lower Miocene Sequence

Eocene to lower Miocene strata are more than 4,880 m thick in the central Santa Cruz Mountains and nearly 2,650 m thick in the northern Gabilan Range. The sequence in the central Santa Cruz Mountains is assigned to the Eocene Butano Sandstone, Eocene-to-Oligocene San Lorenzo Formation, Oligocene Zayante Sandstone, Oligocene to lower Miocene Vaqueros Sandstone, and lower Miocene Lambert Shale (Fig. 4).

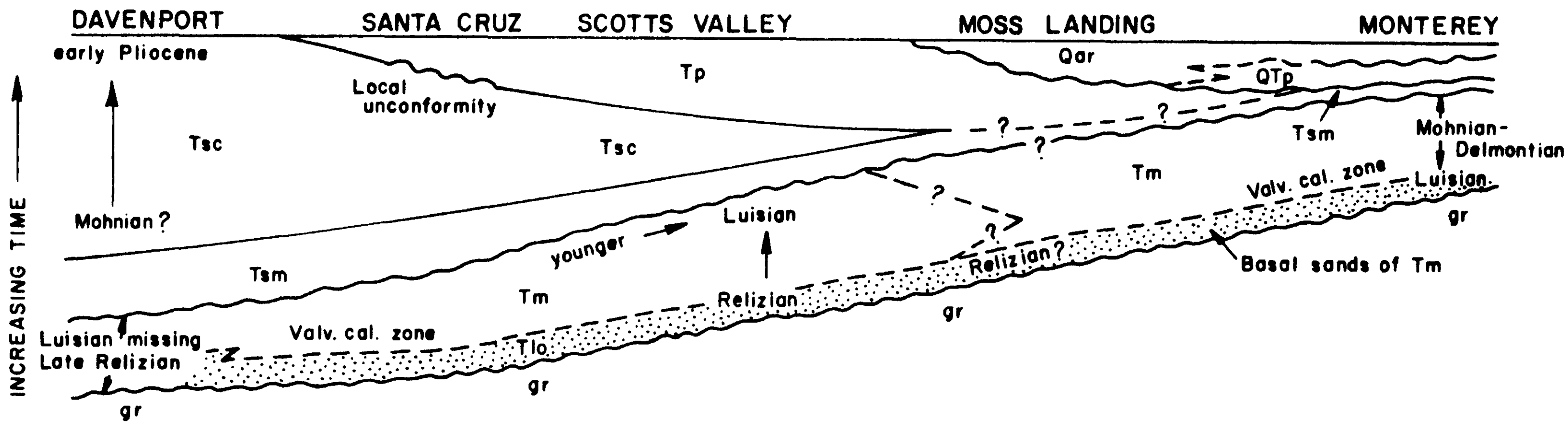
The Eocene to lower Miocene sequence in the northern Gabilan Range is represented by the Eocene-to-Oligocene San Juan Bautista Formation of Kerr and Schenck (1925), Oligocene Pinecate Formation of Kerr and Schenck (1925), and an unnamed lower Miocene unit of sandstone and volcanic rocks. Throughout much of the Monterey Bay region, including the upper Salinas Valley area and the northern Santa Lucia Range, the Eocene to lower Miocene sequence is absent, leaving a large hiatus that extends from the Penutian (lower Eocene) through Saucesian (lower Miocene) foraminiferal stages of Kleinpell (1938) and Mallory (1959).

Middle Miocene Sequence

Approximately 975 m of middle Miocene sedimentary rocks are found in the central Santa Cruz Mountains and are assigned to the Lompico Sandstone of Clark (1966) and the Monterey Formation. These two formations are in conformable contact. Monterey strata throughout the Santa Cruz Mountains are unconformably overlain by the Santa Margarita Sandstone and the hiatus between them appears to encompass most of the Mohnian Stage of Kleinpell (1938) (J. C. Clark, oral commun., 1973).

The middle Miocene sequence in the upper Salinas Valley and northern Santa Lucia Range is approximately 1,265 m thick and is composed of the Red Beds of Robinson Canyon, marine sandstones of the Temblor Formation of Trask (1926), and the Monterey Formation. These formations are in conformable contact. The contact between the Monterey Formation and the overlying Santa Margarita Formation of upper Miocene age appears conformable in outcrop, but may be an unconformity in the subsurface (T. W. Dibblee, oral commun., 1974). Middle Miocene rocks appear to be absent in the northern Gabilan Range.

Middle Miocene strata of the Monterey Bay area reflect a northwest to southeast marine transgression (Fig. 7). Near Davenport, the Monterey Formation and the Lompico Sandstone of Clark (1966) are late Relizian in age and overlie an erosional surface on basement. The Monterey Formation



Qar - Aromas Red Sands of Allen (1946); eolian-Pleistocene
QTp - Paso Robles Formation; non-marine, locally marine at base - late Pliocene to early Pleistocene
Tp - Purisima Formation; marine, brackish
Tsc - Santa Cruz Mudstone of Clark (1966); marine, shelf deposits
Tsm - Santa Margarita Formation; marine, nearshore
Tm - Monterey Formation
Tlo - Lompico Sandstone of Clark (1966)
} marine, nearshore to shelf deposits. Tm undiff. in Santa Cruz Mts., includes Tsc
gr - Granite rocks

Figure 7. - Generalized stratigraphic cross-section showing transgressive-regressive relationships of Neogene sedimentary units in the on-land regions adjacent to Monterey Bay. Diagram prepared with the assistance of J. C. Clark.

near Scotts Valley is younger (Luisian), and toward the Monterey Peninsula, in the type Monterey area, the Lompico Sandstone lenses out and Monterey strata are younger still (Mohnian-Delmontian of Kleinpell, 1938). In addition, the contact between the Monterey Formation and the overlying Santa Margarita, which is an unconformity in the Santa Cruz Mountains, appears conformable in the Monterey area (J. C. Clark, oral commun., 1973).

Upper Miocene-to-Pliocene Sequence

The upper Miocene-to-Pliocene sequence in the central Santa Cruz Mountains is more than 1,065 m thick, and consists of the upper Miocene Santa Margarita Sandstone, upper Miocene-to-lower Pliocene Santa Cruz Mudstone of Clark (1966), and the Pliocene Purisima Formation. These units are in mutually conformable contact. Upper Miocene strata are locally absent to the south, and this sequence is represented by 610 m of strata belonging to the Pliocene Purisima Formation in the northern Gabilan Range and by about 490 m of sedimentary rocks of the upper Miocene Santa Margarita and the Pliocene-to-lower Pleistocene Paso Robles Formations in the northern Santa Lucia Range. However, the Pliocene Purisima Formation may be as much as 3,050 m thick and the Pliocene-to-lower Pleistocene Paso Robles Formation as much as 760 m thick in the subsurface of the adjacent Salinas Valley.

Upper Miocene-to-Pliocene strata, like the middle Miocene sequence, are time transgressive from northwest to southeast, and undergo several facies changes (Fig. 7). Near Davenport, the Luisian is missing as is the Pliocene Purisima Formation of Delmontian or younger age. The Pliocene Purisima Formation laps onto the Santa Cruz Mudstone in the southern part of the Santa Cruz Mountains and locally, in the Santa Cruz area, the contact between these two formations is unconformable. In the Monterey area, the Paso Robles Formation probably lies unconformably on strata of the Monterey and, locally, on the Santa Margarita Formation (J. C. Clark, oral commun., 1973).

Pleistocene-to-Holocene Sequence

The Pleistocene is represented in the central Santa Cruz Mountains by marine terrace deposits that are exposed along the coast. Pleistocene deposits are composed mostly of Aromas Sand and are 305 m thick in the upper Salinas Valley, 245 m thick in the Monterey area, and are also present in the northern Gabilan Range. The Aromas Sand is mostly eolian deposits that depositionally overlie the Paso Robles Formation and locally rest unconformably (?) on the Purisima Formation. Pleistocene sediments in the Santa Cruz to Monterey lowland area comprise some 395 m of valley fill deposits, marine and valley terrace deposits, older alluvium, and older sand dunes, and in the northern Santa Lucia Range consist mostly of older alluvium and marine terrace deposits.

Holocene deposits in the Monterey Bay region consist principally of sand dunes, flood-plain deposits, alluvium, and landslide deposits.

CHAPTER II

AGE AND CHARACTER OF ROCKS IN THE OFFSHORE MONTEREY BAY REGION

INTRODUCTION

Galliher (1932, Pl. III) was the first to construct a map showing the locations and lithologies of rock outcrops and the distribution of Holocene sediment in Monterey Bay. He dredged granitic rock from the south wall of Monterey Canyon and the north wall of Carmel Canyon and collected granitic rock samples from the shelf of Monterey Bay near Point Pinos. In addition, Galliher (1932) collected shale of the middle Miocene Monterey Formation from exposures in shallow water at the south end of Monterey Harbor. Shepard and Emery (1941) and Martin (1964) dredged granodiorite from the south wall of Monterey Canyon and the head of Carmel Canyon, and upper Pliocene sedimentary rocks from the north wall of Monterey Canyon. Martin (1964) also dredged upper Pliocene sedimentary rocks from Soquel Canyon and the south wall of Monterey Canyon, and metamorphic rocks and middle Miocene sedimentary rocks from the west wall of Carmel Canyon (Fig. 8).

Sea floor samples for this study were collected from the shelf, slope and canyon walls in the Monterey Bay region during the period from 1969 to 1971. Sampling stations were selected using detailed continuous seismic reflection profiles. In addition, dredging stations were located so as to sample between the dredging sites from which Martin (1964) collected samples of unconsolidated rock. Forty-one dredge hauls, ten vibra-cores, and two gravity cores were collected, and

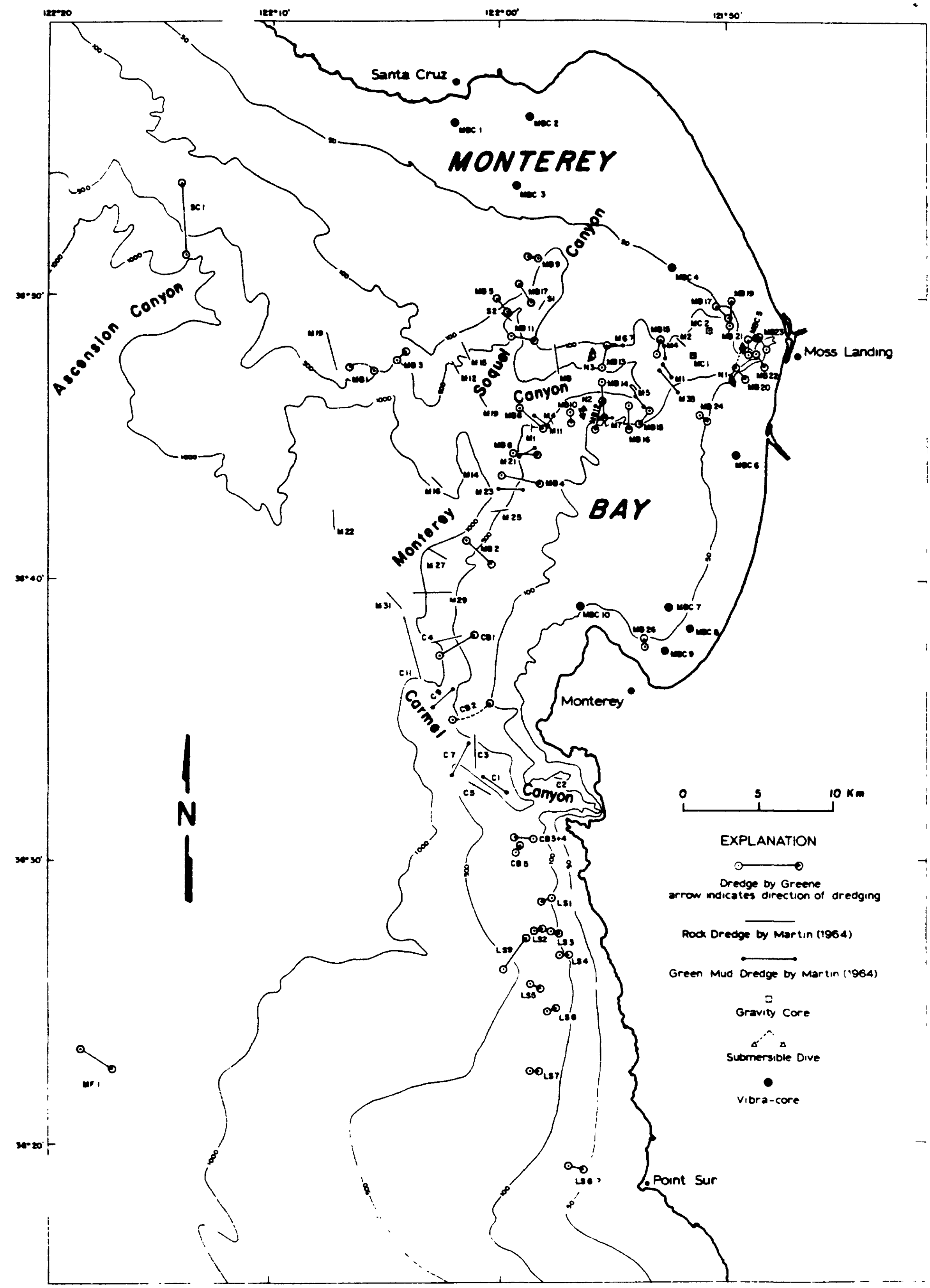


Figure 8. - Map showing sample locations in the Monterey Bay region. Letters and numbers refer to samples described in the text and in Appendix II.

three submersible dives were made. The locations of samples taken during this study as well as those taken in previous studies are shown in Figure 8.

Most dredging for this study was done in Monterey, Soquel, and Carmel Canyons; however, two successful dredge hauls were made on the shelf of southern Monterey Bay and one was made on the continental slope northwest of Santa Cruz (Fig. 8). Several additional dredgings were made by the writer and J. C. Dohrenwend (1971) on the continental shelf between Point Lobos and Point Sur, and a single dredge haul was collected from the unnamed seaknoll located on the continental slope west of Point Sur.

Distinguishing sea floor samples collected from outcrop from those that have undergone transport, and consequently are not in place, is very important in marine geologic studies. This commonly requires difficult judgements, particularly in the evaluation of samples from dredge hauls. Criteria established by Emery and Shepard (1945) and Uchupi and Emery (1963) were used to evaluate all dredge samples collected during this study. According to these criteria, rock samples dredged from outcrops generally exhibit some combination of the following characteristics:

1. Fresh fractures are present.
2. Individual rocks are of large size.
3. Rocks of the same lithology are abundant.
4. Individual rocks display high angularity.
5. Fragile or poorly consolidated rocks are present.
6. Sample collection is accompanied by strong pulls on dredge cable.
7. The dredged outcrop is sufficiently firm to stop progress of ship.

Consolidated rock was recovered in 30 of the dredge hauls; of these 19 are considered to have been collected from outcrop. The rationale used in categorizing a sample as having been collected from outcrop is indicated with the sample description in Appendix II.

Cores were obtained from unconsolidated sediments using a vibrating corer and a standard Phleger gravity corer. Vibra-coring was carried out aboard the R/V OCEANEER by Dr. R. A. Andrews of the Naval Postgraduate School using a device capable of recovering cores 7 cm in diameter, and as much as 6 m long, from water depths up to 300 m. A 3 m Phleger corer was used to obtain the gravity cores in water depths in excess of 300 m. Vibra-cores were taken where seismic reflection profiles suggested that penetration of the unconsolidated sediment cover was possible, in an attempt to recover bedrock (Fig. 8). Only one vibra-core recovered bedrock, although two others may have bottomed in bedrock. The core lengths range from 0.3 m to 6.4 m and have an average length of 4.25 m. Gravity coring, using a 3 m Phleger corer, was employed in Monterey Canyon where water depths exceed 300 m, and was focused on two sites at which seismic reflection profiles suggest slumping.

Three dives were made into Monterey Canyon in the research submersible NEKTON ALPHA to observe the physiography and geological processes active in the canyon and to collect bedrock samples. NEKTON ALPHA is a 4.5 m long, 2-person submersible capable of operating in water depths as great as 305 m (Fig. 9). One dive was made to a depth of 230 m in the head of Monterey Canyon, another was made to a depth of 290 m along the south wall of the canyon, and the third was made to a depth of 255 m along the north wall of the canyon (Fig. 8). Each dive yielded about 1.5 hours of sea-floor observations, and on one dive (dive #2), samples

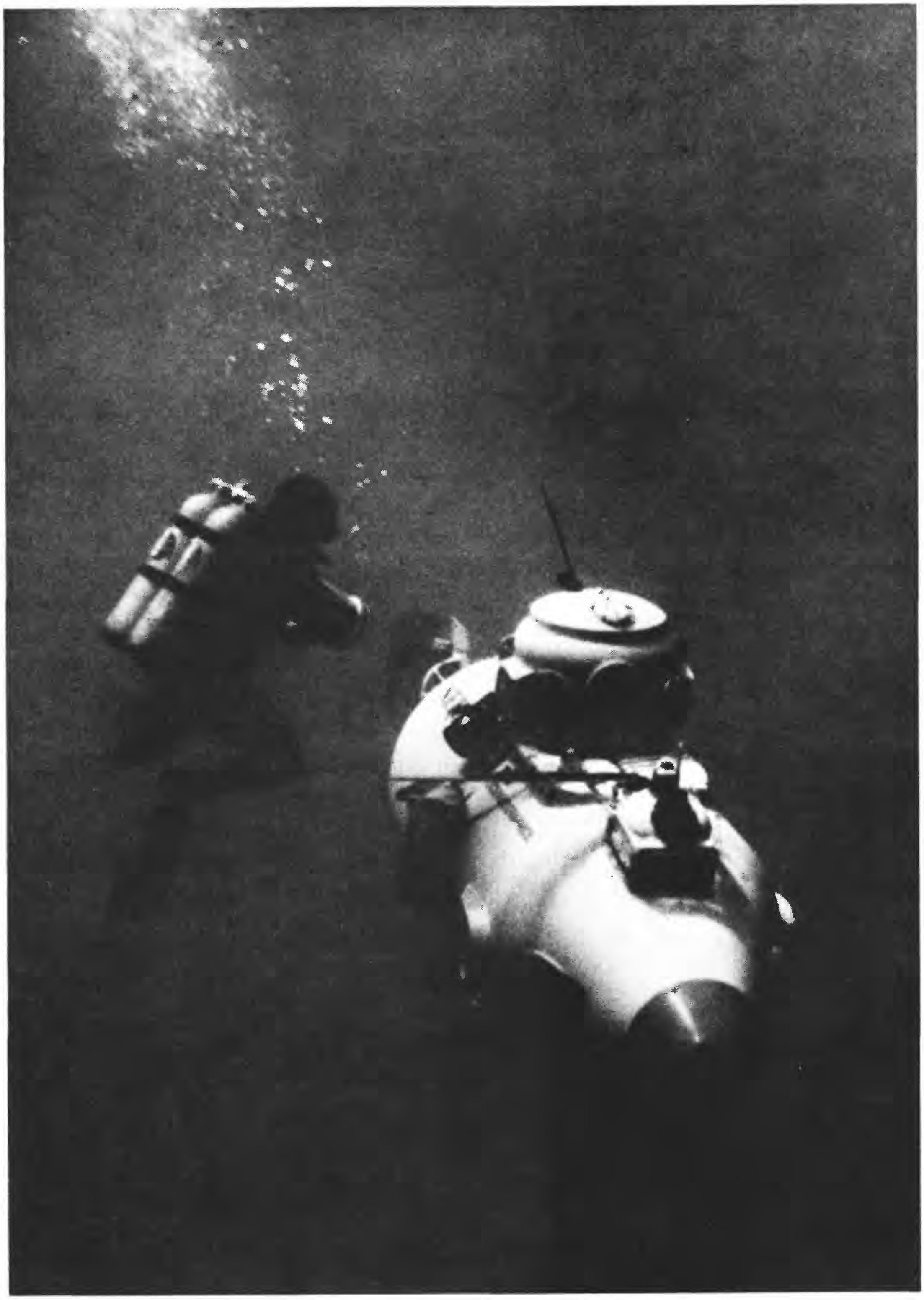


Figure 9. - Photograph of submersible NEKTON ALPHA, used for observation of the Monterey submarine canyon (photo courtesy of General Oceanographics, Inc.).

of consolidated rock were collected.

Lithologic, petrologic and paleontologic descriptions of samples and the geographic locations of samples are included in Appendix II. Condensed descriptions of Martin's (1964) dredge samples also are included in Appendix II. Dredged rocks were described principally from hand specimen although selected samples were examined in thin section. Dr. J. C. Ingle, Jr., Stanford University, identified foraminifers in selected samples, and Dr. W. O. Addicott of the U.S. Geological Survey identified megafossils. Radiographs were taken of gravity cores and both gravity and vibra-cores were split and examined for sedimentary structures.

BASEMENT ROCKS

Salinian basement rocks of the Monterey Bay region consist mostly of Mesozoic granitic intrusives and high grade metasediments; they are widely exposed in the Santa Cruz Mountains and in the Gabilan and Santa Lucia Ranges, and underlie younger rocks in the Gabilan Mesa area (Pl. 3). Intrusive plutonic rocks are predominant and range in composition from very felsic alaskites to dark gabbros, but contain roof pendants of older marble, schist, quartzite and other metamorphic rocks (Ross and Brabb, 1972, p. 273). Plutonic rocks on Ben Lomond Mountain and in the northern Gabilan Range comprise several intrusive bodies that are predominantly quartz diorite, but range from quartz diorite to adamellite (Clark and Rietman, 1973, p. 4). Potassium-argon age determination on granitic rocks from Ben Lomond Mountain and of the Gabilan Range gives dates of 71.0 ± 0.9 and 79.9 m.y., respectively (California Division of Mines and Geology, 1965, p. 16; Compton, 1966, p. 277). Metasedimentary rocks preserved as roof pendants in the southern Santa Cruz Mountains and northern Gabilan Range are believed to represent metamorphosed sandstone, shale, and carbonates deposited in miogeosynclinal environments (Clark and Rietman, 1973, p. 4). These rocks are assigned a probable Paleozoic age (Bowen and Gray, 1959). Similarities in lithology and metamorphic grade suggest that these metasediments are correlative with the Sur Series of Trask (1926) in the Santa Lucia Range (Clark and Rietman, 1973, p. 5).

Basement rocks comprising the "Monterey mass" of Ross and Brabb (1972) on the Monterey Peninsula and in the northern Santa Lucia Range consist principally of coarse-grained, porphyritic granodiorite having a modal composition of about 50% sodic plagioclase, 30% quartz, 15 to 20% biotite. The core of the Santa Lucia Range is composed principally of medium- to coarse-grained holocrystalline intrusive rocks of the Santa Lucia quartz diorite of Trask (1926). The quartz diorites of Gabilan Mesa and the Santa Lucia granodiorites have been assigned potassium-argon ages of 83.8 and 81.6 m.y., respectively, by Curtis and others (1958, p. 11).

Offshore Samples

Igneous Rocks

Granitic basement rocks were dredged at seven localities (MB-2, 3, and 26; CB-1, 2, 3 and 5) along the south wall of Monterey Canyon and the east wall of Carmel Canyon, and at one locality (MB-26) on the shelf just seaward of Monterey (Fig. 8). These rocks were recovered at or near their place of outcrop. Granitic rocks recovered at two other localities were probably transported as clasts. Martin (1964, p. 62) dredged granodiorite from the same areas in Monterey Canyon as well as from both sides of the nearshore reaches of Carmel Canyon (Martin's dredge locations M-25 and 27; C-2, 3 and 4).

Most samples (all except MB-26, CB-3 and CB-15) of granitic rocks taken during this study were analyzed petrologically by D. C. Ross of the U.S. Geological Survey, who found them to be principally porphyritic biotite granodiorite and very similar in modal composition to intrusive rocks of the "Monterey mass" of Ross and Brabb (1972) exposed on the Monterey Peninsula (Fig. 10). Some samples are coarsely porphyritic with K-feldspar phenocrysts as large as 20 mm. In contrast, the granitic rocks dredged by Martin (1964) from Monterey Canyon lack the well developed phenocrysts of orthoclase present in these samples and in rocks from nearby exposures on land. The rocks described by Martin (1964) also contain significantly less plagioclase (25% vs. 50%) and more K-feldspar (30% vs. 15 to 20%) than typical granodiorites from the "Monterey mass" of Ross and Brabb (1972). Finer-grained felsic rocks also were collected together with the coarser-grained "Monterey mass" rocks in the dredge hauls. These are dike rocks, but could be local variants of the "Monterey mass" rocks, as could the samples described by Martin (1964).

The granitic rocks collected in Monterey Bay indicate that the porphyritic biotite granodiorite of Monterey Peninsula is also the dominant basement rock type in the adjacent offshore area of Monterey Bay. These rocks extend in outcrop from the west wall of Carmel Canyon northward along the south wall of Monterey Canyon, eventually reaching its north wall just west of Soquel Canyon (Pl. 3).

Metamorphic Rocks

Metamorphic rocks were recovered from only three dredge hauls (MB-5, CB-2, and LS-5) and all clasts appear to have been transported (Fig. 8).

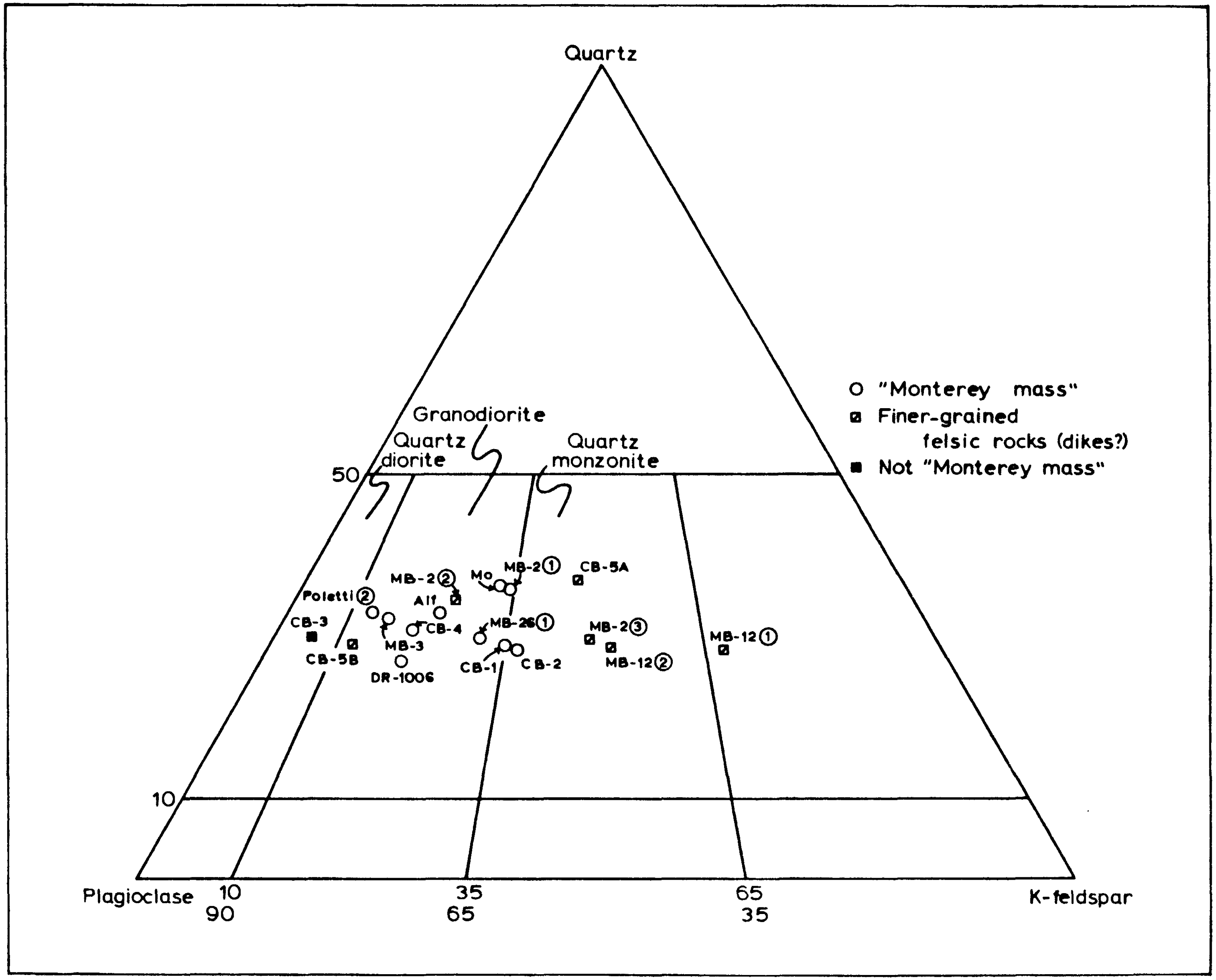


Figure 10. - Ternary diagram showing modal composition of the granitic rocks in the Monterey Bay region. Analysis by D. C. Ross (written commun., 1972).

Sample MB-5, from the northwest wall of Soquel Canyon, and sample CB-2, from the eastern tributary to Carmel Canyon, contain a few well rounded pebbles of gneiss. Sample LS-5, from the Point Lobos-Point Sur shelf, contains a few fragments of highly altered metasedimentary rock that are angular and may have undergone little transport (Dohrenwend, 1971). Metamorphic rock was also dredged by Martin (1964), who recovered quartzite in a haul (M-31) from the west wall of Carmel Canyon. All of these metamorphic rocks may have been derived from the pre-Cretaceous Sur Series of Trask (1926), which is composed principally of schist, quartzite, gneiss, and crystalline limestone (Trask, 1926, p. 127), and is exposed in the Santa Lucia Range a short distance southeast of the dredge sites.

Sedimentary Rocks

Most sedimentary rocks collected in the offshore Monterey Bay region are consolidated to semi-consolidated mudstone, siltstone, sandstone, and conglomerate derived from the middle Miocene Monterey Formation and Pliocene Purisima Formation. A relatively small amount of limestone and dolomite, and some sandstone and conglomerate of undetermined age, also were recovered from dredge hauls in Monterey Bay.

Rocks of Unknown Association

Dredge haul MF-1, from the east flank of the unnamed seaknoll off Point Sur (Fig. 8), recovered many subrounded, grey-brown, phosphate-coated, perforated boulders of dolomite that are unlike other samples collected in this region. The roundness, absence of fresh surfaces, and encrustation of all surfaces by marine organisms indicate that these clasts were not in place. However, the dolomite boulders probably were not transported far because the seaknoll from which they were taken is the highest topographic feature in the area. In addition to dolomite, which makes up 80% of the sample, this haul contained boulders of medium-grained, yellowish-brown sandstone composed of quartz and metamorphic rock fragments, and a few well rounded pebbles of granitic rock. The dolomite is barren of microfossils. However, it is lithologically similar to other dolomite samples that occur as interbeds and concretions in the Monterey and thus may be of Miocene age (J. C. Clark, written commun., 1975).

Coarse sandstone (sample CB-4) was dredged from the eastern tributary to Carmel Canyon, and conglomerates were collected in dredge hauls CB-4 and 5, located on the western head of the western tributary to Carmel Canyon (Fig. 8). Both samples are barren of fossils and their age is indeterminate. The sandstone appears in thin section to consist of angular fragments of siltstone, quartz, and plagioclase feldspar. Most of the siltstone fragments are fractured and sheared, suggesting derivation from a fault zone. The conglomerate clasts are principally rounded quartz, chert, lithic fragments, and granitic rock pebbles in a coarse sand matrix cemented by sparry calcite. These samples appear to have been collected near their place of outcrop (App. II), and may be from Cretaceous or lower Tertiary strata, since rocks of this age and of similar character crop out nearby on shore.

MIDDLE MIOCENE MONTEREY FORMATION

General

The Monterey Formation, where it is exposed on land in the Monterey Bay region, consists of rhythmically bedded, organic mudstone, diatomaceous and siliceous shale and sandstone, and thinly layered chert (Galliher, 1930;

Cummings, Touring and Brabb, 1962). Bentonite and dolomite are interbedded with the formation in the Felton-Santa Cruz area. The Monterey Formation has a maximum thickness of about 820 m in the Santa Cruz area. Here it locally underlies the Santa Margarita Sandstone with unconformity and the Lompico Sandstone with conformity. Monterey strata exposed in the Felton-Santa Cruz area are assigned to the late Relizian and Luisian foraminiferal stages (Clark, 1966, p. 97-99). Monterey strata exposed in the type area of the unit near Monterey are 965 m thick and have been assigned to the Luisian, Mohnian and Delmontian stages (Galliher, 1930; Kleinpell, 1938). The Monterey Formation on the Monterey Peninsula unconformably overlies granodioritic basement rocks.

Offshore Samples

Three dredged samples, SC-1, MB-4, and LS-7, and one vibra-core, MBC-9, contain Monterey-like rocks of probable middle Miocene age. These samples are widely spaced; SC-1 is from the slope northwest of Santa Cruz, MB-4 is from the south wall of Monterey Canyon, LS-7 is from the central part of the Point Lobos-Point Sur shelf, and MCB-9 is from the shelf of southern Monterey Bay near Monterey (Fig. 8). The samples are lithologically dissimilar. Sample SC-1 contains subangular to subrounded, cobble-sized clasts of yellowish-grey to light olive-grey limestone and siliceous siltstone that were dredged from or near their outcrop (App. II). This sample is barren of age-diagnostic fossils but is believed to be middle Miocene in age, as it resembles rock types common in Relizian strata in exposures of the Monterey Formation onshore (Kleinpell, 1938, p. 119). However, limestone is also common in the pre-Cretaceous Sur Series of Trask (1926); thus a pre-Cretaceous age cannot be ruled out (Martin, 1964, p. 61).

Sample MB-4 is mostly coarse-grained granitic or arkosic sandstone. This sandstone appears in thin section to be composed of fragments of silicic volcanic and granitic rocks, microcline, and fresh and altered plagioclase, and is cemented by sparry calcite. The sample resembles Santa Margarita Sandstone in the Santa Cruz Mountains, but because of its proximity to exposures of the Monterey Peninsula, it is more likely to be from the basal sandstone member of the Monterey Formation (J. C. Clark, oral commun., 1974). About 5% of sample MB-4 is composed of semi-consolidated, grey, fossiliferous siltstone that did not yield age-diagnostic fossils. Most mineral grains in this siltstone are too small to identify in thin section, but the larger grains appear to be mostly quartz, iron(?)-rich opaque minerals, chlorite and biotite, and probable volcanic and lithic rock fragments. These rocks are petrographically dissimilar to other late Tertiary rocks collected in the region. The rocks present in sample MB-4 probably were not dredged from outcrop; however, their outcrops probably were nearby as neither rock type had undergone appreciable transport.

The third sample (LS-7) contains fragments of brown to light-grey, well-indurated claystone, and silty to sandy claystone and shale dredged on or near a fault scarp in the south-central Point Lobos-Point Sur shelf (Fig. 8). Dohrenwend (1971, p. 48) reports the composition of these rocks to be 5% quartz and feldspar of silt to fine sand size, 5 to 15% marine microfossils, and 80 to 95% clay matrix. The microfauna examined in thin section by J. C. Ingle, Jr. include abundant diatoms and a benthonic foraminiferal fauna dominated by unidentified species of Bolivina and Bulimina, strongly suggesting that the dredge sample is from the Monterey Formation. Furthermore, the presence of a large specimen of Valvulineria, possibly

V. californica, suggests a Luisian (upper middle Miocene) age for the rock (Dohrenwend, 1971, p. A1; J. C. Ingle, Jr., written commun., 1973; note: see description of dredge sample LS-7 in Appendix II for full text of this written commun.). This sample probably was dredged from outcrop.

The vibra-core sample MBC-9 contains 3.3 m of mud and well sorted arkosic sand. The lower 0.6 m is olive-green mud containing chert fragments, and the upper 2.4 m is a well sorted, medium-grained, greenish-white arkosic sand that grades upward into greenish-grey, fine-grained sand. Several angular, freshly broken, chert fragments in the core catcher suggest that the corer bottomed in Monterey chert.

Martin (1964) recovered rocks of probable middle Miocene age in four dredge hauls (S-2, C-5, 11, and M-31) in Soquel and Carmel Canyons. All but sample S-2 were dated using microfossils. An arkosic sandstone in the undated sample (S-2) is described as consisting mostly of quartz and orthoclase, with a minor amount of plagioclase, poorly cemented by a clay matrix (Martin, 1964, p. 60). This description suggests that the sample could be from the Santa Margarita Sandstone or from the basal sandstone of the Monterey Formation. The sample location, the west wall of Soquel Canyon near the Santa Cruz area where Santa Margarita sandstone is exposed, suggests that sample S-2 is from the Santa Margarita. The Santa Margarita Sandstone in the Monterey Bay region is of late Miocene (Mohnian-Delmontian) age (Clark, 1966, p. 131).

Martin's dredge samples M-31 and C-11 from the west wall of Carmel Canyon are composed of angular fragments of dark to light brown, banded, siliceous siltstone that contain radiolarians and diatoms characteristic of the Monterey Formation. A middle Miocene age is assigned to this sample by Martin (1964, p. 59) based on the analysis of diatoms.

A well indurated micrite or micritic skeletal limestone was recovered in Martin's (1964) dredge haul C-5 located high on the west wall of Carmel Canyon. Diatoms within the limestone yielded a middle Miocene age.

Dredge samples containing middle Miocene rocks suggest that the Monterey Formation is exposed locally along the south wall of Monterey Canyon, below the shelf edge in southern Monterey Bay, along both walls of Carmel Canyon, and on the central part of the Point Lobos-Point Sur shelf. Middle Miocene rocks may also crop out on the continental slope off Santa Cruz, as suggested by the seismic reflection profiles discussed in the preceding section.

PLIOCENE-PLEISTOCENE* PURISIMA FORMATION

General

The Purisima Formation in the northern Santa Cruz Mountains consists of marine, fine-grained sandstone,shale and conglomerate and has a maximum thickness of 1,722 m (Cummings, Touring and Brabb, 1962). The formation has been divided into five major lithologic members:

Tunitas Sandstone Member (youngest)

Lobitos Mudstone Member

San Gregorio Sandstone Member

Pomponio Silty Mudstone and Siltstone Member

Tahana Sandstone and Siltstone Member (oldest)

The Tahana Member forms the basal part of the Purisima Formation, and consists of greenish-grey, medium- to fine-grained sandstone and siltstone, and dark grey, silty mudstone, with pebble conglomerate beds at its base. It has a maximum thickness of 655 m. The sandstones are composed of

---

* The Purisima Formation may include strata of Pleistocene age based on recent correlations (Ingle, 1973, p. 956).

plagioclase and subordinate quartz, with some andesite and, less commonly, basalt fragments, cuspate shards of volcanic glass, and pumice. Heavy minerals commonly present are green hornblende, oxyhornblende, enstatite, hypersthene, biotite, and glaucophane. Calcite and chlorite commonly fill irregular interstices as secondary cement. Microfossils include foraminiferas, diatoms, and ostracods. Megafossils commonly present include echinoderms, barnacles, mollusks, marine vertebrate bones, sponge spicules, fish fragments, and echinoid spines (Cummings, Touring and Brabb, 1962, p. 200).

The Pomponio Member consists of alternating beds of medium grey to white or light grey, hard and soft, silicified mudstone, siltstone, and porcellanite. The member has a maximum thickness of 700 m. Sandstone composition is similar to that of the Tahana Member. At the type locality the member is barren of age diagnostic fossils but in other areas it contains abundant megafossils and some microfossils similar to those described for the Tahana Member (Cummings, Touring, and Brabb, 1962, p. 202).

The San Gregorio Member is composed mostly of fine- to coarse-grained, greenish-grey to light brown, massive sandstone with irregularly distributed pebbles of varicolored chert and basic volcanic rocks. It has a maximum thickness of 137 m. Sandstone composition is similar to that of the Tahana Member. The San Gregorio Member also contains irregular calcareous concretions. Megafossils are abundant locally in the upper part of the member, but few microfossils have been described (Cummings, Touring and Brabb, 1962, p. 204).

The Lobitos Member consists of massive, dark grey to reddish or yellowish brown, micaceous and silty mudstone that contains fossiliferous lenses and a distinctive white tuff bed. The member has a maximum thickness of 137 m. Sandstone composition is similar to that of the Tahana Member, except that glass shards and very fine grains of glauconite are common locally (Cummings, Touring, and Brabb, 1962, p. 204).

The Tunitas Member is composed of massive, greenish-grey to light grey or very pale grey-orange, fine-grained, well sorted, concretionary sandstone, and has a maximum thickness of 122 m. The sandstone is composed mostly of feldspar and andesitic rock fragments, and locally it is cemented by calcite and chlorite. Megafossils are both common and well preserved (Cummings, Touring, and Brabb, 1962, p. 208).

Offshore Samples

Twenty-six dredge samples collected in the Monterey Bay region for this study contain material derived from the Purisima Formation. Twenty-three of these are mostly siltstone or mudstone, eight are principally sandstone, and two are conglomerate. Twenty-two of the samples appear to have been collected at or near their place of outcrop and four appear to have undergone substantial transport. Purisima sandstone was collected from outcrop during one submersible dive (N-2), and one vibracore (MBC-2) appears to have bottomed in Purisima sandstone. Martin (1964) recovered Purisima rocks in ten dredge hauls, eight of which were probably collected from or near their outcrops and three of which appeared to have been transported. Lithology of most Purisima rocks dredged from Monterey Bay is similar to that described for the Tahana Member by Cummings, Touring , and Brabb (1962, p. 198). The dredge samples generally consist of well indurated to semi-consolidated, angular to subrounded boulders, cobbles, and pebbles ranging in color from greenish-grey on fresh surfaces to yellowish-grey or greyish-orange on weathered surfaces. Glauconite is abundant in many samples and phosphorite coatings are common. Many are highly fossiliferous, containing abundant foraminifera, radiolarians, diatoms, sponge spicules, statocysts of shrimp mollusks, echinoids, scaphopods, corals, brachiopods, barnacles, and bryozoans. These rocks commonly are perforated by worm burrows or borings and are covered on one or more sides by modern marine encrustations of calcareous worm tubes, bryozoans, corals, siliceous sponges, and in some cases by brachiopods, barnacles, and rock scallops. The siltstone and mudstone clasts are generally too fine-grained for a thin-section identification of all of the mineral constituents. However, the sand-size material present appears to be mostly quartz, plagioclase, fragments of volcanic rock and shards of volcanic glass, iron(?)-rich opaque minerals, and less commonly, fine-grained, unstable rock fragments. The grains commonly are cemented by secondary sparry calcite or chlorite.

Microfossils identified in the siltstone and mudstone samples are all representative of the Purisima and Merced Formations of Pliocene to early Pleistocene age in the area surrounding Monterey Bay and on the San Francisco Peninsula (see faunal analysis by J. C. Ingle, Jr., App. II). Most, if not all, of the benthonic foraminiferal species common to the Purisima-Merced sequence are still living, and thus are not age diagnostic in an evolutionary sense. However, the benthonic species do exhibit a series of systematic biofacies changes with time, concurrent with filling of the basin and transgression of the adjacent slopes during Pliocene and early Pleistocene time. Consequently, deeper water (middle bathyal) biofacies are typical of the lower part of the Purisima Formation, and shallower water biofacies are common higher in the Purisima Formation and in the overlying Merced Formation. Shallow water species also occur as displaced elements in the deeper water biofacies. These biofacies trends can be used, in turn, to interpret the relative ages of the Monterey Bay Purisima samples, with deeper water faunas representing older intervals and shallow water biofacies representing younger horizons (J. C. Ingle, Jr., written commun., 1972).

Planktonic foraminiferal biofacies in the Purisima-Merced sequence on shore appear to exhibit temperature-induced variations that can be correlated with major Pliocene and early Pleistocene paleoclimatic events recognized over wide areas of the North Pacific. However, planktonic faunas are meager in most of the recent Monterey dredge samples. The lower part of the Purisima Formation contains dextral coiling populations of _Globigerina pachyderma_ indicative of water temperatures higher than those typical of this latitude today, reflecting a major warm interval recognized in the Pliocene over the entire North Pacific. Only one dredge sample, MB-11, contains a population of this species that is predominantly dextrally coiled. Sinistral coiling populations of _G. pachyderma_ are dominant in the upper Purisima-Merced interval (J. C. Ingle, Jr., written commun., 1972). Using the paleobathymetric implications of both benthonic assemblages and planktonic species, J. C. Ingle (written commun., 1972) tentatively assigned each of the Monterey Bay dredge samples he examined to a stratigraphic position within the Purisima Formation. All of these samples are Pliocene in age based on their estimated position within the Purisima sequence (see App. II). Detailed biostratigraphic study of the Purisima Formation will likely provide a more detailed framework into which these samples can be placed (J. C. Ingle, Jr., written commun., 1972).

Megafaunal assemblages were studes by W. O. Addicott (written commun., 1972) and J. G. Vedder (written commun., 1972); most are Pliocene and Pleistocene in age in terms of the Pacific Coast megainvertebrate chronology of

Weaver and others (1944) (see App. II). The majority of samples contain shallow-water assemblages that can be correlated with the upper part of the Purisima Formation of the Santa Cruz Mountains and the lower part of the Merced Formation of the northern part of the San Francisco Peninsula. All occurrences onshore are of late Pliocene age in terms of a twofold provincial subdivision of the Pliocene epoch (W. O. Addicott, written commun., 1972).

An attempt is made here to assign the dredge samples collected during this study to members of the Purisima Formation described by Cummings, Touring, and Brabb (1962), on the basis of megafauna and lithology. This correlation is at best speculative, and it should be remembered that commonly the distance traversed along a slope during a dredge haul is sufficiently long to incorporate the lithology of more than one member in any sample.

North Wall of Monterey Canyon and Soquel Canyon

Dredge samples collected in Soquel Canyon and along the seaward end of the north wall of Monterey Canyon (Fig. 8) are composed of consolidated siltstone and mudstone containing benthonic foraminiferal assemblages suggestive of middle to upper bathyal paleodepths (1,500 to 200 m). Three samples (MB-5, 7, and 9) from the northwest wall of Soquel Canyon were collected at depths much shallower than those suggested by the foraminiferal assemblages, apparently suggesting late Pliocene to Pleistocene uplift of this material. Sample MB-5, which was dredged at depths from 360 to 90 m, contains a middle to upper Purisima foraminiferal fauna suggestive of depths between 1,500 and 600 m. Samples MB-7 and MB-9 were dredged from depths of 210 to 105 m and 110 m to 80 m, respectively, and both contain middle Purisima foraminiferal faunas suggestive of depths of deposition between 600 and 200 m. These rocks lack fresh fracture surfaces, and high cable tensions were not noted during dredging, suggesting that these samples were not dredged from outcrop. However, the lithologic uniformity of the dredged material suggests that the outcrops were close by, and that these rocks probably had been transported only a short distance down-slope. Dredge sample MB-11 was taken at depths between 550 and 110 m along the southeast wall of Soquel Canyon. This sample contains middle Purisima foraminiferal assemblages thought to indicate depths between 600 and 200 m, suggesting an absence of uplift. This sample also appears to have been transported, and may have been displaced further down-slope than the other samples from Soquel Canyon.

The lithologies of dredge samples MB-1, 3, 4, 7, 9, and 11 are similar to those described for the Tahana, Pomponio, and San Gregorio Members of the Purisima Formation by Cummings, Touring, and Brabb (1962). The predominant coarse grains are quartz, plagioclase, fragments of volcanic rock, biotite, chlorite; the rocks are commonly cemented by sparry calcite. The samples are light bluish-grey or greenish-grey on fresh surfaces and yellow-grey on weathered surfaces. One sample, MB-11, consists of unconsolidated to semi-consolidated mudstone and sand containing randomly scattered pebbles of well rounded, varicolored chert and volcanic rock, suggesting that it may be equivalent to the San Gregorio Sandstone Member of Cummings. Touring, and Brabb (1962). Martin's (1964) samples of Purisima rocks from the north wall of Monterey Canyon and Soquel Canyon also consist mostly of consolidated siltstones that represent strata in the mid-part of the Purisima Formation.

Dredge samples MB-13 and MB-15 collected east of Soquel Canyon contain middle Purisima foraminiferal assemblages representative of upper bathyal depths (600 to 200 m); both were dredged at depths between 500 and 100 m. Sample MB-13 is greyish-olive, unconsolidated silt and clay containing several small boulders and cobbles of light bluish-grey to dusty yellow or yellowish-grey, consolidated, sandy siltstone. Sample MB-15 is similar in composition except that the siltstone clasts are of gravel size, angular to subangular in shape. The siltstone clasts in both samples appear to have been transported downslope only a short distance from outcrop. These siltstones are similar in gross lithology to siltstones in the Tahana or Lobitos Members of the Purisima Formation.

Three dredge hauls (MB-17, 19, and 21) recovered consolidated and unconsolidated material from the Purisima Formation in the head of Monterey Canyon. Samples MB-17 and 19 contain late Pliocene foraminiferal assemblages typical of the upper Purisima Formation. These samples suggest middle and inner shelf (neritic) depositional environments and depths ranging from 75 to 25 m. Pliocene foraminiferal assemblages in dredge sample MB-21 suggest outer shelf (neritic to upper bathyal) environments and depths ranging from 200 to 75 m. Samples MB-17 and 19, collected at depths of 100 to 55 m and 200 to 50 m, respectively, are thought to have been collected near their outcrops, whereas sample MB-21 is taken at depths from 150 to 40 m and is thought to have been transported. The color and general appearance (App. II) of the siltstones suggest that these samples may be from the Lobitos and Tunitas Members and Tunitas Members of the Purisima Formation. Dredge hauls by Martin (1964) in the headward part of Monterey Canyon recovered only green mud.

South Wall of Monterey Canyon

Two dredge samples (MB-2 and MB-6) from the south wall of Monterey Canyon also contain rocks of the Purisima Formation. Dredge MB-2 recovered two very large boulders of sandy to pebbly, highly fossiliferous siltstone. Molluskan fossils, including the gastropod *Antiplanes* sp. and the pelecypods *Clinocardium meekianum* (Gabb), *Macoma* sp., and *Patinopecten*, indicate a Pliocene age in terms of the Pacific Coast megainvertebrate chronology of Weaver and others (1944). These mollusks are common in shallow facies of the Purisima Formation in the Santa Cruz Mountains, according to W. O. Addicott (written commun., 1972); their association suggests an inner sublittoral (neritic) environment, possibly at depths of 60 to 30 m. The size and angularity of the boulders, and the high wire tension observed during this haul, suggest that sample MB-2 was dredged from or near its place of outcrop. It was dredged at depths from 915 to 230 m, suggesting that this area has undergone subsidence since late Pliocene time.

Sample MB-6 contains a Pliocene, lower Purisima foraminiferal assemblage typical of the lower Purisima Formation and suggestive of deposition at lower to middle bathyal depths, between 2500 and 1500 m. The sample was dredged from a depth of 550 to 180 m, suggesting that this area has undergone uplift since late Pliocene-early Pleistocene time. A few pelecypods, including *Macoma* sp., *Solen*(?) shell fragments, and a lower Purisima fauna that probably has been reworked, are also present in this sample.

Samples MB-2 and MB-6 are similar in lithology. They consist of consolidated to semi-consolidated, sandy siltstone containing irregularly distributed, rounded pebbles of varicolored chert and volcanic rocks. The rocks are highly perforated and range in color from dark greenish-grey on fresh surfaces to yellowish-brown or light brown on weathered surfaces. Some have phosphatic coatings. These two samples resemble siltstones in the Tahana, Pomponio, and San Gregorio Members of Cummings, Touring, and

Brabb (1962). This stratigraphic position is also suggested by the presence in sample MB-2 of Patinopecten, which in the Santa Cruz area onshore is generally found only in the three lower members of the Purisima Formation (Cummings, Touring, and Brabb, 1962, pl. 24). The presence of the irregularly distributed chert and volcanic pebbles suggests that they may be correlative with the San Gregorio Member. Martin (1964) did not recover rocks identifiable as Purisima in his dredge hauls along the seaward end of the south wall of Monterey Canyon.

Six Pliocene rock samples were collected from the landward end of the south wall of Monterey Canyon. These samples display considerable variation in lithology and fossil fauna, perhaps due to the very close spacing and variable length of dredge traverses made here in order to delimit an outcrop of Purisima discovered during the second dive of the research submersible NEKTON ALPHA. This dive was made about 2 km east of the major meander in Monterey Canyon (Fig. 8) by H. E. Clifton of the U. S. Geological Survey, who reported encountering a 15 m high cliff of outcropping rock at a depth of 250 m. The cliff face is oriented northeast-southwest and is several tens of meters wide. Bedding in the exposure is well defined and dips about five degrees toward the southeast. Numerous near-vertical joints cross the outcrop. Rock overhangs, apparently of resistant beds, protrude from the cliff face as much as a meter. A small cave 1 to 3 m wide and 1 m high extends 3 to 4 m into the cliff near the base (Fig. 11a). Numerous small rock borings also are visible near the base. Many rock fragments protrude from the mud bottom at the foot of the cliff (Fig. 11b); some of these rock fragments were collected during the dives.

Rock samples taken *in situ* are grey, consolidated, highly perforated siltstone and fossiliferous sandstone. Several cobble-size clasts have

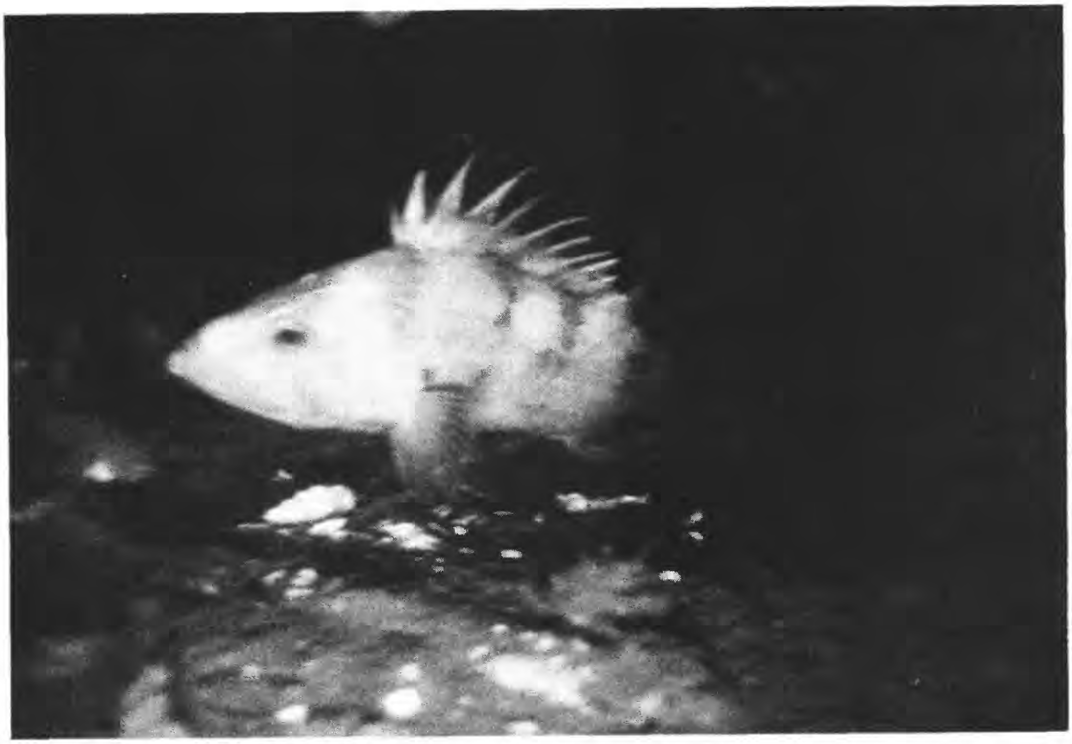


Figure 11a. Photograph of a small cave within the Purisima Formation exposed along the south wall of Monterey Canyon. Fish is approximately 0.5 m long. (Photo by H. E. Clifton; taken from submersible NEKTON ALPHA).

Figure 11b. - Photograph of rocks protruding from canyon floor deposits at the south wall of Monterey Canyon. Large rock on right is approximately 0.4 m in length. (Photo by H. E. Clifton; taken from submersible NEKTON ALPHA).

fresh fracture surfaces. Siliceous sponges are commonly attached to one side of these rocks, and the perforations are those of worms or crustaceans (J. G. Vedder, written commun., 1972). The pelecypod Patinopecten cf. Patinopecten healeyi (Arnold), which is found in these rock samples, is restricted to the Pliocene epoch of West Coast molluskan paleontologists (J. G. Vedder, written commun., 1972), and is found only in the Pomponio and San Gregorio Members of the Purisima Formation (Cummings, Touring, and Brabb, 1962, Pl. 24).

Dredge haul MB-8, located a short distance east of the large meander in Monterey Canyon (Fig. 8), extended from the canyon axis nearly to the shelf break, encompassing a depth range from 830 to 370 m. A second dredge haul, MB-10, was made nearly along the shelf break and encompassed depths ranging from 275 to 120 m. Sample MB-8 consists of one freshly broken fragment of extensively burrowed semi-consolidated siltstone. The only fossils present are shrimp statocysts and spirillina sp., and are undiagnostic as to age. This fragment resembles siltstone collected during the submersible dive and may be from the San Gregorio or Lobitos Member of Cummings, Touring, and Brabb (1962).

Four dredge samples (MB-12, 14, 16 and 18) from the south wall of Monterey Canyon just east of the submersible dive location (Fig. 8) contain foraminiferal assemblages typical of the lower and middle Purisima Formation. Sample MB-12, dredged at depths from 400 to 135 m, contains large, angular cobbles and boulders of consolidated, sandy siltstone and cobbles of fine-grained, highly fossiliferous sandstone that bear a middle Purisima foraminiferal fauna suggesting deposition at upper bathyal depths (600 to 200 m). This sample also contains a Pliocene shallow marine megafauna that is correlative with the upper part of the Purisima Formation in the Santa Cruz

Mountains, the lower part of the type Merced Formation in the northern part of the San Francisco Peninsula, and the upper part of the Merced(?) Formation in Sonoma County (W. O. Addicott, written commun., 1972; App. II). The coarser grains of the siltstone appear in thin section to be composed of subangular quartz, plagioclase, biotite, chlorite, and lithic fragments. Clasts in the sandstone are mostly quartz and fragments of silicic volcanic and granitic rock. The lithology and molluskan fauna in this sample, together with the presence of the echinoid Dendraster sp., which is restricted to the San Gregorio Sandstone Member of the Purisima Formation (Cummings, Touring, and Brabb, 1962, Pl. 24), suggest that the sample is from the San Gregorio Member of Cummings, Touring and Brabb (1962).

Sample MB-14 was collected along a traverse extending from the axis of Monterey Canyon to the shelf edge at depths ranging from 550 to 230 m. This sample is unconsolidated, sandy siltstone containing abundant lower to middle Purisima foraminifers suggestive of lower bathyal depths of 2500 to 1500 m. This deep-water fauna may reflect late Pliocene-early Pleistocene uplift of this sediment.

Sample MB-16, collected farther east (Fig. 8) at depths ranging from 350 to 110 m, is composed of consolidated to semi-consolidated, fossiliferous, arkosic sandstone and angular fragments of siltstone. The foraminiferal fauna is typical of the middle Purisima and suggests an upper bathyal or lower neritic (depths of 200 to 75 m) depositional environment. Most of this sample is from the upper 100 m of the canyon wall, and probably has not been transported far from the outcrop at which it originated.

Sample MB-18 is composed of well indurated, subangular to subrounded, highly fossiliferous, perforated boulders of very pale orange conglomerate and fine-grained sandstone. The conglomerate consists mostly of well rounded pebbles of chert, and volcanic and metamorphic rock fragments in a matrix of fine-grained sandstone having calcareous cement. Color ranges from light bluish-grey on fresh surfaces to greyish-orange or moderate yellowish-brown on weathered surfaces. Calcareous worm tubes, bryozoans, corals, barnacles, small rock scallops, and few siliceous sponges are attached to one or two sides of the boulders. The foraminiferal fauna is meager, indicating only a Pliocene age and a correlation with the Purisima Formation. Mollusks examined suggest a Miocene or Pliocene age. Pelecypods similar to the large Chione collected in this sample (App. II) are not known in faunas in the Santa Cruz Mountains that are generally considered to be late Pliocene in age. However, similar pelecypods occur in the lower Pliocene Pancho Rico Formation in the Salinas basin as well as in Miocene formations in central California (W. O. Addicott, written commun., 1972). The other mollusks are too small or too poorly preserved to be useful in age determination (W. O. Addicott, written commun., 1972). The lithology of this sample suggests that it may be from the San Gregorio Member of the Purisima Formation of Cummings, Touring, and Brabb (1962). The sample was collected from outcrop; its location high on the wall of Monterey Canyon also suggests correlation with the San Gregorio Member.

Dredge haul MB-22, from the south wall of Monterey Canyon at its head, is composed of unconsolidated silt and sand from depths of 165 to 18 m. These sediments contain middle to upper Purisima foraminiferal assemblages indicative of deposition at upper bathyal to lower neritic depths (200 to 75 m). Dredge hauls by Martin (1964) along the central part of the south wall of Monterey Canyon contain highly varied lithologies.

Only three of these (M-9, 17, and 19) appear to have recovered material from the Pliocene Purisima Formation. Martin's (1964) dredge hauls in the upper part of the Monterey Canyon recovered only green mud.

Point Lobos-Point Sur shelf

Seven dredge hauls (CB-3, 4, 5, and LS-1, 3, 4, and 6) from the Point Lobos-Point Sur shelf recovered angular to subrounded fragments of friable to well indurated, greenish-grey siltstone and mudstone that may be Pliocene in age (Table A, App. II; Dohrenwend, 1971, p. 50). These rocks are composed of quartz, K-feldspar, plagioclase, glauconite, chlorite, pyrite, and rock fragments. Many quartz grains have overgrowths of sparry calcite. Biogenic material is sparse, consisting of radiolaria, sponge spicules, fish bones, and fecal pellets (Dohrenwend, 1971, p. 52). These rocks appear similar to Purisima siltstone and mudstone found elsewhere in Monterey Bay, but are mapped as Tertiary-Quaternary undifferentiated in the absence of definitive age data.

Summary

The Pliocene Purisima Formation is exposed locally along both walls of Monterey Canyon, as indicated by the recovery of Purisima rock dredge hauls in the Monterey Bay area. In addition, Purisima strata probably extend more or less continuously along both walls of Monterey Canyon from the shelf edge nearly to the head of the canyon, beneath a cover of unconsolidated sediment. Assignment of these samples to various members of the Purisima Formation of Cummings, Touring, and Brabb (1962) indicates that the most common lithologies in the offshore area are those typical of the Pomponio, San Gregorio, and Lobitos Members. The Tahana Member appears to crop out in the outer part of the canyon, near the shelf edge, whereas the Lobitos Member appears to be exposed in the head of the canyon, reflecting a stratigraphic progression from older to younger rocks in the landward direction. Rocks resembling Purisima have been dredged from the central part of the Point Lobos-Point Sur shelf, suggesting that Pliocene rocks may be present in this area as well.

UNCONSOLIDATED QUATERNARY SEDIMENT

Six dredge and vibra-core samples collected in the Monterey Bay region during this study contain only unconsolidated Quaternary material. Two of these dredge hauls (MB-10 and LS-9) recovered fossil faunas diagnostic of Pleistocene age. Sample MB-10 contains unconsolidated, greenish-olive grey, sandy silt and subrounded to well rounded, coarse gravel composed mostly of granite, siliceous siltstone, and chert. The dredge haul was made along the upper 100 m of the south wall of Monterey Canyon and extended a short distance onto the adjacent shelf, at depths from 275 to 120 m (Fig. 8). Microfossils and megafossils are abundant in this sample. The megafauna suggests a probable Pleistocene age (App. II); similar faunal assemblages from off the southwest coast of Oregon have been dated at about 15,000 years b.p. (W. O. Addicott, written commun., 1972). All fossils present represent species living today. The vast majority of species have been reported living in the Monterey Bay area. However, two of the gastropods, Cryptonatica aleutica and Bittium challisae, are today restricted to northern latitudes, having been reported no farther south than the northwestern coast of Washington. The southern endpoint for the present range of the pectinites, marked by Patinopecten caurinus, is near Point Reyes, California, well north of this occurrence in Pleistocene sediments. These shifts in faunal distribution indicate that at the time of deposition the marine climate off the central California coast was somewhat cooler than at present, which also suggests a Pleistocene age. One of the species, *Tellina carpenteri*, has the appearance of a modern specimen; the original shell coloration is present and the soft parts are intact,. although desiccated. Other specimens are not so well preserved. This assemblage of fossils clearly reflects a sublittoral (neritic) environment, and similar forms live today off the California coast at depths ranging from about 37 to 70 m (W. O. Addicott, written commun., 1972). Thus, the depths of deposition reflected by this Pleistocene fossil fauna are substantially less than those from which the material was dredged.

Although megafossils in sample MB-10 appear, for the most part, to be Pleistocene in age, several mollusks present are common in the Pliocene Purisima Formation. The gastropods *Bittium eschrichti* Bartsh var., *Bittium* cf. *B. attenuatum* Carpenter, *Bittium* cf. *B. challisae* Bartsh, *Bittium* sp., and *Buccinum* sp. are reported from the Pomponio Member of the Purisima Formation; the pelecypod *Clinocardium* cf. *nutalli* (Conrad) occurs in the Tunitas and San Gregorio Members; the pelecypod *Macoma* cf. *M. calcarea* (Gmelin) is reported from the San Gregorio, Pomponio, and Tahana Members (Cummings, Touring, and Brabb, 1962, Pl. 24; J. C. Clark, oral commun., 1973).

Microfossils (foraminifers) in sample MB-10 are typical of the middle Purisima Formation and suggest deposition at upper bathyal depths (600 to 200 m). This difference between microfossil and megafossil age assignments may result from mixing of the sample during dredging. The dredge probably recovered middle Purisima rocks from the canyon wall and Pleistocene unconsolidated fossiliferous sediments from the shelf. Rock samples recovered near dredge site MB-10, but from lower on the canyon wall, are middle Purisima. Pleistocene marine terrace deposits of coarse gravel and sand are reported by Malone (1970) to crop out on the shelf several kilometers south of dredge location MB-10. These deposits may extend northward into the area dredged, and may be represented by the fossiliferous Pleistocene material in MB-10. Malone (1970) suggests that Pleistocene sea level stood 100 to 110 m lower than at present to account for the formation of this terrace deposit. This is consistent with Pleistocene megafossils in dredge haul MB-10 that indicate a Pleistocene sea level position 85 to 205 m lower than at present. In addition, it seems probable that shallow marine deposits of Pleistocene age extend around the south rim of Monterey Canyon from near Cypress Point to the head of the canyon.

Two dredge hauls (LS-8 and 9) recovered Pleistocene sediment on the Point Lobos-Point Sur shelf. Sample LS-8 from near Point Sur consists of a few angular to subrounded pebbles of granite, red chert, and shale. Sample LS-9, collected near the edge of the south central part of the shelf at depths from 300 to 180 m (Fig. 7), consists of unconsolidated, highly fossiliferous, medium- to coarse-grained, olive-grey sand. A few rounded pebbles of granite, chert, and shale are scattered randomly throughout the sand. Megafossils are abundant, and the assemblage suggests that this sample was deposited not later than late Pleistocene time, as all of the taxa identified are still living (W. O. Addicott, written commun., 1972).

An unusual assemblage of megafossils in Sample LS-9 suggests depths of deposition substantially less than those from which it was dredged. The most common invertebrate fossils in sample LS-9 are extensively abraded plates of Balanus and fragments of a rather large, thick-shelled Mytilus. The presence of these taxa, together with mollusks such as Tegula, the doubtfully identified fissurellid Astrea, and Pododesmus, suggests extremely shallow water -- the innermost sublittoral or inter-tidal zone. On the other hand, specimens of Paracyanthus, Astarte (at the latitude of Monterey Bay), Cyclocardia, Dentalium berryi, and Glycymeris suggest depths no shallower than 35 to 45 m, according to fairly detailed data concerning this distribution of modern faunas along this part of the California coast. These fossils appear to be a mixed depth assemblage representing middle sublittoral and inner sublittoral depths (W. O. Addicott, written commun., 1972), indicating that during early Pleistocene time shallow marine sediments were being deposited along the edge of the Point Lobos-Point Sur shelf.

The assemblage in sample LS-9 is of a special interest from a zoogeographic standpoint because of the presence of the pelecypod genus Astarte. This genus is characteristic of the highest latitudes of the North Pacific and the Bering Sea, and until recently (Addicott and Greene, 1974) had not been reported as a fossil or modern specimen south of Puget Sound, more than 1300 km to the north. The species A. bennetti, which is abundant in Sample LS-9, is clearly distinct from the four species of Astarte that are known to range as far south as Puget Sound. Its southernmost modern occurrence is in the Bering Sea, although it ranges into the middle latitudes of the western Pacific (Kyushu Island, Japan), where it is found in the outer part of the sublittoral zone. The presence of Astarte in the Pleistocene assemblage near Monterey Bay suggests that Pleistocene water temperatures were much lower than present day temperatures at this latitude (W. O. Addicott, written commun., 1972). The fossil fauna in Sample MB-10 also suggests that Pleistocene water temperatures in the Monterey Bay area were similar to those in the Arctic today. The fauna contains Cryptonatica aleutica, Bittium challisae, and Patinopecten caurinus. In addition, a skull fragment from a Hydrodamalis (Stellar's Sea Cow) is reported to have been dredged from the floor of Monterey Bay, and dated as 18,940 ± 1,100 years old (Jones, 1967). The Stellar's Sea Cow, now extinct, was reported during historic time only from the vicinity of the Komandorsky Islands. The fossil record of this mammal is scant, but it appears to have been limited in occurrence to the Aleutian Island area during the Pleistocene (D. M. Hopkins, written commun., 1972).

Three dredge hauls at the head of Monterey Canyon and eight vibra-cores from the shallow southern and northern parts of Monterey Bay recovered green mud, silt, and sand of probable late Pleistocene to Holocene age. In addition, two gravity cores from the headward part of Monterey Canyon penetrated canyon fill of probable Holocene age and slump deposits of probable late Pleistocene or Holocene age. Gravity core MC-1 (Fig. 8) penetrated 2.3 m of well laminated and bedded silt and clay, and a very small amount of fine-grained sand (App. II) in the canyon floor, at a depth of 300 m. Radiographs reveal well developed horizontal layering and several intervals of bioturbation, but no graded bedding; this suggests that recent deposition in this part of the canyon has been by processes other than turbidity flow.

Gravity core MC-2 recovered 2.3 m of silt and clay, thought to represent slump deposits, from the base of the north wall of the canyon at a depth of 180 m (Fig. 8). Radiographs of this core show sedimentary structures similar to those seen in core MC-1 (App. II). The surface layers of this core are highly reworked by marine benthonic organisms and probably represent a presently active zone of bioturbation.

Cores MC-1 and MC-2 were taken from widely differing depositional environments, MC-1 from the canyon axis where active down-canyon sediment transport would be expected, and MC-2 from the base of the canyon wall where deposition by slumping could be anticipated. However, the cores are similar in structure and lithology, suggesting that the mode of deposition at both sites is similar. Moreover, it appears that deposition rather than sediment transport and erosion is presently dominant in the upper reaches of Monterey Canyon, in contrast to earlier phases of canyon history.

Submersible dive 1 was made in the headward part of Monterey Canyon, about 2 km east of the location of core MC-1 (Fig. 8). The submersible's traverse cut obliquely across the canyon axis. During this dive no sedimentary structure indicative of active sediment transport or erosion was noted. In addition, an unusual, previously uncharted depression was discovered in the canyon within 4 km of the canyon head. Water depth was observed to increase as the submersible traveled up-canyon; when a depth of 230 m (twice the charted depth) was reached, the submersible hung up on an unknown object on the sea floor. The inclination of the basin wall at this point was observed to be about 45 degrees. The dive was terminated when the submersible was freed, so that the depth of the bottom of this depression was not ascertained. Origin of this depression is uncertain; it may result from a lateral debris slide into the canyon that blocked the canyon axis. If so, the time of this slide would mark the end of the period of active sand transport through the canyon from sources at its head.

SUMMARY OF LITHOLOGIC DISTRIBUTION

Cretaceous granodiorite typical of the "Monterey mass" of Ross and Brabb (1972) appears to be exposed on the floor of Carmel Bay, along both walls of Carmel Canyon, on the shallow shelf between Monterey and Cypress Point, and along the seaward part of the south wall of Monterey Canyon (Pl. 3). All metamorphic rocks recovered appear to have been transported, and no evidence of exposed metamorphic basement was found.

Middle Miocene rocks of the Monterey Formation are exposed locally in a narrow band along the seaward part of the south wall of Monterey

Canyon, where these strata appear to overlie Cretaceous granodiorite. Middle Miocene Monterey shale also crops out on the central part of the Point Lobos-Point Sur shelf and along the upper part of the west wall of Carmel Canyon. Limestone belonging to the Monterey Formation or to the Sur Series of Trask (1926) was recovered at a single locality on the slope near the most southerly head of Ascension Canyon.

The Pliocene Purisima Formation crops out or is covered by thin surficial sediments along both walls of Monterey Canyon. Lithologies and megafossil assemblages suggest that these exposures are mostly of the Pomponio and San Gregorio Members (Cummings, Touring, and Brabb, 1962) of this formation, particularly along the south wall of the canyon, east of the large meander. An up-canyon stratigraphic progression from older to younger appears to be present, with the Tahana Member exposed in the lower part of the canyon, the younger Lobitos Member exposed farther up the canyon, and possibly the still younger Tunitas Member exposed in the headward part of the canyon. Bathymetric interpretations from benthonic foraminiferal assemblages suggest that at the time of their deposition, depths over much of Monterey Bay were greater than those that now characterize the region. This may indicate late Pliocene or early Pleistocene uplift along the middle part of the south wall of Monterey Canyon and along the northwest wall of Soquel Canyon.

Shallow marine deposits of Pleistocene age are present along the seaward part of the south rim of Monterey Canyon in Monterey Bay, and along the seaward part of the Point Lobos-Point Sur shelf. Pleistocene microfossils and invertebrate megafossils from the Monterey Bay region suggest that the Pleistocene paleoclimate was much cooler than present climatic conditions at this latitude and was similar to the modern marine climate in the Bering Sea.

Gravity cores and observations made during a submersible dive near the head of Monterey Canyon suggest that sand is probably not being actively transported down the canyon today. The passage of sediment through the canyon from sources at the canyon head may be blocked by a large lateral slump or slide from the canyon wall into the main channel.

CHAPTER III

INTERPRETATION OF SEISMIC REFLECTION PROFILES

GENERAL DISCUSSION

The criteria used to distinguish units in the seismic reflection profiles are based on acoustical seismic signal characteristics and reflector types, and on the presence of consistently identifiable structural and sedimentary features such as truncated bedding (unconformities), sequences of prograded beds, cross-bedding, and parallel bedding. Line drawings of seismic profiles are used in this report to show the results of interpretation of the seismic records. A line drawing is a refined, optically "filtered", hand-drawn representation of a seismic profile with the geological bias of the interpreter added. The line drawings of most seismic profiles interpreted for this study are included in Appendix III. Several line drawings are shown with photographs of the actual seismic profiles to illustrate the difference between raw and interpreted data.

The upper 150 m of subsurface materials in the geologic cross sections are interpreted from high resolution records. However, most of the profiles used as illustrations in this report are constructed from both intermediate and deep penetration, low resolution seismic records. As a result the geologic cross-section contains more detail than is evident in the upper part of the intermediate and deep penetration seismic profiles and line drawings. This is due to the masking effect of the "bubble pulse"[1/] of the lower

---

1/ A "bubble pulse" consists of attenuating reverberations that linger in the water column after the primary pulse has been produced. These reverberations are reflected back from the ocean bottom and appear as pseudo-sea floor traces on the seismic record and effectively cancel any signal reflected from shallow structures immediately beneath the sea floor.

resolution, deeper penetration records, which hides the upper 60 m of sub-bottom.

Depths to individual seismic reflectors are calculated using assumed average seismic velocities of (a) 1.5 km/sec in water and in sediments less than 200 m below the sea floor on high resolution records, (b) 1.8 km/sec in unconsolidated and semi-consolidated materials in the upper 400 m of intermediate penetration records, and (c) 2.0 to 2.5 km/sec for consolidated sedimentary rocks at depths greater than 400 m and overlying the acoustic basement, on both intermediate and deep penetration records. No corrections were made for changes in sea level during the survey.

Vertical exaggeration of seismic profiles varies with the type of profile and the seismic velocity assumed in calculating the exaggeration. When an average velocity of 1.7 km/sec is assumed, the shallow penetration, high resolution profiles have an average exaggeration of 7:1. Intermediate and deep penetration seismic records have vertical exaggerations of 5:1 and 6:1, respectively, assuming an average velocity of 1.8 km/sec for both types of profiles. Apparent dips, which may approximate true dips, are calculated where two or more profiles cross. Unfortunately, true dips are completely accurate only where true velocities are known. Where bedding and fault planes dip more than about 35°, the vertical exaggeration inherent in the seismic profiles precludes determining actual dips. Thus, faults that dip 35° or more in the profiles appear vertical, and bedding that dips 35° or more appears approximately vertical or is indistinguishable.

Strongly contrasting lithologic units within a stratigraphic section generally exhibit independent, distinct, acoustical signatures depending upon their density, velocity, and structure. It is possible to differentiate units of igneous and metamorphic rocks or highly folded, well lithified sedimentary rocks from well-bedded, consolidated to semi-consolidated sediments on the basis of their characteristic seismic signatures. Correlation of such seismic units with rock units exposed on land, in well holes, and offshore (from sea floor samples) leads to the development of a geological "seismic" stratigraphy that can be used to construct an offshore geologic map.

Thirteen (13) units are identified in seismic profiles east of the Palo Colorado-San Gregorio fault zone, and seven are identified in profiles west of the fault zone. These units are correlated in part on their acoustical, structural, and depositional characteristics and in part on their geographical location and stratigraphic position. The geologic units, from youngest to oldest, are given in the following tables:

TABLE 1

Seismic Units of the Monterey Bay Region
(East of the Palo Colorado-San Gregorio Fault Zone)

Age	Unit	Map Symbol
Quaternary	Unconsolidated deposits	Q
Quaternary	Canyon fill deposits	Qcf
Quaternary	Submarine landslide and slump deposits	Qls
Quaternary	Deltaic deposits	Qd
Pleistocene	Aromas Sand	Qar
Late Pliocene-Pleistocene	Aromas Sand and Paso Robles Formation	QTap
Tertiary-Quaternary	Deltaic deposits	TQd
Pliocene	Purisima Formation	Tp
Late Miocene-early Pliocene	Santa Cruz Mudstone of Clark (1966)	Tsc
Late Miocene-early Pliocene	Santa Margarita Sandstone and Santa Cruz Mudstone of Clark (1966)	Tsm-Tsc
	or	
Late Miocene - middle Miocene	Santa Margarita Sandstone and Monterey shale	Tsm-Tm
Middle Miocene	Monterey Formation	Tm
Mesozoic	Granitic rocks	gdp

TABLE 2

Seismic Units of the Monterey Bay Region

(West of the Palo Colorado-San Gregorio Fault Zone)

Age	Unit	Map Symbol
Quaternary	Landslide deposits	Qls
Quaternary-Tertiary	Unconsolidated deposits, undifferentiated	QTu
Pliocene(?)	Sedimentary rocks	P
Miocene(?)	Sedimentary rocks	M
Tertiary	Undifferentiated rocks	Tu
Cretaceous-Jurassic	Franciscan rocks	KJf
Mesozoic	Metamorphic and consolidated sedimentary rocks	mr

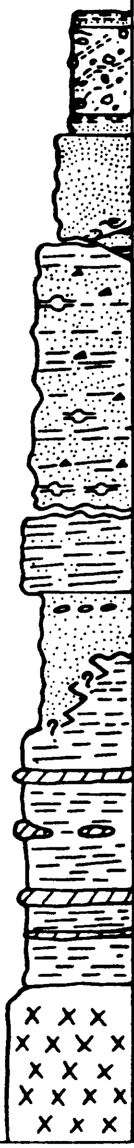
Areas in which these units are exposed on the sea floor or are buried beneath a thin cover of unconsolidated marine sediment are delineated on the geologic map (Pl. 3). Many of these units crop out in Monterey Canyon, and their stratigraphic relationships in this area are shown in composite stratigraphic sections constructed for northern Monterey Bay, southern Monterey Bay, and the region west of the Palo Colorado-San Gregorio fault zone (Figs. 12, 13, and 14).

Criteria used to catalogue faults in seismic profiles of this study are the following: well-defined faults - (1) prominent reflectors are clearly displaced, (2) prominent reflectors are abruptly discontinued or are juxtaposed with an interval having differing seismic characteristics, or (3) the dips of reflectors change abruptly along a distinct boundary. Inferred faults - (1) prominent reflectors show small displacements, and some shallow reflectors may be bent rather than broken, (2) prominent reflectors are discontinuous and seismic characteristics differ across a relatively obscure, seismically disturbed zone, or (3) the dips of reflectors differ across a seismically disturbed zone. Faults are shown as questionable where interpretations are based on (1) a shift in phase of reflectors that is not related to instrumental malfunction, (2) bent or broken reflectors that can be correlated with faults identified on adjacent seismic lines, (3) discontinuation of weak reflectors, or (4) a zone across which seismic characteristics differ, particularly if this zone appears similar to and aligned with faults identified on adjacent lines. Questionable or inferred faults are shown, in some cases, where topographic lineaments of known origin are aligned with the trend of known faults.

STRATIGRAPHY OF THE OFFSHORE MONTEREY BAY REGION

The stratigraphy of the offshore Monterey Bay region is divided into four sequences that can be correlated with the major Tertiary sequences

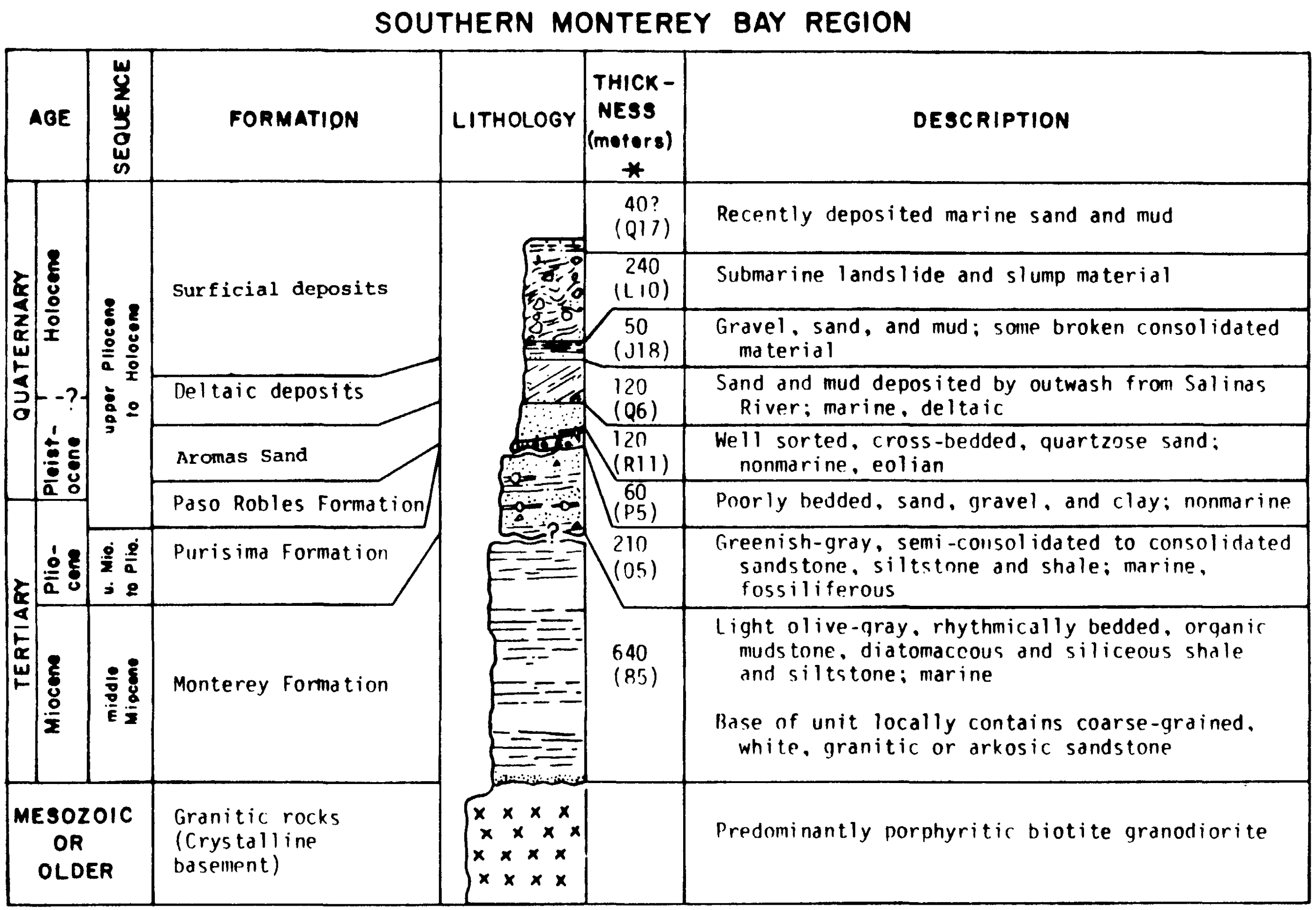
NORTHERN MONTEREY BAY REGION



AGE		SEQUENCE	FORMATION	LITHOLOGY	THICKNESS (meters) *	DESCRIPTION
QUATERNARY	Holocene	Upper Pliocene to Holocene	Surficial deposits		40 (F4)	Recently deposited marine sand and mud.
					240 (F17)	Submarine landslide and slump material.
					50 (518)	Gravel, sand, and mud; some broken consolidated material.
	Pleistocene		Aromas Sand		300 (K2)	Well sorted, cross-bedded, quartzose sand; nonmarine, eolian. Fluvial locally at base.
TERTIARY	Pliocene		Deltaic material		± 40 (B4)	Sand and mud; marine, deltaic.
		Upper Miocene to Pliocene	Purisima Formation		670+ (C14)	Greenish-gray, semi-consolidated to consolidated sandstone, siltstone, and shale; marine, generally fossiliferous.
	Miocene		Santa Cruz Mudstone of Clark (1966)		200+ (C14)	Siliceous, organic mudstone; marine.
			Santa Margarita (?) Sandstone		370? (G7)	Bedded arkosic sandstone (?)
		Middle Miocene	Monterey Formation		550 (F9)	Light olive-gray, rhythmically bedded, organic mudstone, diatomaceous and siliceous shale and siltstone; marine.
MESOZOIC OR OLDER			Granitic rocks (crystalline basement)			Probably predominantly granodiorite.

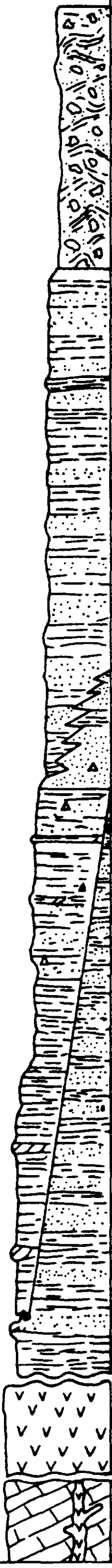
*Letters and number in parentheses indicate seismic line and position where thicknesses were calculated.

Figure 12. - Composite stratigraphic section of the northern part of Monterey Bay, east of the Palo Colorado - San Gregorio fault zone.



*Letter and numbers in parentheses indicate seismic line and position where thicknesses were calculated.

Figure 13. - Composite stratigraphic section of the southern part of Monterey Bay, east of the Palo Colorado-San Gregorio fault zone.



AGE		ROCKS	THICKNESS (meters) *	DESCRIPTION
QUATERNARY	HOLOCENE -?- PLEISTOCENE	Submarine landslide and slump deposits	850? (23-1400)	Submarine landslide and slump material?
-?- TERTIARY	-?- PLIOCENE (?)	Sedimentary rocks, undifferentiated	1450 (5-1500)	**Appears to be composed of unconsolidated to semi-consolidated sand, silt, and clay; marine.**
TERTIARY	PLIOCENE (?)	Sedimentary rocks	1000 (7-0130)	Appears to be composed of sandstone and shale, may be Purisima cr equivalent; marine?
TERTIARY	-?- MIOCENE (?)	Sedimentary rocks	1300+ (13-2230)	Appears to be composed of rhythmically bedded shale, may be Monterey or equivalent; marine?
TERTIARY	MIOCENE (?)	Sedimentary rocks, undifferentiated	1950 (40600)	Consolidated to semi-consolidated sedimentary rocks. Possibly some intrusive volcanics?
CRETACEOUS OR JURASSIC		Franciscan rocks		Eugeosynclinal sedimentary and volcanic rocks; graywacke sandstone and greenstone?
MESOZOIC OR OLDER		Metamorphic(?) rock		Probably composed of schist to gneiss with local intrusions of volcanic rocks. May include Sur series of Trask (1926)?

*Numbers in parentheses indicate seismic line number and time position where thicknesses were calculated.

Figure 14. - Composite stratigraphic section of the western Monterey Bay region, west of the Palo Colorado San Gregorio fault zone.

described onshore by Clark (1966) and Clark and Rietman (1973). These sequences of seismically distinct strata in the offshore area represent a (1) pre-middle Miocene interval, (2) middle Miocene interval, (3) upper Miocene to Pliocene interval, and an (4) upper Pliocene and Pleistocene to Holocene interval. These sequences are bounded by unconformities, similar to their counterparts on land. However, the Paleocene and Eocene-to-lower Miocene sequences described on land by Clark and Rietman (1973) apparently are not present offshore.

Stratigraphy East of the Palo Colorado-San Gregorio Fault Zone

Pre-middle Miocene Sequence

The pre-middle Miocene sequence in the Monterey Bay region east of the Palo Colorado-San Gregorio fault zone consists mostly of Mesozoic crystalline basement rocks. These rocks, represented by acoustical "basement" in the seismic profiles, generally exhibit a very strong reflection beneath which there is little or no seismic coherency and where many hyperbolic and multiple reflections occur. This strong reflection can be correlated readily from one seismic line to another, to onshore and nearshore areas, and to submarine canyon walls and slopes where the basement rocks are known to crop out. Exposures of these basement rocks are generally limited to the southwest part of Monterey Bay (Pls. 3 and 4; Fig. 15). Sea floor samples in this area indicate that acoustic "basement" is composed of biotite granodiorite porphyry.

The depth of burial of the basement complex in offshore areas ranges from exposure in Monterey Canyon and the nearshore area adjacent to Monterey Peninsula to nearly 1,000 m (1.0 sec) in the northwest part of Monterey Bay (Pls. 3 and 4). Onshore, basement rocks crop out on the Monterey Peninsula, in the Santa Lucia Range, and on Ben Lomond Mountain, and are encountered

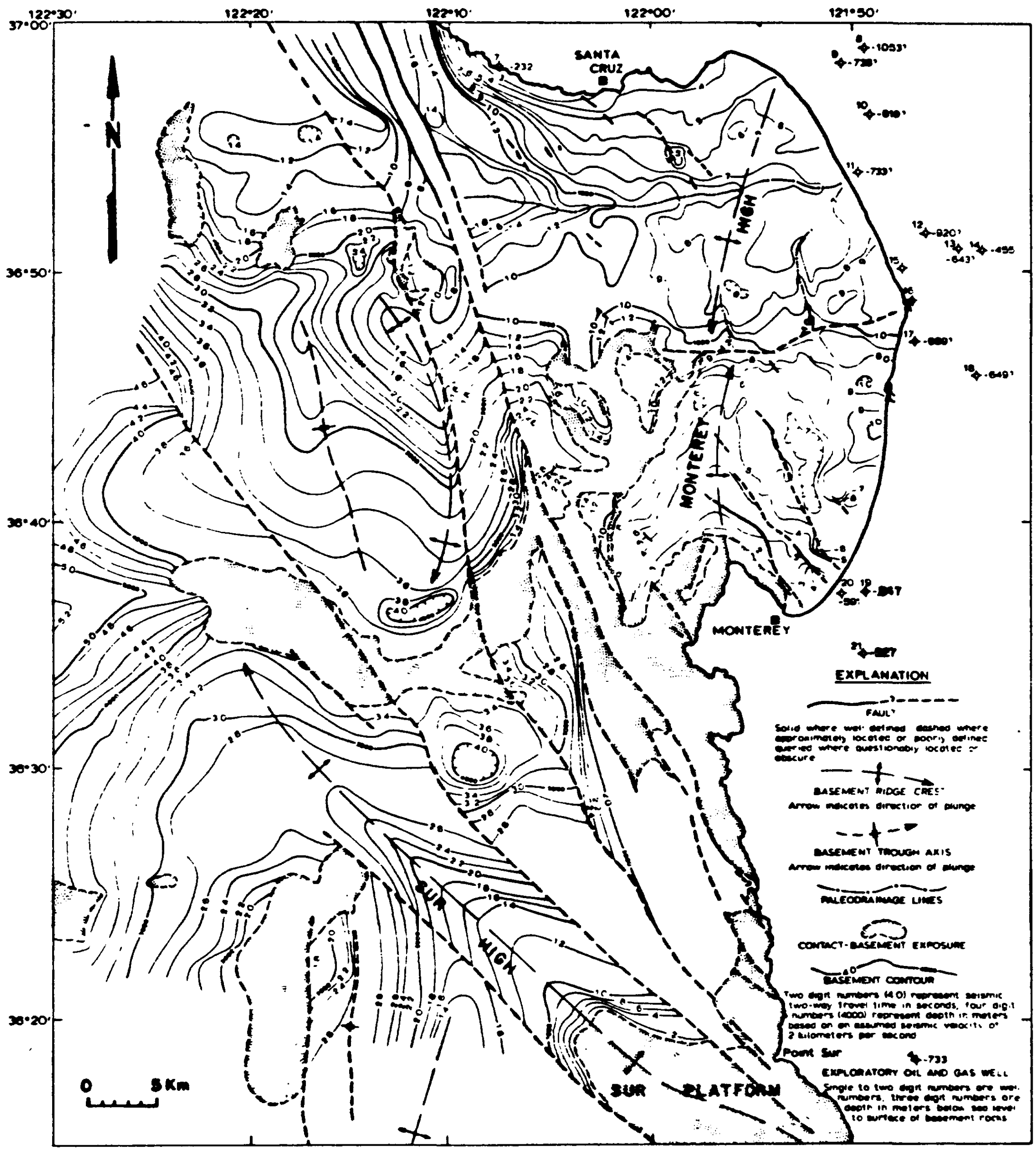


Fig. 15 BASEMENT CONTOUR MAP
MONTEREY BAY REGION, CALIFORNIA

at depths of about 1,000 m in the Soquel-Aptos area (see log of well 8, Fig. 15; Appendix II).

Seismic profiles show the basement surface to be undulating and irregular throughout the Monterey Bay region, suggesting that it represents an erosional surface (Figs. 16, 17, and 18). Several paleodrainage lines are interpreted from the structural contours of the basement surface (Fig. 15). The most prominent of these lines is located in northern Monterey Bay, and appears to represent an east-west trending river valley or submarine canyon. It extends from just offshore of La Selva Beach seaward to the Palo Colorado-San Gregorio fault zone, where it is truncated abruptly. However, there is no surface expression of this valley in the Miocene structural contour map (Fig. 25) nor in the present day bathymetry, indicating that the valley or canyon was not active in post-Miocene time. Minor drainages can be seen along the south flank of a bedrock high located north of Monterey Canyon (Fig. 15). Monterey Canyon is eroded into basement on the outer shelf, whereas the headward part of the canyon is cut into sedimentary rocks that overlie basement. However, basement rocks beneath the upper part of the canyon are faulted (Fig. 15) and may have been displaced in such a fashion as to control the development of a fairly steep walled valley.

A basement high plunges from the tip of the Monterey Peninsula northward to Monterey Canyon, where it is truncated by erosion (Fig. 15). Another basement high plunges southwestward from Aptos to Monterey Canyon, where it also is truncated by the canyon. These two basement highs may once have been continuous; if so, this block was bisected by the erosion of Monterey Canyon between Late Cretaceous and middle Miocene time. Micropaleontologic evidence from the overlying Purisima Formation (App. II) and arched marine terraces in the Aptos area (Alexander, 1953) suggest episodes

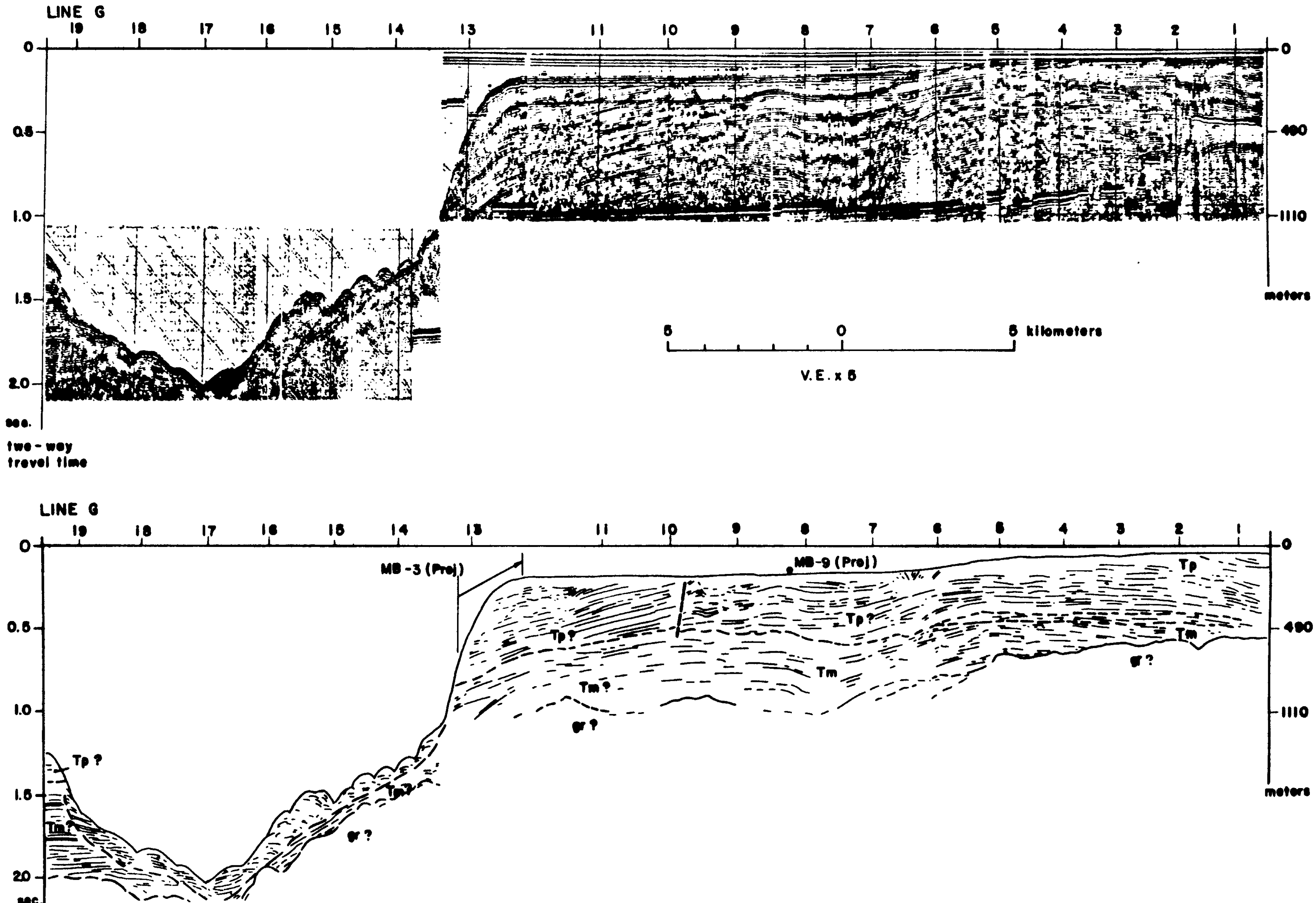


Figure 16. - Intermediate penetration (26 kj) seismic reflection profile and interpretive line drawing of Line G across the shelf and canyon of northern Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols; arrows indicate dredge hauls taken parallel to profile and dots perpendicular to profile; see Fig. 8 for sample location).

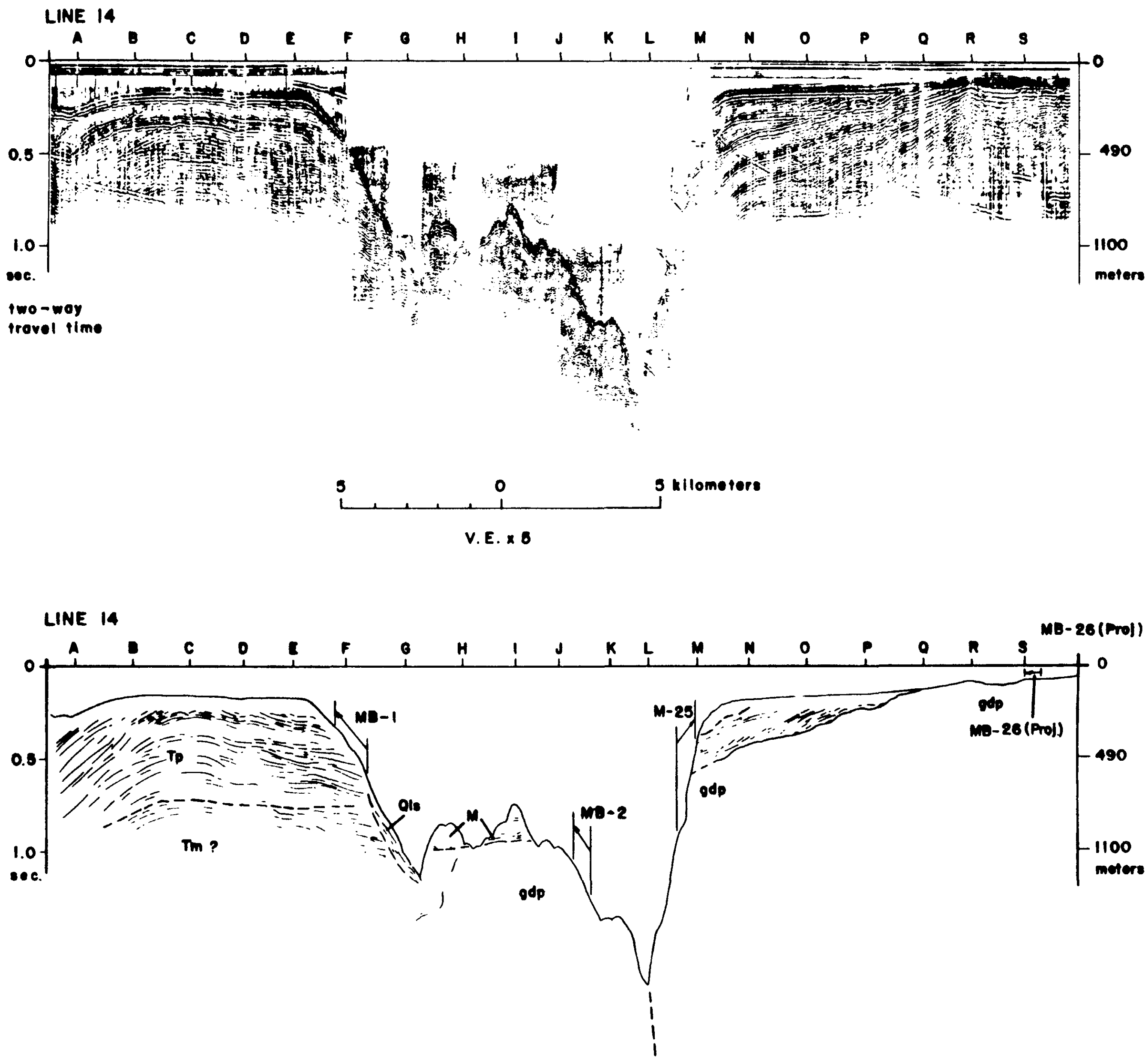


Figure 17. - Intermediate penetration (26 kj) seismic reflection profile and interpretive line drawing of Line 14 across the shelf and canyon of western Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols; arrows indicate dredge hauls; see Fig. 8 for sample locations).

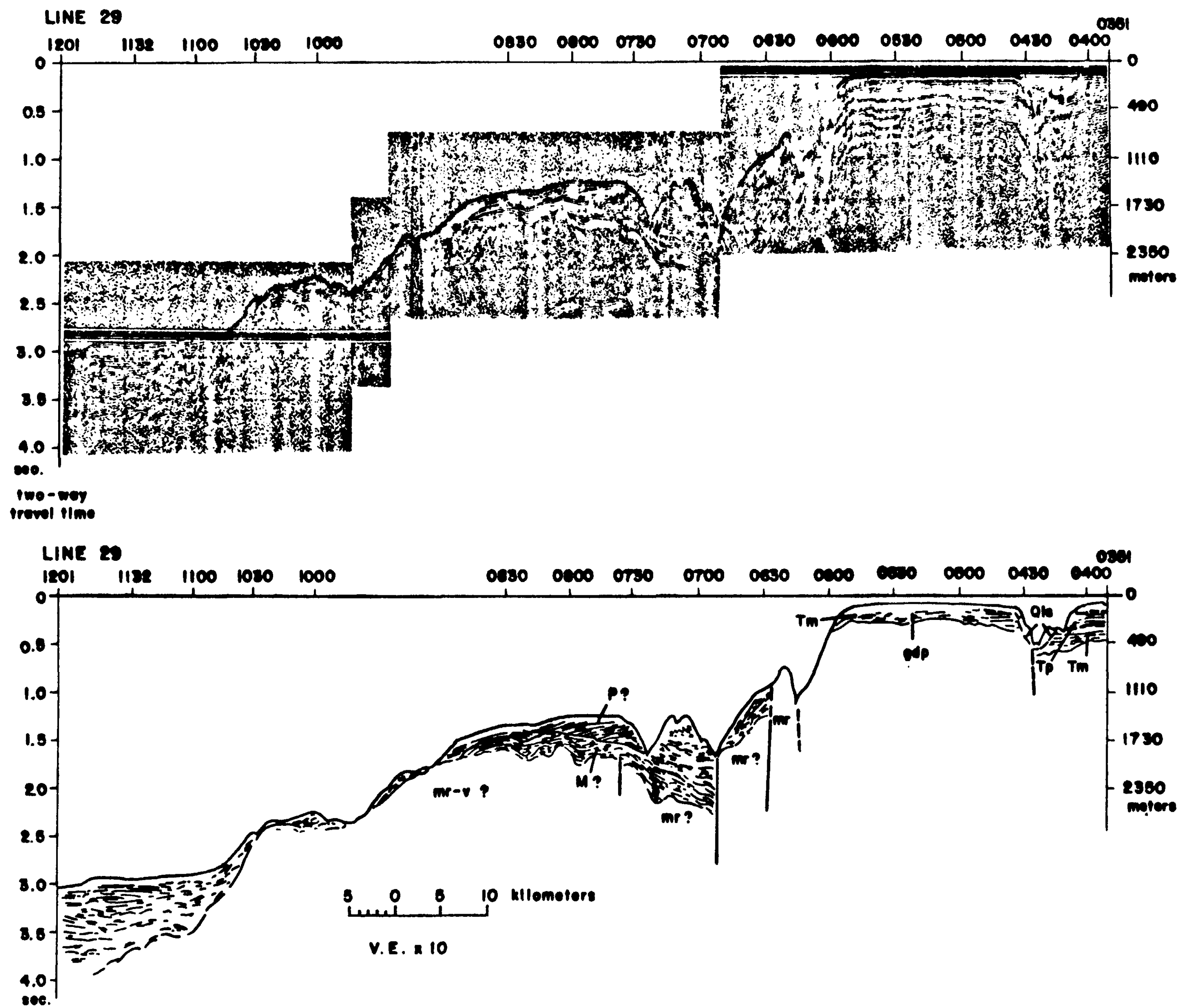


Figure 18. - Deep penetration (160 kj) seismic reflection profile and interpretive line drawing of Line 29 across the continental shelf and slope of southern Monterey Bay.

of late Pliocene to early Pleistocene uplift. Thus, this basement high, here named the Monterey high, has been subjected to recurrent uplift since early Miocene time, with the most recent occurrence in late Pliocene to Holocene time.

Middle Miocene Sequence

Monterey Formation

The middle Miocene sequence is composed of diatomaceous and siliceous shale and sandstone of the Monterey Formation. Seismic reflectors in this unit are strong, continuous, and repetitive, and seismic incoherency and noise are minimal.

The Monterey Formation in Monterey Bay unconformably overlies the crystalline basement complex. In northern Monterey Bay the Monterey Formation appears to be unconformable beneath the Santa Margarita Sandstone, although locally these two units may interfinger (Figs. 19 and 20). Distinguishing between the Santa Margarita Sandstone and Monterey Formation is difficult due to the similarity in their seismic characteristics, and the contact between them is generally inferred. In southern Monterey Bay, the Monterey Formation is exposed or is unconformable beneath the Pliocene Purisima Formation (Pl. 3; Figs. 13, 17, and 21). The upper boundary of the Monterey Formation is hard to define, as the seismic signal changes gradually across the Purisima-Monterey boundary. However, an estimated top of the Monterey Formation was established in seismic records using onshore well-hole data (Greene, 1970).

A water well completed recently near Castroville (Fontes No. 1; Pl. 3) bottomed in the Monterey Formation at a total depth of 523.6 m (517.6 m below S.L.) (R. R. Thorup, written commun., 1976). Foraminiferal assemblages from side wall cuttings indicate that the contact between the

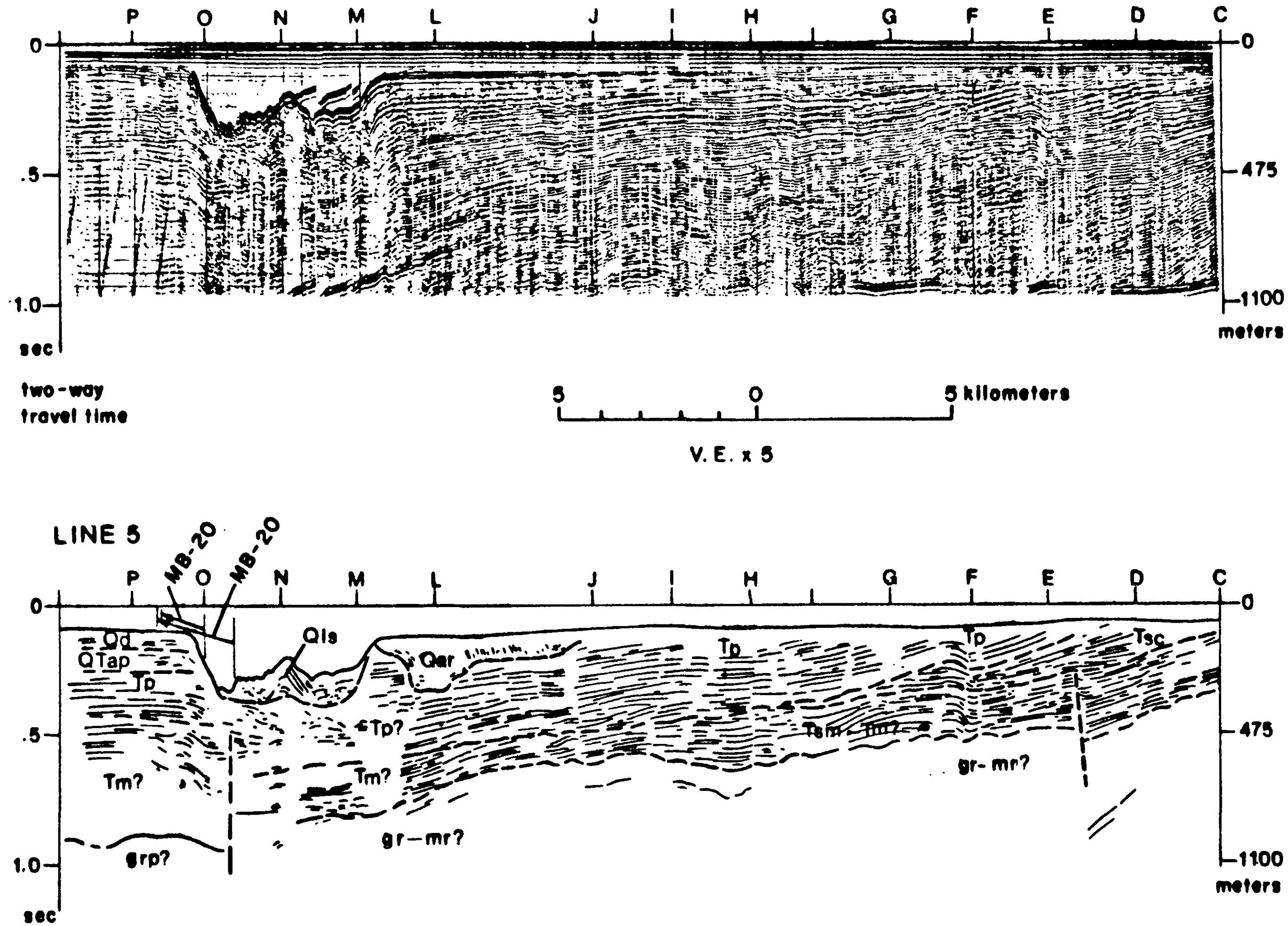


Figure 19. - Intermediate penetration (26 kj) seismic reflection profile and interpretive line drawing of Line 5 across northern Monterey Bay and lower Monterey Canyon (see Fig. 2 for location and Plate 3 for explanation of symbols; arrows indicate dredge hauls; see Fig. 8 for sample locations).

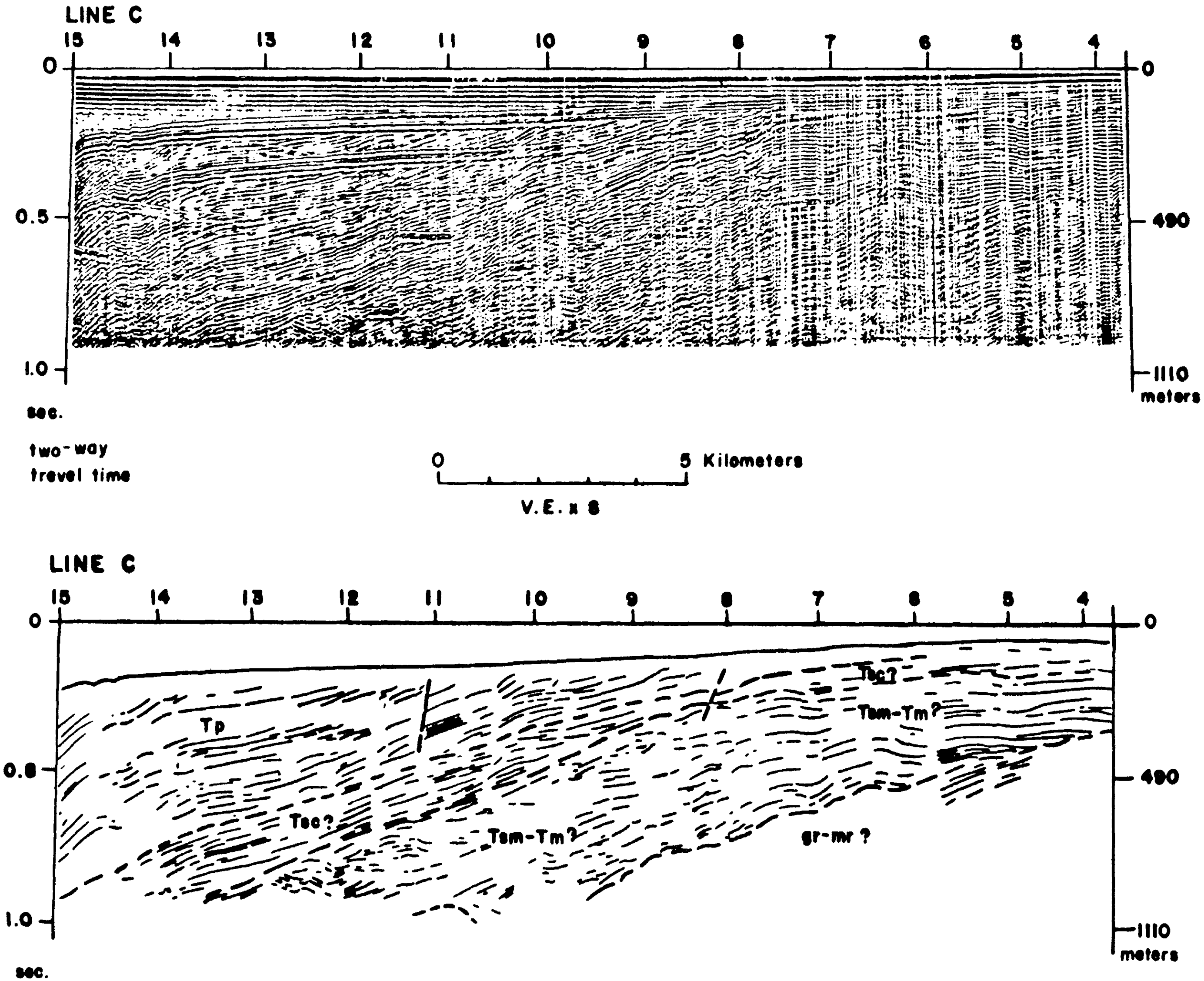


Figure 20. - Intermediate penetration (26 kj) seismic reflection profile and interpretive line drawing of Line C across the nearshore shelf of Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

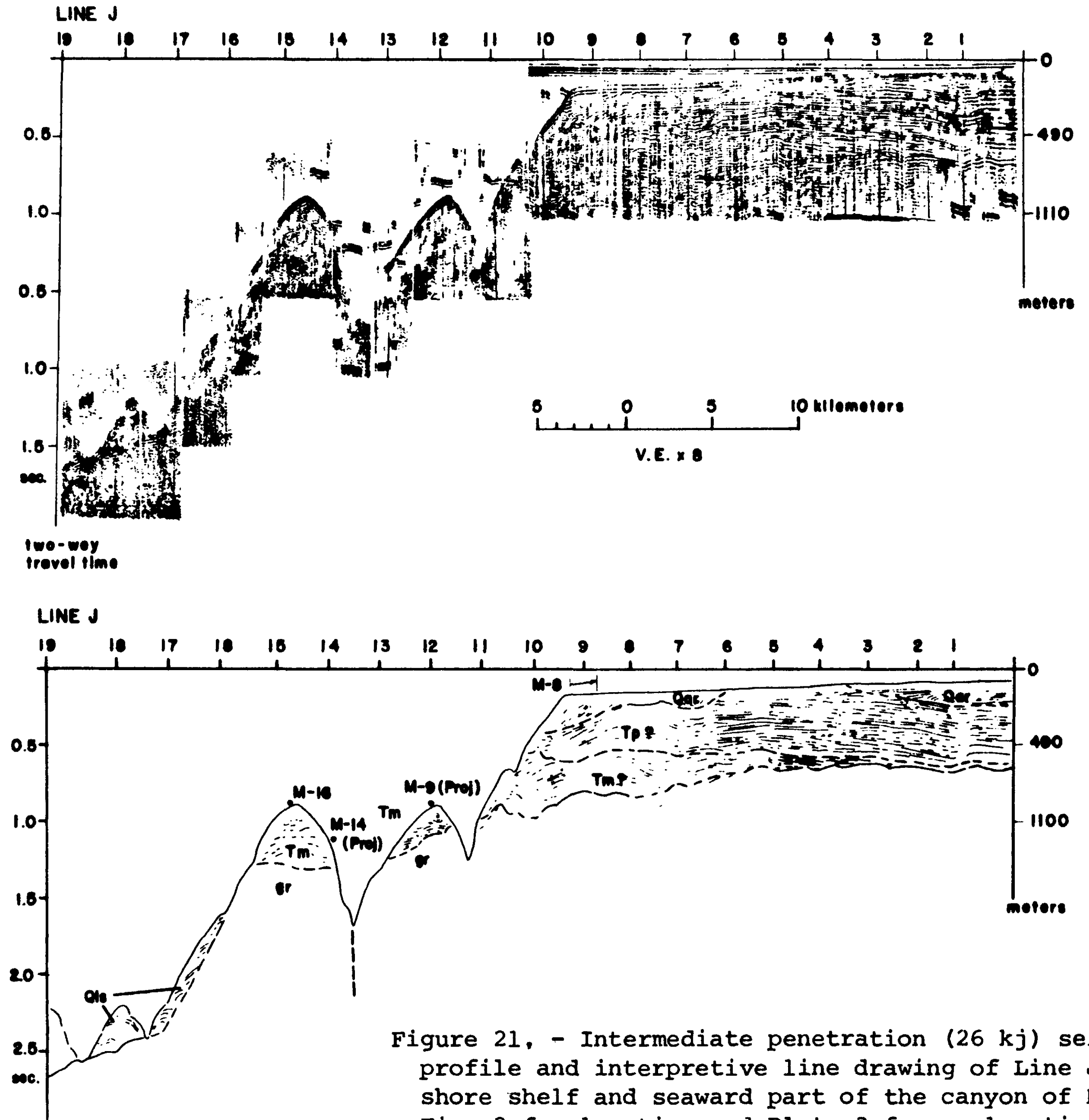


Figure 21. - Intermediate penetration (26 kj) seismic reflection profile and interpretive line drawing of Line J across the nearshore shelf and seaward part of the canyon of Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols; dots indicate dredge hauls; see Fig. 8 for sample locations).

Monterey and Santa Margarita (?) Sandstone occurs at 482 m below sea level, the contact between the Santa Margarita (?) and the Purisima Formation is at (-)436 m, and the contact between the Purisima and the Aromas Sand is at (-)350 m (R. E. Arnal, written commun., 1976). Extrapolation of these contacts into the offshore suggests that the correlation with the acoustical stratigraphy identified in the seismic reflection profiles is valid.

The Monterey Formation crops out on the southern and southwestern shelf of Monterey Bay, and forms a thin band along the southern and northern walls of Monterey Canyon. Isolated outcrops of this unit probably are present at two locations in the canyon near the large meander (Pl. 3). The Monterey Formation ranges in thickness from 0 m where it wedges out against granodiorite on the Monterey Peninsula, to about 640 m (0.64 sec) beneath the southern part of the Salinas River delta (Pl. 3; Fig. 13).

The Monterey Formation in the southern Monterey Bay generally dips 2° to 8° west-northwest. However, these strata are deformed and folded along a 6 km wide northwest-trending zone, the Monterey Bay fault zone, that extends approximately 20 km seaward from the Monterey bight. Dips in the Monterey Formation in northern Monterey Bay range from horizontal in the Soquel-Aptos region to about 16° NW along the break in slope in the extreme western part of the bay (Pl. 3). A discordance, present locally in the Monterey Formation, is indicated in the extreme southern part of Monterey Bay (Pl. 3). This discordance is not evident in adjacent onshore exposures (Clark and others, 1974), and probably is a minor feature restricted to the Monterey bight area and representing the effect of a minor tectonic event on the Monterey Peninsula during middle Miocene time.

Upper Miocene to Pliocene Sequence

The upper Miocene to Pliocene interval is represented by the Santa Margarita Sandstone, Santa Cruz Mudstone of Clark (1966), and the Purisima Formation. The Santa Margarita Sandstone and Santa Cruz Mudstone of Clark (1966) have seismic characteristics similar to the Monterey Formation and are very difficult to separate from the underlying Monterey on the seismic records. Consequently, the boundary between these two units has been extrapolated into the offshore using data from the Fontes No. 1 water well located onshore.

Santa Margarita Sandstone

Identification of the Santa Margarita Sandstone offshore is based on the assumption that strata identified as Santa Margarita in well-holes on land are correlative with a well bedded seismic unit in the extreme northern Monterey Bay (see intermediate penetration Profiles A through L and 1 through 12, App. III; also Figs. 16, 19, 20, 21, 22, 23, 27, 28, 30, 33, and 34). This seismic unit locally appears to be conformable beneath the Santa Cruz Mudstone of Clark (1966) and it may overlie the Monterey Formation with unconformity. The extent of this unit toward the south and southwest is unknown, but it is inferred to grade laterally into the upper part of the Monterey Formation. This unit is shown on seismic profiles as Santa Margarita-Monterey undifferentiated in areas in which correlation with onshore data was not possible (Fig. 22).

Thickness and extent of the Santa Margarita Sandstone are difficult to determine due to its similarity on seismic profiles to the Monterey Formation. The estimated maximum thickness of the Santa Margarita, 370 m (0.37 sec) near the head of Soquel Canyon, may include some strata of the Monterey Formation.

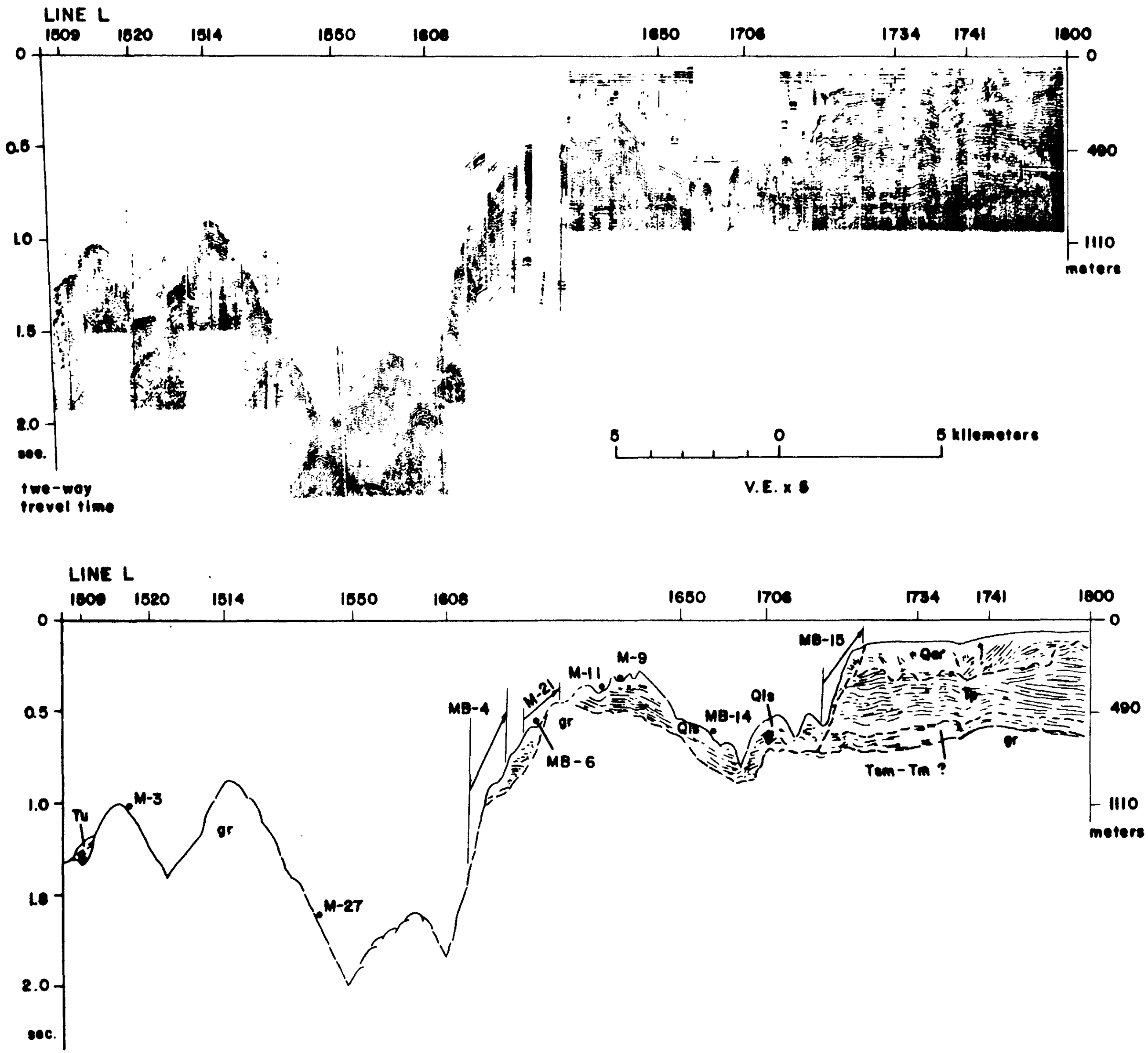


Figure 22. - Intermediate penetration (26 kj) seismic reflection profile and interpretive line drawing of Line L across the continental shelf, slope and canyon of Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols; arrows indicate dredge hauls taken parallel to profile and dots perpendicular to profile; see Fig. 8 for sample locations).

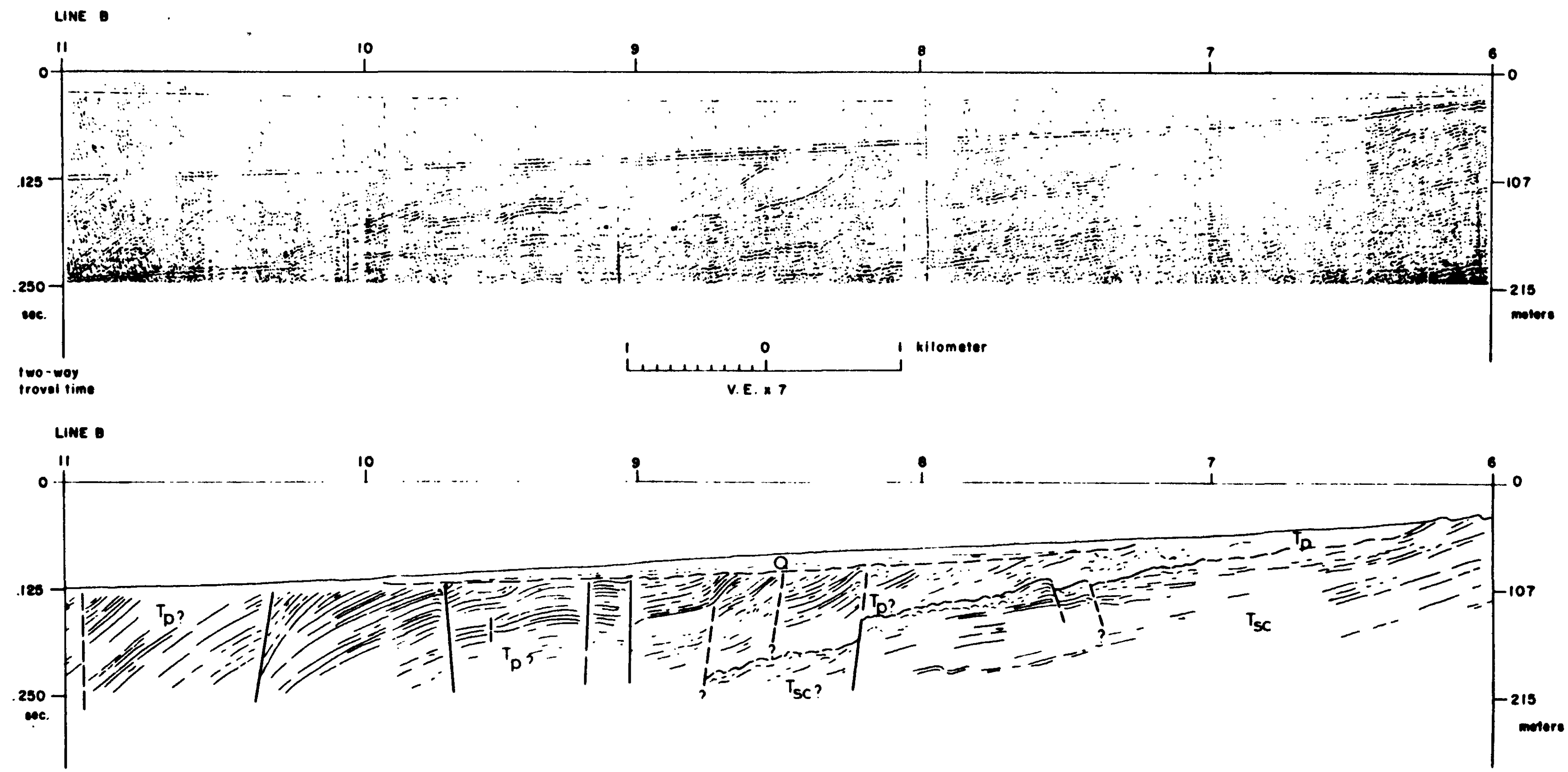


Figure 23. - High resolution (.6 kj) seismic reflection profile and interpretive line drawing of Line B across nearshore shelf of southern Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

Santa Cruz Mudstone of Clark (1966)

Correlation of the onshore Santa Cruz Mudstone of Clark (1966) with its offshore equivalent can be made with reasonable certainty. Exposures of the Santa Cruz Mudstone of Clark (1966) in the sea cliffs west and north of Santa Cruz can be easily traced to a seismic unit that crops out on the sea floor adjacent to these cliffs. This unit appears in seismic profiles as a thin package of discontinuous reflectors that are truncated along an overlying erosional surface (Fig. 23). This erosional surface is very irregular and is easily correlated from one high resolution profile to another. However, on deep penetration records the lower part of the unit is more difficult to differentiate from adjacent units, and consequently may include some Santa Margarita and Monterey strata.

The Santa Cruz Mudstone of Clark (1966) crops out in the extreme northern and northwestern parts of Monterey Bay and along the nearshore shelf between Año Nuevo Point and Santa Cruz (Pl. 3). Its maximum thickness is estimated to be more than 200 m (0.23 sec) at the edge of this shelf 5 km north of Monterey Canyon; however, the thickness at this location may include some strata of the adjacent Santa Margarita Sandstone and Monterey Formation.

Miocene strata compose the most extensive sedimentary unit identified in Monterey Bay, and are found throughout the region except in the area nearshore to the Monterey Peninsula. By treating Miocene rocks as a single seismic unit, accurate estimates of thickness and structural configuration can be made, and an isopach map of Miocene sedimentary rocks (Fig. 24) and a Miocene structural contour map (Fig. 25) have been constructed. The total thickness of Miocene strata in Monterey Bay ranges from 0 m around the Monterey Peninsula and in the outer Monterey Canyon to more than 700 m (0.107 sec) thick in the northwestern part of the bay.

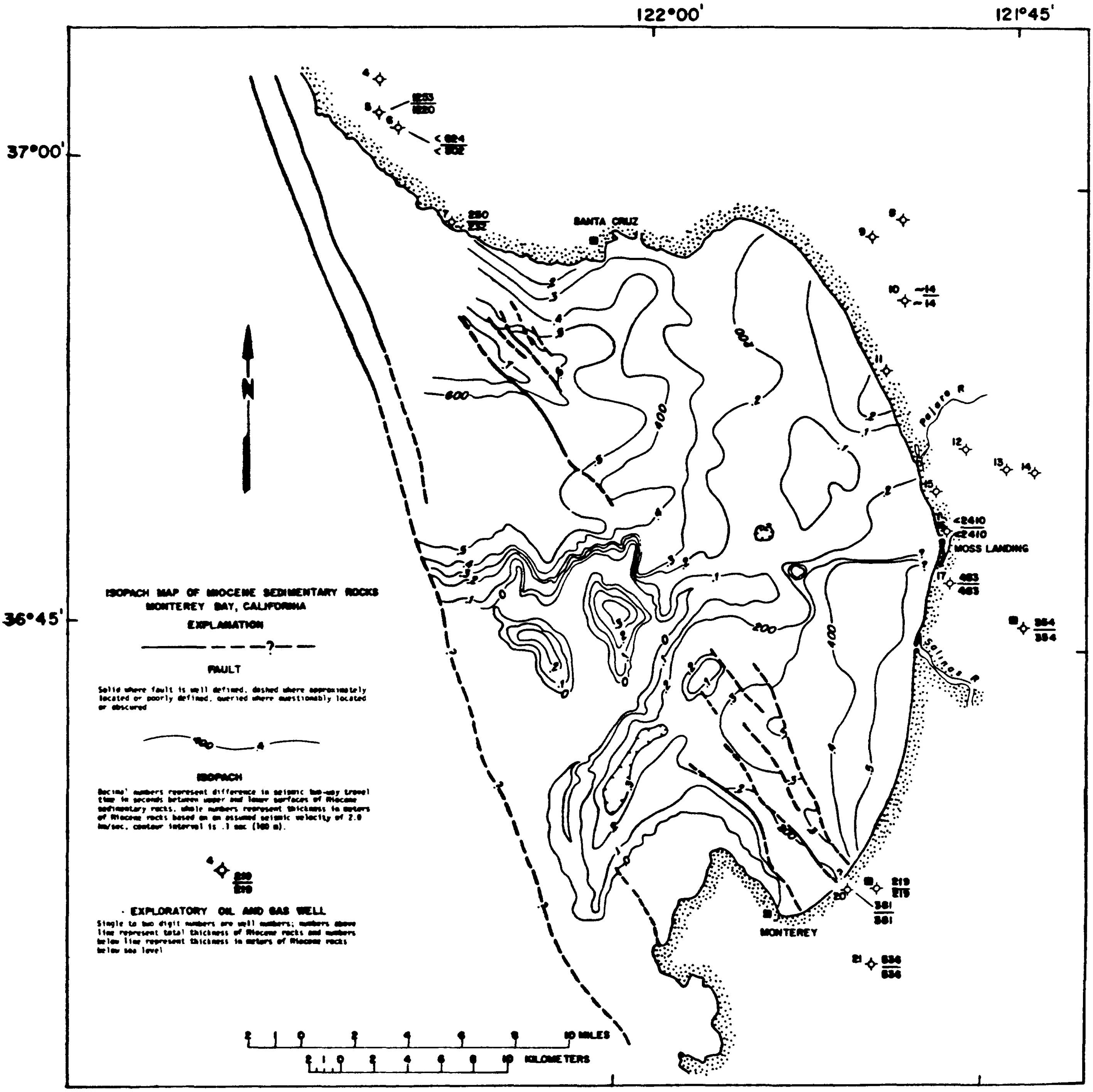


Fig. 24 – ISOPACH MAP OF MIOCENE SEDIMENTARY ROCKS MONTEREY BAY, CALIFORNIA

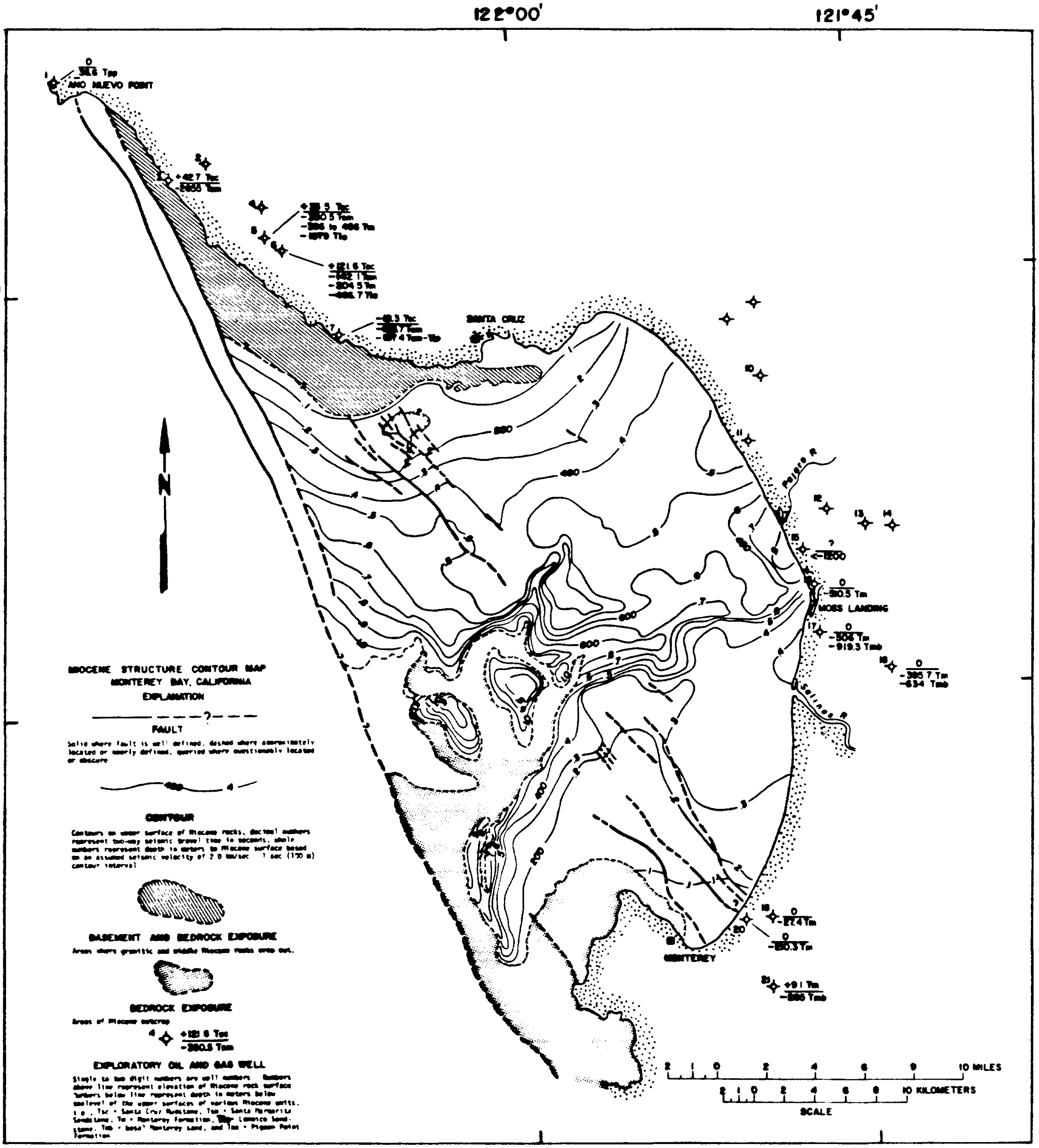


Fig. 25 – MIOCENE STRUCTURE CONTOUR MAP MONTEREY BAY, CALIFORNIA

The Miocene section increases in thickness both west and east of a line extending from the Monterey Peninsula northward to Aptos. This line corresponds in position to the axis of the basement ridge forming the Monterey high (Fig. 15). The thickness of the Miocene interval penetrated in oil and gas exploratory wells on land near the coast of Monterey Bay is approximately equivalent to that present offshore (Fig. 24), ranging from 219 m near Monterey to more than 2,410 m at Moss Landing. A small shoreward protrusion, representing an increase in thickness of the Miocene section, is apparent on the isopach map near the mouth of the San Lorenzo River. This relatively thick section may reflect the presence of an embayment or subsiding trough during Miocene time.

The Miocene structure contour map (Fig. 25) shows the surface of the Miocene rocks to be a gentle plain that dips southward toward Monterey Canyon, and eastward and westward away from the axis of the Monterey high. Dips in Monterey strata vary from nearly horizontal to greater than 15^{o} where the strata are folded. The depth of burial ranges from exposure in the Monterey bight and along the Santa Cruz shelf to more than 600 m (0.6 sec) beneath the thick cover of Pliocene sediments at the shelf edge north of Monterey Canyon (Figs. 24 and 25). Burial depths for Miocene strata on land are similar, ranging from exposure near Monterey to more than 510 m at Moss Landing.

Purisima Formation

The upper part of the upper Miocene-to-Pliocene sequence offshore is composed of the Pliocene Purisima Formation, which consists of semi-consolidated to consolidated sandstone, siltstone, and shale. This unit is strongly to weakly reflected in seismic profiles and has continuous to locally discontinuous seismic "bedding". Purisima strata appear to lie unconformably upon the Monterey Formation throughout most of the area, except in nearshore parts of northern Monterey Bay, where they overlie the Santa Cruz Mudstone of Clark (1966) (Figs. 19 and 23). A disconformable or conformable relationship may exist between the Monterey and Purisima Formations in western Monterey Bay, where the contact between Miocene and Pliocene rocks is deeply buried (Figs. 19 and 20).

The Purisima Formation is the second most extensive sedimentary unit in Monterey Bay, and is present in the subsurface throughout most of the northern part of the bay and in parts of southern Monterey Bay. Outcrops of the Purisima Formation have been mapped in the nearshore Capitola-Aptos area and on parts of the outer shelves of southern and northern Monterey Bay (Pl. 3). Purisima strata also crop out in Monterey Canyon in a broad band along the upper part of the north wall, and in a thin band and in slump scarps along the upper part of the south wall.

Strata of the Pliocene Purisima Formation vary in thickness from 0 m in the central part of southern Monterey Bay and along the nearshore shelf west of Santa Cruz, to more than 600 m (0.6 sec) in the westernmost part of the northern Monterey Bay shelf (Fig. 26). Purisima strata have an aggregate thickness of more than 400 m (0.4 sec) near the mouth of the Pajaro River and off La Selva Beach. Approximately equivalent thicknesses of Pliocene rocks are present in adjacent onshore areas (see well data, App. II, and Fig. 26). Purisima strata dip about 8° to the west or northwest in southern Monterey Bay, from 2° to 16° to the southwest in northwestern Monterey Bay, and from 0° to 4° to the east or southeast just seaward of the Soquel-Aptos area (Pl. 3 and Fig. 27).

A wedge-shaped body of sediments interdigitated with Pliocene Purisima and Holocene strata (see Profiles B and 4, App. III) at the mouth of the

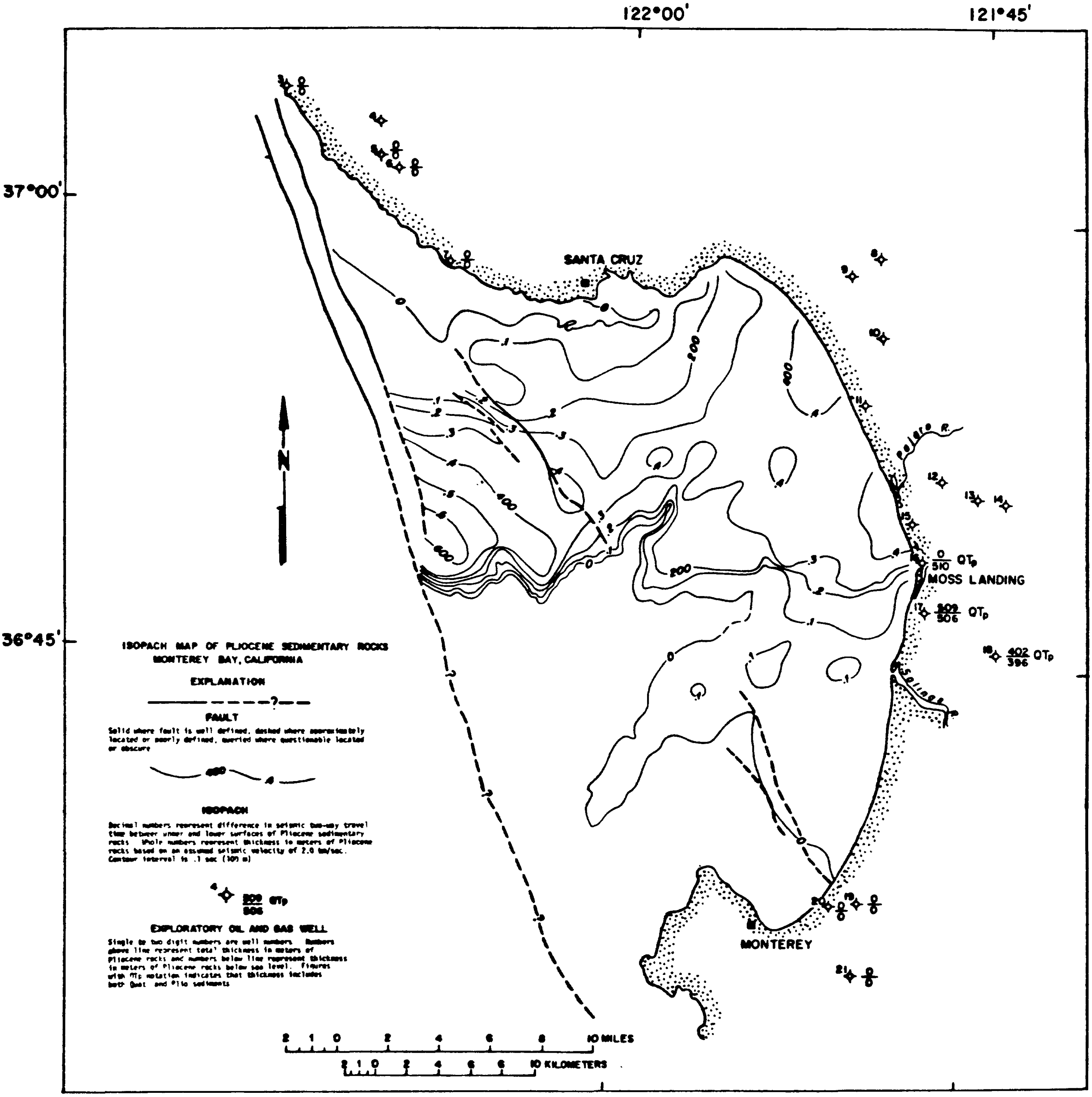


Fig. 26 – ISOPACH MAP OF PLIOCENE SEDIMENTARY ROCKS MONTEREY BAY, CALIFORNIA

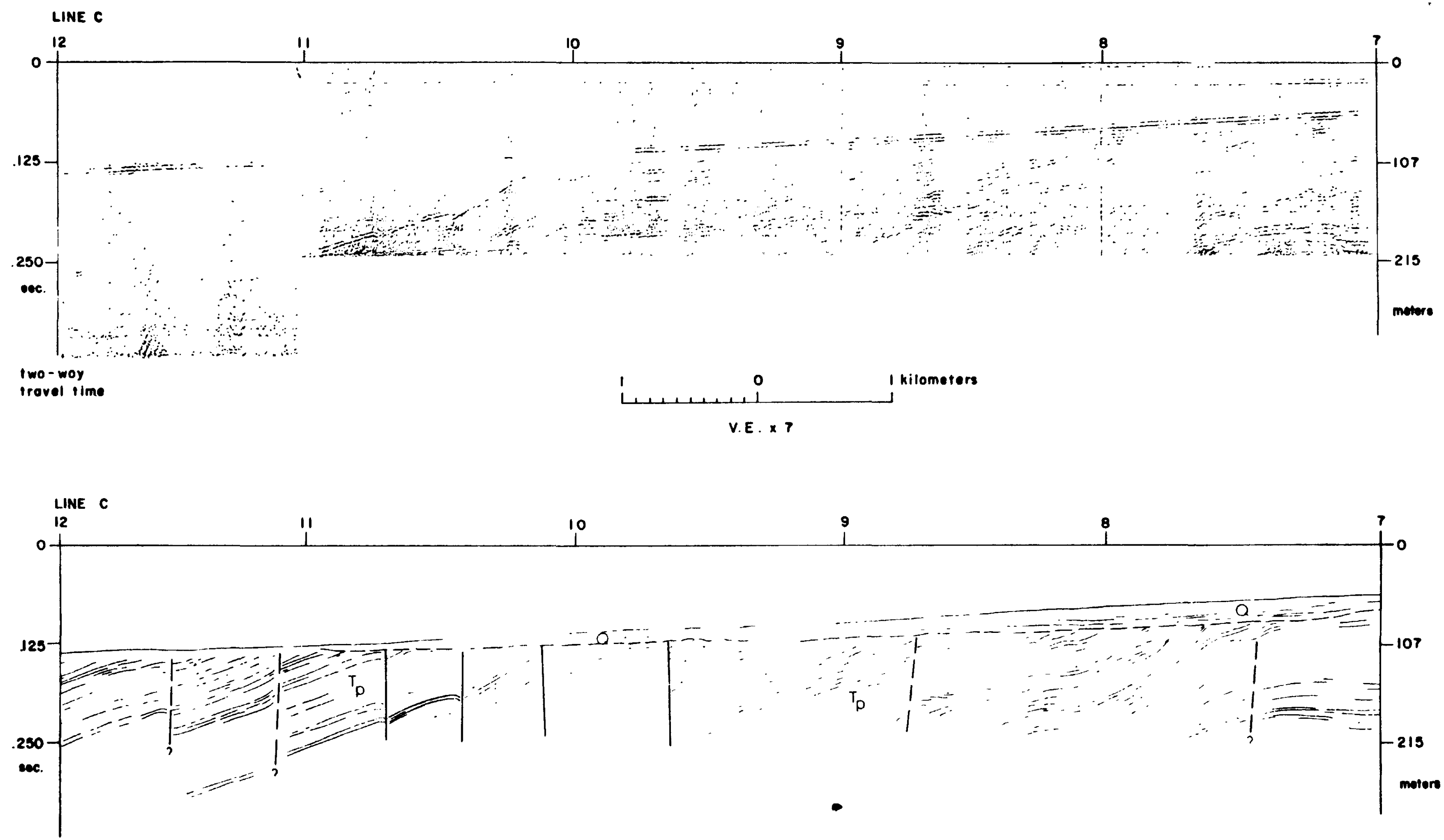


Figure 27. - High resolution (.6 kj) seismic reflection profile and interpretive line drawing of Line C across the nearshore shelf of southern Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

San Lorenzo River is believed to represent a deltaic lens deposited during late Pliocene to recent time (Pl. 3). Acoustically, the unit is composed of a few discontinuous reflectors that scatter or absorb seismic energy. Onshore, deltaic and fluvial sediments have been identified that appear to be related to a former position of the mouth of the San Lorenzo River (R. L. Phillips, oral commun., 1975). These deposits may be onshore equivalents of the unusual acoustical unit identified in the offshore.

Upper Pliocene-and-Pleistocene to Holocene Sequence

The Pliocene-and-Pleistocene to Holocene interval in the offshore comprises three units: (1) upper-Pliocene-to-Pleistocene Paso Robles Formation and the Pleistocene Aromas Sands, combined as an undifferentiated Aromas-Paso Robles unit in southern Monterey Bay, (2) Pleistocene Aromas Sand, and (3) surficial deposits comprising Quaternary deltaic sediments of the Salinas River, canyon fill, slump and submarine landslide deposits, and Holocene marine sediments.

Aromas-Paso Robles Unit and Aromas Sand

The basal part of the upper Pliocene-Pleistocene to Holocene sequence is represented by the Aromas Sand in northern Monterey Bay and by the undifferentiated Aromas-Paso Robles unit in southern Monterey Bay. In the seismic profiles the Aromas Sand in northern Monterey Bay is represented by many weak, discontinuous and cross-bedded reflectors (Fig. 28); the unit appears to acoustically scatter or absorb a large amount of seismic energy. The Aromas and Paso Robles units in southern Monterey Bay appear as weak, random, and discontinuous reflectors, and cannot be separated on the seismic records.

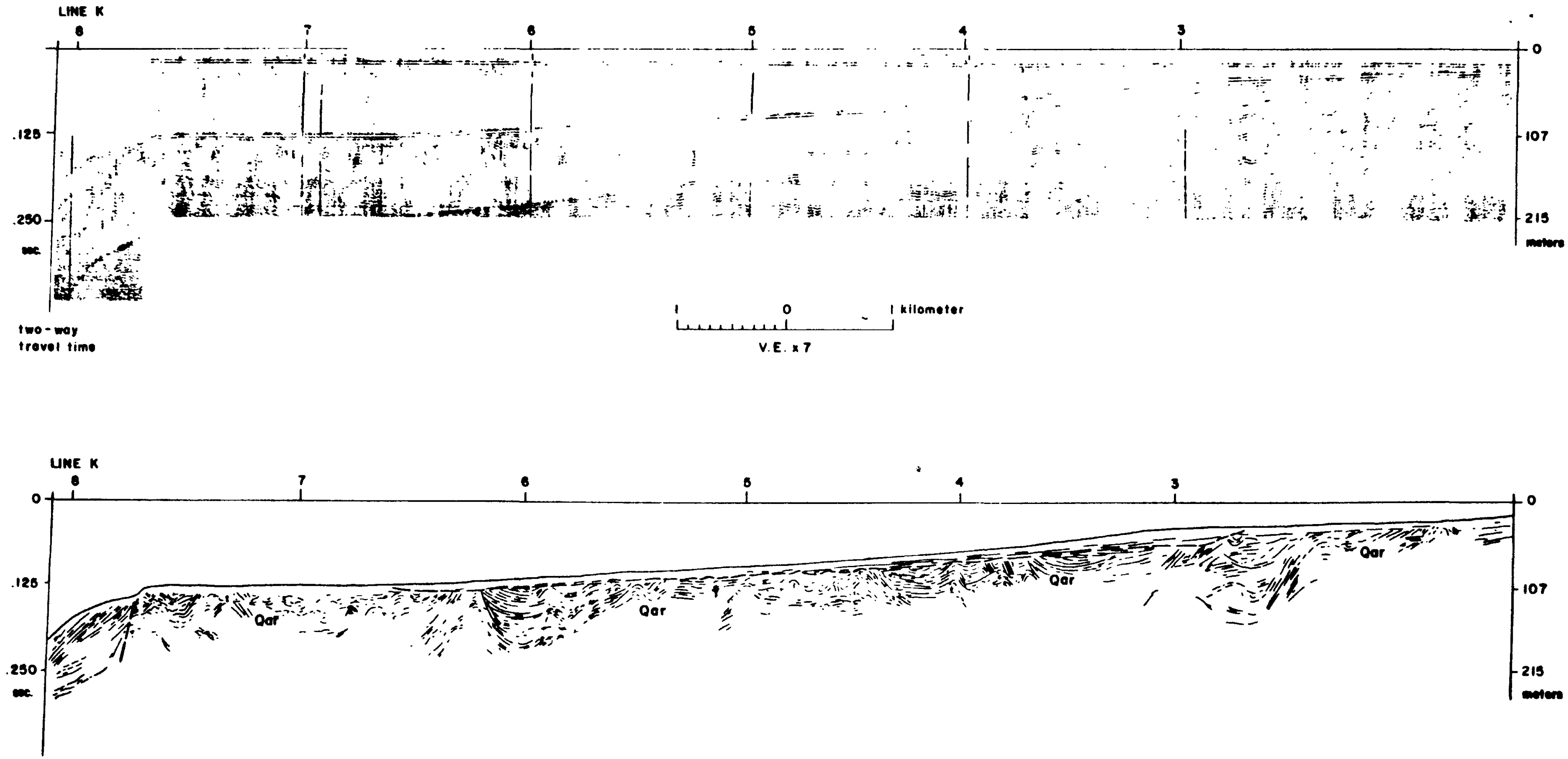


Figure 28. - High resolution (.6 kj) seismic reflection profile and interpretive line drawing of Line K across shelf of northern Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

The Aromas Sand extends seaward for more than 10 km from the mouth of the Pajaro River (Fig. 29). Outcrops of Aromas Sand are present near shore in the area between Soquel and the mouth of the Pajaro River, in slump scarps along the upper part of the north wall of Monterey Canyon, and on the shelf between Monterey and Soquel Canyons (Pl. 3). The Aromas Sand appears to unconformably overlie the Purisima Formation and locally is unconformable beneath Holocene marine sediments. Cross-bedded Aromas strata fill erosional channels in many locations. Seismic profiles suggest that the Aromas Sand is, in turn, underlain by flat-lying sediments, possibly fluvial in origin, that fill the channel bottoms (Fig. 30). This observation is consistent with the relationship between the Aromas Sand and Purisima Formation observed on land by Dupré (1975, p. 100). The scale and form of the cross-bedding suggests that the Aromas is mostly eolian. If this is correct, the northern and western limits of the Aromas Sand represent a Pleistocene shoreline, with the southern boundary being marked by the Monterey Canyon. The Aromas Sand in northern Monterey Bay ranges in thickness from 0 m along its seaward limit to more than 255 m near the mouth of the Pajaro River (Fig. 29).

In southern Monterey Bay the undifferentiated Aromas-Paso Robles unit appears to extend westward for more than 8 km from the mouth of the Salinas River (Pl. 3). Its seaward extent is difficult to determine accurately because it appears to interfinger with Holocene surficial sediments. The undifferentiated Aromas-Paso Robles unit crops out locally along the upper part of the south wall of Monterey Canyon and off Fort Ord (Pl. 3). It appears to unconformably overlie the Purisima Formation, although locally this contact may be conformable or disconformable (Figs. 13 and 22).

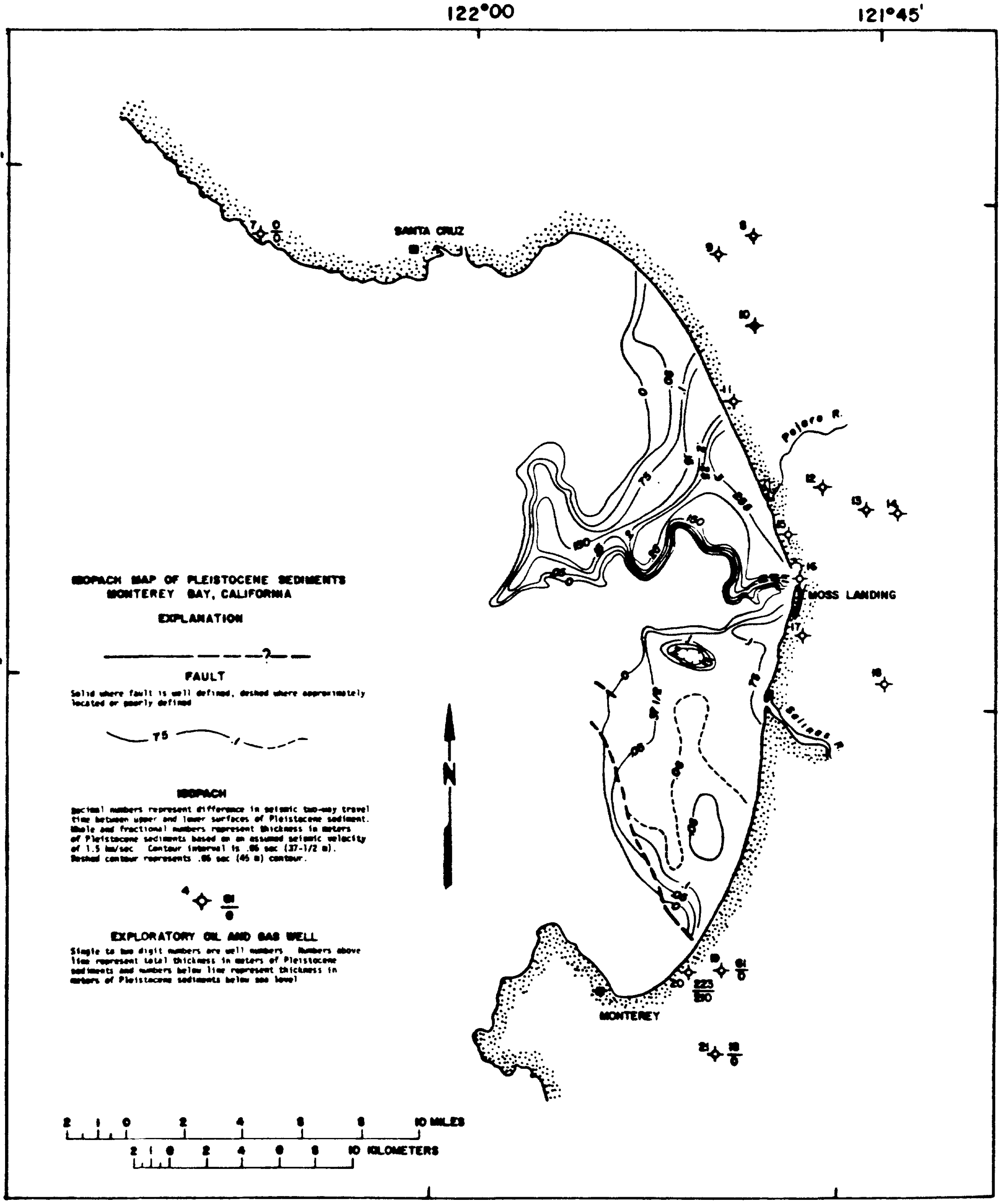


Fig. 29 – ISOPACH MAP OF PLEISTOCENE SEDIMENTS MONTEREY BAY, CALIFORNIA

This unit onlaps the northern edge of the band of folded and faulted Monterey strata in the Monterey Bay fault zone. The Aromas-Paso Robles unit is overlain by Salinas River deltaic deposits, but their contact is difficult to identify in seismic profiles. Its thickness ranges from 0 m along its seaward edge to more than 75 m in the nearshore area between Moss Landing and the Salinas River (Fig. 29).

Deltaic deposit

The upper part of the upper Pliocene-and-Pleistocene to Holocene sequence in southern Monterey Bay is represented by Quaternary deltaic deposits of the Salinas River. These deposits have a distinct deltaic shape, and are thickest (approximately 90 m thick) about 2 km south of the present location of the river mouth (Fig. 31). This unit is characterized in the seismic profiles by the absence of well defined, continuous reflectors. Deltaic sediments are exposed in the headward part of the south wall of Monterey Canyon (Pl. 3), and elsewhere are covered by a thin veneer of Holocene marine sediment.

Canyon fill, slump, and landslide materials

Canyon fill deposits appear as thin packages of weak, horizontal reflectors on the floor of Monterey Canyon. These deposits are most prominent near the head of Monterey Canyon and in the seaward part of the canyon that makes a 90-degree bend to the south (Pl. 3).

Many submarine slumps and landslides in Monterey Canyon have been identified in the seismic profiles (Pl. 2; Figs. 16, 19, 22). They have a distinctive longitudinal profile, characterized by a flat top and hummocky toes (Fig. 32); internal reflectors commonly appear deformed, folded, and rotated. Pliocene and Quaternary deposits are exposed in many

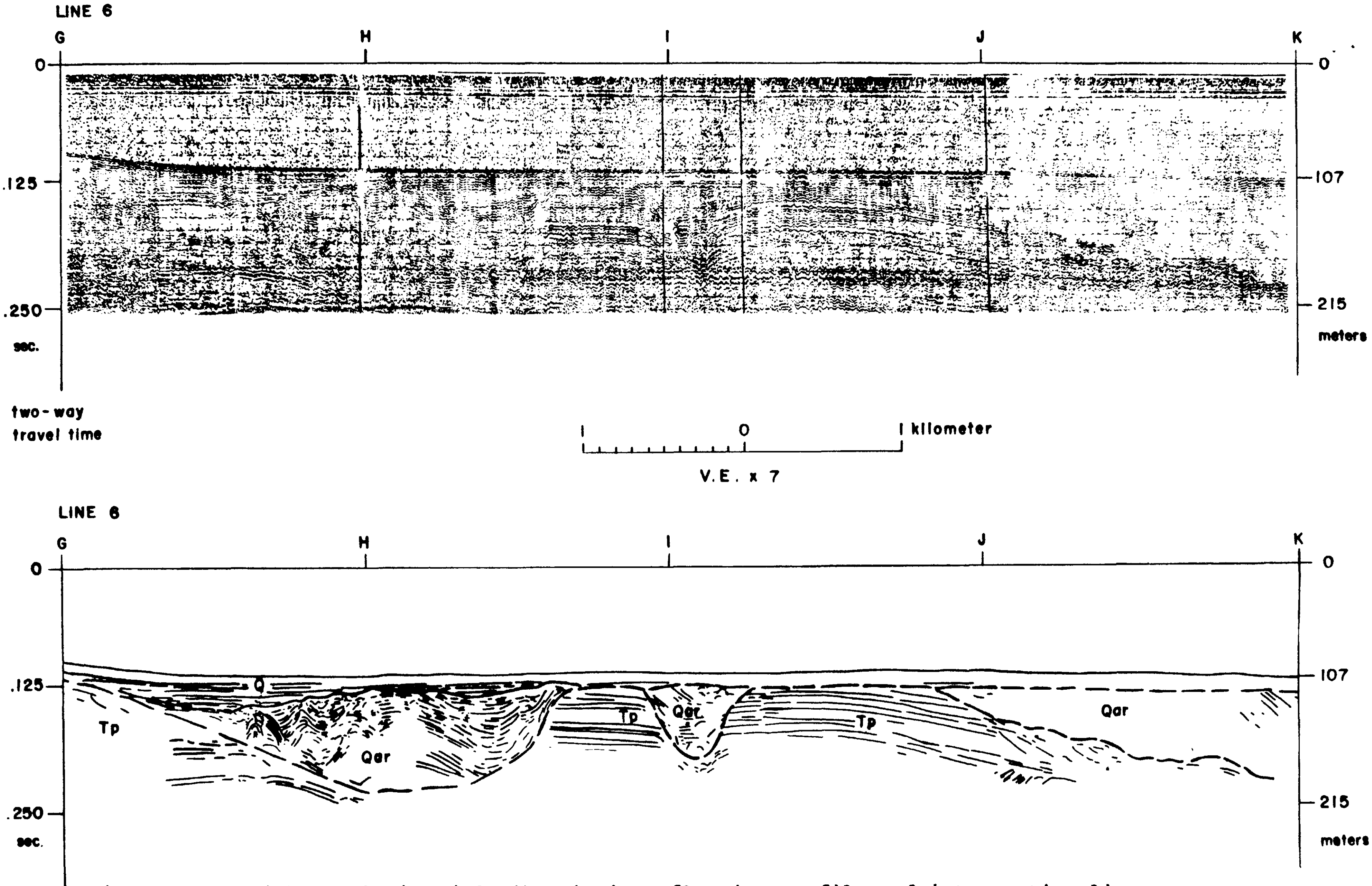


Figure 30. - High resolution (.6 kj) seismic reflection profile and interpretive line drawing of Line 6 across the nearshore shelf of Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

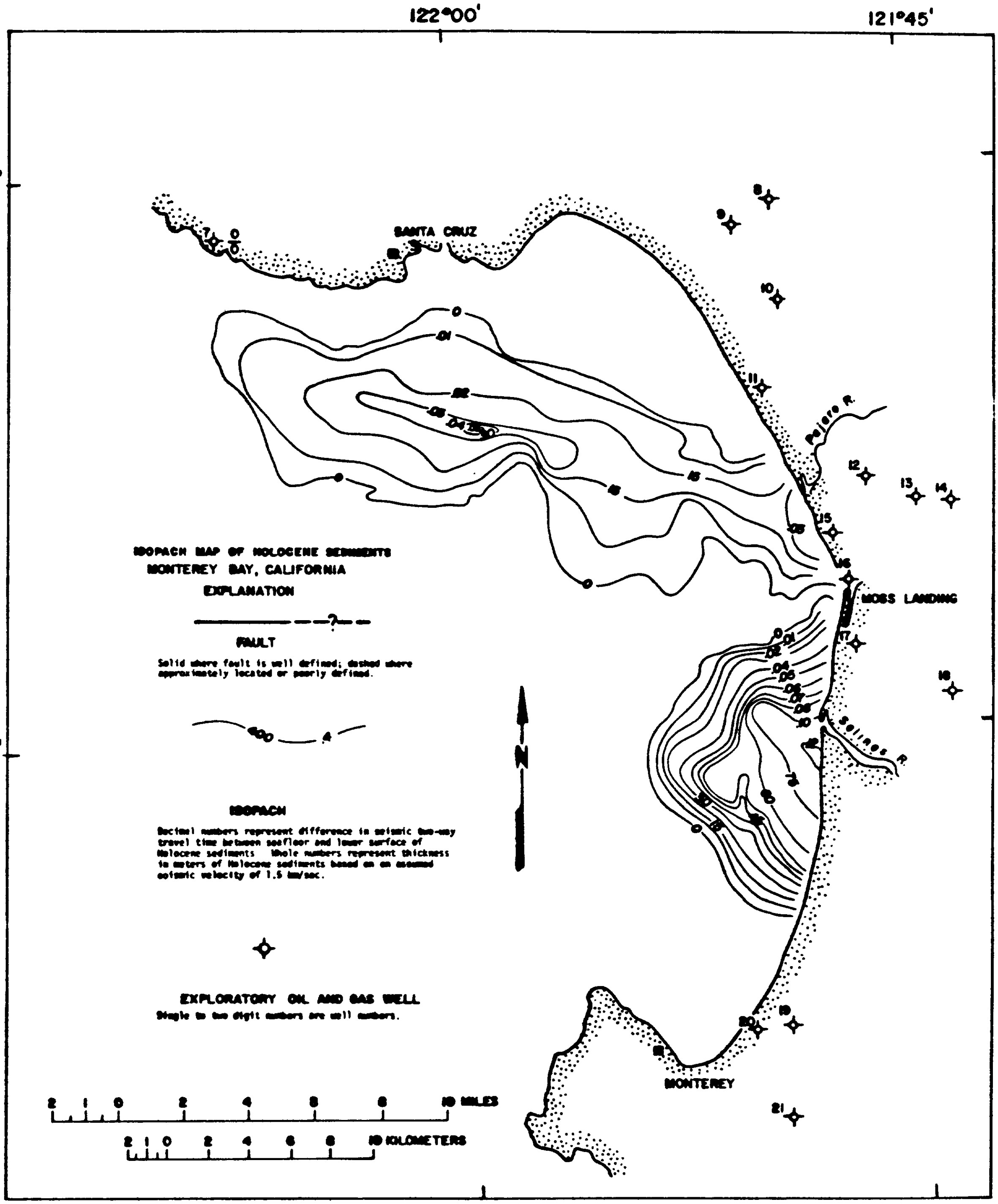


Fig.31 - ISOPACH MAP OF HOLOCENE SEDIMENTS
MONTEREY BAY, CALIFORNIA

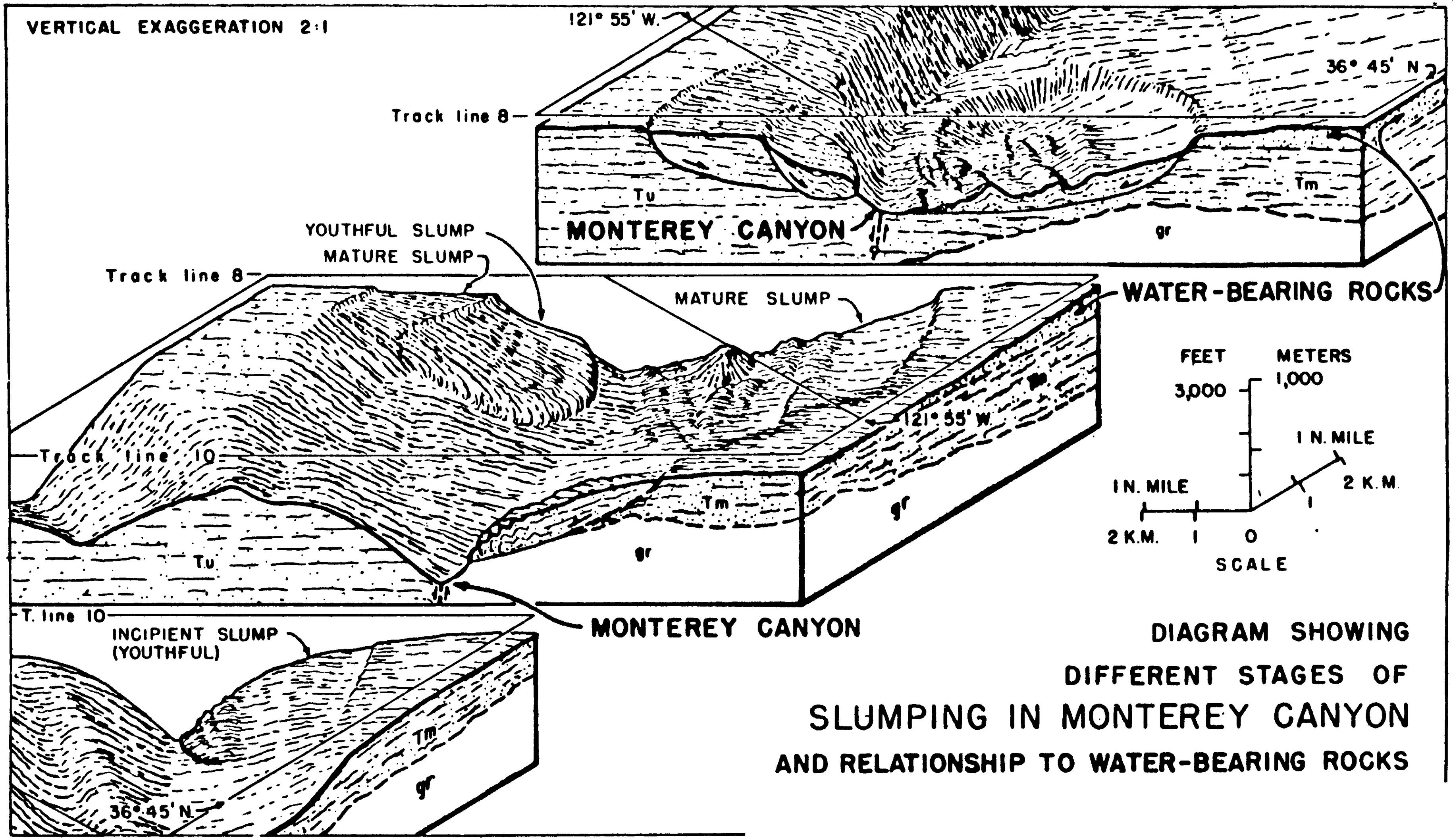


DIAGRAM SHOWING
DIFFERENT STAGES OF
SLUMPING IN MONTEREY CANYON
AND RELATIONSHIP TO WATER-BEARING ROCKS

Fig. 32

of the headward scarps. Landslide and slump deposits appear to be composed mostly of displaced late Tertiary and Quaternary materials.

Holocene sediments

Holocene marine surficial deposits in northern Monterey Bay extend as an elongate body from the mouth of the Pajaro River westward for more than about 25 km, paralleling the coastline west of Santa Cruz (Fig. 31). These sediments unconformably overlie the Pliocene Purisima Formation (Fig. 27) and the Pleistocene Aromas Sand (Figs. 28 and 30). These Holocene deposits range from 0 m thick at their depositional edge to nearly 40 m thick near the head of Soquel Canyon (Fig. 31). Holocene deposits are nearly 25 m thick near shore between the Pajaro River and Moss Landing where they probably represent recent deltaic sediments from the Pajaro River.

Stratigraphy West of the Palo Colorado-San Gregorio Fault Zone

The geophysical and geological character of the area west of the Palo Colorado-San Gregorio fault zone is not so well known as the area to the east. Hence, the stratigraphy west of the fault zone is based mostly on inferences from seismic data, with no direct lithologic control or correlation with onshore data (Fig. 14). Ages assigned to acoustic units in this area are speculative, and are based on crude correlations with similar units described in the outer Santa Cruz Basin by Hoskins and Griffiths (1971).

Three major stratigraphic units have been established from the seismic profiles: pre-middle Tertiary, middle Tertiary, and late Tertiary-to-Quaternary. The pre-middle Tertiary sequence is composed of acoustical "basement" comprising Cretaceous to early Tertiary sedimentary rocks, Mesozoic or older metamorphic rocks, and Cretaceous or Jurassic rocks of the Franciscan assemblage (Fig. 14). The middle Tertiary sequence includes sedimentary rocks of questionable Miocene age. The late Tertiary to Quaternary sequence is composed of Pliocene sedimentary rocks and unconsolidated marine sediments, submarine landslide deposits, and slump deposits.

Pre-middle Tertiary Sequence

Acoustical "basement" rocks of the pre-middle Tertiary sequence are represented in most deep penetration seismic profiles (Figs. 33 and 34). Acoustical basement in the area west of the Palo Colorado-San Gregorio fault zone is here thought to consist of well lithified sedimentary or metamorphic rocks, and possibly basic intrusive and volcanic rocks. Rocks of the Sur series of Trask (1926), and Cretaceous and Oligocene sedimentary rocks similar to those described by Hoskins and Griffiths (1971, p. 218) from the outer Santa Cruz Basin to the north, may also be present. All of these rocks reflect seismic energy strongly. Rocks forming acoustic basement appear on seismic records to crop out in the head of Ascension Canyon, in Monterey Canyon, and possibly along the unnamed seaknoll on the slope west of Point Sur (Pl. 3). Three samples (SC-1, MF-1, and LS-5) that may represent basement rock have been collected from this offshore basement terrane. These samples contain limestone, dolomite, and highly altered metasediments that may have lithologic affinities to the Franciscan assemblage and Sur Series, although a certain correlation cannot be made purely on lithologic grounds.

Franciscan rocks appear to form the acoustic basement in the extreme southeastern corner of the offshore area. This unit strongly returns seismic energy, and many multiple and hyperbolic reflectors are seen beneath the "basement" surface. It crops out on the shelf west and south of Point Sur, west of the Sur fault, and can be correlated with Franciscan rocks exposed onshore (Pl. 3). A basement ridge that extends northwestward (Fig. 5) from the Point Sur shelf also may be composed of Franciscan rocks.

Middle Tertiary Sequence

The middle Tertiary sequence unconformably overlies acoustical basement. The basal part of the sequence is composed of a vertical succession of many strong, continuous reflectors, similar in appearance to thinly bedded rocks of the Monterey Formation, and is more than 1,300 m thick in a sedimentary basin just south of Ascension Canyon (Pl. 3; Fig. 14). These rocks appear to be exposed along the west and north walls of outer Monterey Canyon and along the east walls of two tributaries that enter Monterey Canyon from the north (Pl. 3).

Late Tertiary to Quaternary Sequence

Pliocene (?) sedimentary rocks form the lower part of this sequence, overlying sedimentary rocks of probable Miocene age with unconformity, and locally with disconformity or conformity (Figs. 18, 33 and 34). These rocks may be equivalent in age to the Purisima Formation. This unit appears in seismic profiles as continuous to discontinuous, weak to strong reflectors. It is nearly 1,000 m thick in the sedimentary basin just south of Ascension Canyon (Pl. 3; Fig. 14), and appears to crop out on the south wall of Monterey Canyon (Pl. 3).

The Tertiary sequence is mapped as undifferentiated sedimentary rocks where the unconformity between Miocene and Pliocene units is poorly defined or absent (Fig. 14). These rocks are more than 1,900 m thick beneath the shelf near the head of Ascension Canyon (Pl. 3; Fig. 14). Rocks of this unit are also involved in the northern part of the Palo Colorado-

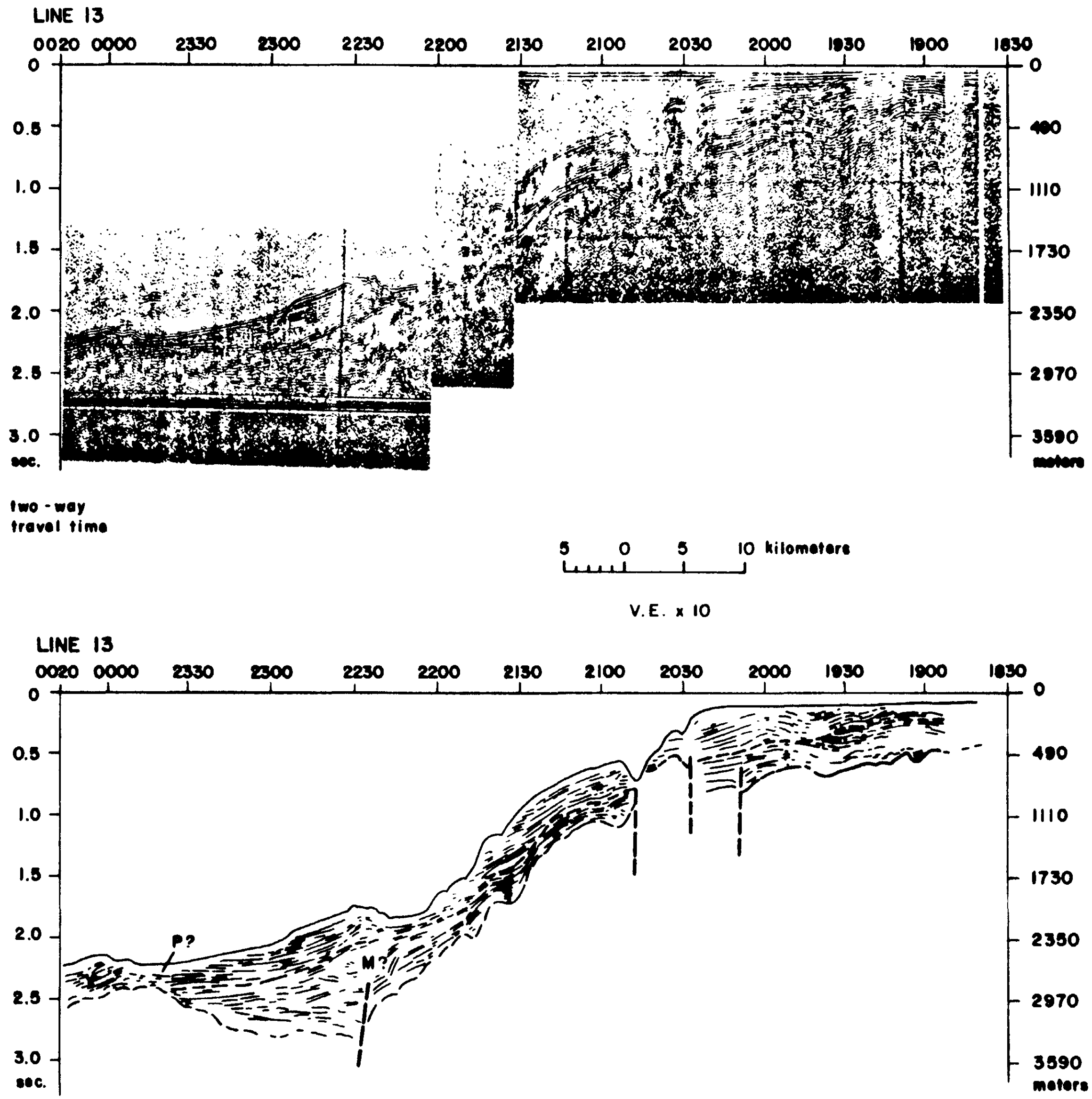


Figure 33. - Deep penetration (160 kj) seismic reflection profile and interpretive line drawing of Line 13 across the continental shelf and slope of northern Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

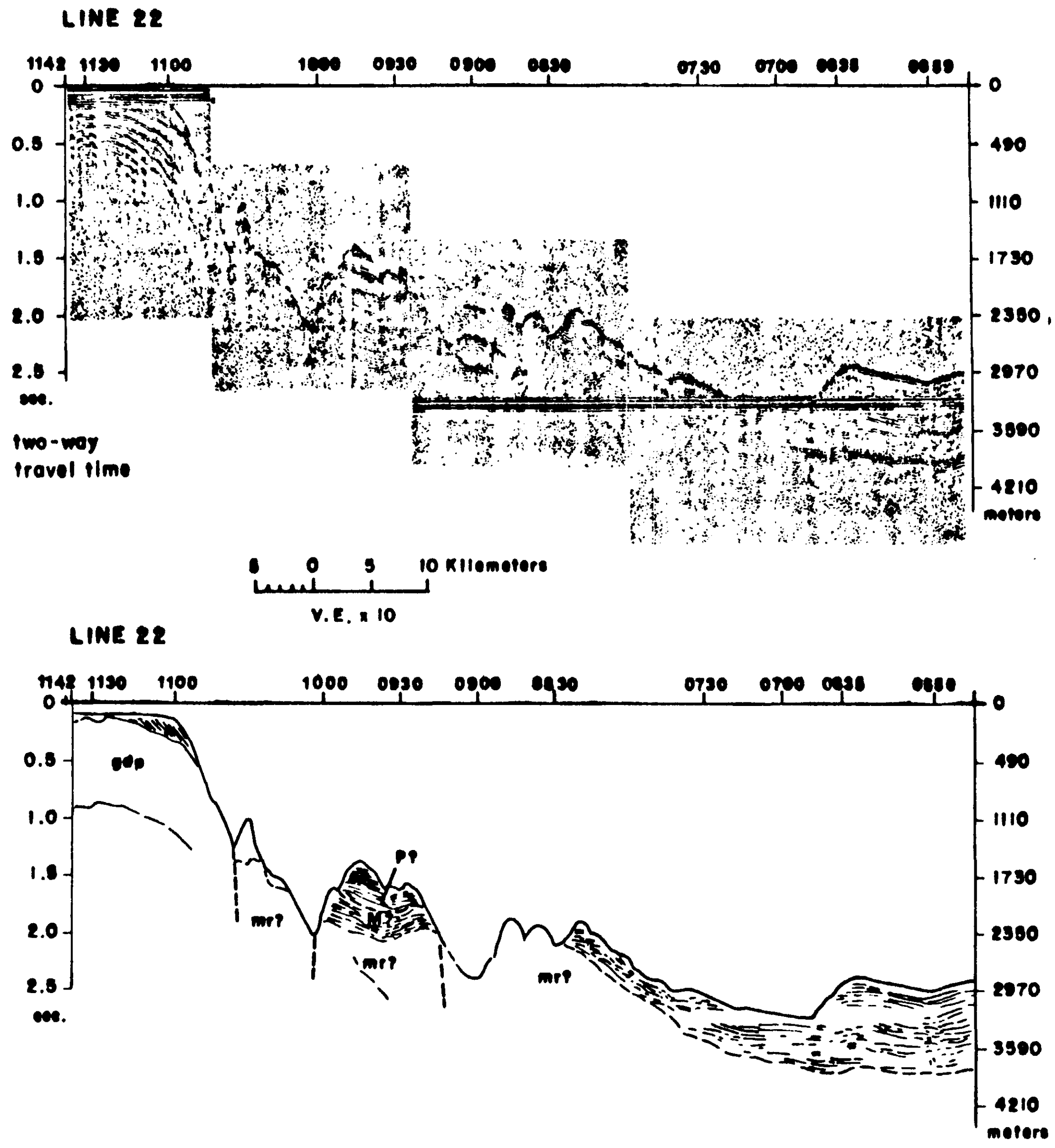


Figure 34. - Deep penetration (160 kj) seismic reflection profile and interpretive line drawing of Line 22 across the continental shelf and slope of south Monterey Bay (see Fig. 2 for location and Plate 3 for explanation of symbols).

San Gregorio fault zone where seismic profiles suggest that they are highly sheared and faulted.

The upper part of this sequence is a unit comprising undifferentiated late Tertiary to Quaternary sediments of probable marine origin, mostly sands and muds, and submarine landslide and slump deposits. This unit contains many flat-lying, continuous to discontinuous reflectors in which submarine slumps appear as distorted, folded, and weak internal reflectors (Figs. 18 and 34). It is limited in extent to the northern and southern parts of the area west of the Palo Colorado-San Gregorio fault zone. This unit lies conformably or disconformably upon, and appears locally to grade laterally into, the underlying Tertiary sequence (Figs. 18 and 34). It is about 1,450 m thick on the slope near the head of Ascension Canyon (Pl. 3).

A single, very large submarine slump is present on the west wall of Monterey Canyon a short distance west of the Palo Colorado-San Gregorio fault zone. The slump material is derived mostly from Tertiary sedimentary rocks, and may be as much as 850 m thick.

STRUCTURE

The structure of the Monterey Bay region offshore is complex and is produced largely by post-Miocene tectonic events. Major structures in the Monterey Bay region include faults, folds, and fault-bounded basement ridges associated with sedimentary basins (horsts and grabens). The structural grain of the region is variable in trend, and may chronicle shifts in stress field or changes in the Pacific-American plate boundary since Miocene time. Structural trend is generally northwest-southeast for the region as a whole. However, the Palo Colorado-San Gregorio fault zone trends north-south, obliquely truncating structures in Monterey Bay (Pl. 3). Structures west of the Palo Colorado-San Gregorio fault zone expand westward away from the fault zone, with a pivot point somewhere south of Point Sur. Faults farthest west are oriented more nearly east-west than structures nearer the fault zone. South and west of the pivot point, structures are oriented nearly north-south.

Seismic profiles provide much information concerning the location, depth, and age of strata affected by faulting. This information is presented on Plates 5 and 6. Major faults were defined using criteria outlined in Appendix I. Many previously unmapped faults were identified on seismic profiles in the Monterey Bay area during this investigation. Some of these faults extend onshore. Earthquake epicenters and geologic evidence for recent offset indicate that several faults are active. Seismically active faults come onshore near Año Nuevo Point, and between the towns of Marina and Point Sur to the south.

Faults in the Monterey Bay region lie primarily within two major northwest-trending, intersecting fault zones, the Palo Colorado-San Gregorio and Monterey Bay fault zones (Pl. 5). The Palo Colorado-San Gregorio fault zone is a narrow (approximately 3 km wide) feature defined by one or two faults. It appears to merge to the south with the Serra Hill and Palo Colorado faults onshore near Kasler and Hurricane Points (Trask, 1926; Jennings and Strand, 1958; Gilbert, 1971), and to the north with the San Gregorio fault and a thrust fault, or a fault mapped about 500 m east of the thrust, on Año Nuevo Point (described by Clark (1970a) and Evans and Lajoie (written commun., 1971)). The length of this zone, including its on-land segments, is at least 125 km; however, its total length may be considerably greater, for it appears to join faults at Half Moon Bay that in turn join the San Andreas fault northwest of the Golden Gate (Cooper, 1971). It also may join the Coast Ridge fault to the south (Ross, 1976).

The Monterey Bay fault zone (previously termed the Tularcitos fault zone by Greene (1970)),is located in Monterey Bay between Monterey and Santa Cruz and forms a diffuse zone, 10 to 15 km wide, of short, en echelon, northwest-trending faults. This zone may comprise the offshore extensions of northwest-trending faults in the Salinas Valley and the Sierra de Salinas to the southeast. To the north, this zone appears to terminate against the Palo Colorado-San Gregorio fault zone.

The probable offshore extension of the Sur-Nacimiento fault zone forms a third major fault that parallels the Palo Colorado-San Gregorio fault zone farther offshore along the southwest edge of the Monterey Bay region.

To facilitate discussion, the Palo Colorado-San Gregorio fault zone is divided into three geographic segments, the Cypress Point-Point Sur shelf, Monterey Bay, and Año Nuevo Point-Santa Cruz shelf segments; the Monterey Bay fault zone is divided into southern and northern Monterey Bay segments.

Sur-Nacimiento Fault Zone

Several faults identified on the shelf between Point Sur and Cypress Point are aligned with faults onshore in the Sur-Nacimiento fault zone, a major structural feature in the southern Monterey Bay region. This zone is a belt of faults of various kinds and ages that extends about 300 km southeastward from the Sur fault zone (Page, 1970a) and includes the Sur thrust zone, the Nacimiento fault, and several smaller faults.

Seismic reflection profiles do not reveal the subsurface bedrock structure and associated major faults on the shelf area between Point Sur and Hurricane Point, where the offshore extension of the thrust zone should be found. This zone of poor reflectivity is bounded on the south by faults that are buried beneath about 200 m of late Tertiary (?) sediments and may parallel the northwest trend of the faults onshore (Pl. 5). The westernmost of these faults may be the offshore trace of the Sur-Nacimiento fault. The two longest faults diverge toward the northwest; both may be part of a longer fault zone that extends southeastward, parallel to the coast. The presence of tightly folded and sheared rocks onshore south of Point Sur suggests that such a fault zone may be present offshore (W. G. Gilbert, oral commun., 1970; Ross, 1976).

Palo Colorado-San Gregorio Fault Zone

Cypress Point-Point Sur Shelf

Two faults trend northwestward from the coast in this area; the southernmost crosses the coast near Hurricane Point and the northernmost near Kasler Point (Pl. 5). The former comprises three segments. The central and northern segments are marked by abrupt termination of well defined reflectors (bedded sedimentary rocks) southwest of the fault against a zone of seismic incoherence (crystalline rocks) (Pl. 7, section N-N'); the southern segment may bend eastward and join the Serra Hill fault. The Serra Hill fault (Trask, 1976) is a major thrust fault that emerges from the ocean just north of Hurricane Point and trends southeast on land (Gilbert, 1971). Near Hurricane Point, the fault dips 50°-60° NE. Mesozoic grandiorite northeast of this fault is thrust over upper Miocene sandstone. Gilbert (1971) estimates that the vertical separation on the fault is at least 300 m. The offshore continuation of this fault trends northwest down the axis of the western tributary of Carmel Canyon, and may have controlled the location of this canyon (Pls. 5, 7, section M-M').

Northeast of the offshore extension of the Serra Hill fault, near Kasler Point, a well defined and fairly continuous offshore fault is identified. The southern part of this fault is located by seismic reflection and bathymetric profiles. This fault lies between locally disturbed stratified rocks to the southwest, and crystalline or well indurated sedimentary rocks to the northeast (Pl. 7, section M-M'). It appears to be upthrown on the northeast; Dohrenwend (1971, p. 35) calculated that Pliocene and Pleistocene sedimentary rocks at least 200 m thick have been brought into fault contact with the quartz diorite. Sandy siltstone, rather than quartz diorite, was dredged on the upthrown side of the fault (Dohrenwend, 1971; Ellsworth, 1971), but seismic records show a reflecting unit having the appearance of crystalline rocks north of the fault. Any sediment overlying quartz diorite east of the fault must be less than about 3 m thick and concealed within the seismic bubble pulse.

A west-facing, 2 m high scarp is associated with the fault northeast of Kasler Point. Ellsworth (1971) and Dohrenwend (1971) have suggested that because the scarp consists of easily erodable siltstone, it probably was produced by recent fault offset, rather than differential erosion. High resolution (7.5 kHz) bathymetric profiles indicate that this scarp swings eastward and may connect with the Palo Colorado fault on land (Dohrenwend, 1971; Ellsworth, 1971; Pl. 5). Graham (1976), however, believes that the Palo Colorado fault is minor and not presently active, and that this offshore fault trends into a fault within the Sur-Nacimiento fault zone.

The Palo Colorado fault onshore has been described as a southeast-trending thrust that parallels the coast for approximately 2 km, ultimately bending to the east, with Mesozoic quartz diorite thrust over Cretaceous sandstone (Trask, 1926). According to Trask (1926), the fault plane probably dips 70° NE, with separation of about a thousand meters.

The Palo Colorado fault is well-defined in seismic reflection profiles across a deeply incised eastern tributary of Carmel Canyon off Point Lobos (Pl. 7, section M-M'). The east wall of this tributary is composed of granitic rock, and stratified sediments 120 m thick overlie a probable granitic basement in the west wall. These relationships suggest at least 120 m of separation, with relative upward movement of the east wall. A dredge haul at the base of the west wall of this tributary collected a quartz diorite rock with cataclastic texture (tectonically deformed quartz diorite with broken and bent phenocrysts), which is consistent with the presence of a fault in the tributary valley.

Monterey Bay

Seismic reflection is of little help in following faults in Carmel and Monterey Canyons because the steep bottom topography produces complex seismic reflections (side echoes and hyperbolic reflections) that obscure subbottom reflections. However, Martin and Emery (1967, Fig. 5) dredged well indurated middle Miocene limestone from the west wall of the canyon, and granodiorite from the east wall. Using this evidence, together with high precision depth records showing linear elements in the sea floor topography, the Palo Colorado-San Gregorio fault is projected along the axis of Carmel Canyon. Thus, the fault zone, including the offshore extension of the Serra Hill fault, trends approximately N25°W down Carmel Canyon in Monterey Bay.

Near the junction of Carmel and Monterey Canyons, Martin and Emery (1967, p. 2289) show a narrow band of pre-Cretaceous(?) metamorphic rocks between two northwest-trending parallel faults that separate it from middle

Miocene siliceous siltstone on the west and Cretaceous intrusive rocks on the east. These faults are generalized on Plate 5, appearing as a single fault, which is then extended northwestward, following linear topographic elements, to the southern edge of the Año Nuevo Point-Santa Cruz shelf, where seismic records clearly indicate faulting.

Año Nuevo Point-Santa Cruz Shelf

Two northwest-trending parallel faults cut across the Año Nuevo Point-Santa Cruz shelf (Pl. 3). These faults appear to be continuous for more than 26 km, and bound a zone of deformed, steeply dipping rocks. Seismic reflections suggest that dips exceed 35° in some areas or that the rocks are extensively sheared (Pl. 8, profiles A-A', D-D'). Hoskins and Griffiths (1971) show faults in approximately the same locations, but suggest that these faults do not affect rocks above a buried erosional unconformity of late Miocene age. However, both intermediate penetration and high resolution profiles made during this study indicate that these faults cut the younger overlying rocks, and in some places closely approach the ocean floor.

Faults onshore that are the probable continuation of the offshore faults described above also show evidence of relatively young displacement. The easternmost of these faults lies directly on the trend with the main strand of the San Gregorio fault, which, as mapped by Clark (1970), has juxtaposed the Pliocene Purisima Formation to the west against the upper Miocene to early Pliocene Santa Cruz Mudstone. The westernmost fault lies on trend with faults on Año Nuevo Point, which the Miocene Monterey Shale has thrust (northeast side up) over Pleistocene marine terrace deposits (Clark, 1970a; J. G. Evans and K. R. Lajoie, written commun., 1971). The presence of a shear zone several meters wide east of Año Nuevo Point suggests that a third fault trends N30°W (K. R. Lajoie, G. E. Weber and J. C. Tinsley, written commun., 1971) into the deformed zone offshore, in what can be considered an extension of the San Gregorio fault zone.

The easternmost fault of the San Gregorio fault zone at Año Nuevo Point could not be distinguished in seismic profiles offshore, to the south, suggesting that it changes character or ends. Hoskins and Griffiths (1971) show it terminating at about the same location as indicated on Plate 5. The westernmost fault in this zone has been extended across Monterey Canyon along linear topographic features on the sea bottom, and is joined with the Carmel Canyon fault. According to this interpretation, faults of the San Gregorio and Palo Colorado systems form a single zone in the Monterey Bay region.

Monterey Bay Fault Zone

Southern Monterey Bay

The Monterey Bay fault zone is composed of many en echelon faults identified both from high-resolution and intermediate-penetration seismic reflection profiles south of Monterey Canyon (Pls. 5 and 8, inter. penetration sections J-J' through L-L'). About one-third of these faults are 1.6 km or more in length and have been correlated between two or more track lines. Two-thirds of the faults, however, were identified on only one track line and have been arbitrarily aligned with adjacent faults that have greater continuity.

Recent mapping has demonstrated the onshore continuity of many of the offshore faults of the Monterey Bay fault zone (Clark and others, 1974). Three relatively continuous faults in southern Monterey Bay appear to extend onshore between Fort Ord and Monterey; two are about 9 km long and the third is approximately 3 km. One of the 9 km-long faults may be the offshore extension of the Chupines fault, which appears to enter the bay north of Monterey near Seaside. Clark (written commun., 1976) is unable to map this fault on shore near the coast. Seismic reflection profiles from the offshore area and geophysical data on land indicate that the two 9 km-long faults exhibit the same sense of separation as the Chupines and Tularcitos-Navy faults on land. All four faults have Tertiary sedimentary rocks downthrown on the northeast against Mesozoic granite on the southwest (Pl. 7, Section K-K', fix 14.5, and Sections K-K' and L-L', between fixes 11 and 12). However, high resolution profiles across the nearshore part of the southernmost fault offshore show drag folds indicating the opposite sense of displacement, i.e., northeast side upthrown. This drag folding could be the result of recent fault motion, which might differ from the predominant displacement, or may indicate that the fault has a component of strike slip.

On land, the Chupines fault trends northwestward from the Sierra de Salinas and extends beneath an area of alluvial deposits several kilometers wide near the coast. The fault is well defined in the mountains, where the Miocene Monterey Formation locally lies in fault contact with lower Pleistocene Aromas Sand (Jennings and Strand, 1958; Bowen, 1969; California State Dept. of Water Resources, 1970), and with granitic basement rocks at depth (Clark and others, 1974). Sieck (1964) has interpreted gravity data to indicate that the Chupines fault lies beneath the alluvium at the foot of the mountains, and has suggested that dip-slip movement along the fault may have displaced the Monterey Formation near Canyon del Rey. The fault exhibits a vertical separation of about 300 m, upthrown to the southwest. The Chupines fault is more than 26 km long if it is an on-land continuation of one of the more continuous faults in the Monterey Bay fault zone.

The Navy fault, a southwest-dipping reverse fault where exposed, is a second major onshore fault that may be continuous with faults offshore in southern Monterey Bay. The Navy fault has been mapped in a northerly direction across Carmel Valley and the Meadow Tract area of the Monterey Peninsula. It then passes beneath alluvium at the base of the mountains, and finally trends out to sea near the U.S. Navy Postgraduate School (Clark and others, 1974). The Navy fault may represent the northwestward continuation of the Tularcitos fault, but the continuity of these fractures across Carmel Valley is uncertain. If the Tularcitos-Navy fault continues into Monterey Bay and joins the southernmost of the relatively continuous faults offshore, its length would be more than 42 km. Dibblee (oral commun., 1973) believes,based on his field studies in this area, that the Tularcitos fault bends slightly west of the Meadow Tract area and dies out to the northwest, in Carmel Valley; however, a zone of discontinuous faults may extend northwestward from the Tularcitos fault across the Meadow Tract area toward Seaside.

The northeastern boundary of the Monterey Bay fault zone in southern Monterey Bay is gradational and is formed by a relatively continuous fault and several discontinuous en echelon faults (Pls. 5 and 7, Section P-P', fix 10.5). This boundary may be the offshore extension of the King City fault (Clark, 1930; Reed, 1933). Projection of the continuous fault shows it to be aligned with the inferred trace of the King City fault (also called Gabilan fault), as projected from the base of the Sierra de Salinas to the ocean just south of the town of Marina.

On land, the King City fault is a high-angle reverse fault along which granitic rocks of the Sierra de Salinas are uplifted to form the western border of the Salinas Valley (Reed, 1925, 1933; Clark, 1930; Sieck, 1964, p. 20). Vertical separation along this fault decreases to the north, toward Monterey Bay, where it may die out. The King City fault is presumed to extend beneath the southwest margin of the Salinas Valley at least as far southeastward as the area west of Greenfield (Clark, 1930, p. 204; Reed, 1933, p. 43-44; Schombel, 1943; Durham, oral commun., 1972). Gravity data from the southern margin of the Salinas Valley suggest about 2500 m of vertical separation (Fairborn, 1963), wheareas gravity data from the west end of the Sierra de Salinas indicate between 900 and 1200 m of separation (Sieck, 1964). If the King City fault and faults forming the northeast boundary of the Monterey Bay fault zone are continuous, the vertical separation decreases to about 240 m where the fault crosses Section J-J' offshore (Pls. 5 and 7).

The Reliz fault was first mapped as a branch of the King City fault (Schombel, 1943); however, Durham (1970, p. 2) terminates the Reliz fault about 4 km south of the King City fault near Olsen Ranch (Pl. 5). Other workers, including Gribi (1967, p. 91), Walrond and others (1967), and Tinsley (1975), believe that the Reliz fault extends northwestward along the base of Sierra de Salinas into the King City fault, and refer to both faults as the Reliz fault. Dibblee (1972) concurs with the latter interpretation on the basis of the linearity and near alignment of the steep front of the Sierra de Salinas with the Reliz fault south of Olsen Ranch. Dibblee (1972) also considers the Reliz fault to be part of a system including the Rinconada fault, which extends for more than 110 km farther to the southeast.

Projection of the King City fault beneath the alluvial cover of the lower Salinas Valley near the Monterey coast is inferred from water well data. These data also suggest that the fault has a probable post-Pleistocene vertical separation of 30 m, south side up, near the town of Marina about 3 km from the coast (California State Dept. of Water Resources, 1970, Sheet 5 of Pl. 2). Movement along the fault has juxtaposed the Miocene Monterey Formation, on the southwest, with the upper Pliocene to lower Pleistocene Paso Robles Formation. Farther southeast, at Fort Ord, the Paso Robles Formation southwest of the fault occurs in the subsurface at an elevation of 30 m above sea level. The Paso Robles is not encountered to the northeast, across the fault, but deposits here occur at an elevation of more than 160 m below sea level (R. S. Ford, written commun., 1972).

The southwest limit of the Monterey Bay fault zone in southern Monterey Bay is formed by a series of parallel faults that trend northwestward from Cypress Point (Pl. 5). Three of these faults displace the sea floor by 1 m to 5 m; two show relative uplift on the southwest and the other shows relative uplift on the northeast. The most continuous fault in this boundary zone may connect with the on-land Cypress Point fault that extends southeastward from Cypress Point to Pescadero Point, and across Carmel Bay to connect with a fault on Abalone Point, just north of the mouth of Carmel River (Bowen, 1969; Clark and others, 1974).

Northern Monterey Bay

North of Monterey Canyon, the Monterey Bay fault zone is composed of many faults identified primarily from high resolution seismic records (Pl. 5 and 7, H. R. Sections A-A' through E-E'). Most faults are downthrown on the northeast, or landward, side. About one-third of these faults are 1.6 km in length and have been correlated between two or more tracklines. Two-thirds of the faults cannot be correlated between adjacent tracklines but are arbitrarily shown to be oriented parallel with adjacent faults having greater continuity.

The longest fault is in the center of the zone and is at least 9.6 km long (Pls. 5 and 7, Sections C-C' and E'E', between fixes 9 and 10). Drag folds and offset, gently dipping reflectors associated with this fault can be correlated from line to line on high resolution records, and the fault can be traced on the basis of its seismic characteristics on intermediate and deep penetration profiles.

The northeast edge of the Monterey Bay fault zone in northern Monterey Bay is gradational, and is evident as a decrease in the number of discontinuous faults. The Monterey Bay fault zone does not appear to continue across the trace of the Palo Colorado-San Gregorio fault zone.

Faults probably continue beneath Monterey Canyon, but could not be identified by the seismic reflection method used in this investigation. Linear trends in the topography of the bay floor within the Monterey Bay fault zone parallel the trend of the faulting, as do the large northwest meander in Monterey Canyon and the channels of small valleys tributary to the canyon. The position of all of these features may be fault controlled.

Deep penetration (160 kj) seismic reflection profiles provide evidence for the "Monterey Canyon fault", previously inferred to lie beneath, and parallel to, the headward axis of Monterey Canyon (Greene, 1970). Cretaceous granites forming the basement complex occur at shallower depths on the south side of the canyon than on the north; the apparent vertical separation is approximately 60 m to 150 m, south side up (Fig. 35), and increases in amount farther offshore.

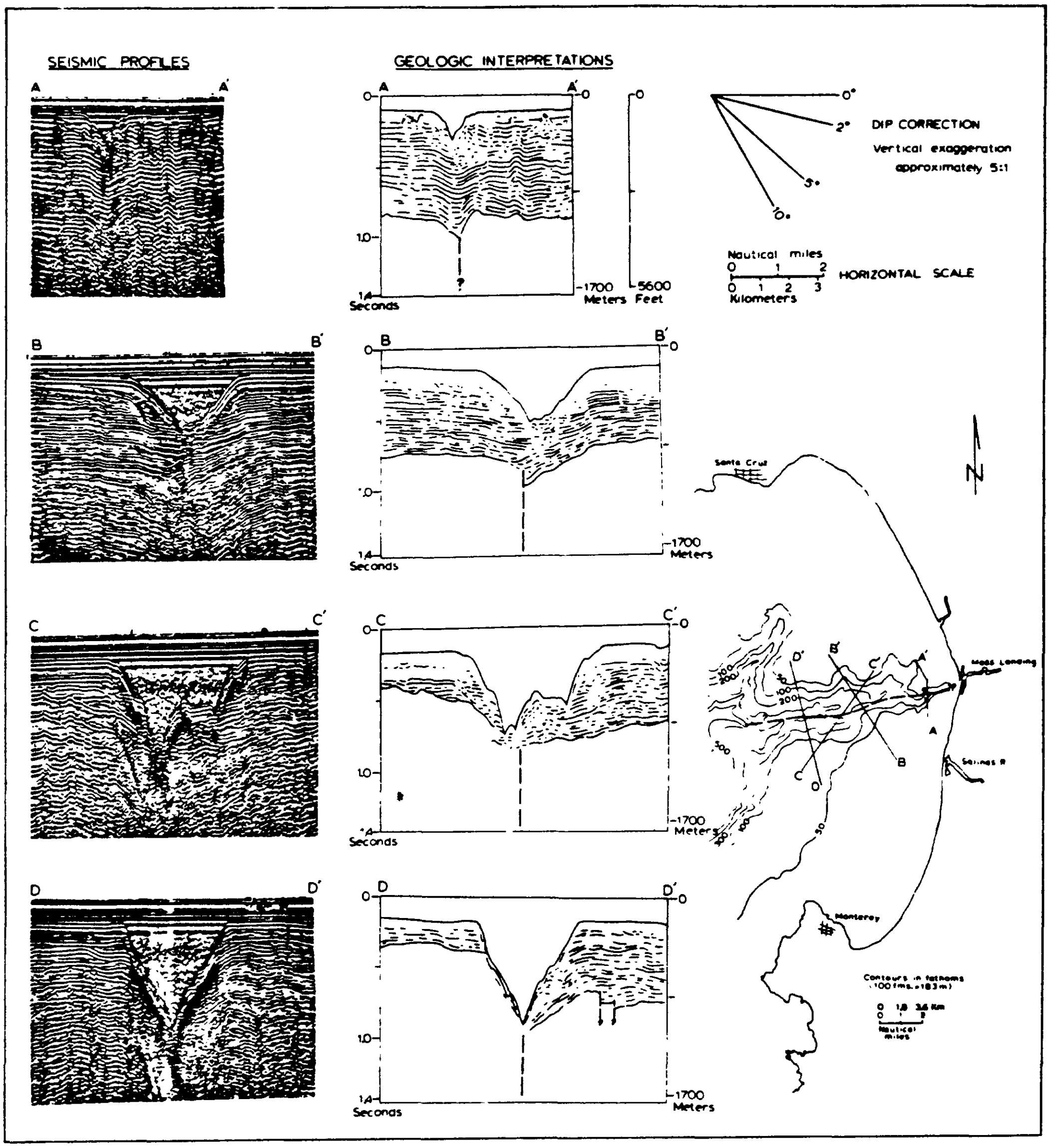


Figure 35. - Deep penetration (160 kj) seismic profiles and geologic interpretations across Monterey Canyon showing location of Monterey Canyon fault.

The Monterey Canyon fault is approximately 10 km long and follows the axis of the canyon from the meander to the mouth of Elkhorn Slough (Pl. 5). The fault may extend onshore, and could be responsible for the trough in basement rocks beneath Elkhorn Slough (Starke and Howard, 1968). Shallow reflectors are poorly defined in the 160 kj seismic profiles, and it is difficult to determine the youngest strata cut by the Monterey Canyon fault. However, this fault probably does not extend upward to the base of the modern canyon fill.

Ascension Fault

The Ascension fault lies about 5 km west of the Palo Colorado-San Gregorio fault zone, paralleling it for almost 70 km to the southernmost head of Ascension Canyon (Pls. 3 and 5). Seismic reflection data collected by the U.S. Geological Survey to the north indicate a northward continuation of the fault for more than 20 km (D. S. McCulloch, oral commun., 1976). The youngest rocks displaced by this fault appear to be Miocene, based on the offset of reflectors of probable Miocene age, and the lack of offset of reflectors in the overlying strata of probable Pliocene age, in seismic reflection profiles.

Other Offshore Faults

West of the Palo Colorado-San Gregorio fault zone, four other faults have been inferred from deep penetration seismic profiles (Pl. 3). The youngest rocks displaced by these faults are probably of Miocene age, making these faults older, in general, than those comprising the Palo Colorado-San Gregorio and Monterey Bay fault zones. None of these faults displaces the sea floor.

Two other faults extend N50°W from the Point Sur shelf. These linear faults are the northeastern and southwestern margins of the basement ridge that forms the Sur platform. The northeastern fault is at least 80 km long; it passes about 11 km seaward of Point Sur and probably continues to the south, paralleling the southern Sur coast.

The fourth fault is located along the east side of the unnamed sea-knoll on the continental slope due west of Point Sur. This fault is oriented nortn-south, as are structures to the south. It appears to be only 15 km long, but may extend a greater distance to the south.

Proceeding from west to east, the orientation of most faults seaward of the Palo Colorado-San Gregorio fault zone changes from northwest-southeast to nearly north-south. The southern ends of the most nearshore faults appear to approach a common juncture south of Point Sur. D. S. McCulloch (oral commun., 1976) observes that faults seaward of the Sur Coast trend northwest-southeast until they approach Point Sur, where their trend appears to change abruptly to a nearly east-west orientation.

Sea Floor Scarps and Discontinuities Not Due to Faulting

Several sea floor scarps mapped in the Monterey Bay region resemble faults but appear to have had other origins. These features are most common in central Monterey Bay, in and around Monterey Canyon near Moss Landing, and along the shelf break at the top of the continental slope. The most abundant of these are slump scarps along most of the walls in the headward part of Monterey Canyon (dashed single-hachured line on Pl. 5; also see Pl. 7, Section 8-8'). Similar scarps occur at a depth of about 125 m near the edge of the continental shelf. Hummocky topography downslope from some of these scarps indicates that they are related to the slumping of unconsolidated sediment.

Other seaward-facing scarps at the edge of the continental shelf appear to be erosional features at the landward edge of young sediments deposited with foreset bedding on a prograding continental slope (dashed double-hachured line on Pl. 5; also see Pl. 7, Section E-E', fix 14). E. Silver (oral commun., 1971) attributes similar features along the northern California coast to wave erosion and accompanying deposition during lowered sea level; Dietz (1952, p. 1809) has advanced a similar explanation for features on the shelf edge of the eastern United States. However, some of these scarps may be associated with downslope creep of continental shelf sediments.

An arcuate subsurface break, covered by about 10 m of sediment, is present on the south side of the head of Monterey Canyon (Pl. 5). This feature approximately parallels the canyon, and the north side is down-dropped an unknown amount. This subsurface break appears to be the head of an incipient slump that has moved toward Monterey Canyon. It may have become stable and covered by late Holocene sediment, or the slump may be active, in which case the break may be propagating toward the surface.

Seismicity and Evidence for Recent Faulting

Earthquakes in the Monterey Bay region indicate that the Palo Colorado-San Gregorio and Monterey Bay fault zones are seismically active. Historical accounts of earthquakes in the region date back to 1836. Information for the period before installation of seismographs in 1934 is based on reports of earthquakes noted by inhabitants of the area; the locations of these earlier quakes cannot be determined accurately. The earthquake history of the region from 1836 to 1968 has been summarized by Griggs (1973).

Sites of reliably located earthquakes recorded between October 1926 and June 1976 in the Monterey Bay area are shown on Plate 6 and listed on

Table 3. Epicenters of earthquakes east of the San Andreas fault are not plotted, nor are epicenters located east of the Salinas Valley in the south, and east of the Zayante fault in the north. All epicenters after November 1972 are located tentatively and their positions may change with further refinement of pertinent seismic data. In addition, only post-1972 earthquakes located west of the San Andreas fault zone have been plotted; those associated with the San Andreas are not plotted (see Table 4).

The largest recorded earthquakes in the Monterey Bay region occurred in 1926. Steinbrugge (1968, p. 77) has described these as follows:

> 1926 October 22, 4:35 A.M. Center on the continental shelf off Monterey Bay. Intensity VIII at Santa Cruz, where many chimneys were thrown down: VII at Capitola, Monterey, Salinas and Soquel. Felt from Healdsburg to Lompoc (a distance of 250 miles or 450 km) and east to the Sierra, an area of nearly 100,000 square miles (180,000 square km). Another shock one hour later was similar to the first in almost every respect.

Detection of earthquakes and determination of their locations and focal depths (hypocenters) in the Monterey Bay area are difficult because the area lies largely outside of the network of seismographic stations. Epicenter locations for earthquakes that occurred before 1969 probably are accurate to $\pm$ 10 km. Epicenters of earthquakes since 1969, the year during which additional seismographs were installed, probably are accurate to $\pm$ 5 km. Focal depths probably are accurate to $\pm$ 10 km and most appear to be shallow--within 15 km of the surface.

Eighty-two earthquakes of magnitude 0.9 to 6.1 occurred beneath Monterey Bay and the adjacent bay margin (in the area bounded by latitude $36^{\circ}30'$N to $37^{\circ}00'$N and longitude $121^{\circ}45'$W to $121^{\circ}30'$W) between 1926 and September 19, 1972. Ninety-six earthquakes of magnitude .06 to 2.9 occurred in this area from September 20, 1972 to June 21, 1976. Earthquake activity

Table 3.--Earthquakes in the Monterey Bay area (within lat 36°30'N to 37°00'N and long 121°45'W to 122°30'W), October 22, 1926 through September 19, 1972

Origin Time (Greenwich Mean Time)										
Year	Month	Day	Hour	Minute	Second	Latitude (N)	Longitude (W)	Focal Depth (Km)	Magnitude	Reference
1926	OCT	22	12	35	11.0	36°15.0'	122° 0.0'		6.1	Richter, 1958
1926	OCT	22	13	35	27.0	36°45.0'	122° 0.0'		6.1	
1934	APR	23	16	8	0.0	37° 0.0'	122° 0.0'		4.0	California Department of
1935	JUN	18	4	15	0.0	37° 0.0'	122° 0.0'		4.0	Water Resources (1964)
1936	SEP	24	14	12	0.0	37° 0.0'	122° 0.0'		4.0	
1937	OCT	27	15	53	0.0	37° 0.0'	122° 0.0'		4.5	
1937	NOV	12	2	50	0.0	37° 0.0'	122° 0.0'		4.8	
1938	FEB	12	20	0	0.0	37° 0.0'	122° 0.0'		4.5	
1939	JUL	17	9	24	0.0	37° 0.0'	122° 0.0'		4.5	
1940	MAR	2	13	27	0.0	37° 0.0'	122° 0.0'		4.0	
1941	APR	14	16	16	54.0	36°48.0'	121°48.0'		4.0	
1941	MAY	28	6	23	18.0	37° 0.0'	122° 0.0'		4.5	
1946	AUG	5	4	8	44.0	36°51.0'	121°47.0'		4.1	
1947	JUN	22	23	30	0.0	37° 0.0'	121°46.0'		4.7	
1947	NOV	15	22	30	0.0	36°47.0'	122° 7.0'		4.1	
1956	NOV	22	16	43	50.0	37° 0.0'	122° 0.0'		4.2	
1958	NOV	7	21	33	34.0	36°52.0'	121°53.0'		4.3	
1962	AUG	5	10	58	26.3	36°52.7'	122°17.5'		2.7	Bulletin of Seismographic
1962	SEP	14	8	49	49.9	36°38.4'	121°46.7'		3.0	Stations, University of
1962	SEP	17	7	16	34.3	36°35.2'	121°52.6'		2.6	California, Berkeley (1962)
1962	DEC	24	0	16	23.4	36°50.9'	121°47.4'		3.7	
1963	MAR	19	18	20	5.0	36°56.6'	121°45.5'		3.0	
1964	AUG	31	17	10	19.1	36°59.1'	121°47.0'		2.5	
1965	APR	6	30	31	59.1	36°48.0'	121°58.0'		3.3	
1965	APR	6	11	23	10.4	36°49.6'	122° 6.7'		2.5	
1966	APR	3	21	17	58.5	37° 0.0'	121°46.0'		2.6	
1966	MAY	5	15	7	10.5	36°56.0'	122°13.0'		2.5	
1966	JUN	2	13	12	20.4	36°58.0'	122°12.0'		2.9	
1966	OCT	25	20	54	42.5	36°55.8'	121°48.2'		2.9	
1967	FEB	5	7	36	23.3	36°47.5'	122° 7.4'		2.6	
1968	MAR	6	8	34	6.0	36°58.0'	122°10.0'		2.5	
1969	JAN	13	5	12	32.9	36°45.9'	122° 5.6'	5.0	2.0	Lee and others, 1972a
1969	MAY	6	7	8	43.4	36°46.0'	122° 1.4'	12.6	0.9	
1969	JUN	19	6	46	4.3	36°36.2'	121°47.6'	5.0	1.1	
1969	JUL	29	21	48	17.2	36°53.7'	122° 8.9'	11.6	1.9	
1969	OCT	14	15	1	58.6	36°45.2'	122° 2.6'	7.2	1.7	
1969	NOV	6	19	40	26.6	36°51.8'	122° 8.5'	9.7	2.6	
1970	FEB	2	19	23	17.5	36°59.0'	122°14.1'	8.7	2.2	Lee and others, 1972b
1970	FEB	27	23	21	45.6	36°46.0'	121°58.9'	5.0	2.2	
1970	APR	15	21	0	14.1	36°44.9'	121°51.5'	5.0	1.2	
1970	MAY	14	8	26	6.6	36°44.5'	122° 3.7'	10.0	1.0	
1970	AUG	4	4	14	23.4	36°45.0'	122° 3.5'	9.0	4.7	
1970	AUG	4	4	44	7.4	36°45.0'	122° 2.6'	9.2	3.0	
1970	AUG	4	4	48	53.8	36°45.8'	122° 1.8'	13.3	1.6	
1970	AUG	7	7	44	59.6	36°58.4'	122° 6.4'	5.0	1.0	
1970	AUG	7	8	15	17.1	36°59.4'	122° 7.1'	5.0	1.1	
1970	AUG	23	17	53	48.6	36°45.4'	122° 2.8'	9.6	3.7	
1970	SEP	29	10	58	32.4	36°59.3'	121°47.4'	12.6	2.0	
1970	SEP	29	11	1	28.7	36°59.4'	121°47.8'	13.2	1.3	
1970	SEP	29	11	58	33.1	36°59.4'	121°47.5'	9.8	1.3	
1970	SEP	29	22	17	2.7	36°59.2'	121°48.7'	13.7	1.0	
1970	SEP	30	13	41	56.8	36°59.3'	121°47.6'	11.9	1.3	
1970	SEP	30	18	27	3.6	36°59.6'	121°47.4'	11.7	1.3	
1970	OCT	1	8	3	51.7	36°59.3'	121°48.7'	13.9	1.2	
1970	OCT	17	8	28	41.1	36°59.1'	121°48.0'	12.8	1.6	
1070	DEC	4	0	14	46.1	36°49.6	122° 7.0'	10.0	1.1	
1971	JAN	15	1	3	55.6	36°46.5'	122° 1.8'	10.0	1.3	Lee and others, 1972c
1971	MAR	3	0	41	38.8	36°51.9'	121°56.3'	11.1	1.1	
1971	MAR	8	9	10	18.9	36°48.5'	122° 6.4'	8.5	2.3	
1971	MAR	8	18	31	46.5	36°48.1'	122° 7.2'	8.6	4.1	
1971	MAR	9	15	35	16.3	36°48.4'	122° 7.5'	9.0	4.4	
1971	MAR	9	23	7	0.6	36°48.1'	122° 5.8'	10.0	1.4	
1971	MAR	10	4	31	22.0	36°48.8'	122° 7.2'	9.2	1.9	
1971	MAR	10	9	15	42.8	36°47.9'	122° 7.1'	0.4	2.6	
1971	MAR	11	12	12	17.8	36°48.3'	122° 7.0'	9.3	1.8	
1971	MAR	11	16	33	37.8	36°48.2'	122° 7.2'	9.8	1.6	
1971	MAR	26	1	2	40.1	36°48.4'	122° 6.4'	8.2	2.3	
1971	MAR	26	1	41	18.8	36°48.5'	122° 6.4'	9.3	2.0	
1971	APR	16	12	58	32.2	36°49.2'	122° 6.6'	8.2	4.4	
1971	APR	16	14	11	18.7	36°49.4'	122° 6.7'	10.0	1.8	
1971	APR	16	16	15	50.5	36°49.4'	122° 6.4'	7.2	1.2	
1971	APR	16	16	19	33.3	36°49.1	122° 6.6'	9.3	1.8	
1971	MAY	21	20	10	30.0	36°59.4'	121°47.4'	13.4	1.7	
1971	MAY	28	8	57	33.2	36°47.8'	122° 6.1'	8.2	1.8	
1971	JUL	13	14	17	31.9	36°41.9'	121°47.8'	12.9	1.2	
1971	SEP	18	0	28	52.9	36°36.1'	121°56.9'	3.0	1.0	
1972	APR	30	12	43	26.0	36°40.3'	122° 0.2'	5.2	2.1	Wesson and others, 1973
1972	JUN	29	15	0	4.8	36°33.4'	121°50.6'	7.5	1.6	
1972	JUL	5	18	54	56.2	36°32.2'	121°56.7'	2.1	1.0	Wesson, written comm.,
1972	JUL	0	22	16	47.5	36°58.2'	122°13.2'	10.0	1.5	1973 (preliminary
1972	AUG	26	2	53	27.1	36°46.0'	121°48.7'	8.9	1.5	locations)
1972	SEP	19	20	10	31.3	36°59.9'	122°13.8'	8.3	1.8	

Table 4.--Preliminary locations of earthquakes in the Monterey Bay area (within lat 36°15'N to 37°15'N and long 121°15'W to 122°30'W not including those epicenters associated with the San Andreas fault system), September 20, 1972 through May, 1976.

Origin Time (Greenwich Mean Time)										
Year	Month	Day	Hour	Minute	Second	Latitude (N)	Longitude (W)	Focal Depth (Km)	Magnitude	Reference
1972	SEP	23	05	03	0.5	36-29.2	121-30.6	6.7	1.3	Wesson and others, 1973
1972	OCT	22	20	12	54.3	36-29.1	121-30.3	3.6	1.2	Wesson and others, 1974a
	NOV	20	16	31	56.6	37- 8.1	122-21.7	7.0	1.4	
	DEC	14	19	20	53.0	36-49.5	121-57.3	12.8	1.5	
		29	09	44	42.1	36-47.4	122- 5.6	9.6	2.2	
1973	JAN	04	05	13	17.4	36-22.5	121-51.7	9.3	1.4	Wesson and others, 1974b
		14	17	18	54.4	36-28.2	121-38.0	9.9	1.2	
		21	20	04	44.7	36-37.8	121-55.1	8.1	1.7	
	FEB	27	12	26	46.6	36-48.0	122- 6.5	8.4	2.5	
	MAR	21	00	01	6.9	36-27.3	121-29.5	6.9	2.1	
	APR	11	19	55	21.7	36-26.9	121-30.0	4.6	0.7	Bufe and others, 1975
	MAY	17	19	38	5.0	36-18.3	121-24.8	3.2	1.4	
	JUN	22	07	41	39.4	36-15.4	121-29.0	1.1	1.3	
		22	08	26	35.4	36-16.2	121-29.0	3.1	1.9	
	JUL	04	16	22	38.3	36-52.8	121-51.3	6.3	1.6	
		28	18	43	59.3	37- 3.8	121-55.9	4.1	1.5	
	AUG	05	17	57	54.8	36-16.9	121-32.1	9.5	1.6	Bufe and others, 1976
		06	17	16	30.6	36-22.5	121-52.4	12.5	1.4	
	SEP	17	02	45	59.4	36-55.5	122-10.8	5.8	0.9	
	OCT	04	23	55	29.5	36-57.3	121-59.9	0.2	1.0	
		22	04	58	3.6	37- 2.7	121-52.6	15.4	0.8	
	DEC	07	23	54	56.3	36-45.6	121-35.4	2.3	2.4	
		29	20	39	56.9	36-21.0	121-53.8	9.2	1.4	
1974	JAN	11	05	29	42.2	37-10.4	122- 6.9	3.8	1.2	
		28	10	10	12.0	36-21.0	121-53.4	10.8	1.7	
		29	02	29	22.7	36-49.6	121-58.0	14.8	1.5	
		29	14	18	41.3	36-28.9	121-49.1	10.9	1.0	
	FEB	07	09	48	24.1	37- 0.1	121-50.3	13.4	0.6	
		16	07	31	59.9	36-59.8	121-49.9	12.2	1.3	
		18	05	12	31.5	36-29.4	121-27.6	9.6	1.4	
	MAR	18	05	49	4.3	36-43.1	122- 2.8	6.0	1.4	
		18	18	43	50.8	36-19.7	121-49.1	9.3	2.3	
		24	01	37	15.1	37- 8.0	122-18.4	11.2	2.9	
	MAY	01	11	17	30.3	37-11.2	122-25.3	8.0	1.8	
		03	18	30	12.5	36-17.5	121-25.7	5.0	1.9	
		13	16	46	30.3	37- 7.6	172-18.6	11.8	1.5	
		23	02	26	17.3	36-15.5	121-51.8	8.6	1.4	
	JUN	13	18	27	41.6	36-28.8	121-48.9	8.8	1.6	
	AUG	29	21	10	31.5	36-20.4	121-53.8	12.5	1.5	
	SEP	21	00	02	54.0	36-27.3	121-38.9	11.9	1.0	
		23	11	10	27.4	36-21.5	121-53.3	12.4	1.6	
		24	10	44	17.8	36-21.8	121-52.8	12.3	1.1	
	OCT	20	07	48	31.7	36-29.6	121-48.5	10.5	1.7	
	DEC	10	23	16	48.3	37- 2.8	122- 8.1	0.3	1.7	
		30	16	28	16.6	36-34.4	121-54.4	7.8	2.4	
1975	JAN	10	10	42	46.5	36-16.0	121-42.1	9.0	2.0	
		10	11	06	13.5	36-15.9	121-42.5	11.0	1.9	
	FEB	18	23	16	6.3	37- 0.9	122- 8.6	4.6	1.1	
	MAY	04	06	53	17.6	36-17.9	121-25.7	6.7	2.0	
		07	12	15	9.5	37- 5.1	122-15.9	11.3	2.3	
	JUN	20	18	33	35.0	36-36.4	121-53.9	3.3	1.7	
		28	05	55	3.1	36-42.2	122- 2.5	7.8	1.9	
		28	06	00	43.2	36-43.1	122- 0.9	5.6	1.3	
	JUL	01	05	15	1.8	36-19.3	121-24.2	2.8	2.0	
	AUG	07	04	52	36.3	36-37.1	121-54.7	8.5	1.6	
		20	16	18	18.7	36-21.3	121-50.7	0.3	1.7	
	SEP	10	11	18	32.3	37- 5.2	122-20.6	7.5	1.7	
		13	15	14	52.9	37- 0.3	121-53.3	9.0	1.0	
		26	22	15	5.8	37- 2.0	122- 8.4	4.4	1.7	
	OCT	13	13	11	57.3	36-30.6	121-50.2	7.7	1.3	
		21	16	58	13.9	36-30.7	121-49.2	8.6	1.7	
	NOV	27	00	01	34.6	36-44.6	121-36.3	5.1	2.1	
		27	03	42	28.3	36-43.0	122- 4.6	6.9	2.2	
	DEC	05	12	14	17.2	36-42.8	122- 4.7	11.6	1.5	
		19	19	24	44.7	36-34.2	121-57.2	7.4	1.8	
		20	01	01	59.9	36-34.1	121-56.8	1.0	2.0	
		20	05	09	33.3	36-34.3	121-57.8	3.3	1.8	
		27	10	32	2.3	36-50.9	122- 7.8	6.8	1.8	
		28	08	33	2.4	36-50.8	122- 8.3	8.6	2.8	
1976	JAN	04	19	16	39.9	36-34.6	121-55.4	4.7	2.0	
		07	06	58	17.5	36-34.3	121-55.2	4.6	1.8	
		10	21	55	5.0	36-34.1	121-55.8	5.1	2.1	
		10	21	58	50.9	36-34.2	121-56.7	6.3	1.8	
		11	08	21	53.3	36-34.2	121-55.8	5.5	1.8	
		11	18	36	51.9	36-34.1	121-55.9	5.7	2.5	
		12	15	41	35.0	36-44.9	121-28.9	7.1	1.2	
		12	16	09	13.9	36-34.3	121-55.4	5.2	2.2	
		12	18	56	58.4	36-34.2	121-56.6	5.9	1.7	
		13	03	12	9.7	36-34.3	121-56.2	5.3	1.6	
		13	21	29	44.3	36-34.0	121-55.5	4.9	2.0	
		13	21	40	35.1	36-34.0	121-55.7	4.2	1.3	
		14	00	16	50.0	36-34.1	121-55.6	5.3	2.3	
		14	00	18	18.4	36-34.1	121-55.5	6.0	1.8	
		14	23	23	24.4	36-34.2	121-56.0	6.3	1.8	
		16	00	28	14.5	36-34.2	121-56.7	5.7	1.7	
		16	00	31	0.2	36-34.3	121-56.3	5.5	1.5	
		19	13	54	21.9	36-34.1	121-56.1	5.6	1.8	
		22	00	00	24.1	36-44.9	121-36.3	3.7	2.7	
		31	22	25	1.5	36-59.5	121-56.8	12.5	1.4	
	MAR	22	01	15	21.8	36-42.4	122- 4.3	7.4	2.0	
	APR	12	17	38	43.1	36-25.7	121-26.2	4.1	1.3	
	MAY	17	20	18	30.0	36-17.1	121-27.3	7.2	2.1	
		25	22	15	49.1	37- 1.7	122- 8.9	6.0	2.1	
		27	12	38	16.0	36-18.5	121-24.2	5.2	1.8	
		30	20	59	28.2	36-18.1	121-27.1	3.7	2.2	
	JUN	01	10	44	24.7	36-18.2	121-26.9	1.0	1.5	

since 1972 has been fairly uniform in frequency with 18 events occurring in 1973, 22 in 1974, and 24 in 1975. The number of small earthquakes reported has increased greatly as a result of improvements in the methods of detection. This trend is evident in Tables 3 and 4; two earthquakes of magnitude 4 or greater were reported between 1934 and 1961, 14 earthquakes of magnitude 2.5 or greater were reported from 1962 through 1968, 45 earthquakes of magnitude 0.9 or greater were reported from 1969 through 1971, six earthquakes of magnitude 1.0 or greater were reported from 1971 through November 1972, and 89 earthquakes of 0.9 or greater were reported from 1972 through June, 1976.

The location and frequency of epicenters indicate where and how often faulting occurs. In addition, fault-plane solutions from seismic records can reveal the direction of movement on some faults. Many epicenters in the Monterey Bay area lie within discrete zones associated with faults, whereas others are more widely dispersed. The greatest concentration is along the San Andreas fault. Here, the more recent epicenters (solid circles on Pl. 6) are closer to the fault than are those located before 1969. This apparent difference in distribution may result from recent refinements in the accuracy with which epicenters can be located. Epicenters also are concentrated in two groups in central Monterey Bay. One group is located at the northwest end of the Monterey Bay fault zone, where it abuts the Palo Colorado-San Gregorio fault zone; the other is a linear zone that trends northwestward along the Palo Colorado-San Gregorio fault zone. A small group of epicenters is also present to the south, where the Palo Colorado-San Gregorio fault zone extends on land.

Three discrete groups of epicenters are present onshore in the southeastern part of the area (Pl. 6). One group of 15 epicenters (magnitude

0.7 to 4.5) lies at the junction of the Salinas Valley and the northeast edge of the Santa Lucia range, a few kilometers southwest of Gonzales, and is possibly related to the King City fault. A short distance to the north is a second, smaller group of eight epicenters (magnitude 1.15 to 2.39) of earthquakes that occurred in 1972; these also may be associated with movement along the King City fault. Fifteen epicenters (magnitude 1.0 to 3.5) located in the vicinity of Basin Creek may be related to movement along faults mapped by Durham (1970) between Bruce Ranch and the Reliz fault.

Eleven earthquakes (magnitude 1.1 to 2.3) have occurred on land between the Palo Colorado and Sur Thrust faults since September 20, 1972. Thirty-two events (magnitude 1.0-2.6) have occurred within the onshore extension of the Monterey Bay fault zone. Nineteen of these events (magnitude 1.3 to 2.5) are clustered just north of Carmel Bay, near the Cypress Point fault, and four events (all greater than magnitude 1.5) are located near the trace of the Navy fault.

Earthquake epicenters generally are scattered in the northwestern onshore area and most appear to be associated with the San Andreas fault. However, earthquakes that have occurred in a narrow (2 km wide) northwest-trending zone located west of the San Andreas fault between San Juan Bautista and Redwood Estates may be related to movement along the Vergeles, Zayante, and Butano faults.

Three earthquakes (magnitude 1.5 to 2.5) occurred on the southwest side of the Gabilan Range near the base of Sugarloaf Mountain in October and November, 1972. Eleven earthquakes have occurred in Happy Valley, just north of Capitola, ten (magnitude 4.0 to 4.5) between 1934 and 1956, and one (magnitude 1.6) in 1969.

Epicenters in the Monterey Bay fault zone are clustered just north of Monterey Canyon. These earthquakes, three of which occurred in August, 1970, ranged in magnitude from 0.9 to 4.7. Six events (magnitude 1.3 to 2.2) have occurred since September 20, 1972 within the meander of Monterey Canyon. Seismic records have been analyzed to determine the direction of movement of the rocks on either side of the fault during these earthquakes (Greene and others, 1977). If the movement is toward a seismograph, the first motion of seismic waves is directed upward (indicating the ground is undergoing compression); if away, it is directed downward (indicating the ground is undergoing dilatation). Knowing the location of the hypocenter and the direction of first motion that reaches several seismographs, it is possible to define two quadrants of compression and two of dilatation. However, this kind of analysis produces two possible planes along which the fault displacement might have occurred, and these planes lie at right angles to each other.

Analyses of the higher magnitude events within the cluster of eight epicenters in the Monterey Bay fault zone (epicenters 6 to 8, Pl. 6) indicate that the fault planes are nearly vertical and that strike-slip movement has occurred along a fault or faults trending northeast or northwest. Reflection profiles contain evidence of northwest-trending faults, but none showing a northeast trend. Consequently, the first motion studies are interpreted as indicating that right-lateral strike-slip is occurring on northwest-trending faults in this area.

The two large earthquakes (magnitude 6.1) that occurred in 1926 also have been located within the Monterey Bay fault zone by Richter (1958). However, the locations of these epicenters probably are not known with sufficient accuracy for certain assignment to a specific fault zone.

Most faults in the Monterey Bay fault zone displace late Tertiary and Pleistocene sediments. North of Monterey Canyon, faults extend to within 6 m of the ocean floor; most displace late Pliocene strata, some displace Pleistocene deposits, and a few may displace Holocene deposits. South of Monterey Canyon, most faults close to shore near Monterey also extend to within 6 m of the ocean floor and cut Pleistocene deposits. Some cut Holocene deposits as well. Farther offshore in southern Monterey Bay, faults appear to be older because they displace upper Tertiary and older strata and are covered by about 100 m of Quaternary sediment. A few faults cut only Cretaceous granites and strata of lower to middle Tertiary age.

Scarps are associated with seven faults in the Monterey Bay fault zone (Pl. 6); three of these are located on the southwest margin of the zone, two are on the shelf flanking the head of Soquel Canyon, one is just offshore from the town of Seaside, and one is on the shelf near the meander in Monterey Canyon. Five of these scarps face landward, and the lithology of the sea floor on both sides of the scarps appears to be the same. Consequently, these are not wave-cut scarps associated with a lower stand of sea level, nor are they likely to have been formed by differential erosion.

A cluster of 16 epicenters in the Palo Colorado-San Gregorio fault zone represents earthquakes ranging in magnitude from 1.0 to 4.4 (Pl. 6). Three of these (magnitude 4.1 to 4.4) occurred during the spring of 1971. Fault-plane solutions for five earthquakes since 1969 (inset on Pl. 6) indicate that fault planes are nearly vertical and that motion is predominantly right-lateral strike-slip. Solutions for four of these earthquakes indicate a trend of approximately N20°W, parallel to the Palo Colorado-San Gregorio fault zone. The solution for the fifth earthquake indicates a trend parallel to the strike of the Monterey Bay fault zone (N60°W $\pm$ 10°), suggesting that a spatial tie exists between the two fault zones.

Twenty-two additional epicenters lie in or near the Palo Colorado-San Gregorio fault zone offshore or cluster along its on-land extension, the San Gregorio fault. These earthquakes range in magnitude from 0.9 to 2.3; two occurred in July and September, 1972 and the remainder have occurred between September 1972 and June 1976.

The two faults located south of Año Nuevo Point appear in seismic reflection profiles to extend to within 6 m or less of the ocean floor (Pls. 5 and 8, Sections A-A', B-B' and C-C'). These faults cut latest Tertiary strata and probably cut Holocene deposits as well. The easternmost of these two faults coincides with a topographic break in the ocean floor separating flat-lying young sediment on the west from higher-standing bedrock on the east. This topographic break might result partly from recent fault displacement.

The Palo Colorado-San Gregorio fault zone southeast of Monterey Canyon has been quiet seismically throughout the period of record, but there is no reason to think that it will remain so. Indeed, the segment of the San Andreas fault that generated the 1906 San Francisco earthquake is also quiet seismically, although most agree that it will probably generate another large earthquake.

Two epicenters are located off Kasler Point and several others are located on the Palo Colorado fault on land near Rocky Point. The location accuracy of these epicenters is not adequate to permit a tie to a specific fault. However, geologic evidence exists for relatively recent fault displacement in this area. The sea floor scarp on the Palo Colorado-San Gregorio fault zone just north of Kasler Point can be followed for 5 km, and cuts Holocene deposits. In addition, a sheared zone in the coastal terrace between Rocky Point and Kasler Point contains many faults that appear to extend into deposits of probable Pleistocene age. Some of these faults offset an elevated Pleistocene wave-cut platform and may displace the overlying Holocene alluvial deposits as well.

Faults on the Cypress Point-Point Sur shelf differ in age. The faults seaward of Hurricane Point, including the offshore projection of Sur fault, extend to within 50 m of the ocean floor and cut late Tertiary strata (Pl. 6). They appear to be covered with unfaulted Quaternary sediments. Two faults on the shelf northwest of Hurricane Point appear from seismic reflection profiles to extend to within 6 m of the ocean floor, and locally cut Holocene deposits. The southern part of the probable offshore extension of the Serra Hill fault cuts late Pleistocene and possibly Holocene deposits.

Estimates of Earthquake Magnitude

Estimation of the potential magnitudes of earthquakes on nearby faults is necessary to anticipate the seismic forces to which man-made structures in the area might be subjected. Presently there is no completely satisfactory method for making such a prediction. One widely used technique involves comparison of the length of surface breakage on faults with the magnitudes of their associated earthquakes (Tocher, 1958; Iida, 1965; Albee and Smith, 1967; Bonilla, 1967; Bonilla and Buchanan, 1970).

Estimating the possible magnitude of a large earthquake using this empirical relationship necessitates making an assumption as to the length of fault that might rupture in a single event. Wentworth and others (1972) assumed a rupture length equal to half the mapped length of the fault in their estimates of the magnitudes of earthquakes that might occur on several faults in California, arguing that rupture is not likely to involve the entire length of a fault. After comparing fault length and fault rupture length for data from southern California (Allen and others, 1965) and considering evidence presented by Bonilla (1967) and original literature that indicates surface rupture length for ten historic North American events in which 2% to 75% of the fault length ruptured, they suggested that the half length be used but cautioned that it must be considered only approximate at best.

Application of this empirical relationship to the Palo Colorado-San Gregorio fault zone also necessitates defining the fault length. The fault is here considered to be a continuous zone approximately 135 km long. It may extend farther to the north and join the Seal Cove fault at Half Moon Bay (D. S. McCulloch, oral commun., 1975). An extension of the Seal Cove fault, in turn, has been shown to join the San Andreas fault zone at Bolinas (Cooper, 1971). Consequently, half lengths of 65 km and 100 km are used in calculating the estimates of magnitude listed in Table 3.

An earthquake of greater magnitude than that indicated in Table 5 is possible for the Palo Colorado-San Gregorio fault zones for several reasons: (1) the magnitudes listed in Table 5 are derived from least squares approximations (that is, some earthquakes have larger and smaller magnitudes for a given rupture length); (2) the rupture length might exceed half the mapped length; and (3) the Palo Colorado-San Gregorio fault zone might extend farther south than is shown on the map. The latter possibility also has been suggested by Greene and others (1973), Ross (1976), Graham (1976), and Silver (1977).

A rough estimate of maximum earthquake magnitude on the Palo Colorado-San Gregorio fault zone also can be made by comparing it with the nearby

Table 5. Estimates of earthquake magnitude for the Palo Colorado-San Gregorio fault zone

	Estimated magnitude					
Fault half length (km)	1. Tocher (1958)	2. Iida (1965)	3. Albee and Smith (1967)	4. Bonilla (1967)	5. Bonilla and Buchanan (1970)	Average
65	7.2	7.4	7.6	7.6	7.4	7.4
100	7.4	7.6	7.8	7.8	7.9	7.7

Magnitudes were established as follows:

1. M = 0.9 X log surface rupture length (L) in km + 5.6

2. M = 0.76 (log L km) + 6.07

3. Least-squares fit of M vs L for California, Nevada and Baja California earthquakes on Albee and Smith's Fig. 4

4. M = 1.51 (log L miles) + 5.14

5. Read from graph of M vs L for earthquakes worldwide on strike-slip faults

Hayward fault. These faults are similar in many aspects. Both faults are long; the Hayward fault is 160 km long, including on-trend strands of the active Rodgers Creek and Healdsburg faults (Brown, 1970), and the Palo Colorado-San Gregorio fault zone is 250 km long. Both faults exhibit right-lateral, strike-slip displacement and have earthquake hypocentera at approximately the same depth. Finally, both the Hayward and the Palo Colorado-San Gregorio faults join the San Andreas fault and are part of that fault system. Consequently, they both respond to stresses causing earthquakes on the San Andreas fault. The Hayward fault, which has been called an "active branch" of the San Andreas fault (Richter, 1958, p. 476), undergoes tectonic creep (Radbruch and others, 1966) and has a long history of seismic activity. The Palo Colorado-San Gregorio fault zone also appears to respond to stress along the San Andreas fault; a sequence of small earthquakes and creep on the San Andreas fault near Pinnacles National Monument began with a tremor of magnitude 2.6 (July 22, 1970) near San Juan Bautista, and ended with an earthquake of magnitude 4.3 (August 3, 1970) in Monterey Bay.

Two major earthquakes have occurred on the Hayward fault during historic time, in 1836 and 1868. Direct measurement of earthquake magnitude was not possible at that time, but the damage caused by these earthquakes indicates that they were large. Lawson (1908, p. 434) notes that the 1868 earthquake was regarded by observers as equal to the 1906 earthquake in severity. Steinbrugge (1968, p. 73-74) summarizes the Hayward earthquakes as follows:

> 1836 June 10, 7:30 A.M. One of the five largest earthquakes centered in the San Francisco Bay region in historic times. Ground breakage along the line of the Hayward fault at the base of the hills east of the bay, extending from Mission San Jose to San Pablo. As strong or stronger than the shock of October 21, 1868, which had its

center along the same fault. At least one fore-shock; numerous aftershocks for at least a month. 1868 October 21, 7:53 A.M. One of California's great shocks, and second of the two large Bay Area shocks of the 1860's. Surface breakage was observed on the Hayward fault from Warm Springs to San Leandro, a distance of about 20 miles. The maximum horizontal offset was about 3 feet. Intensity X at Hayward, where every building was damaged, and many demolished. Intensity IX at San Francisco, where, as in earlier large shocks, damage was chiefly confined to buildings on filled ground along the bayshore. About 30 persons lost their lives in this shock. This earthquake was felt at places 175 miles from the source.

Slemmons (1967) has assigned magnitudes of 7 ± 0.5 to these two earthquakes. This is in agreement with estimated magnitudes shown in Table 5. If the analogy between the Hayward and the Palo Colorado-San Gregorio faults is valid, then the latter fault zone is capable of producing major earthquakes.

Summary

1. Two major fault zones are present in the offshore Monterey Bay area. The longer of these, the Palo Colorado-San Gregorio fault zone, is a narrow, northwest-trending zone that joins the Palo Colorado fault (and possibly the Serra Hill and Sur faults) south of Monterey with the San Gregorio fault zone to the north near Año Nuevo Point. The Monterey Bay fault zone is on trend with the Salinas Valley, faults in the Salinas Valley, and the Sierra de Salinas. It comprises a wide belt of faults crossing the floor of Monterey Bay and the Monterey submarine canyon; this zone closely approaches, but does not appear to cross, the Palo Colorado-San Gregorio fault zone.
2. New detailed geophysical data (continuous subbottom acoustic profiles) are interpreted as indicating that these fault zones have had a long history. Evidence of fairly recent movement is seen in the displacement of young sediment and the presence of scarps associated with some faults on the modern sea floor.

3. Both fault zones are active seismically, as indicated by associated earthquake epicenters.
4. Fault-plane solutions of eight recent earthquakes in these fault zones indicate that the sense of fault displacement is similar to that on the San Andreas fault. Movements along these nearly vertical faults have been horizontal (strike-slip), with rocks on the seaward side displaced relatively northward.
5. These fault zones are near areas of population growth. Consequently, estimates of the largest earthquake that might be produced by the longer of the two zones, the Palo Colorado-San Gregorio fault zone, is useful for regional planning. The empirical relationship between fault rupture length and magnitude of associated earthquakes on other faults suggests that an earthquake of magnitude 7.2 to 7.9 could occur on the Palo Colorado-San Gregorio fault zone. Magnitudes of historical earthquakes on the Hayward fault in the east San Francisco Bay area and similarities between the Hayward and Palo Colorado-San Gregorio fault zones support the conclusion that the Palo Colorado-San Gregorio fault zone is capable of producing large earthquakes (estimated magnitude 7 $\pm$ 0.5).

Folds

Bedding of Tertiary sedimentary rocks is generally flat-lying or homoclinal in the Monterey Bay region. The most complex structures occur in the Monterey Bay fault zone, where Tertiary rocks have been severely contorted and compressed into tight synclinal and anticlinal folds (see profiles S and T, App. III).

East of Palo Colorado Fault Zone

Anticlines and synclines in the Monterey Bay fault and fold belt are short and have orientations that appear to range from about N70°W to N80°W (Pl. 3). These orientations are largely inferred, as many folds cannot be correlated from one seismic trackline to another. Major folds near shore, in the Monterey bight area, have orientations that parallel faulting (N50°W); some folds extend onshore and join folds mapped in the subsurface by Clark and others (1974). These folds probably have been formed, or are being formed at present, by compressional forces associated with strike-slip along faults within the Monterey Bay fault zone.

Folding and shearing within the northern part of the Palo Colorado-San Gregorio fault zone have severely distorted the sedimentary strata between the two major faults of the zone. Most folds within this zone have flank dips greater than 35 degrees.

The only other folded structures east of the Palo Colorado-San Gregorio fault zone are located in northern Monterey Bay. Five short, discontinuous folds in gently dipping strata of the Pliocene Purisima Formation are located between the head of Soquel Canyon and the Capitola-Aptos coastline (Pl. 3). In addition, several discontinuous folds occur in Miocene marine strata and late Tertiary to Quaternary deltaic deposits offshore from Santa Cruz. These structures are oriented approximately N80°W.

West of the Palo Colorado-San Gregorio Fault Zone

West of the Palo Colorado-San Gregorio fault zone, Tertiary sedimentary rocks are strongly folded along the northwest part of the Point Sur shelf and slope, between faults fanning outward from the shelf (Pl. 3). Orientation of these folds ranges from east-west to about N80°W. These folds appear to be the result of motion along nearby faults, and are limited in occurrence to areas of shallow basement. In addition, a faulted syncline has been mapped in the area between Monterey Canyon and the Point Sur shelf. The only other significant fold in this area is a large syncline, apparently depositional in origin, located on the slope between Monterey and Ascension Canyon (Pl. 3).

Sedimentary Basins and Basement Ridges

No significant sedimentary basins are present within Monterey Bay proper. A relatively flat-topped granitic basement complex supports a late Tertiary sedimentary cover of less than 1,000 m (Pl. 9). A subtle basement ridge, the Monterey high, trends northward from the Monterey Peninsula to the Soquel-Aptos area and probably limits the seaward extension of the on-land Salinas basin. The sedimentary section within the Salinas basin presumably thins northwestward and laps out onto the Monterey high.

A major sedimentary basin seaward of Monterey Bay is described by Hoskins and Griffiths (1971, p. 261) as follows:

> The outer Santa Cruz basin extends northwest from Monterey for 80 miles (130 km) to about $37^{\circ}30'$N lat., where it appears to merge with the continental slope. It is a shallow, post-Miocene syncline which encompasses approximately 1,400 sq. mi. (3,630 sq. km) of Miocene and younger marine beds.

The authors note that the basin axis plunges continuously toward the northwest and that structural trends within the basin generally parallel this axis. They conclude that the basement is granite, although basement rocks do not crop out on either of the basement ridges (Pigeon Point and Santa Cruz highs) that bound the basin to the northeast and southwest.

The extreme southeast end of the outer Santa Cruz basin of Hoskins and Griffiths (1971) appears as a synclinal sedimentary basin on deep penetration seismic profiles collected along the continental slope between Ascension and Monterey Canyons (Pl. 3; Profiles A-A' and I-I', Pl. 9). Tertiary sediments have an aggregate thickness of more than 2,000 m in this basin. This sedimentary sequence thins abruptly to the south and west where the rocks lap onto a basement ridge, here termed the Point Sur high. A south-plunging, arcuate basement dome forms the east boundary of the basin (Fig. 15).

The Point Sur high is a northwest-plunging basement ridge that appears to be the buried seaward extension of the Point Sur platform. This ridge extends offshore for more than 60 km and appears to die out beneath Monterey Canyon (Pls. 3 and 4; Fig. 15). A small synclinal sedimentary basin extends an unknown distance southward from the unnamed seaknoll on the slope due west of Point Sur.

Submarine Landslides and Slumps

Many submarine landslides and slumps have been identified from the seismic profiles, most within Monterey Canyon. The topographic profiles of these features vary from intact, downdropped, backward-rotated blocks with hummocky toes, to hummocky masses of sediment at the base of steep canyon walls (Fig. 32).

One slump appears to be in an embryonic stage of formation and has been mapped as an "incipient slump" (Pl. 3; Fig. 32). Displacement near the head of this slump is slight, and surficial sediments are gently wrinkled downslope, perhaps indicating the development of the toe. Another slump has two distinct scarps and appears to consist of a slump within a slump (Pl. 3; Fig. 32). Both slumps have flat tops, but only the lower one has a well defined, hummocky toe.

All submarine landslides and slumps, with the exception of the incipient slump, have well developed headward scarps that are easily identified in the seismic profiles. Several of these features are more than 4 km wide, and they have an average area of more than 8 sq. km. The largest slumps are located in the lower part of Monterey Canyon, where it bends 90° to the south along the Palo Colorado-San Gregorio fault zone. These slumps collectively cover an area of about 19.5 sq. km. If this volume of slumped material were displaced rapidly, as during an earthquake, it could generate a sizeable tsunami--one that might affect the surrounding lowland areas. Direct (submersible) observation of the sea floor near sites of suspected undersea slumping,about one month after moderate earthquakes (magnitude 3.0-4.7) centered in this area,revealed no indication of active slumping or submarine sliding. Moreover, small scale disruptions attributable to internal mass movement, e.g. cracks and scarps, were not evident on the sea floor. However, due to the restricted visibility and limited extent of the submersible traverses, it is not possible to state with certainty that sea floor mass movement did not accompany these earthquakes.

Slumps and slides along the north wall of Monterey Canyon appear to originate in buried Quaternary channel or canyon fill, and probably were facilitated by the lack of consolidation and unstable nature of these deposits. Slumps and slides along the central and seaward parts of the north wall of the canyon probably contain material displaced from outcrops of the Pliocene Purisima Formation, the Pleistocene Aromas Sand, and the Quaternary deposits overlying these units. Along the landward parts of the south wall of Monterey Canyon, slumps and slides originate in semiconsolidated to unconsolidated Quaternary sediments of the Paso Robles-Aromas Sand unit and in Holocene deltaic deposits. Slumps along the seaward and central parts of the south wall cut into strata of the Purisima and Monterey formations.

The large amount of modern slumping observed in Monterey Canyon suggests that undercutting and canyon wall erosion initiated in Pleistocene time may still be active today. Although complete damming of Monterey Canyon by slumps is not apparent on any seismic profiles, some profiles indicate that the toes of some slumps extend across the canyon axis. The toes of some of these slumps are cut by V-shaped channels, suggesting very recent erosion (Fig. 22). Observations made during a recent submersible dive in the headward part of Monterey Canyon suggest that a slump may have blocked the down-canyon flow of sediment in this area. A previously uncharted basin was observed near the head of the canyon during the dive. The origin of this basin is uncertain, but may result from blocking of the canyon axis by slides into the canyon. If so, these slides would mark the end of active sand transport through the canyon from sources at its head. Shallow cores taken in the canyon axis seaward of this basin lack sand (see description of core MC-1, App. II), and bedforms suggestive of bed load transport were not observed farther down-canyon during the dive.

A large buried stream channel was identified on the shelf immediately north of Monterey Canyon (Pl. 3). This channel parallels the canyon axis, is about 230 m deep and 2 km wide, and is buried beneath 52 m of Quaternary sediment. Thin, flat-lying, fluvial (?) deposits appear to rest on the channel floor and are overlain by eolian Aromas Sand. Parts of this channel and its fill are exposed along the landward part of the north wall of Monterey Canyon.

Several additional short, discontinuous, buried channels are apparent on the seismic profiles. However, none of these are large or extensive.

These short, discontinuous channels may represent parts of meandering streams on an ancient flood plain, whereas the larger channel may represent a former course of the Salinas River cut during a low stand of sea level. Many of the smaller channels appear to be filled with Aromas Sand.

MAGNETICS

General Discussion

Magnetic data collected in Monterey Bay consist of magnetic values recorded continuously along most of the geophysical tracklines (Fig. 36). Data recorded on an analog strip chart were digitized by hand and were corrected by computer for the effect of the regional field (IGRF); magnetic residual values were obtained by subtracting IGRF values from observed values. No corrections were made for diurnal variation or magnetic storms. Cursory observations of base station data indicate no magnetic storms during the time of the survey. Because the offshore magnetic data were collected between 0800 and 1800 hours each day and the changes in magnetic values for the Monterey Bay region during these times were small, the application of these corrections would not significantly alter the results. A total intensity residual magnetic anomaly map was constructed from the corrected residual data (Fig. 37).

Interpretation of Magnetic Profiles

The total intensity residual magnetic map shows a magnetic trend that generally parallels the northwest-southeast structural grain of the region. Magnetic high and low anomalies are arbitrarily picked where closures of isogammas are above -110 and below -200 residual intensity values, respectively.

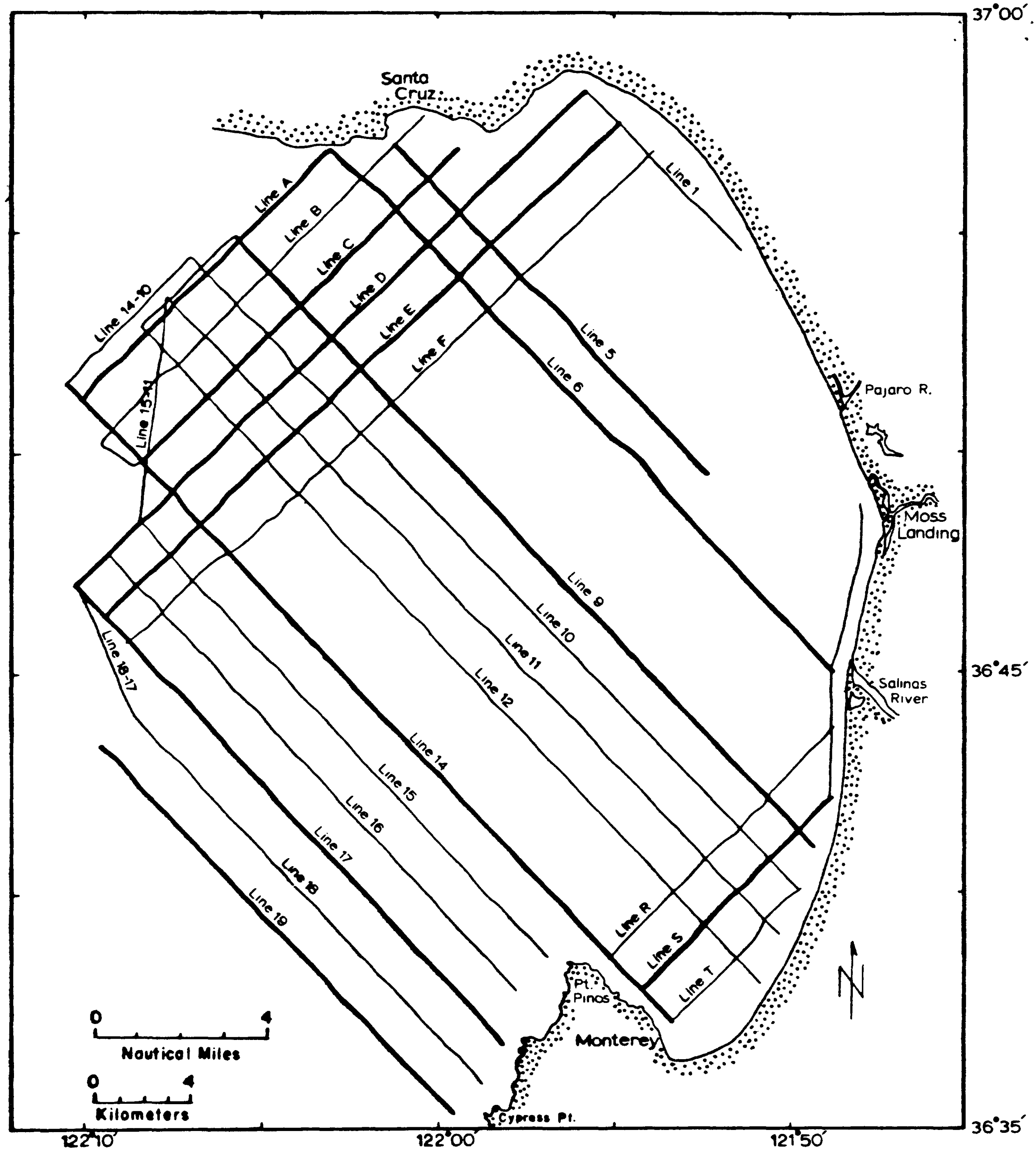
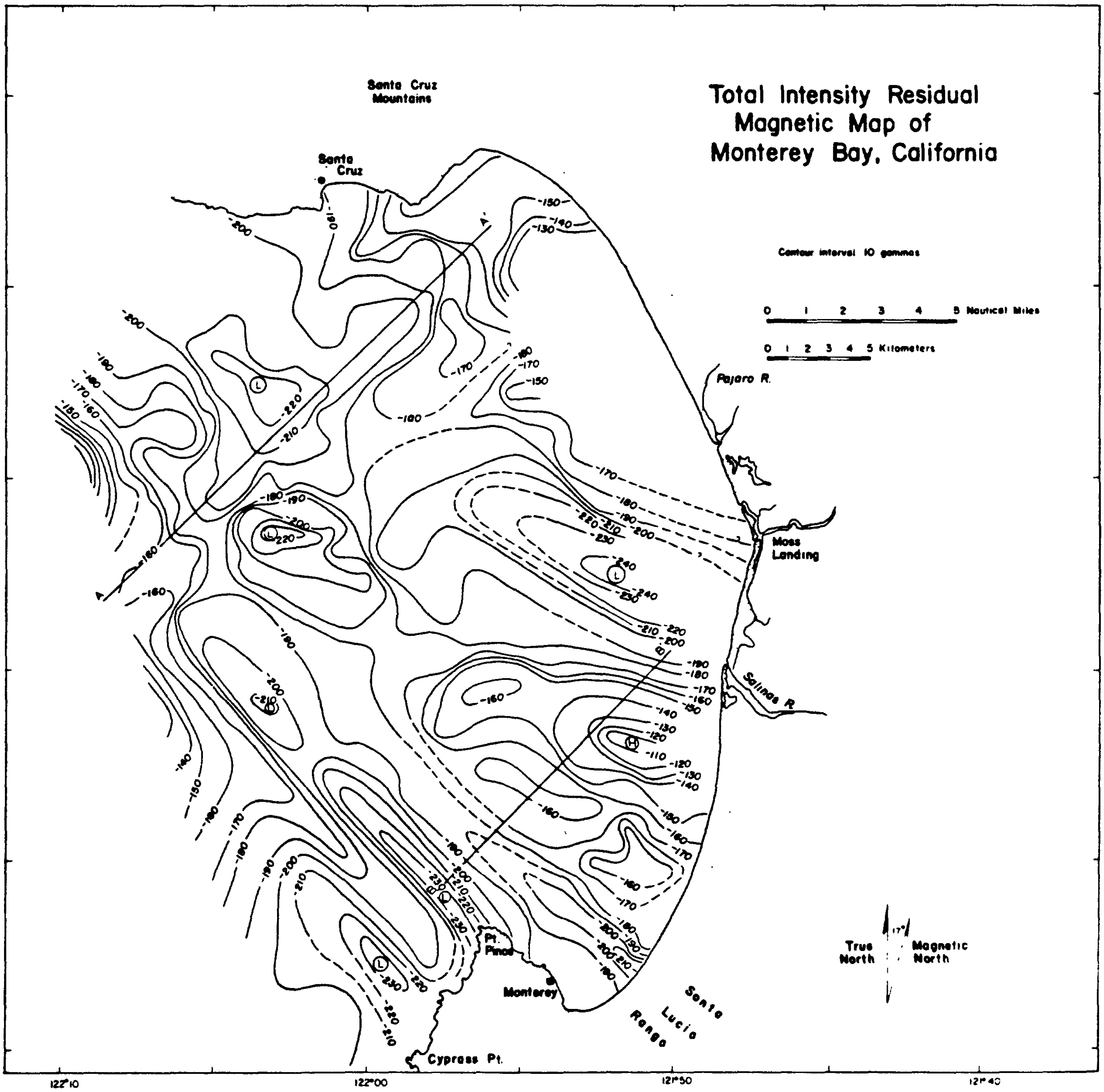


Figure 36. - Map showing locations of magnetic profiles collected by R/V POLARIS in 1970. Heavy lines refer to profiles in Appendix IV.



Total Intensity Residual Magnetic Map of Monterey Bay, California
Contour interval 10 gammas
Santa Cruz Mountains
Santa Cruz
Pajaro R.
Moss Landing
Salinas R.
Pt. Pinos
Monterey
Cypress Pt.
Santa Lucia Range
True North
Magnetic North
Nautical Miles
Kilometers
122°10
122°00
121°50
121°40
37°00
36°50
36°40

Figure 37

Seven magnetic low and one magnetic high anomalies are shown on the total intensity residual magnetic map (Fig. 37). All low anomalies are below -220 gammas. Two of the low anomalies or magnetic troughs are located beneath the shelf between Point Pinos and Cypress Point, trend northwest-southeast, and decrease in value to the northwest. Another low is located west of Point Pinos, beneath outer Monterey Canyon. The distinct linear trend of these three anomalies seems unnatural; however, good magnetic cross-ties having less than 5 gamma variations indicate that the features are real rather than the result of instrumental or navigational errors.

Two additional northwest-southeast oriented magnetic lows are located north of the previously described magnetic troughs (Fig. 37). One anomaly is beneath Monterey Canyon and the other is beneath the shelf immediately north of the canyon.

The remaining two low anomalies are located in the east-central part of Monterey Bay and in the Monterey bight area. The strongest and most extensive low is nearly east-west in trend and extends from the vicinity of Moss Landing seaward generally beneath Monterey Canyon. In addition, a magnetic trough extends northwestward from the coast in the Monterey bight area. Both anomalies decrease in magnetic intensity from east to west.

The single magnetic high is located southwest of the mouth of the Salinas River. It trends generally east-west and decreases in intensity toward the west.

The orientations of magnetic anomalies in Monterey Bay appear to reflect only the regional structural trend. Magnetic troughs in and around the Monterey bight are the result of faulting within the Monterey

Bay fault zone. Surface topography and the depth to the basement rocks are not reflected in the magnetic map. Conversely, where basement rocks crop out or are shown by seismic reflection profiles to be buried at shallow depths, magnetic lows, rather than highs, are present. This is evident in the comparison of magnetic and seismic reflection profiles (Fig. 38). The sole exception to this generalization is in northern Monterey Bay, where the northernmost magnetic low may represent the magnetic expression of the buried canyon. Topographic features, even those as profound as Monterey Canyon, are not reflected by the magnetic map.

Conclusions

Comparison of magnetic data with seismic reflection data showing the structural surface of the basement complex indicates that the basement rocks are relatively nonmagnetic and cannot be used to determine the structural configuration and depth to basement in Monterey Bay. This is not unexpected, as the basement complex in the bay is thought to be composed mostly of biotite granodiorite porphyry. Felsic plutonic and volcanic rocks contain fewer magnetic minerals than do basic rocks and, therefore, should produce anomalies not related to the depth and structural surface of the basement (Nettleton, 1971, p. 88). The anomalies represented on the total intensity residual magnetic anomaly map evidently express magnetic lateral variation within the basement rocks themselves. Also, the lack of any prominent magnetic high suggests that nowhere within Monterey Bay are there large bodies of mafic volcanic or mafic and ultramafic rocks characteristic of the Franciscan rocks or similar to the onshore volcanic rocks that crop out near Año Nuevo Point and Carmel.

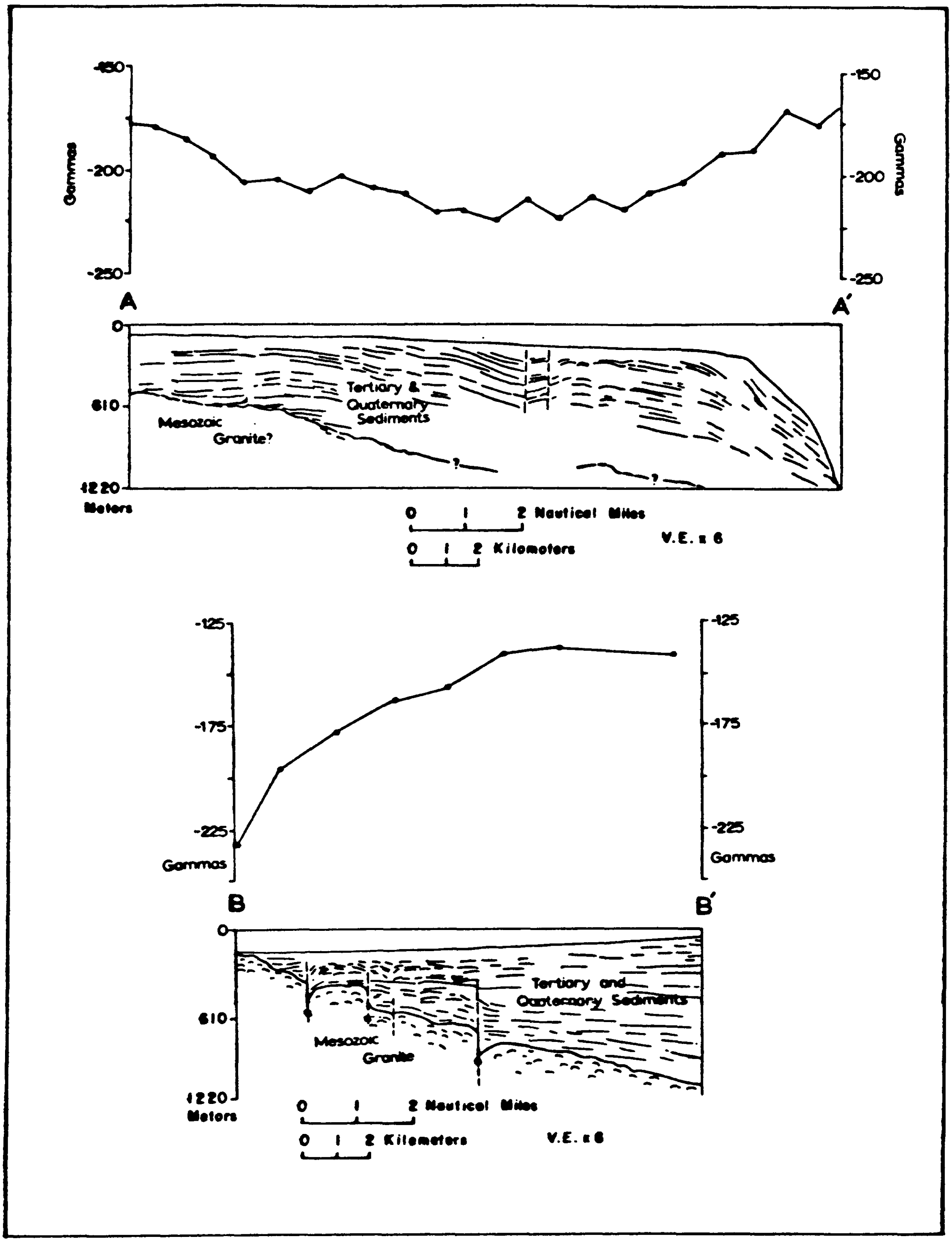


Figure 38. - Sections A-A' and B-B' showing the generalized relationship between residual magnetic intensity and bedrock geology (see Fig. 36 for locations).

CHAPTER IV

GEOLOGIC HISTORY

GENERAL DISCUSSION

Like most of the California coastal region, the Monterey Bay area has experienced a complex late Cenozoic sedimentary and tectonic history. Tectonic uplift and depression have produced a succession of regressive and transgressive sedimentary units, while contemporaneous right-slip along faults of the San Andreas system have offset major structural and lithologic elements (Hill and Dibblee, 1953; King, 1959; Hamilton, 1969; Page, 1970a; Suppe, 1970). In addition, diastrophism resulting in the deformation or removal of some sedimentary units has produced three regional and several local unconformities within the upper Tertiary rocks (Fig. 39). In the Monterey Bay offshore area only the Neogene history is recorded in the sedimentary rocks, whereas onshore the Neogene and locally the Paleogene history is recorded. Paleogene units, if originally present offshore, were removed completely by pre-middle Miocene erosion.

During Late Cretaceous and early Tertiary time, subduction and underthrusting of an oceanic (Farallon) plate occurred along the continental margin off central and southern California (Atwater, 1970; Atwater and Molnar, 1973). Monterey Bay at this time was located in the north part of the southern California Continental Borderland, near the present location of the Transverse Ranges. Subduction ceased in the Monterey Bay in early Tertiary time (∿21 m.y.b.p.), coincident with the northward migration through the region of the Mendocino triple junction. Thereafter the relative motion between the Pacific and North American plates was expressed as strike-slip along the San Andreas fault system (McKenzie

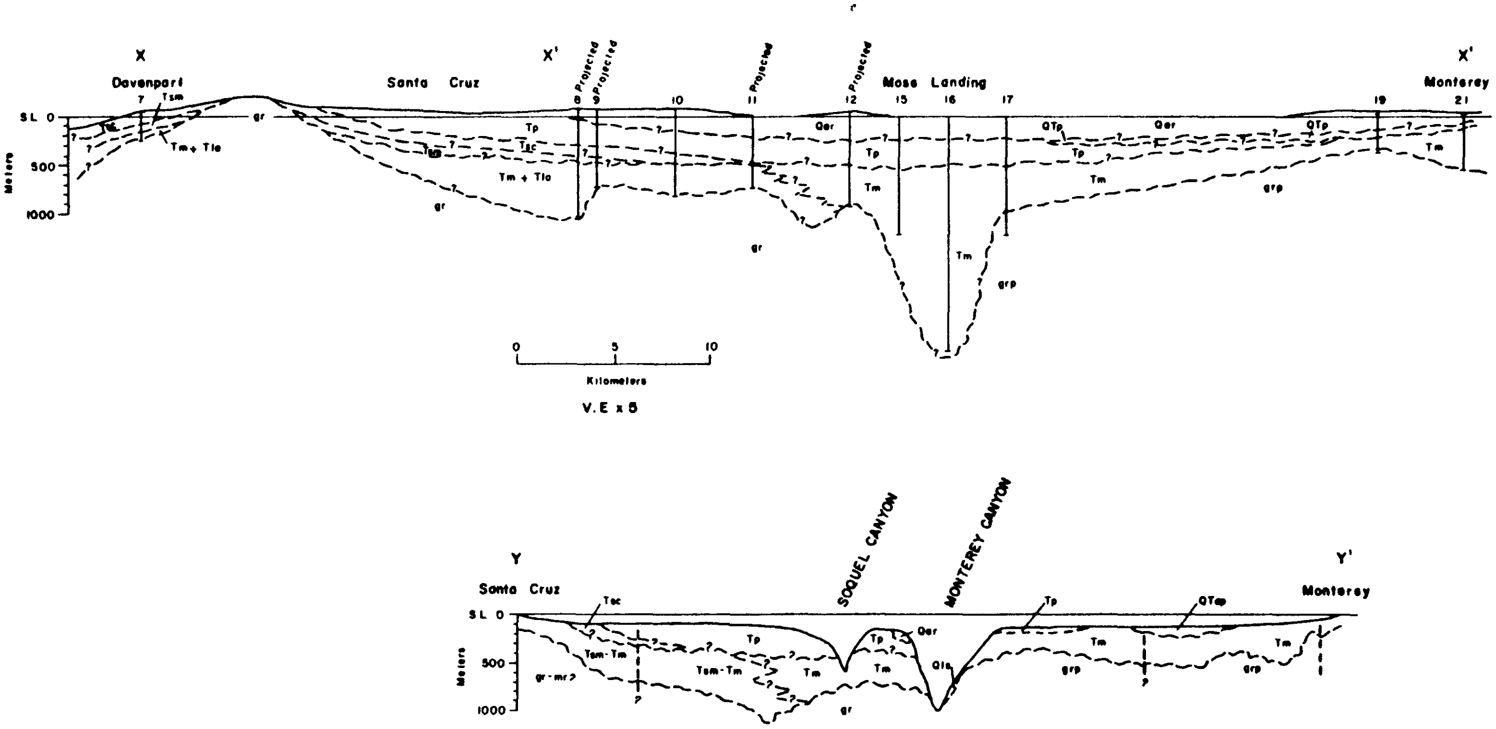


Figure 39, - Idealized onshore-offshore stratigraphic sections for the Monterey Bay region (see Plate 3 for location).

and Parker, 1967; Morgan, 1968; Atwater, 1970; Atwater and Molnar, 1973). Although the boundary between these two rigid plates is commonly created as a single through-going transform fault, several workers think it likely that some motion is taken up on other faults paralleling the San Andreas (Atwater, 1970; Johnson and Normark, 1974).

Johnson and Normark (1974) and Howell (1976) have suggested that slivering and northwestward extension of the Salinian block occurred along faults west of the San Andreas during Neogene time. However, Howell (1975) and Clarke, Howell, and Nilsen (1975) argue for a Late Cretaceous episode of slivering south of the Monterey Bay region in order to create the borderland physiography inferred for Late Cretaceous and Paleogene rocks of west central California. The style of faulting observed in the Monterey Bay offshore area suggests that the Salinian block in this region has a history of tectonic "slivering" that continues into the present (Pl. 5). Elongation of the block is resulting from strike-slip along faults inside the block that are within the San Andreas fault system. The Palo Colorado-San Gregorio fault zone, like the Hayward fault zone, is part of the San Andreas fault system (Greene and others, 1973). Also, stresses built up in the San Andreas fault system are released along faults within the Monterey Bay fault zone. Burford (1971) noted that a sequence of fault creep and small earthquakes on the San Andreas fault near Pinnacles National Monument abruptly ceased with a magnitude 4.3 earthquake (August 3, 1970) in Monterey Bay, probably within the Monterey Bay fault zone. Thus, the San Andreas fault system is considered here to extend westward to the Palo Colorado-San Gregorio fault zone and to incorporate most active faults within the Salinian block in the Monterey Bay area.

One probable effect of slivering the Salinian block is to produce a serrated, rather than a straight, western boundary for the block (Fig. 40).

Fragmentation of this margin as the Salinian block moves northward along the San Andreas fault seems likely; in this case fragments and slivers of basement rocks may have been pushed ahead of the main block or shoved out alongside the block, where they exist as isolated pods west of the Sur-Nacimiento and Palo Colorado-San Gregorio fault zones. A basement sliver formed in this manner may be present west of the Palo Colorado-San Gregorio fault zone in Monterey Bay (Fig. 40). In addition, right-lateral motion along the Palo Colorado-San Gregorio fault zone may be elongating and narrowing the Salinian block in the Monterey Bay area.

OROGRAPHIC BLOCKS

The Monterey Bay region has been subdivided into relatively small "orographic" blocks on the basis of basement elevations (Fig. 2). Negative blocks produced structural troughs in which sediments have accumulated, whereas positive blocks were ridges or upland areas subject to erosion. Vertical movement of these blocks is recorded in their stratigraphies so that a history of their relative movements can be inferred (Clark and Rietman, 1973).

The "orographic" blocks of various authors have been redefined on the basis of the subsurface data collected from Monterey Bay for this report (Fig. 41). Four blocks--the Ben Lomond, Monterey, Salinas, and Santa Lucia--appear to have had a major influence on the Tertiary stratigraphy of the offshore area east of the Palo Colorado-San Gregorio fault zone (Fig. 15).

The southern edge of the Ben Lomond positive block abruptly plunges to the southwest in northern Monterey Bay (Fig. 15). Strata of the Monterey block to the south lap onto and wedge out against this basement high (Figs. 24, 25, and 26). The Monterey block forms a relatively flat, shallow basin

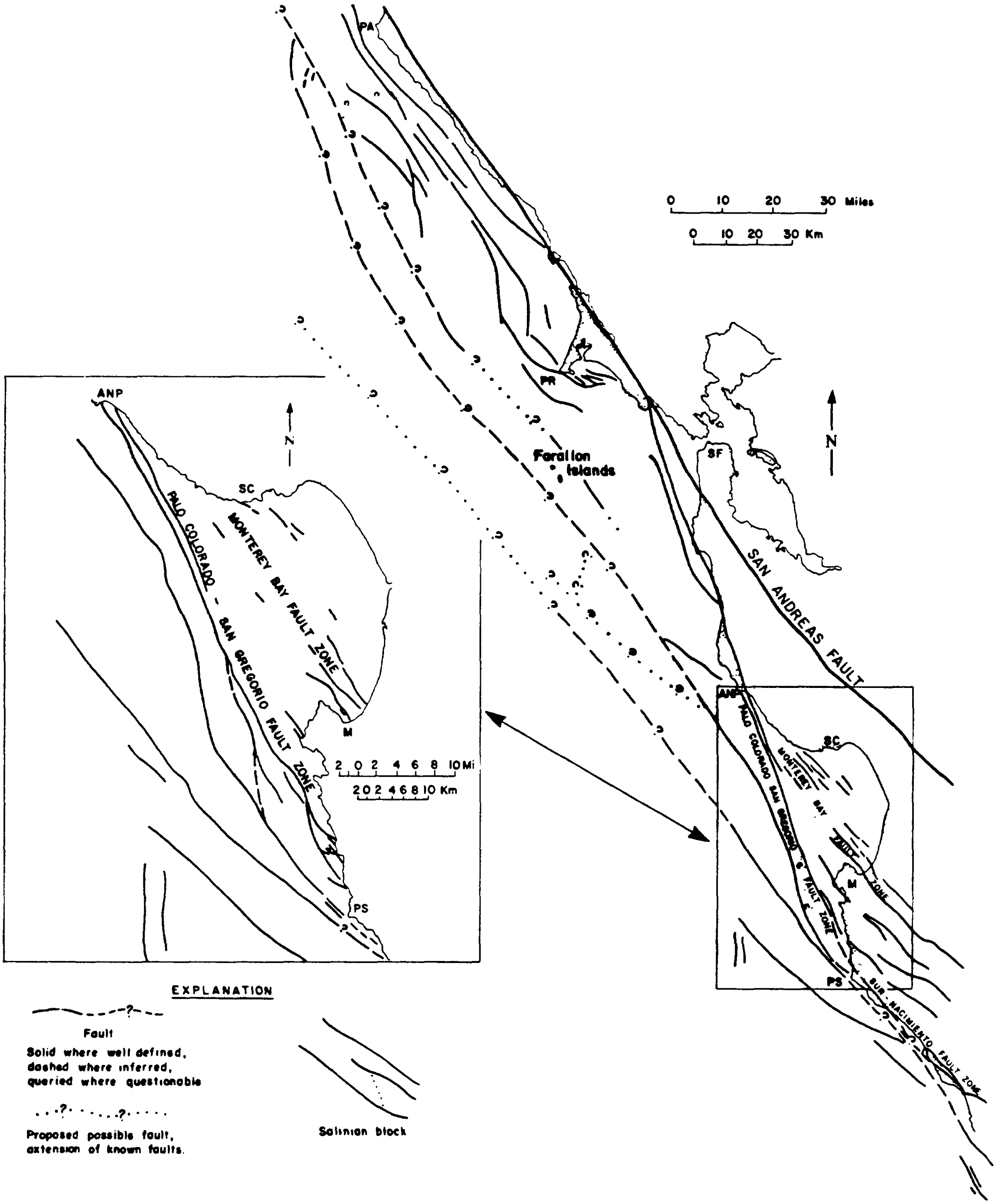


Figure 40. - Map showing proposed boundary of the northern half of the Salinian block.

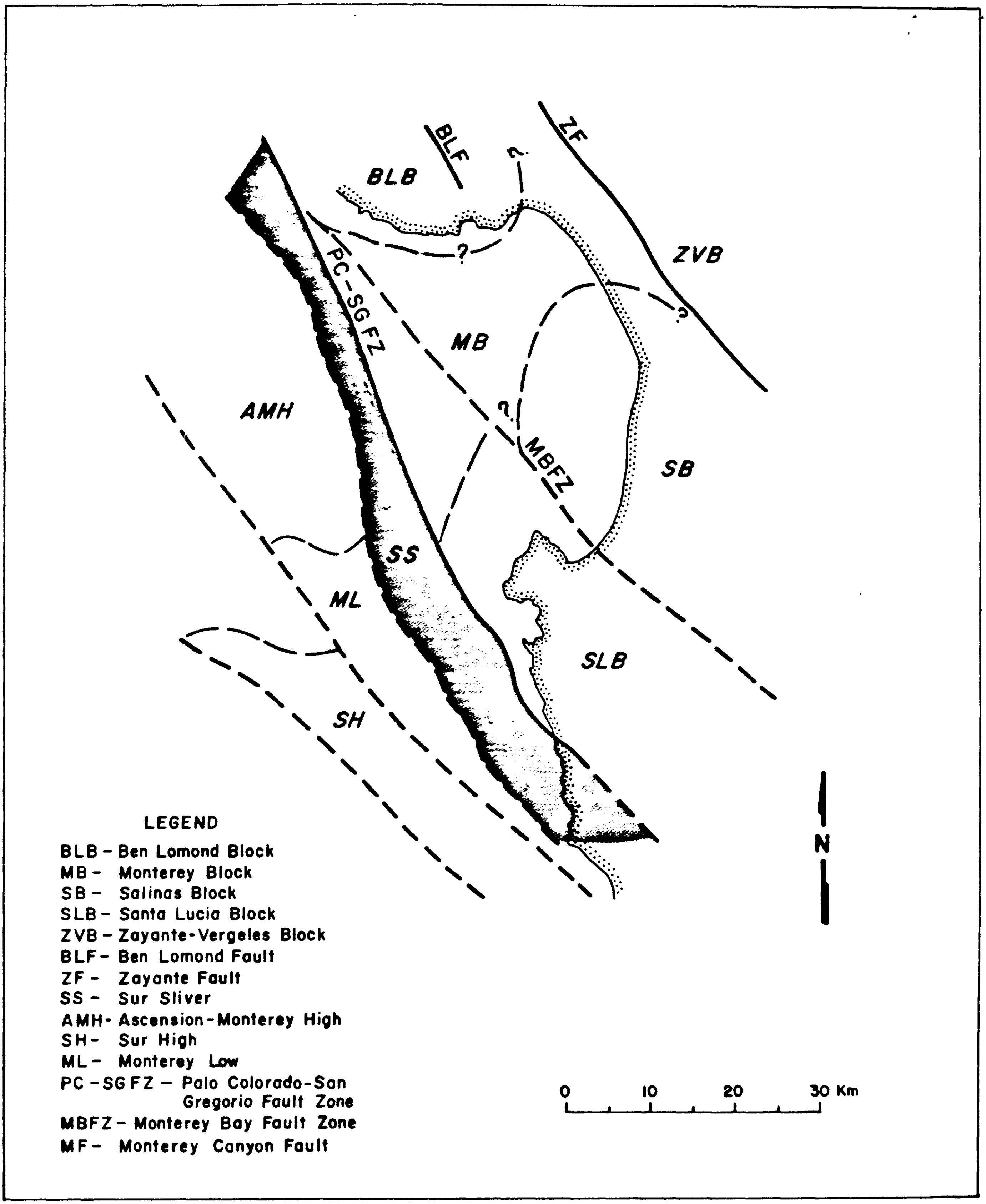


Figure 41. - Orographic blocks of the Monterey Bay region based on offshore geophysical data discussed in this report.

that extends from the Zayante fault onshore westward to the Palo Colorado-San Gregorio fault zone, where it may be truncated. In the southwestern part of Monterey Bay the northern edge of the Santa Lucia positive block, which forms the northern Santa Lucia Range and the Monterey Peninsula, is separated from the Monterey block to the north by Monterey Canyon. To the east, faults within the Monterey Bay fault zone mark the boundary between the Santa Lucia and Salinas blocks. The Salinas negative block contains sediments of the Salinas basin that lap onto the Monterey high (Figs. 24 and 26). The Monterey high separates the Monterey and Salinas blocks.

Identification of "orographic" blocks west of the Palo Colorado-San Gregorio fault zone is difficult because of the absence of data, and because true and acoustical basement are not correlative. However, a discrete zone of complexly deformed rocks lying between the Palo Colorado-San Gregorio fault and a fairly continuous unnamed fault to the southwest (here named the Ascension fault) separates the contrasting tectonic regimes of the Monterey Bay area and the continental slope (Fig. 41). This zone is here termed the Sur sliver; it appears to be composed of many slices having diverse lithologies and is characterized by neither positive nor negative displacement.

Although the relief of actual basement has not been confidently identified in the seismic profiles west of the Palo Colorado-San Gregorio fault, its nature is probably expressed in overlying sedimentary units. Acoustical basement is assumed to either directly represent true basement or to indirectly express basement relief; thus, three tectonic blocks can be delineated along the continental slope seaward of the Monterey Bay area. These are the Ascension-Monterey high, the Monterey low, and the Sur high (Fig. 41).

The Ascension-Monterey high is an acoustical basement dome supporting the submarine upland between Ascension and Monterey submarine canyons. It is bounded both on the east and west by faults that appear to displace only Miocene and older strata. To the southeast these same faults bound the Monterey low, which is bisected by the Monterey sea valley. The Sur high lies in fault contact along the southwest side of the Monterey low. This is an acoustical basement high extending northwestward from Point Sur and also is bounded by faults that appear to displace only Miocene and older strata (Fig. 41), indicating that development of the high ceased in Miocene time.

TECTONIC RECONSTRUCTION

Reconstruction of past tectonic events is discussed here with the aid of palinspastic and paleogeographic maps. These idealized maps clearly illustrate the Cenozoic development of major faults in the Monterey Bay region of the Salinian block (Figs. 42 and 43) and are based in part on modifications of maps presented by Addicott (1973), Clarke, Howell, and Nilsen (1975), Nilsen and Link (1975), and Graham (1976). However, palinspastic maps presented in this report represent the author's interpretations of fault patterns, offset history, and physiographic features that constitute "piercing points" or cross fault ties (e.g., submarine canyons and paleodrainages). More speculative aspects of these maps include estimated time of initial motion along faults. Although most faults are depicted by a single trace, in reality many probably consist of several faults, commonly en echelon, within a broad fault zone. The Palo Colorado-San Gregorio fault zone is typical in this regard, consisting of many shorter, en echelon faults adjacent to the main faults.

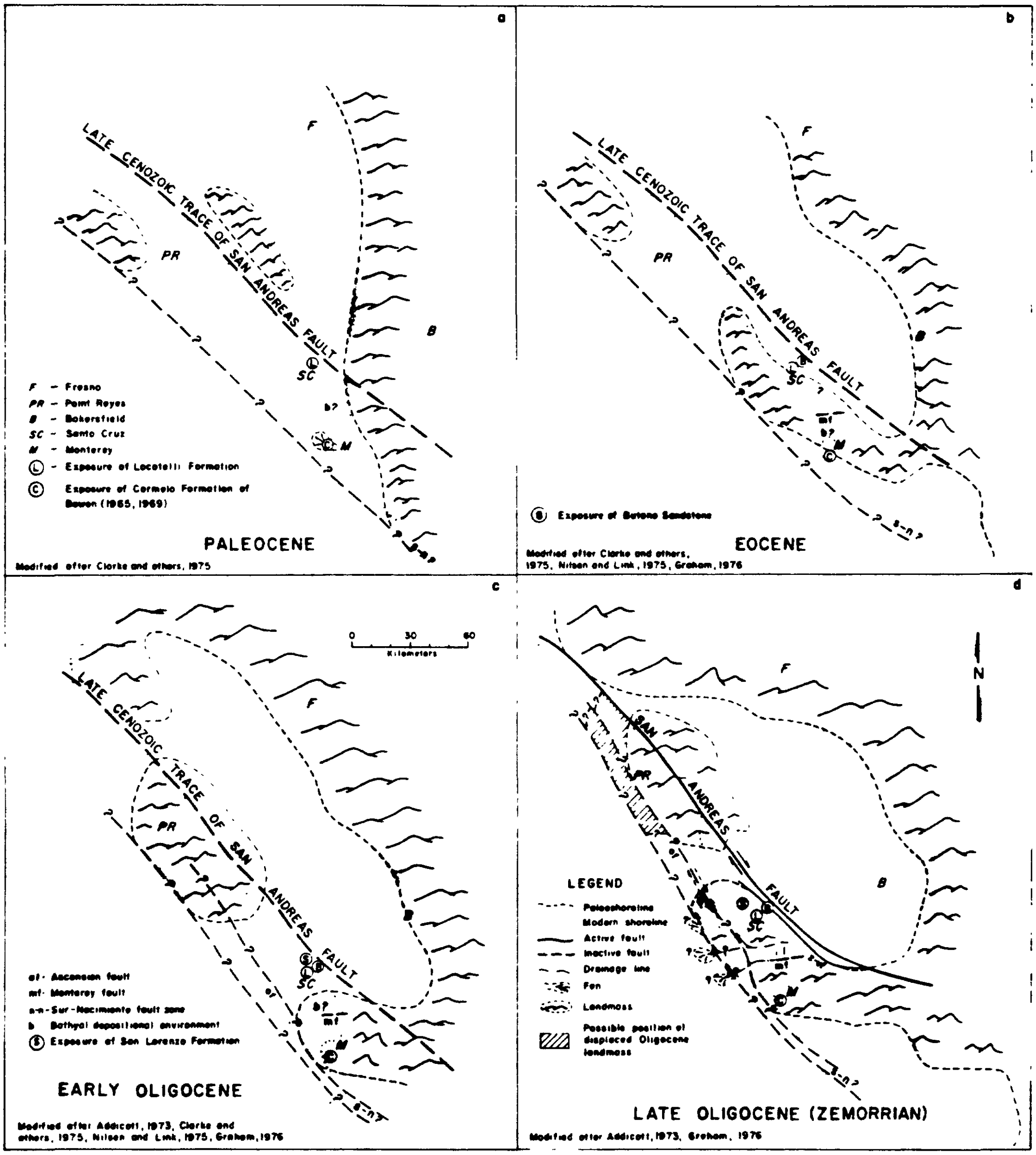


Figure 42A. - Paleogeographic maps of the Monterey Bay region.

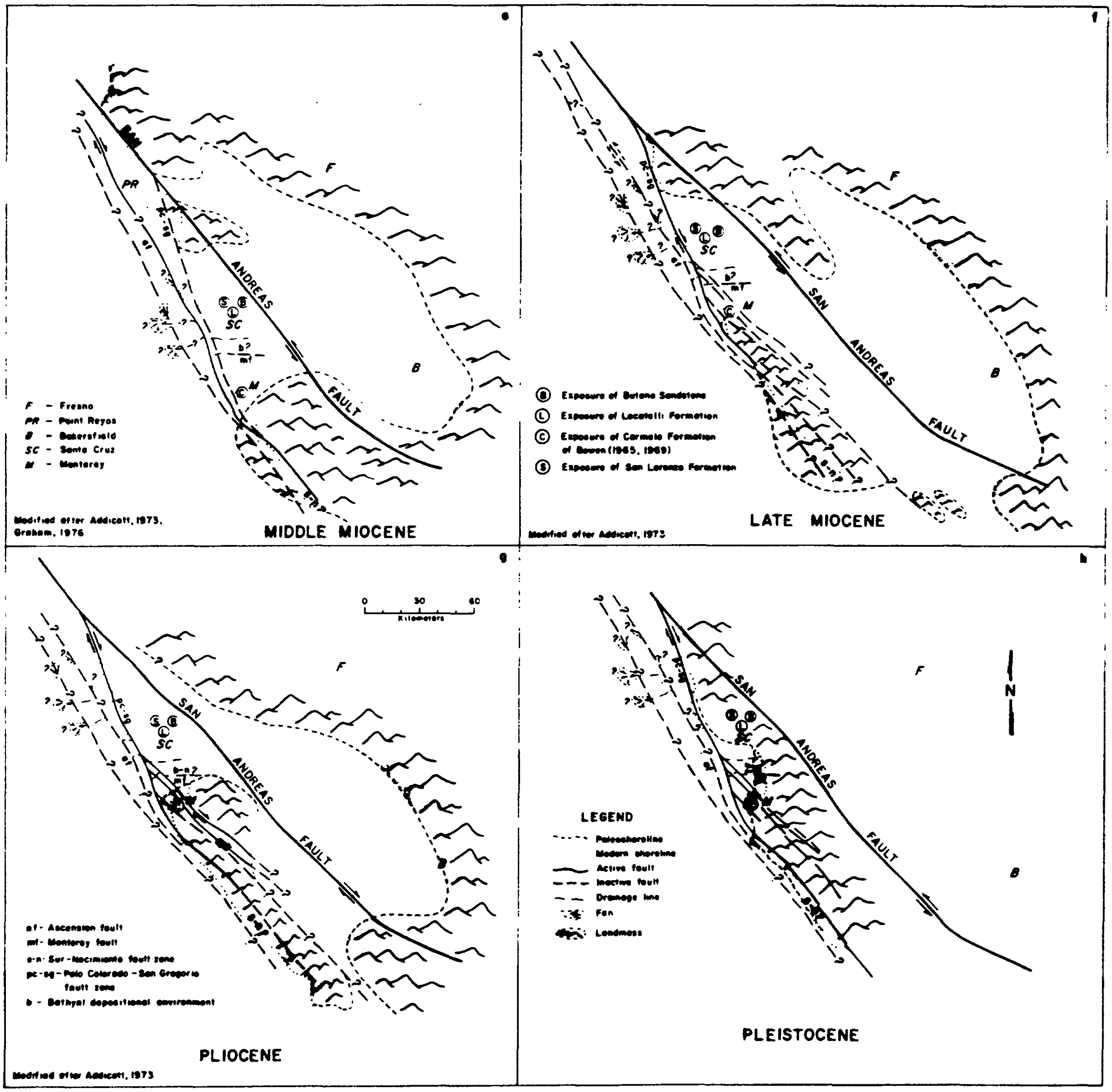


Figure 42B. - Paleogeographic maps of the Monterey Bay region.

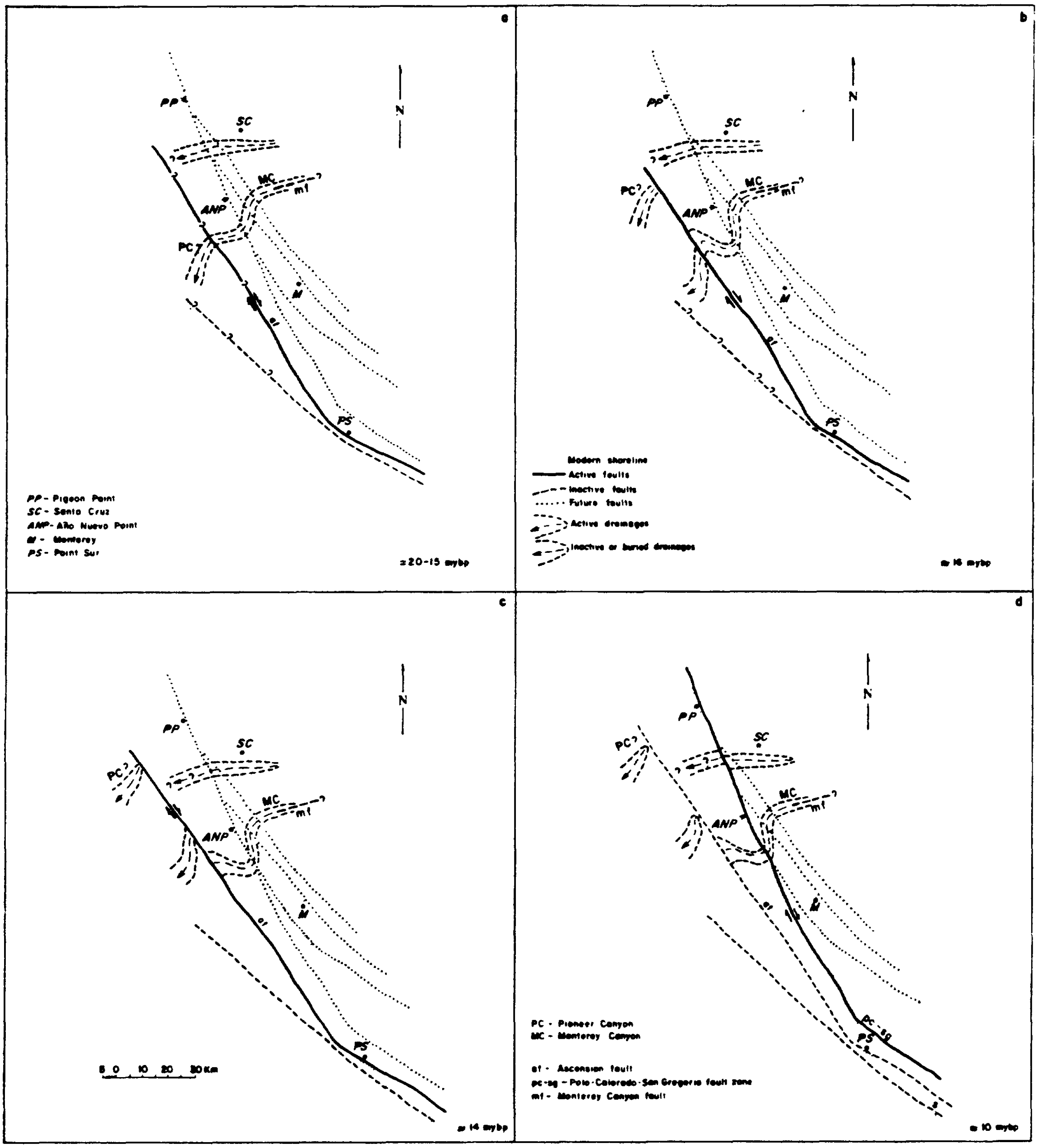


Figure 43A. - Palinspastic fault maps of the Monterey Bay region showing displacement of present-day topographic features along major fault zones for the period between 20 and 10 m.y. ago.

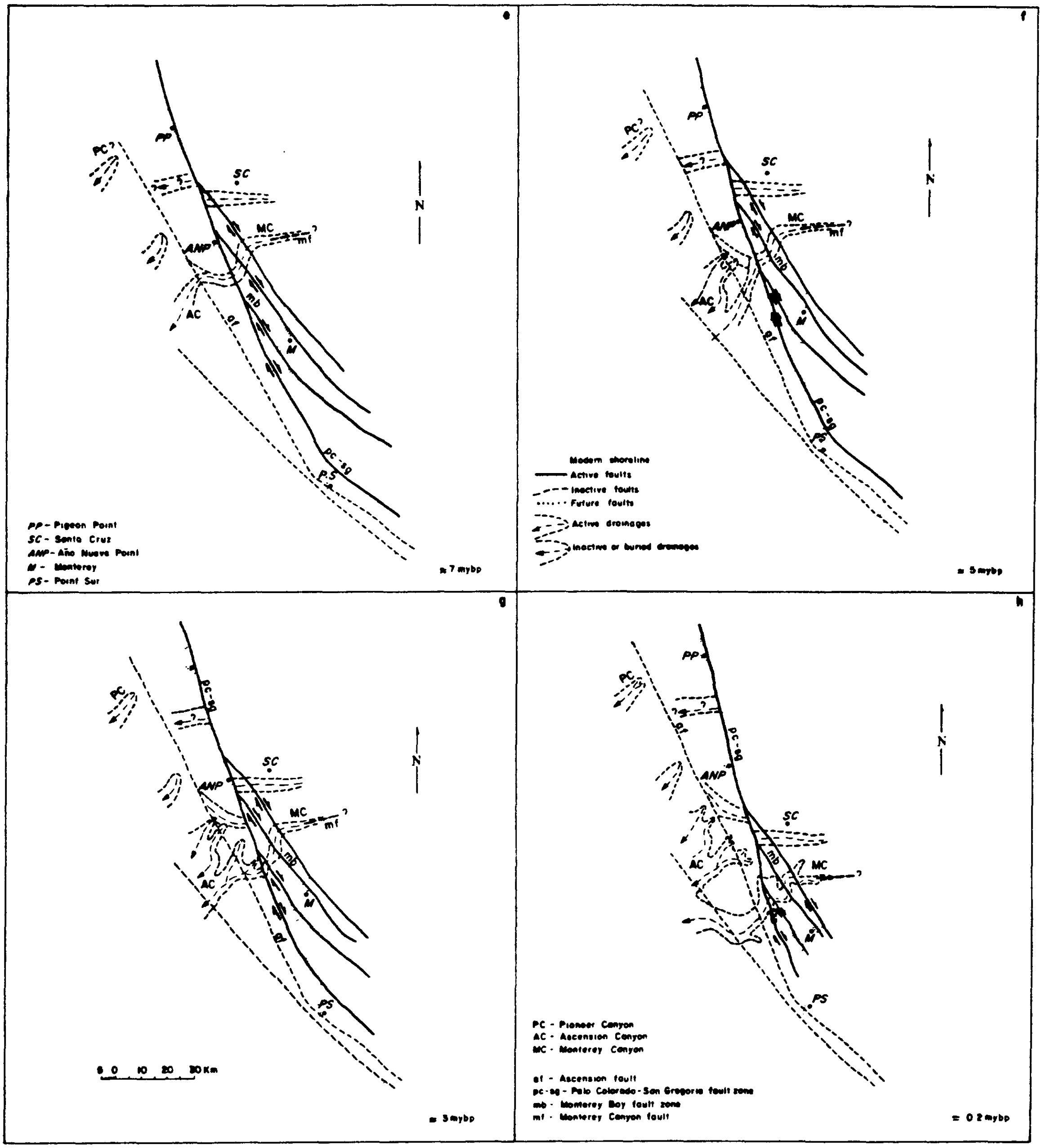


Figure 43B. - Palinspastic fault maps of the Monterey Bay region showing probable displacement of present-day topographic features along major fault zones for the period between 7 and 0.2 m.y. ago.

Dredging in Monterey Canyon and onshore well data indicate that Paleogene rocks are missing in Monterey Bay and that Neogene sediments directly lie upon a Mesozoic crystalline basement complex (Fig. 7, App. II). Onshore in the Santa Cruz Mountains, Clark (oral commun., 1976) reports that the Paleocene Locatelli Formation appears to be downfaulted into the basement rocks. Seismic reflection data show that no such relationship occurs offshore and that all sedimentary units throughout Monterey Bay unconformably overlie a flat erosional surface cut into the basement rocks (App. III). This erosional surface has been described from well data in the Salinas Valley by Martin and Emery (1967), who named it the "Elkhorn erosion surface". Other workers have also reported the existence of this surface locally within the Monterey Bay region (Starke and Howard, 1968; Hoskins and Griffiths, 1971).

Because of the absence of Paleogene and older sedimentary rocks in the offshore part of the Salinian block, the pre-Neogene tectonics must be reconstructed from onshore data. Therefore, the author has drawn on paleogeographic maps constructed by other workers to describe the paleotectonics for the Paleogene period (Addicott, 1973; Clarke, Howell, and Nilsen, 1975; Nilsen and Link, 1975; Graham, 1976). Modified forms of these maps for this period are shown in Figure 42a, b, and c.

Clark and Rietman (1973) recently proposed an emerging land mass that was uplifted along the Zayante-Vergeles fault during Zemorrian time. This landmass formed a positive block to the south of the fault and composes Clark and Rietman's (1973) Ben Lomond-Gabilan block. Continued uplift of this block during the Zemorrian separated the early Tertiary Santa Cruz basin of the Santa Cruz Mountains from the Santa Lucia basin to the south (Fig. 4; Clark and Rietman, 1973). Most Paleogene sediments that may have overlain the crystalline and metasedimentary basement of the block were stripped off during this time and the "Elkhorn erosion surface" of Martin and Emery (1967) formed.

By early Miocene time, relief of the "Elkhorn erosion surface" was well established. Seismic reflection data show two large paleodrainages (canyons) incised into the basement rocks (Fig. 15). One of these canyons trends east-west, bisecting the Monterey block. It deepens and widens to the west and, according to the seismic reflection data, is filled with middle Miocene and younger material indicating pre-middle Miocene erosion (probably Oligocene to early Miocene). The other paleodrainage is believed to be ancestral to Monterey Canyon. Beneath the headward part of Monterey Canyon is a buried canyon incised into the basement complex. This canyon is also filled with middle Miocene and younger material as shown by the seismic reflection data and extrapolation of onshore well data offshore. The Pajaro Gorge on land immediately headward of Monterey Canyon is also filled with Miocene and younger sediments (Starke and Howard, 1968). Therefore, a pre-middle Miocene origin for the canyon is inferred. Localization of the headward part of the canyon probably was influenced by the Monterey fault (Fig. 42d).

Carmel Canyon may have also formed during the emergent episode in Zemorrian time. Although no sedimentary record that can be used for chronology is associated with the canyon, its relation as a tributary to Monterey Canyon and its similar lithology (eroded into granodiorite) suggest a common origin, common to the other paleodrainages in the area. The north-south trend of the lower part of Carmel Canyon is controlled by faulting that is active today (Greene and others, 1973). Initial movement of this fault is unknown but, as discussed later, is thought to have occurred in early Miocene time.

The seismic reflection data (App. III) and lithologic samples (App. II) recently collected in Monterey Bay suggest that the "Elkhorn erosion surface" and associated paleodrainages were probably formed sometime between Cretaceous and early Miocene time. Erosion of these features probably occurred subaerially on the emergent Ben Lomond-Gabilan block (Clark and Rietman, 1973), as proposed by Starke and Howard (1968), between Oligocene and early Miocene time (Zemorrian-early Relizian). The widening and deepening of the paleodrainages to the west indicate an uplift along an eastern boundary and tilting to the west. This is in accord with the westward tilting and eastward uplift of the positive Ben Lomond-Gabilan block on the basis of a westward migration of a marine-terrestrial sediment interface. Eroded Paleogene sediments and Cretaceous granitic basement ("Monterey mass" of Ross and Brabb, 1972) detritus, therefore, were transported west and may have been deposited as fans located at the mouth of the canyons and/or at the base of the continental slope.

Middle Miocene to Upper Miocene Events

In early middle Miocene (late Relizian) time, rapid subsidence led to a regional transgression and marine sediments began to cover the eroded basement complex and fill the canyons (Fig. 42e). Two landmasses are thought to have existed in close proximity to Monterey Bay during this time (Addicott, 1973). The Ben Lomond pluton was also emergent and supplied detritus to middle Miocene seas at least during late Relizian time (Clark, 1966, p. 115).

The Lompico Sandstone of Clark (1966) was deposited as a shallow-water, basal, transgressive unit in the southern Santa Cruz Mountains area (Clark, 1966). At the same time, and throughout the middle Miocene (Relizian through Luisian), sediments comprising the diatomaceous and siliceous siltstones of the Monterey Formation were deposited in a moderately deep-water basin that covered most of Monterey Bay (Figs. 40 and 42e). The areal extent of Monterey sedimentation increased with continued subsidence of the Monterey Bay region and it eventually conformably overlapped the Lompico Sandstone of Clark (1966). These two units are time-transgressive to the east and probably interfinger in the central part of the Monterey Bay region, between Moss Landing and Santa Cruz (Clark, oral commun., 1976; Fig. 40).

Unconformities observed in the offshore seismic reflection profiles (App. III), in on-land exposures (Clark, 1966; Clark and Rietman, 1973), and in on-land wells (App. II) indicate that between middle and late Miocene times much of the Monterey Bay region was emergent. During this time an extensive erosional surface was developed on the Lompico-Monterey beds in the present-day onshore areas adjacent to Monterey Bay. The Lompico-Monterey unit here is overlain unconformably by the upper Miocene Santa Margarita and younger units. This unconformity is probably the peneplane surface of middle Miocene age that underlies the Watsonville lowland (Starke and Howard, 1968). Also, where it is exposed in the Santa Cruz Mountains, it indicates that nowhere in that area was sedimentation continuous from middle Miocene into late Miocene and Pliocene time (Clark, 1966, p. 153). Offshore, this erosional surface appears in seismic reflection profiles to exist on the middle Miocene sequence principally on the Monterey Formation. To confidently distinguish contacts between the various units in the northwestern Monterey Bay area is difficult, because of the similarities in the acoustical characteristics of the Miocene sediments (Monterey Formation, Santa Margarita Sandstone, and Santa Cruz Mudstone of Clark, 1966, p. 153). Thus, the existence of the middle/late Miocene unconformity in this area is indeterminant (Fig. 40; App. III). In the extreme western part of Monterey Bay, this middle Miocene unconformity is impossible to identify. Continuous sedimentation may have taken place here throughout the middle Miocene, to late Miocene or Pliocene time. In the Salinas Valley (Salinas Basin) the Monterey Formation is middle to late Miocene (Relizian to Delmontian) in age (Gribi, 1967, p. 19), a time period that includes both the Monterey Formation and the Santa Cruz Mudstone of Clark (1966) in the Santa Cruz Mountains area to the north (Clark, 1966, p. 154). The westward thickening of these units from both the Santa Cruz Mountains and Gabilan Range areas suggests that these areas were positive and bordered on the west by a strongly negative basin (Clark, 1966, p. 154) where sedimentation may have been continuous. If this is so, then somewhere in the western and northwestern parts of Monterey Bay, interfingering of the Santa Margarita Sandstone and Santa Cruz Mudstone of Clark (1966) with the Monterey Formation may have occurred.

No evidence exists to indicate activity within the submarine canyons during the middle to upper Miocene depositional episode. On the contrary, apparent uninterrupted sedimentation in the canyons, as shown in the seismic profiles (App. III) by conformable flat-lying beds of Monterey-like strata filling the canyons, suggests that the canyons were probably too deep and far removed from sediment sources to stay flushed. In Monterey Canyon, although the Monterey strata from the canyon's wall is cut by the present-day canyon, equally thick flat-lying beds on either side of the canyon indicate that the middle Miocene sediments were eroded here after and not during their deposition. However, partial exhumation of Monterey Canyon may have taken place during the late middle Miocene regression and later transgression. Although erosion of the modern Monterey Canyon has removed any record of this possible exhumation, the general thinning of Miocene strata toward the canyon suggests that partial excavation may have resulted during late Miocene-Pliocene time (Figs. 24 and 25).

In late early Miocene time, diastrophism elevated the Monterey Bay region above sea level. The tectonic activity producing the episode of emergence appears to have been relatively slow and gentle in Monterey Bay, as middle Miocene strata are gently folded, gently dipping, or flat-lying, except locally within or near fault zones. About this time the Mendocino triple junction of Atwater (1970) developed and started migrating north. A transform fault was propagated and the arc-trench system that existed before the triple junction formed was cancelled by the northward movement of the triple junction. This transform fault (San Andreas fault) became the active margin between the North American and Pacific plates; the tectonic deformation of the Monterey Bay region is the result of this activity.

Miocene and Pliocene Events

Widespread transgression resulted from subsidence in late Miocene and early Pliocene time. The shape of the modern Monterey Bay developed and early Tertiary strata were gently folded during this period, principally from differential downwarping of the bay and circumferential uplift of the bay's margin (Starke and Howard, 1968, p. 823). However, right-slip along faults within the Monterey Bay fault zone probably also contributed significantly to the configuration of the southern shoreline, especially the granitic promontory forming the present-day Monterey Peninsula.

In the Santa Cruz area, the Santa Margarita Sandstone was deposited on the late middle Miocene erosional surface cut into the Monterey Formation and older units, and the Santa Cruz Mudstone of Clark (1966) was deposited on the Santa Margarita (Clark, 1966, p. 132). However, during the late Miocene-Pliocene transgression the Ben Lomond block locally remained emergent until Mohnian-Delmontian time, when it was transgressed from the west (Clark, 1966, p. 151) and sediments of late Miocene and early Pliocene age lapped onto the basement rocks of the block (Figs. 6 and 42g). During early Pliocene time the Purisima Formation was conformably deposited upon the Santa Cruz Mudstone of Clark (1966) in this same area; however, locally a disconformable contact is present (Clark, 1966, p. 140-141).

Farther south basinal sediments were deposited over much of the northern Monterey Bay and Salinas Valley area (Monterey and Salinas blocks) in late Miocene to early Pliocene time. However, a large, elongated landmass that extended northward to near the present location of Monterey comprised most of the southern Monterey Bay area (i.e. most of the Santa Lucia block) (Fig. 42f; Addicott, 1973). The configuration of this landmass may have been controlled by faults within the Palo Colorado-San Gregorio and Monterey Bay fault zones.

Seismic reflection profiles throughout most of the northern and central part of the bay indicate that the Purisima Formation lies unconformably upon the Monterey Formation (Fig. 40, App. II). Any excavation of Monterey Canyon that may have previously occurred would have been filled at that time.

Foraminiferal samples collected by dredging flat-lying Pliocene strata where they are cut by Monterey Canyon provide evidence concerning Pliocene bathymetric trends in Monterey Bay. Because most of the benthonic foraminiferal species common to the Purisima Formation are still living, they are not age diagnostic in an evolutionary sense. However, systematic biofacies changes with time are shown by the benthonic species within the Purisima-Merced sequence on land, since deposition proceeded to fill the basin and slope areas during the Pliocene to early Pleistocene interval. Thus, deeper water (middle bathyal) biofacies are typical of the lower parts of the Purisima Formation in Monterey Bay, while the shallower water biofacies are common to the higher and thus younger parts of the formation (J. C. Ingle, Jr., written commun., 1972). Assemblages from Pliocene strata exposed in the deeper, seaward part of Monterey Canyon indicate lower neritic to bathyal depths, whereas assemblages from samples in the intermediate and headward parts of the canyon indicate upper bathyal to lower neritic and middle to upper neritic depths, respectively (Fig. 7, App. II). Also, megafauna assemblages and lithologic analysis of the Pliocene samples suggest that lower to upper members of the Purisima Formation as described by Cummings, Touring, and Brabb (1962) are exposed in the outer part of the canyon, but only the upper members of the unit are exposed near the canyon's head (App. II). Therefore, Monterey Bay appears to have experienced basin filling that lasted throughout the Pliocene and into the Pleistocene.

Many foraminiferal assemblages from Pliocene samples collected along the basement ridge (here called the Monterey high) extending from the Monterey Peninsula to Capitola (Fig. 15) across the central part of Monterey Bay indicate much greater depths than now exist in that area (App. II). This suggests that post-Pliocene uplift along this basement ridge was greater than in surrounding areas.

The Purisima Formation records continuation of a marine transgression in the Pliocene that was initiated by deposition of the Santa Margarita Sandstone in late Miocene time (Clark, 1966, p. 151). However, in late Pliocene-early Pleistocene time most of the Santa Lucia and Ben Lomond blocks, and parts of the Salinas block, appear to have been emergent (Fig. 42g; Addicott, 1973). The large embayment that had existed east and southeast of Monterey Bay during the late Miocene became progressively smaller and shallower (Figs. 42f and 42g; Addicott, 1973). The northwest margin of the land mass that comprised the Santa Lucia and northern Salinas blocks appears to have had a northeast trend; the buried headward end of the ancestral Monterey Canyon, which includes Pajaro Gorge, extended southwest in close proximity to this margin (Fig. 42g). Seaways to the open ocean cut through the Monterey Bay area (Fig. 42g) and formation of the modern Monterey Canyon may have begun during late Pliocene time (Martin, 1964, p. 128). Initially, sediments were probably transported seaward along an axial depression that resulted from differential compaction of older deposits in the buried canyon. The transport of sediments along the canyon would have caused erosion of the older canyon fill, leading ultimately to exhumation of the canyon. Excavation of the canyon would have then been aided by the large sediment loads transported through the canyon from the shrinking bay to the east, and perhaps also by tidal action. Finally, by late Pliocene or early Pleistocene time, the area of the present Watsonville lowland was emergent, the Salinas River was formed, and terrestrial debris was being transported down the river, across the flat coastal plain, and into the upper reaches of Monterey Canyon (Martin, 1964, p. 137; Dupré, 1975).

Late Pliocene to Holocene Event

Regression of the sea continued until late Pliocene or early Pleistocene, by which time most of Monterey Bay was emergent. An extensive erosional surface was developed, and streams draining the surrounding region meandered across the flat coastal plain that occupied the present area of

Monterey Bay. Erosion of a large offshore channel, probably by the ancestral Salinas River, took place during an early retreat of the Pleistocene sea (Figs. 19 and 30; Pl. 3). The course of the Salinas River during this period appears to have coincided closely with that of the buried Pajaro Gorge and ancestral Monterey Canyon (Martin, 1964; Tinsley, 1975). Although the Salinas River was near its base level (Woodford, 1951) and meandered across a wide coastal plain, partial exhumation of the Pliocene and older sedimentary fill of the ancestral Monterey Canyon probably began at this time. Subaerial erosion and excavation of the canyon proceeded rapidly during emergent periods of the Pleistocene. Large volumes of sediment were transported to the mouth of the canyon near the present shelf break, contributing to erosion of the upper canyon, while turbidity currents proceeded to carve the lower part of Monterey Canyon.

Origin and development of Soquel Canyon probably occurred at this time, as its head is located in an area that would have been part of the low, flat-lying, emergent, coastal plain during the Wisconsin low stand of sea level. Although the seismic reflection profiles show no buried stream channels between land and the canyon's head, extension of the San Lorenzo River may have eroded the canyon (Martin, 1964, p. 141). No faults, buried channels, or other structural features observed in the seismic reflection profiles that could have controlled its development are associated with the canyon.

Several episodes of transgression and regression associated with eustatic changes of sea level during the Pleistocene followed the initial planation of the coastal plain and helped shape the present-day configuration of the continental shelf. In the Monterey Bay region, Quaternary tectonism generally elevated the Ben Lomond Mountain and Santa Lucia Range areas with downbowing of Monterey Bay and the surrounding lowland areas of the Pajaro and Salinas Valleys. Marine terraces that now stand well above sea level between Año Nuevo Point and the Pajaro River and between Monterey and Point Sur developed during Pleistocene time and since have been elevated tectonically (Alexander, 1953). An age of 70,000 to 125,000 years (Sangamon), based on amino acid dating, has been assigned to the lowest emergent marine terrace north of Santa Cruz (G. E. Weber, oral commun., 1975). Higher terraces are older, and some terraces preserved in the Watsonville lowlands are from Sangamon time (Dupré, 1975). Tectonic uplift of Pleistocene terraces in the Monterey Bay region is greatest in the Aptos-Capitola area (Alexander, 1953; Bradley and Griggs, 1976). This area is the landward end of the basement ridge (Monterey high) in Monterey Bay that likewise appears to have undergone the greatest uplift since late Pliocene time.

The shoreline in the Monterey Bay region during late Pleistocene varied in position from near the outer edge of the present continental shelf during the lowest stand of sea level, to near coincidence with the present shoreline during the highest stand of sea level. In Monterey Bay proper, the shoreline during the highest stand of sea level is defined by the western limits of the Pleistocene Aromas Sand of an eolian origin and the terrestrial deposits of the Paso Robles Formation (Fig. 42h). An unusual wave-cut platform on the Purisima Formation developed during the late Pleistocene, remnants of which are present today within the 30 m (100 ft) isobath of Point Santa Cruz. P. Kinney (oral commun., 1976) indicates that this platform is strewn with boulders ranging in size from 0.5 to 2 m in diameter. These boulders appear to be cannonball concretions derived from the Purisima Formation by wave erosion of the friable sandstone surrounding the concretions.

Planktonic foraminiferal biofacies in the Purisima-Merced sequence appear to reflect temperature fluctuations during the Pliocene-early Pleistocene interval. The presence of exclusively dextrally coiling populations of Globigerina pachyderma in the lower Purisima strata of Monterey Bay indicates that Pliocene water temperatures were somewhat higher than temperatures typical of this latitude today, consistent with the major warm interval recognized in Pliocene strata over the entire North Pacific (Ingle, 1973). However, water temperatures apparently were cooler during middle to late Pleistocene time. Fauna containing Astarte bennetti, Cryptonatica aleutica, Bittium challisae, and Patinopecten caurinus have been collected from the continental shelf between Carmel and Point Sur, and a skull fragment of Hydrodamalis (Stellar's sea cow) has been dredged from the floor of Monterey Bay and dated at 18,940 ± 1,100 years old (Jones, 1967); these fossils suggest that Pleistocene water temperatures in this region were similar to those that exist today in the Arctic (Addicott and Greene, 1974).

A large amount of sediment was supplied to the immediate area of Monterey Bay throughout the middle Pleistocene by the Salinas and Pajaro Rivers and by smaller streams (Martin, 1964, p. 139). Much of this sediment accumulated in the Watsonville lowlands. The development of extensive sand dune fields is evidenced today by the eolian Aromas Sand and older Pleistocene dunes that exist on land and offshore between Aptos and Monterey (Pl. 3). As the courses of the Salinas and Pajaro Rivers and other streams shifted back and forth across the coastal plain, the eolian sands filled the abandoned parts of the channels. On land today, Aromas Sand lies directly upon flat-lying, fluvial deposits of buried Wisconsin stream channels (Dupré, 1975).

The close of the Pleistocene was marked by a major regional transgression in which Holocene sediments were deposited in newly inundated areas. Sediment gravity flows transported sediments down Monterey, Soquel, and Carmel Canyons, furthering the processes of canyon excavation and shaping. Slumping of unconsolidated to semi-consolidated materials from the canyon's walls has probably also aided the process of canyon exhumation (Martin, 1964, p. 150). A reasonable assumption is that slumped debris blocked the canyon axis and interrupted down-canyon transport from time to time. A slump appears to have recently blocked the upper reaches of the present-day Monterey Canyon, thereby disrupting the down-canyon transport of sediment until the slump either is broached or overtopped. During the late Pleistocene or early Holocene the Salinas River shifted course to its present position (Martin, 1964, p. 140), at which time the present Salinas River delta began to form. This delta appears to be accumulating most of the flood-borne sediment of the Salinas River, although some is carried beyond the shelf edge into Monterey Canyon.

GEOLOGIC HISTORY WEST OF THE PALO COLORADO-SAN GREGORIO FAULT ZONE

Regional structure and stratigraphy west of the Palo Colorado-San Gregorio fault zone is different and less well understood than that known east of the fault zone. Because of right slip along faults within the Palo Colorado-San Gregorio and Monterey Bay fault zones, and along the Ascension Fault, differing structural units are juxtaposed on either side of the Sur sliver. Little is known about the basement configuration west of the Sur sliver. Seismic reflection profiles in the region show an acoustical basement, which may not represent the true basement surface, with sediment of presumed late Tertiary age lying unconformably upon it (Fig. 5).

Several prominent basins and ridges are present along the outer continental shelf of central California (Curray, 1965, 1966; Hoskins and Griffiths, 1971; Silver and others, 1971; fig. 40). The outermost ridge (Santa Cruz high of Hoskins and Griffiths, 1971) lies northwest of Monterey Bay and south of the Farallon Islands. The second ridge (Pigeon Point high of Hoskins and Griffiths, 1971) lies farther shoreward and northward of Monterey Bay. Between these two ridges lies the outer Santa Cruz basin of Hoskins and Griffiths (1971). South of the outer Santa Cruz basin three stratigraphic sequences bounded by major unconformities have been identified in the seismic profiles: a pre-Tertiary to early Tertiary sequence, a middle Tertiary sequence, and a late Tertiary-to-Quaternary sequence. Lithology of the basement complex in this latter area is not known. The pre-Tertiary to early Tertiary sequence may be composed of crystalline basement rocks or well lithified Oligocene and Cretaceous sedimentary rocks as suggested by Hoskins and Griffiths (1971, p. 218). The middle Tertiary sequence lies unconformably upon the acoustical basement and acoustically looks similar to the middle Miocene Monterey Formation observed in seismic reflection profiles east of the Palo Colorado-San Gregorio fault zone (Fig. 33). Probable Pliocene sedimentary rocks unconformably, or locally disconformably, overlie rocks of the middle Tertiary sequence (Figs. 33 and 34) and compose the lower part of the late Tertiary-to-Quaternary sequence. The upper part of this sequence is composed of unconsolidated deposits that conformably lie upon and locally interfinger with Pliocene sediments.

ROLE OF FAULTING IN SUBMARINE CANYON DEVELOPMENT

New evidence of faulting offshore in the Monterey Bay region suggests that the headless canyons located on the slope north of Monterey Bay, the anomalous meander in Monterey Canyon, and the 90° shift in courses of lower Monterey and Carmel Canyons all resulted from lateral faulting. Palinspastic reconstructions indicate that the inactive (?) submarine canyons present on the slopes north of Monterey Bay are displaced from their original positions near the lower part of Monterey Canyon. The meander in Monterey Canyon and the shift in course of lower Monterey and Carmel Canyons resulted from erosion along fault zones weakened by strike-slip faulting.

Origin of many headless canyons is unknown and has led to much speculation (Shepard and Dill, 1966). The model presented here gives an alternate explanation for the development of headless canyons in many areas and specifically those located along continental margins subjected to strike-slip faulting. The existence of canyons that just notch the continental shelf and are far removed from any major source of sediment is a paradox. In areas where evidence clearly demonstrating a fluvial origin for headless canyons is absent, and strike-slip faulting has been, or is, active, palinspastic reconstruction may demonstrate past alignment of headless canyons with features that could have supplied or focused the erosional processes needed for development. This hypothesis is developed from the present-day canyon configurations and fault patterns that exist in the Monterey Bay region and that were discussed fully in the preceding pages.

Approximately 20 m.y. ago, right-lateral strike-slip began in the Southern California Continental Borderland (Atwater, 1970), the location of the Monterey Bay region prior to its displacement northward along the San Andreas fault. Motion along the Ascension fault likely preceded movement on the San Andreas Fault due to the eastward movement of the

Farallon plate and northward migration of the Mendocino triple junction. Right-slip on the Ascension fault displaced northward the lower part of Monterey Canyon that had been eroded subaerially during the Zemorrian uplift in the Monterey Bay area (Figs. 42d and 43a; Clark and Rietman, 1973). The displaced canyon, inactive and buried at the time of its displacement, was later rejuvenated through excavation in the Pleistocene as Pioneer Canyon, some 110 km northwest of the present-day Monterey Canyon.

The unnamed headless canyon that exists today between Pioneer and Ascension Canyons formed in the same manner as Pioneer Canyon, some time between middle and late Miocene time (Fig. 43b). Activity ceased along Ascension fault between 14 and 10 m.y. ago, as suggested by unfaulted Pliocene(?) sediments overlying the fault in seismic profiles; stress was apparently transferred eastward with strike-slip initiated along the Palo Colorado-San Gregorio fault zone (Fig. 43c, d).

Faults within the Monterey Bay fault zone are shown in the seismic reflection profiles to displace Quaternary and older rocks. Initiation of fault activity within this zone is unknown, but because of its relationship to the Palo Colorado-San Gregorio fault zone (Pl. 5) activity is assumed to have started at nearly the same time as initiation of motion along the Palo Colorado-San Gregorio fault zone (Fig. 43e).

Evolution of the present configuration of the coastline in the Monterey Bay region began with initiation of activity along faults within the Palo Colorado-San Gregorio and Monterey Bay fault zones. The Monterey Peninsula, a sliver between two active faults within the Santa Lucia block, may have begun to migrate northwestward at this time (Fig. 43e, f). Also, right-lateral displacement along the Palo Colorado-San Gregorio fault zone moved the older channels of the lower Monterey Canyon and the unnamed buried canyon that bisects the Monterey block (Fig. 15) northwestward away from the upper part of these channels. Ascension Canyon (Fig. 43e), located northwest of the present-day Monterey Canyon (Pl. 1), may have begun to develop as a seaward channel to Monterey Canyon, becoming displaced from Monterey Canyon by progressive offset along the Palo Colorado-San Gregorio fault zone. If the heads of Ascension Canyon, Pioneer Canyon, and the canyon intermediate between the two have been displaced from the lower Monterey Canyon, then right-lateral motion or sediment transport down Monterey Canyon appear to have increased since about 7 m.y. ago (Fig. 43e, f, g, h). Such an increase in the rate of offset would explain the relatively close spacing (1 to 4 km) of the heads of Ascension Canyon as compared to the spacing (about 30 km) between Pioneer Canyon and the canyons between Pioneer and Ascension Canyons; the greater distance between the latter two results from offset along Ascension fault prior to about 7 m.y. ago. This magnitude of increase in the rate of offset along coastal faults beginning about 10 m.y. ago was proposed by Hein (1973), and may coincide with the transfer of stress from Ascension fault westward to the Palo Colorado-San Gregorio fault zone. A change in the direction of motion between the North American and Pacific plates at about this time also has been postulated by Silver (1974).

Canyons and fans west of the Palo Colorado-San Gregorio fault zone continued to be displaced northwestward throughout late Tertiary and Quaternary time. Displacement along faults of the Palo Colorado-San Gregorio and Monterey Bay fault zones is continuing today (Fig. 43g, h). Meanders in Monterey Canyon were probably initiated by right-lateral slip along faults associated with the Palo Colorado-San Gregorio system.

The meander within the Monterey Bay fault zone appears to be a consequence of erosion in areas weakened by faulting and is enhanced by the presence of resistant basement rocks at shallow depths within a fault sliver which is bounded by the meander. The canyon was cut along a westward trend until basement rocks were encountered in the fault sliver. Erosion then proceeded northwestward along the fault, skirting the more resistant basement mass. Once past the granitic sliver, the channel was cut westward again until it encountered less resistant rocks in the fault zone on the opposite side of the sliver. Erosion then followed this fault until the older channel farther down-canyon was recaptured.

The anomalous projection of the Monterey Peninsula from an otherwise smooth, crescentic coastline probably was caused by displacement of about 10 km along faults within the Monterey Bay fault zone, principally along the Tularcitos-Navy fault (Fig. 43g, h). Similarly, other parts of the coastline slivered between faults within the Monterey Bay fault zone have been moved right-laterally into their present position.

Exhumation of the buried, headless canyons that had been displaced earlier from their upper reaches along faults offshore commenced during the lowest stand of sea level in Wisconsin (?) time. Differential compaction of the older fill of these canyons presumably would form depressed troughs along which streams transporting sediments to the Wisconsin shoreline (near the edge of the present continental shelf) would preferentially develop. Excavation of these canyons continued through the Pleistocene, and perhaps is continuing today in Pioneer and Ascension Canyons.

The entire Salinian block was being displaced northward along the San Andreas fault (Atwater, 1970) at the same time right-slip was occurring along the western edge of the Salinian block, and along faults within the Palo Colorado-San Gregorio and Monterey Bay fault zones and other offshore faults. During the time the Monterey Bay area was emergent (Zemorrian time), the Monterey Bay region of the Salinian block was located adjacent to the present-day Transverse Ranges. Continued right-slip on the San Andreas fault moved this area into its present position in relation to the overall regional features, but small scale displacement on faults within the Salinian block shaped and positioned the coastline and physiographic features within the Monterey Bay region.

It is proposed here that the headless canyons now present along the continental slope north of Monterey Bay have been displaced from the lower part of Monterey Canyon along a series of faults that includes the Palo Colorado-San Gregorio and Monterey Bay fault zones. A total offset of approximately 110 km is indicated by the present separation of Monterey and Pioneer canyons (Fig. 43h); this offset has taken place since early Miocene time during the period when subduction of the Farallon plate ceased and northward migration of the Mendocino triple junction took place (McKenzie and Parker, 1967; Morgan, 1968; Atwater, 1970). About 70 km of this offset appears to have been on the Palo Colorado-San Gregorio and Monterey Bay fault zones, based on the distance between the most northwest head of Ascension Canyon and Monterey Canyon. The total displacement along the San Andreas fault since about early Miocene time is approximately 305 km (Turner and others, 1970; Matthews, 1973; Huffman and others, 1973). In addition, post-middle Miocene displacement along the Reliz-Rinconada fault zone of about 64 km has been postulated by Dibblee (1972). The combined offsets along all of these fault zones amount to 479 km. This is 91 km less than the estimated total displacement between the Pacific and North American plates (570 km) calculated by Atwater and Molnar (1973). However, this amount of displacement may have occurred along other faults (Johnson and Normark, 1974) within the Santa Lucia block, and perhaps along faults within the Salinas or Zayante-Vergeles blocks as well.

This model proposes significant post-middle Miocene motion along the Palo Colorado-San Gregorio fault zone. This is a point of conjecture in recent studies of this region. Ross (1976) supports the possibility of significant post-Cretaceous strike-slip, basing his conclusion on the fact that dissimilar metamorphic terranes are separated by the rather continuous Palo Colorado-Coast Ridge fault zone--a suggestion of major displacement. However, Graham (1976) contends that displacement must occur on a fault offshore, along the Sur shelf, or on faults near the Sur fault zone, rather than on the Palo Colorado fault within the Santa Lucia block. It is noteworthy that the Palo Colorado-San Gregorio-Coast Ridge fault zone refers to several faults, many of which exhibit active seismicity, rather than to a single trace. The style of faulting observed in these fault zones suggests that the total offset along the broadly defined San Andreas system must be distributed along many en echelon faults within the zones, rather than along any single trace. Therefore, the mapped width of these zones may increase once faults outside of the present zones are shown to have similar post-middle Miocene offset.

This model of progressive offset of the lower Monterey Canyon can be readily tested. If the headless canyons now located north of Monterey Bay originally formed as lower reaches of Monterey Canyon, then granitic gravels buried within these canyons should have been derived from the granitic "Monterey mass" described by Ross (1973). If, however, these canyons formed in their present positions in relation to the continental source terrane to the east, then their fill should consist largely of granitic debris derived from the Ben Lomond block north of Monterey Bay. R. W. Kistler (oral commun., 1976) believes that the isotopic ratios of the Monterey granitic rocks differ from those of the granitic rocks in the Ben Lomond block. If so, granitic clasts in the beheaded submarine canyons north of Monterey Bay can be identified as to source.

Submarine fans, which may have developed west of the Salinian block in middle Miocene time and have been displaced to the north by post-middle Miocene faulting, should be buried beneath the continental slope between Año Nuevo Point and the Farallon Islands. Marine seismic reflection profiling should reveal the location of these fans, and if they are not deeply buried, they may possibly be sampled. If the fans developed in middle Miocene time near the terminus of the Monterey paleodrainages as proposed, they should contain arkosic sands derived from granitic basement rocks of the "Monterey mass" (Ross, 1973) and possibly also reworked Paleogene sediments. Modern seismic reflection techniques also should permit detection of buried paleodrainages. The unnamed buried canyon cut into basement rocks of northern Monterey Bay is well defined on seismic reflection records, and its westward extension should be readily identifiable if present in the basement rocks west of the Palo Colorado-San Gregorio fault zone and north of Monterey Bay. If this feature can be located, a precise measurement of post-middle Miocene displacement along the Palo Colorado-San Gregorio fault zone can be obtained.

FUTURE

Continued right-slip along the Palo Colorado-San Gregorio fault zone will result in northward displacement of the Sur coastal region west of the fault zone (with the Pacific plate); eventually this region will be positioned offshore to the west of Monterey Bay. Continued right-slip along the Monterey Bay fault zone will carry the Monterey Peninsula farther out into the bay. Should motion continue, the Monterey Peninsula will be carried northward into the Palo Colorado-San Gregorio fault zone; if the latter fault zone remains active, it will in turn carry the peninsula still farther northward. Should the peninsula remain emergent throughout its northerly migration, Monterey Bay will shallow and eventually will be cut off from the open ocean. Barring tectonic or eustatic submergence or elevation of sea level, the bay eventually may fill with sediments supplied by the Salinas, Pajaro, and San Lorenzo Rivers.

The time required for this highly speculative scenario of the closing and filling of Monterey Bay is dependent on the rates of motion along the fault zones involved, which have not yet been determined. However, if as postulated above, displacements along these fault zones totaling approximately 110 km have occurred in the last 20 m.y., a tentative rate of 0.5 cm/yr is suggested. Assuming constant motion, approximately 5.5 to 10 m.y. would be required to totally isolate Monterey Bay from the open ocean. However, a constant motion model is hard to defend, as most recent data suggest a model of sporadic motion (Atwater and Molnar, 1973; Hein, 1973). The main motion between the North American and Pacific plates is now along the San Andreas fault, which increased its rate of motion when the Gulf of California opened, approximately 5 m.y. ago (Atwater and Molnar, 1973). Although the main plate motion is along the San Andreas fault, stress is released on faults west of the San Andreas (these faults are considered to be part of the San Andreas fault system (Greene and others, 1973)). Displacement along faults within the system is expected to continue as long as there is motion between the two plates.

REFERENCES

_____1929-1968, Bulletin of Seismographic Stations: University of Calif., Berkeley (various authors, 1962-1968 issues).

Addicott, W. O., 1973, Oligocene molluscan biostratigraphy and paleontology of the lower part of the type Temblor Formation, California: U. S. Geol. Survey Prof. Paper 791, p. 1-48.

Addicott, W. O., and Greene, H. G., 1974, Zoogeographic significance of a late Quaternary occurrence of the bivalve Astarte off the central California coast: The Veliger, California Malacozoological Soc., Inc., v. 16, no. 3, p. 249-252.

Albee, A. L., and Smith, J. L., 1967, Geological criteria for nuclear power plant location: Society of Mining Engineers Trans., v. 238, p. 430-434.

Alexander, C. S., 1953, The marine and stream terraces of the Capitola-Watsonville area: Univ. California Pub. Geog., v. 10, p. 1-44.

Allen, J. E., 1946, Geology of the San Juan Bautista quadrangle, California: Calif. Div. Mines and Geology Bull. 133, 112 p.

Allen, C. R., St. Amand, P., Richter, C. F., and Nordquist, J. M., 1965, Relationship between seismicity and geologic structure in the southern California region: Seismol. Soc. America Bull., v. 55, no. 4, p. 753-797.

Arnal, R. E., Dittmer, E., and Shumaker, E., 1974, Sand transport studies in Monterey Bay, California: Cont. Moss Landing Marine Lab., Tech. Pub. 73-5, pub. National Seagrant Program.

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geol. Soc. America Bull., v. 81, no. 12, p. 3513-3536.

Atwater, T., and Molnar, P., 1973, Relative motion of the Pacific and North American plates deducted from sea-floor spreading in the Atlantic, Indian, and South Pacific Oceans: Stanford Univ. Publ. Geol. Sci., v. 13, p. 136-148.

Baldwin, T. A., 1963, Land forms of the Salinas Valley, California: in Guidebook to the Geology of the Salinas Valley and the San Andreas Fault: Pacific Sect., Am. Assoc. Petroleum Geologists-Soc. Econ. Paleontologists and Mineralogists Annual Spring Field Trip, p. 11-13.

Beal, C. H., 1915, The geology of the Monterey Quadrangle, California: M. A. thesis, Stanford Univ., Stanford, Calif., 87 p.

Bonilla, M. G., 1967, Historic surface faulting in continental United States and adjacent parts of Mexico: U. S. Geol. Survey open-file rept.; also U. S. Atomic Energy Comm. Rept. TID-24124, 36 p.

Bonilla, M. G., and Buchanan, J. M., 1970, Interim report on worldwide historic surface faulting: U.S. Geol. Survey open-file rept., 32 p.

Bowen, O. E., Jr., 1965, Stratigraphy, structure, and oil possibilities in Monterey and Salinas quadrangles, California (abs.): Am. Assoc. Petroleum Geologists Bull., v. 49, no. 7, p. 1081.

_____ 1969, Geologic map of Monterey quadrangle: California Div. Mines and Geology open-file map, scale 1:62,500.

Bowen, O. E., Jr., and Gray, C. H., Jr., 1959, Geology and economic possibilities of the limestone and dolomite deposits of the northern Gabilan Range, California: California Div. Mines Spec. Rept. 56, 40 p.

Brabb, E. E. (compiler), 1970, Preliminary geologic map of the central Santa Cruz Mountains, California: U. S. Geol. Survey open-file map, scale 1:62,500.

Bradley, W. C., and Griggs, G. B., 1976, Form, genesis, and deformation of central California wave-cut platforms: Geol. Soc. America Bull., v. 87, no. 3, p. 433-449.

Brooks, R. A., 1973, A bottom gravity survey of the shallow water regions of southern Monterey Bay and its geological interpretation: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 57 p.

Bufe, C. G., Lester, F. W., Meagher, K. L., and Wesson, R. L., Catalog of earthquakes along the San Andreas fault system in central California, April-June, 1973: U. S. Geol. Survey open-file rept. 75-125, 44 p.

Burford, R. O., 1971, Fault creep and related seismicity along the San Andreas fault system between Pinnacles National Monument and San Juan Bautista (abs.), in Cordilleran Sec. 67th Ann. Mtg., Hayward, Calif: Geol. Soc. America, Abs. with Program, v. 2, no. 2, p. 90-91.

California Division of Mines and Geology, 1965, Potassium-argon age dates from some California localities: California Div. Mines and Geology Mineral Inf. Service, v. 18, no. 1.

California State Department of Water Resources, 1964, Crustal strain and fault movement investigation: faults and earthquake epicenters in California: Calif. Dept. Water Resources Bull. 116-2, 96 p.

_____1970, Sea-water intrusion into the lower Salinas Valley, a progress report: Calif. Dept. Water Resources open-file report, 28 p.

Christensen, M. N., 1966, Quaternary of the California Coast Ranges, in Geology of northern California, E. H. Bailey (ed.): Calif. Div. Mines and Geology Bull. 190, p. 305-314.

Clark, B. L., 1930, Tectonics of the Coast Ranges of middle California: Geol. Soc. America Bull., v. 41, p. 747-828.

Clark, J. C., 1966, Tertiary stratigraphy of the Felton-Santa Cruz area, Santa Cruz Mountains, California: Ph.D. thesis, Stanford Univ., Stanford, Calif., 184 p.

_____1970a, Geologic map of the Davenport area, Santa Cruz County, California: U. S. Geol. Survey open-file rept., scale 1:24,000.

_____ (compiler), 1970b, Preliminary geologic and gravity maps of the Santa Cruz-San Juan Bautista area, Santa Cruz, Santa Clara, Monterey and San Benito Counties, California: U. S. Geol. Survey open-file map, scale 1:125,000.

Clark, J. C., and Rietman, J. D., 1973, Oligocene stratigraphy, tectonics, and paleogeography southwest of the San Andreas fault, Santa Cruz Mountains and Gabilan Range, California Coast Ranges: U. S. Geol. Survey Prof. Paper 783, 18 p.

Clark, J. C., Dibblee, T. W., Jr., Greene, H. G., and Bowen, O. E., Jr., 1974, Preliminary geologic map of the Monterey and Seaside 7.5-minute quadrangles, Monterey County, California: U. S. Geol. Survey Misc. Field Studies Map MF-577, scale 1:24,000.

Clarke, S. H., Jr., Howell, D. G., and Nilsen, T. H., 1975, Paleogene geography of California: Paleogene Symposium, Pac. Section, Soc. Econ. Paleontologists and Mineralogists, p. 121-154.

Compton, R. R., 1966, Granitic and metamorphic rocks of the Salinian block, California Coast Ranges, <u>in</u> Geology of northern California, E. H. Bailey (ed.): Calif. Div. Mines and Geology Bull. 190, p. 277-287.

Cooper, A., 1971, Structure of the continental shelf west of San Francisco, California: U. S. Geol. Survey open-file rept., 65 p.

Cronyn, B. C., 1973, An underwater gravity survey and investigation of northern Monterey Bay: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 57 p.

Cummings, J. C., Touring, R. M., and Brabb, E. E., 1962, Geology of the northern Santa Cruz Mountains, California, in Bowen, O. E., Jr. (ed.), Geologic guide to the gas and oil fields of northern California: California Div. Mines Bull. 181, p. 179-220.

Curray, J. R., 1965, Structure of the continental margin off central California: Trans. New York Acad. Sci., ser. II, v. 27, no. 7, p. 794-801.

_____1966, Geologic structure of the continental margin from subbottom profiles, northern and central California: in Geology of northern California, E. H. Bailey (ed.), Calif. Div. Mines and Geology Bull. 190, p. 337-342.

Curtis, G. H., Evernden, J. F., and Lipson, J., 1958, Age determination of some granitic rocks in California by the potassium-argon method: Calif. Div. Mines Spec. Rept. 54, 16 p.

Davidson, G., 1897, The submerged valleys of the coast of California U.S.A., and of Lower California, Mexico: Calif. Acad. Sci. Proc., 3rd ser., v. 1, p. 73-103, rev. by W.S.T. Smith, 1897, Jour. Geology, v. 5, p. 533-534.

Dibblee, T. W., Jr., 1972, The Rinconada fault in the southern Coast Ranges, California, and its significance: Geol. Soc. America Abs. with Programs, Cordilleran Sec., v. 4, no. 3, p. 145-146.

_____1973, Geologic map of the Pt. Sur Quadrangle, California: U.S. Geol. Survey open-file map, scale 1:62,500.

Dibblee, T. W., Jr., and Clark, J. C., 1973, Geologic map of the Monterey Quadrangle, California: U. S. Geol. Survey, open-file map, scale 1:62,500.

Dietz, R. S., 1952, Geomorphic evolution of continental terrace (continental shelf and slope): Amer. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1802-1819.

Dohrenwend, J. C., 1971, Marine geology of the continental shelf between Point Lobos and Point Sur, California: A reconnaissance: Independent Research Rept., Dept. Geology, Stanford Univ., Stanford, Calif., 60 p.

Dorman, C. E., 1968, The southern Monterey Bay littoral cell: a preliminary budget study: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 234 p.

Dupré, W. R., 1975, Quaternary history of the Watsonville lowlands, north-central Monterey Bay region, California: Ph.D. thesis, Stanford Univ., Stanford, Calif., 145 p.

Durham, D. L., 1965, Evidence of large strike-slip displacement along a fault in the southern Salinas Valley, California: U.S. Geol. Survey Prof. Paper 525-D, p. D106-D111.

_____1970, Geology of the Sycamore Flat and Paraiso Springs quadrangles, Monterey County, California: U.S. Geol. Survey Bull. 1285, 34 p.

_____1974, Geology of the southern Salinas Valley: U.S. Geol. Survey Prof. Paper 819, 111 p.

Ellsworth, W. L., 1971, Geology of the continental shelf, Point Lobos to Point Sur, California: Independent Research Rept., Dept. Geophysics, Stanford Univ., Stanford, Calif., 33 p.

Emery, K. O., and Shepard, F. P., 1945, Lithology of the sea floor off southern California: Geol. Soc. America Bull., v. 56, p. 431-478.

Fairborn, J. W., 1963, Gravity survey and interpretation of the northern portion of the Salinas Valley: student rept., Stanford Univ., Stanford, Calif., 33 p.

Frydenlund, D. D., 1974, Structural geology of the continental margin off Pt. Año Nuevo, California: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 55 p.

Galliher, E. W., 1930, A study of the Monterey Formation, California, at the type locality: M.A. thesis, Stanford Univ., Stanford, Calif.

_____ 1932, Sediments of Monterey Bay, California: in Mining in California, Calif. Div. Mines and Geology, v. 28, no. 1, p. 42-79.

Gilbert, W. G., 1971, Sur fault zone, Monterey County, California: Ph.D. thesis, Dept. Geol., Stanford Univ., Stanford, Calif., 80 p.

Graham, S. A., 1976, Tertiary sedimentary tectonics of the central Salinian block of California: Ph.D. thesis, Stanford Univ., Stanford, Calif., 510 p.

Greene, H. G., 1970, Geology of southern Monterey Bay and its relationship to the ground water basin and salt water intrusion: U.S. Geol. Survey open-file rept., 50 p.

Greene, H. G., Lee, W. H. K., McCulloch, D. S., and Brabb, E. E., 1973, Faults and earthquakes in the Monterey Bay region, California: U. S. Geol. Survey, San Francisco Bay Region Environment and Resources Planning Study, Basic Data Contribution 58, 14 p.

Greene, H. G., McCrory, P. A., Lajoie, K. R., Ellsworth, W. L., and Gawthrop, W. H., in prep. Map showing faults and seismicity, San Mateo, Santa Cruz, and Monterey counties, California: U.S. Geol. Survey open-file map, scale 1:250,000.

Gribi, E. A., Jr., 1967, The Salinas basin oil province, in Payne, M. B. (chm.), Guidebook to the geology of Salinas Valley and the San Andreas fault, p. 16-27: Pacific Secs., Am. Assoc. Petroleum Geologists and Soc. Econ. Paleontologists and Mineralogists, 168 p.

Griggs, G. B., 1973, Recent earthquake activity between Monterey and Half Moon Bay, California: Calif. Geology, Calif. Div. Mines and Geology, p. 101-110.

Hall, N. T., Sarna-Wojcicki, A. M., and Dupré, W. R., 1974, Faults and their potential hazards in Santa Cruz County: U.S. Geol. Survey Misc. Field Studies Map MF-626, scale 1:62,500.

Hamilton, W., 1969, Mesozoic California and the underflow of Pacific mantle: Geol. Soc. America Bull., v. 80, no. 12, p. 2409-2430.

Hein, J. R., 1973, Deep-sea sediment source areas: implications of variable rates of movement between California and the Pacific plate: Nature, v. 241, p. 40-41.

Hickey, J. J., 1968, Hydrogeologic study of the Soquel-Aptos area, Santa Cruz County, California: U.S. Geol. Survey open-file report, 48 p.

Hill, M. L., and Dibblee, T. W., Jr., 1953, San Andreas, Garlock, and Big Pine faults, California - a study of the character, history and tectonic significance of their displacements: Geol. Soc. America Bull., v. 64, no. 4. p. 443-458.

Hoskins, E. G., and Griffiths, J. R., 1971, Hydrocarbon potential of northern and central California offshore: in Cram, I. H. (ed.), Future petroleum provinces of the U.S. - their geology and potential: Amer. Assoc. Petroleum Geologists Mem. 15, v. 1, p. 212-228.

Howell, D. G., 1975, Hypothesis suggesting 700 kilometres of right slip in California along northwest oriented faults: Geology, v. 3, no. 2, p. 81-83.

_____1976, Aspects of the geologic history of the California Continental Borderland, in Aspects of the geologic history of the California Continental Borderland, D. G. Howell (ed.): Pac. Sec. American Assoc. Pet. Geol., Misc. Publ. 24, p. 2-5.

Huffman, O. F., Turner, O. L., and Jack, R. N., 1973, Offset of late Oligocene-early Miocene volcanic rocks along the San Andreas fault in central California, _in_ Kovach, R. L., and Nur, A. (eds.), Proc. Conf. Tectonic Problems of the San Andreas fault system: Stanford Univ. Pubs. Geol. Sci., v. 13, p. 368-373.

Iida, K., 1965, Earthquake magnitude, earthquake fault, and source dimensions: Nagoya Univ., Jour. Earth Sci., v. 13, no. 2, p. 115-132.

Ingle, J. C., Jr., 1973, Summary comments on Neogene biostratigraphy, physical stratigraphy, and paleo-oceanography in the marginal northeastern Pacific Ocean, _in_ Kulm, L. D., von Huene, R., _et al_., 1973, Initial Reports of the Deep Sea Drilling Project: vol. 18, Washington, D. C. (U. S. Gov. Printing Office), p. 949-960.

Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geol. Soc. America Bull., v. 65, no. 9, p. 937-938.

Jennings, C. W., and Burnett, J. L., 1961, Geologic map of California, _in_ O. P. Jenkins (ed.), San Francisco sheet: Calif. Div. Mines and Geology, scale 1:250,000.

Jennings, C. W., and Strand, R. G., 1958, Geologic map of California, _in_ O. P. Jenkins (ed.), Santa Cruz sheet: Calif. Div. Mines and Geology, scale 1:250,000.

Jensen, J. A., 1976, A photographic reconnaissance of the microrelief in the Monterey and Carmel submarine canyons, California: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 142 p.

Johnson, W. M., 1855, Extracts from a report on the features of the country between Pajaro and Salinas River, California: Ann. Rept. U. S. Coast Survey, 1854, app. 22, p. 31-32.

Johnson, J. D., and Normark, W. R., 1974, Neogene tectonic evolution of the Salinian block, west-central California: Geology, v. 2, p. 11-16.

Jones, R. E., 1967, A Hydrodamalis skull fragment from Monterey Bay, California: Jour. Mammalogy, v. 48, no. 1, p. 143-144.

Kerr, P. F., and Schenck, H. G., 1925, Active thrust-faults in San Benito County, California: Geol. Soc. America Bull., v. 36, no. 3, p. 465-494.

King, P. B., 1959, The Evolution of North America: Princeton Univ. Press, Princeton, New Jersey, 189 p.

Kleinpell, R. M., 1938, Miocene stratigraphy of California: Tulsa, Okla., Am. Assoc. Petroleum Geologists Pub., 450 p.

Lawson, A. C., 1893, The geology of Carmelo Bay: California Univ. Pubs. Geol. Sci. Bull., v. 1, no. 1, p. 1-59.

Lawson, A. C., and others, 1908, The California earthquake of April 18, 1906, Report of the State Earthquake Investigation Commission: Carnegie Inst. Washington Pub. 87, 3 v., 1 atlas.

Lee, W. H. K., Roller, J. C., Bauer, P. G., and Johnson, J. D., 1972a, Catalog of earthquakes along the San Andreas fault system in central California for the year 1969: U. S. Geol. Survey open-file rept., 48 p.

Lee, W. H. K., Roller, J. C., Meagher, K. L., and Bennett, R. E., 1972b, Catalog of earthquakes along the San Andreas fault system in central California for the year 1970: U. S. Geol. Survey open-file rept., 73 p.

Lee, W. H. K., Meagher, K. L., Bennett, R. E., and Matamoros, E. E., 1972c, Catalog of earthquakes along the San Andreas fault system in central California for the year 1971: U. S. Geol. Survey open-file rept., 67 p.

Louderback, G. D., 1942, History of the University of California seismographic stations and related activities: Bull. Seismol. Soc. America, v. 32, p. 205-230.

_____1947, California earthquakes of the 1830's: Bull. Seismol. Soc. America, v. 37, p. 33-74.

Mallory, V. S., 1959, Lower Tertiary biostratigraphy of the California coast ranges: Tulsa, Okla., Am. Assoc. Petroleum Geologists Pub., 416 p.

Malone, M. J., 1970, A pebble-cobble deposit in Monterey Bay, California: M. S. thesis, Naval Postgraduate School, Monterey, Calif., 45 p.

Martin, B. D., 1964, Monterey submarine canyon, California: Genesis and relationship to continental geology: Ph.D. thesis, Univ. Southern California, Los Angeles, Calif., 249 p.

Martin, B. D., and Emery, K. O., 1967, Geology of Monterey Canyon, California: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 2281-2304.

Matthews, V., 1973, Pinnacles-Neenach correlation: A restriction for models of the Transverse Ranges and the big bend in the San Andreas fault: Geol. Soc. America Bull., v. 84, no. 2, p. 683-688.

McKee, E. D., and Weir, G. W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geol. Soc. America Bull., v. 64, no. 4, p. 381-390.

McKenzie, D. P., and Parker, R. L., 1967, The North Pacific: an example of tectonics on a sphere: Nature, v. 216, p. 1276-1280.

Moore, D. G., 1969, Reflection profiling studies in the California Continental Borderland: Structure and Quaternary turbidite basins: Geol. Soc. America Special Paper 107, Geol. Soc. America, Boulder, Colo., 142 p.

Morgan, W. J., 1968, Rises, trenches, great faults and crustal blocks: Jour. Geophys. Research, v. 73, p. 1959-1982.

Muir, K. S., 1972, Geology and ground water of the Pajaro Valley area, Santa Cruz and Monterey counties, California: U. S. Geol. Survey open-file report, 33 p.

Nettleton, L. L., 1971, Elementary gravity and magnetics for geologists and seismologists: Society of Exploration Geophysicists, 118 p.

Nilsen, T. H., and Link, M. H., 1975, Stratigraphy, sedimentology and offset along the San Andreas fault of Eocene to lower Miocene strata of the northern Santa Lucia Range and the San Emigdio Mountains, Coast Ranges, central California: Paleogene Symposium, Pac. Section, Soc. Econ. Paleontologists and Mineralogists, p. 367-400.

Page, B. M., 1966, Geology of the Coast Ranges of California, in Bailey, E. H. (ed.), Geology of northern California: Calif. Div. Mines and Geology Bull. 190, p. 255-275.

_____1970a, Sur-Nacimiento fault zone of California: Continental margin tectonics: Geol. Soc. America Bull., v. 81, no. 3, p. 667-690.

_____1970b, Time of completion of underthrusting of Franciscan beneath Great Valley rocks west of Salinian block, California: Geol. Soc. America Bull., v. 81, p. 2825-2833.

Radbruch, D. H., Bonilla, M. G., Lennert, B. J., Blanchard, F. B., Laverty, C. L., Cluff, L. S., and Steinbrugge, K. V., 1966, Tectonic creep in the Hayward fault zone, California: U. S. Geol. Survey Circular 525, 13 p.

Reed, R. D., 1925, The post-Monterey disturbance in the Salinas Valley, California: Jour. Geology, v. 33, p. 588-607.

_____1933, Geology of California: Amer. Assoc. Petroleum Geologists, Tulsa, Okla., 355p.

Richter, C. F., 1958, Elementary seismology: W. H. Freeman & Co., San Francisco, Calif., 768 p.

Ross, D. C., 1973, Are the granitic rocks of the Salinian block trondhjemitic?: Jour. Res. U.S. Geol. Survey, v. 1, no. 3, p. 251-254.

_____1974, Map showing basement geology and locations of wells drilled to basement, Salinian block, central and southern Coast Ranges, California: U.S. Geol. Survey Misc. Field Studies Map MF-588, scale 1:500,000.

_____1976, Reconnaissance geologic map of pre-Cenozoic basement rocks, northern Santa Lucia Range, Monterey County, California: U.S. Geol. Survey, Misc. Field Studies Map, MF-750, scale 1:25,000.

Ross, D. C., and Brabb, E. E., 1972, Petrography and structural relations of granitic basement rocks in the Monterey Bay area, California: Jour. Res. U. S. Geol. Survey, v. 1, p. 273-282.

Rusnak, G. A., 1966, The continental margin of northern and central California, _in_ E. H. Bailey (ed.), Geology of northern California: Calif. Div. Mines and Geology Bull. 190, p. 325-335.

Schombel, L. F., 1943, Soledad quadrangle (Calif.): Calif. Div. Mines and Geology Bull. 118, p. 467-470.

Shepard, F. P., 1948, Investigation of the head of Monterey Submarine Canyon: Scripps Inst. Oceanography, Submarine Geology Rept. 1, 15 p.

Shepard, F. P., and Dill, R. F., 1966, Submarine canyons and other sea valleys: Rand McNally, Chicago, Ill., 381 p.

Shepard, F. P., and Emery, K. O., 1941, Submarine topography off the California coast: Geol. Soc. America Spec. Paper No. 31, p. 103-112.

Sieck, H. C., 1964, A gravity investigation of the Monterey-Salinas area, California: student rept., Dept. Geophysics, Stanford Univ., Stanford, Calif., 40 p.

Silver, E. A., Curray, J. R., and Cooper, A. K., 1971, Tectonic development of the continental margin off central California: Geological Society of Sacramento, Annual Field Trip Guidebook, p. 1-10.

Silver, E. A., 1974, Basin development along translational continental margins, in Dickinson, W. R. (ed.), Geologic interpretations from global tectonics with applications for California geology and petroleum exploration: San Joaquin Geologic Society Short Course Notes.

_____1977, Are the San Gregorio and Hosgri fault zones a single fault system?: Geol. Soc. America (Abs. with Programs), Cordilleran Sec., 73rd Annual Meeting, vol. 9, no. 4, p. 500.

Simpson, J. P. III, 1972, The geology of Carmel Bay, California: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 74 p.

Slemmons, D. B., 1967, Pliocene and Quaternary crustal movements of the Basin and Range Province, U.S.A.: Osaka City Univ., Jour. Geo-Science, v. 10, Art. 1-11, p. 91-103.

Souto, A. P. D., 1973, A bottom gravity survey of Carmel Bay, California: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 57 p.

Spikes, C. H., 1973, A gravimetric survey of the Santa Cruz-Año Nuevo Point continental shelf and adjacent coastline: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 114 p.

Starke, G. W., and Howard, A. D., 1968, Polygenetic origin of Monterey Submarine Canyon: Geol. Soc. America Bull., v. 79, no. 7., p. 813-826.

Steinbrugge, K. V., 1968, Earthquake hazard in the San Francisco Bay area: a continuing problem in public policy: Institute of Governmental Studies, University of California, Berkeley, Calif., 80 p.

Suppe, J. E., 1970, Offset of Late Mesozoic basement terrains by the San Andreas fault system: Geol. Soc. America Bull., v. 81, p. 3253-3258.

Taliaferro, N. L., 1943, Geologic history and structure of the central Coast Ranges of California: Calif. Div. Mines and Geology Bull., 118, p. 119-163.

Tinsley, J. C. III, 1975, Quaternary geology of northern Salinas Valley, Monterey County, California: Ph.D. thesis, Stanford Univ., Stanford, Calif., 189 p.

Tocher, D., 1958, Earthquake energy and ground breakage: Seismol. Soc. America Bull., v. 48, no. 2, p. 147-153.

Trask, P. D., 1926, Geology of Point Sur Quadrangle, California: Univ. Calif. Publ. Bull. Dept. Geol. Sci., v. 16, no. 6, p. 119-186.

Turner, D. L., Curtis, G. H., Berry, F. A. F., and Jack, R. N., 1970, Age relationship between the Pinnacles and Parkfield felsites and felsite clasts in the southern Temblor Range, California: implications for San Andreas fault displacement: Geol. Soc. America Abs. with Programs, Cordilleran Sec., v. 2, p. 154-155.

Uchupi, E., and Emery, K. O., 1963, The continental slope between San Francisco, California and Cedros Island, Mexico: Deep-Sea Research, v. 10, p. 397-447.

Walrond, H., Thorup, R. R., Gribi, E. H., Jr., and Rogers, T. H., 1967, Geologic map of the Gabilan uplift and adjacent areas, Monterey, San Benito, Fresno and Santa Cruz Counties, in Guidebook, Gabilan Range and adjacent San Andreas fault: Pacific Sec., AAPG-SEPM Annual Field Trip.

Weaver, C. E., and others, 1944, Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America Bull., v. 55, no. 5, p. 569-598.

Wentworth, C. M., Bonilla, M. G., and Buchanan, J. M., 1972, Seismic environment of the sodium pump test facility site at Burro Flats, Ventura County,California: U. S. Geol. Survey open-file report, 42 p.

Wesson, R. L., Bennett, R. E., and Meagher, K. L., 1972, Catalog of earthquakes along the San Andreas fault system in central California, January-March, 1972: U.S. Geol. Survey open-file rept., 60 p.

Wesson, R. L., Bennett, R. E., and Lester, F. W., 1973, Catalog of earthquakes along the San Andreas fault system in central California, April-June, 1972: U.S. Geol. Survey open-file rept., 49 p.

Wesson, R. L., Lester, F. W., and Meagher, K. L., 1974a, Catalog of earthquakes along the San Andreas fault system in central California, Oct.-Dec. 1972: U.S. Geol. Survey open-file rept., 46 p.

_____1974b, Catalog of earthquakes along the San Andreas fault system in central California, Jan.-March 1973: U.S. Geol. Survey open-file rept. 74-186, 47 p.

Wolf, S. C., 1970, Coastal currents and mass transport of surface sediments over the shelf regions of Monterey Bay, California: Marine Geol., v. 8, p. 321-336.

Wood, H. O., and Heck, N. H., 1966, Earthquake history of the United States, Part II: Stronger earthquakes of California and western Nevada: U.S. Govt. Printing Office, Washington, D. C., 48 p.

Woodford, A. O., 1951, Stream gradients and Monterey sea valley: Geol. Soc. America Bull., v. 62, p. 799-852.

Woodring, W. P., 1938, Pliocene and Pleistocene deformation in the California Coast Ranges (abs.): Geol. Soc. America Bull., Proc. for 1937, v. 49, p. 212.

Woodson, W. B. III, 1973, A bottom gravity survey of the continental shelf between Point Lobos and Point Sur, California: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 112 p.

Wright, R. H. (comp.), 1972, Map showing locations of sampled data by radiocarbon methods in the San Francisco Bay region: U.S. Geol. Survey Misc. Field Studies Map MF-317, Scale 1:500,000.

Yancey, T. E., 1968, Recent sediments of Monterey Bay, California: Univ. Calif., Hydraulic Eng. Lab., Tech. Report HEL-2-18, Berkeley, Calif., 145 p.

Zardeskas, R. A., 1971, A bathymetric chart of Carmel Bay, California: M.S. thesis, Naval Postgraduate School, Monterey, Calif., 108 p.

APPENDIX I

METHODS AND PROCEDURES

Geophysical data in this report were collected during four surveys and consist of continuous, single channel, seismic reflection profiles, and of bathymetric and magnetic profiles. In the Monterey Bay area, the R/V POLARIS ran surveys in 1969 and 1970 and the R/V BARTLETT in 1969 and 1972. Data from the 1970 POLARIS survey are presented in Appendix III (Interpretation of Seismic Profiles) and in Appendix IV (Magnetic Profiles). On both POLARIS surveys, intermediate penetration, low resolution (sparker) and shallow penetration, high resolution (mini-sparker) seismic reflection profiles were obtained. The BARTLETT surveys gathered only intermediate penetration (18 kj) and deep penetration (80-160 kj, sparker) seismic profiles. Magnetic and bathymetric profiles were collected on all surveys.

Sea floor samples of bedrock and unconsolidated sediment were gathered with a dredge and with several types of cores. Most samples from Monterey Bay were collected by Stanford University's research vessel PROTEUS (vibracore samples from this area were taken by the R/V OCEANEER); those from the outer continental slope of the Monterey Bay region were taken by the R/V BARTLETT. The samples are used to determine surface stratigraphy and to correlate lithology with subsurface reflectors.

SEISMIC PROFILES

The shallow penetration, high resolution system achieved approximately 60 m of penetration with about 1 m of resolution; the 18 kj, 26 kj, and 80-160 kj systems achieved 1000-1500 m of penetration with 5 m of resolution. General specifications of all these systems are in Tables A and B. Principles and techniques of reduction and interpretation of continuous

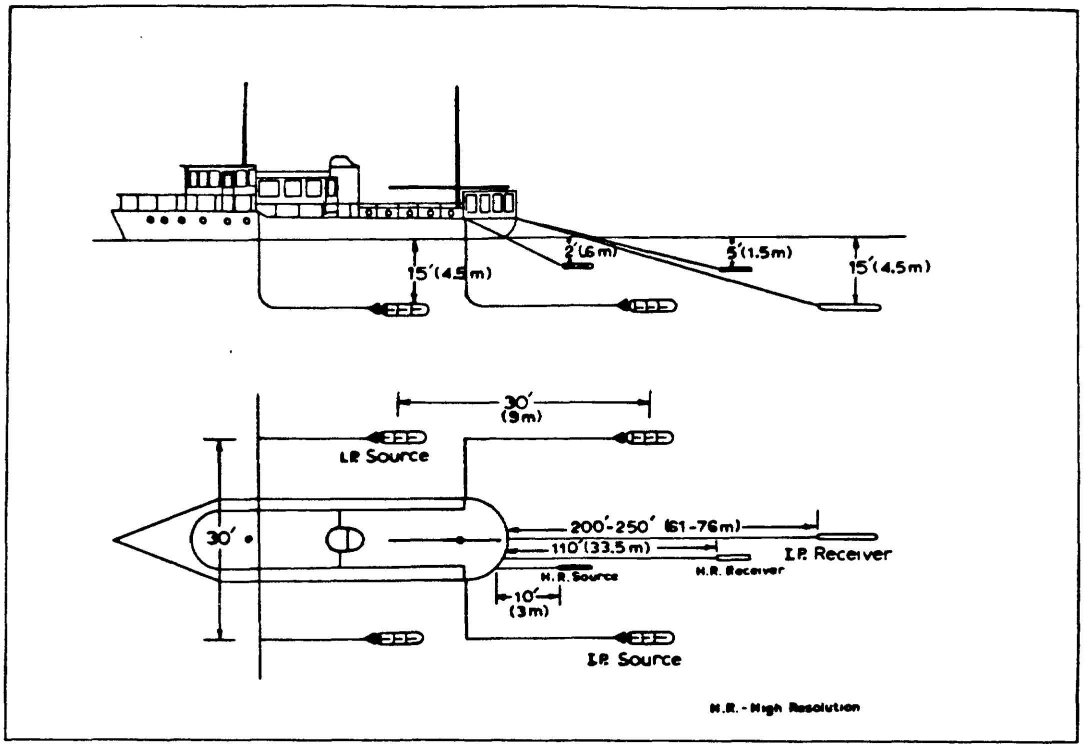


Figure A. - Towing arrangement of seismic sound sources and hydrophone streamers used in the 1969 POLARIS survey. Not drawn to scale.

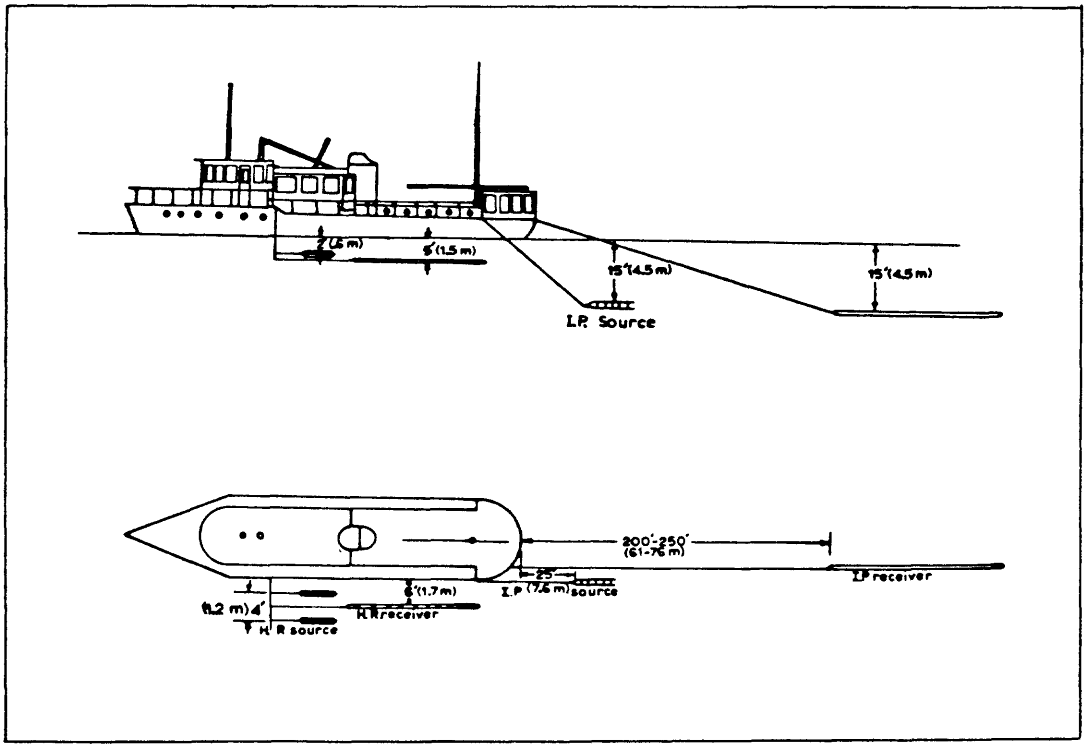


Figure B. - Towing arrangement of seismic sound sources and hydrophone streamers used in the 1970 POLARIS survey. Not drawn to scale.

TABLE A

Survey Date	Energy (kJ)	Filters Hi cut/Lo cut	Sweep rate (sec)	Fire rate (sec)	Fundamental source frequency (Hz)	Sound source: Depth towed (m)	Sound source: Distance towed behind vessel (m)	Hydrophones: Depth towed (m)	Hydrophones: Separation from source (m)	Remarks
1969 R/V POLARIS	0.6	645/250	0.25	0.75	1000	0.6	3	1.5	30.5 in line	A 6 m, non-preamplified hydrophone cable with 11 crystal elements spaced 0.3 m apart was used. A single multi-point electrode sound source was used (see fig. A).
1970 R/V POLARIS	.6-.8	590/100	0.25	0.50	800	0.6	1.2-2.4	1.5	1.5 in line	A 6 m, non-preamplified hydrophone streamer with 11 crystal elements spaced 0.3 m apart was used. Two electrode sound sources spaced 1.2 m apart and towed abeam were used. Hydrophone streamer was towed between sparker electrodes (see fig. B).
1969 R/V POLARIS	8-12	125/40	1.0	3.0	85	4.5	Abeam	4.5	55 & 70	A 61 m active section, preamplified hydrophone cable with 100 crystal elements spaced ~0.6 m apart was used. Four 3-electrode EG&G sparker cage sound sources towed in a planar array were used (see fig. A).
1969 R/V BARTELETT	18	205/20 (varied)	1	4	85	4.5	10	4.5	80	A 61 m active, preamplified hydrophone calde with 100 crystal elements spaced ~0.6 m apart was used. A single 3 electrode EG&G sparker cage sound source was used.
1972 R/V BARTLETT	80-160	76/20	4	4	50	4.5	20	4.5	70	A 61 m active section preamplified hydrophone streamer with 100 crystal elements spaced 0.6 m apart was used. a single point sparker electrode (ladder) was used.

TABLE D

1969 R/V POLARIS	8-12	125/40	1.0	3.0	85	4.5	Abeam	4.5	55 & 70	A 61 m active section preamplified hydrophone cable with 100 crystal elements spaced ~0.6 m apart was used. Four 3-electrode EG&G sparker cage sound sources towed in a planar array were used (see fig. A).
1969 R/V BARTLETT	18	205/20 (varied)	1	4	85	4.5	10	4.5	80 (in line)	A 61 m active, preamplified hydrophone cable with 100 crystal elements spaced ~0.6 m apart was used. A single 3-electrode EG&G sparker cage sound source was used.
1970 R/V POLARIS	26	125/20	1.5	3.0	80	4.5	7.6	4.5	53.4 & 68.4	A 42.6 m active section preamplified hydrophone cable with 100 crystal elements spaced 0.3 to 0.6 m apart and a 50-phone, 22.8 m active section preamplified streamer were used. Only 1 streamer was used at a time. A single point sparker electrode called a "ladder," a named coined because of wooden steplike braces that separate the positive electrode from the ground electrode, was used (see fig. B).
1972 R/V BARTLETT	80-160	76/20	4	4	50	4.5	20	4.5	70	A 61 m active section preamplified hydrophone streamer with 100 crystal elements spaced 0.6 m apart was used. A single point sparker electrode (ladder) was used.

seismic reflection profiles are identical to those described by Moore (1969).

MAGNETICS

A Varian direct reading proton precession magnetometer was used to measure the earth's total field in the Monterey Bay region. This system consists of a sensing head, amplifiers, digital-analog converter, power supply, and an analog strip-chart recorder. The sensing head was usually towed about 100 m behind the survey vessel, at a depth of 10 to 20 m and at speeds from 4 to 8 knots. Data were recorded continuously at a 6 second sampling rate; accuracy of the system is $\pm$ 1 gamma.

Observed magnetic values were taken from the strip-chart at five minute intervals. They were digitized and, together with navigation data, were submitted to a computer for removal of the regional field values (IGRF). The residual values thus obtained were plotted by computer at a scale of 1:100,000 and contoured by hand, producing a total magnetic intensity residual anomaly map (Fig. 37). No corrections for daily variation or magnetic storms were applied to the residual values.

SAMPLING

The sampling area is chosen by examination of seismic reflection profiles to locate steep slopes where exposures of consolidated bedrock or basement rocks may be found. The dredging vessel then crosses the exposures slowly, to obtain an low-exaggeration, precise bathymetric profile. The slope most likely to consist of in-place (or nearly in-place) bedrock is selected as the dredging site. A pipe dredge 30 cm in diameter and 1 m long was used for most samples; however, sample MB-24 was collected with a pipe dredge 15 cm in diameter and 0.5 m in length.

The location of each sample is determined by the wire angle, the speed and position of the dredging vessel, and the depth range of the outcrop being dredged. The precise location of the sample site depends on the accuracy of the navigation system used during the sampling operation; the samples collected by the R/V PROTEUS are within 500 m of their plotted position. Sample depths were calculated using the angle of the wire, the length of the wire, and the depth value on the PDR (Precision Depth Recorder) at the time high tensiometer readings indicated that consolidated rock was being dredged. Also, for some samples, a depth gauge was attached to the dredging wire 100 m above the dredge.

Unconsolidated core samples were randomly collected from the shallow shelf areas of Monterey Bay with a vibrating core 7 cm in diameter and 6 m in length. Seismic reflection data indicated areas where a thin veneer of sediment overlies bedrock; small samples of bedrock, as well as the sediments, were sometimes rcovered when the corer vibrated through the sediments and bottomed in bedrock. Positions of core sites from the R/V OCEANEER are accurate within 200 m.

In situ bedrock samples were collected by the submersible NEKTON ALPHA using a mechanical arm. Navigation used by the attending vessel and detailed bathymetric measurements place the location of these samples within $\pm$ 300 m.

Phleger cores collected by the R/V PROTEUS are from a submarine slump and canyon fill material in Monterey Canyon. The Phleger gravity corer used in this study consists of a 50 kg weight stand attached to a pipe 3 m long and 3 cm in diameter. The corer is allowed to drop by free-falling through the water column; its weight and velocity drive it into the unconsolidated sediment on the sea bottom. Its penetration depth is dependent upon its velocity at the time it enters the substrata and the texture, cohesiveness, and compaction of the substrata.

NAVIGATION

Several types of navigation systems with varying accuracy were used in the collection of data for this study. A modified anti-aircraft radar artillery director system mounted in a mobile van was used for precision navigation in the Monterey Bay region during the 1969 POLARIS survey. The system was placed near Moss Landing, on a hill 18 m high, where it could direct the movement of the survey vessel. An antenna producing high-accuracy, narrow-beam radar signals electronically "locked" onto the survey vessel and tracked it throughout a 38 km radius. Movement of the vessel was monitored and recorded by an x-y plotting system within the van. By placing a 1:50,000-scale mapped representation of the survey grid lines on the x-y plotter, the radar operator could direct the survey vessel to make course and speed changes that would keep it along a certain grid line. This system has an accuracy of ± 15 m.

The navigation used by the R/V POLARIS on the 1969 survey of the continental shelves from Point Sur to Cypress Point and from Santa Cruz to San Francisco, and in 1970 in Monterey Bay was less accurate than the system discussed above. Locations were determined primarily by shipboard radar bearing and by range fixes; position accuracy is approximately ±300 m. Supplementary polaris-bearing fixes were occasionally taken when visibility permitted.

Positioning instruments aboard the R/V BARTLETT consist of radar, loran A, and a satellite navigator. Accuracy of navigation varied from about ± 300 m near shore to approximately ± 1000 m in areas over 100 km offshore. Radar bearing and ranges were the principal navigational methods used in position of the sampling vessels. Data colled by the R/V PROTEUS, R/V OCEANEER, and the submersible NEKTON ALPHA all have a location accuracy of about 300 m. On sampling sites close to shore, where radar was supplemented with visual bearings, accuracy improved to about $\pm$ 200 m; further offshore accuracy deteriorated to about $\pm$ 500 m.

APPENDIX II

SAMPLE DESCRIPTIONS AND PALEONTOLOGIC AND WELL-HOLE DATA

This appendix includes lithologic, petrologic, and paleontologic descriptions of samples collected from the sea floor in the Monterey Bay region by dredge, vibra-core, phleger core, and a submersible. Faunas contained within the samples have been identified by J. C. Ingle, Jr., W. O. Addicott, and J. G. Vedder. This appendix also contains condensed descriptions of dredge samples collected in Monterey Bay by Martin (1964) and stratigraphic descriptions of on-land exploratory oil and gas wells reported by Clark and Rietman (1973) and Clark and others (1974). All sample locations are shown in Figure 8 and all well locations are shown in Figure 15.

Ship station numbers have been changed to report numbers in figures and plates, but the original station number is given in parentheses after the report number. Odd report numbers in Monterey Canyon indicate positions north of the axis of the canyon and even report numbers indicate positions south of the axis. In Monterey Canyon integers increase landward. Prefix letters MB, CB, LS, SC, and MF refer to dredge sites in Monterey Bay, Carmel Bay, Point Lobos-Point Sur shelf, Santa Cruz slope, and Monterey Fan, respectively. Prefix letters MC, MBC, and N are for Monterey Canyon Core, Monterey Bay Core, and NEKTON samples, respectively.

Dredge stations of Martin (1964) are shown with prefix letters M, C, and S, which represent locations in Monterey, Carmel, and Soquel Canyons, respectively. Martin's (1964) odd station numbers indicate a location on the south or west walls of canyons and even numbers indicate locations on the north or east walls of canyons, with all integers increasing seaward.

SC-1 (G-36) Pipe dredge (12")

Location: Santa Cruz slope

Start: 122°14.20'W 36°52.00'N

Finish: 122°14.70'W 36°55.00'N

Depth: 600-400 meters

Lith: LIMESTONE AND SILICEOUS SILTSTONE - three subangular to subrounded cobbles, all about 8x5x3 cm. Color ranged from yellowish-grey (5Y8/1) and light olive grey (5Y6/1) on weathered surfaces to light bluish-grey (5B7/1) on fresh surfaces. Very little marine growth on the rocks. Represents 50% of the total sample.

SILTSTONE - about 15 cobbles and pebbles of yellowish-grey (5Y7/2) siltstone. A few worm tubes present in some cobbles. Sizes range from 6x5x2 cm to less than 2x2x2 cm. Represents 20% of total sample.

UNCONSOLIDATED PEBBLY SILT - cohesive, greenish-olive green (5GY3/2) silt; many angular chips of friable mudstone and siltstone; some sand stringers. Much glauconite. Represents 30% of total sample. In thin section the siltstone chips are very fine-grained. Quite different from most samples looked at in thin section. About 3% larger grains of subangular to subrounded quartz present; largest grain about .08 mm. Approximately 5% opaque minerals, probably iron(?)-rich. Remainder of sample too fine-grained to distinguish mineral types. Does not look like Purisima.

Weight: 16.5 kg of consolidated rock

SC-1 (G-36) continued

Paleo: None

Remarks: Two runs made. First run, bottom of dredge ripped out on outcrop. Second run produced a full dredge. Upper part of dredge contained silicified sandstone, some of which appeared to be freshly broken. Other hard rocks in the top of the dredge were pebbles of slate and siltstone. The remainder of the dredge sample consists of coarse- to medium-grained sand, silt, and clay containing small angular fragments of siltstone. Dredge worked hard during operation with many bounces and high wire tension. Consolidated rocks probably taken in place from outcrop or shallow subcrop near the upper part of the slope. The lower part of the slope appears to be covered with silt and clay containing fragments of the consolidated rock that crops out upslope.

MONTEREY BAY

MB-1 (G-27) Pipe dredge (12")

Location: Monterey Canyon - outer north wall

Start: 122°05.45'W 36°47.45'N

Finish: 122°06.05'W 36°47.55'N

Depth: 460-275 meters

Lith: SILTSTONE - two well rounded cobbles of well indurated siltstone with some phosphatic coating. One cobble is 8x4x4 cm in size and the other is a fractured piece from a larger cobble. Represents 1% of total sample.

MUD - greyish olive green (5GY8/1) wet, greenish-grey (5GY6/1) dry, mud with silt interfingers and a few fossil fragments. Represents 99% of total sample. In thin section the siltstone is coarse-grained with fine-grained sand scattered throughout; largest grain is about .06 mm. About 30% subangular quartz with an average size of about .05 mm. Approximately 5% volcanic(?) and lithic rock fragments and about 5% chlorite. The remainder of the grains too fine-grained to disseminate. Lithologically appears like Purisima.

Paleo: Sample of siltstone submitted for micropaleontology gave the following foraminifera and microfossils:

Benthonic Species

Buccella frigida (Cushman)
Cassidella nodosa (R. E. and K. C. Stewart)
Cassidulina lomitensis Galloway and Wissler
Epistominella pacifica (R. E. and K. C. Stewart)
Nonionella cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer
Uvigerina peregrina Cushman

MB-1 (G-27) continued

Planktonic Species

Globigerina bulloides d'Orbigny

Miscellaneous

Diatoms
Radiolaria
Sponge spicules
Glauconite

Age: Pliocene-middle(?) Purisima Formation; fauna representing deposition at upper bathyal depths (200-600 m).

Weight: 9.3 kg of consolidated rock.

Remarks: Dredge full - cohesive green-grey mud with yellow oxidation bands, fossil shell fragments and gravel. Some cobbles of siltstone. Dredge did not work hard, no bounces or abnormal wire tension. Sample taken was not in place, but represents transported material.

MB-3 (G-28) Pipe dredge (12")

Location: Monterey Canyon - outer north slope

Start: 122°4.50'W 36°47.60'N

Finish: 122°4.05'W 36°48.10'N

Depth: 600-145 m

Lith: SILTSTONE - semi-consolidated to consolidated, subrounded to subangular boulders, cobbles, and pebbles of fossiliferous siltstone. Largest boulder is 13x11x4 cm and average size is 4x4x6 cm. Color ranges from yellowish-grey (5Y7/2) on weathered surfaces to light greenish-grey (5G8/1) on fresh surfaces. Very little marine growth. Few fragments of molluskan fossil shells. Some chunks of siltstone are well bored and burrowed; one large calcareous worm tube 9 cm long and 1 3/4 cm in diameter. One whole pelecypod shell. Represents 40% of total sample. In thin section the sample is similar to MB-1 (G-27) with about 30% subangular quartz grains, average size about .07 mm; few shards of volcanic(?) fragments and lithic rock fragments totaling about 10% of sample. Lithologically appears like Purisima.

GRANITE - one angular cobble (8x5x3 cm) of porphyritic biotite granodiorite with K-feldspar phenocrysts. Represents less than 1% of total sample. In thin section rock appears to be a biotite granodiorite.

UNCONSOLIDATED SAND AND MUD - greyish olive green (5GY3/2) wet muds with a few rounded pebbles. 60% of total sample.

MB-3 (G-28) continued

Paleo: Sample of siltstone submitted for micropaleontology gave the following foraminifera and other microfossils:

Benthonic Species

Cassidulina islandica Norvang
Cassidulina limbata Cushman and Hughes
Cassidulina translucens Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Haplophragmoides sp.
Pullenia salisburyi Stewart and Stewart
Trifarina baggi (Galloway and Wissler)
Trifarina semitrigona (Galloway and Wissler)
Uvigerina peregrina Cushman

Miscellaneous Microfossils

Rare radiolarians
Statocysts of shrimp

Age: Pliocene-lower to middle(?) Purisima Formation.

Remarks: Dredge full - top of dredge contained mostly coarse-grained, greenish sand containing fine gravel-sized, angular, siltstone fragments; fossiliferous. Bottom of dredge contained subrounded chunks of grey siltstone that look very much like the exposure of Pliocene Purisima in the cliffs near Capitola. No fresh fractures or surfaces observed. A subangular to subrounded boulder of granodiorite found in bottom of dredge; fresh surface exposed. Dredge hung up at start of operation and was sufficient to bring the ship to a halt. The granodiorite was probably recovered in place from an outcrop at 600 m depth. Siltstone not in place and recovered from slope material, probably overlying subcrops of siltstone.

MB-5 (G-32) Pipe dredge (12")

Location: Soquel Canyon northwest wall

Start: 122°59.50'W 36°49.45'N

Finish: 122°0.00'W 36°49.95'N

Depth: 360-90 meters

Lith: SILTSTONE - subangular to well rounded (most subangular) small boulders and cobbles. All very thoroughly bored and burrowed with very little marine growth on surfaces; some corals and siliceous sponges attached to one side of a few cobbles. Color ranges from greyish-orange (10YR7/4) to yellowish-grey (5Y7/2) on weathered surface and from yellowish-grey (5Y8/1) to light bluish-grey (5B7/1) on fresh. Size of largest boulder is 19x16x10 cm; rocks generally average 8x7x5 cm in size. One boulder is well rounded, probably concretionary, sandy siltstone 17x9x6 cm in size. A few samples appear to be well cemented with a calcareous cement. Some fossil fragments. Represents about 40% of total sample. In thin section, sample is very fine-grained, too fine-grained to identify all minerals. Quartz is predominant large-grained mineral with the largest being about .06 mm in size. A small amount of volcanic and lithic rock fragments is present. Most larger-grained minerals have secondary calcite growth. Lithologically similar to Purisima.

GRANITE OR METAMORPHIC - one well rounded granite or metamorphic cobble. Represents less than 1% of total sample.

MB-5 (G-32) continued

UNCONSOLIDATED SAND - sandy greyish olive green (5GY3/2) wet muds with a few rounded pebbles. 60% of total sample.

Weight: 24.0 kg of consolidated rock.

Paleo: Two siltstone samples submitted for micropaleontology gave the following foraminifera and microfossils:

SAMPLE #1

Benthonic Species

Bolivina pacifica Cushman and McCulloch
Bolivina spissa Cushman
Buccella frigida (Cushman)
Cassidulina delicata Cushman
Cassidulina limbata Cushman and Hughes
Cassidulina minuta Cushman
Cibicides lobatus (Montague)
Epistominella pacifica (R. E. and K. C. Stewart)
Lagena striata (d'Orbigny)
Nonionella miocenica stella Cushman and Moyer
Trifarina baggi (Galloway and Wissler)
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma

Miscellaneous

Diatoms
Sponge spicules
Glauconite

Age: Pliocene - upper to middle Purisima Formation; faunas representing deposition of middle bathyal depths (600-1500 m).

SAMPLE #2

Benthonic Species

Bulimina marginata denudata Cushman and Parker
Cassidulina limbata Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Epistominella subperuviana (Cushman)

MB-5 (G-32) continued

Benthonic Species

Haplophragmoides columbiensi Cushman
Nonionella miocenica stella Cushman and Moyer
Trifarina baggi (Galloway and Wissler)
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg) - mixed coiling

Age: Pliocene - middle to upper Purisima Formation.

Remarks: Dredge full - top of dredge contained coarse greenish-grey sands and mud with large angular chunks of fossiliferous siltstone. Bottom of dredge contained smaller angular chunks of siltstone in a greenish-grey cohesive mud. Samples of siltstone look very much like Purisima exposed in cliffs near Capitola. No fresh surfaces were observed on siltstone. Lots of bouncing by dredge and high wire tension during operation. Siltstone probably not taken in place but the angularity of the specimens recovered suggest that the sample was close to the outcrop or subcrop.

MONTEREY BAY

MB-7(G-29) Pipe dredge (12")

Location: Soquel Canyon - NW wall

Start: 121°58.50'W 36°49.75'N

Finish: 121°59.05'W 36°50.45'N

Depth: 210-105 meters

Lith: SILTSTONE - semi- to well-consolidated, subangular to subrounded, pebbles to small boulders of siltstone that are thoroughly bored and burrowed. Color varies from yellowish-grey (5Y7/2) on weathered surface to light greenish-grey (5GY8/1) on fresh surfaces. Very little marine growth. Largest boulder size is 13x9x4 cm and average size is 6x5x2 cm. About 30 large boulders total. Represents about 70% of total sample. In thin section rock is fine-grained; difficult to identify all minerals. Larger-grained minerals consist of subangular to subrounded quartz (about 30%), biotite (about 2%), chlorite (about 3%), and a few volcanic and lithic rock fragments. Largest grain is about .35 mm. Sample appears lithologically similar to Purisima.

MUD - greyish olive green (5GY3/2) mud with angular pebbles of siltstone. 30% of total sample.

Weight: 9.2 kg of consolidated rock.

Paleo: Three siltstone samples submitted for micropaleontologic analysis gave the following foraminifera and microfossils:

MB-7 (G-29) continued

SAMPLE #1

Benthonic Species

Bolivina spissa Cushman
Bulimina denudata (Cushman and Parker)
Cassidulina limbata Cushman and Hughes
Cassidulina minuta Cushman
Cassidulina subglobosa quadrata Cushman and Hughes
Epistominella exigua (Brady)
Epistominella pacifica (R. E. and K. C. Stewart)
Nonionella basispinata (Cushman and Moyer)
Pullenia salisburyi Stewart and Stewart
Trifarina baggi (Galloway and Wissler)
Trochammina pacifica Cushman

Planktonic Species

Globigerina pachyderma (Ehrenberg)
Globigerina quinqueloba Natland

Miscellaneous

Radiolaria
Sponge spicules
Glauconite

Age: Pliocene - middle Purisima Formation; faunas representing deposition at upper bathyal depths (200-600 m).

SAMPLE #2

Benthonic Species

Buccella frigida (Cushman)
Cassidulina californica Cushman and Hughes
Cassidulina limbata Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Haplophragmoides columbiensi Cushman
Nonionella basispinata (Cushman and Moyer)
Pullenia malkinae Coryell and Mossman
Pullenia salisburyi Stewart and Stewart
Spirillina sp.
Trifarina baggi (Galloway and Wissler)
Trifarina semitrigona (Galloway and Wissler)
Trochammina pacifica Cushman
Uvigerina peregrina Cushman

Planktonic Species

Globigerina pachyderma (Ehrenberg) - predominantly dextral

MB-7 (G-29) continued

Age: Pliocene - lower to middle Purisima Formation (?)

SAMPLE #3

Benthonic Species

Cassidulina islandica Norvang
Nonionella basispinata (Cushman and Moyer)
Uvigerina peregrina Cushman

Planktonic Species

Globigerinoides ruber (d'Orbigny)

Age: Pliocene - Purisima Formation

Remarks: Dredge full - many angular, fossiliferous boulders and cobbles of siltstone in a greenish-grey mud. Many boulders have worm burrows. No fresh surfaces observed. Dredge did not work much and no high wire tension. Siltstone was not in place but the angularity of the boulders suggest that the outcrop or subcrop was close by. Fauna similar to that found in dredge MB-12 (G-51), and appears to be similar to the shallow water facies of the Purisima Formation exposed in the cliffs near Capitola.

MB-9 (G-25) Pipe dredge (12")

Location: Soquel Canyon - NW wall (head)

Start: 121°58.05'W 36°41.25'N

Finish: 121°58.60'W 36°51.45'N

Depth: 110-80 meters

Lith: SILTSTONE - semi- to fairly consolidated subangular cobbles; largest is 5.5x7x2.5 cm, severely burrowed and bored. Color ranges from yellowish-grey (5Y7/2) on exposed surfaces to light greenish-grey (5GY8/1) on fresh surfaces. Very little marine growth. Little phosphatic coating. Represents about 50% of total sample. In thin section this rock is too fine-grained to identify all minerals. Predominant coarser-grained minerals are composed of quartz and some feldspars, volcanic and rock fragments. Largest grain is about 1 mm in size. Appears to be lithologically similar to Purisima.

MUD - greyish olive green (5GY3/2) wet mud with silt stringers. 50% of total sample.

Weight: 7.0 kg of consolidated rock.

Paleo: Siltstone sample submitted for micropaleontology gave the following foraminifera and other microfossils:

Benthonic Species

Bolivina spissa Cushman
Buccella frigida (Cushman)
Cassidulina californica Cushman and Hughes
Nonionella basispinata (Cushman and Moyer)
Nonionella miocenica stella Cushman and Moyer
Pullenia salisburyi Stewart and Stewart
Trochammina pacifica Cushman
Uvigerina peregrina Cushman

MB-9 (G-25) continued

Planktonic Species

Globigerina pachyderma (Ehrenberg) dextral dominant coiling

Age: Pliocene - lower to middle(?) Purisima Formation

Remarks: Dredge full - cohesive blue-grey mud with cobble-sized, angular chunks of siltstone, some with oxidation bands and containing worm borings. Dredge did not work hard, nor was there any abnormal wire tension. Sample appears to have not been in place; however, the large quantity and angularity of the siltstone fragments suggest that the outcrop or subcrop was close by.

MB-11 (G-33) Pipe dredge (12")

Location: Soquel Canyon - SE wall

Start: 121°59.45'W 36°48.55'N

Finish: 121°58.40'W 36°48.45'N

Depth: 550-110 meters

Lith: UNCONSOLIDATED TO SEMI-CONSOLIDATED MUDSTONE - Yellowish-grey (5Y8/1) sandy muds with well rounded pebbles scattered throughout. Some mudstone burrowed with worm borings. Represents 20% of total sample.

UNCONSOLIDATED SANDS - greyish olive green (5GY3/2) sands with glauconite. Fairly well sorted, subangular to subrounded grains. Represents 80% of total sample.

Many living brachiopods recovered.

Weight: 36.5 kg semi-consolidated material.

Paleo: Semi-consolidated mud samples submitted for micropaleontology gave the following foraminifera and microfossils:

Benthonic Species

Bolivina spissa Cushman
Buccella frigida (Cushman)
Bulimina denudata (Cushman and Parker)
Cancris auricula (Finchell and Moll)
Cassidulina limbata Cushman and Hughes
Cassidulina lomitensis Galloway and Wissler
Cassidulina minuta Cushman
Cassidulina subglobosa quadrata Cushman and Hughes
Cassidulina subglobosa subglobosa Brady
Cassidulina tortuosa Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Cibicides Mckannai Galloway and Wissler
Elphidium clavatum Cushman
Epistominella pacifica (R. E. and K. C. Stewart)
Globobulimina pacifica Cushman

MB-11 (G-33) continued

Haplophragmoides columbiensi Cushman
Pullenia malkinae Coryell and Mossman
Rotorbinella lomaensis (Bandy)
Textularia conica d'Orbigny
Trifarina baggi (Galloway and Wissler)
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg) - dominant dextral coiling
Globigerina quinqueloba Natland
"Orbulina"

Miscellaneous

Sponge spicules
Glauconite

Age: Pliocene - middle(?) Purisima Formation; faunas representing deposition at upper bathyal depths (200-600 m).

Remarks: Dredge full - greenish-grey sand and gravel with small angular chunks of mudstone. Not much bouncing of dredge, no abnormal wire tension. Sample not in place, but transported, probably a short distance. Sample probably from slump detritus on wall of canyon and from bottom material on shelf floor.

MB-13 (G-41) Pipe dredge (12")

Location: Monterey Canyon - north wall

Start: 121°55.50'W 36°47.50'N

Finish: 121°55.30'W 36°48.25'N

Depth: 500-110 meters

Lith: SILTSTONE - several small boulders and cobbles (average size 8x8x5 cm, largest size 13x10x8 cm) of subangular, semi-consolidated, sandy siltstone. Some samples are well bored and burrowed and a few are phosphatically coated. Color ranges from dusky yellow (5Y6/4) and yellowish-grey (5Y7/2) on weathered surfaces to light bluish-grey (5B7/1) on fresh surfaces. Two chunks partially covered with calcareous worm tubes, bryozoans, and corals. Some limonitic staining. A few fossil fragments. Represents about 60% of total sample.

UNCONSOLIDATED SILT AND CLAY - greyish-olive (10Y4/2) mud. Represents about 40% of total sample.

Weight: 24.3 kg of consolidated rock.

Paleo: Sample of siltstone submitted for micropaleontologic analysis gave the following foraminifera and other microfossils:

Benthonic Species

Elphidium clavatum Cushman
Epistominella pacifica (R. E. and K. C. Stewart)

Miscellaneous

Diatoms
Radiolaria
Glauconite

Age: Pliocene - middle(?) Purisima Formation; fauna representing deposition at upper bathyal depths (200-600 m).

MB-13 (G-41) continued

Remarks: Dredge full - top part of dredge contained mud with inclusions of angular fragments of siltstone and lenses of reddish-brown sand. Bottom of dredge contained angular, friable, grey sandstone and siltstone perforated with many worm burrows. Dredge worked by bouncing; moderate cable tension, not enough to slow the progress of the ship; however, siltstone was collected not in place on the slope, but probably close to subcrop at a depth of about 200 meters.

MONTEREY BAY

MB-15 (G-53) Pipe dredge (12")

Location: Monterey Canyon - north wall

Start: $121^{\circ}53.25'$W $36^{\circ}47.90'$N

Finish: $121^{\circ}53.00'$W $36^{\circ}48.50'$N

Depth: 410-85 meters

Lith: UNCONSOLIDATED SANDY SILT - olive-grey (5Y3/2), fine sands to silt and muds. Some fossiliferous molluskan fragments, large pelecypod shell fragments. Some angular to subangular siltstone fragments. Represents 100% of total sample.

Weight: Not made.

Paleo: Siltstone fragments submitted for micropaleontology gave the following foraminifera and microfossils:

Benthonic Species

Bolivina pseudoplicata Heron-Allen and Earland
Bolivina spissa Cushman
Buccella frigida (Cushman)
Bulimina denudata (Cushman and Parker)
Buliminella elegantissima (d'Orbigny)
Cassidulina lomitensis Galloway and Wissler
Cassidulina minuta Cushman
Cibicides spiralis Natland
Eilohedra levicula (Resig)
Elphidium clavatum Cushman
Epistominella exigua (Brady)
Globobulimina pacifica Cushman
Lagena striata (d'Orbigny)
Nonionella cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer
Pullenia malkinae Coryell and Mossman
Trifarina spp.
Uvigerina peregrina Cushman

Planktonic Species

Globigerina pachyderma (Ehrenberg) dominant coiling is sinistral
Globigerina quinqueloba Natland
Globigernita glutinita (Egger)
Globigerinita uvula (Ehrenberg)

MB-15 (G-53) continued

Miscellaneous

Diatoms
Radiolaria
Sponge spicules
Glauconite abundant

Age: Pliocene - middle(?) Purisima Formation; fauna representing deposition at upper bathyal depths (200-600 m).

Remarks: Dredge full - mud with well sorted fossiliferous grey sands. Sample probably represents transported material.

MONTEREY BAY

MB-17 (G-44) Pipe dredge (12")

Location: Monterey Canyon - north wall (head)

Start: 121°49.95'W 36°49.10'N

Finish: 121°50.50'W 36°49.55'N

Depth: 100-55 meters

Lith: UNCONSOLIDATED SILT - Olive-grey (5Y3/2) sandy silts with perhaps some clay. Sands appear well sorted. Mud. Represents 100% of total sample.

Weight: None made.

Paleo: A sample of silt submitted for micropaleontologic analysis gave the following foraminifera and microfossils.

Benthonic Species

Bolivina vaughani Natland
Buccella frigida (Cushman)
Buliminella elegantissima (d'Orbigny)
Cassidella seminuda (Natland)
Elphidium translucens Natland
Nonionella basispinata (Cushman and Moyer)
Nonionella Cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer

Miscellaneous

Diatoms
Sponge spicules

Age: Early Pleistocene - late Pliocene; upper Purisima Formation(?); fauna representing deposition of inner to middle shelf (neritic) depths (25-75 m).

Remarks: Dredge half full - grey mud and sand. Sample probably transported, but not far.

MB-19 (G-21) Pipe dredge (12")

Location: Monterey Canyon - north wall (head)

Start: 121°49.90'W 36°49.00'N

Finish: 121°49.80'W 36°49.80'N

Depth: 200-50 meters

Lith: SILTSTONE - Small cobble (8x6x5 cm), subrounded, light bluish-grey (5B7/1) siltstone. Represents about 5% of total sample. UNCONSOLIDATED SAND AND SILT - moderate olive-brown (5Y4/4) sand, silt, and mud with some interfingers of well rounded "p-gravel". Silts and muds contained fossil fragments. Represents about 95% of total sample.

Weight: 5.3 kg of consolidated rock.

Paleo: A sample of siltstone submitted for micropaleontology gave the following foraminifera and microfossils:

Benthonic Species

Bolivina pacifica Cushman and McCulloch
Buccella frigida (Cushman)
Bulimina denudata (Cushman and Parker)
Buliminella elegantissima (d'Orbigny)
Cassidella seminuda (Natland)
Elphidium incertum (Williamson)
Elphidium translucens Natland
Epistominella subperuviana (Cushman)
Haplophragmoides sp.
Nonionella basispinata (Cushman and Moyer)
Nonionella miocenica stella Cushman and Moyer
Quinqueloculina spp.
Rotorbinella lomaensis (Bandy)
Textularia conica d'Orbigny
Trochammina aff. *nitida* Brady
Trochammina pacifica Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina quinqueloba Natland

MB-21 (G-22) Pipe dredge (12")

Location: Monterey Canyon - north wall (head)

Start: 121°49.10'W 36°47.80'N

Finish: 121°49.10'W 36°48.50'N

Depth: 150-40 meters

Lith: SILTSTONE - fossiliferous angular chunks of semi-consolidated, greenish-grey (5GY6/1) siltstone or mudstone. Largest piece is 14x9x6 cm in size; no marine growth. Some burrows, but very few. About 10 chunks recovered. Represents about 35% of total sample.

UNCONSOLIDATED SILT - light olive-grey (5Y6/1) silt with some mud and fine-grained sands. 65% of total sample.

Weight: 4.7 kg of consolidated rock.

Paleo: Siltstone submitted for micropaleontology gave the following foraminifera and other microfossils:

Benthonic Species

Ammonia beccari (Cushman)
Bolivina spissa Cushman
Buccella frigida (Cushman)
Buliminella elegantissima (d'Orbigny)
Cassidella nodosa (R. E. and K. C. Stewart)
Cassidella seminuda (Natland)
Cibicides fletcheri Galloway and Wissler
Elphidiella hannai (Cushman and Grant)
Elphidium clavatum Cushman
Elphidium incertum (Williamson)
Elphidium translucens Natland
Epistominella exigua (Brady)
Globobulimina pacifica Cushman
Nonionella Cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer
Trifarina baggi (Galloway and Wissler)
Trochaminina Kellettae Thalman
Trochammina pacifica Cushman

MB-19 (G-21) continued

Miscellaneous

Diatoms
Radiolaria
Sponge spicules
Glauconite

Age: Early Pleistocene - late Pliocene; upper Purisima Formation(?); fauna representing deposition at inner to middle shelf (neritic) depths (25-75 m).

Remarks: Dredge full - brown to grey mud and sand with few small subangular cobbles of bluish-grey siltstone. A large quantity of well rounded gravel was interlayered with the buff to blue-grey sands (Paso Robles?). Siltstone not in place.

MB-21 (G-22) continued

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina quinqueloba Natland
Globigerinoides ruber (d'Orbigny)

Miscellaneous

Diatoms
Sponge spicules

Age: Pliocene - upper to middle Purisima Formation; faunas representing deposition at outer shelf (neritic) to upper bathyal transitional depths (75-200 m).

Remarks: Dredge full - brown to grey, medium-grained, well sorted sand with black H_2S layers. Also contained subangular to subrounded, blue-grey, well consolidated, fossiliferous siltstone; some included fragments of pelecypod shells; looks very much like Purisima that crops out in cliffs near Capitola; siltstone probably not taken in place but near outcrop or subcrop.

MB-23 (G-42) Pipe dredge (12")

Location: Monterey Canyon - north wall (head)

Start: 121°48.55'W 36°48.55'N

Finish: 121°48.10'W 36°48.00'N

Depth: 130-30 meters

Lith: SILTY SAND - greenish-grey, fine-grained sand and silt.

Represents 100% of total sample.

Weight: None made

Paleo: None

Remarks: Dredge 1/3 full - green mud, probably Holocene(?) material.

MONTEREY BAY

MB-2 (G-47) Pipe dredge (12")

Location: Monterey Canyon - outer south wall

Start: $122^{\circ}01.75'$ $36^{\circ}41.4'N$

Finish: $122^{\circ}0.5'W$ $36^{\circ}0.55'N$

Depth: 915-230 meters

Lith: GRANITE - very angular granitic rocks ranging in size from 18x12x3 cm to less than 2x2x2 cm with an average of 5x4x3 cm. Some have fresh fractures indicating that they were broken from the outcrop during the dredging operation. Not much growth on surfaces, and where present only on one side. Represents about 70% of total sample.

SILTSTONE - two very large boulders, 30x32x25 cm and 25x25x10 cm of sandy and pebbly, highly fossiliferous siltstone, moderate yellowish-brown (10YR5/4) to light brown (5YR5/6) on weathered surfaces and dark greenish-grey (5G4/1) on fresh surfaces. Surfaces of boulders are severely bored and burrowed and are subrounded in shape. Surfaces covered with phosphate and calcareous worm tubes, bryozoans, corals, and siliceous sponges. Small pebbles less than 1 cm in diameter consist of chert, slate, and other lithic fragments, well rounded and scattered sparsely throughout mud matrix. Probably transported from outcrop upslope. Represents about 10% of total sample. In thin section the siltstone appears to be Purisima, based on its heavy mineral suite and volcanic rock fragments. However, grains within the rock are too fine-grained to identify.

MB-2 (G-47) continued

MUD - dark greenish-grey muds (5GY4/1). Represents about 20% of total sample.

Weight: 37.8 kg of consolidated rock.

Paleo: A few well rounded, fossiliferous cobbles of limey and sandy siltstone submitted for macropaleontology gave the following molluskan faunas:

Gastropod:

Antiplanes sp. - internal mold

Pelecypods:

Clinocardium meekianum (Gabb) - external molds
Macoma sp. - fragment of a large, articulated specimen
Patinopecten? - fragment of a large specimen
Barnacle Fragment

Age and correlation:

This small assemblage is of Pliocene age in terms of the Pacific Coast megainvertebrate sequence of Weaver and others (1944). These mollusks are of common occurrence in the shallower facies of the Purisima Formation of the Santa Cruz Mountains.

Environmental inferences:

The association of mollusks suggests a shallow water environment - inner sublittoral (neritic) zone, possibly between 27 to 55 meters.

Remarks: Dredge 3/4 full - top of dredge contained several rounded cobbles and two large boulders of fossiliferous siltstone (many pectin casts) in mud. Bottom of dredge contained very angular pebbles, cobbles, and boulders of granite; fresh

MB-2 (G-47) continued

fractures observed. Dredge worked hard and "hung up" several times during initial part of operation; no abnormal wire tension during final part of operation. Granite and, most likely, siltstone taken in place.

MB-4 (G-50) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 122°00.00'W 36°43.85'N

Finish: 121°58.40'W 36°43.50'N

Depth: 915-175 meters

Lith: SANDSTONE - coarse-grained, granitic or arkosic sandstone, well consolidated, friable. Phosphatic covered, subrounded, single rock 11x7.5x5 cm with limonite coating. Whole rock highly weathered with iron stain throughout. Represents less than 1% of total sample. In thin section rock appears to be an arkosic sandstone with silicic volcanic and granitic rock fragments, microcline feldspar, fresh and altered plagioclase feldspar, and cemented spar calcite. Sample petrographically similar to Santa Margarita in Santa Cruz Mountains, but probably is the basal sand member of the Monterey Formation (J. C. Clark, oral commun., 1974).

SILTSTONE - semi-consolidated, grey, fossiliferous siltstone. Represents less than 5% of total sample. In thin section this rock is similar to sample SC-1 (G-36). Too fine-grained to identify all minerals but larger grains consist of quartz (about 3%), iron(?)-rich opaques (about 10%), chlorite and biotite (less than 1%), and a few volcanic(?) and lithic(?) fragments. Largest grain is .09 mm. Rock does not appear to be Purisima.

SANDY SILTSTONE - greenish-grey, unconsolidated sandy siltstone with scattered inclusions of well rounded pebbles. Represents about 5% of total sample.

MB-4 (G-50) continued

MUD - greenish-grey mud. Represents about 90% of sample.

Weight: 16.1 kg of consolidated rock.

Paleo: None

Remarks: Dredge full - cohesive blue-grey mud with interbeds of greenish coarse-grained sands. Bottom of dredge contained many angular, pebble-sized fragments of well consolidated siltstone and one small boulder of coarse-grained granitic sandstone. High wire tension and bouncing of dredge during the start of the operation suggest that the sandstone and possibly some siltstone were taken from or very close to the outcrop or subcrop.

MB-6 (G-48) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: $121^{\circ}59.20'W$ $36^{\circ}44.55'N$

Finish: $121^{\circ}58.50'W$ $36^{\circ}44.45'N$

Depth: 550-180 meters

Lith: SILTSTONE - consolidated to semi-consolidated; some well indurated, greenish-grey (5G6/1), sandy to gravelly siltstone with many fossil shell fragments; few well preserved pelecypods. Rocks are subangular to subrounded and are well bored and burrowed. No sedimentary structures seen; very heterogeneous with well rounded "p-gravel" of chert, granite, shale, and various other types of lithic clasts. Largest chunk is 25x16x10 cm. Calcitic cemented matrix. Represents about 10% of sample.

UNCONSOLIDATED SAND AND SILT - coarse-grained sand and silt, olive-grey (5Y4/1) in color. Represents about 70% of sample.

MUD - sandy silt to mud, fossiliferous with well rounded pebbles and fine-grained gravel consisting of chert, quartzite, and rock fragments. Greenish-grey (5G6/1) in color. Represents about 20% of sample.

Weight: 53.2 kg of consolidated rock.

Paleo: Two siltstone samples submitted for micropaleontology gave the following foraminifera and other microfossils:

MB-6 (G-48) continued

SAMPLE # 1

Benthonic Species

Bolivina pacifica Cushman and McCulloch
Bolivina pseudoplicata Heron-Allen and Earland

Age: Early Pliocene(?) - lower Purisima Formation; fauna representing deposition at lower middle bathyal depths (1500-2500 m).

SAMPLE # 2

Benthonic Species

Buccella frigida (Cushman)
Cassidulina limbata Cushman and Hughes
Elphidiella hannai Cushman and Grant

Planktonic Species

Globigerina bulloides d'Orbigny

Age: Pliocene - upper(?) Purisima Formation. Sample submitted for macropaleontology contained the following molluskan fauna.

Pelecypods:

Macoma sp. - large, thick-shelled fragment
Solen? - fragments
Undetermined fragments

Age: Indeterminate

Remarks: Dredge full - coarse-grained, greenish-grey, fossiliferous sand interlayered with well rounded gravel and chunks of mud. Few angular fragments of friable, worm-burrowed siltstone. Some bouncing of dredge during operation, but no abnormally high wire tension. Sample probably collected along debris

MB-6 (G-48) continued

slope. The angularity of the few siltstone fragments and the lack of organic growth on the samples suggest that they were probably transported a short distance from outcrop or subcrop.

Bolivina seminuda Cushman
Bolivina spissa Cushman
Buccella frigida (Cushman)
Buccella tenerrima (Bandy)
Bulimina pagoda Cushman
Cassidulina delicata Cushman
Cassidulina limbata Cushman and Hughes
Cassidulina minuta Cushman
Cassidulina norcrossi Cushman
Cassidulina subglobosa quadrata Cushman and Hughes
Cassidulina translucens Cushman and Hughes
Cassidulina tortuosa Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Cibicides spiralis Natland
Elphidium clavatum Cushman
Elphidium incertum (Williamson)
Epistominella exigua (Brady)
Epistominella pacifica (R. E. and K. C. Stewart)
Epistominella subperuviana (Cushman)
Fissurina lucida (Williamson)
Haplophragmoides columbiensis Cushman
Melonis barleeanus (Williamson)
Nonionella cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer
Planulina ornata (d'Orbigny)
Rotorbinella lomaensis (Bandy)
Sigmoilina tenus (Czjzek)
Suggrunda eckisi Natland
Trifarina spp.
Uvigerina hispido costato Cushman and Todd
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenburg) - sinistral dominant coiling
Globigerina quinqueloba Natland
Globigerinita uvula (Ehrenberg)

MB-6 (G-48) continued

Miscellaneous

Diatoms
Radiolaria
Sponge spicules
Glauconite

MONTEREY BAY

MB-8 (G-20) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 121°58.85'W 36°45.05'N

Finish: 121°58.00'W 36°45.30'N

Depth: 830-370 meters

Lith: SILTSTONE - angular, freshly broken chunks of severely bored and burrowed, semi- to fairly well-consolidated siltstone. Color ranges from yellowish-grey (5Y7/2) on weathered surfaces to greenish-grey (5GY6/1) on fresh surfaces. Largest piece is 18x15x6 cm. Little marine growth. Some phosphatic coating. Represents about 40% of sample. In thin section is very fine-grained. Large clasts consist of subangular quartz and about 10% of volcanic(?) and other lithic rock fragments. Largest grain is about .06 mm in size. Rock is lithologically similar to Purisima.

MUD - greyish olive green (5GY3/2). Represents about 60% of sample.

Weight: 13.0 kg of consolidated rock

Paleo: Siltstone sample submitted for micropaleontology gave the following fauna:

Statocysts of shrimp
Spirillina sp.

Age: Indeterminant; undiagnostic fauna

Remarks: Dredge full - mud and sand with rounded to angular pebbles and boulders of siltstone. Bottom of dredge contained many boulders of siltstone, few showing fresh fractures, and mud.

MB-8 (G-20) continued

Top of dredge contained mud and sand with one large angular slab of clean-looking consolidated siltstone with fresh surfaces and no marine growth or worm borings. Dredge bounced gently during operation, no abnormal wire tension. Sample probably transported except for clean-looking siltstone slab that probably was taken in place; older-looking siltstone may have been transported only a short distance from outcrop or subcrop. Probably is Pliocene Purisima Formation.

MONTEREY BAY

MB-10 (G-30) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 121°56.60'W 36°45.54'N

Finish: 121°56.55'W 36°45.50'N

Depth: 275-120 meters

Lith: UNCONSOLIDATED SANDY SILTS - greyish olive green (5GY3/2) sandy silt with many fossil fragments. Represents about 80% of sample. No consolidated rocks.

GRAVEL - subrounded to well rounded, coarse-grained gravels composed mostly of granite and siliceous siltstones and chert. Largest clast is a granite about 6x5x4 cm. Represents about 20% of sample.

Weight: None made

Paleo: Sample of sandy silt submitted for micropaleontology gave the following foraminifera and other microfossils:

Benthonic Species

Buccella frigida (Cushman)
Bulimina denudata (Cushman and Parker)
Cancris auricula (Fichell and Moll)
Cassidella nodosa (R. E. and K. C. Stewart)
Cassidulina limbata Cushman and Hughes
Cassidulina subglobosa subglobosa Brady
Cassidulina tortuosa Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Epistominella exigua (Brady)
Epistominella pacifica (R. E. and K. C. Stewart)
Epistominella subperuviana (Cushman)
Globobulimina pacifica Cushman
Lagena striata (d'Orbigny)
Nonionella miocenica stella Cushman and Moyer
Pullenia malkinae Coryell and Mossman
Rotorbinella lomaensis (Bandy)
Textularia earlandi F. L. Parker
Trifarina baggi (Galloway and Wissler)
Trochaminina Kellettae Thalman
Uvigerina peregrina Cushman

MB-10 (G-30) continued

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg) sinistral dominant coiling
Globigerina quinqueloba Natland
Globigerinita glutinata (Egger)

Miscellaneous

Diatoms
Radiolaria
Sponge spicules
Phosphorite
Glauconite abundant

Age: Pliocene - middle(?) Purisima Formation; faunas representing deposition at upper bathyal depths (200-600 m).

Megafossils collected from this sample submitted for identification gave the following fauna:

Gastropods:

Acteocina eximia (Baird)
Amphissa columbiana Dall
Antiplanes sp.
Bittium eschrichti Bartsch var.
Bittium cf. *B. attenuatum* Carpenter
Bittium cf. *B. challisae* Bartsch
Bittium sp.
Buccinum sp.
Cryptonatica aleutica (Dall)
"Margarites" sp.
Rectiplanes cf. *R. santarosana* (Dall)
Serpulorbis sp. - frag.
Solariella peramabilis Carpenter
Solariella varicosa (Mighel and Adams)

Pelecypods:

Chlamys hastata hericius (Gould)
Chlamys rubida hindsi (Carpenter)
Clinocardium cf. *C. nuttalli* (Conrad)
Compsomyax sp. - frag.
Cyclocardia ventricosa montereyensis (Smith and Gordon)
Cyclocardia sp.
Hiatella?
Macoma cf. *M. calcarea* (Gmelin)
Macoma elimata Dunnill and Coan

MB-10 (G-30) continued

Patinopecten cf. *P. caurinusy* (Gould)
Psephidia ovalis Dall
Tellina carpenteri Dall

Coral:

Carophyllia alaskensis Vaughn

Brachiopod:

Terebratulina unguicula Carpenter

Age: Probably Pleistocene. All of the species in this assemblage are still living; the vast majority of them have been reported from the Monterey Bay area. Two of the gatropods, *Cryptonatica aleutica* and *Bittium challisae*, are today restricted to northern latitudes, having been reported no farther south than the northwestern coast of Washington. The southern endpoint for the range of one of the pectinids, *Patinopecten caurinus*, is near Point Reyes, California, indicating that it, too, is an extralimital, northward-ranging species. These post-depositional shifts point to a Pleistocene age and to a somewhat cooler marine climate than exists off the central California coast today. One of the species, *Tellina carpenteri*, appears to be a modern specimen; it has original shell coloration and the soft parts are intact although desiccated. None of the other specimens are preserved in this condition. Similar faunal assemblages from off the southwest coast of Oregon have been dated at about 15,000 years (W. O. Addicott, written commun., 1971).

The gastropod fauna *Bittium* eschrichti Bartsch var., *Bittium* cf. *B. attenuatum* Carpenter, *Bittium* cf. *B. challisae* Bartsch,

MB-10 (G-30) continued

Bittium sp., and Buccinum sp. are diagnostic of the Pomponio mudstone and siltstone member of the Purisima Formation. The pelecypod Clinocardium cf. C. nuttalli (Conrad) is diagnostic of the Tunitas and San Gregorio sandstone members of the Purisima Formation, and the pelecypod Macoma cf. M. calcarea (Gmelin) is diagnostic of the San Gregorio, Pomponio and Tahana sandstone and siltstone members of the Purisima Formation (Cummings, Touring and Brabb, 1962; Clark, oral commun., 1973).

Depth: This is clearly a sublittoral (neritic) assemblage. A range from about 35 to 70 meters is suggested according to available data on depth ranges of these species off the California coast. This is considerably shallower than the depth from which the material was dredged--about 275 to 120 meters (W. O. Addicott, written commun., 1971).

Remarks: Dredge full of highly fossiliferous sand and gravel. No abnormal working of dredge during the operation. Sample probably represents Pleistocene sediments with some transported(?) Pliocene material.

MB-12 (G-51) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 121°55.50'W 36°46.30'N

Finish: 121°55.85'W 36°45.45'N

Depth: 400-135 meters

Lith: SILTSTONE - large (largest size is 18x10x7 cm), angular, well consolidated, sandy siltstone; greyish-orange (10YR7/4) on weathered surfaces, greenish-grey (5GY6/1) on fresh surfaces. Highly fossiliferous; some pieces are severely burrowed. Many rocks are partially covered with bryozoans, calcareous worm tubes, and barnacles; some have phosphatic coating. One rounded concretionary rock present. Represents about 35% of total sample. In thin section siltstone appears to be coarser-grained than other siltstones collected in the canyon. The larger grains (some ranging up to .06 mm in size) are composed principally of subangular quartz (about 10% of coarse-grained material), plagioclase feldspar, biotite, chlorite, and some lithic rock fragments. Appears similar to Purisima lithology.

SANDSTONE - two large angular boulders (24x16x11 cm and 35x25x20 cm) and several smaller cobbles of fine-grained, highly fossiliferous and perforated sandstone; dusky-yellow (5Y6/4) to yellowish-grey (5Y7/2) on weathered surfaces and pale greenish-yellow (10Y8/2) on fresh surfaces. Many holad-type borings found on surface of sandstone. Some samples, especially the fossiliferous ones, contain fine-grained gravel with chert, volcanic, granitic, and other lithic fragments. Represents less than 1% of sample. Fossils consist mainly of pelecypods. In thin section the sandstone is fine-grained and appears similar to MB-4 (G-50), but is finer-grained. The predominant clasts are quartz, silicic volcanic and granitic rock fragments. Could be basal sand to Monterey Formation.

GRANITE - three well rounded granitic cobbles; the largest is 5x4x3 cm. Represents less than 1% of total sample. In thin section rock looks like a granodiorite.

MUD - unconsolidated sandy silt to mud, fossiliferous, contains many well rounded pebbles of chert, quartzite and other lithic fragments; pebbles are generally less than 3 cm in size. Represents about 65% of total sample.

Paleo: Samples of siltstone submitted for micropaleontology consisted of the following faunas and other microfossils:

SAMPLE #1

Benthonic species

Bolivina pseudoplicata Heron-Allen and Earland
Bolivina spissa Cushman
Buccella frigida (Cushman)
Buliminella elegantissima (d'Orbigny)
Cassidulina delicata Cushman
Cassidulina limbata Cushman and Hughes
Cassidulina subglobosa quadrata Cushman and Hughes
Cassidulina translucens Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Elphidium clavatum Cushman
Epistominella pacifica (R. E. and K. C. Stewart)
Globobulimina pacifica Cushman
Nonionella basispinata (Cushman and Moyer)
Nonionella cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer
Trifarina baggi (Galloway and Wissler)
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg) - sinistral dominant coiling
Globigerina quinqueloba Natland

Miscellaneous

Sponge spicules
Glauconite
Phosphorite

Age: Pliocene - middle(?) Purisima Formation; faunas representing deposition at upper bathyal depths (200-600 m).

SAMPLE #2

Undiagnostic microfossils; unrecognizable casts of replaced foraminiferal tests.

SAMPLE #3

Benthonic Species

Ambitropus evax (Bandy)
Bolivina acuminata Natland
Bolivina pacifica Cushman and McCulloch
Bolivina spissa Cushman
Bulimina marginata denudata Cushman and Parker
Cassidulina islandica Norvang
Cassidulina limbata Cushman and Hughes
Cassidulina translucens Cushman and Hughes
Nonionella basispinata (Cushman and Moyer)
Trifarina baggi (Galloway and Wissler)
Uvigerina juncea Cushman and Todd
Uvigerina peregrina Cushman

Planktonic Species

Globigerina pachyderma (Ehrenberg) dextral dominant coiling
Globigerina quinqueloba Natland

Age: Pliocene - lower to middle(?) Purisima Formation.

SAMPLE #4

Benthonic Species

Cassidulina limbata Cushman and Hughes
Spirillina sp.

MB-12 (G-51) continued

Textularia sp.
Trifarina baggi (Galloway and Wissler)

Planktonic Species

Globigerina pachyderma (Ehrenberg) - dextral dominant coiling

Age: Pliocene - Purisima Formation

Samples of fossiliferous siltstone submitted for macropaleontology contained the following molluskan fauna:

SAMPLE #1

Gastropods:

Crepidula princeps Conrad?
Naticids
Mitrella sp.
Nassarius grammatus (Dall)
Ophiodermella cf. *O. graciosana* (Arnold)

Pelecypods:

Anadara cf. *A. trilineata* (Conrad)
Macoma sp.
Mytilid
Siliqua sp.
Solen?
Spisula sp.

Age and correlation: Pliocene, probably upper part of the Pliocene in terms of a twofold provincial subdivision of the epoch.

SAMPLE #2

Gastropods:

Crepidula princeps Conrad
Nassarius grammatus (Dall)
Nassarius californianus (Conrad)? - fragments
?Neptunea - small, decorticated specimen
Neverita sp. - abundant

Pelecypods:

Anadara trilineata (Conrad) - abundant
?Cryptomya
Macoma aff. *M. nasuta* (Conrad)

?*Modiolus* - fragments
?*Solen* - fragment
Spisula sp.
Yoldia sp.

Echinoid:

Dendraster sp.

Age and correlation: this shallow water assemblage is of Pliocene age and can be correlated, with confidence, with the upper part of the Purisima Formation of the Santa Cruz Mountains, the lower part of the type Merced Formation of the northern part of the San Francisco Peninsula, and exposures in the upper part of the Merced(?) Formation of Sonoma County. All of these onshore occurrences are of late Pliocene age in terms of a twofold provincial subdivision of this epoch (W. O. Addicott, written commun., 1971).

Weight: 33 kg of consolidated rock

Remarks: Dredge full - upper part of dredge contained cohesive mud with well rounded gravel interbeds and lenses of black to grey, highly fossiliferous sands. Bottom part of dredge filled with well indurated, perforated, fossiliferous siltstone that contains many pelecypods and gastropods. No siltstone or sandstone rock sample exhibited fresh surfaces, suggesting that sample was not taken in place. Dredge worked hard at start of operation; some abnormally high wire tension. The lack of fresh fractures and the attachment of marine growth on most sides of the boulders indicate that the sample has been transported. However, the angularity of the rocks and the abundance of common lithologies suggest that the outcrop or subcrop is close to sample location.

MONTEREY BAY

MB-14 (G-40) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 121°55.50'W 36°46.95'N

Finish: 121°55.45'W 36°45.65'N

Depth: 550-230 meters

Lith: UNCONSOLIDATED SILTSTONE - sandy siltstone with distinct stringers of fine- to medium-grained sands. Highly fossiliferous with fragments of pelecypod shells and whole gastropod shells. One small fish(?) vertebrate. Three well rounded to subrounded chert pebbles 4x3x2 cm in size and few other well rounded shale and chert pebbles of smaller sizes. Color ranges from olive grey (5Y3/2) wet to greenish-grey (5GY6/1) dry. Represents about 20% of sample.

MUD - green-grey mud and sand. Represents about 80% of total sample.

Paleo: Siltstone samples submitted for micropaleontology contained the following foraminifera and other microfossils:

Benthonic Species

Bolivina pseudoplicata Heron-Allen and Earland
Bolivina seminuda Cushman
Bolivina spissa Cushman
Buccella frigida (Cushman)
Buccella tenerrima (Bandy)
Buliminella elegantissima (d'Orbigny)
Cassidulina limbata Cushman and Hughes
Cassidulina minuta Cushman
Cassidulina norcrossi Cushman
Cassidulina subglobosa quadrata Cushman and Hughes
Cassidulina translucens Cushman and Hughes
Cibicides McKannai Galloway and Wissler
Cibicides spiralis Natland
Elphidium clavatum Cushman
Elphidium incertum (Williamson)

Epistominella pacifica (R. E. and K. C. Stewart)
Epistominella subperuviana (Cushman)
Fissurina lucida (Williamson)
Lagena striata (d'Orbigny)
Nonionella basispinata (Cushman and Moyer)
Nonionella cushmani R. E. and K. C. Stewart
Nonionella miocenica stella Cushman and Moyer
Polynorphina charlottensis (Cushman)
Rotorbinella versaformis (Bandy)
Trifarina baggi (Galloway and Wissler)
Uvigerina hispido costato Cushman and Todd
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg) - sinistral dominant coiling
Globigerina quinqueloba Natland
Globigerinita glutinata (Egger)
Globigerinita uvula (Ehrenberg)

Miscellaneous

Diatoms
Radiolaria
Glauconite
Phosphorite

Age: Pliocene - middle to lower Purisima Formation; faunas representing deposition at lower bathyal depths (1500-2500 m).

Weight: 21.5 kg of unconsolidated siltstone.

Remarks: Dredge full - top of dredge consisted of cohesive blue-grey clay with highly fossiliferous silt and sand stringers and some rounded pebbles. Many pelecypod shells. Middle part of dredge cohesive clay with many small rounded pebbles. Bottom part of dredge contained medium- to coarse-grained sand that included much organic debris, i.e., tree limbs, twigs, bark, etc. Dredge worked hard only near end of operation. Most of this dredge sample was not in place but represents transported material. The unconsolidated siltstone may have come from a site very close to the outcrop or subcrop.

MB-16 (G-52) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 121°54.35'W 36°47.60'N

Finish: 121°54.25'W 36°45.30'N

Depth: 350-110 meters

Lith: SANDSTONE - light olive grey (5Y5/2), consolidated to semi-consolidated, fossiliferous, arkosic sandstone. Samples are perforated with U-shaped worm tubes; many pelecypod shell fragments included. Samples consist of many small, friable, angular fragments with only three pieces larger than 3 cm in diameter; largest piece measures 5x19x13 cm. One subrounded pebble of sandstone, 3x3x2 cm in size, is well lithified and contains inclusions of opaque minerăl grains. No marine growth present. Represents about 5% of total dredge sample.

SILTSTONE - one tabular chunk of siltstone measuring 6x6x3.5 cm, perforated with worm tubes and coated with phosphorite and limonite. No marine growth or fresh surfaces. Many angular fragments or chips of siltstone. In thin section appears lithologically similar to siltstone sample MB-12 (G-51). Matrix too fine-grained to identify minerals. Coarser grains consist of quartz, plagioclase feldspar, biotite, and lithic and volcanic(?) rock fragments. Largest grain is about .07 mm in size. Looks lithologically similar to Purisima. Represents about 20% of total sample.

GRANITE - one well rounded pebble of granodiorite. No marine growth. Represents less than 1% of total sample.

MB-16 (G-52) continued

MUD - olive-green to blue-grey; cohesive silt. Represents between 70 and 75% of total sample.

Paleo: Sample of siltstone submitted for micropaleontology contained the following foraminifera and other microfossils:

Benthonic Species

Bolivina interjuncta Galloway and Wissler
Bolivina pseudoplicata Heron-Allen and Earland
Bolivina spissa Cushman
Bolivina vaughani Natland
Buccella frigida (Cushman)
Bulimina denudata (Cushman and Parker)
Buliminella elegantissima (d'Orbigny)
Cancris auricula (Fichell and Moll)
Cassidella seminuda (Natland)
Cassidulina limbata Cushman and Hughes
Cassidulina subglobosa quadrata Cushman and Hughes
Elphidium clavatum Cushman
Epistominella pacifica (R. E. and K. C. Stewart)
Epistominella subperuviana (Cushman)
Globobulimina pacifica Cushman
Lagena striata (d'Orbigny)
Nonionella miocenica stella Cushman and Moyer
Sigmoilina tenuis (Czjzek)
Trochammina pacifica Cushman
Uvigerina peregrina Cushman

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina pachyderma (Ehrenberg) - sinistral dominant coiling
Globigerina quinqueloba Natland

Miscellaneous

Diatoms
Radiolaria
Sponge spicules
Glauconite abundant

Age: Pliocene - middle(?) Purisima Formation; faunas representing deposition at outer shelf (neritic) to upper bathyal transitional depths (75-200 m).

MB-16 (G-52) continued

Weight: 5.0 kg of consolidated rock.

Remarks: Dredge full of grey-green mud with large chunks of black to grey, cohesive sand and many small angular fragments of friable siltstone; some fossils visible. Dredge sample collected mostly along upper 100 m of canyon wall. No abnormal working of dredge. Samples of consolidated rocks not in place; however, since dredge collected material from upper part of canyon wall, consolidated rock fragments probably have not been transported far from outcrop or subcrop.

MB-18(G-46) Pipe dredge (12")

Location: Monterey Canyon - south wall

Start: 121°53.45'W 36°46.00'N

Finish: 121°54.00'W 36°45.50'N

Depth: 230-110 meters

Lith: CONGLOMERATE - subangular, highly fossiliferous boulders (over 20 boulders) with very pale orange (10YR8/2), well rounded, pebble-sized clasts of chert. Other clasts are composed of lithic and volcanic(?)rocks. A fine-grained sand matrix. Color varies from greyish-orange (10YR7/4) to moderate yellowish-brown (10YR5/4) on weathered surfaces to light bluish-grey (5B7/1) on fresh surfaces. Cement is calcareous, well indurated. Surfaces of boulders are well burrowed with marine growth, calcareous worm tubes, bryozoans, corals, barnacles, small rock scallops, and some siliceous sponges. Sizes of the boulders range from 20x17x13 cm to 4x4x4 cm. Represents about 90% of total sample.

SANDSTONE - subrounded to subangular sandstone boulders with same appearance and characteristics as sandy matrix of conglomerate, and probably represents a sandy facies of the conglomerate. Fairly friable. No muds or unconsolidated material. Represents about 10% of total sample.

Weight: 17.4 kg of consolidated rock

Paleo: Sample of sandstone submitted for micropaleontology contained the following foraminifera:

Benthonic Species

Buccella frigida (Cushman)
Trifarina sp. (broken)

Planktonic Species

Globigerina pachyderma (Ehrenberg) - 1 dextral specimen

Age: Pliocene - Purisima formation

Sample submitted for macropaleontology contained the following molluskan fauna:

Gastropods:

Bittium sp.
Calyptraea sp.
Naticid
Olivella sp.
Trochid - minute
Turrid - minute

Pelecypods:

Cardiid - internal mold
Cyclocardia - fragment
Chione - large fragment with sharp, raised ribs
Undetermined fragments

Age: Miocene or Pliocene. Pelecypods similar to the large Chione are not known to occur in faunas generally classified as late Pliocene in the Santa Cruz Mountains to the north. Similar pelecypods do occur, however, in the lower Pliocene Pancho Rico Formation of the Salinas basin as well as in Miocene formations in central California. The other mollusks are too small, or too poorly preserved, to be useful in age determination (W. O. Addicott, written commun., 1971).

Remarks: Dredge 1/4 full - freshly broken well consolidated, fossiliferous conglomerate and coarse-grained sandstone. Dredge worked hard with high wire tension. Very clean dredge haul sample.

MB-18 (G-46) continued

Rocks taken in place. This sample appears lithologically similar to the sandstone found in the San Gregorio sandstone member of the Purisima Formation.

MB-20 (G-24) Pipe dredge (12")

Location: Monterey Canyon - south wall (head)

Start: 121°49.55'W 36°47.45'N

Finish: 121°49.20'W 36°47.00'N

Depth: 230-30 meters

Lith: MUD - greyish olive green (5GY3/2), silty, micaceous mud.

No consolidated rock samples.

Weight: None

Paleo: None

Remarks: Dredge full - black to grey mud.

MONTEREY BAY

MB-22 (G-43) Pipe dredge (12")

Location: Monterey Canyon - south wall (head)

Start: 121°48.70'W 36°47.90'N

Finish: 121°48.40'W 36°47.40'N

Depth: 165-18 meters

Lith: UNCONSOLIDATED SILTS AND SAND - olive-grey (5Y3/2), well sorted, fine, sandy silt. Represents 100% of total sample.

Weight: None

Paleo: Sample submitted for micropaleontology contained the following foraminifera and other microfossils:

Benthonic Species

Ammonia beccari (Cushman)
Bolivina spissa Cushman
Buliminella elegantissima (d'Orbigny)
Cassidella nodosa (R. E. and K. C. Stewart)
Cassidella seminuda (Natland)
Elphidium clavatum Cushman
Elphidium incertum (Williamson)
Epistominella subperuviana (Cushman)
Globobulimina pyrula (d'Orbigny)
Haplophragmoides columbiensis Cushman
Nonionella basispinata (Cushman and Moyer)
Nonionella miocenica stella Cushman and Moyer
Quinqueloculina spp.
Suggrurda eckisi Natland
Textularia earlandi F. L. Parker

Planktonic Species

Globigerina bulloides d'Orbigny
Globigerina quinqueloba Natland

Miscellaneous

Diatoms
Radiolaria
Sponge spicules

MB-22 (G-43) continued

Age: Pliocene - upper to middle Purisima Formation; sample represents deposition at outer shelf (neritic) to upper bathyal transitional depths (75-200 m).

Remarks: Dredge full - well sorted, fine- to medium-grained, greenish-brown, well sorted sands and silts. Transported.

MB-24 (70-001-PD-013) Pipe dredge (6")

Location: Salinas Delta

Start: 121°51.20'W 36°45.70'N

Finish: 121°50.80'W 36°45.50'N

Depth: 60-50 meters

Lith: UNCONSOLIDATED SAND AND SILT - black to greenish-grey, fine-grained sand and silt.

Weight: None made

Paleo: None

Remarks: Dredge half full - sandy silt that apparently was in place under reducing conditions with much organic matter; probably Holocene in age.

MONTEREY BAY

MB-26 (G-10) Pipe dredge (12")

Location: Monterey

Start: 121°53.70'W 36°37.50'N

Finish: 121°53.70'W 36°37.80'N

Depth: 35-55 meters

Lith: GRANITE - four boulder-sized, angular chunks of granodiorite with some marine growth and distinct fresh fractures on one boulder. Represents about 5% of sample.

UNCONSOLIDATED SAND - grey-green, poorly sorted, fossiliferous (abundant shell fragments), silty sand. Represents about 95% of sample.

Weight: None made

Remarks: Dredge 3/4 full - silty sand with several boulders of granite. Fresh fractures on one boulder and high wire tension with hard bouncing of dredge indicate that the granitic rocks were in place or very close to outcrop of granodiorite.

N-2 NEKTON Submersible Dive

Location: Monterey Canyon - south wall

Start: 121°56.00'W 36°46.10'N

Finish: 121°56.10'W 36°45.70'N

Depth: 300 meters

Lith: SILTSTONE AND SANDSTONE - grey, consolidated, perforated siltstone and fossiliferous sandstone; several cobble-sized pieces freshly broken off from outcrop. The perforated "siltstone" has remains of siliceous sponges attached. Presumably the burrows are those of a worm or crustacean; they are not pholad or mytilid (e.g., Lithophaga) mollusk borings which would indicate relatively shallow water (J. G. Vedder, written commun., 1972).

Weight: None made

Paleo: Sample of fossiliferous sandstone contains:

Pelecypods:

Patinopecten cf. *Patinopecten healeyi* (Arnold) - incomplete left valve and other fragments with evenly spaced, regular ribbing that suggests assignment to this species rather than to *Patinopecten löhri* (Hertlein) (Arnold's *Pecten oweni*), which has irregular ribbing (J. G. Vedder, written commun., 1972).

Age: Both *P.* healeyi and *P. löhri* are restricted to the Pliocene epoch as used by West Coast molluskan paleontologists. P. *lohri* may be a variant of *P. healeyi*, since their stratigraphic ranges overlap in the Purisima Formation (J. G. Vedder, written commun., 1972).

N-2 NEKTON Submersible Dive continued

Remarks: Samples were taken in situ by an articulating arm of the submersible at a well exposed, vertical outcrop on the south side of Monterey Canyon. Photos of the outcrop were also taken.

CB-1 (G-54) Pipe dredge (12")

Location: Carmel Canyon - outer eastern wall

Start: 122°00.75'W 36°37.55'N

Finish: 122°01.50'W 36°38.25'N

Depth: 1005-175 meters

Lith: GRANITE - very angular granitic boulders, cobbles, and pebbles ranging in size from 12x12x7 cm to less than 1x1x1 cm with an average size of approximately 4x5x2 cm. Many boulders exhibit fresh fractures; exposed sides are generally phosphatically coated and covered with bryozoans, calcareous worm tubes, and barnacles. Five of the granitic cobbles are well rounded and range in size from 14x8x6 cm to 5x4x3 cm. Represents about 20% of total sample. In thin section rock is a biotite granodiorite.

SILTSTONE - one very well rounded, broken and perforated, siltstone cobble, 6x6x5 cm in size, and one siltstone "rod" 10 cm long and 2 cm in diameter, perforated with small diameter worm burrows. "Rod" could be cast of larger diameter worm burrow. Bryozoans attached to both rocks, and both were colored greenish-grey (5GY6/1). Represents less than 1% of total sample.

MUD - greenish-grey (5GY6/1) mud. Represents about 80% of total sample.

Weight: 29.0 kg of consolidated rock.

CB-1 (G-54) continued

Remarks: Dredge half full - sandy-silty mud with angular to subrounded boulders and cobbles of granite concentrated at bottom of dredge. Dredge worked hard and bounced many times during first part of dredging operation; high wire tension. Granites probably taken from in place. Siltstone transported.

MONTEREY BAY

CB-2 (G-45) Pipe dredge (12")

Location: Carmel Canyon - outer eastern wall

Start: 122°02.45'W 36°35.05'N

Finish: 122°00.65'W 36°35.60'N

Depth: 915-175 meters

Lith: GRANITE - over 20 very angular cobbles and pebbles ranging in size from 13x7x5 cm to less than 2x2x2 cm. Some have freshly fractured faces. Most are phosphatically coated and several are partially covered with calcareous worm tubes, bryozoans and corals. One cobble is rounded and is about 4x3x2 cm in size. In thin section rock appears to be a granodiorite. Represents about 99% of sample.

CHERT - one angular pebble (6x3x3 cm in size) of red chert with fine calcitic veins.

GNEISS - one small (4x3x2 cm in size), subrounded cobble.

No unconsolidated rocks.

Paleo: None

Weight: 5.0 kg

Remarks: Dredge 1/6 full - very angular granitic boulders, cobbles, and pebbles, some showing fresh surfaces. No unconsolidated material, very clean dredge haul. Dredge bounced many times and worked hard throughout operation. Sample taken from in place.

CARMEL BAY

CB-3 (CB-1) Pipe dredge (12")

Location: Carmel Canyon - western wall of eastern tributary.

Start: 121°58.70'W 36°30.70'N

Finish: 121°59.60'W 36°30.80'N

Depth: 450-120 meters

Lith: GRANITE - ten rounded to sub-angular pebbles (largest is 7x3x2 cm and average size is 3.5x2x1 cm), yellowish-grey (5Y7/2), fine- to medium-grained, granitic rocks. Some rocks are perforated and some have freshly fractured surfaces indicating they may have been broken off larger rocks. Very little marine growth. Represents about 99% of total sample. In thin section appears to be a quartz diorite.

SILTSTONE - one, small (2x2x2 cm), angular, yellowish-grey (5Y7/2), perforated pebble. One side appears freshly fractured and other sides coated with phosphorite. Represents about 1% of total sample.

Paleo: None

Weight: None

Remarks: Dredge full - angular to rounded fragments of sandstone and siltstone. Dredge worked moderately hard with few bounces during operation. Sample probably not taken in place but from debris pile a short distance downslope of granitic outcrop. For more detailed description of this sample see Table A (dredge haul number CB-1) by Dohrenwend (1971) included in this appendix.

CARMEL BAY

CB-4 (CB-2) Pipe dredge (12")

Location: Carmel Canyon - western wall of eastern tributary

Start: 121°58.70'W 36°30.70'N

Finish: 121°59.60'W 36°30.80'N

Depth: 150-100 meters

Lith: GRANITE - five angular to well rounded boulders (largest is 17x13x9 cm); no fresh surfaces. Most are thinly covered with phosphorite and fairly well covered with calcareous worm burrows, corals, and bryozoans. In thin section appears to be a granodiorite. Represents about 70% of total sample.

SANDSTONE - two large boulders about 13x9x8 cm in size, perforated, coated with a thin layer of phosphate and covered on most sides with calcareous worm tubes and bryozoans. No fresh surfaces. In thin section one boulder is coarse-grained or granular sandstone with predominant clasts of angular siltstone fragments; the remainder of clasts are quartz and plagioclase feldspar. The other boulder in thin section is a well sorted, coarse-grained sandstone with predominant clasts of quartz; other clasts are composed of metamorphic(?) and lithic rock fragments and plagioclase feldspar. Clasts have been fractured and sheared. This sample does not resemble any sandstone samples collected in Monterey Bay. Represents about 25% of sample.

SILTSTONE - one freshly fractured piece of a well rounded boulder of perforated, light olive grey (5Y6/1), fine-grained siltstone. Boulder is phosphatically coated and covered with

CB-4 (CB-2) continued

calcareous worm burrows and bryozoans. In thin section rock is too fine-grained to distinguish minerals. Largest clast is about 0.4 mm and is quartz. Represents less than 5% of total sample.

CHERT AND MYLONITE(?) - one 3x3x2 cm, highly sheared, brown chert pebble included within a fine-grained conglomerate and angular, coarse-grained, sandy matrix, and one small (2.5x2x1 cm), well rounded, white, chert pebble with small amount of coarse-grained sandstone attached. One subangular pebble of sheared ultrabasic(?). These pebbles appear to have been derived from a conglomerate. All of these pebbles may be from a fault gouge as they are highly sheared and fractured.

Paleo: None

Weight: None made

Remarks: Dredge 1/6 full - boulders, cobbles and pebbles of granite, sandstone, and siltstone; no unconsolidated material, very clean dredge haul. Rocks not taken in place, but probably were not transported far from outcrops. Dredge haul made in same location as CB-3 (CB-1) but did not collect material below 150 meters. For more detailed description of this sample see Table A (dredge haul number CB-2) by Dohrenwend (1971) included in this appendix.

CB-5 (CB-14) Pipe dredge (12")

Location: Carmel Canyon - western wall (head) of western tributary

Start: 121°59.40'W 36°30.20'N

Finish: 121°59.30'W 36°30.50'N

Depth: 400-200 meters

Lith: GRANITE - several angular boulders (largest about 18 cm in diameter) of medium-grey granodiorite. Little marine growth. Some have fresh surfaces. Represents about 10% of total sample.

MUDSTONE - many large boulders (largest about 30 cm in diameter) of angular, light to medium greenish-grey, well indurated, silty mudstone. In thin section predominant clasts consist of quartz, K-feldspar, plagioclase, chlorite, and biotite. Represents about 65% of total sample.

CONGLOMERATE - several subangular to subrounded, moderately indurated, lightly perforated, grey-green, pebble conglomerate. Pebbles consist primarily of quartz, chert, and lithic, granitic, and metamorphic rock fragments. Cemented with spar calcite. Represents about 25% of total sample.

Paleo: None

Weight: None made

Remarks: Dredge about 1/4 full - granite and siltstone boulders; no unconsolidated material; very clean dredge haul. Some high wire tension and hard bounces by dredge during operation. Sample does not appear to have been taken in place, but has not been transported far from outcrop. For more detailed analysis of this dredge haul see Table A (dredge haul number CB-3) by Dohrenwend (1971) included in this appendix.

POINT LOBOS - POINT SUR SHELF

LS-1 to LS-7 (CB-4 to CB-10) Pipe dredge (12")

These dredge hauls are described in detail by Dohrenwend (1971) and, therefore, are not described further here. Dohrenwend's tables A, B, and C that describe these dredge samples are included below. Also included below is a report on microfossils contained in samples from dredge haul LS-7 (CB-9) prepared by J. C. Ingle, Jr.

Table A - Dredge Haul Sample Data: Data relevant to bedrock criteria (after Dohrenwend, 1971)

GENERAL ROCK TYPE	DREDGE NUMBERS	WEIGHT (LBS)	PERCENT OF HAUL	MAXIMUM DIMENSION	TOUGHNESS AND INDURATION	ANGULARITY	CONDITION OF ROCK SURFACES	BEDROCK?
Granodiorite	CB-3,4 (CB-1,2) (CB-3) CB-5	70 6	44 % 8 %	30 cm 18 cm	very tough	angular	rough and uneven; no worm or pholad borings	yes
Silty mudstone	CB-3,4 (CB-1,2) (CB-3) CB-5	60 50	37 % 66 %	30 cm	tough and well indurated	angular	many worm holes; some pholad borings	yes
Sandy siltstone	LS-1 (CB-4) (CB-8) LS-3	6 31	48 % 81 %	24 cm	brittle and friable	subrounded to rounded	some worm holes; many pholad borings	yes
Muddy sand-stone and silty mud-stone	LS-4 (CB-5) (CB-6) LS-6	7 1	100 % 100 %	15 cm	moderately tough and indurated	subangular to subrounded	some pholad borings	probably yes
Poorly sorted, fine-grained, lithic arkose	CB-4 (CB-2)	9	20 %	15 cm	very tough and well indurated	subangular to subrounded	few worm holes in an otherwise smooth,even surface	probably yes
Well sorted, coarse-grained arkose	CB-3 (CB-1)	22	19 %	15 cm	very tough and well indurated	subangular to rounded	fairly smooth, even surface; few worm holes	probably yes
Pebble conglomerate	CB-4 (CB-3)	20	26 %	15 cm	tough and moderately indurated	subangular to subrounded	rough surface; few worm holes	probably yes
Limey, very fine-grained sandstone	LS-3 (CB-8)	7	19 %	18 cm	moderately tough and fairly well indurated	very angular	very rough, hackly, and uneven surface	probably yes
Claystone and shale	LS-7 (CB-9)	49	62 %	26 cm	tough to moderately tough and well indurated	angular to subrounded	covered with worm holes; some pholad borings	yes
Highly altered metasediment(?)	LS-5 (CB-10)	1	100 %	8 cm	moderately tough	angular	hackly,uneven surface; some worm holes	?
Pebble conglomerate	CB-5 (CB-4)	6	48 %	12 cm	brittle and friable	subangular	rough, uneven surface; few worm holes	yes

Table B - Dredge Haul Sample Data: Color, Grain Size, Roundness and Sphericity (after Dohrenwend, 1971)

GENERAL ROCK TYPE	DREDGE NUMBERS	COLOR FRESH / WEATHERED	AVERAGE GRAIN SIZE	APPROXIMATE GRAIN SIZE RANGE	GRAIN ROUNDNESS	GRAIN SPHERICITY
Granodiorite	CB-3,4,5 (CB-1,2,3)	medium grey / light to medium brown, grey green	2 mm	.2 - 4 mm	N/A	N/A
Silty mudstone	CB-3,4,5 (CB-1,2,3)	light to medium greenish grey	.05 mm	.01 - .15 mm	angular to subrounded	low
Sandy siltstone	LS-1,3 (CB-4,8)	light greenish grey	.05 mm	.01 - .4 mm	angular to subrounded	very low
Muddy sandstone - sandy mudstone	LS-4,6 (CB-5,6)	medium grey	.05 mm .3 mm	.01 - .3 mm .2 - .7 mm	angular to subrounded	low
Poorly sorted, fine-grained, lithic arkose	CB-4 (CB-2)	medium grey / dark greenish grey	.2 mm	.05 - 1 mm	angular to subangular	low
Well sorted, coarse-grained arkose	CB-3 (CB-1)	light brownish grey / medium grey-green, brown	.8 mm	.25 - 2.5 mm	subrounded to rounded	medium
Pebble conglomerate	CB-5 (CB-3)	Light grey green / dark grey green	2 mm	.5 - 30 mm	subrounded to rounded	low
Pebble conglomerate	LS-1 (CB-4)	yellow-orange brown	.25 mm 5 mm	.05 - 1 mm 2 - 50 mm	angular to subangular rounded to subrounded	ranges from high to low
Limey, very fine-grained sandstone	LS-3 (CB-8)	dark grey / orange brown	.1 mm	.05 - .25 mm	very angular to subangular	low
Claystone and shale	LS-7 (CB-9)	light yellow, medium grey / dark brownish-blackish grey	--- GRAIN SIZE TOO SMALL FOR 60X MICROSCOPIC STUDY ---			
Highly altered metasediment(?)	LS-5 (CB-10)	orange brown to black	grain size highly variable	original grains approx. 2-4 mm	N/A	N/A

Table C - Dredge Haul Sample Data: Mineralogy, Paleontology and Structure (after Dohrenwend, 1971)

GENERAL ROCK TYPE	DREDGE NUMBERS	ABUNDANT MINERALS (GRAINS)	MATRIX	BIOCLASTIC MATERIAL	STRUCTURE + BEDDING	ADDITIONAL COMMENTS
Granodiorite	CB-3,4,5 (CB-1,2,3)	Plagioclase, K-feldspar, microcline, quartz, biotite	N/A	N/A	graphic intergrowths of quartz and feldspar are common	some of the quartz grains show straining
Silty mudstone	CB-3,4,5 (CB-1,2,3)	quartz, K-feldspar, plagioclase, glauconite, pyrite, chlorite, biotite	70 - 80 % grain size <<.005 mm partially calcite	less than 1 % radiolaria, sponge spicules, fish bones, fecal pellets	indistinct bedding up to 12 cm thick	calcite spar borders on silt grains
Sandy siltstone	LS-1,3 (CB-4,8)	quartz, K-feldspar, glauconite, chlorite, pyrite, rock fragments	40 - 60 % grain size <.005 mm	same as for silty mudstone but less abundant	distinct bedding approx. 2 cm thick	Calc. spar borders on silt grains - 3 directions of rock cleavage
Muddy sandstone - silty mudstone	LS-4,6 (CB-5,6)	quartz, K-feldspar, plagioclase, chlorite, pyrite, glauconite, rock fragments	40 - 50 % grain size <.005 mm	same as for silty mudstone; also fossil pholad borings	distinct bedding 1 - 4 cm thick	Samples studied contained two distinct grain size populations mixed together
Poorly sorted, fine-grained, lithic arkose	CB-4 (CB-2)	quartz, rock fragments, chlorite, K-feldspar, plagioclase, glauconite, pyrite, hornblende	25 - 35 % grain size <.05 mm mostly calcite spar	a few fish bones and radiolaria	pronounced orientation of flat or elongate grains in parallel planes	authigenic chlorite very abundant
Well sorted, coarse-grained arkose	CB-3 (CB-1)	quartz, plagioclase, microcline, K-feldspar, biotite rock fragments - granodiorite, sandstone	30 - 40 % grain size <.05 mm calcite spar	none observed	no bedding or structure observed in hand or micro-specimen	crystals of spar surround and radiate from sand grains
Pebble conglomerate	CB-5 (CB-3)	quartz, feldspar, glauconite, biotite, chert rock fragments - granodiorite, metamorphics	15 - 25 % calcite spar	none observed	no bedding or structure observed in hand or micro-specimen	younger than the granodiorite
Pebble conglomerate	LS-1 (CB-4)	rock fragments up to 5 cm granodiorite, silty mudstone, chert, quartz, glauconite, biotite	25 - 35 % calcite spar cemented sand	none observed	no bedding or structure observed in hand or micro-specimen	younger than silty mudstone granodiorite
Limey, very poorly sorted sandstone	LS-3 (CB-8)	quartz, plagioclase, microcline, biotite, chlorite, rock fragments	30 - 40 % grain size <.05 mm calcite spar	none observed	no bedding or structure observed in hand or micro-specimen	
Claystone and shale	LS-7 (CB-9)	silt-size quartz and feldspar 5%; fossils, 5 - 15%	75 - 85% some spar - grain size <<.005 mm	foraminifera radiolaria diatoms	distinct bedding 5 - 10 cm thick freq. laminated	on the basis of some of the forams tentatively dated as Miocene
Highly altered metasediment(?)	LS-5 (CB-10)	pyrite, calcite, and 6 or more unidentified minerals	N/A	none	extreme alteration	highly weathered throughout

REPORT ON MICROFOSSILS IN SAMPLES LS-7(CB-9-6) and LS-7(CB-9-1)

Prepared by

James C. Ingle, Jr.
Department of Geology
Stanford University

LS-7 (CB-9-6) (thin section)

1. Microfossils observed:

   Abundant unidentified centric diatoms

   Common sponge spicules

   Common unidentified radiolarians

   Common benthonic foraminifera[1/]:

   Bolivina spp.
   "*Virgulina*" sp.
   Bulimina sp.
   Nonionella sp.
   Valvulineria sp. - a large robust form; possibly *V. californica*

2. Analysis:

   The association of abundant diatoms, somewhat laminated microstructure of the sediment, together with a benthonic foraminiferal fauna dominated by species of *Bolivina* and *Bulimina*, strongly suggest this rock was derived from the Miocene Monterey Shale. Furthermore, the presence of a large *Valvulineria*, possibly *V. californica*, suggests a Luisian (upper middle Miocene) age for the rock.

LS-7 (CB-9-1) (thin section)

1. Microfossils observed:

   Common diatoms

   Common benthonic foraminifera[1/]:

   Bulimina sp.
   Bolivina spp.
   Buliminella sp.

1/ Foraminifera were not identified at the species level due to restriction of two-dimensional views provided by thin-sectioned samples (after Dohrenwend, 1971).

Rare planktonic foraminifera[1/]:

Globigerina sp.

2. Analysis:

Again, the association of abundant diatoms and a benthonic foraminiferal fauna dominated by species of Bolivina and Bulimina suggest this rock was derived from the Miocene Monterey Shale.

1/Foraminifera were not identified at the species level due to restriction of two-dimensional views provided by thin sectioned samples (after Dohrenwend, 1971).

POINT LOBOS - POINT SUR SHELF

LS-8 (CB-11) Pipe dredge (12")

Location: Point Sur - location approximate

Start: 121°56.90'W 36°19.20'N

Finish: 121°56.20'W 36°27.10'N

Depth: 60-45 meters

Lith: GRAVEL - few pebbles of angular to subrounded granite, red chert, and shale(?).

Paleo: None

Weight: None made

Remarks: Dredge nearly empty - only a few pebbles of mixed lithology. Dredge worked hard and bounced many times during operation; high wire tension. Shelf here is probably a bedrock shelf with a thin cover of sand and gravel. Sand must have washed out when recovering dredge. Transported sample.

POINT LOBOS - POINT SUR SHELF

LS-9 (CB-12) Pipe dredge (12")

Location: Northern Point Lobos - Point Sur shelf

Start: 122°00.00'W 36°25.90'N

Finish: 121°59.00'W 36°27.10'N

Depth: 300-180 meters

Lith: UNCONSOLIDATED SAND - medium- to coarse-grained, olive-grey (5Y3/2), angular, highly fossiliferous sand with few rounded pebbles of granite, chert, and shale. Represents 100% of sample. No consolidated rocks recovered.

Paleo: Sample submitted for macropaleontology contained the following faunas:

Gastropods:

Amphissa sp.
?*Astraea* sp.
?Fissurellid
Naticid
Tegula cf. *T.* *brunnea* Phillipi

Pelecypods:

Acila sp.
Astarte *bennetti* Dall - abundant
Chlamys sp.
Cyclocardia *ventricosa* (Gould)
Cyclocardia *ventricosa* *montereyana* (Smith and Gordon)?
Cyclocardia sp.
Epilucina *californica* (Conrad)?
Glycymeris cf. *G.* *subobsoleta* (Carpenter) - abundant
Mactrid
Miodontiscus *prolongatus* (Carpenter)?
Mytilus sp. - abundant
Nemocardium *centifilosum* (Carpenter)
?*Pododesmus*

Scaphopod:

Dentalium *berryi* Smith and Gordon

LS-9 (CB-12) continued

Coral:

Paracyathus cf. P. stearnsi Verrill

Brachiopod:

Terebratalia sp.

Barnacles:

Balanus tintinnabulum californicus Pilsbury
Balanus spp. - abundant

Undetermined bryozoan

Age: Probably no older than late Pleistocene. All of the specifically identified taxa in this assemblage are still living.

Comments: This is an unusual assemblage in that it is suggestive of depths substantially shallower than those from which it was dredged and because it contains abundant specimens of Astarte, a cool-temperate to cold water pelecypod that has not previously been recorded from south of Puget Sound - between 1300 and 1400 kilometers to the north. The most common invertebrates in the sample are extensively worn plates of Balanus and fragments of a rather large, thick-shelled Mytilus. These taxa plus mollusks such as Tegula and the doubtfully identified fissurellid, Astrea, and Pododesmus are suggestive of extremely shallow water - the highest reaches of the inner sublittoral zone or the inter-tidal zone. On the other hand, specimens of Paracyathus, Astarte (at this latitude), Cyclocardia, Dentalium berryi, and Glycymeris suggest substantially greater depths - no shallower than 35 to 45 meters - according to fairly detailed distributional data from this part of the California coast. Although this is difficult to substantiate, the fossils appear to be a mixed depth assemblage of species representing middle sublittoral and high inner sublittoral depths. The assemblage is of a special interest zoogeographically because the genus Astarte has never been reported as a fossil or modern specimen from south of the Puget Sound area. Actually it is characteristic of the highest latitudes of the North Pacific and the Bering Sea. The species A. bennetti is clearly distinct from the four species of Astarte that are known to range as far south as Puget Sound. Its southernmost modern occurrence is in the Bering Sea, although it ranges into the middle latitudes of the western Pacific (Kyushu Island, Japan) where it is found in the outer part of the sublittoral zone. The occurrence of Astarte in the Pleistocene assemblage from near Monterey Bay suggests water temperature substantially cooler than at this latitude today (W. O. Addicott, written commun., 1972).

Weight: None made

Remarks: Dredge full - well sorted, medium- to coarse-grained, fossiliferous, granitic sands. Sample probably transported. One well preserved shark's tooth also recovered.

CONTINENTAL SLOPE

<u>MF-1</u> Pipe Dredge (12")

Location: Unnamed seaknoll

Start: 122°15.80'W 36°22.40'N

Finish: 122°19.80'W 36°22.70'N

Depth: 1,190-825 meters

Lith: DOLOMITE - many large, subrounded boulders of fine-grained, grey-brown, highly perforated dolomite. Some boulders may have pholad borings. All boulders phospatically coated; most sides covered with bryozoans, calcareous worm tubes, and other marine growth. No fresh surfaces. Represents about 80% of total sample.

SANDSTONE - several small, subangular, well indurated, medium-grained, yellowish-brown, sandstone boulders. Clasts appear to be composed predominantly of quartz, lithic, and metamorphic rock fragments. No fresh surfaces. Represents about 20% of total sample.

GRANITE - a few well rounded pebbles of granitic rock.

Weight: None made

Paleo: Sample of dolomite submitted for micropaleontology (coccolith) was barren.

Age: Indeterminant

Remarks: Dredge full - subrounded, phosphatically coated, fine-grained dolomite and sandstone. Dredge worked hard during operation, abnormally high wire tension. Sample probably transported, MF-1 continued

based on angularity of specimens. However, since the dolomite lithology is so prominent, the sample is not believed to have travelled far; dolomite probably makes up this seaknoll.

MBC-1 (70-OC1-VC-009) Vibra-core

Location: Santa Cruz
122°02.15'W 36°56.21'N

Water Depth: 26 meters

Penetration Depth: 4.5 meters

Total Core Length: 4.5 meters

Description: Core consists of massive, cohesive, greenish-grey mud; no sedimentary structures visible. Core catcher full of clay.

Paleo: None

Remarks: Core did not hit bedrock, but bottomed in clay. Sample probably represents deposition in Holocene time.

NORTHERN MONTEREY BAY SHELF

MBC-2 (70-OC1-VC-008) Vibra-core

Location: Santa Cruz
121°58.95'W 36°56.36'N

Water Depth: 17 meters

Penetration Depth: .6 meters

Total Core Length: .3 meters

Description: Core consists of dark-grey mud. No sedimentary structures visible. Fragments of consolidated, friable, fine-grained sandstone and mud caught in core catcher.

Remarks: Core appears to have bottomed in bedrock. Bedrock probably Pliocene Purisima Formation.

NORTHERN MONTEREY BAY SHELF

MBC-3 (70-OCl-VC-010) Vibra-core

Location: Santa Cruz
121°59.49'W 36°53.97'N

Water Depth: 36 meters

Penetration Depth: 5.5 meters

Total Core Length: 5.3 meters

Description: Core consists of fairly homogeneous, fine- to medium-grained, greenish-grey, fossiliferous sand. Several interbeds of shell fragments.

Remarks: Core did not hit bedrock. Sample probably of Holocene age.

NORTHERN MONTEREY BAY SHELF

MBC-4 (70-OC1-VC-012) Vibra-core

Location: Offshore mouth of Pajaro River
$121^{o}52.42'W$ $36^{o}50.92'N$

Water Depth: 50 meters

Penetration Depth: 6.4 meters

Total Core Length: 2.7 meters

Description: Core consists of fairly homogeneous, dark greenish-grey, fine- to medium-grained sand. No sedimentary structures visible.

Remarks: Core did not bottom in bedrock. Sample probably of Holocene age. Lost about 3.7 meters of sample because core catcher did not close.

MBC-5 (70-OC1-VC-014) Vibra-core

Location: Head of Monterey Canyon - Moss Landing
121°48.72'W 36°48.63'N

Water Depth: 32.3 meters

Penetration Depth: 6.4 meters

Total Core Length: 6.4 meters

Description: From bottom to top core is composed of about 1.5 m of grey mud, grading upwards into fine-grained, greenish-grey sand about 1.6 m thick. A sharp contact exists between the top of the greenish-grey, fine-grained sand and an overlying layer of coarse-grained, whitish-grey sand. The whitish-grey sand is about .6 m thick and grades upward in a very coarse-grained sand about .6 m thick that in turn grades back into a coarse-grained sand layer about .5 m thick. The upper 1.5 m of the core is coarse-grained sand that grades into a very coarse-grained, pebbly sand. The sands in the upper 3.2 m of the core are all whitish-grey in color.

Remarks: Core did not bottom in bedrock. Sample probably late Pleistocene or Holocene age.

MBC-6 (70-OC1-VC-015) Vibra-core

Location: Salinas River delta
121°49.68'W 36°44.31'N

Water Depth: 22 meters

Penetration Depth: 4.8 meters

Total Core Length: 4.7 meters

Description: Core consists principally of greenish-grey, fine-grained sand with clay interbeds. Core bottomed in a highly fossiliferous layer of unconsolidated sand that contains abundant gastropod shells.

Remarks: Core did not bottom in bedrock. Sediment is probably late Pleistocene-Holocene age.

SOUTHERN MONTEREY BAY SHELF

MBC-7 (70-OC1-VC-016) Vibra-core

Location: Monterey shelf
$121^{\circ}59.91'W$ $36^{\circ}39.08'N$

Water Depth: 67 meters

Penetration Depth: 6.4 meters

Total Core Length: 5.3 meters

Description: Core consists of homogeneous, fine- to medium-grained, greenish-grey sand. No sedimentary structures visible.

Remarks: Core probably bottomed on bedrock but no sample recovered. Sediment probably late Pleistocene-Holocene age.

SOUTHERN MONTEREY BAY SHELF

MBC-8 (70-OC1-VC-018) Vibra-core

Location: Monterey shelf
121°51.70'W 36°38.10'N

Water Depth: 38.4 meters

Penetration Depth: 6.4 meters?

Total Core Length: 5.5 meters

Description: From bottom to top core contained about 3.7 m of brownish-grey, silty sand, which grades upward into medium- to coarse-grained, very clean sand that is about 1.5 m thick. The upper .3 m of the core is composed of grey, coarse-grained sand.

Remarks: Core did not appear to hit bedrock. Core catcher open on recovery. Age of sample is probably late Pleistocene to Holocene age.

SOUTHERN MONTEREY BAY SHELF

MBC-9 (70-OC1-VC-017) Vibra-core

Location: Monterey shelf
36°37.40'N 121°52.85'W

Water Depth: 40.5 meters

Penetration Depth: 3.35 meters

Total Core Length: 3.3 meters

Description: Core consists principally of mud and well sorted sand. Lower .6 m of core composed of olive-green mud with chips of chert. Upper 2.4 m of core composed of very clean, well sorted, medium-grained, greenish-white granitic sand that grades upward into greenish-grey, fine-grained sand. Several angular, freshly broken chunks of chert caught in core catcher.

Remarks: Core bottomed in chert (middle Miocene Monterey Formation). In this location the Monterey Formation appears to lie close to the surface beneath about 3 m of probably late Pleistocene-Holocene sand and mud.

MBC-10 (70-OCl-VC-020) Vibra-core

Location: Point Pinos
$121^\circ 55.88'$W $36^\circ 39.17'$N

Water Depth: 65.8 meters

Penetration Depth: ?

Total Core Length: 4.5 meters

Description: Core consists principally of greenish-brown to grey, medium- to coarse-grained, clean, granitic sand. Bottom half of core composed of fine-grained, silty sand that grades upward into coarse-grained sand.

Remarks: Core did not bottom in bedrock. Sample probably late Pleistocene-Holocene in age.

MONTEREY BAY

MC-1 (G-16) Phleger gravity core

Location: Monterey Canyon - axis, near head
121°51.45'W 36°47.81'N

Water Depth: 300 meters

Penetration Depth: 2.3 meters

Total Core Length: 1.09 meters

Description: Radiographs of the core show it to be fairly well laminated with several distinct zones of bioturbation. The upper 7 cm consist of silts interlaminated with clay and overlie a 26 cm thick bioturbated zone; many worm burrows can be seen. Between 33 and 54 cm down, the core has fairly well laminated silts with interlaminated clay, and exhibits some reworking by organisms, but not enough to completely destroy bedding. A thin silt layer between 54 and 60 cm is perforated with many worm burrows, but appears not to be completely reworked by organisms, as laminations are still faintly visible. From 60 to about 83 cm down, silts are intercalated with clays; some bioturbation can be seen in the lower part of this sequence. Between 83 and 87 cm down laminated silt exists; below this, from 87 to 95 cm, the silts are bioturbated. From 95 cm to the bottom of the core interlaminated silts and clays are present.

Remarks: Core probably represents Holocene canyon fill deposits. No distinct gradation is present and it is questionable whether this material was deposited by a turbidity flow.

MC-2 (G-17) Phleger gravity core

Location: Monterey Canyon - foot of northern wall
121°50.75'W 36°48.80'N

Water Depth: 180 meters

Penetration Depth: 2.3 meters

Total Core Length: 1.26 meters

Description: Radiographs of this core show well laminated silt and clay with several zones of bioturbation; quite similar to MC-1 (G-16). From the top of the core down to about 20 cm, clays are interlaminated with silts. Between 20 and 30 cm is a highly bioturbated zone, highly perforated with worm burrows. From 30 to 41 cm down, non-laminated silty clay exists. Well laminated silt and clay interbeds are present between 41 and 51 cm; underlying this, a well worked (bioturbated) zone extends down to 65 cm. The upper part of the bioturbated zone is more disturbed than the lower part, where laminations are still faintly visible. From 65 to 76 cm clay and silt are interlaminated. Below 76 cm a partly reworked zone of silt extends down to approximately 110 cm. In a bioturbated sequence between 80 and 97 cm, faint laminations of silt and clay can be seen with only one well developed worm burrow present. From 110 cm down to the bottom of the core, to 126 cm, a well developed silt and clay interlaminated sequence exists.

Remarks: Core may have been taken from slump deposits at base of canyon wall. Surface part of core highly reworked and probably represents an active bioturbation zone. Deposit may range in age from late Pleistocene to Holocene.

CONDENSED DESCRIPTION OF DREDGE HAULS
COLLECTED BY MARTIN (1964)

Numbers are in order from outer canyon to head

M-18 (8129)

Location: Monterey Canyon - outer northern wall

Start: 122°08.00'W 36°45.50'N

Finish: 122°08.25'W 36°47.25'N

Depth: 1096.8 - 292.5 meters

Lith: SILTSTONE

Weight: 4.5 kg

Remarks: Not in place. Possible subcrop higher up on canyon wall.

M-16 (8156)

Location: Monterey Canyon - northern wall (meander)

Start: 122°02.50'W 36°43.00'N

Finish: 122°01.83'W 36°42.58'N

Depth: 945-895.7 meters

Lith: SILTSTONE

Weight: 2.2 kg

Remarks: In place. Resembles Pliocene Purisima Formation.

M-14 (7464)

Location: Monterey Canyon - northern wall (meander)

Start: 122°01.03'W 36°44.83'N

Finish: 122°04.25'W 36°45.05'N

Depth: 972.5-914 meters

Lith: SILTSTONE (95% of total sample)

GRANODIORITE

Weight: 43.1 kg

Remarks: Granodiorite probably not in place; siltstone may have been in place.

M-12 (8124)

Location: Monterey Canyon - northern wall

Start: 122°01.25'W 36°45.87'N

Finish: 122°03.45'W 36°47.40'N

Depth: 872-201.1 meters

Lith: SILTSTONE

Weight: 22.9 kg

Remarks: Siltstone probably in place.

M-10 (7475)

Location: Monterey Canyon - northern wall

Start: 122°01.58'W 36°47.03'N

Finish: 122°02.72'W 36°48.28'N

Depth: 548.4 - 91.4 meters

Lith: SANDY SILTSTONE

Weight: 13.6 kg

Remarks: Resembles Pliocene Purisima Formation

S-2 (7476)

Location: Soquel Canyon - western wall

Start: 121°59.48'W 36°48.98'N

Finish: 122°00.50'W 36°49.55'N

Depth: 493.6 - 310.8 meters

Lith: SANDSTONE

Remarks: Sandstone probably in place. Appearance of "granite wash". Unlike any other rock type dredged from canyon.

S-1 (8163)

Location: Soquel Canyon - eastern wall

Start: 121°57.50'W 36°50.77'N

Finish: 121°57.75'W 36°50.30'N

Depth: 243.1-195.6 meters

Lith: SANDSTONE (75% of total sample)
SILTSTONE

Weight: 15.8 kg

Remarks: In place. Siltstone resembles Pliocene Purisima Formation.

M-8 (8131)

Location: Monterey Canyon - northern wall

Start: 121°56.33'W 36°46.55'N

Finish: 121°56.30'W 36°48.05'N

Depth: 521-182.8 meters

Lith: SILTSTONE

Weight: 11.4 kg

Remarks: May be in place, similar to other dredge samples in canyon. May be Pliocene Purisima Formation.

M-6

Green mud dredge haul.

M-4

Green mud dredge haul.

M-2

Green mud dredge haul.

M-22 (8157)

Location: Monterey Canyon - outer southern wall

Start: 122°07.50'W 36°40.25'N

Finish: 122°07.58'W 36°40.67'N

Depth: 1261.3-1096.8 meters

Lith: CHERT

SILTSTONE

M-22 (8157) continued

Weight: None

Remarks: Probably not in place. Siltstone is probably dominant lithology beneath mud cover.

M-27 (7462)

Location: Monterey Canyon - outer southern wall

Start: 122°01.08'W 36°42.00'N

Finish: 122°00.75'W 36°41.17'N

Depth: 1425.8-438.7 meters

Lith: GRANODIORITE - not porphyritic

Weight: 1.3 kg

Remarks: Rock type in place.

M-25 (8152)

Location: Monterey Canyon - outer southern wall

Start: 122°01.00'W 36°42.53'N

Finish: 121°57.75'W 36°42.50'N

Depth: 1005.4-365.6 meters

Lith: GRANODIORITE - not porphyritic

Remarks: Rock type in place.

M-23

Green mud dredge haul.

M-21

Green mud dredge haul.

M-19 (8155)

Location: Monterey Canyon - southern wall (meander)

Start: 122°01.75'W 36°45.33'N

Finish: 122°00.25'W 36°44.83'N

Depth: 1065.7-974.3 meters

Lith: SILTSTONE

SANDSTONE (50% of total sample)

Weight: 2.6 kg

Remarks: Transported(?)

M-17 (8154)

Location: Monterey Canyon - southern wall (meander)

Start: 121°59.17'W 36°46.00'N

Finish: 121°59.20'W 36°45.30'N

Depth: 882.9-292.5 meters

Lith: SANDSTONE

Remarks: Probably in place

M-11

Green mud dredge haul.

M-9 (7461)

Location: Monterey Canyon - inner southern wall

Start: 121°57.62'W 36°46.83'N

Finish: 121°56.47'W 36°45.87'N

Depth: 329-274.2 meters

Lith: SILTSTONE (45% of total sample)

SANDSTONE (45% of total sample)

LIMESTONE (7% of total sample) similar to C-5 (8165)

GRANODIORITE

Weight: 52.4 kg

Remarks: Most varied lithology of all dredgings. Limestone and granodiorite not in place. Siltstone and sandstone probably in place, with siltstone the dominant lithology.

M-7

Green mud dredge haul.

M-5

Green mud dredge haul.

M-3

Green mud dredge haul.

M-1

Green mud dredge haul.

Martin's Dredge Description (cont.)

M-31 (7471)

Location: Carmel Canyon - outer western wall

Start: 122°06.50'W 36°40.20'N

Finish: 122°04.37'W 36°38.72'N

Depth: 1608.6-1371 meters

Lith: SILTSTONE

QUARTZITE

Weight: .12 kg

Remarks: Both rock types considered in place

C-11 (8160)

Location: Carmel Canyon - outer western wall

Start: 122°04.00'W 36°36.67'N

Finish: 122°03.58'W 36°37.17'N

Depth: 1389.3-822.6 meters

Lith: SILTSTONE (100% of total sample)

Weight: none given

Remarks: About 75% of the siltstone appears similar to Monterey shale. In place?

C-9

Green mud dredge haul.

C-7

Green mud dredge haul.

C-5 (8165)

Location: Carmel Canyon - middle western wall

Start: 122°01.67'W 36°32.75'N

Finish: 122°00.70'W 36°32.25'N

Depth: 449.7-365.6 meters

Lith: LIMESTONE

Weight: 0.7 kg

Remarks: In place. Microfaunas contained in sample indicate rock to be middle Miocene in age.

C-3 (7468)

Location: Carmel Canyon - middle western wall

Start: 122°01.30'W 36°34.40'N

Finish: 122°01.30'W 36°33.25'N

Depth: 621.5-402.2 meters

Lith: GRANODIORITE - slickensides present

FAULT GOUGE

Weight: 13.6 kg

Remarks: Sample probably taken from fault zone or very close to a fault zone.

C-1

Green mud dredge haul.

C-2 (8162)

Location: Carmel Canyon - northern head

Start: 121°57.56'W 36°32.83'N

Finish: 121°57.90'W 36°32.85'N

Depth: 182.8-137.1 meters

Lith: GRANODIORITE

Weight: 13.1 kg

Remarks: Transported, but probably not far from outcrop.

M-29 (8126)

Location: Carmel Canyon - outer eastern wall

Start: 122°05.67'W 36°40.33'N

Finish: 122°00.33'W 36°39.20'N

Depth: 1169.9-365.6 meters

Lith: SANDSTONE (90% of total sample) fossiliferous

LIMESTONE

Weight: 20.4 kg

Remarks: Sample not in place, probably transported down Carmel Canyon.

C-4 (7470)

Location: Carmel Canyon - outer eastern wall

Start: 122°03.28'W 36°37.67'N

Finish: 122°01.58'W 36°38.00'N

Depth: 1096.8 - 310.8 meters

Lith: GRANODIORITE and FELSITE - phenocrysts present

Weight: 56.7 kg

Remarks: Rock type probably in place.

EXPLORATORY OIL AND GAS WELLS
MONTEREY BAY REGION, CALIFORNIA

1. Richfield Oil Corp. - Steele core hole No. 1; projected sec. 29, T.9S, R.4W; elev. 40' (12.2 m); September 1963.

   70-160' (21.3 - 48.8 m) Purisima Formation(?)
   160-2675' (48.8 - 815.3 m) Pigeon Point Formation

2. Shell Oil Co. - Davenport core hole No. 2; sec. 17, T.10S, R.3W; elev. 320' (97.5 m); September 1965

   No information

3. Texaco, Inc. - Poletti No. 1; projected sec. 13, T.10S, R.4W; elev. 140' (42.7 m); January 1957

   0-8850' (0-2697.5 m) Santa Cruz Mudstone
   (6680-8349' (2097-2544.8 m) Mohnian, possibly upper Mohnian (upper Miocene))
   8850-9140' (2697.5 - 2785.9 m) Santa Margarita Sandstone
   9140-9197' (2785.9 - 2803.3 m) biotite granodiorite

4. Shell Oil Co. - Davenport core hole No. 4; projected sec. 21, T.10S, R.3W; elev. 860'+ (262.2 m); February 1966

   No information

5. Shell Oil Co. - Davenport core hole No. 1; sec. 34, T.10S, R. 3W; elev. 110' (33.5 m); August 1964

   0-1260' (0-384 m) Santa Cruz Mudstone
   1260-1410' (384-429.8 m) Santa Margarita Sandstone
   1410-1605' (429.8 - 489.2 m) Santa Margarita Sandstone(?) or Monterey Formation(?)
   1605-3650' (489.2 - 1112.5 m) Monterey Formation
   1730-1744'(527.3 - 531.6 m) probably Relizian (middle Miocene)
   3280' (999.7) Upper Relizian (middle Miocene)
   3650-4110' (1112.5-1252.7 m) Lompico Sandstone
   4110-4315' (1252.7 - 1315.2 m) "granite"

6. Shell Oil Co. - Davenport core hole No. 3; sec. 35, T.10S, R.3W; elev. 399' (121.6 m); August 1965

   0-865' (0-263.7 m) Santa Cruz Mudstone
   865-1070' (263.7 - 326.1 m) Santa Margarita Sandstone
   1070-1930' (326.1 - 588.3 m) Monterey Formation
   1930-2046' (588.3 - 623.6 m) Lompico Sandstone(?)

7. Humble Oil & Refining Co. - L.P. Scaroni No. 1; projected sec. 19, T.11S, R.2W; elev. 60' (18.3 m); January 1958

   0-400' (0-122 m) Santa Cruz Mudstone
   400-675' (122-205.7 m) Santa Margarita Sandstone

675-820' (205.7 - 250 m) Monterey Formation(?) and/or Lompico Sandstone(?)
820-885' (250-269.8 m) "granite"

8. Texaco, Inc. - M Light No. 1; sec. 14, T.11S, R.1E

3694' (1126 m) "granite" T.D.

9. Texaco, Inc. - Pierce No. 1; projected sec. 15, T.11S, R.1E

2670' (813.8 m) "granite" T.D.

10. Texaco, Inc. - Carpenter No. 1; projected sec. 35, T.11S, R.1E

2985' (909.8 m) "granite" T.D.

11. Texaco, Inc. - Blake No. 1, projected sec. 11, T.12S, R.1E

2463' (750.7 m) "granite" T.D.

12. Western Gulf Oil Co. - Johnson No. 1; projected sec. 19, T.12S, R.2E

3198' (974.8 m) "granite" T.D.

13. Texaco, Inc. - Seaboard Oil Co. - Robert Blohm No. 2; projected sec. 34, T.12S, R.2E

2188' (667 m) "granite" T.D.

14. Jergins Oil North American Cons. - Blohm No. 1; projected sec. 34, T.12S, R.2E; elev. 413' (125.9 m), June 1949

1905-1935' (580.6-589.8 m) "granite"

15. Elba Oil Co. - Elba No. 1; projected sec. 6, T.13S, R.2E

3970' (1210 m) Pliocene (Purisima?) T.D.

16. Bayside Development Co. - Vierra No. 1; sec. 7, T.13S, R.2E; November 1944

0-2003' (0-510.5 m) Quaternary - Pliocene
2003-7916' (510.5 - 2412.8 m) Miocene

17. Texas Co. - Pieri No. 1; sec. 19, T.13S, R.2E; elev. 4' (1.2 m); September 1949

0-1670' (0-509 m) Quaternary - Pliocene
1670-3026' (509-922.3 m) Monterey Formation
3026-3255' (922.3-992.1 m) basal Monterey sand
3255-3991' (992.1-1216.5 m) "granite"

OIL AND GAS WELLS (continued)

18. Texas Co. - Davies No. 1; projected sec. 34, T.13S, R.2E; April 1949

0-1318' (0-401.7 m) Quaternary - Pliocene
1318-2100' (401.7-640 m) Monterey Formation
2100-2150' (640-655.3 m) basal Monterey sand
2150-2219' (655.3-676.4 m) "granite"

19. John S. Horn - G. J. Nol; projected sec. 23, T.15S, R.1E; elev. 240' (73.2 m); November 1949

0-200' (0-61 m) sand (dune and Aromas?)
200-330' (61-100.6 m) Paso Robles Formation
330-1050' (100.6 - 320 m) Monterey Shale
930-1015' (283.5-309.4 m) some sandstone
1050-1237' (320-377 m) granite?

20. Sand Bowl Group - Metz No. 1; projected sec. 22, T.15S, R.1E; elev. 40' (12.2 m); February 1948

0-540' (0-164.6 m) sand (dune, Aromas and Paso Robles?)
540-730' (164.6-222.5 m) Paso Robles Formation
730-1980' (222.5-603.5 m) Monterey Shale
1160-1430' (353.6-435.9 m) sandstone
1980-2151' (603.5-655.6 m) granite? or granite debris

21. John S. Horn - T.A. Nol; projected sec. 35, T.15S, R.1E; elev. 90' (27.4 m); August 1949

0-60' (0-18.3 m) soil and surface sand
60-1025' (18.3-312.4 m) Monterey Shale
1025-1820' (312.4-554.7 m) coarse sandstone
1820-1837' (554.7-560 m) granite?

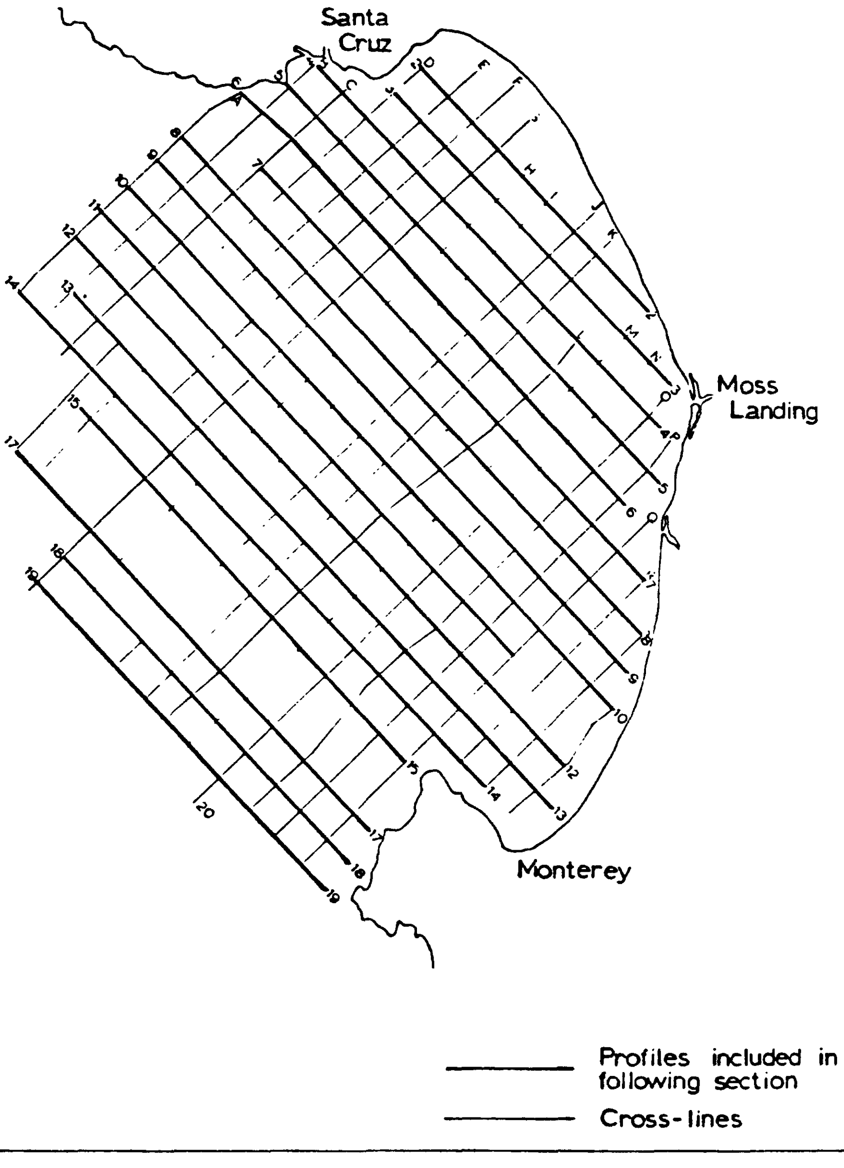
APPENDIX III

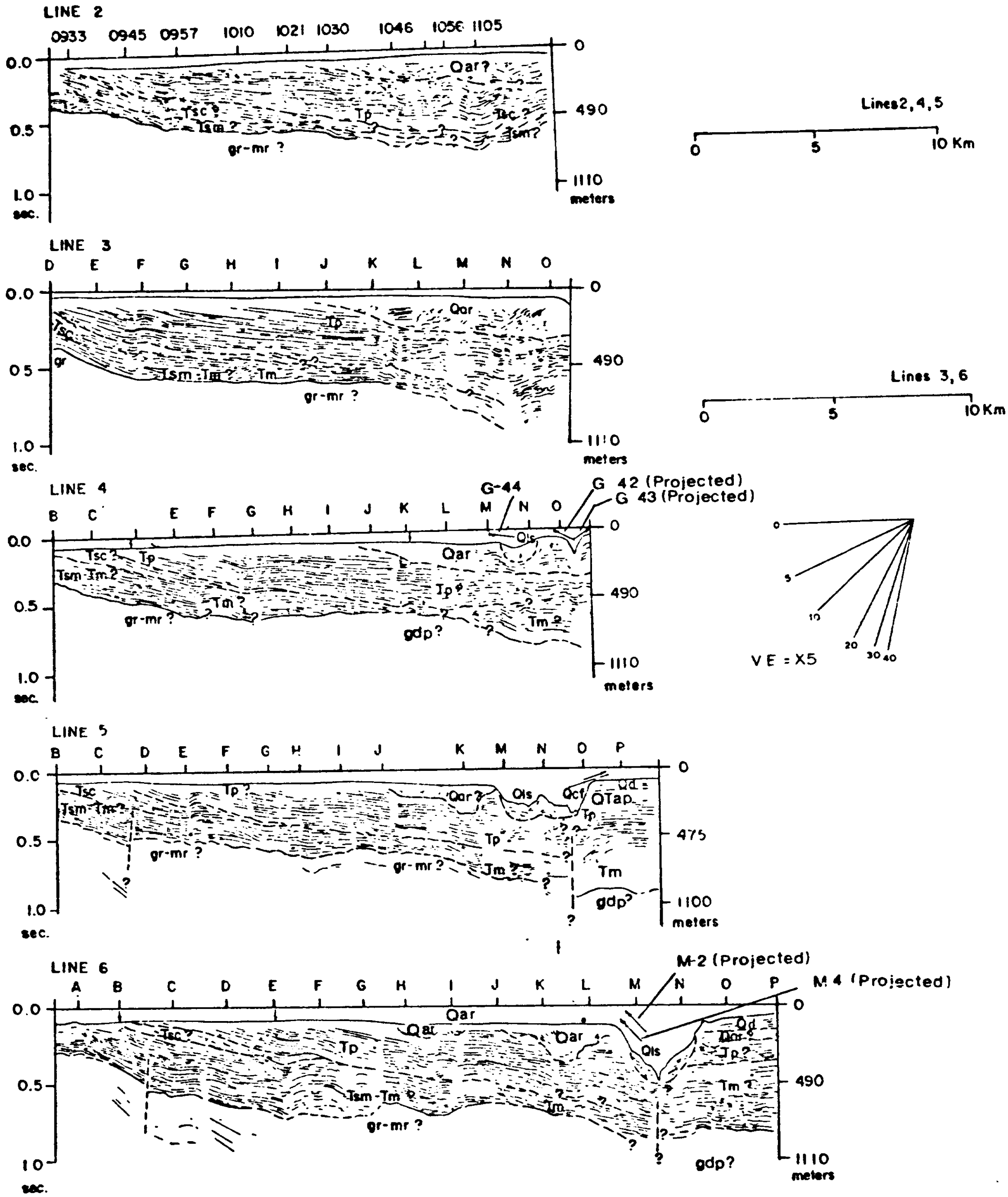
INTERPRETATIONS OF SEISMIC PROFILES

This appendix is composed of line drawings of all the seismic reflection profiles collected in Monterey Bay during the 1970 survey. The appendix consists of four sections: (1) numbered intermediate penetration profiles oriented northwest-southeast, (2) lettered intermediate penetration profiles oriented northeast-southwest, (3) numbered high resolution profiles oriented northwest-southeast, and (4) lettered high resolution profiles oriented northeast-southwest. Each section is preceded by a map showing the location of each profile (heavy lines).

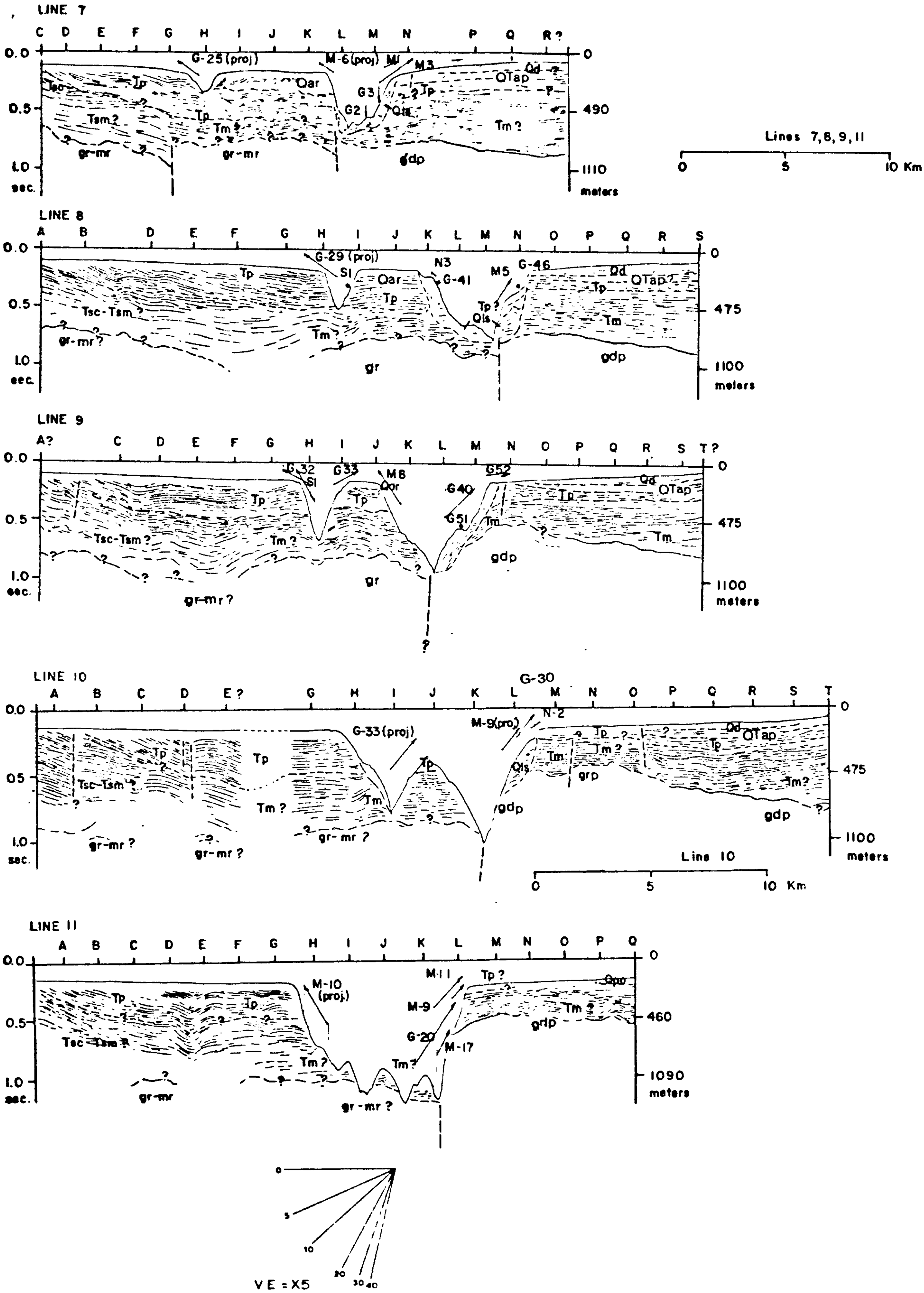
Depths in meters and in time (seconds) are shown on the right and left margins of each profile, respectively. Letters or numbers across the top of the profiles indicate the position of the cross-lines. Geologic symbols are the same as those shown and explained on Plate 3. Lines with arrows refer to dredge hauls run parallel to the profile; the dots refer to dredge hauls perpendicular to the profiles. Location of the dredge sites are shown in Figure 8, and sample descriptions are included in Appendix II.

1. Positions of numbered intermediate penetration seismic reflection profiles included in following section.

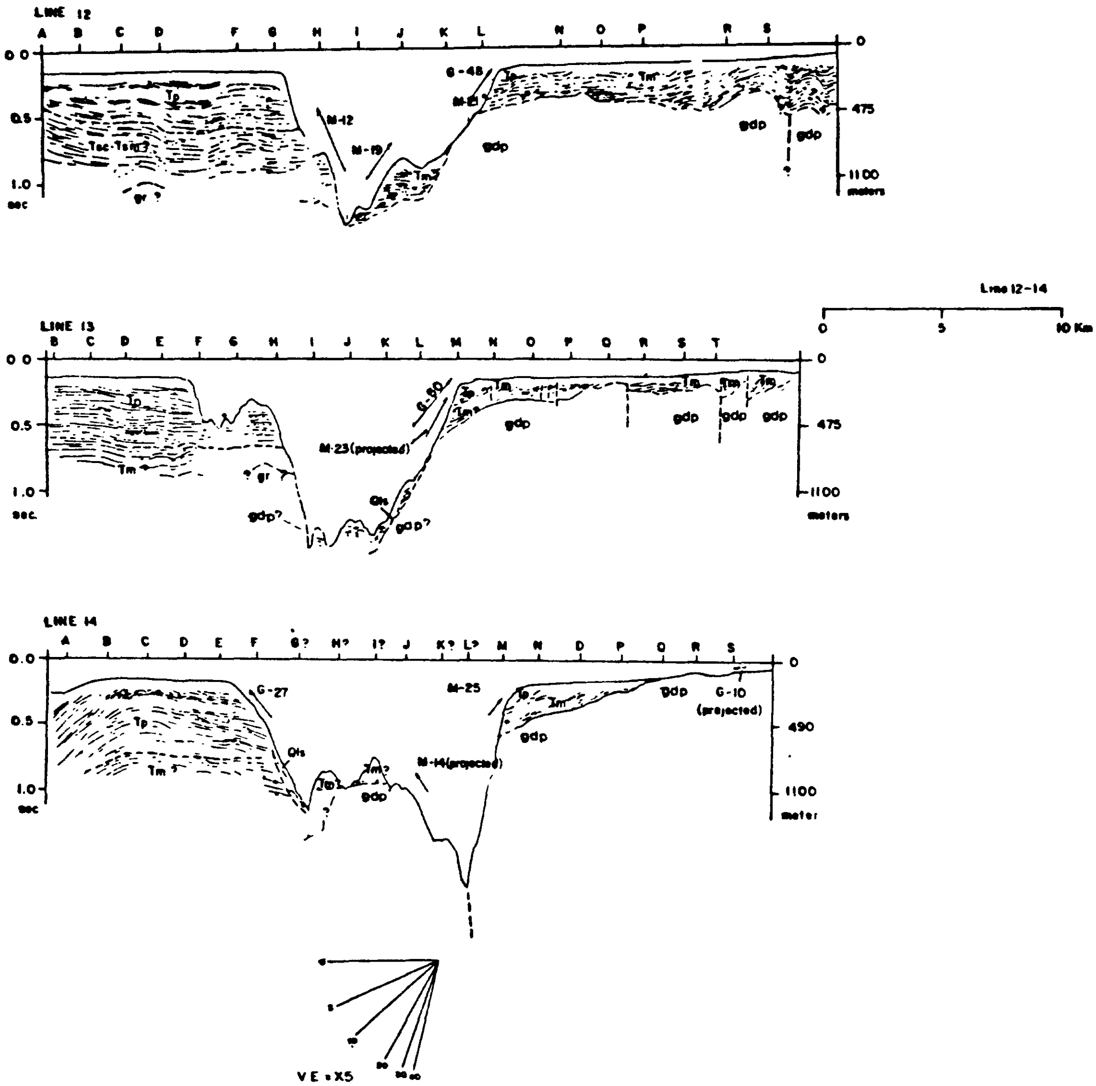




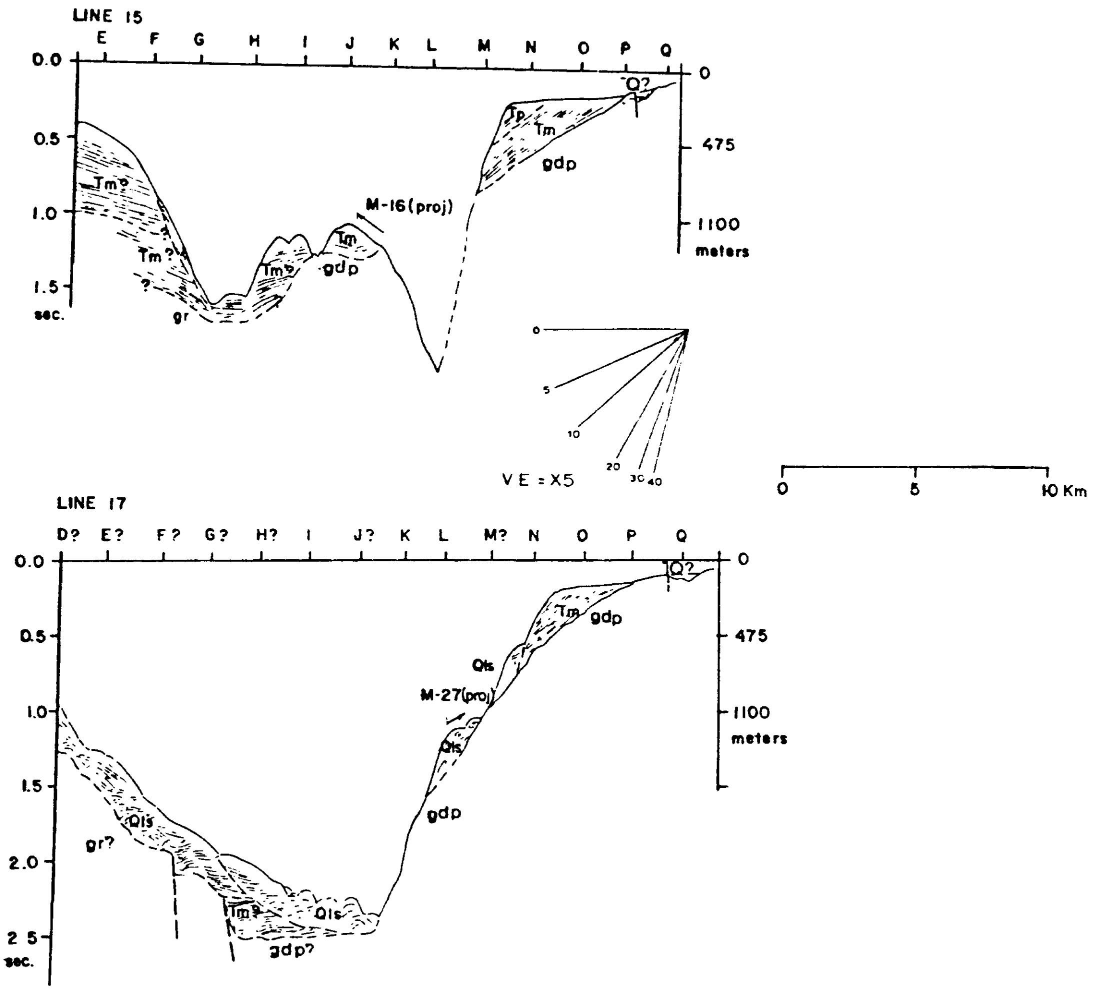
Monterey Bay
Intermediate Penetration Profiles



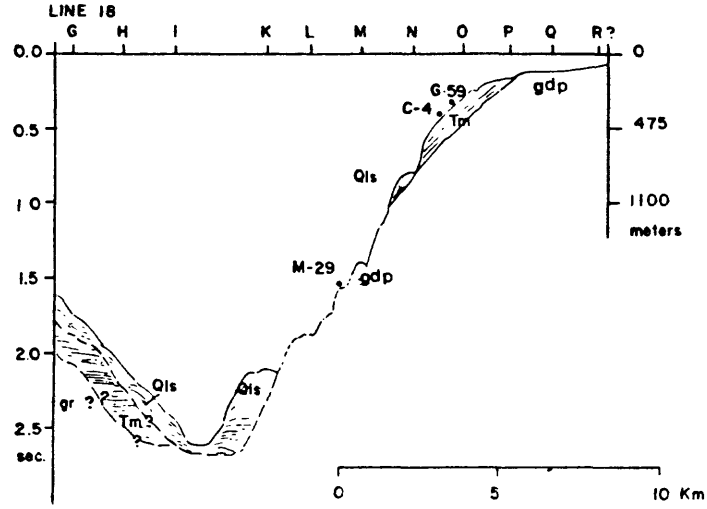
Monterey Bay
Intermediate Penetration Profiles

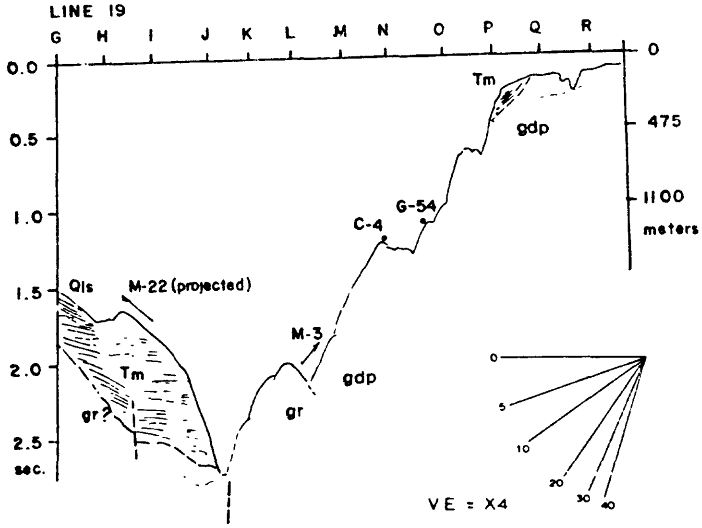


Monterey Bay
Intermediate Penetration Profiles



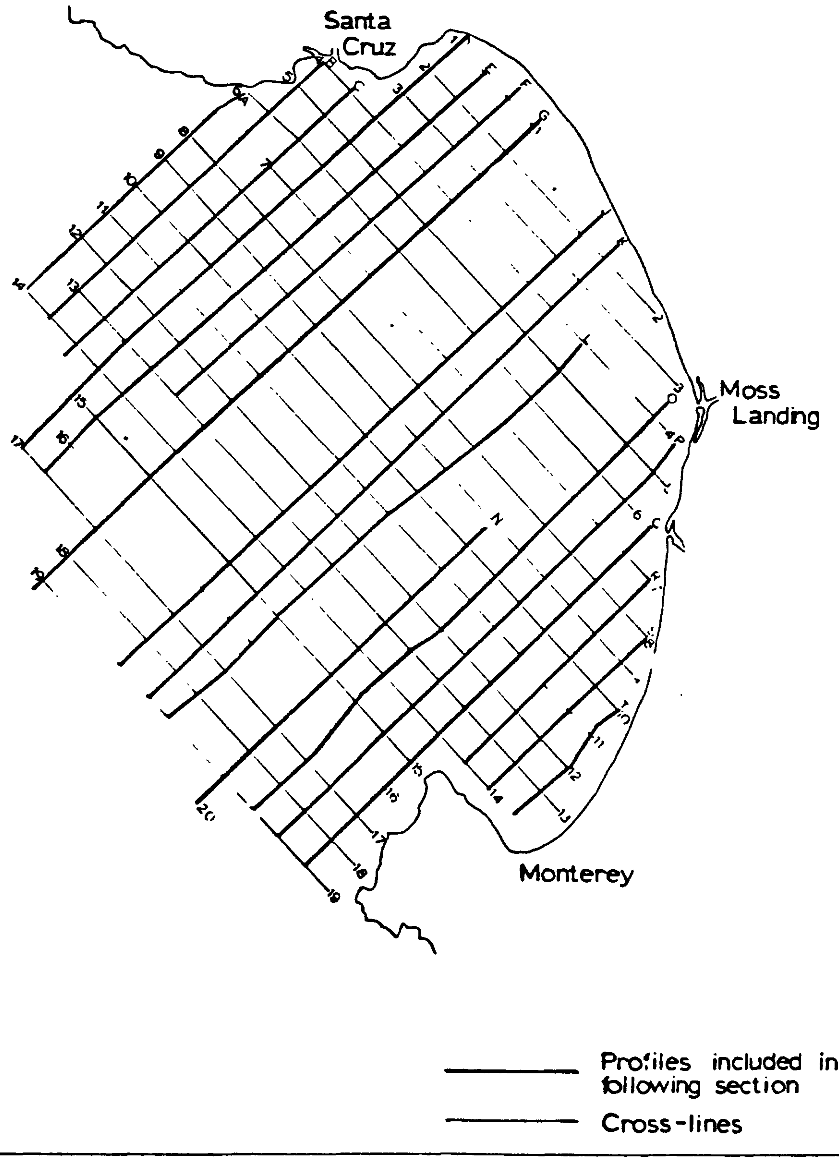
Monterey Bay
Intermediate Penetration Profiles

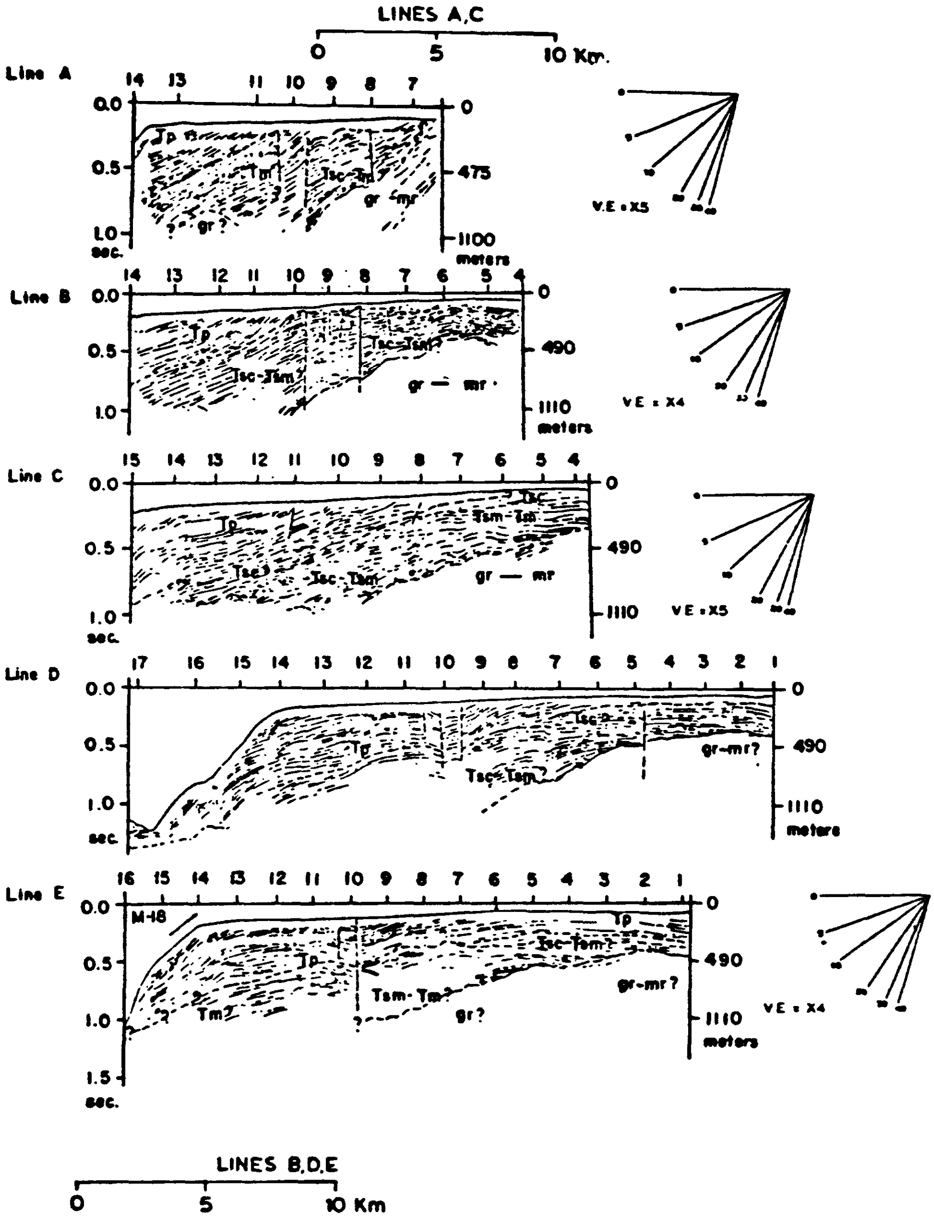




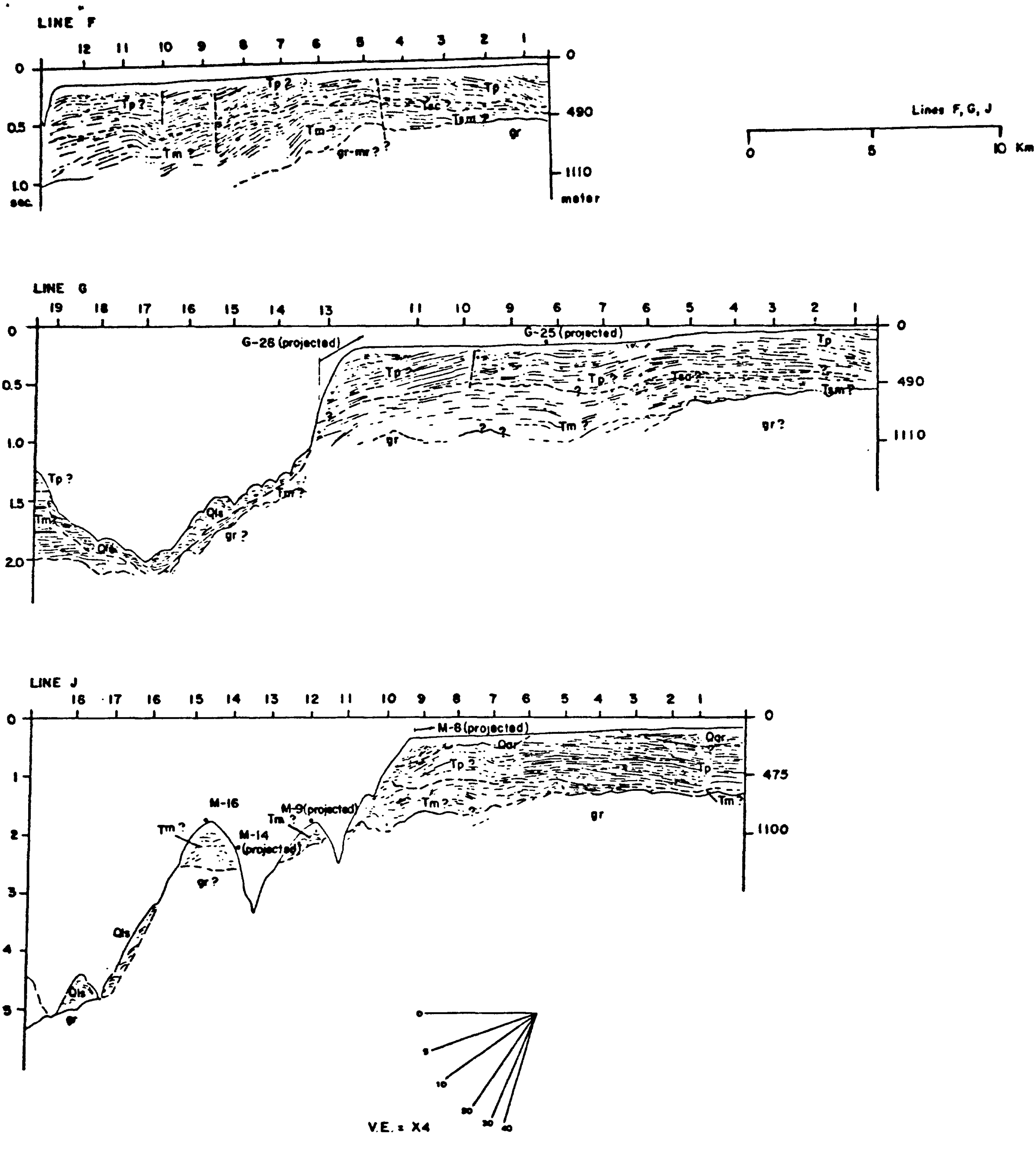
Monterey Bay
Intermediate Penetration Profiles

2. Positions of lettered intermediate penetration seismic reflection profiles included in following section.

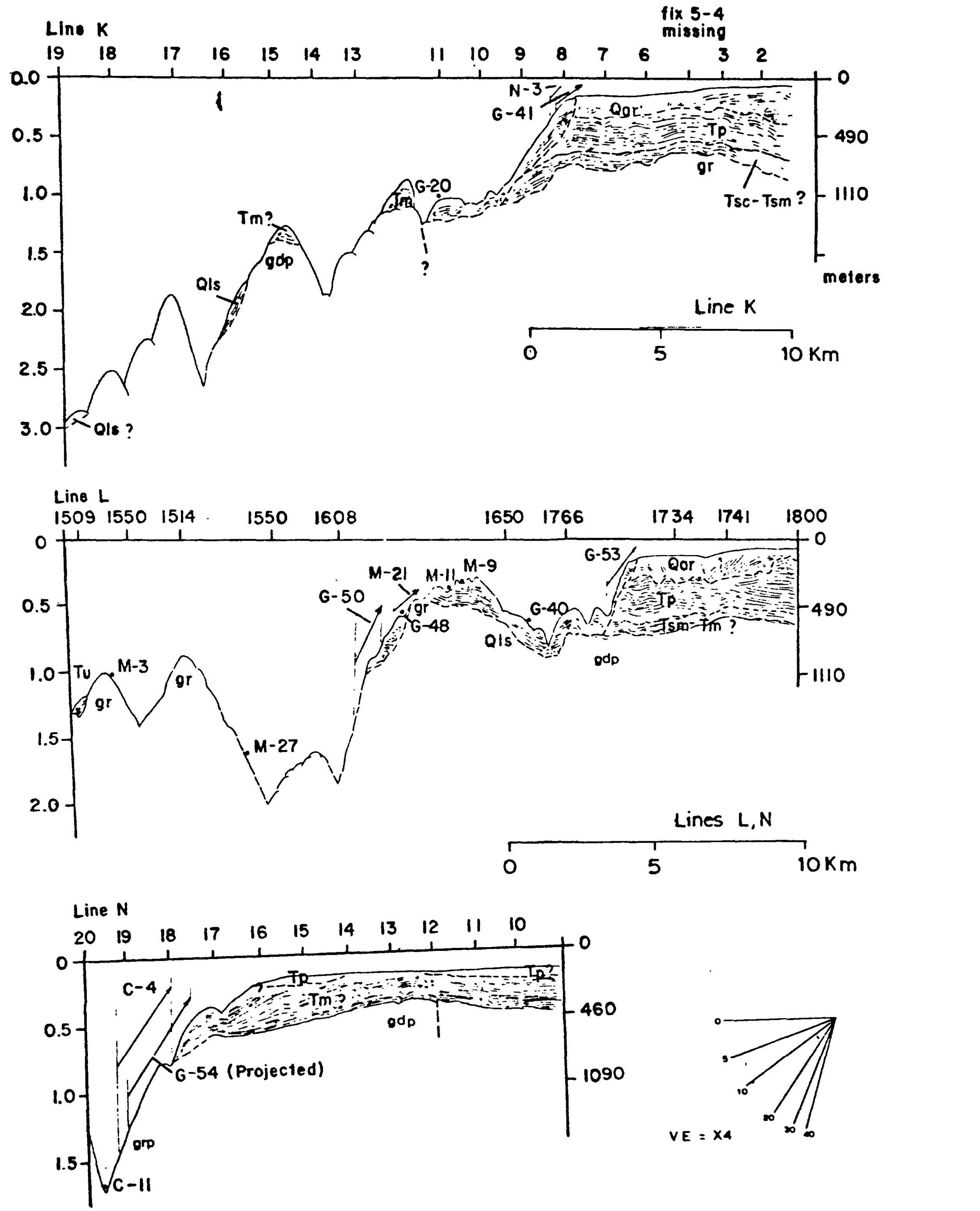




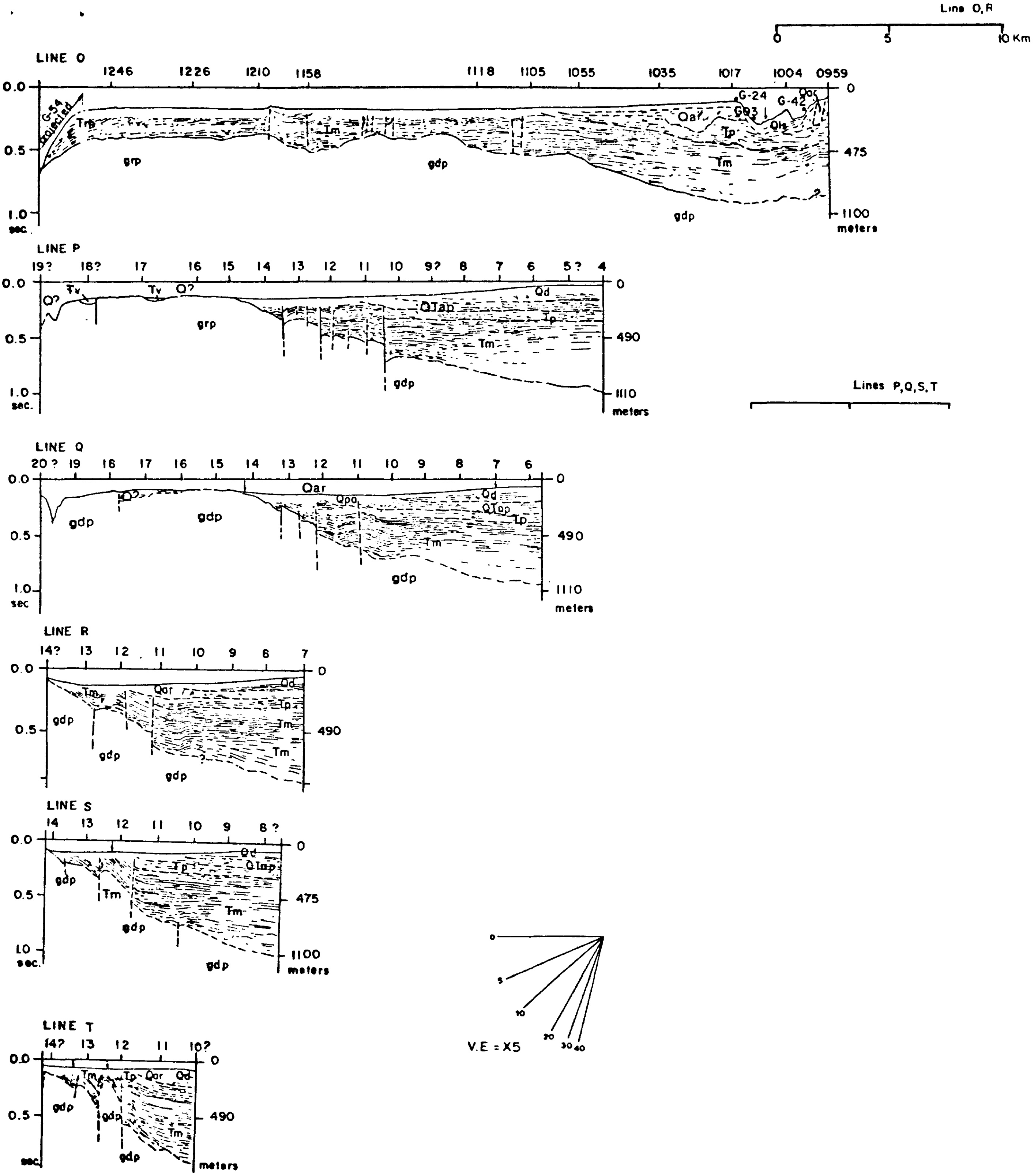
Monterey Bay
Intermediate Penetration Profiles



Monterey Bay
Intermediate Penetration Profiles

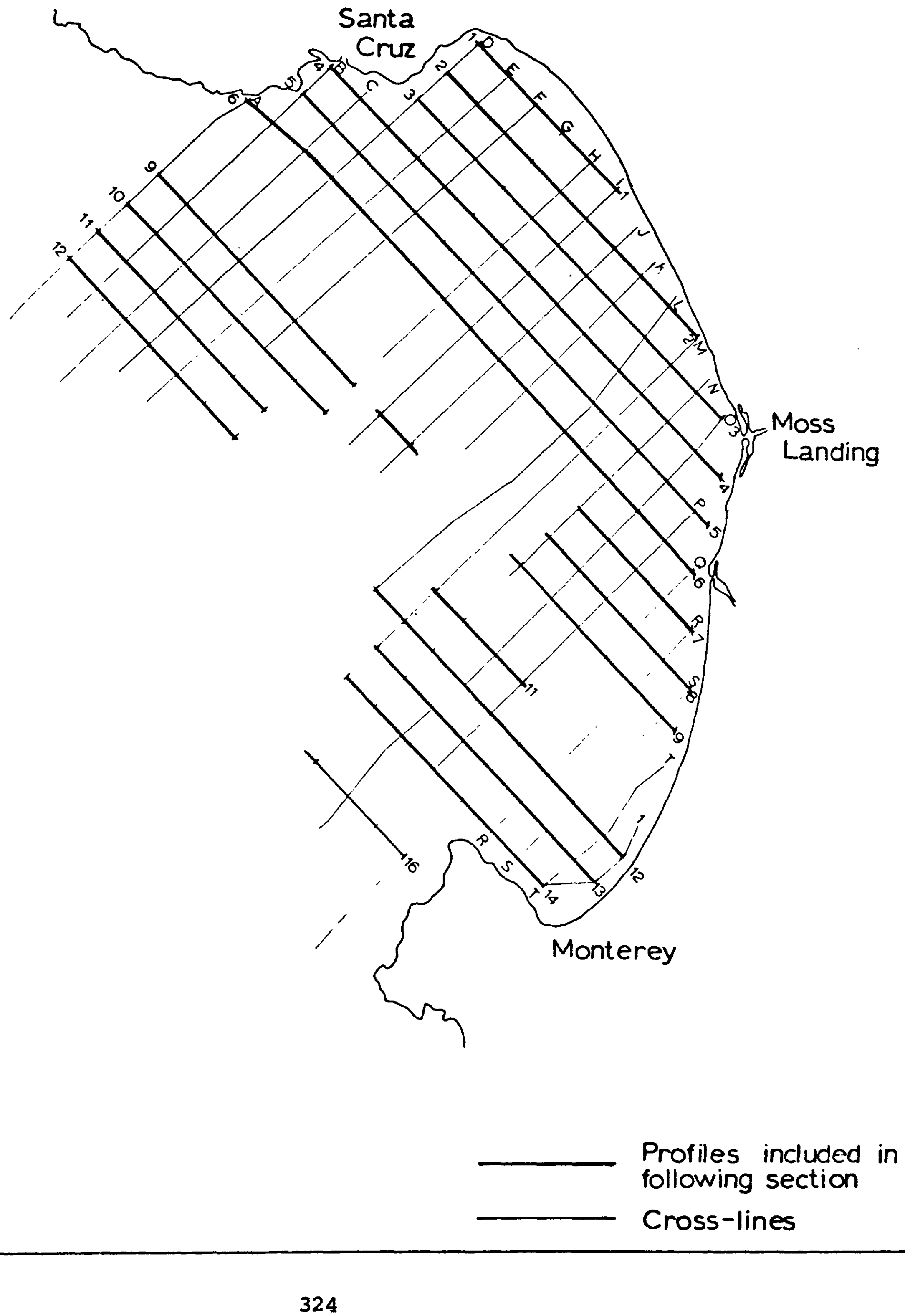


Monterey Bay
Intermediate Penetration Profiles

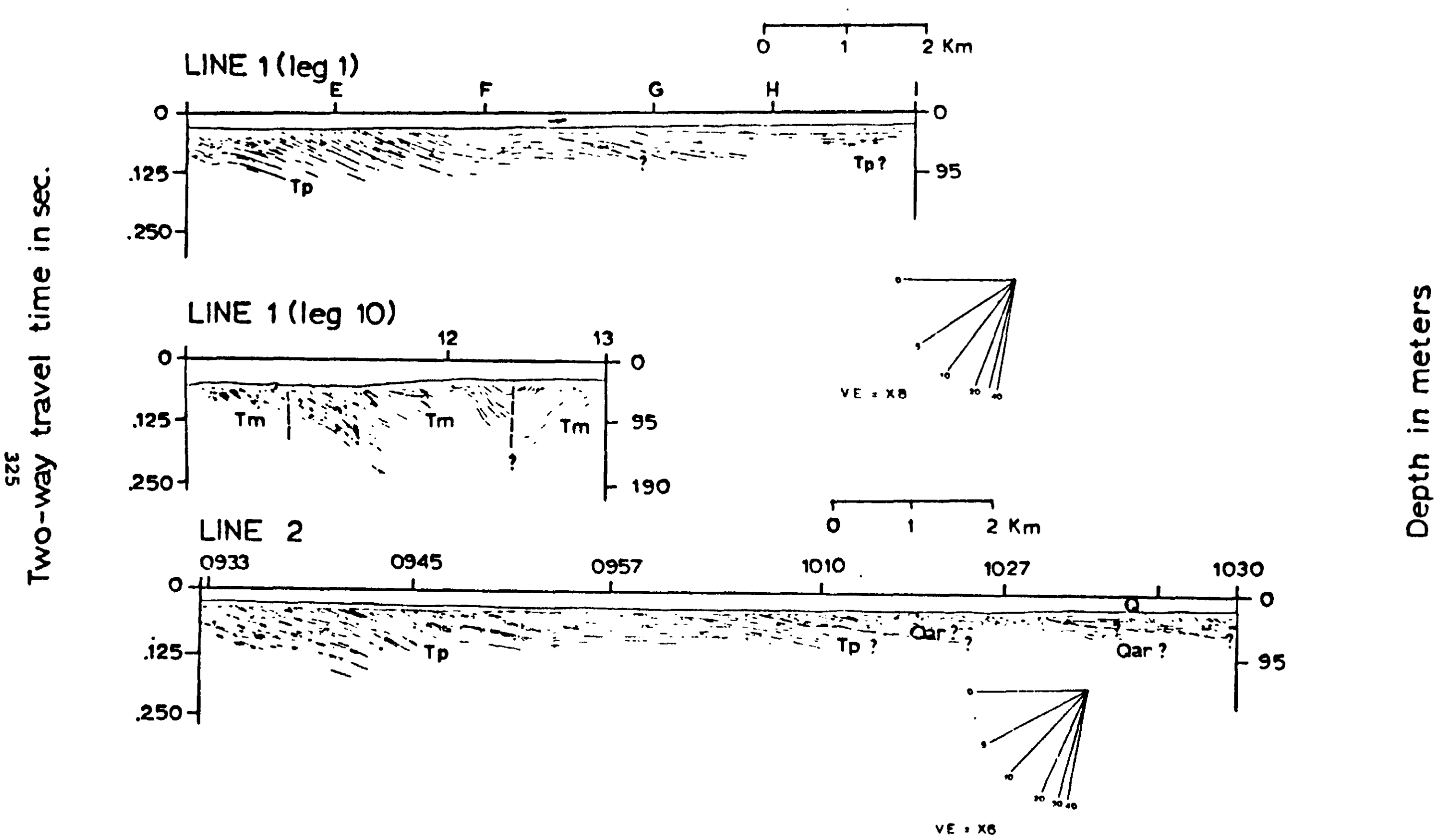


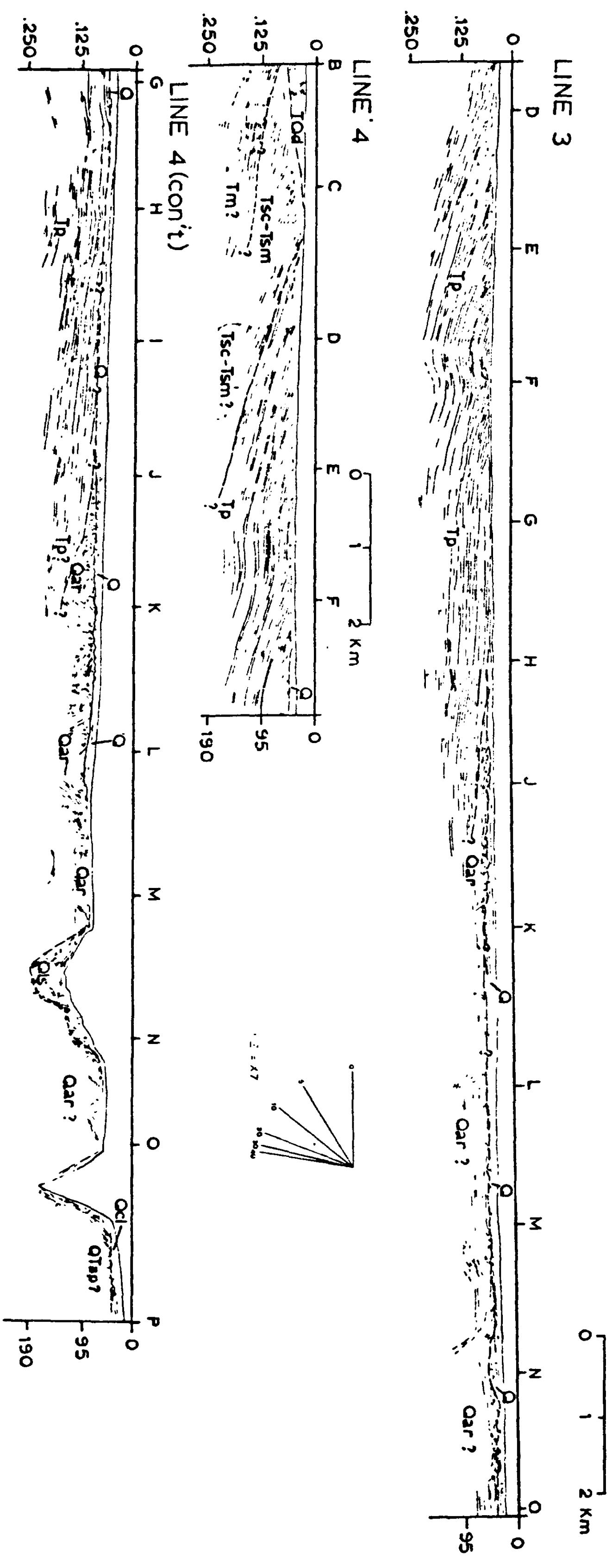
Monterey Bay
Intermediate Penetration Profiles

3. Positions of numbered high resolution seismic reflection profiles included in following section.



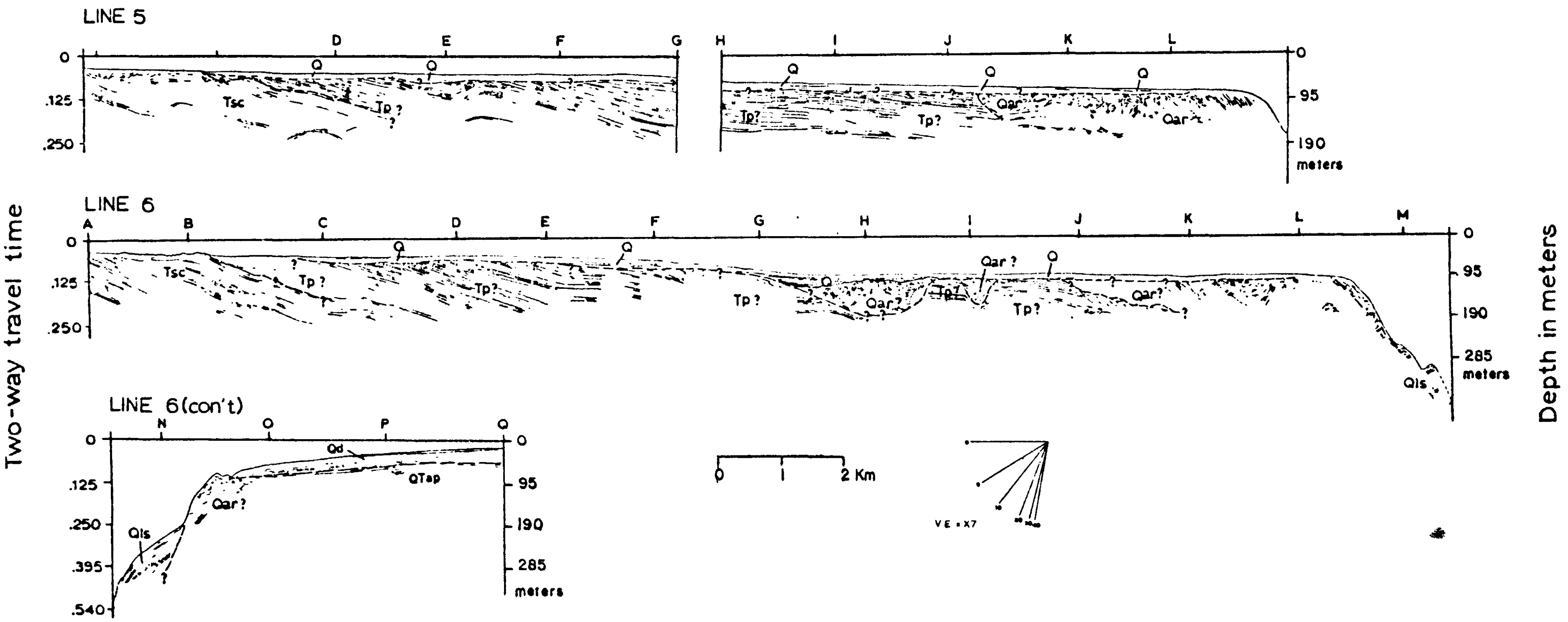
Monterey Bay
High Resolution Profiles



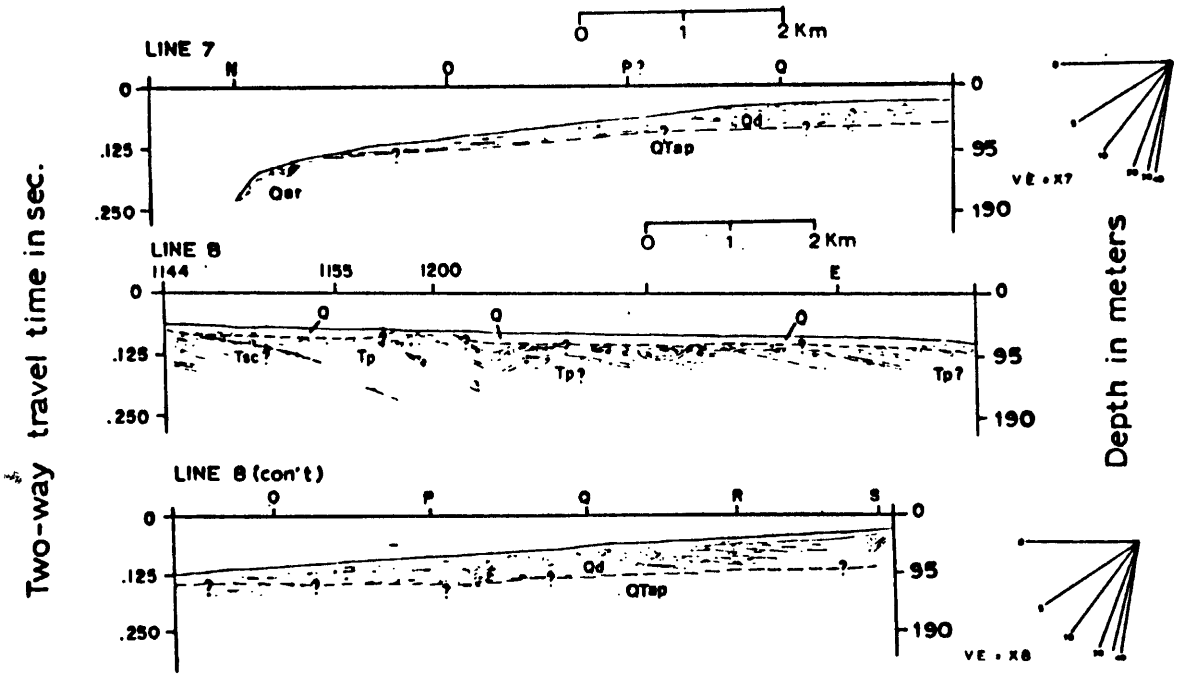


Monterey Bay
High Resolution Profiles

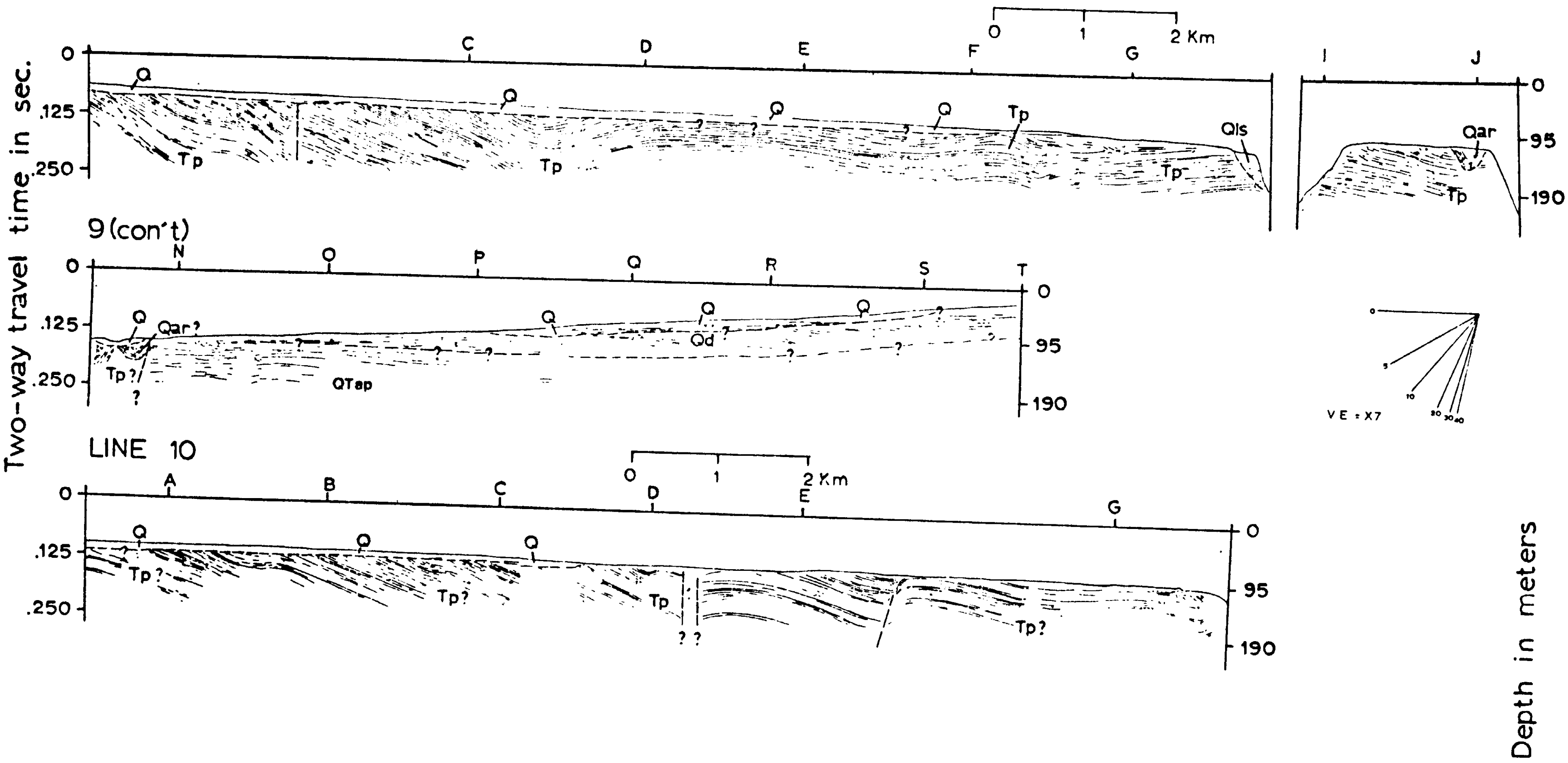
Monterey Bay
High Resolution Profiles

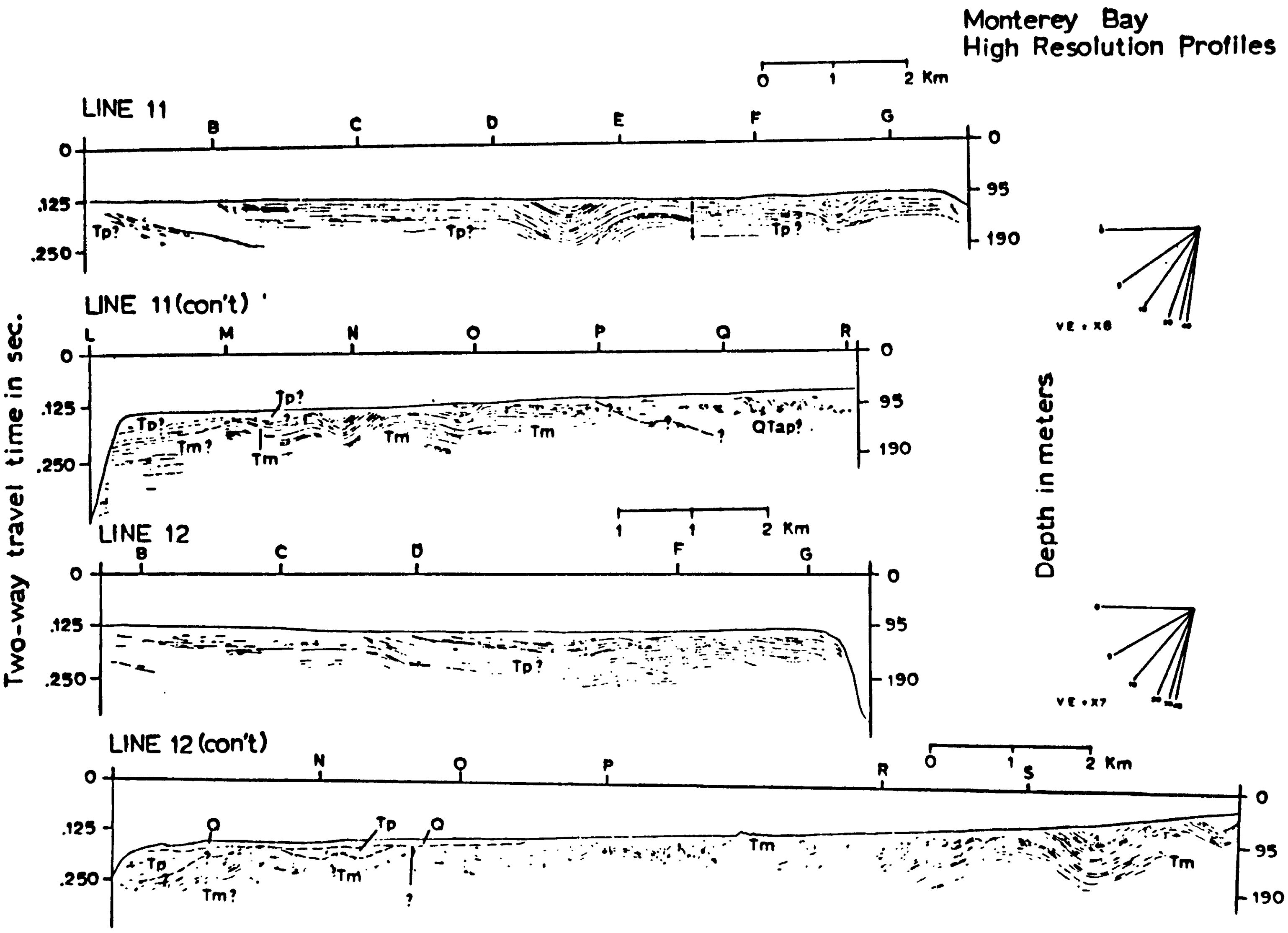


Monterey Bay
High Resolution Profiles



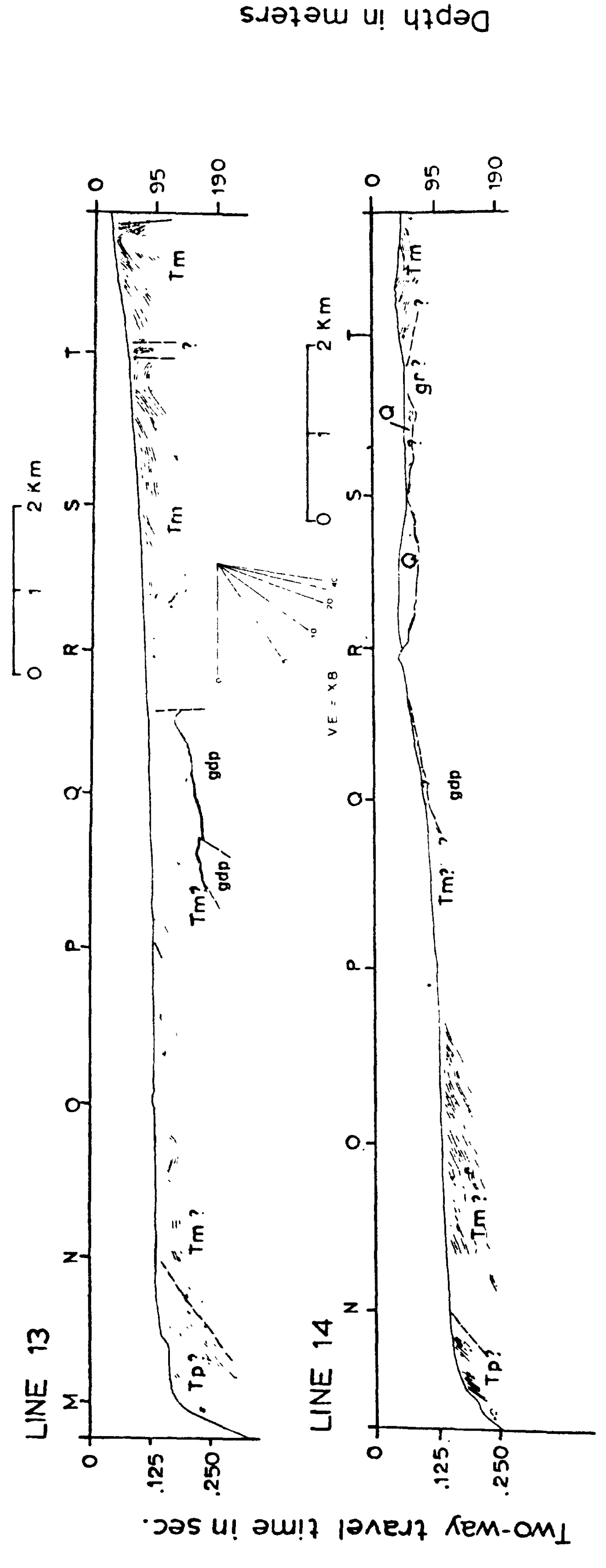
Monterey Bay
High Resolution Profiles



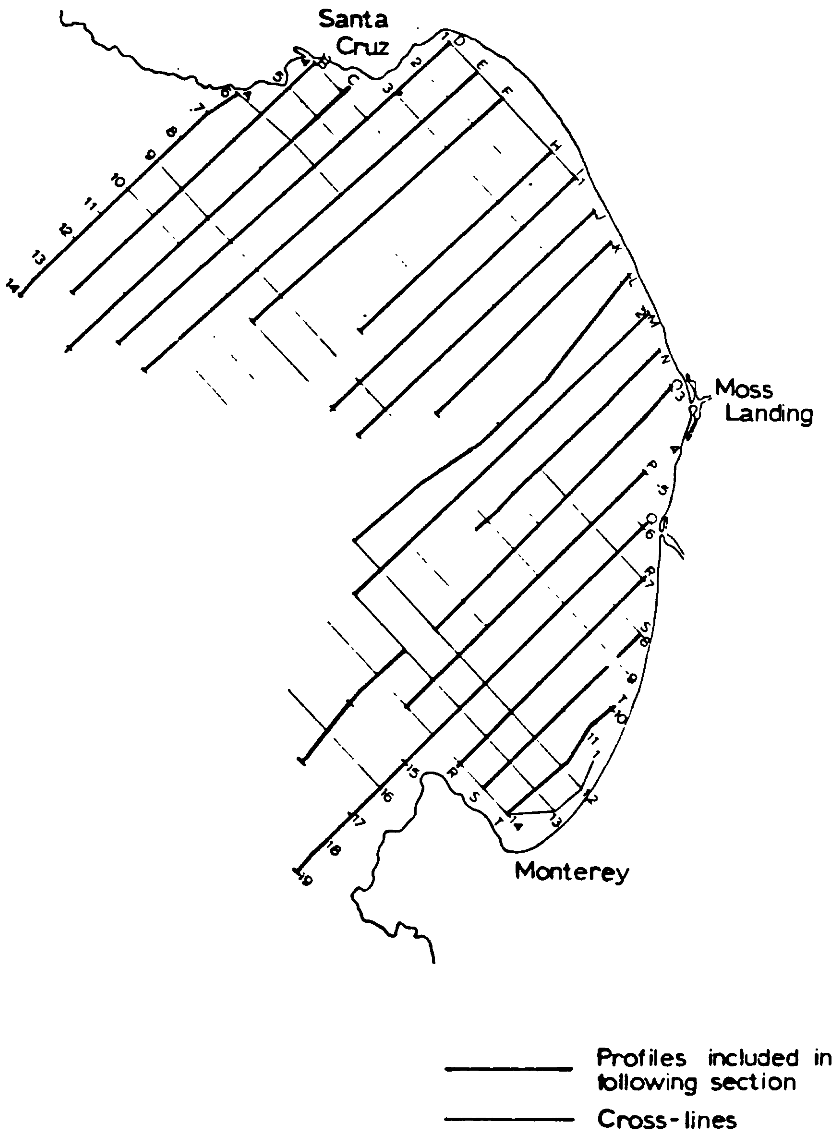


Monterey Bay
High Resolution Profiles
0 1 2 Km
LINE 11
B C D E F G
0
.125
.250
0
95
190
Tp?
Tp?
Tp?
LINE 11(con't)
L M N O P Q R
Tp?
Tp?
Tm?
Tm
Tm
Tm
QTap?
VE • X8
Two-way travel time in sec.
Depth in meters
LINE 12
B C D F G
1 1 2 Km
Tp?
VE • X7
LINE 12 (con't)
N O P R S
0 1 2 Km
Q
Tp
Q
Tp
Tm?
Tm
Tm
Tm

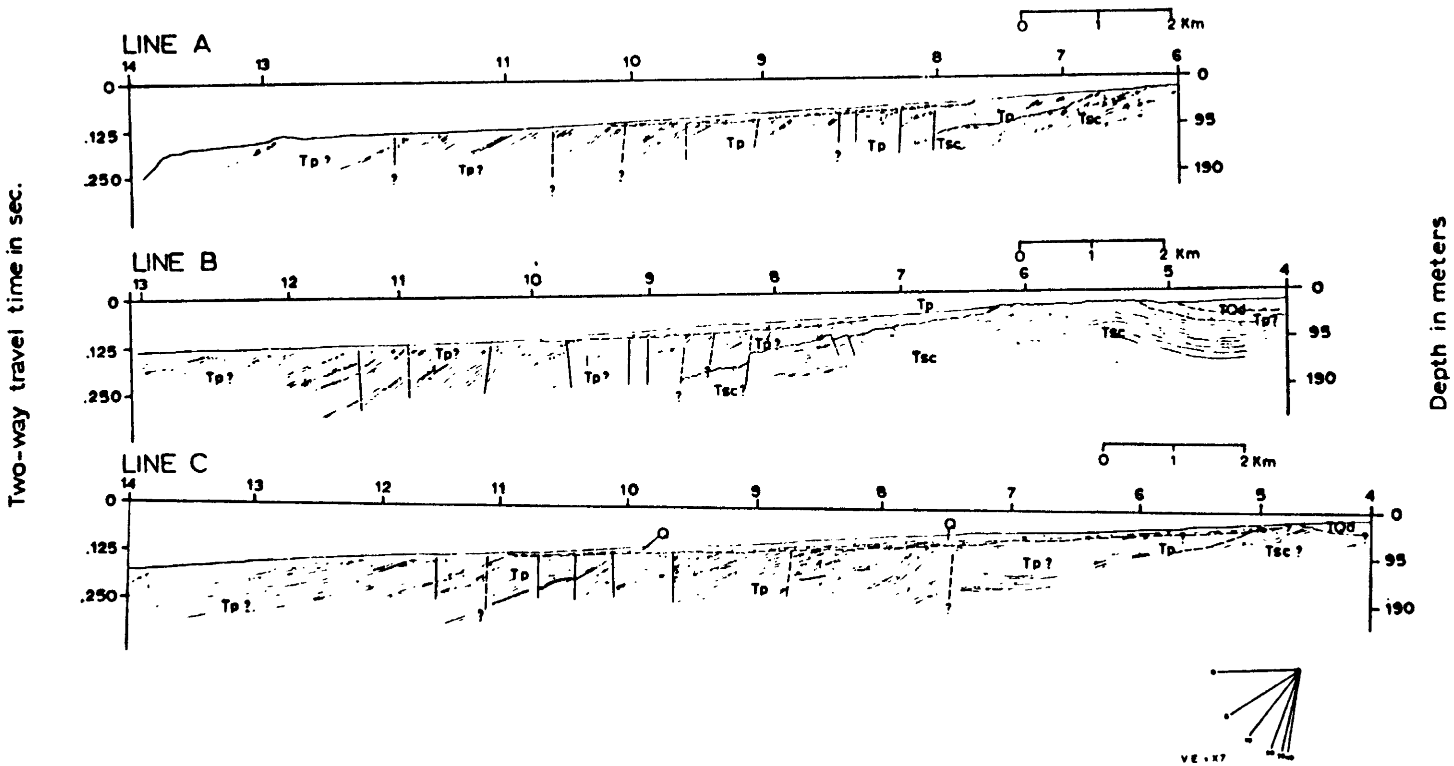
Monterey Bay
High Resolution Profiles



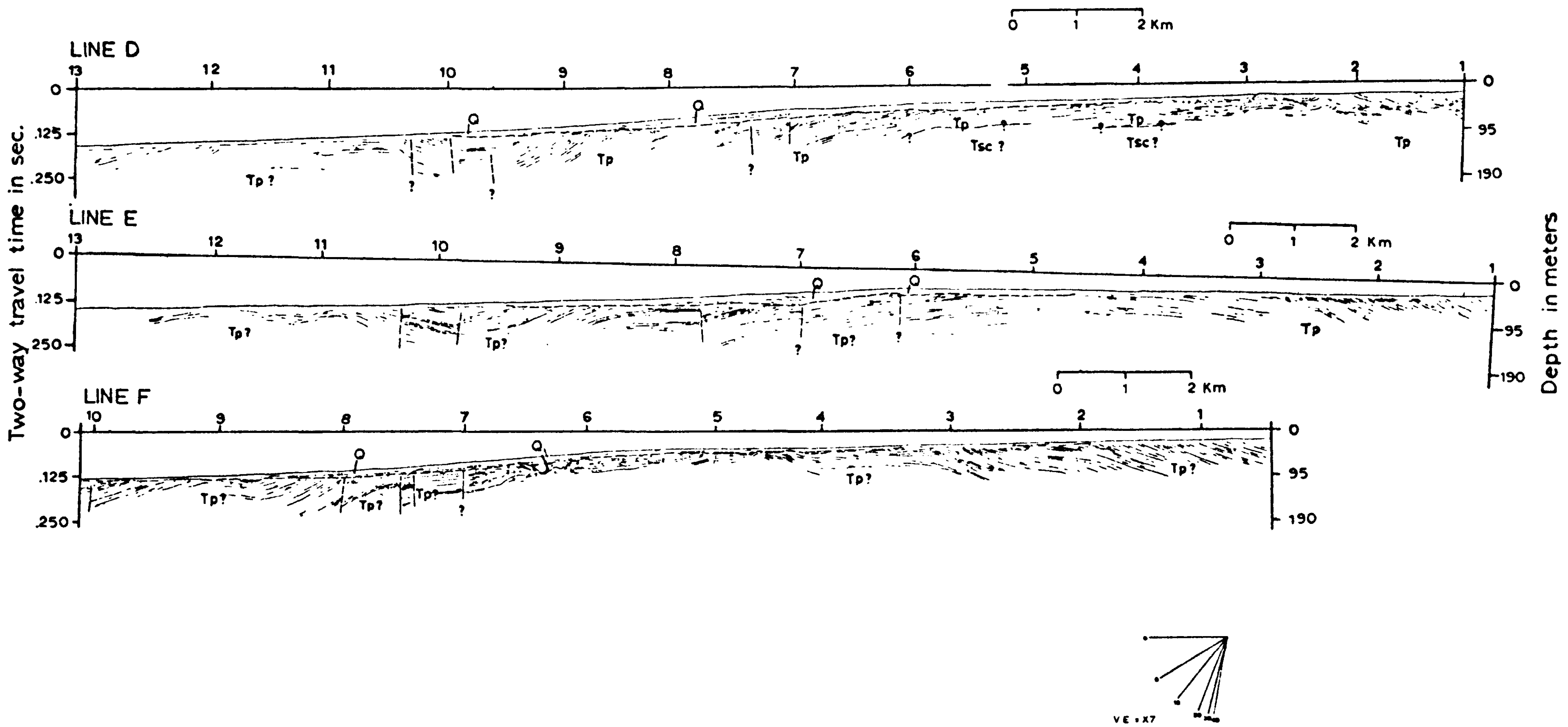
4. Positions of lettered high resolution seismic reflection seismic profiles included in following section.



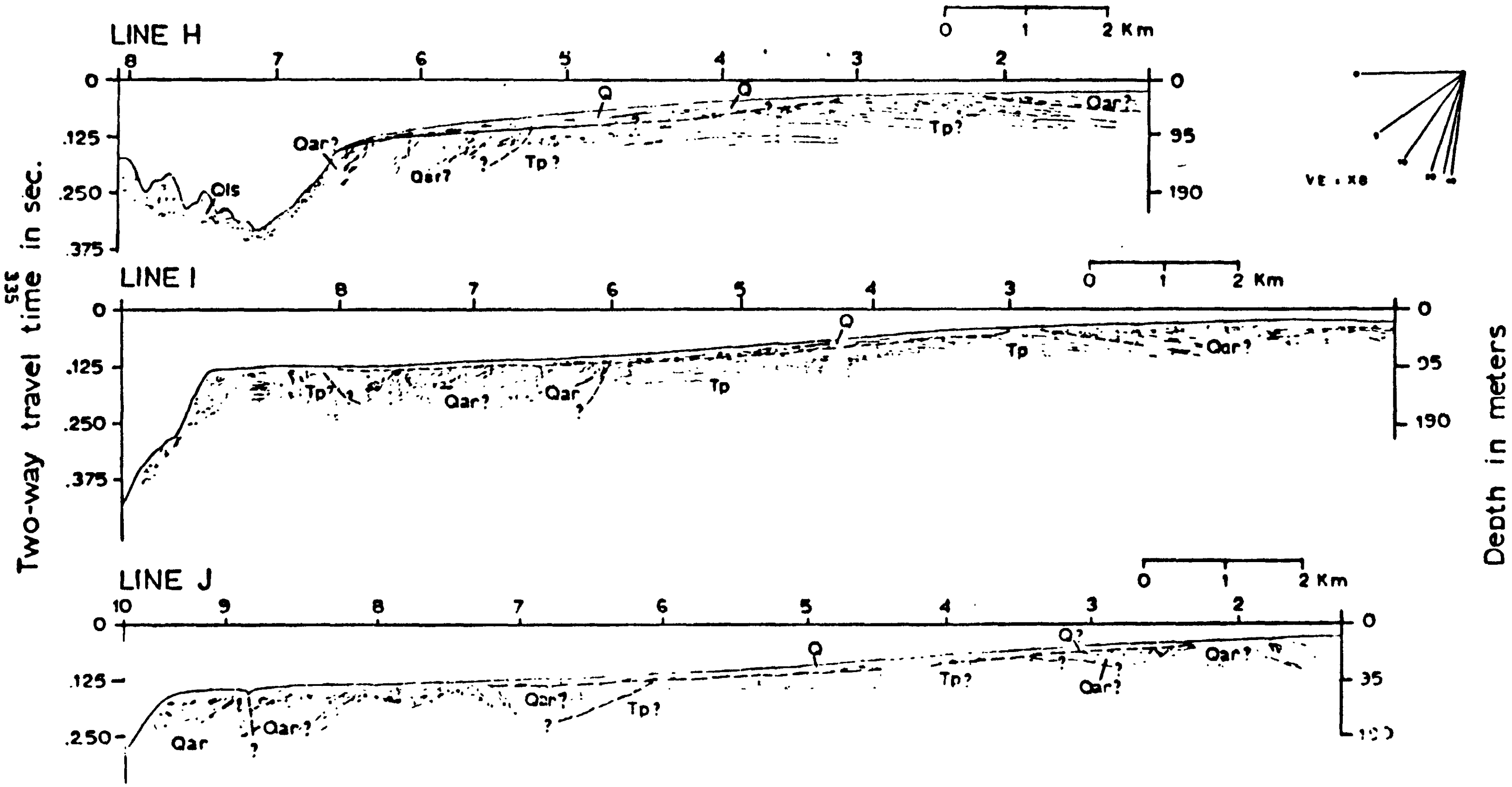
Monterey Bay
High Resolution Profiles



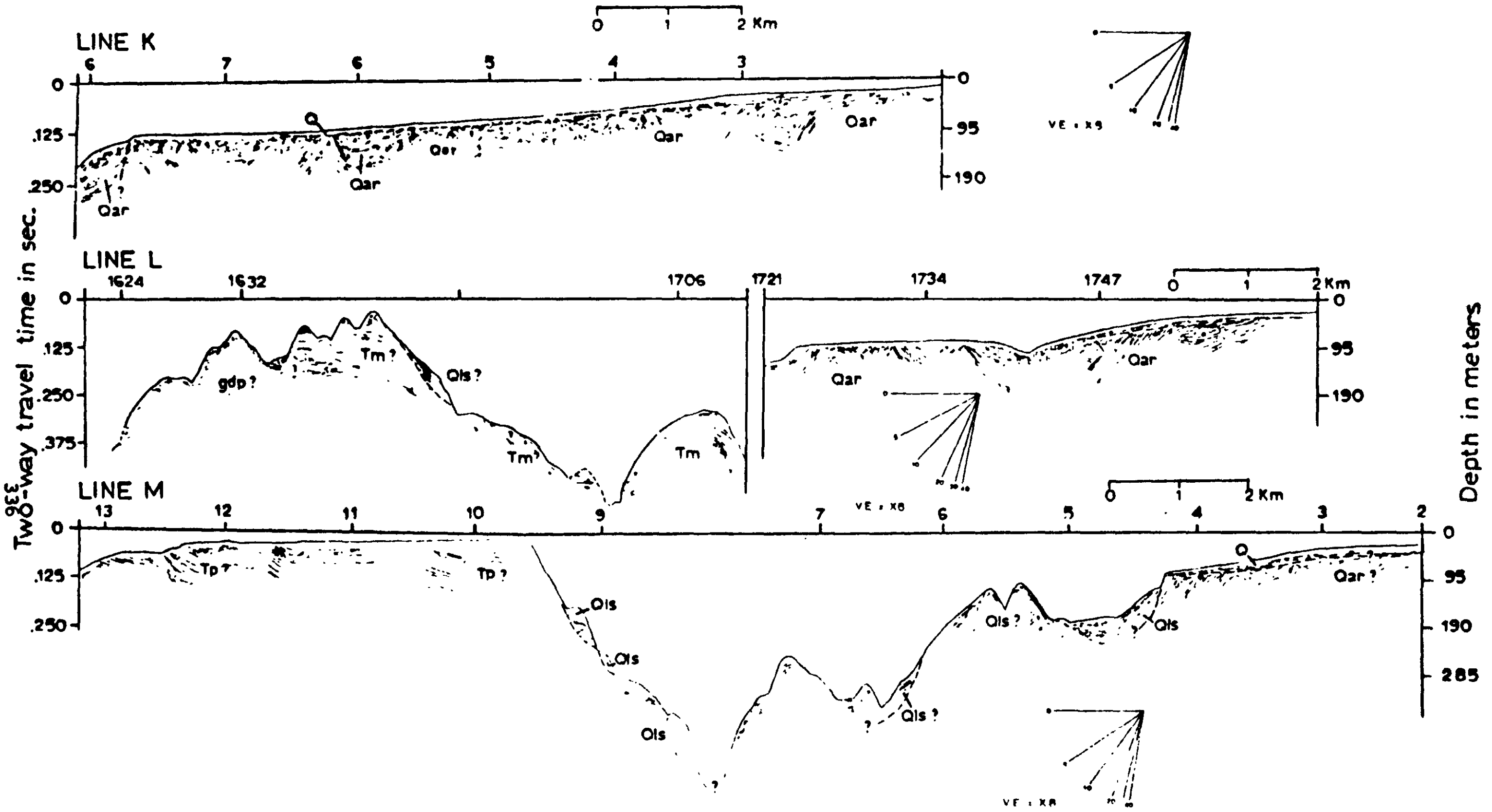
Monterey Bay
High Resolution Profiles



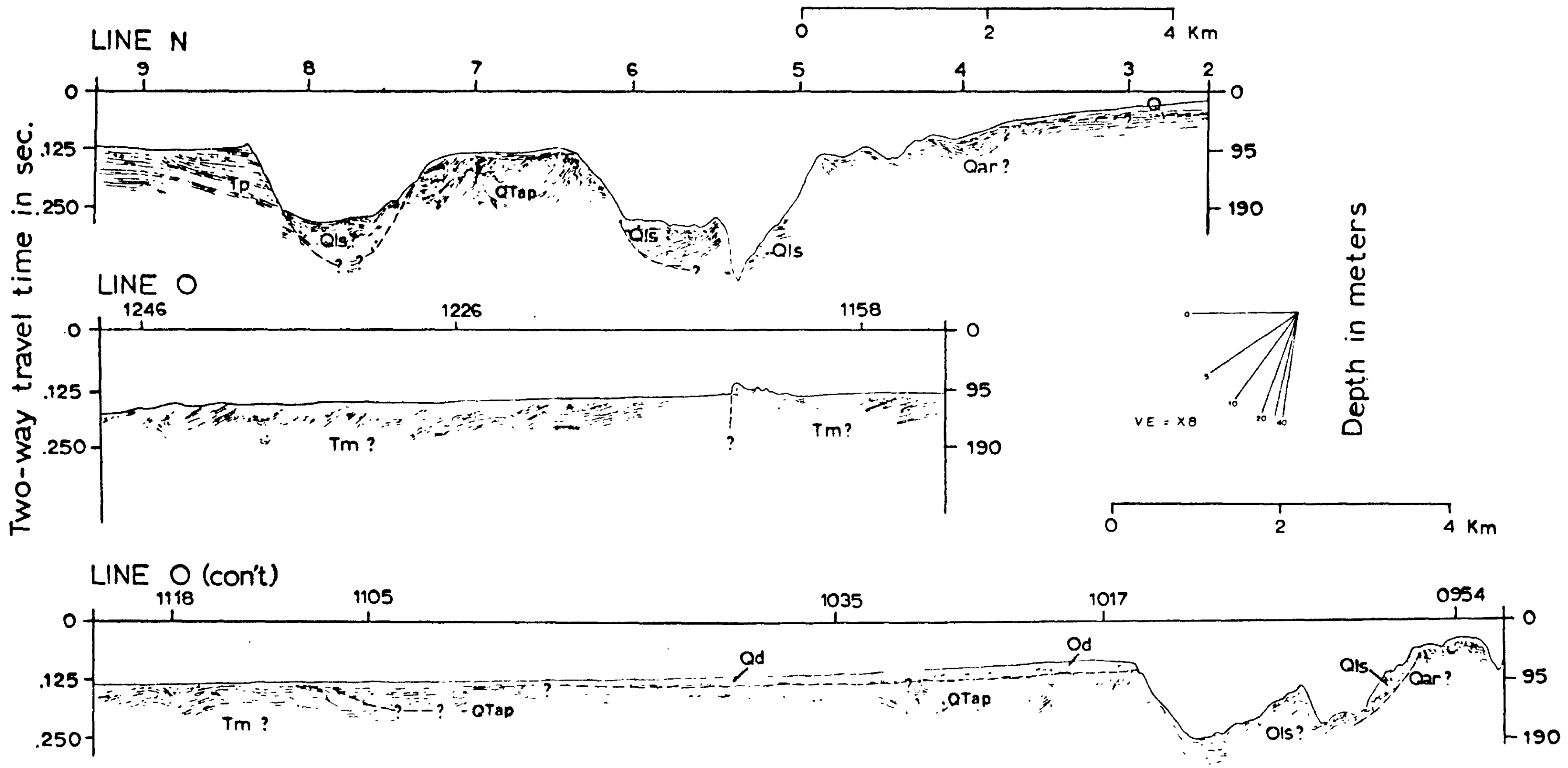
Monterey Bay
High Resolution Profiles



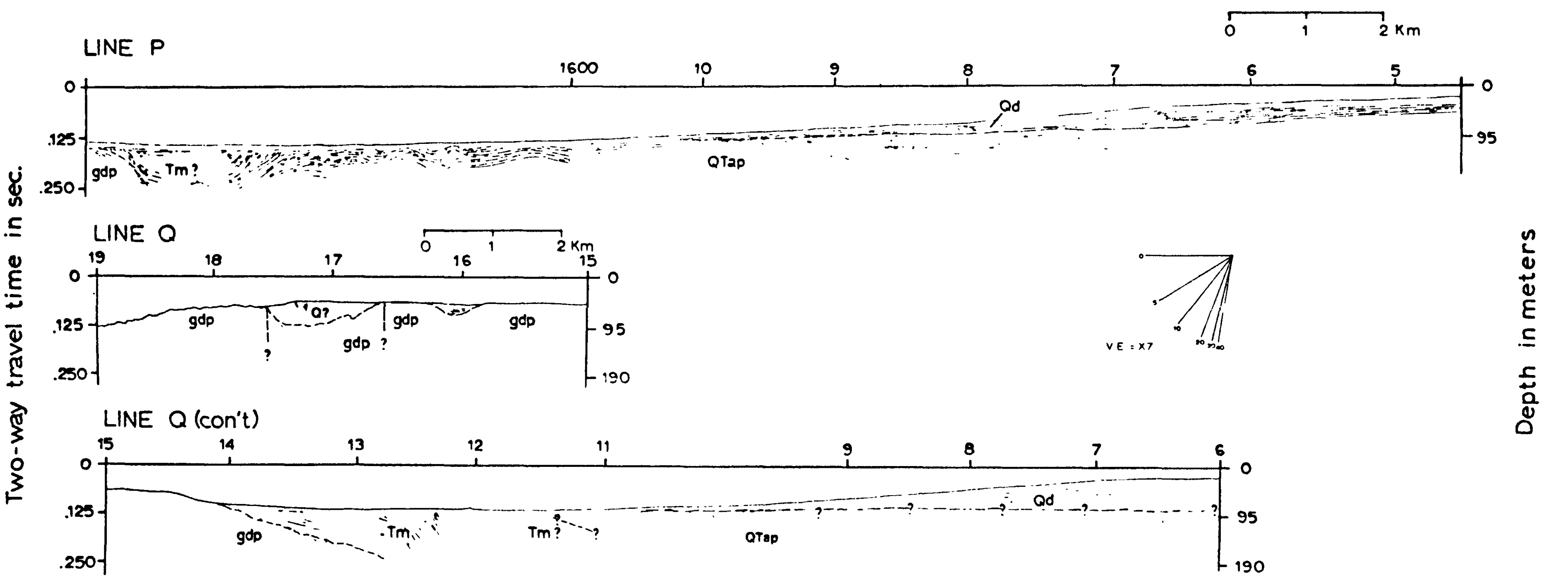
Monterey Bay
High Resolution Profiles



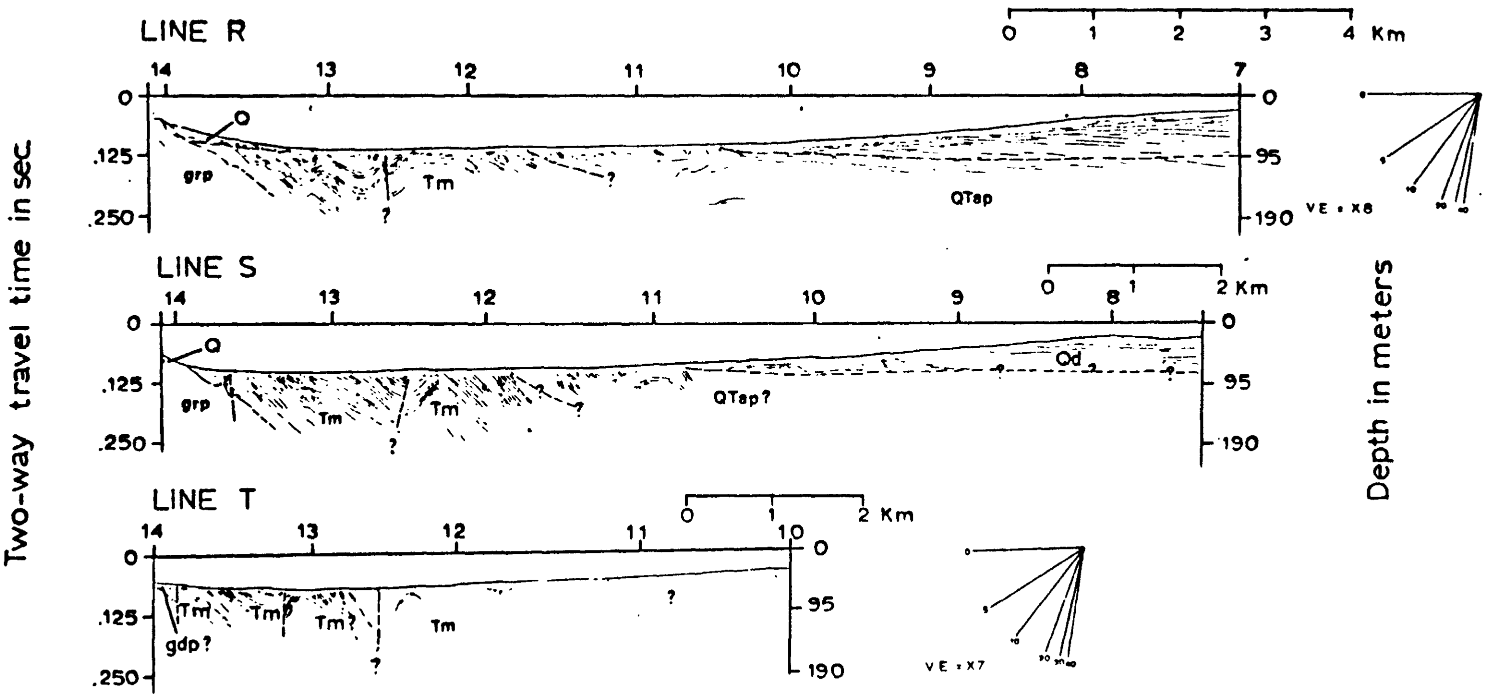
Monterey Bay
High Resolution Profiles



Monterey Bay
High Resolution Profiles



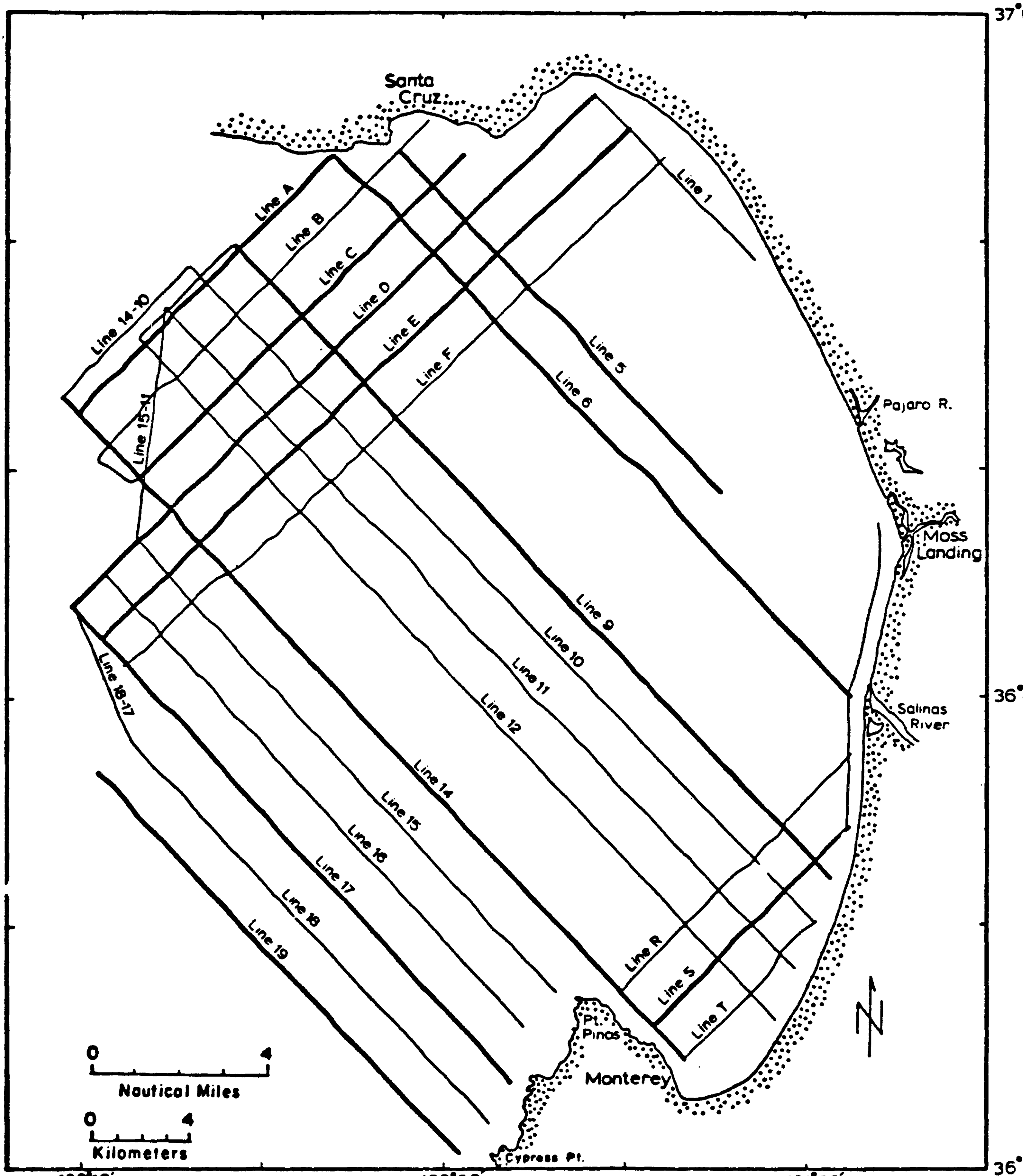
Monterey Bay
High Resolution Profiles

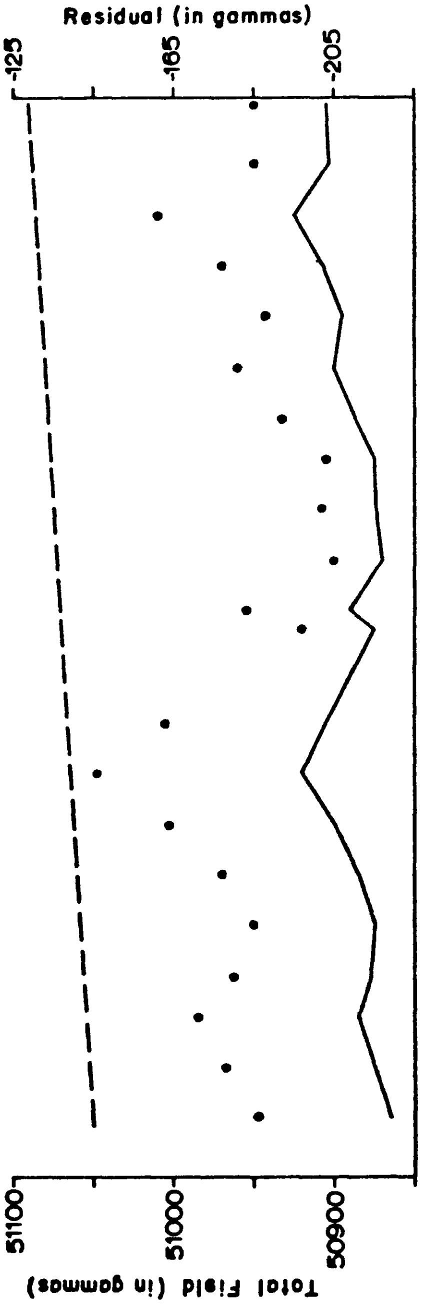


APPENDIX IV

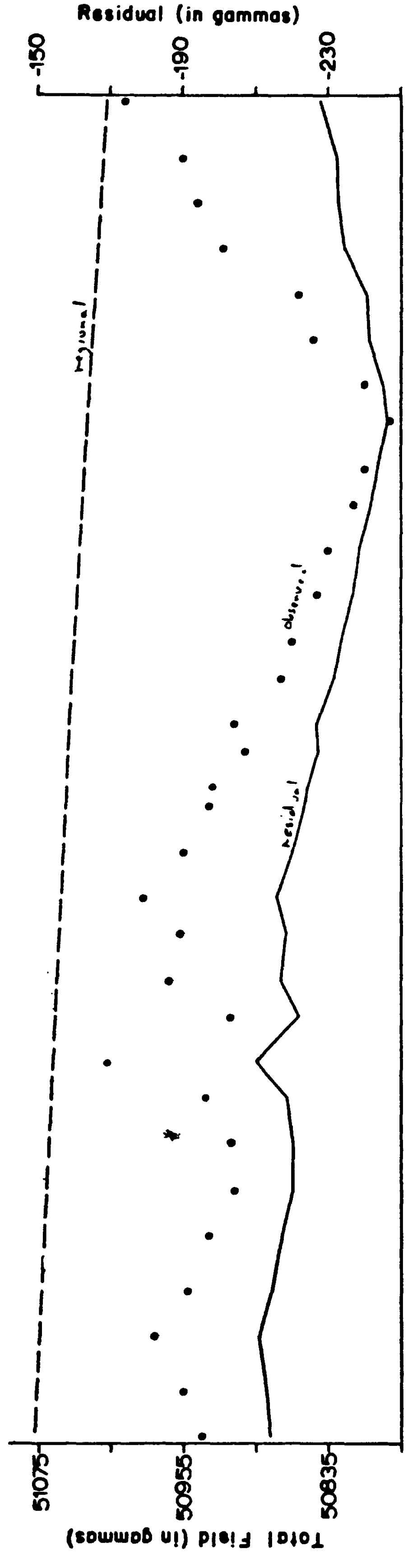
MAGNETIC PROFILES

This appendix contains selected magnetic profiles collected in Monterey Bay during the 1970 survey. A map showing the location of each profile (heavy lines) included in this appendix precedes the profiles. Residual magnetic values and total field values in gammas are on the right and left margins, respectively, of each profile. The regional magnetic curve is shown as a dashed line, the observed magnetic curve as a dotted line, and the residual curve as a solid line.

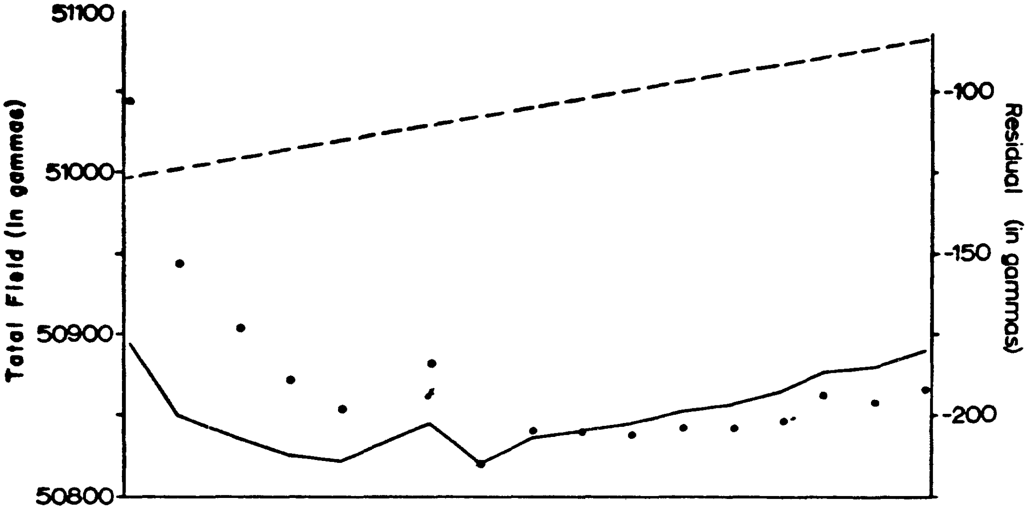

Santa Cruz
Line 1
Line A
Line B
Line C
Line D
Line E
Line F
Line 14-10
Line 15-11
Line 5
Line 6
Line 9
Line 10
Line 11
Line 12
Line 14
Line 15
Line 16
Line 17
Line 18
Line 19
Line 16-17
Line R
Line S
Line T
Pajaro R.
Moss Landing
Salinas River
Pt. Pinos
Monterey
Cypress Pt.
0
4
Nautical Miles
0
4
Kilometers
37°00′
36°45′
36°35′
122°10′
122°00′
121°50′


Residual (in gammas)
-125
-165
-205
51100
51000
50900
Total Field (in gammas)

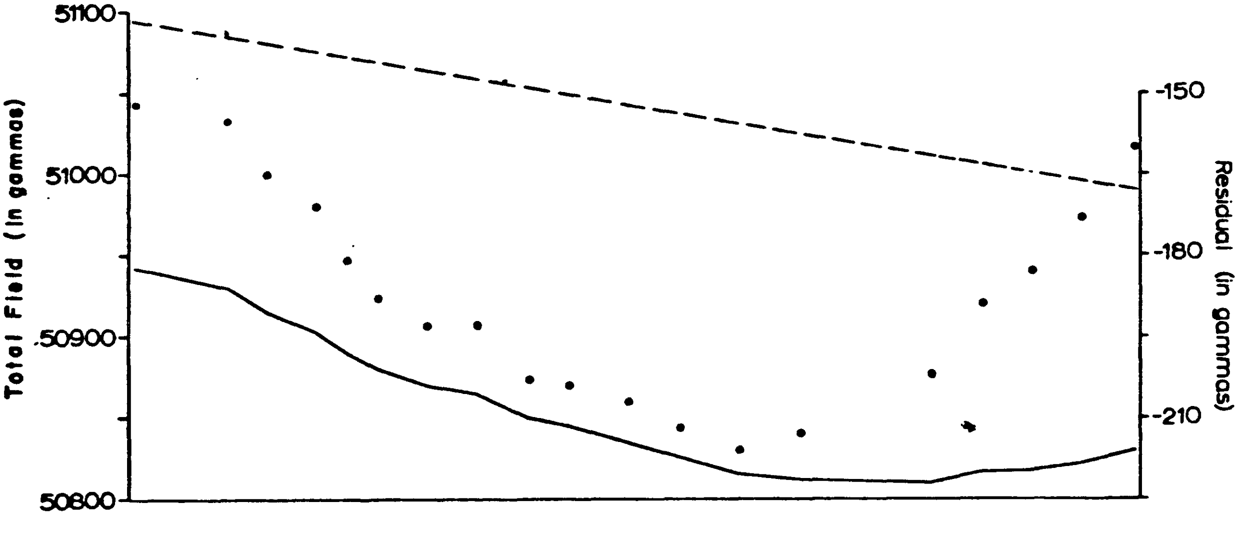
LINE 5


Residual (in gammas)
-150
-190
-230
51075
50955
50835
Total Field (in gammas)

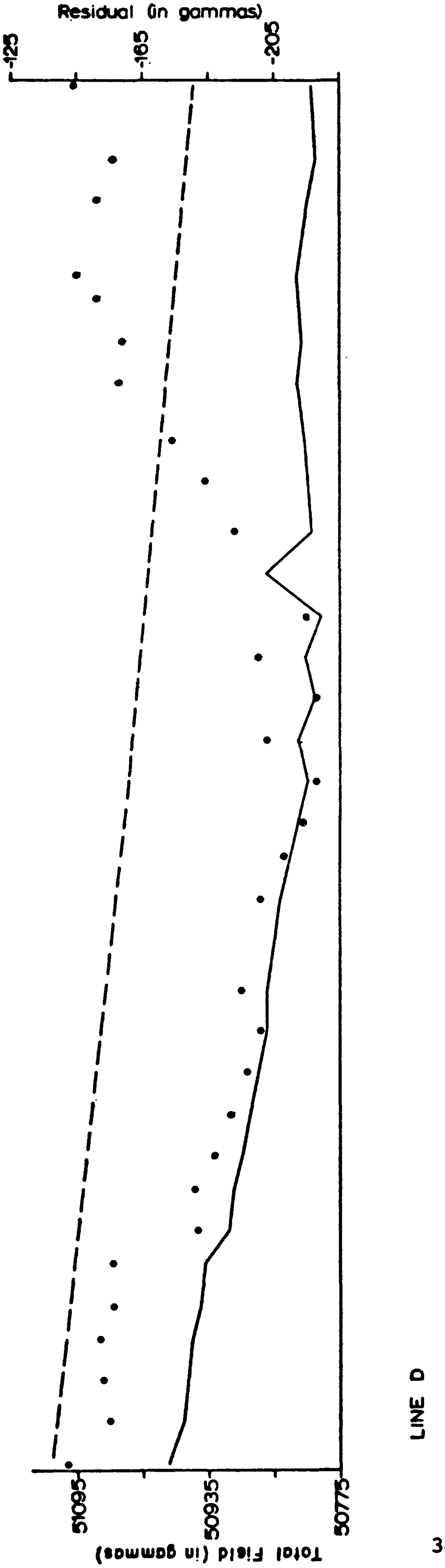
LINE 6

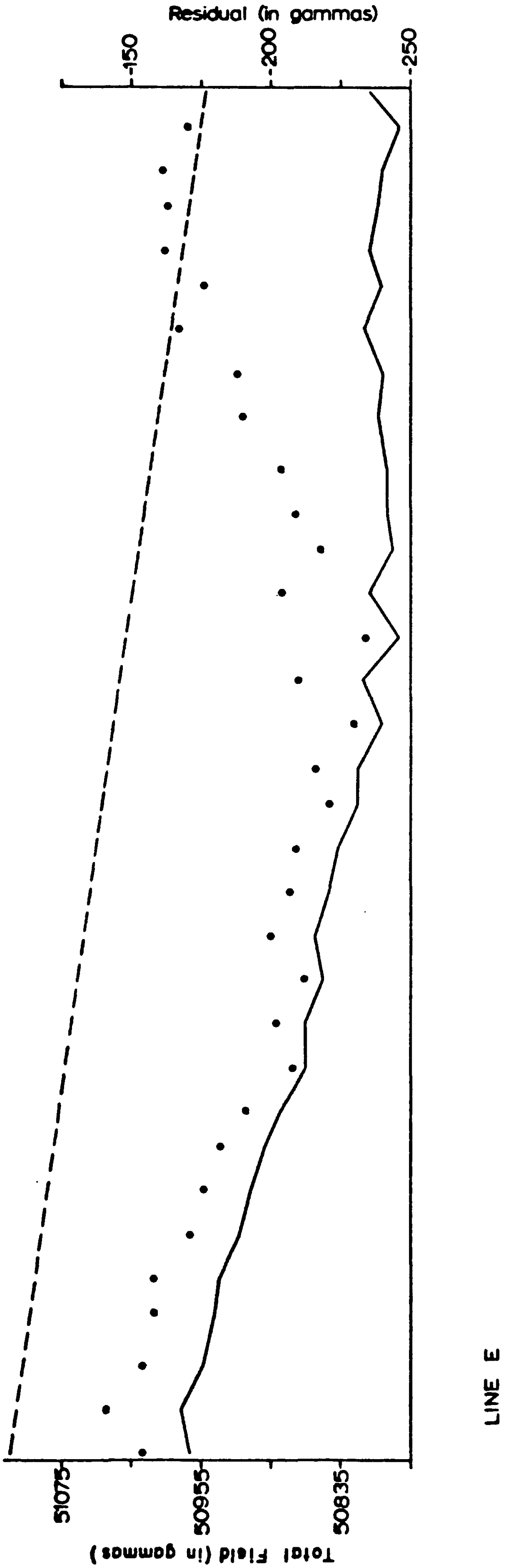

51100
51000
50900
50800
Total Field (in gammas)
-100
-150
-200
Residual (in gammas)

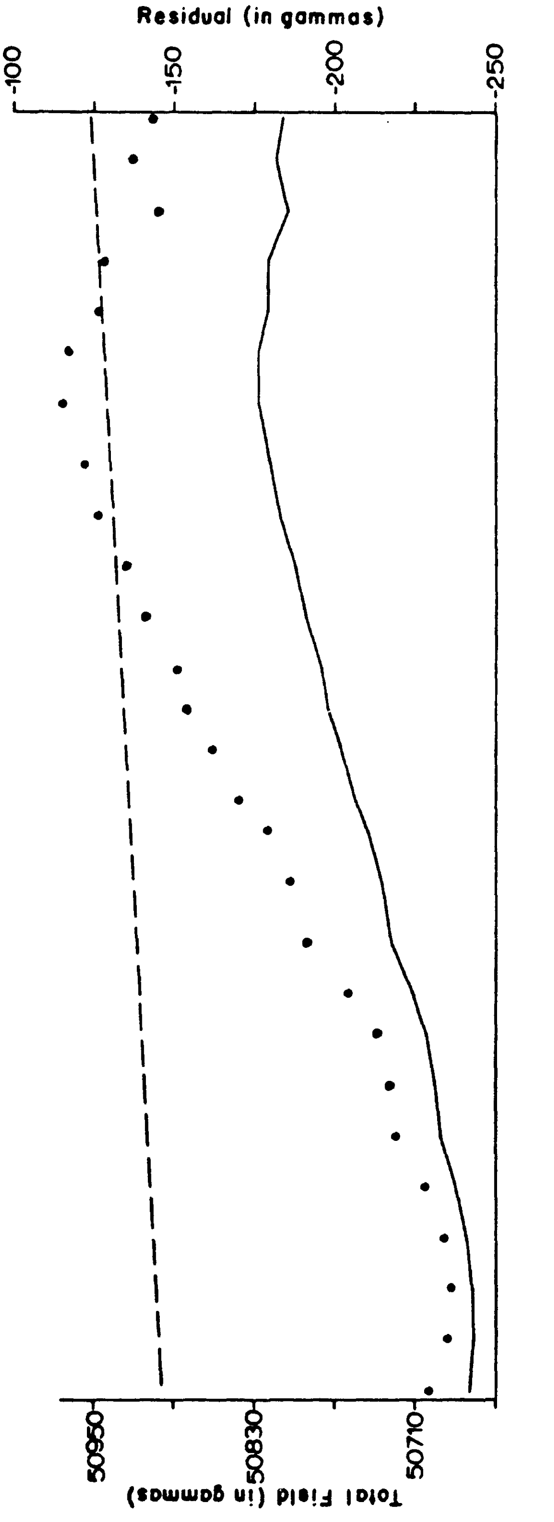
LINE A


51100
51000
50900
50800
Total Field (in gammas)
-150
-180
-210
Residual (in gammas)

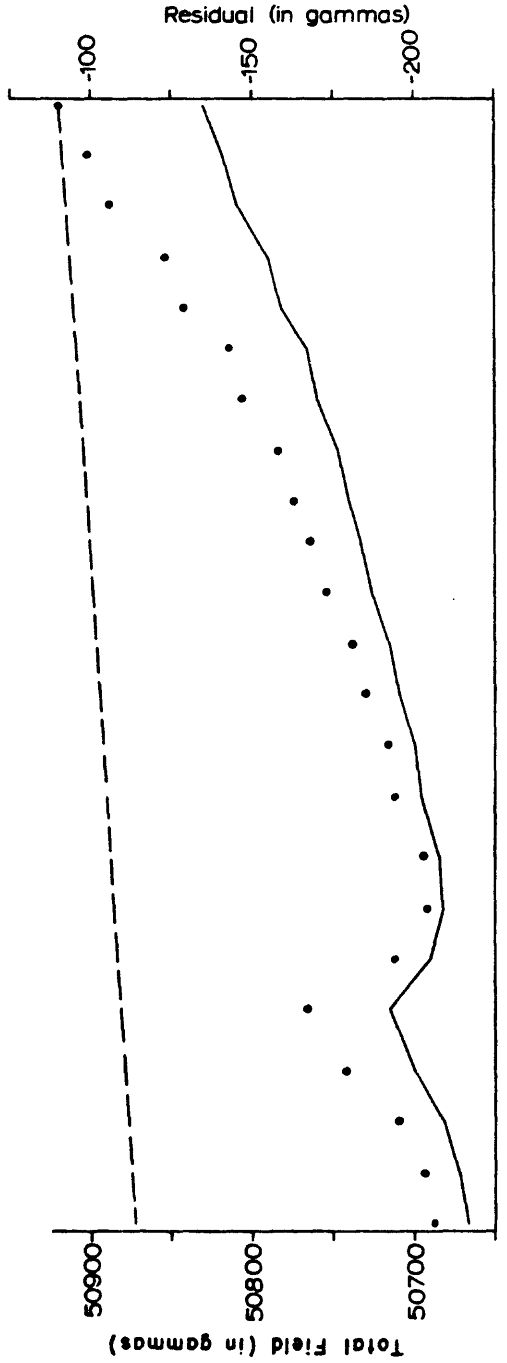
LINE C


Residual (in gammas)
-125
-165
-205
51095
50935
50775
Total Field (in gammas)
LINE D

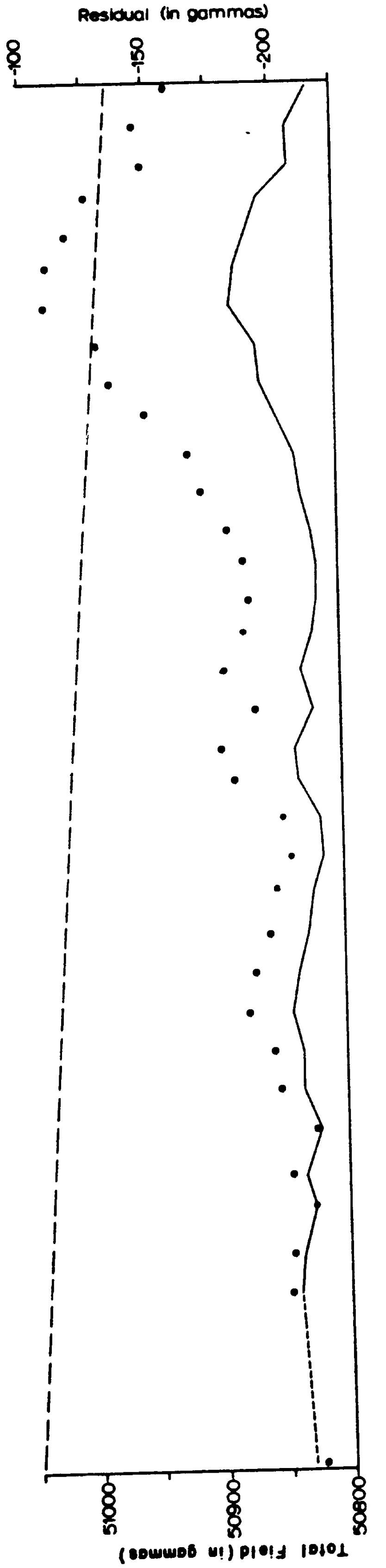

Residual (in gammas)
-150
-200
-250
51075
50955
50835
Total Field (in gammas)
LINE E



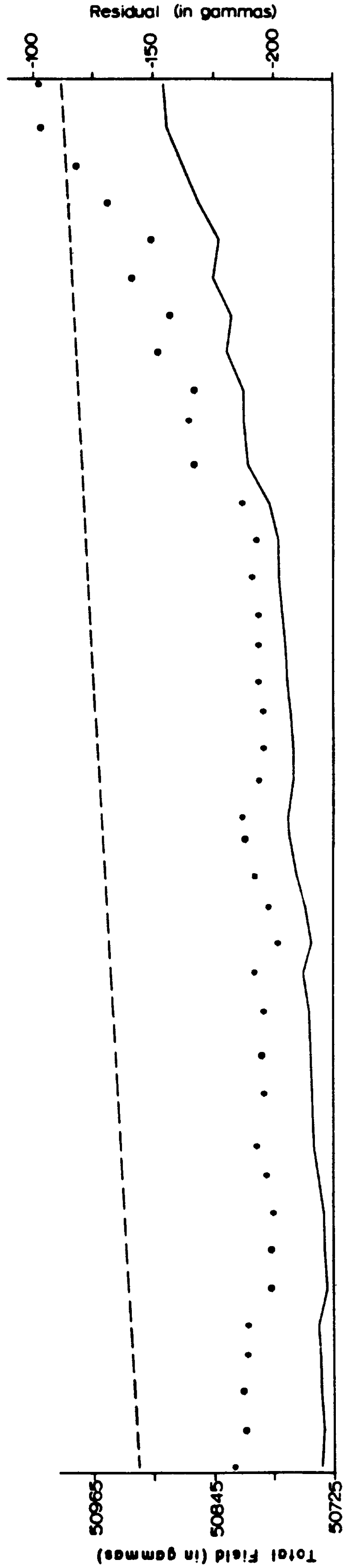
LINE 17



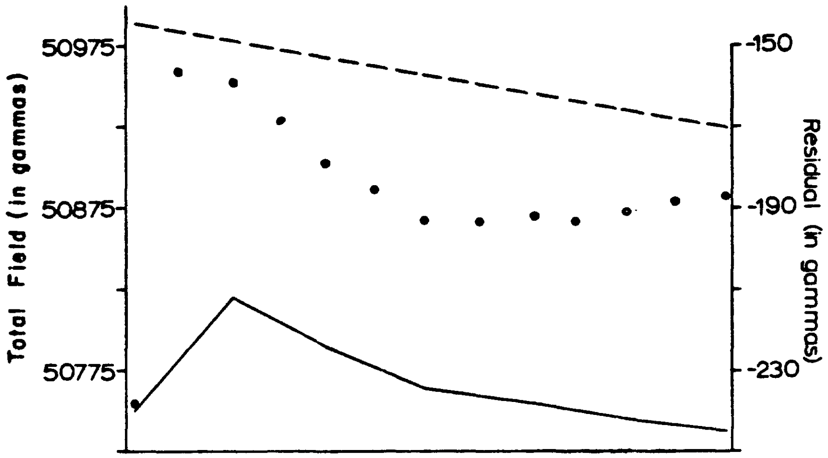
LINE 19



LINE 9



LINE 14



LINE S

☆ GPO 789-107/39