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Recent Sediments of the Central California Continental Shelf, Pillar Point to Pigeon Point: Part C -- Interpretation and Summary of Results

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RECENT SEDIMENTS OF
THE CENTRAL CALIFORNIA
CONTINENTAL SHELF

PILLAR POINT TO PIGEON POINT

PART C. INTERPRETATION AND
SUMMARY OF RESULTS

by

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HYDRAULIC ENGINEERING LABORATORY
COLLEGE OF ENGINEERING



UNIVERSITY OF CALIFORNIA
BERKELEY
OCTOBER, 1973

University of California
Hydraulic Engineering Laboratory

Technical Report
HEL-2-38

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ABSTRACT

Grain size, heavy mineral, and organic content analyses of 43 marine and 9 intertidal and **fluvial** samples plus data from 28 marine samples from a previous study by Sayles (1965) form the data interpreted in this report for the area landward of 90 meters depth (50 fathoms) from Pillar Point to Pigeon Point, California, between the Golden Gate and Monterey Bay.

This study indicates:

- (1) The grain size of the sediment decrease off shore except for a nose of coarser sediment from -36 to -50 meters extending from the north to the latitude of Half Moon Bay.
- (2) The heavy mineralogy is dominated by hornblende with varying amounts of augite and hypersthene. Franciscan minerals are found only in trace amounts.
- (3) Three major source areas for the surface sediment are apparent
(a) a great valley-Sierran source related to the sediments of the present San Francisco offshore bar; (b) a local source related to the drainage basins now emptying directly into the area off shore; (c) a quartz diorite source presumably montara to the north.
- (4) The major distribution pattern of the sediment may be explained
(A) from -90 to -20 meters by the superimposition of local stream drainage on the shelf on relict sediment from the north during lower stands of sea level with limited reworking and mixing of sediments at province boundaries during the last rapid rise of sea level; and from -20 meter to present sea level by partial homogenation of local sediment during a slow rise in sea level.

INTRODUCTION

The following work is part of a continuing study of the sediments and sedimentary processes of the Continental Shelf of Central California done in cooperation between the University of California, Berkeley and the Coastal Engineering Research Center, U.S. Army Corps of Engineers. Sediment analyses were done at the University of California, Berkeley, utilizing the facilities of the Department of Civil Engineering, Hydraulic Engineering Laboratory; the Department of Geology; and the Institute of Marine Resources.

The results of this part of the study is presented in three separate reports.

Part A. Introduction and Grain Size Analysis (Yancey and others, 1970, HEL Report 2-26)

Part B. Mineralogical Data (Lee and others, Hel Report 2-130)

Part C. Interpretation and Summary of Results (this volume).

Reports A and B - raw data is presented with little or no interpretation. In part C we present our interpretations of the data plus background information and the previous work done in the area.

The offshore sampling (Fig. 1) was done 29 to 30 July 1968 on the R/V San Michele by P. Wilde, R. Carter, T. Yancey, E. Silva, and C. Isselhardt. The on shore sampling of beaches and streams was done in April 1970 by J. Lee and T. Yancey. The samples are on file in the sediment collection at the Richmond Field Station of the University of California.

The major goals of this study are: (1) characterization of the sediments, (2) identification of the sedimentary environments and (3) determination of the sediment transport regimes.

TABLE 1 (continued)

TABLE 1c

ANNUAL PRECIPITATION FOR TOWNS
IN AREA IN INCHES

	BEN	LOMAND	DAVENPORT	HALF MOON BAY	SAN GREGORIO
1952	86.01			36.72	
53	51.97			25.78	
54	43.09			19.75	
55	42.49			16.93	
56	46.16			35.00	
57	42.74			23.02	
58	80.71			43.01	
59	48.24			18.66	
60	32.51			16.20	
61	31.01			19.57	
62	50.43		23.02	23.07	25.26
63	67.68		29.13	32.40	37.42
64	36.03		17.02	17.10	20.33
65	60.69		28.21	25.40	28.77
66	34.19		20.77	20.05	21.15
67	70.53		36.57	34.79	39.62
68	33.13		21.58	21.50	24.48

From Geol. Survey Water Supply Paper 1735

TABLE 1 (continued)

TABLE 1d WIND

ANNUAL **PERCENTAGE** FREQUENCY OF
WIND BY SPEED GROUPS AND MEAN
SPEED IN MILES PER HOUR

SAN FRANCISCO	SPEED %	0-3	4-7	8-12	13-18	19-24	25-31
		16	21	26	22	11	3

MEAN SPEED = 10.6 MILES PER HOUR

(CLIMATIC ATLAS OF U.S., 1968, p. 76)

TABLE 1e

MONTHLY FASTEST WIND **AND** DIRECTION
AT SAN FRANCISCO IN MILES PER HOUR

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
SPEED	60	62	52	48	56	48	50	45	48	51	55	53
DIRECTION	SW	SW	NW	W	W	W	W	WNW	S	SW	SSW	S

(CLIMATIC ATLAS OF U.S., 1968, p. 74)

TABLE 2

SEA SURFACE TEMPERATURES
 COASTAL WATERS OFF CENTRAL CALIFORNIA
 IN °FAHRENHEIT 1965

JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
54- 56	54- 56	54- 56	54- 56	52- 54	54- 56	56- 58	58- 60	58- 60	58- 60	60- 62	56- 58
W*	S	S	S	C	C	C	C	C	C	S	S

* WITH RESPECT TO OFF SHORE WATERS

W = WARMER WATER ON SHORE

C = COLDER WATER ON SHORE

S = SAME TEMPERATURE

(CALIF. FISH MARKET SUMMARY, PART II, 1965)

shows the highest velocity winds are not necessarily northwest but in general are blowing off the Pacific Ocean.

OCEANIC:

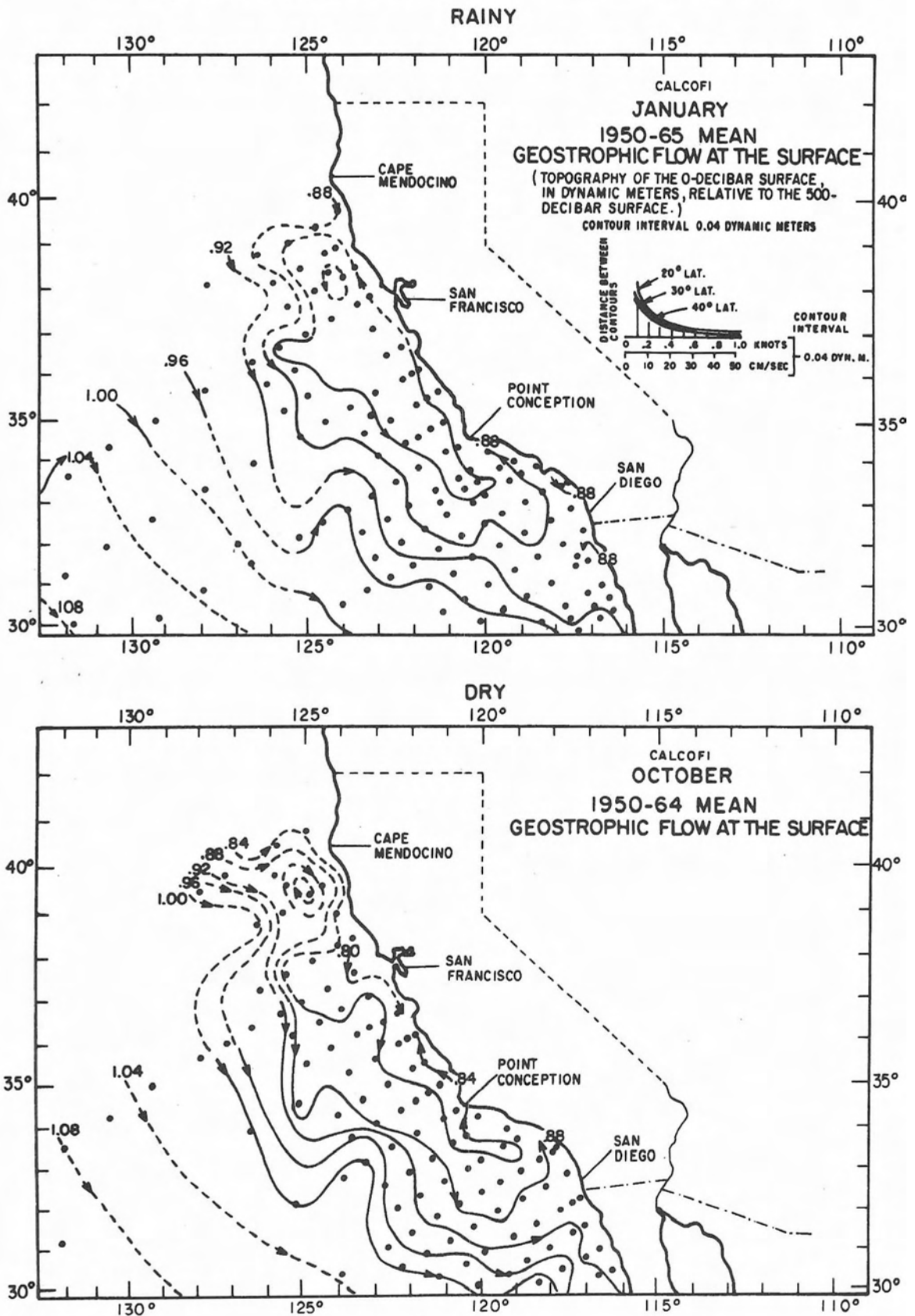
The Pacific Ocean off the Coast of Central California has two basic oceanographic seasons characterized by the direction of the major off-shore currents (1) during the meteorological dry season (May-October) when the southeasterly flowing California current is the prevailing near-shore current, and (2) during the rainy season (November-April) when the northwesterly flowing Davidson Current may flow between the coast and the now off-shore California Current. The dry season may be separated further into two subseasons (a) the Fog Season of late spring and summer when upwelling of cold-nutrient rich water occurs along the coast and (b) the Oceanic Season of late summer and fall when no upwelling occurs. A more detailed description of the oceanographic climate is found in Norris and Kersnar (1971, V.I., p. 21-24) and in the various reports of the California Co-operative Oceanic Fisheries Investigations (CALCOFI). Figure 2 shows the typical geostrophic currents for the two major seasons.

Physical Properties of Coastal Waters:

Synoptic studies of temperature and salinity plus other chemical properties have been done in connection with studies of the California current by CALCOFI. Summary data are presented in Figs. 3 and 4, which show the water temperature is cold reflecting the high latitude source of the California Current and the salinity is somewhat less than the Pacific Ocean average of 35‰ (Sverdrup and others, 1942, p. 123) suggesting (1) dilution by coastal streams and rivers of the Pacific Northwest and from San Francisco Bay and (2) low evaporation with respect

Fig. 2

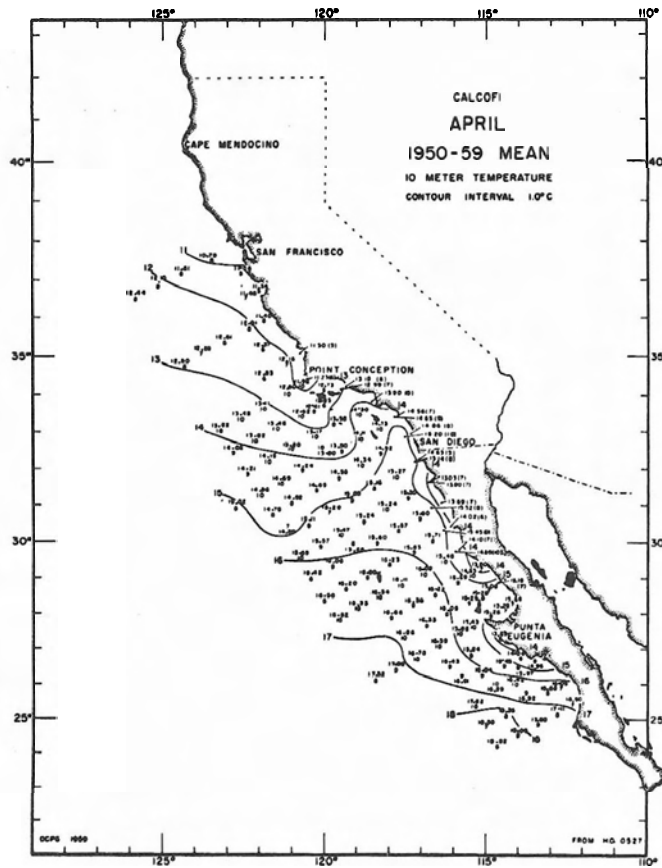
TYPICAL SURFACE GEOSTROPHIC FLOW BY SEASON



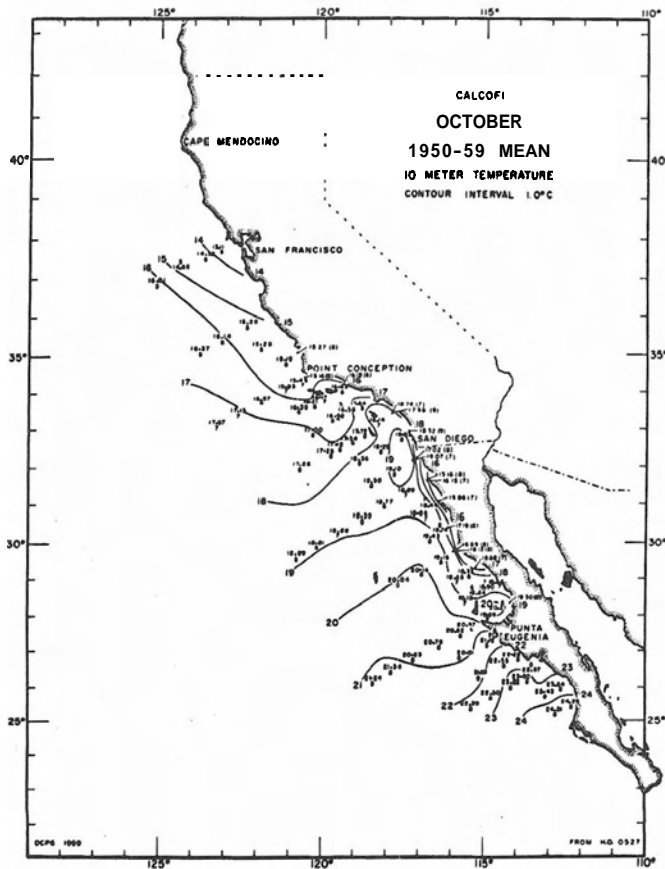
(From Wylie (1966 p, 5,141

Fig. 3

TEMPERATURE
RAINY

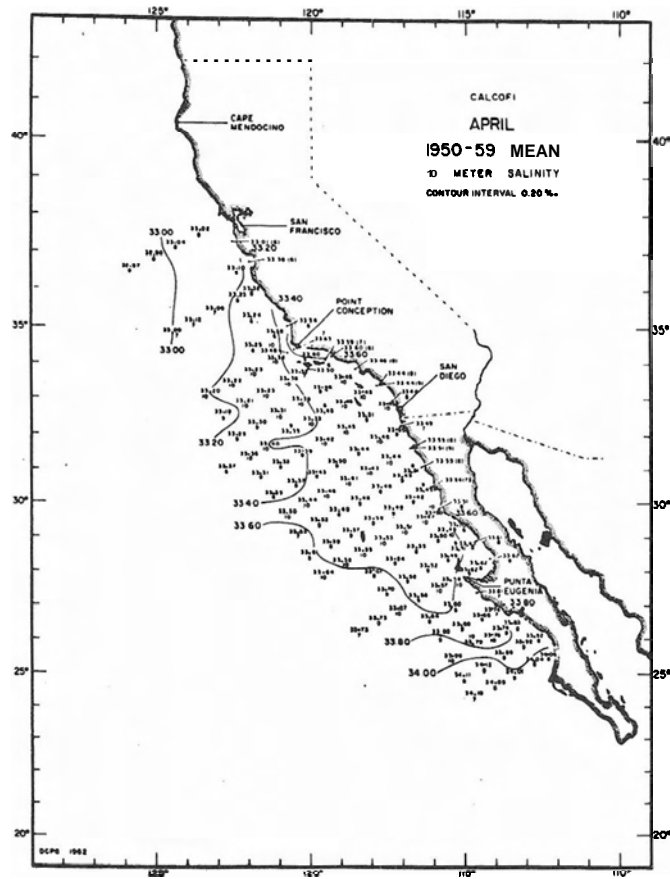


DRY

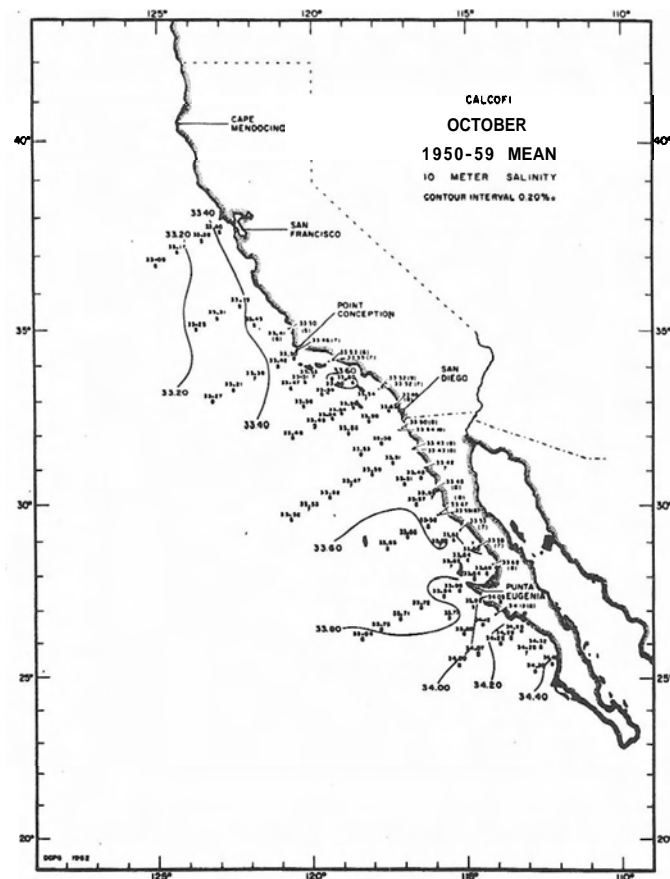


(From Calcofi Atlas #1 (1963))

Fig. 4
SALINITY
RAINY



DRY



(From Calcofi Atlas #1 (1963))

to precipitation over the ocean. The phenomenon of upwelling where the coastal waters are colder than the off-shore waters is depicted in the data of Table 2. Only in January is the near shore waters off Central California actually warmer than the offshore waters.

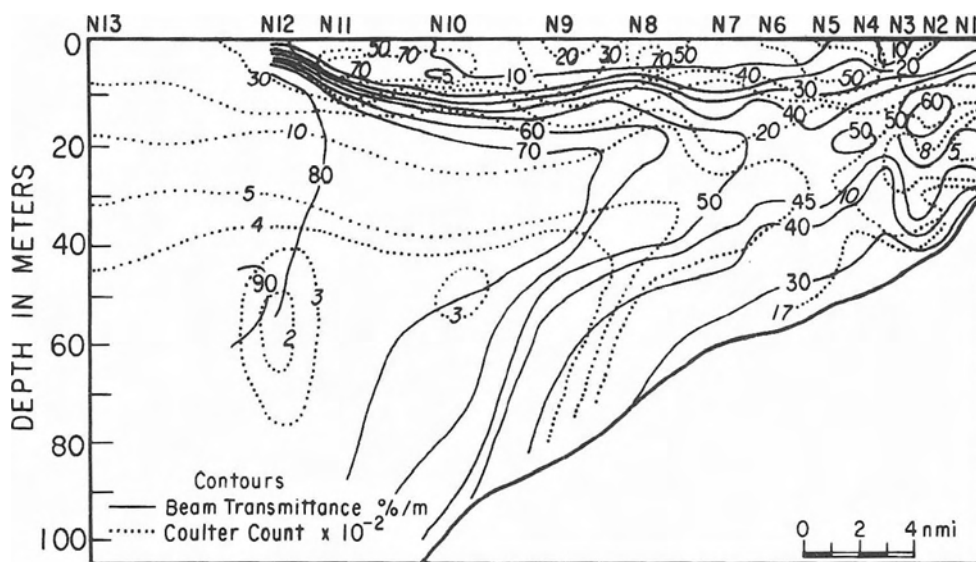
Labyak (1969) has reported on the water clarity properties in the region from San Francisco to Monterey Bay based on one cruise in May. In general for this area the transmittance of light is an inverse function of upwelling as during upwelling the higher nutrient content of the water produces plankton blooms which in the extreme case produce murky red tides. North of Pillar Point the influence of the tides of San Francisco Bay is shown (Fig. 5) in the crescent patch of high particle count water similar to those observed by Norris and Kersnar (1972) caused by severance of the turbid outgoing water from San Francisco by incoming flood-tide ocean water moving in along the shore at the surface. The southward deflection shows the entrapment of the turbid crescent in the California current.

Tides:

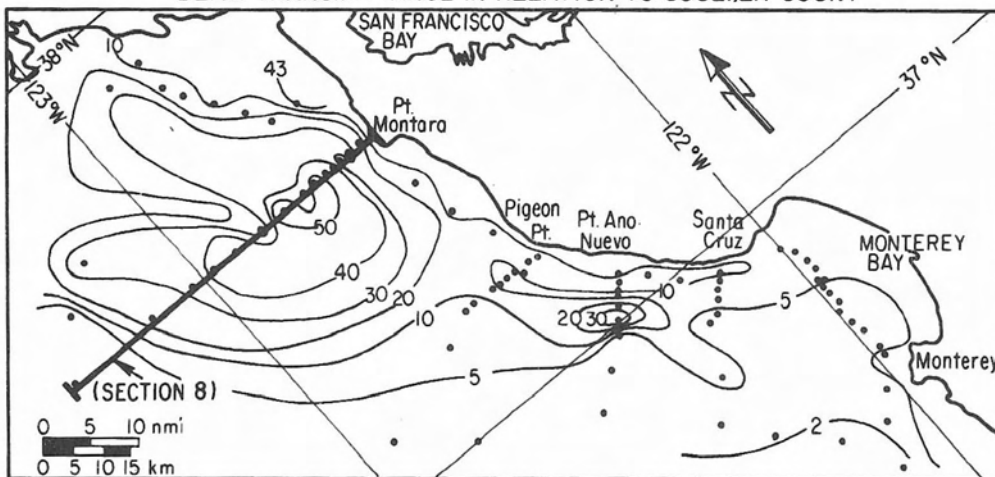
Tides in the area are mixed semidiurnal with a variable high-high, low-high, high-low, and low-low tide over a sidereal day as depicted for San Francisco (Fig. 6). Off shore beyond the influence of San Francisco Bay the tidal range is smaller than for the bay with a mean tide of 3.0 feet at Half Moon Bay and 2.7 feet at Ano Nuevo Island. Tidal currents, although strong in San Francisco Bay (Fig. 7) are too weak and variable to be predicted in the area of interest.

Pelagic tides have been measured at the bottom station OBS 3 160 kilometers west of point Arena (Nowroozi, 1972) at a depth of 3903 meters. Figure 8 shows co-tidal charts for the M_2 (Principal

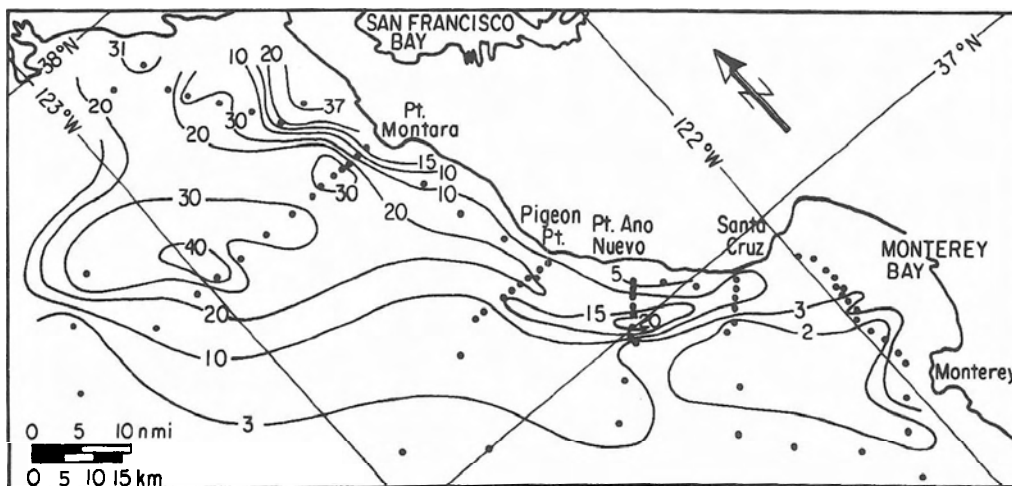
WATER CLARITY CHARACTERISTICS OFF CENTRAL CALIFORNIA



(A) VERTICAL CROSS SECTION 8
BEAM TRANSMITTANCE IN RELATION TO COULTER COUNT



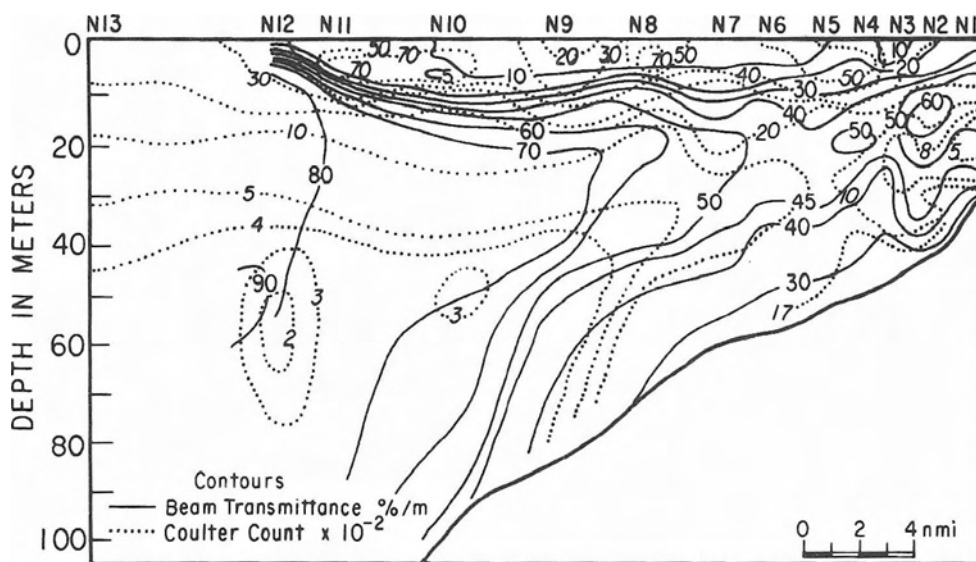
(B) ISOLINES OF TOTAL COULTER COUNT (x 10⁻²) AT THE SURFACE



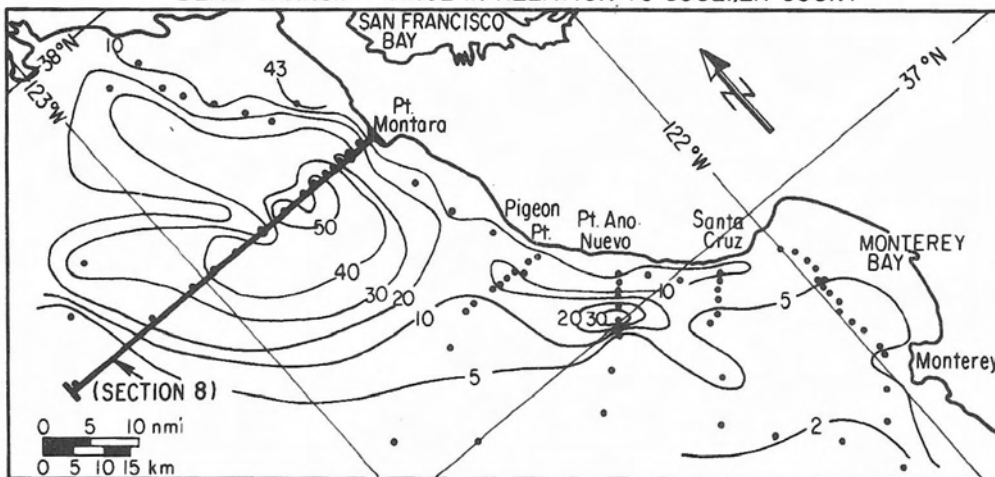
(C) 10 METER ISOLINES OF TOTAL COULTER COUNT (x 10⁻²)

From:
LABYAK (1969 p. 76, 79, 106)

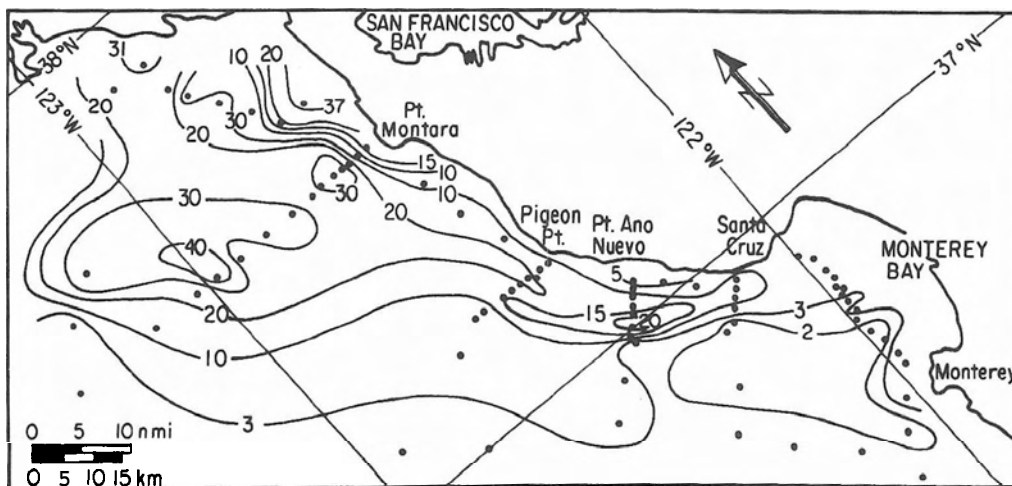
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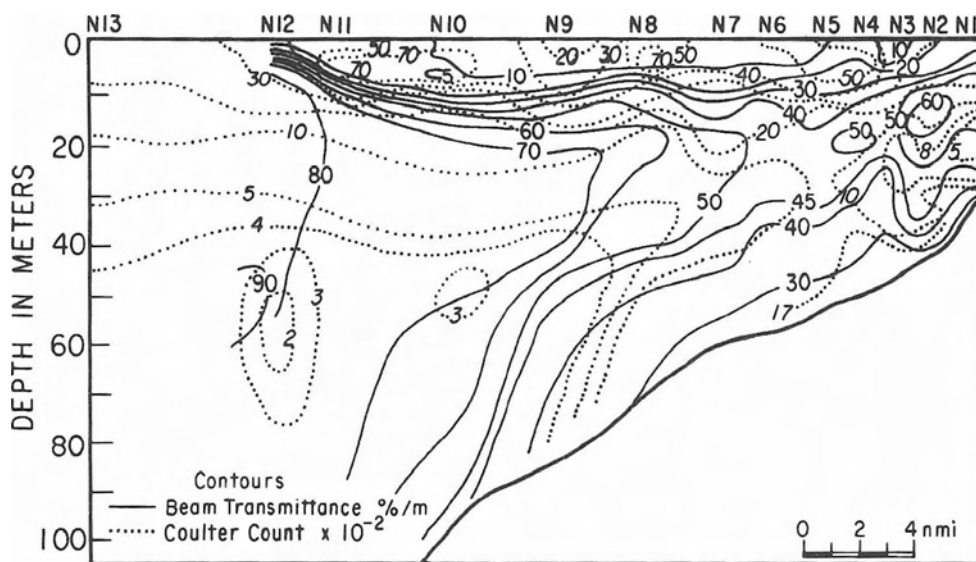
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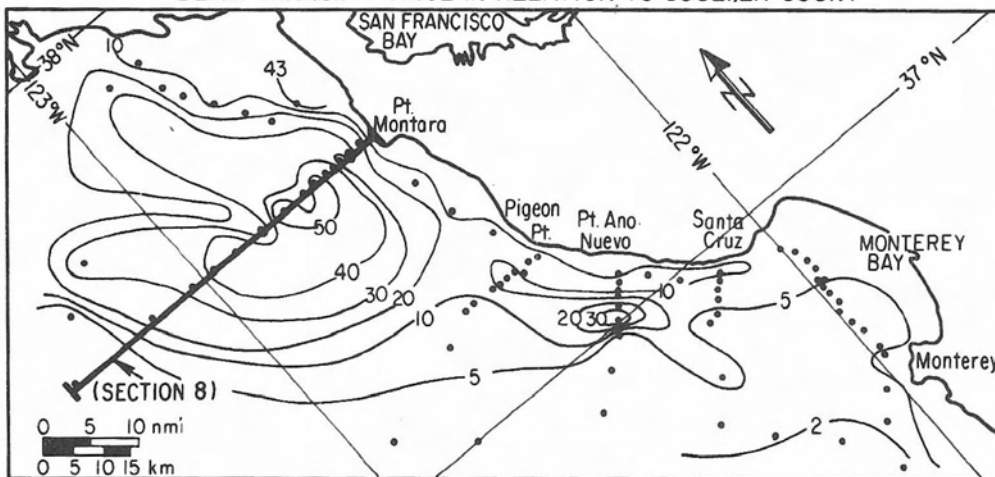
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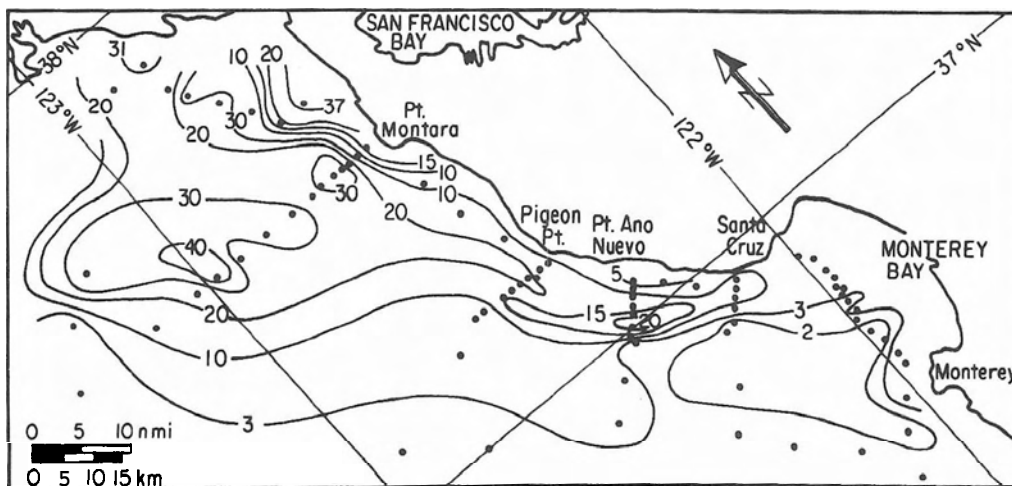
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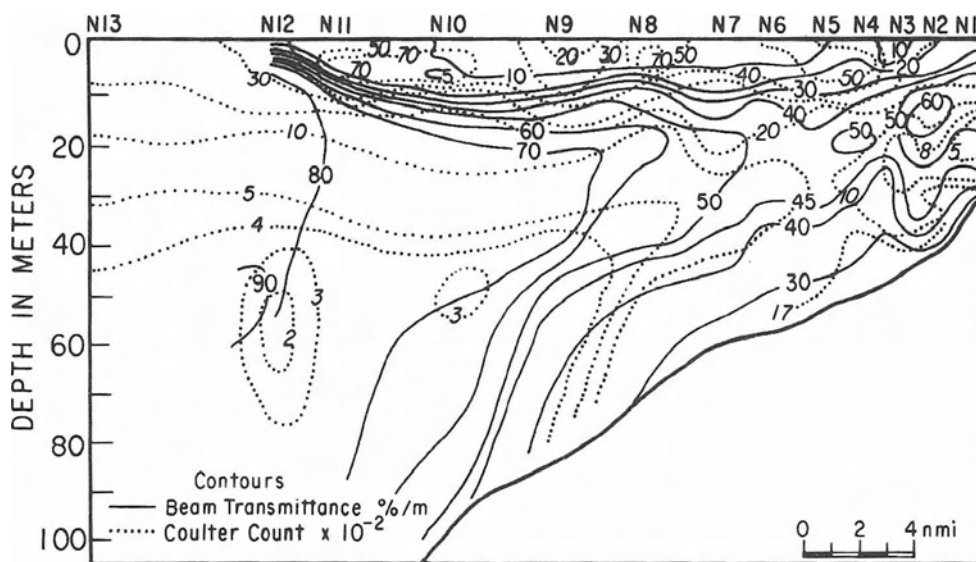
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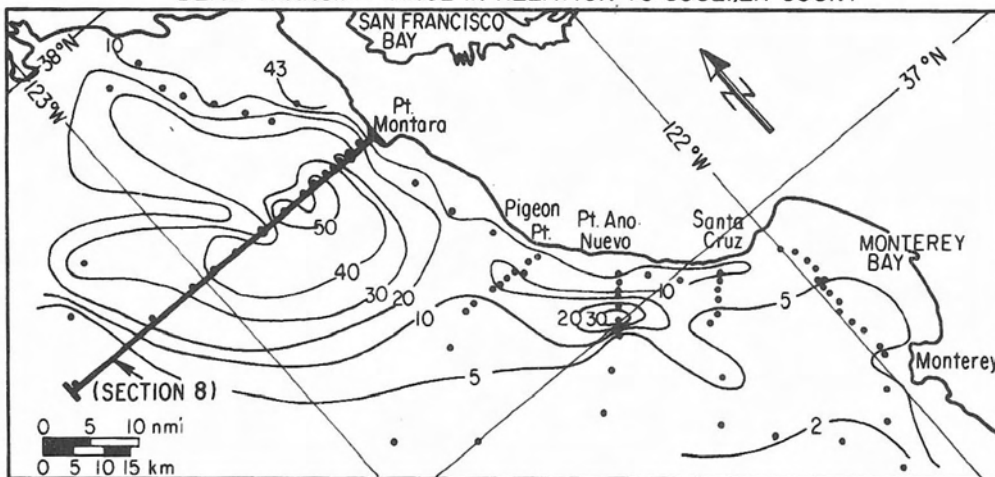
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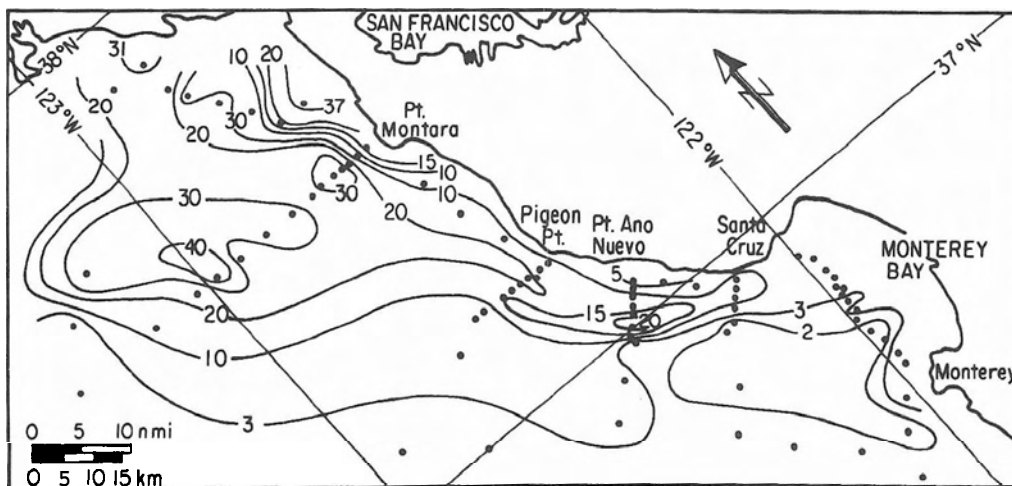
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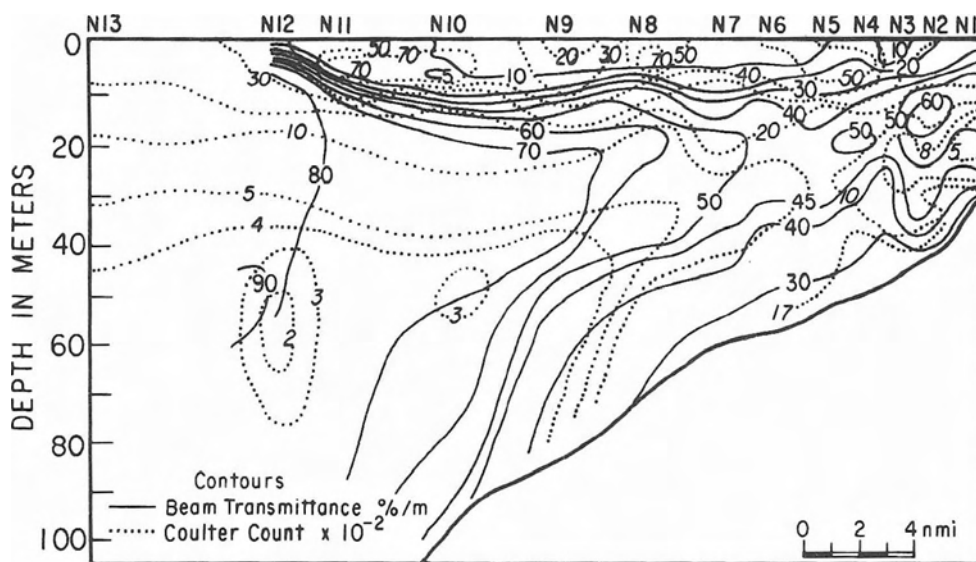
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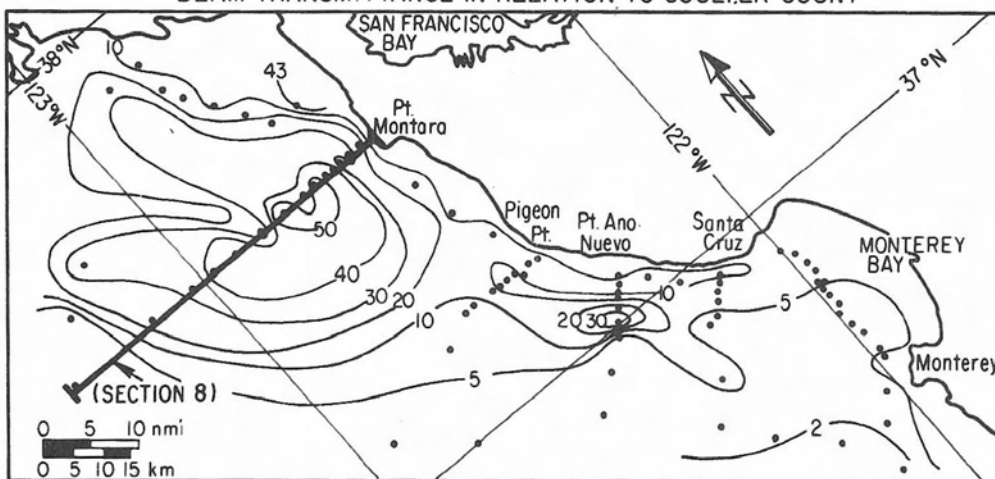
(C) 10 METER ISOLINES OF TOTAL COULTER COUNT (x 10⁻²)

From:
LABYAK (1969 p. 76, 79, 106)

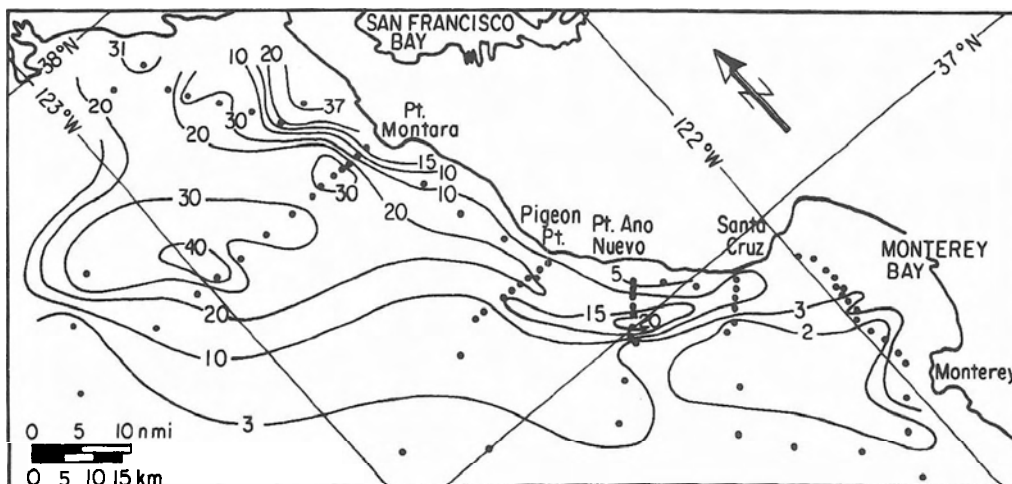
WATER CLARITY CHARACTERISTICS OFF CENTRAL CALIFORNIA



(A) VERTICAL CROSS SECTION 8
BEAM TRANSMITTANCE IN RELATION TO COULTER COUNT



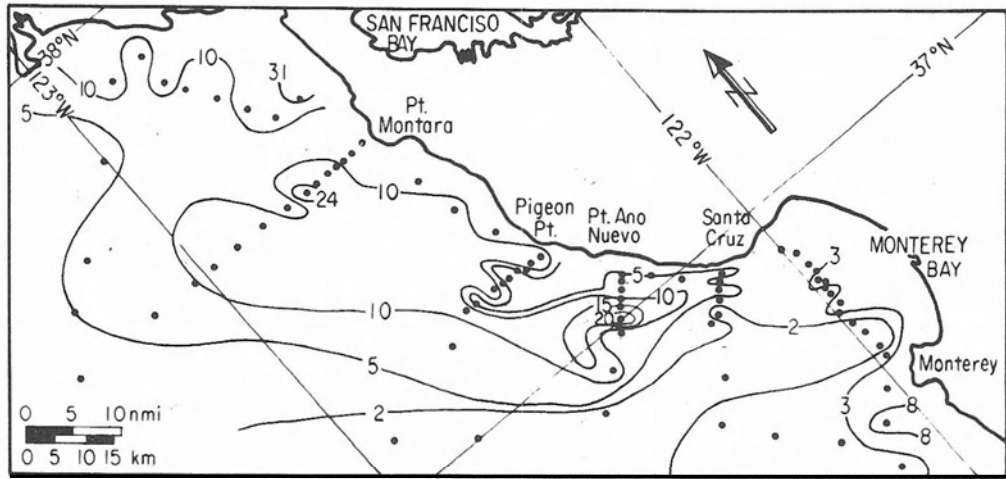
(B) ISOLINES OF TOTAL COULTER COUNT (x 10⁻²) AT THE SURFACE



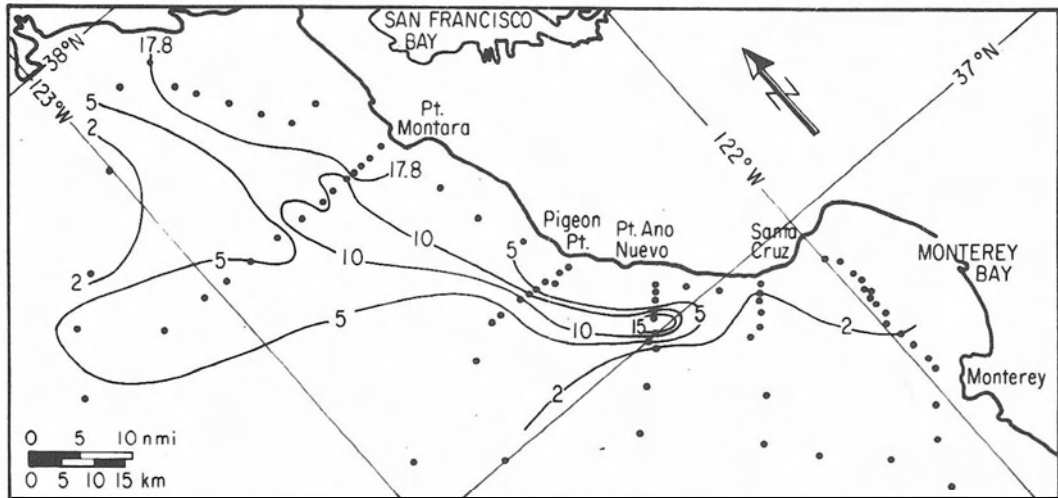
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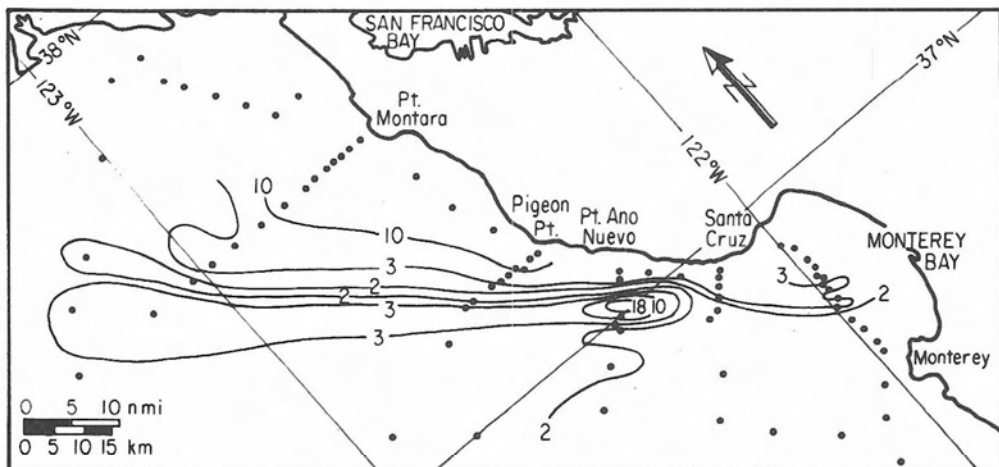
Fig. 5 Cont'd.
WATER CLARITY CHARACTERISTICS
OFF CENTRAL CALIFORNIA
(CONT.)



(D) 20 METER ISOLINES OF TOTAL COULTER COUNT ($\times 10^{-2}$)



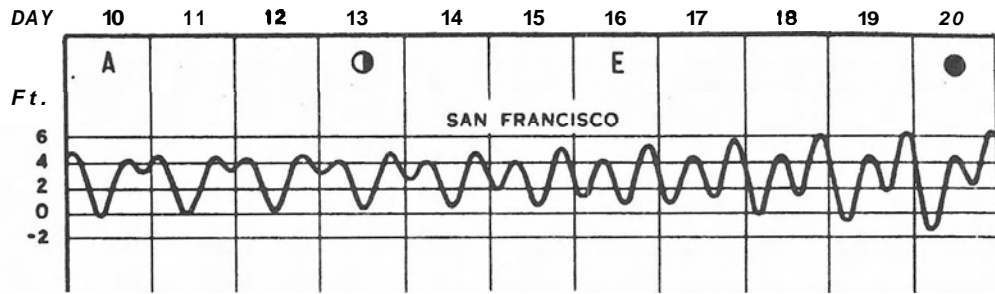
(E) 40 METER ISOLINES OF TOTAL COULTER COUNT ($\times 10^{-2}$)



(F) 61 METER ISOLINES OF TOTAL COULTER COUNT ($\times 10^{-2}$)

From:
LABYAK (1969 p. 82, 85, 88)

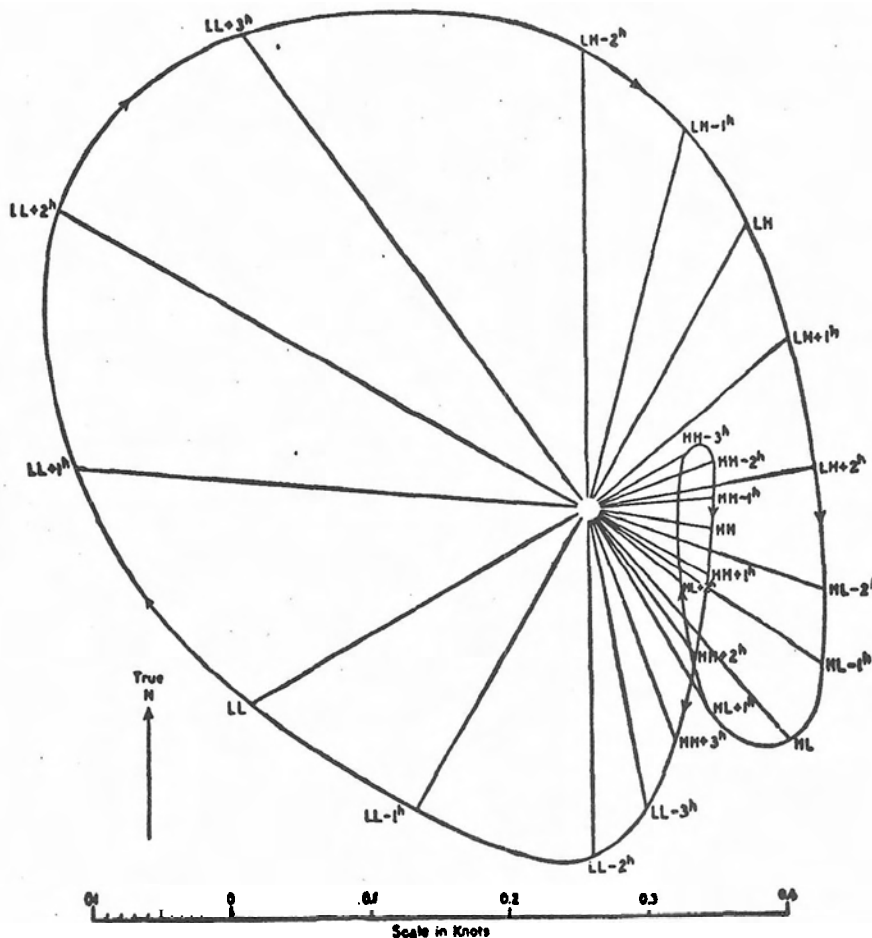
Fig. 6



Lunar data: A - moon in apogee
 ☾ - last quarter
 E - moon on equator
 ● - new moon

PLACE	POSITION		DIFFERENCES				RANGES		Mean Tide Level <i>feet</i>
	Lat.	Long.	Time		Height		Mean	Diurnal	
			High water	Low water	High water	Low water			
	'	'	<i>h. m.</i>	<i>h. m.</i>	<i>feet</i>	<i>feet</i>	<i>feet</i>	<i>feet</i>	
Ano Nuevo Island-----	37 06	122 20	-1 28	-1 10	-0.6	-0.1	3.5	5.2	2.7
Princeton, Halfmoon Bay-----	37 30	122 29	-1 10	-0 56	-0.2	0.0	3.8	5.5	3.0

From Tide Tables (1973, p. 3, 164)



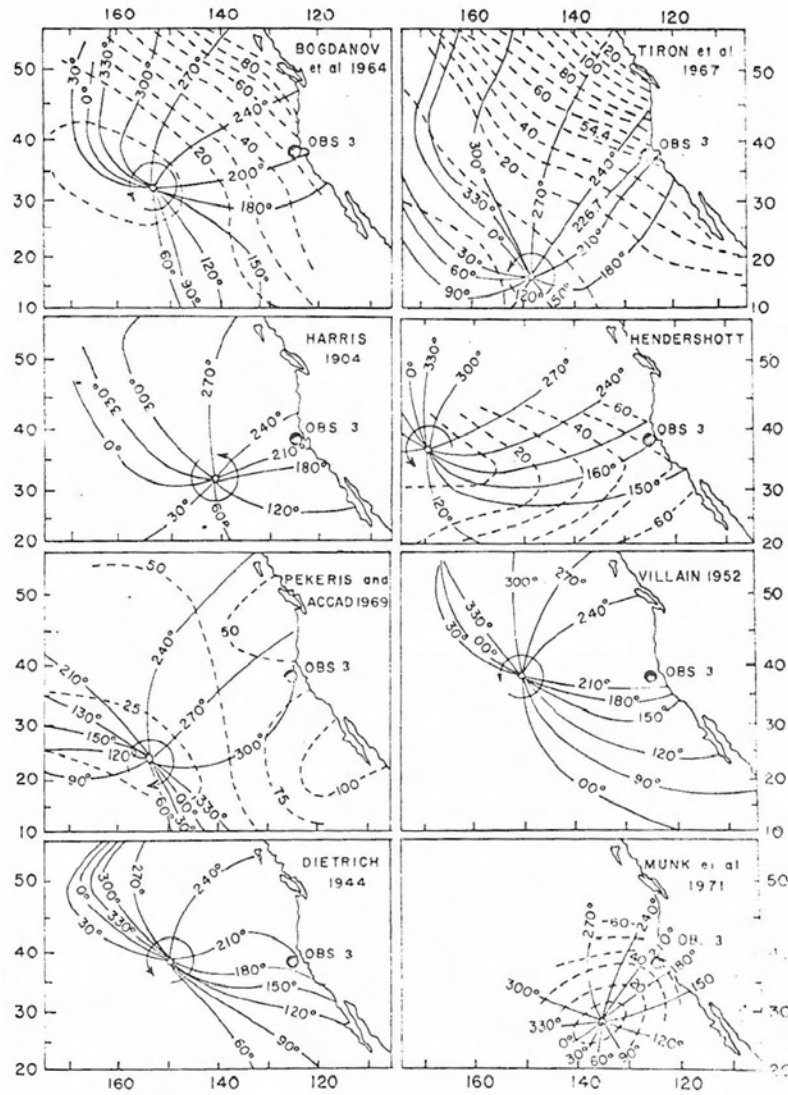
Tidal Current Curve, San Francisco Lightship
 Related to predicted time of tide at San Francisco (Golden Gate), Calif.

Time	Velocity	Direction	Time	Velocity	Direction
<i>Tide Hrs.</i>	<i>Knot</i>	<i>True</i>	<i>Tide Hrs.</i>	<i>Knot</i>	<i>True</i>
HH-3	0.1	060°	LL-3	0.2	170°
HH-2	0.1	070°	LL-2	0.3	180°
HH-1	0.1	085°	LL-1	0.3	210°
HH	0.1	100°	LL	0.8	240°
HH+1	0.1	120°	LL+1	0.3	275°
HH+2	0.1	145°	LL+2	0.4	300°
HH+3	0.2	160°	LL+3	0.4	325°
LH-2	0.3	000°	HL-2	0.2	110°
LH-1	0.3	015°	HL-1	0.2	125°
LH	0.2	030°	HL	0.2	140°
LH+1	0.2	050°	HL+1	0.2	150°
LH+2	0.2	060°	HL+2	0.1	130°

Ano Nuevo Island, 2 miles SW. of----- | 37 05 | 122 22 | Current too weak and variable to be predicted.
 Point Montara, 2 miles west of----- | 37 32 | 122 34 | Current too weak and variable to be predicted.

From Coastal Tidal Currents (1972, pp. 236-237)

Fig. 8



Tidal charts for the northeast Pacific Ocean. The solid circle is the OBS 3 location.

From Nowroozi (1972, p. 442)

Lunar Semidiurnal) constituent of the tide from various sources.

Observed values of M_2 at San Francisco are amplitude" 54.7 cm and Greenwich Epoch: 226.5^o (Munk and others, 1971) which agrees with the OBS 3 Data).

In any case tidal action in the area most likely has little effect on sediment transport.

CURRENTS

1) OPEN OCEAN CURRENTS

The major offshore current off the Central California Coast is the southeasterly flowing California Current which is a geostrophic current comprizing the eastern return gyre of the major clockwise circulation pattern of the North Pacific (Reid and others, 1958). The current is formed by blockage by Asia of westward surface flow along the equator caused by the trade winds. The current is most intense on the western side of the Pacific where it is called the Japanese or Kuroshio Current which is the Pacific analog of the Gulf stream. The current is deflected to the right by the earth's rotation flowing north east, east, and eventually south east off the North American coast as the much diminished California current.

During the winter months a northwesterly flowing current called the Davidson Current interposes itself between the coast and the California Current. The Davidson Current is apparently only a surface current flowing over the California Current and is ephermal in duration. In general the Davidson Current flows during periods of maximum run-off and erosion so is a major transporting agent for suspended sediment

introduced to the ocean by streams. The basic current patterns off the California Coast are shown in Fig. 9.

2) LONGSHORE CURRENTS

In this region (Fig. 10) the prevailing wave direction is west northwest governed by the prevailing wind direction; thus the dominant longshore current direction is southeast or south beyond the tidal influence of San Francisco Bay or South of Point Montara. The influence of the submerged reef projecting south eastward from Pillar Point and Half Moon Bay is minimal with respect to longshore currents as no sand spit has built northwestward from the opposite shore as would be the case if the west north west waves were diffracted around the reef operating a northward drift. Such diffraction although added by tidal currents was demonstrated in Bolinas Bay with respect to Sea Drift Spit (Wilde and others, 1969).

C. PHYSIOGRAPHY AND DRAINAGE

The drainage area immediately adjacent to the offshore area of interest is shown in Fig. 11. All of the streams shown here have severely reduced flow in the summer months consequently their mouths are barred by longshore drift, thus only during the winter rainy season do the streams carry sediment directly into the Pacific. The two largest streams Pescadero Creek (Fig. 12), with a drainage area of 60 square miles and San Gregorio Creek, with a drainage area of 50 square miles are perennial streams. The rest of the streams are essentially ephemeral flowing only during the rainy season.

The area is bounded on the east by the northwest trending crest of the Santa Cruz Mountains which forms the major east-west drainage

From Wilde (1965 p. 8)

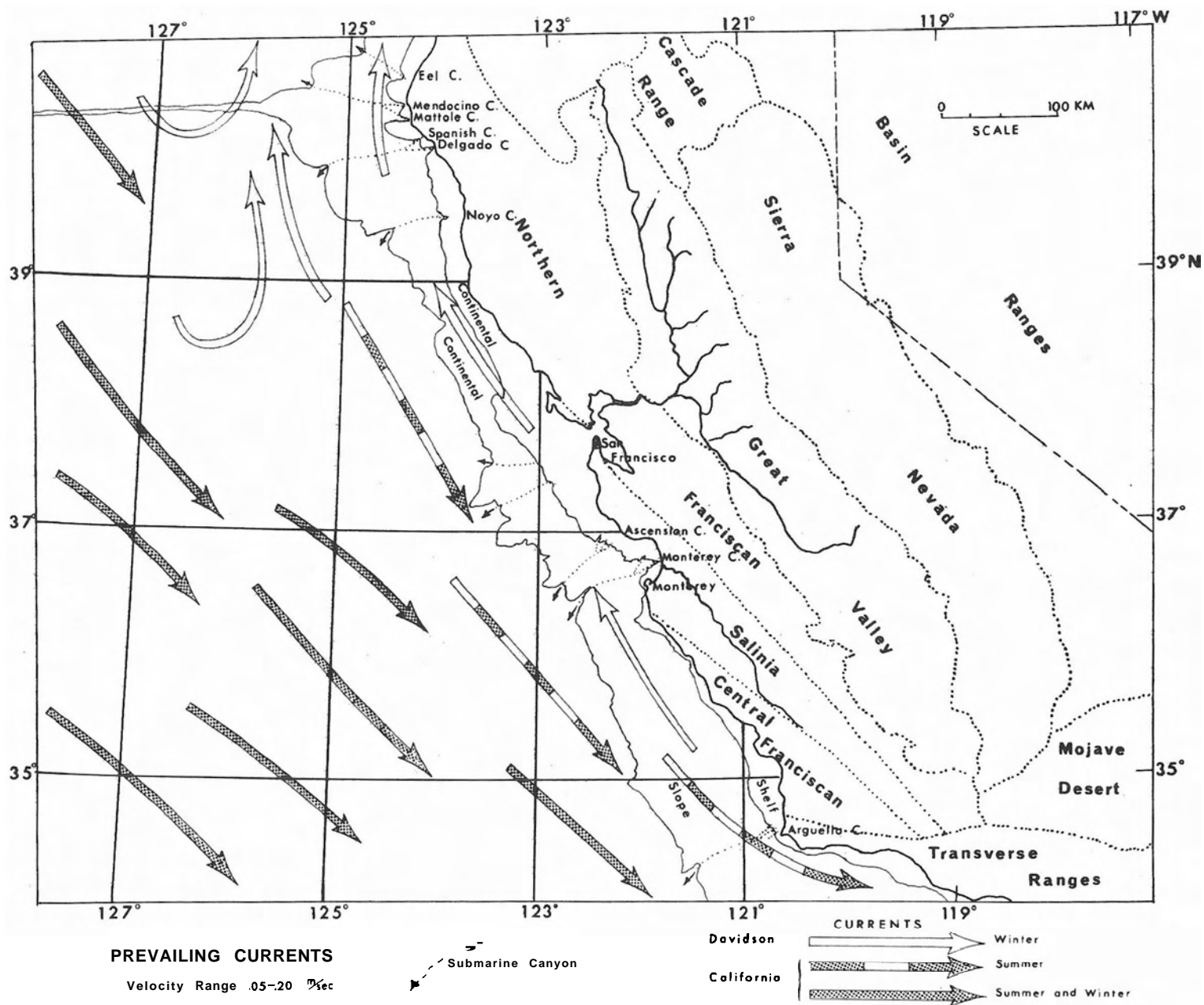
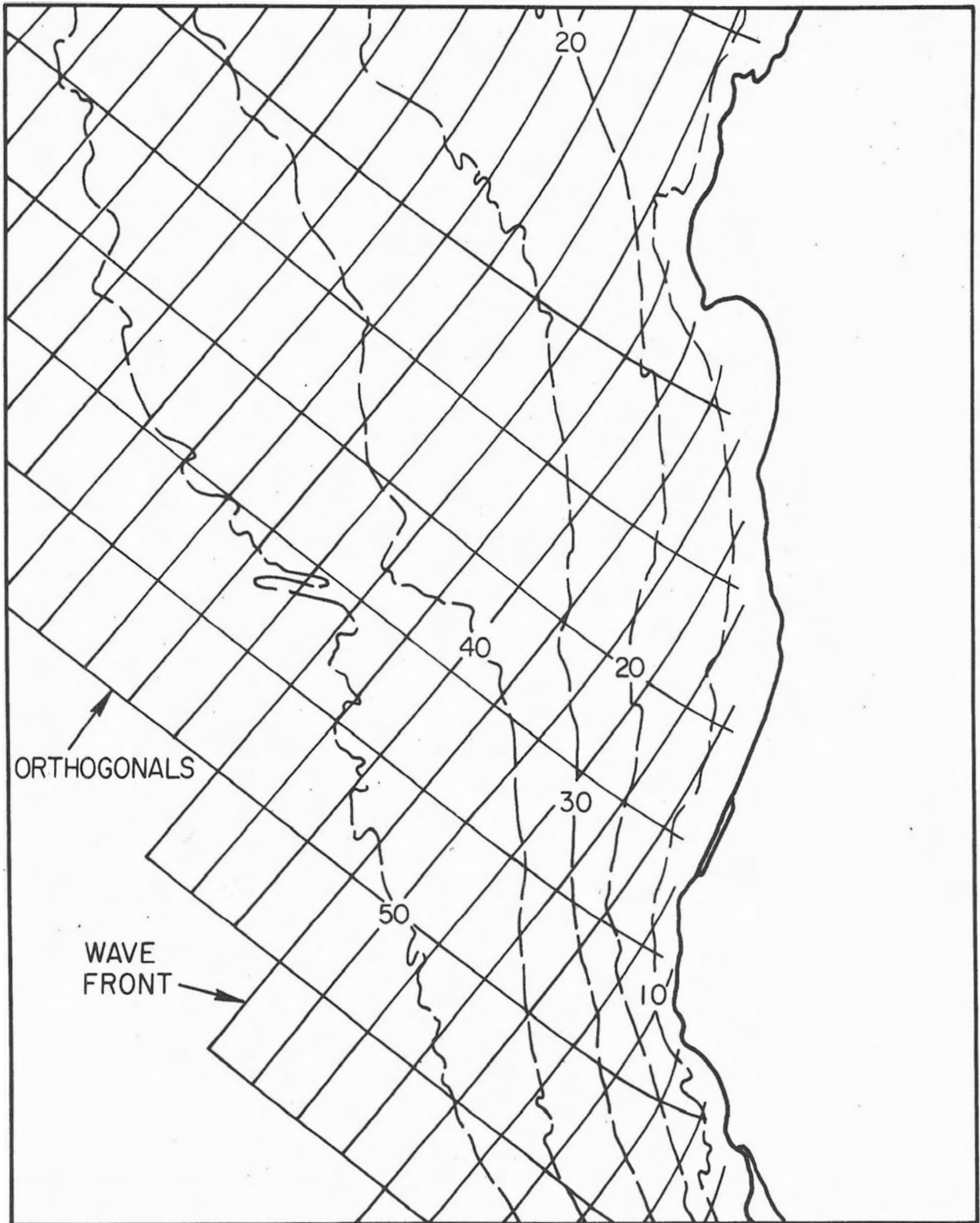


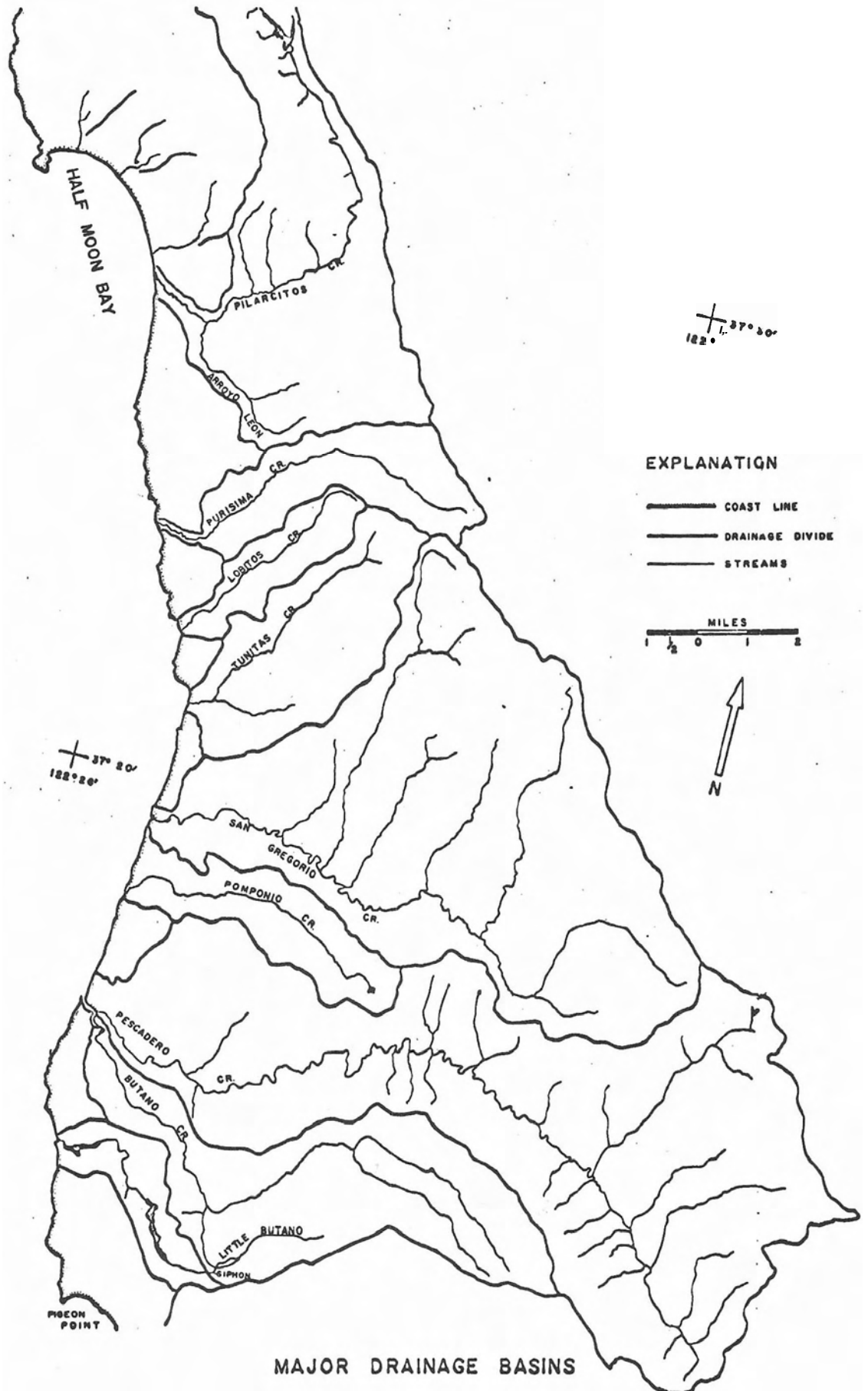
FIG. 9

WAVE DIFFRACTION DIAGRAM 12 SECONDS FROM WNW



DEPTH CONTOURS
IN FATHOMS

Fig. 11



divide. The ridge line just east of Half Moon Bay is called the Cahil Ridge which becomes the Castle Rock Ridge to the south. The Cahil Ridge has an elevation of 2000 to 2500 feet whereas the Castle Rock Ridge rises to 2500 to 3000 feet. The topography of the Santa Cruz Mountains generally slopes westward from the ridge line towards the Pacific Ocean and terminates as a 150 foot sea cliff. This slope is dissected by the streams in the area with the major stream valleys, trending generally perpendicular to the ridgeline. However a secondary ridge called the Butano Ridge trending east-west produces more westerly flowing streams from San Gregorio Creek south to Pigeon Point. Marine terraces occur principally in the northern part of the area from Half Moon Bay south to Tunitas Creek, where the terrace slopes from about an elevation of 150 feet to merge with the beach. The widest part of this terrace about 1.5 miles is at the site of the town of Half Moon Bay. Sloping terrace deposits are found also from the mouth of Pescadero Creek south to Bolsa and Pigeon Point but are not as wide as the terraces at Half Moon Bay. Bold headlands bound the land area on the north as Pillar Point and on the south as Bolsa and Pigeon Point the western boundary is the Pacific Ocean. According to the Coast Pilot (1968, 147) the view of the coast line from the ocean is as follows "From Pigeon Point for 4 miles to Pescadero Point the coast is nearly straight and is composed of reddish cliffs with numerous outlying sunken and visible rocks.. .From Pescadero Creek, 1.5 miles northward of Pescadero Point, the coast for 8 miles northward becomes more broken and rugged with yellow or white vertical cliffs... ..the coast is broken by several small streams in deep steep sided valleys. Northward of the high cliff, a

low flat table land extends northward to Pillar Point and then bends sharply westward to Pillar Point, forming Half Moon Bay." because of the rugged nature of the coast the only protected anchorage is at Half Moon Bay where a breakwater has been added, to protect from south and southwest swell.

The general geomorphology of the Central Coast Ranges is discussed in Branner and others (1909), Willis (1925), and Taliaferro (1943).

D. BATHYMETRY

As shown in Fig. 1, the ocean bottom in this area, for depths shoaler than 30 fathoms has contours approximately parallel to the shore with a slope of about 45 feet/mile. North of $37^{\circ} 20'N$ both the 40 and 50 fathom contour are offset to the west and the bottom slope decreases to 12 feet/mile. North of the area of interest the shelf widens to a maximum in the Gulf of the Farallones and near shore the bottom is reflected as the tidal sediment bar of San Francisco Bay. South of the area the shelf narrows and has a uniform bottom slope of about 45 feet/mile. The shelf has a generally smooth bottom however rocky reefs are reported on the U.S.C. & G.S. chart along the 40 fathom contour and southeast of Pillar Point which forms a navigational hazard to the entrance to Half Moon Bay.

No submarine canyon incise the shelf here which would act as sediment traps. Canyons do exist north of the area just west of the Farallon Islands and south of the area southwest of Point Ano Nuevo. Also there are no apparent submerged stream channels in the area.

E. PREVIOUS WORK

This report and its data precursors (Lee and others, 1971,

Yancey and others, 1970) is the first detailed study of the offshore sediment on the Continental Shelf in this area; although a preliminary report (Yancey and Lee, 1972) on the sedimentary provenance of the Central California Shelf using this data has appeared, and Sayles (1965) reported on some samples in the north of this area. Hutton (1959) did the definitive work on the mineralogy of beach sands of the entire area from Half Moon Bay to Monterey. However, his data are given in the logarithmic format of Evans and others (1933) which are not converted readily back to frequency percent used here.

The pioneering bathymetric charts of Shepard and Emery (1939) forms the basis of bathymetric studies in the area. Some refinements have been made to the bathymetry of the Continental Slope outside the area of interest by Uchupi and Emery (1963). One subbottom profile done in the early days of electronic profiling is reported by Moore and Shumway (1959) off Pigeon Point. However Curray (1965, 1966) has made several improved acoustic subbottom profiles on the Central California Shelf unfortunately not in this area but just north and south. Figure 13 shows the sub-bottom record at the latitude of San Francisco.

The subareal geology has been studied (1) in folio reports by Branner and others (1909) and Lawson (1914); (2) in regional papers on the **Coast Ranges** by Taliaferro (1943), Cummings and others (1962); and (3) in numerous Stanford and University of California, Berkeley theses, mainly quadrangle reports, for example by Darrow (1951), Esser (1958) Mack (1959), Touring (1959), Spotts (1958), and Claussen (1960). Specific topics of interest have been reported such as (1) granitic rocks by Leo (1967) and Compton (1966); (2) Stratigraphy by Hall and others (1959): Upper Cretaceous, Mallory (1959): Lower Tertiary;

Fig. 13

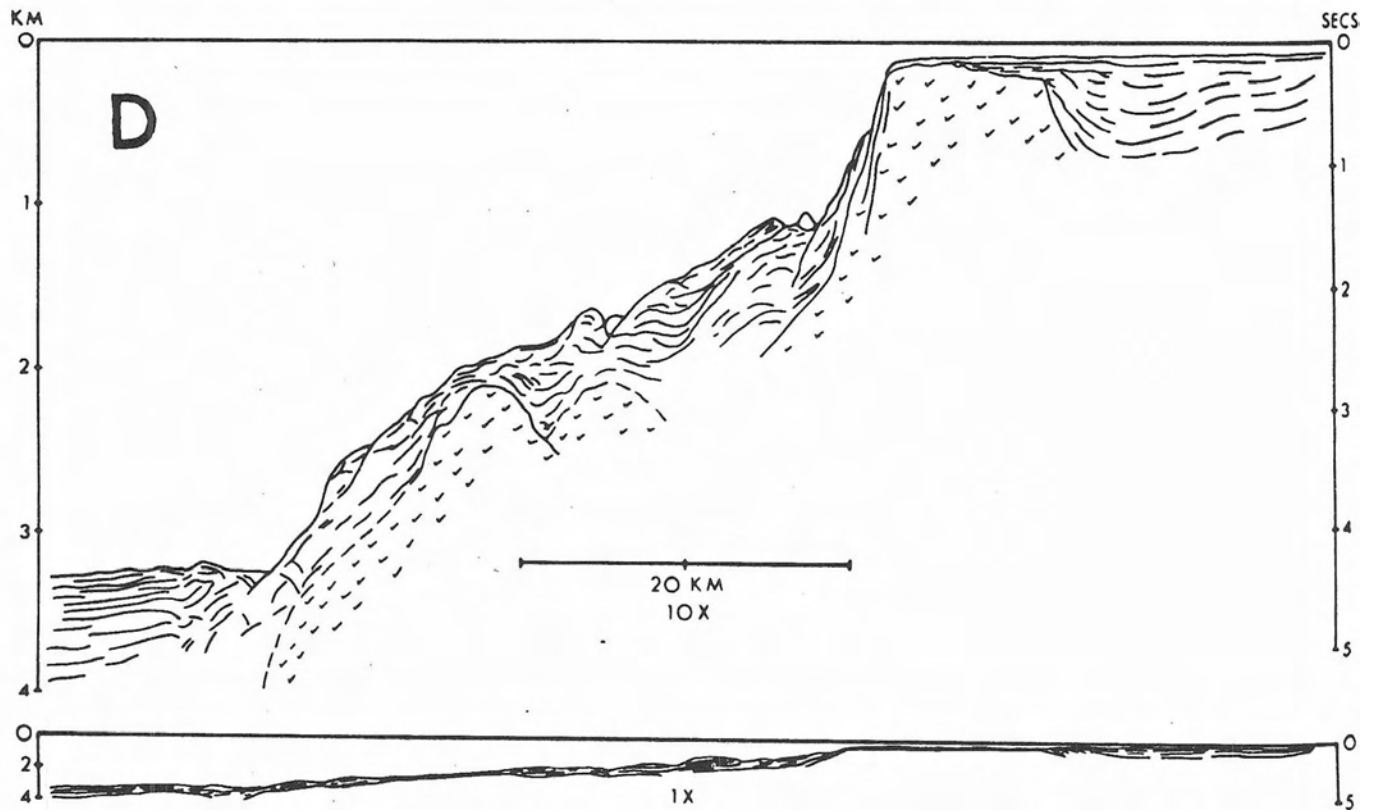
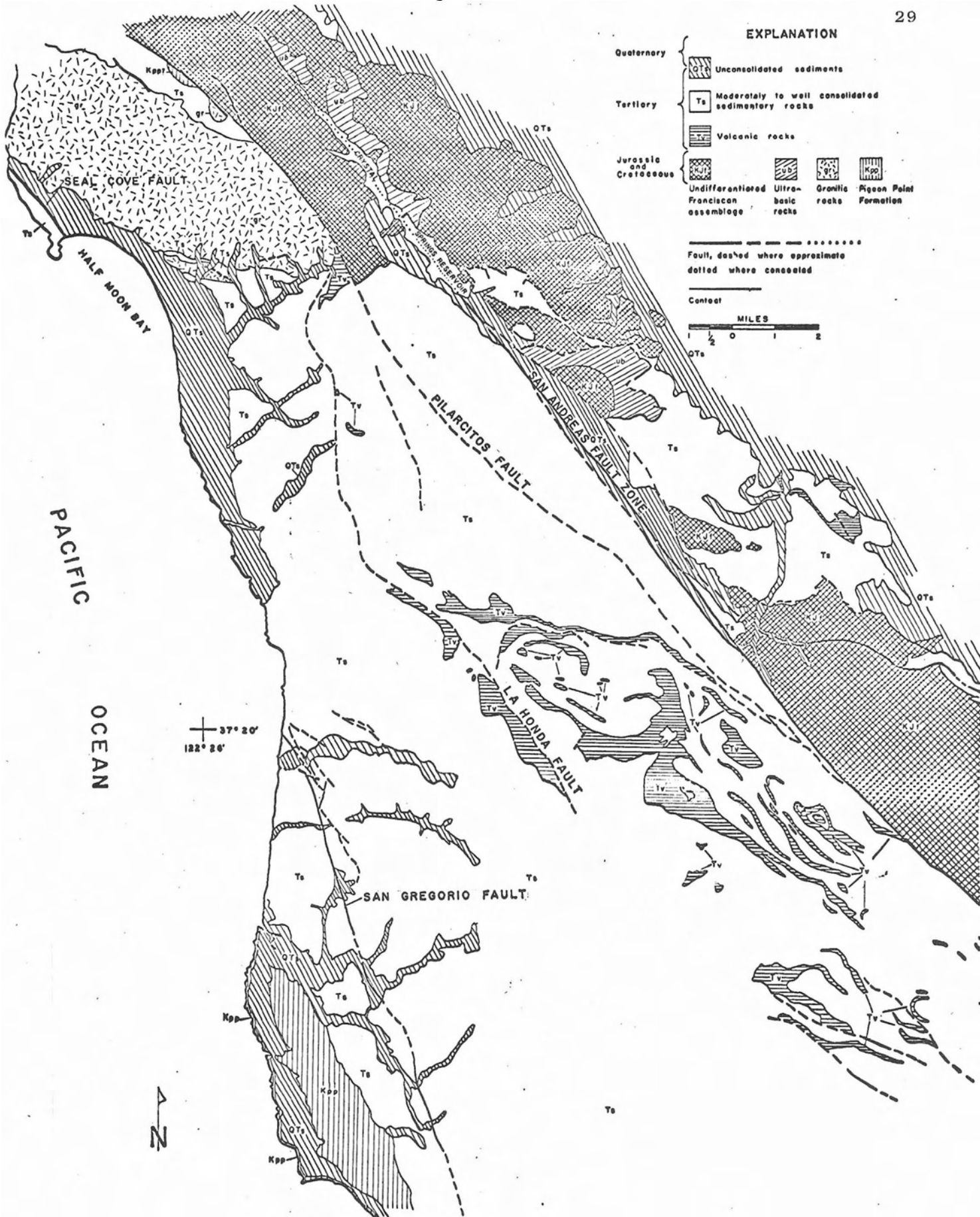


Figure 4. Line drawing of acoustic reflection record along line D of figure 1, passing between Farallon Islands on shelf edge. Upper section has vertical exaggeration 10:1; lower section is natural scale. Note locations of granitic rock (Cretaceous quartz diorite), sediment fill underlying continental shelf, sediment fill at base of slope underlying continental rise, and contorted nature of sedimentary rock (at least in part Miocene) overlying and slumping down on granitic rock on the slope.

From Curray (1966, p. 340)



GENERALIZED GEOLOGIC MAP

HALF MOON BAY TO PIGEON POINT

(adapted from C.W. Jennings and J. L. Burnett, 1961, and E.E. Brobb, 1970)

Babb (1964): San Lorenzo, Kleinpell (1938): Miocene, Bramlette (1946): Monterey, and Clark (1968): Mio-Pliocene Boundary; and (3) Marine Terraces by Bradley (1956, 1957, 1965). The area is covered by the San Francisco sheet of the California State Geologic Map (Jennings and Burleigh, 1961).

Other reports of interest in the region include the California Department of Fish and Game's Offshore survey of Benthic Fauna on the Central California Shelf (Odemar and others, 1968) and Kaiser Engineers (1969) plan for regional treatment and disposal of wastes of the Bay Area, which includes some oceanographic studies.

F. GEOLOGY

The geology of the drainage basins adjacent to the off-shore areas of interest lies in the Salinian Block (Reed, 1933) which is a geologic province underlain by Mesozoic quartz dioritic intrusives bounded on the east by the San Andreas Fault Zone. The quartz dioritic basement crops out in Montana Mountain at the northern edge of the area and in the Ben Lomond Mountains just to the south of the area. Figure 14 gives a generalized geologic map of the area. As the geologic map shows the predominate surface rocks are Tertiary sediments and volcanics with smaller areal amounts of (1) Quaternary and late Tertiary fill and terrace deposits confined mainly along the coast and (2) Upper Cretaceous marine sediments found in a linear band between Pescadero Point and Ano Nuevo at the south. Table 3 gives the stratigraphic sequence from the state geologic map (San Francisco Sheet) for this region and Fig. 15 shows a columnar section for the northern Santa Cruz Mountains.

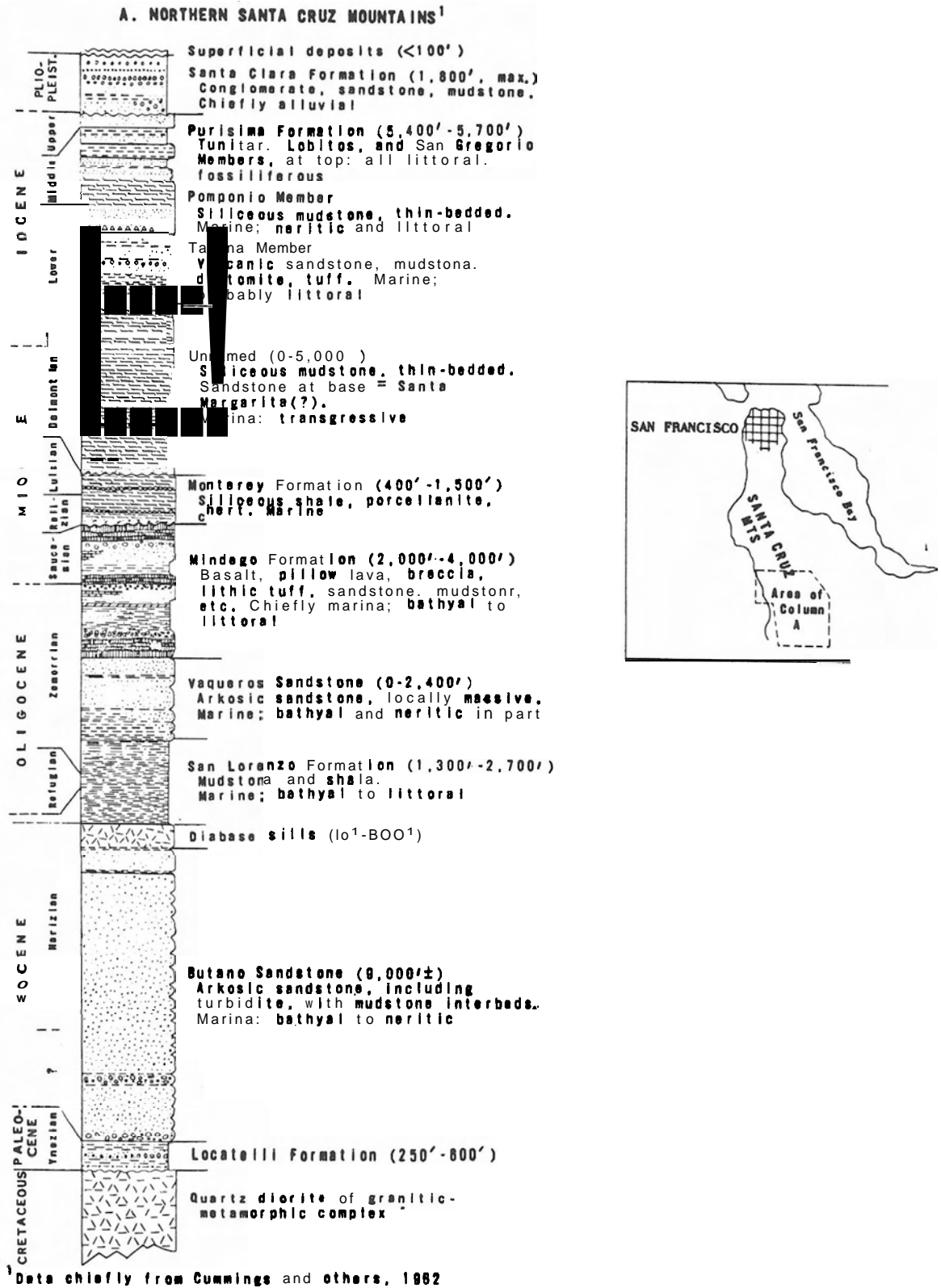
The lineation of both the geologic structure and the topography

TABLE 3

<u>SYMBOL</u>	<u>AGE</u>	<u>FORMATION NAME</u>	<u>ROCK TYPES</u>
Qa1	Quaternary		Alluvium -
Qt	Quaternary		Stream Terrace -
Qm	Quaternary	COLMA	Marine Terrace - Sand and clay
Pm ℓ	Middle and Lower Pliocene	PURISIMA	Conglomerates, sandstones, shales
Mv	Miocene		Basalt Flows, Breccias, pillow lavas; some tuffs
t _i b	Middle Miocene		Intrusive Diabase and basalt sills
M _m	Middle Miocene	Monterey	Marine shales and siltstones
M ℓ	Lower Miocene	Vaqueros	Marine sandstones and siltstones
Φ	Oligocene	San Lorenzo	Marine shales and mudstones
E	Eocene	Butano	Marine sandstones and shale
Ku	Upper Cretaceous	Pigeon Point	Marine sandstones, siltstones, conglomerates
gr	Cretaceous	Montana Ben Lomond	Quartz Diorite and Granodiorite

From Jennings and Burnett (1961)

Fig. 15



is oriented northwest-southeast parallel or sub parallel to the San Andreas Fault as shown by the trace of the Pilarcitos, La Honda, and San Gregorio Faults. Northeast of the San Gregorio Fault the tertiary rocks are folded respectively southwest to northeast into (1) a narrow anticline seen as the Butano Ridge; (2) a broad relatively shallow dipping syncline; and (3) a narrow anticline and syncline thrown against the San Andreas Fault Zone (Fig. 16). Each of these three units is separated by steeply dipping thrust faults.

Southwest of the San Gregorio Fault the oldest rocks exposed are the highly folded and faulted upper Cretaceous (Campanian-Maestrichtian) marine rocks of the Pigeon Point formation. These rocks are overlain by late Tertiary marine sediments (Hall and others, 1959) so that the rest of the older tertiary section is missing on this side of the fault.

The northwest structural trend apparently continues offshore where the edge of the Continental Shelf is part of a northwest trending basement ridge (Curry, 1965, 1966) and the shelf is by a broad syncline at depth overlain by flat lying sediments (Fig. 13). The basement ridge crops out as quartz dioritic rocks of the Farallon Islands just to the north of the area. As the potassium-argon ages of the rocks from the Farallons (89.5 M.Y.) and from Montara Mountain (91.6 M.Y.) are essentially the same, it seems reasonable to assume they form a common emplacement. The age relationship, however, between the synclinal sediments and the ridge are not clear from the acoustic profiles; although Curry (1966) believes the shelf sediments to be younger than the Cretaceous basement ridge or approximately equivalent to the Tertiary section north east of the San Gregorio Fault. Chesterman (1952) reported Miocene rocks dredged from the Continental Slope seaward of

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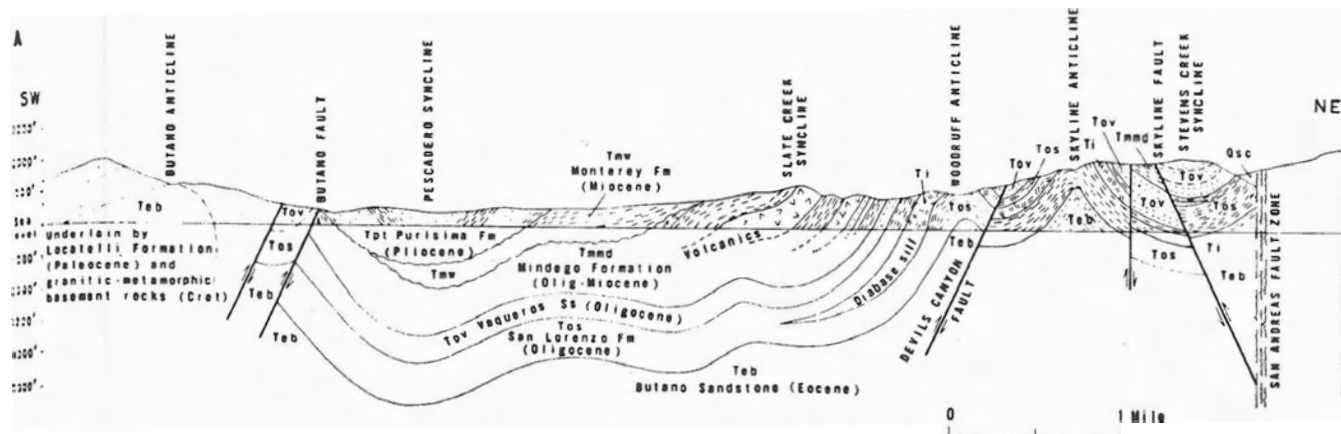
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Fig. 16



From Page (1966, p. 265)

the ridge and Mio-Pliocene rocks dredged to the north near Cordell Bank, which suggest some outcroppings of the mid to late Tertiary section on the shelf and slope. The flat-lying sediments above the angular unconformity cut across the synclinal sediments possibly are ~~H~~olocene transgressional-regressional deposits related to rising and lowerings of sealevel across the shelf during the Pleistocene (see Flint, 1971).

III. SEDIMENTARY DATA

A. GRAIN SIZE PROPERTIES

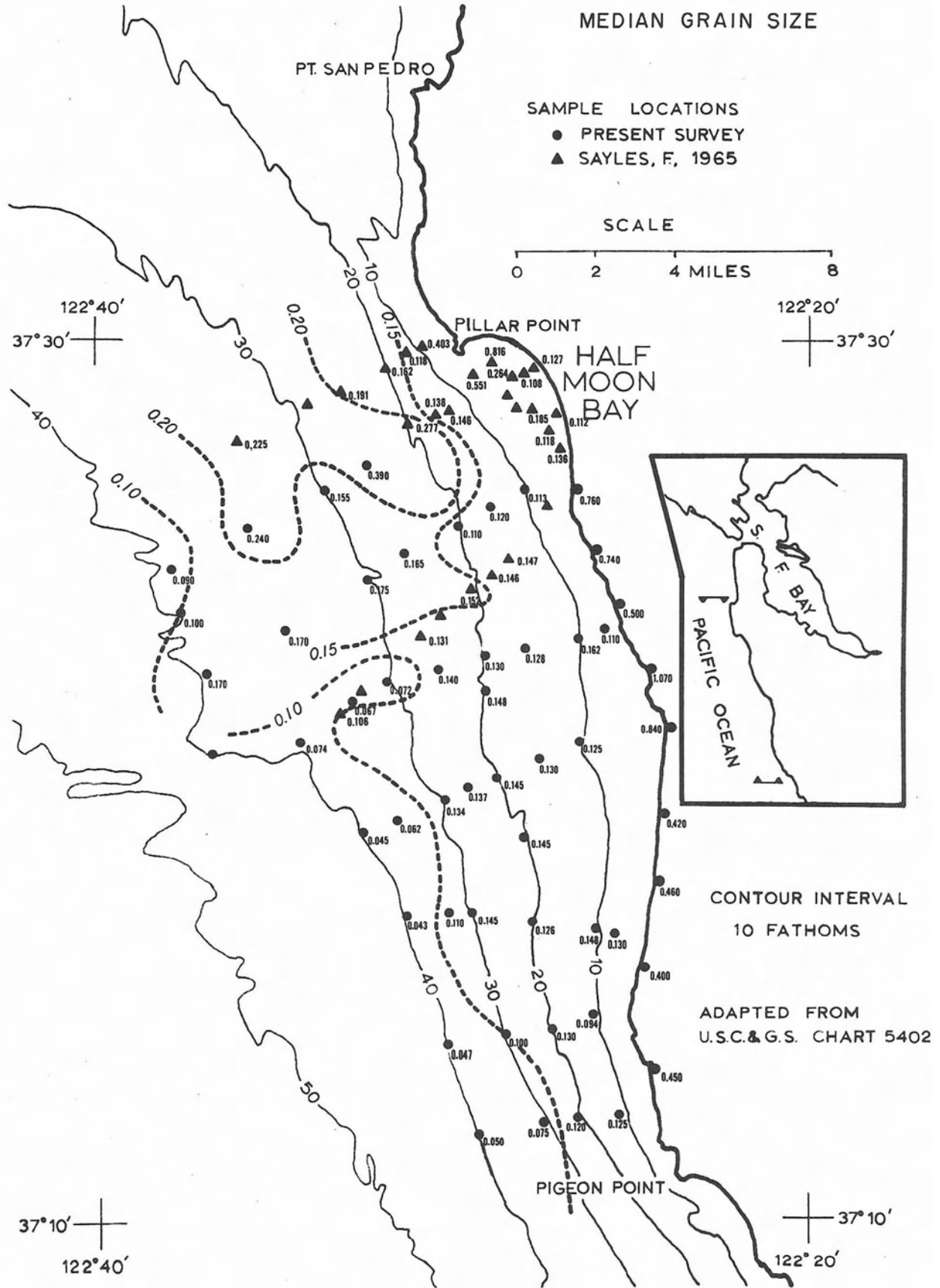
The statistical parameters: median grain size, sorting coefficient, skewness, and kurtosis are derived from data presented in Yancey and others (1970), and Sayles (1965) and are given in Figs. 17, 18, 19 and 20.

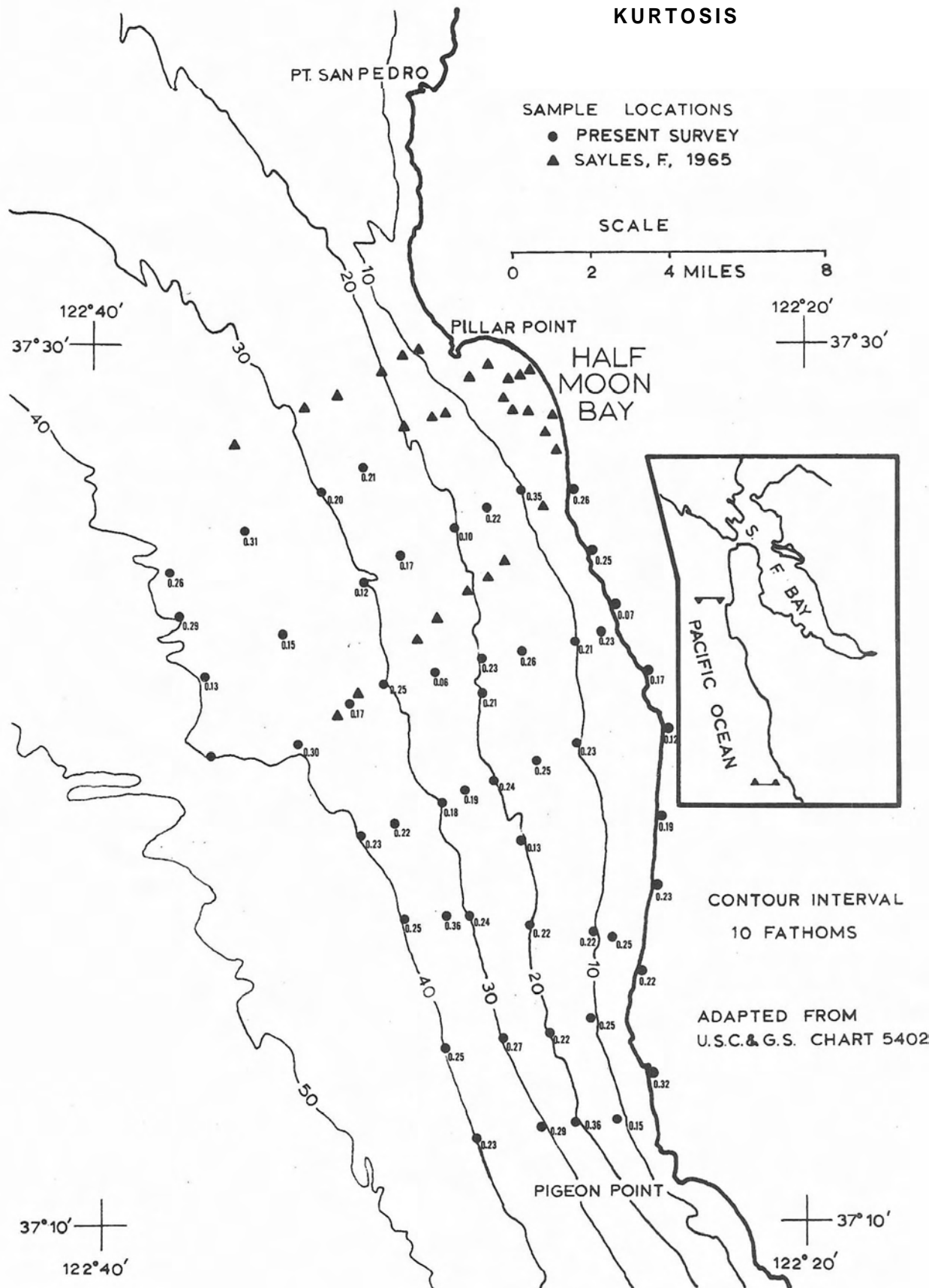
The median grain size of the offshore sediment to about the 30 fathom contour is uniformly about .125 to .150 mm reducing to .1 to .05 mm deeper than 30 fathoms. There are occasional samples with coarser median grain sizes but they do not form any discernible pattern. Inside Half Moon Bay the grain size of the sediment is variable and generally coarser than for sediments on the open continental shelf. Although the sediment show the expected gradient to finer grain size with depth, this trend is not pronounced. Another trend, also subtle, is the tendency for the grain size to decrease along any contour to the south.

Sayles (1965) noted a band of coarse sediments at depths of 15 to 20 fathoms off Pillar Point bounded both shallower and deeper by finer grained sediments. Also coarse sediments are found on and near the rocky reef extending across Half Moon Bay from Pillar Point.

The sediments generally are well sorted with a Trask sorting coefficient value about 1.2. However, two types of poorer sorted sediments occurs being chiefly strongly bi-modal (1) mixtures of coarse sand and gravel with fine sand for samples 2116, 2122, 2125, 2126, 2127, 2135, and 2141 or (2) mixtures of fine sand and silt for samples 2102, 2116, and 2143. For such samples the primary mode is usually in the 0.125 to 0.177mm fraction in both the well and poorer sorted samples with a

Fig. 17





secondary mode either coarser for type (1) or finer for type (2) suggesting a composite source for the poorer sorted sample added to the basic mode of 0.125 to 0.177mm.

The skewness values of around 1.0 indicate in general the well sorted samples also show a symmetrical distribution. The poorer sorted samples with values greater than 1.0 are skewed towards the coarser sizes as shown by values of 2.51, 2.90, 2.26, for samples 2126, 2127, and 2122 and less than 1.0 for those skewed towards the finer sizes as 0.50 for sample 2102.

The physical significance of Kurtosis is not clear, therefore, we shall report only the average value of about .20.

B. MINERALOGY.

Point counts of the heavy mineral fraction (density greater than 2.8) of the sediments have been reported in Sayles (1965) and in Part B (Lee and Others, 1971) of this study. A bulk slide of the heavy mineral content of the 0.61 to 0.246mm size fraction was used for the 1400 series samples and the 0.61 to 0.351mm size fraction for the 2100 series samples. Figure 21 shows the weight percent of the size fraction represented by the slide with respect to the total size distribution which indicates the bulk of the distribution is covered in the slide. The weight percent heavy minerals with respect to the size fraction represented by the slide shows a wide range from less than 1% to almost 20% (Fig. 22). The heavy mineral fraction consists of (A) transparent grains, (B) opaques, chiefly ore minerals, and (C) composite grains (rock fragments) and unknowns. These data are reported as frequency percent by point count (see Part B, Lee and Others, 1971 for detailed

Fig. 22

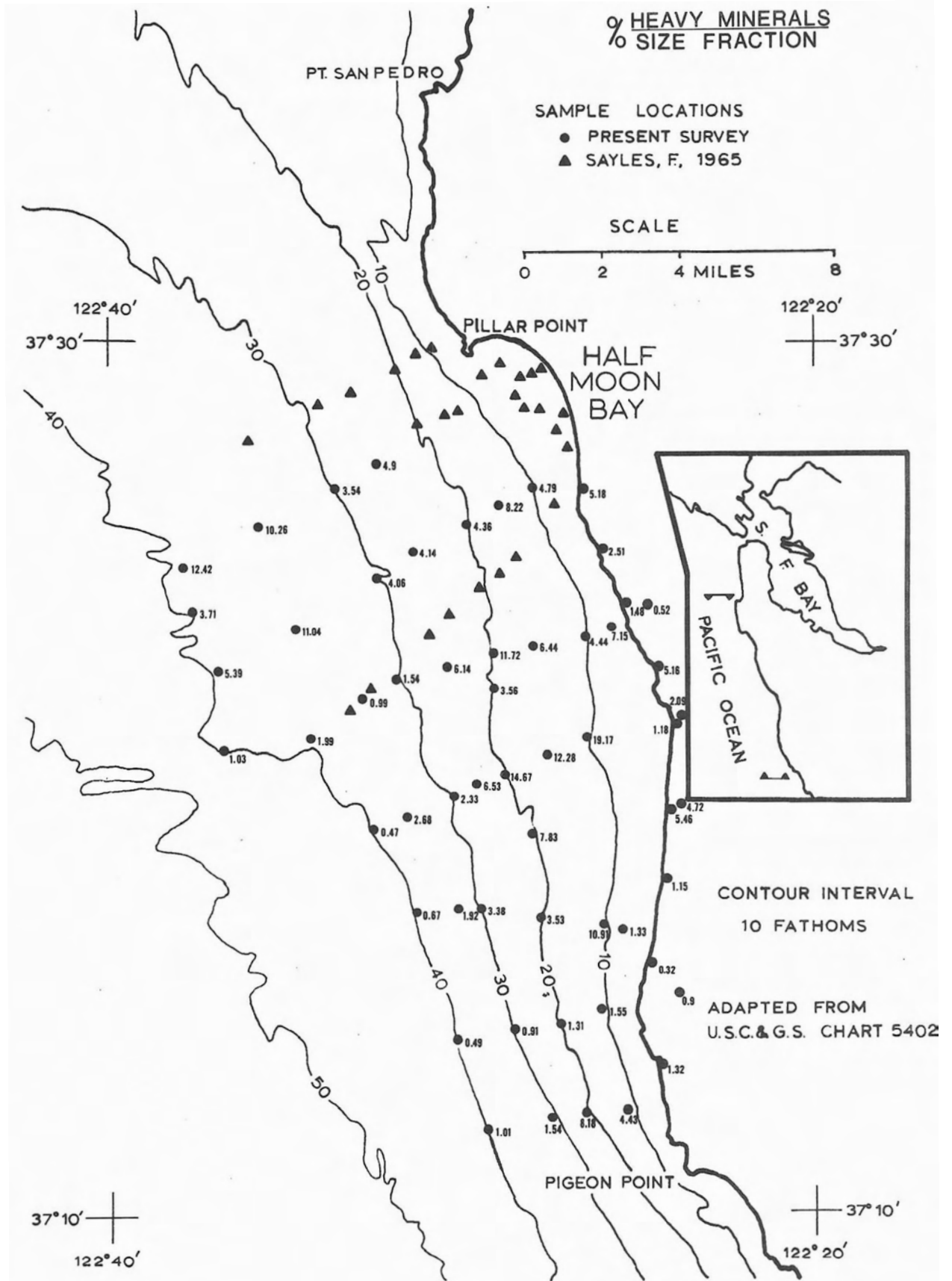
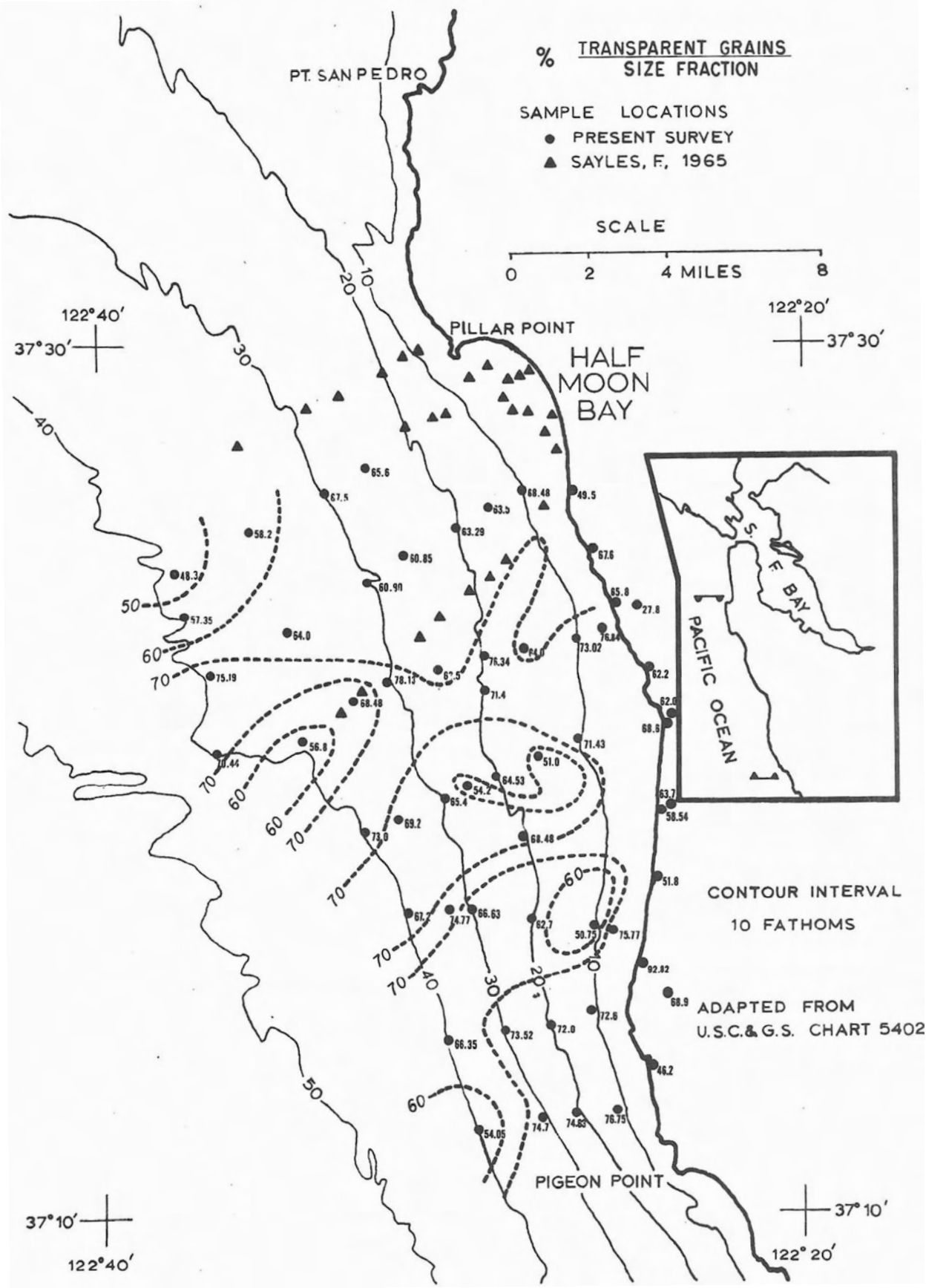
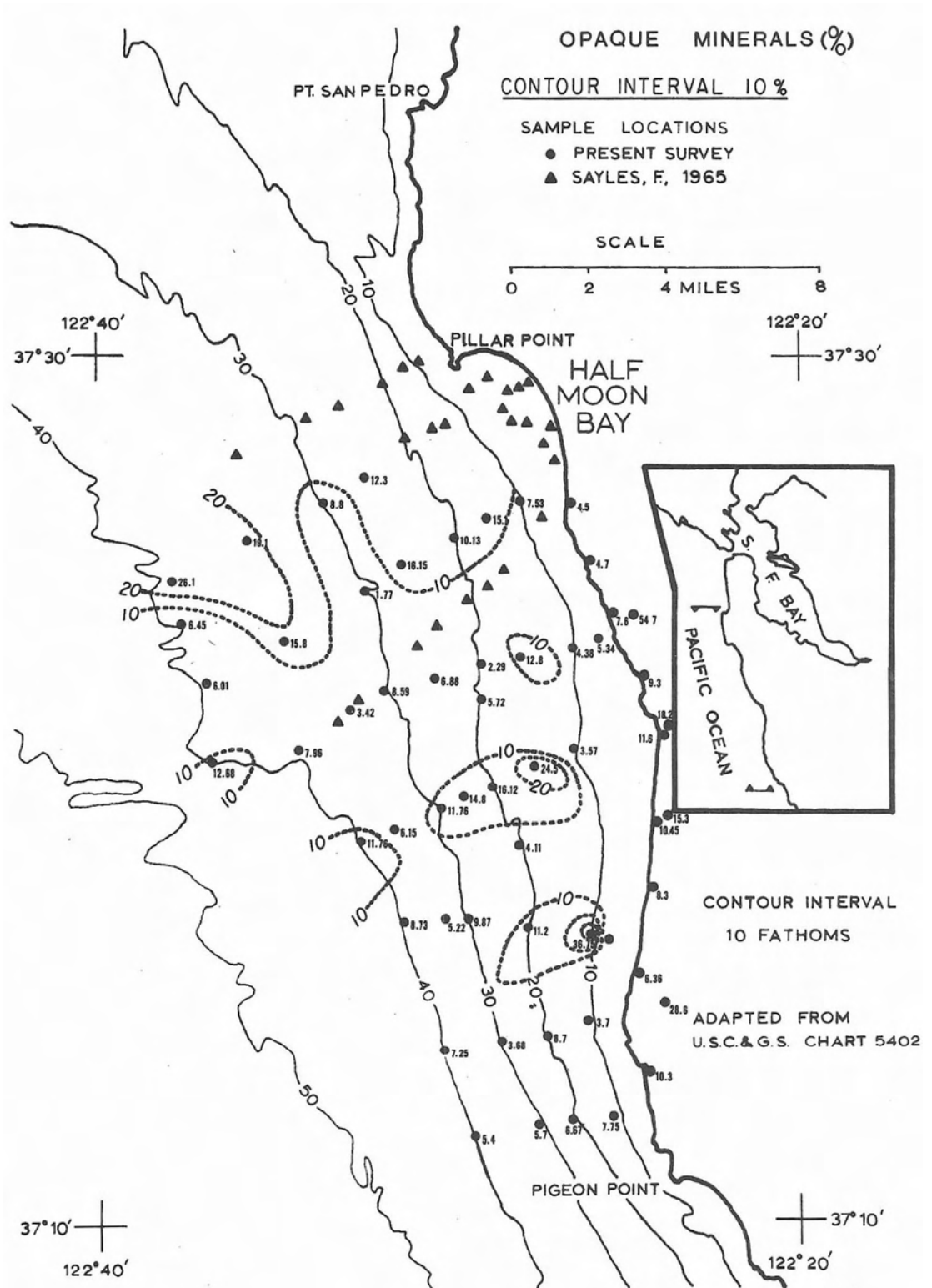


Fig. 23





discussion of procedure) in Fig. 23 for transparent grains and Fig. 24 for opaque grains. The opaque grains consists of metallic grains such as magnetite and pyrite which have a higher density than either the transparent grains or composite grains. Accordingly there is a correlation (compare Figs. 24 and 22) between high opaque mineral content and high weight percent heavy mineral. For example, sample 2110 has a relatively high weight percent heavy mineral of 10.91 of which 36.75% by count is opaque minerals. In general, values of transparent grain content of around 75% yield heavy mineral weight percentages of from 1 to 5 percent.

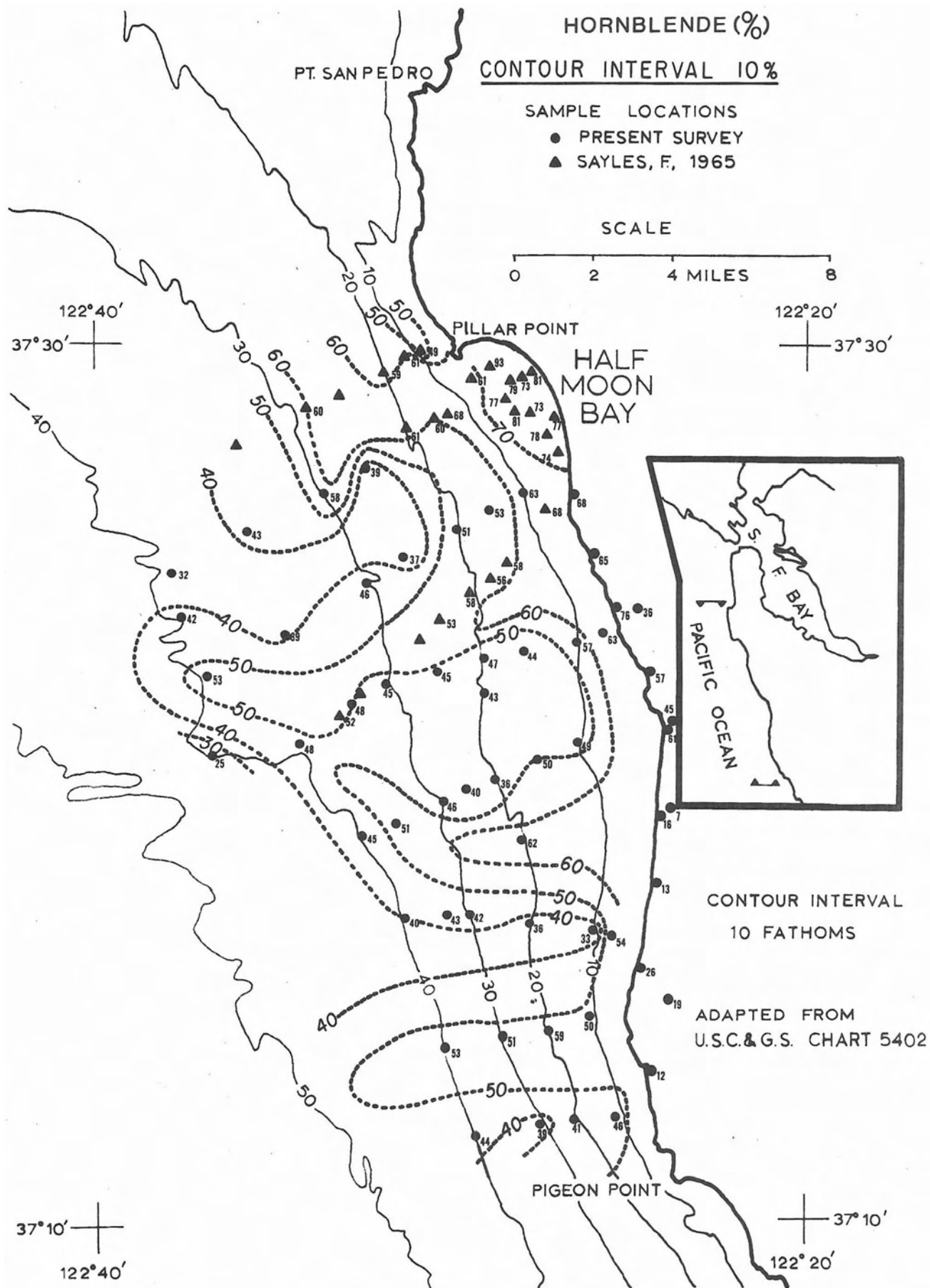
C. MINERALOGICAL PROVINCES

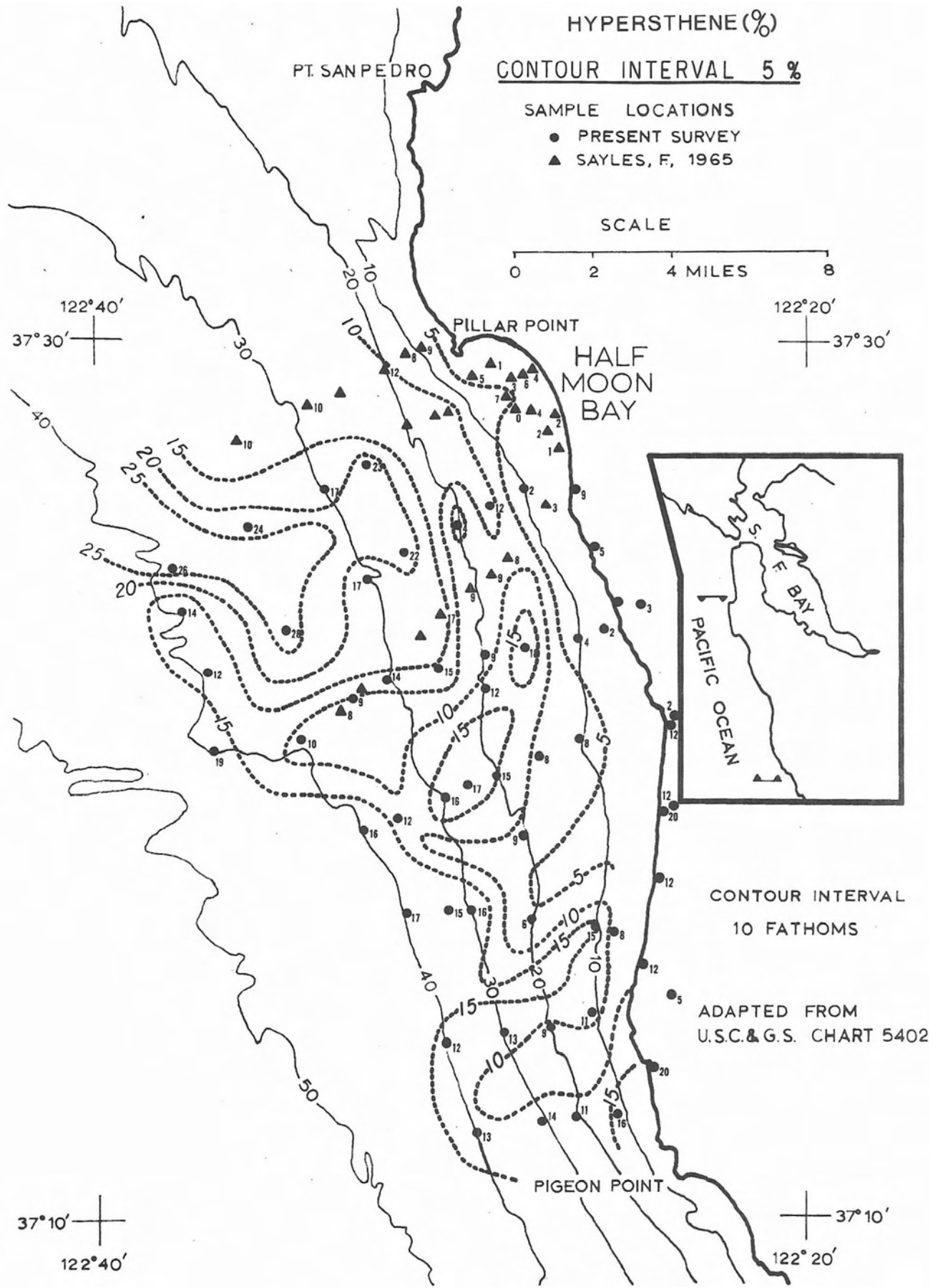
1) MINERAL PERCENTAGE DISTRIBUTION

Frequency percent values with respect to total transparent grains of the more useful heavy minerals: hornblende, hypersthene, augite, Franciscan minerals (Lawsonite plus jadeite) are plotted respectively in figures 25, 26, 27, and 28.

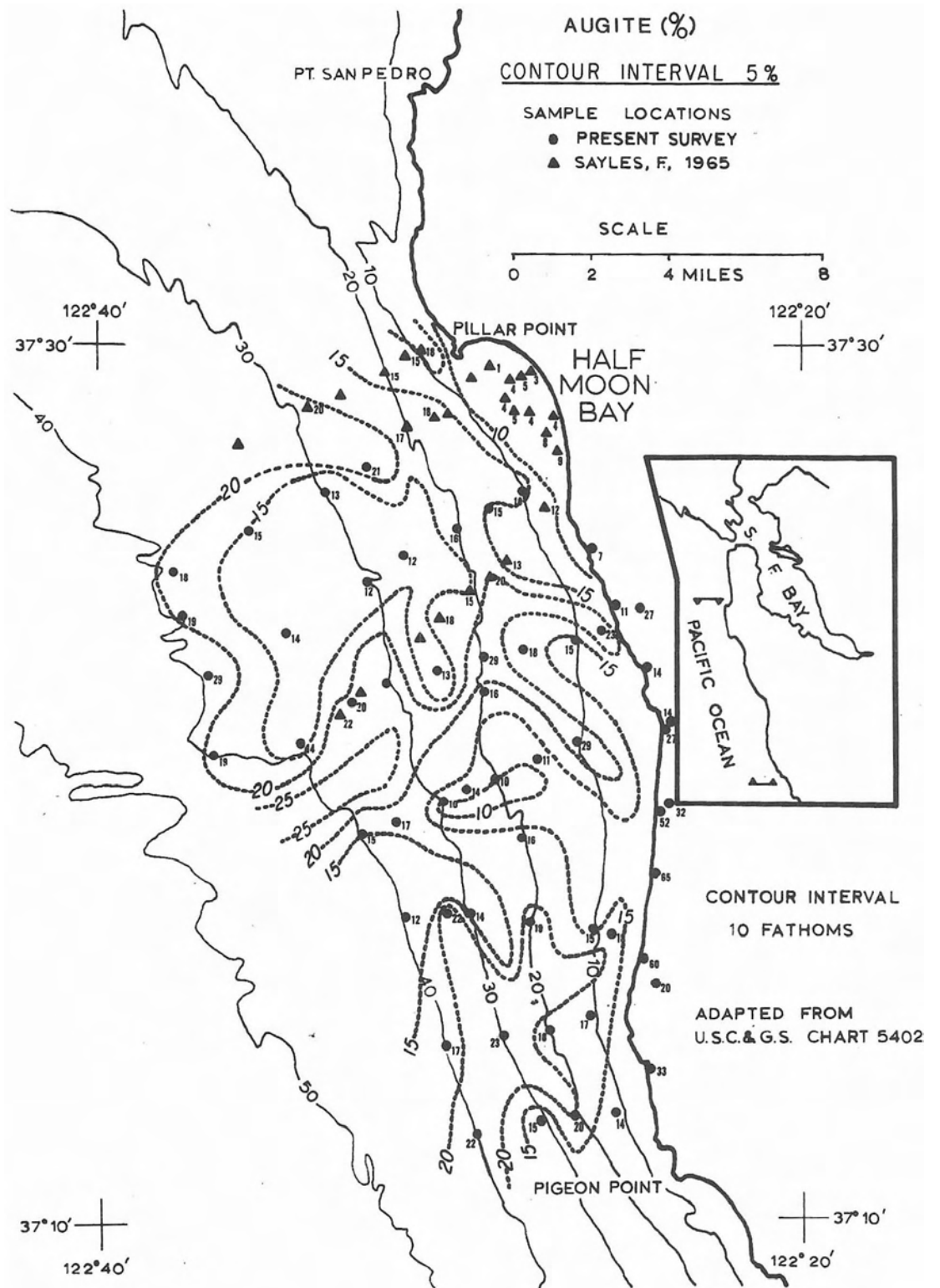
The assemblage is characterized by a high green hornblende with secondary amounts of augite and hypersthene with occasional counts of Franciscan minerals. The distribution of hornblende (Fig. 25) shows high values along the coast decreasing seaward with tongues of high values extending seaward west of the present mouths of Picarcitos, Pompano, and Pescadero Creeks. The decrease of values seaward indicates the basic source of the hornblende is the land. Augite (Fig. 27) has a low distribution inside Half-Moon Bay with a reasonable uniform percentage (10-20) offshore. However, the distribution

Fig. 25

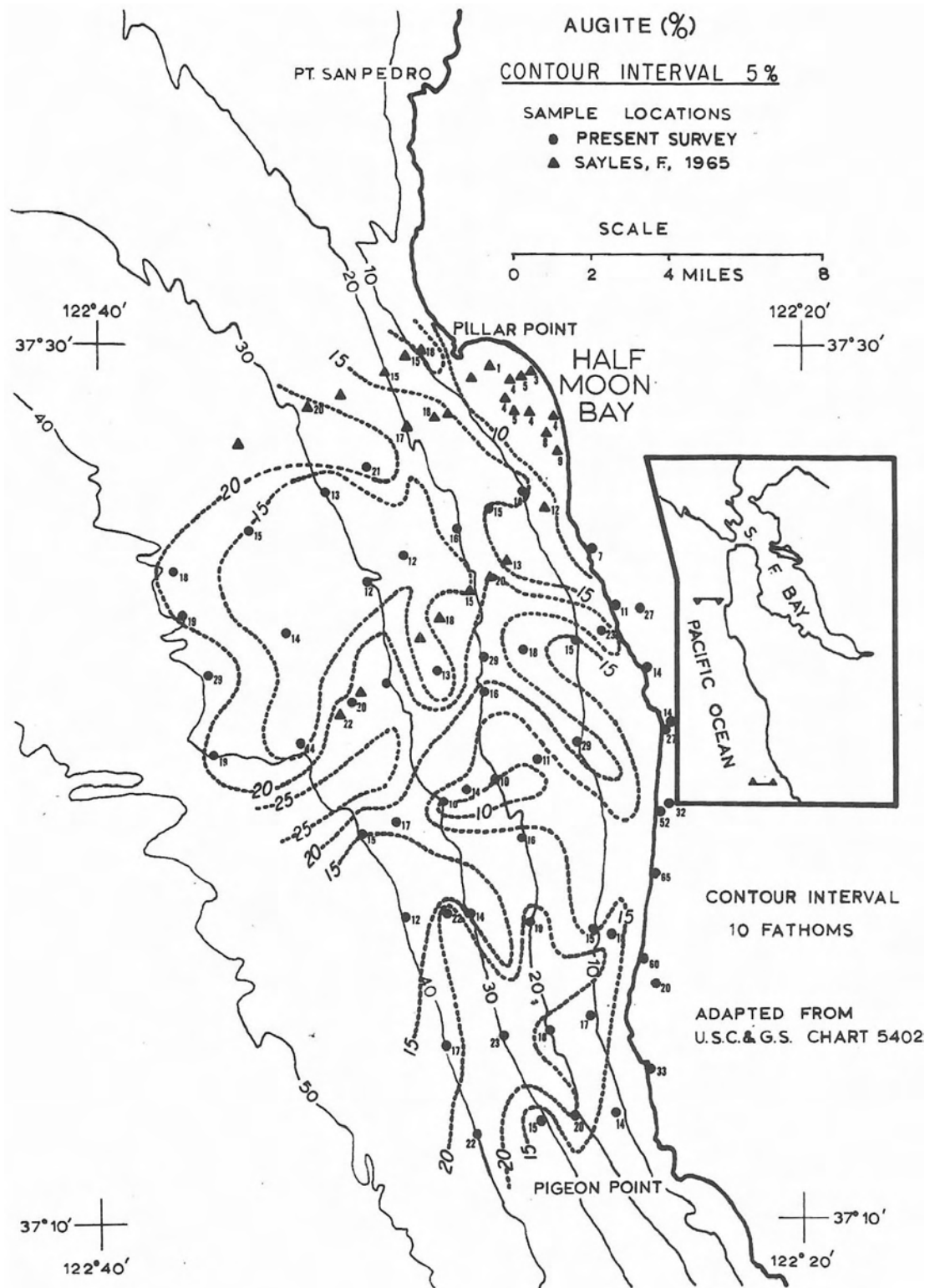




Fig, 27



Fig, 27



Such provinces may be given time stratigraphic significance if the grain size and mineralogic data is considered in the context of Holocene and Pleistocene fluctuations of sea level. Milliman and Emery (1968) have documented the following chronology of most recent sea level changes based on world-wide data:

TABLE 6

- A. Last Previous high stand of sea level 30,000 to 35,000 years ago.
- B. Slow recession to -40 meters from 30,000 to 21,000 years ago.
- C. Rapid recession to -130 meters from 21,000 to 16,000 years ago.
- D. Rapid rise to -10 meters from 16,000 to 5,000 years ago.
- E. Slow rise with plucuations to present level and time.

Thus during the lowest stand of sea level the area covered in this survey was exposed to the atmosphere and stream drainage was developed on the then dry shelf. With rising sea level coinciding with the melting of the continental ice sheets, the **subareal** drainage area would be reduced. If sea level rose slowly, the shelf deposits would be reworked extensively by the advancing surf zone and with significant longshore drift suggested by the flat shelf, the remaining deposits would be relatively homogeneous. If the rise in sea level was rapid, the earlier, low **stand** stream drainage patterns as reflected in their sediments would be preserved. Intermediate rates of sea level rise would produce a spectrum from complete homogenation through a smearing of the drainage patterns in the direction of long shore drift to preservation of the discrete drainage patterns. Still stands of sea level would produce linear belts parallel to the then coast line of

recognizable beach deposits again of relatively homogeneous mineralogy produced by long shore drift.

The interpretation shown in Fig. 37 suggest that the rise in sea level from -90 meters (50 fathoms) to -20 meters (10 fathoms) was rapid preserving the extensions on the shelf of existing streams. Landward of -20 meters (10 fathoms) the surface deposits are more homogeneous suggesting a slower rise in sea level or active reworking of deposits to that depth under present surf conditions. This interpretation agrees with the chronology of Milliman and Emery (1968) for eustatic changes of sea level and further suggest that this part of the California coast although tectonically active did not undergo significant vertical movements during the past 35,000 years.

DEPOSITIONAL HISTORY

Based on the interpretations given in Fig. 37, the sequence of sedimentation on the Continental Shelf in this area is as follows.

PRE WISCONSIN: The oldest or background sediment is the offshore zone shown as lobes and truncated lobes containing moderate amounts of hornblende with high hypersthene. This material has mineralogical affinities with the sediments on the San Francisco offshore bar which because of the high, sediment load from the San Joachin-Sacramento drainage may be the principal source of sediment on the Central California Continental Shelf. The bar material is moved southward due to longshore drift (see Fig. 10). from the Pleistocene extensions of the San Joachin-Sacramento River into this area. The bar deposits

are relatively **homogeneous** and do not show obvious drainage patterns which suggest they have been extensively reworked. The **lobate** surface configuration is due to more recent local transgressive deposits extending out from local streams. As the source of the bar sediments is the extensive drainage of the Great Valley and the Sierras, which has remained unchanged for at least one million years, the characteristics of the bar sediments is time transgressive. For example, sediments presently being deposited on the San Francisco Bar are mineralogically similar but younger than the relict bar-type sediments found on the shelf seaward of Half Moon Bay. In other words, simple mineralogy cannot be used to date the shelf sediments.

ILLINOISIAN??

WISCONSIN GLACIAL STAGE STREAM SEDIMENTS

The linear branching patterns shown in the distribution of these deposits suggest **fluvial** origin particularly as these sediments can be traced shoreward to the present mouths of **Pilarcitos**, **Purisima**, **Tunitas**, **San Gregorio**, and **Pescadero** Creeks. Their mineralogy is characterized by high percentage of transparent grains (Fig. 23), high hornblende (Fig. 25) presumably coming from the **Salinian** Granitic Province on shore, reduction in hypersthene (Fig. 26) caused by dilution with nearer shore material, and reasonably high augite (Fig. 27) coming **chiefly** from streams south of **Tunitas** Creek. The shelf extensions of **Pilarcitos**, **Purisima**, and **Tunitas** Creeks merge on the shelf at **-36 meters** (-20 fathoms) and eventually join the extension of **San Gregorio** Creek at **-72 meters** (-40 fathoms). The glacial **Pescadero** Creek appears to have flowed seaward without any tributaries in this

area.

WISCONSIN TO HOLOCENE DEPOSITS

These deposits are found as a (1) near shore band of sediment characterized by high hornblende and low hypersthene suggesting local Salinian sources and (2) a zone of high hornblende and moderate hypersthene consisting of a reworked mixture of San Francisco Bar material with sediments from the Montara Quartz Diorite. The Salinian tongues of sediment associated with the shelf streams may be regressive deposits laid down by braiding streams during a rapid lowering of sea level (Table 6) which would increase the stream gradient and overall erosion but would favor rapid deposition on the relatively flat shelf. The extent of these deposits seaward of the present -20 meter line (-10 fathoms) may delineate the flood plain of the shelf streams whereas the branching pattern may show the last position of the stream drainage before the rise in sea level. The chief difference being the sediments along the most recent channels have higher undiluted hornblende being less reworked. The belt of these sediments landward of the -20 meter line is related to the slow rise to present sea level being relatively homogeneous and in band parallel to the coast. As with the bar deposits such deposits may be time transgressive because the source areas are providing material throughout the fluctuations of sea level.

HOLOCENE DEPOSITS - The southeast trending reef of Half Moon Bay essentially traps local material **with** high hornblende content (Montara Quartz Diorite) and precludes much mixing or reworking and incorporation with other near-shore sediments.

APPENDIX I
ORGANIC CONTENT OF MARINE SEDIMENTS
FROM HALF MOON BAY
TIM THEISS

INTRODUCTION

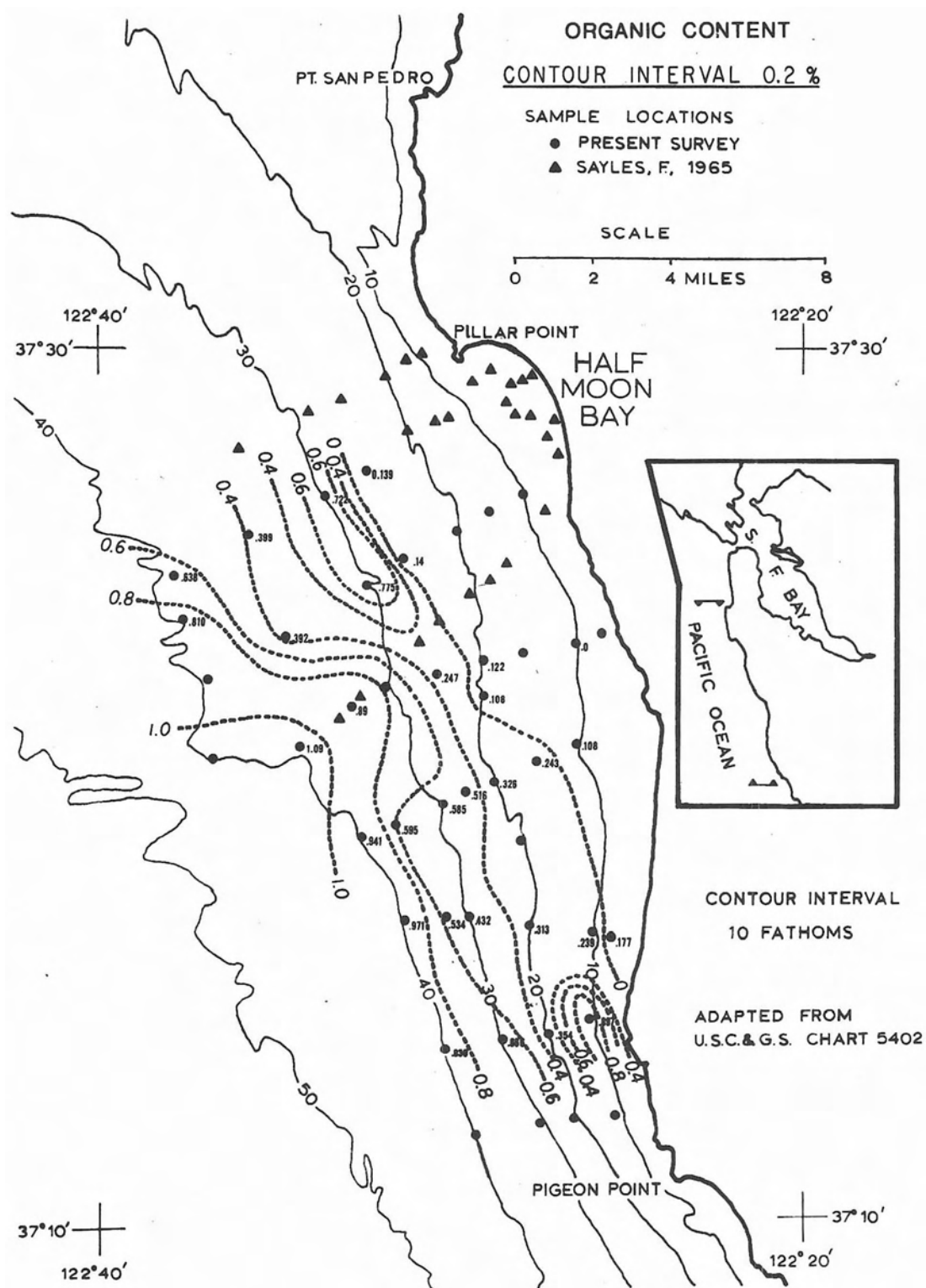
A study of marine sediments sampled off the Northern California coast from Monterey Bay to north of Point Reyes is currently being undertaken by Wilde and associates. Grain size distribution, carbonate content, and other parameters are being investigated. This author examined the organic content of thirty samples (Fig. 38) taken near Half Moon Bay by Wilde and associates. The depth of water at the sample points varied from 5 to 40 fathoms, and the organic contents obtained ranged from zero to about 1 per cent.

EXPERIMENTAL PROCEDURE

Organic content was determined by the chromic acid reduction method developed by Schollenberger (1945). This method is described in Theiss (1969). The samples were heated in chromic acid to 175°C. The amount of dichromate reduced by the oxidized organics was determined by titrating with .2N ferrous ammonium sulphate solution. Chlorides, which interfere with the titration, were removed by washing and filtering the samples.

Modifications of Schollenberger's method were incorporated by the author. Instead of adding a dry weight of potassium dichromate to each test, 5 ml of .1334 M $K_2Cr_2O_7$ solution were added. The amount of

Fig. 38



concentrated sulfuric acid added was then increased from 10 ml to about 12 ml because the addition of the dichromate solution caused the sample contents to boil before reaching the required 175°C. It should be noted that during the **titration**, the blue color did not appear until the titration was near the endpoint. The color change from blue to green was slow but very distinct. The method proved to be fast and efficient.

RESULTS

The experimental data are listed in Table 17. Different weights of samples were used early in the experiment in an attempt to increase the amount of oxidation, but an increase did not occur. Most of the samples weighed .500 gm.

The results showed very low organic contents; only one sample contained more than 1%. These values appear to be too low in view of the fact that Wilde and associates noticed a pungent odor of the sediments when they were gathered. After gathering, the samples were stored in plastic bags inside of cardboard containers which were semi-airtight. Consequently, some of the samples dried out in the upper portions. It is very likely that much oxidation of the organic content took place when the samples were stored. The author was given a small portion of the collected sediment samples, and it is not known if (though it can be assumed that) the author's portions were taken from the tops of the samples where the severe oxidation took place. In spite of the fact that the values seem to be too low, the results can be utilized to demonstrate relationships between the sample points. If all the samples were exposed to the same degree of oxidation potential, then the

TABLE 7

SAMPLE #	mL. Fe SOLUTION REQUIRED IN BLANK	mL. Fe SOLUTION REQUIRED IN SAMPLE	DIFFERENCE (mL.) BETWEEN BLANK-SAMPLE	WEIGHT OF SAMPLE (gm.)	% ORGANIC CONTENT
2105	20.3	14.2	6.1	.500	.830
2106	20.3	15.4	4.9	.500	.666
2107	20.3	17.7	2.6	.500	.354
2108	20.3	13.7	6.6	.500	.897
2109	20.3	19.0	1.3	.500	.177
2110	20.3	18.6	1.7	.500	.232
2111	20.3	18.0	2.3	.500	.313
2112	20.5	17.3	3.2	.500	.432
2113	20.5	16.1	4.4	.500	.594
2114	20.5	13.3	7.2	.500	.971
2115	20.5	13.5	7.0	.500	.941
2116	21.0	18.2	2.8	.310	.595
2117	20.3	16.0	4.3	.500	.585
2118	20.3	16.5	3.8	.500	.516
2119	20.3	17.9	2.4	.500	.326

TABLE 7 (Continued)

SAMPLE #	mL. Fe SOLUTION REQUIRED IN BLANK	mL. Fe SOLUTION REQUIRED IN SAMPLE	DIFFERENCE (mL.) BETWEEN BLANK-SAMPLE	WEIGHT OF SAMPLE (gm.)	% ORGANIC CONTENT
2120	20.5	18.7	1.8	.500	.243
2123	20.9	20.4	.5	.305	.108
2125	20.9	15.3	5.6	.340	1.09
2126	20.5	13.9	6.6	.500	.890
2128	21.0	19.8	1.2	.320	.247
2129	20.9	20.3	.6	.325	.122
2131	21.0	21.0	0	.305	0
2136	20.9	20.2	.7	.330	.140
2137	20.9	20.5	.4	.350	.0775
2138	20.9	18.7	2.2	.500	.392
2140	20.8	14.7	6.1	.500	.810
2141	20.8	16.0	4.8	.500	.638
2142	20.8	17.1	3.0	.500	.399
2143	20.8	18.3	2.5	.230	.722
2144	20.8	20.1	.7	.335	.139

relative position of the samples in terms of organic content should not change appreciably. If this assumption is not valid, then the results are meaningless, and the experiment is invalid.

The results are also plotted on a map of the area (Fig. 38), and isopleths of organic content are sketched in. Except for two isolated points, the results appear to be quite consistent. The organic contents increase with the distance from shore (and with depth along any individual track). This result has been observed by other investigators (Revelle and Shepard, 1939) who noted that the organic content maximum occurs at an intermediate distance offshore. Unfortunately, the sediment sample points do not extend far enough offshore to enable a determination of the organic content maximums in this study. Near shore the turbulence caused by wave action holds the organics in suspension. Farther offshore, because of less turbulence, more organics are deposited. A point is reached, however, when the oxidation rate of the organics exceeds the rate of deposition, and the organic content is expected to decrease.

The isopleths tend to follow the contour lines in the lower half of the area studied but tend to head in a more east-west direction relative to the contour lines in the upper half. The major source of sediments for this area is the Golden Gate, and the sediments, especially the fine material which includes the organics, are held in suspension while the currents move them southward. As the distance from the Golden Gate increases, the turbulence dies down, and more and more organic material is deposited, resulting in larger contents along the same contour line as one progresses southward. Further determinations of

organic contents and extensions of the isopleths are necessary to further substantiate this result.

The two points which do not follow the general patterns may be the result of faulty experimental technique or may be isolated pockets of higher organic content. It is also possible that these samples were not oxidized as much as other samples when in storage.

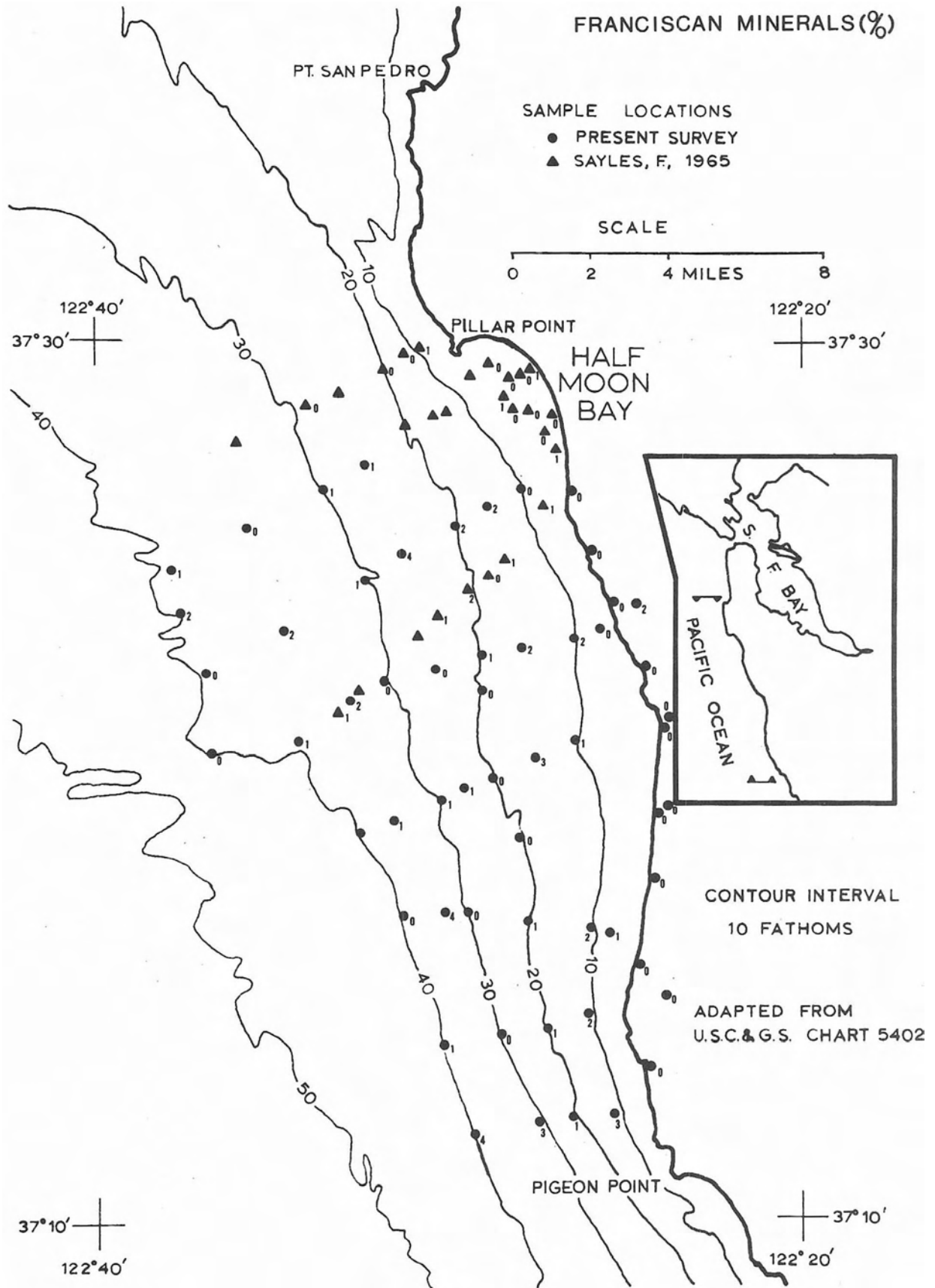
The fact that the organic contents are so low means that small differences in content are being considered. The accuracy of the experimental technique has been estimated at as high as 10% which is much larger than the contents determined. Thus, perhaps one significant figure is all that is warranted.

CONCLUSIONS

The use of Schollenberger's method for the determination of organics is complicated by the presence of chlorides, and because of the difficulty in removing them without removing water soluble and very fine organic material, this method may not be practical for marine study. However, if the proper filters are available, as described in Schollenberger (1945), then the method is justifiable because it gives rapid results, which are sufficiently accurate for marine sediment study.

The results, although they indicate small contents, are consistent and justifiable by the oceanographic conditions of the area. Further investigations of the area would be required in order to fully substantiate the results.

Further studies must evaluate the organic content as soon after sampling as possible in order to avoid the extensive oxidation;



pattern is dendritic in the central part of the area suggesting the relict Pleistocene or lower sea level trace of the combined Pilarcitos-Tunitas Creek drainage. On the beach the percentage of augite is greater to the south of Tunitas Creek (approximately the seaward trace of the San Gregorio fault) than to the north. This substitutes Hutton (1959) early work. However this change is not reflected in the offshore sediments north of Pidgeon Point. Hypersthene values are low inside Half Moon Bay, in the coastal beaches north of Tunitas Creek, and in a tongue extending seaward in the central part of the area. High values are found offshore and to the south.

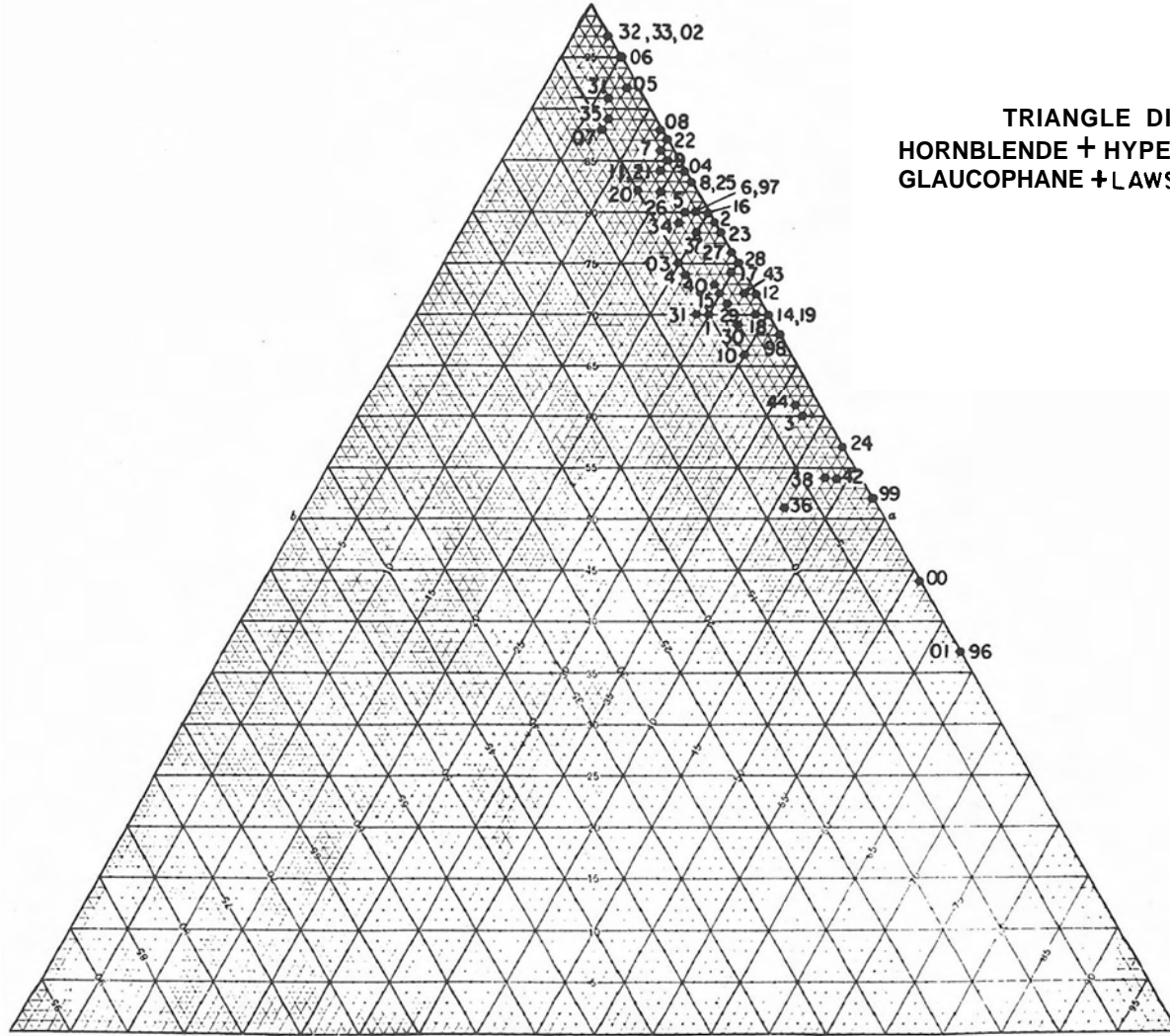
A tongue of high hypersthene content extends into the area from the northwest. The average offshore values are higher than the near-shore and on shore values of hypersthene, thus the chief source of the hypersthene is off-shore. The total Franciscan mineral content (Fig. 28) is very low, never greater than 4 percent of the transparent grains. The beach and stream and near shore material have essentially no Franciscan minerals whereas the off-shore material has a trace suggesting the Franciscan material is not derived from the present drainage basins emptying into the area which has no Franciscan rocks exposed.

Generic End Members Figure 29 shows a plot of the mineralogy of the sediments using three generic end members (1) hornblende (granitic); (2) hypersthene (volcanic); and (3) lawsonite plus jadeite plus glaucophane (Franciscan-metamorphic (see discussion in Wilde and others, 1969, p, 48)). Augite was not included as it could come from either volcanic (Hutton, 1959) or granitic rocks.

**GREEN HORNBLENDE
(GRANITIC)**

**TRIANGLE DIAGRAM.
HORNBLENDE + HYPERSTENE + JADEITE +
GLAUCOPHANE + LAWSONITE = 100 %**

LAWSONITE
+
JADEITE
+
GLAUCOPHANE
(METAMORPHIC)



HYPERSTHENE
(VOLCANIC)

The samples show a gradation between a very high granitic component and a moderate to low volcanic source. The data has three distinct clusters of points. (1) A high granitic component for Half Moon Bay and northern shallow water samples such as 2131, 2132, and 2133, (2) gradation between high granitic to moderate volcanic which includes most of the samples, and (3) moderate to high volcanic content shown by off shore samples 2136, 2138, 2143, in the northwest corner of the area. Complete mineralogic compositions of examples of these three clusters are found in Figs. 30, 31, 32.

SAMPLE 2132

Wt. % of HM/SF 7.15

Location 37° 23.5' 122° 25.7'

Total Grains Counted 131

Depth 9.1 meters 5.0 fathoms

% Transparent Grains 76.34

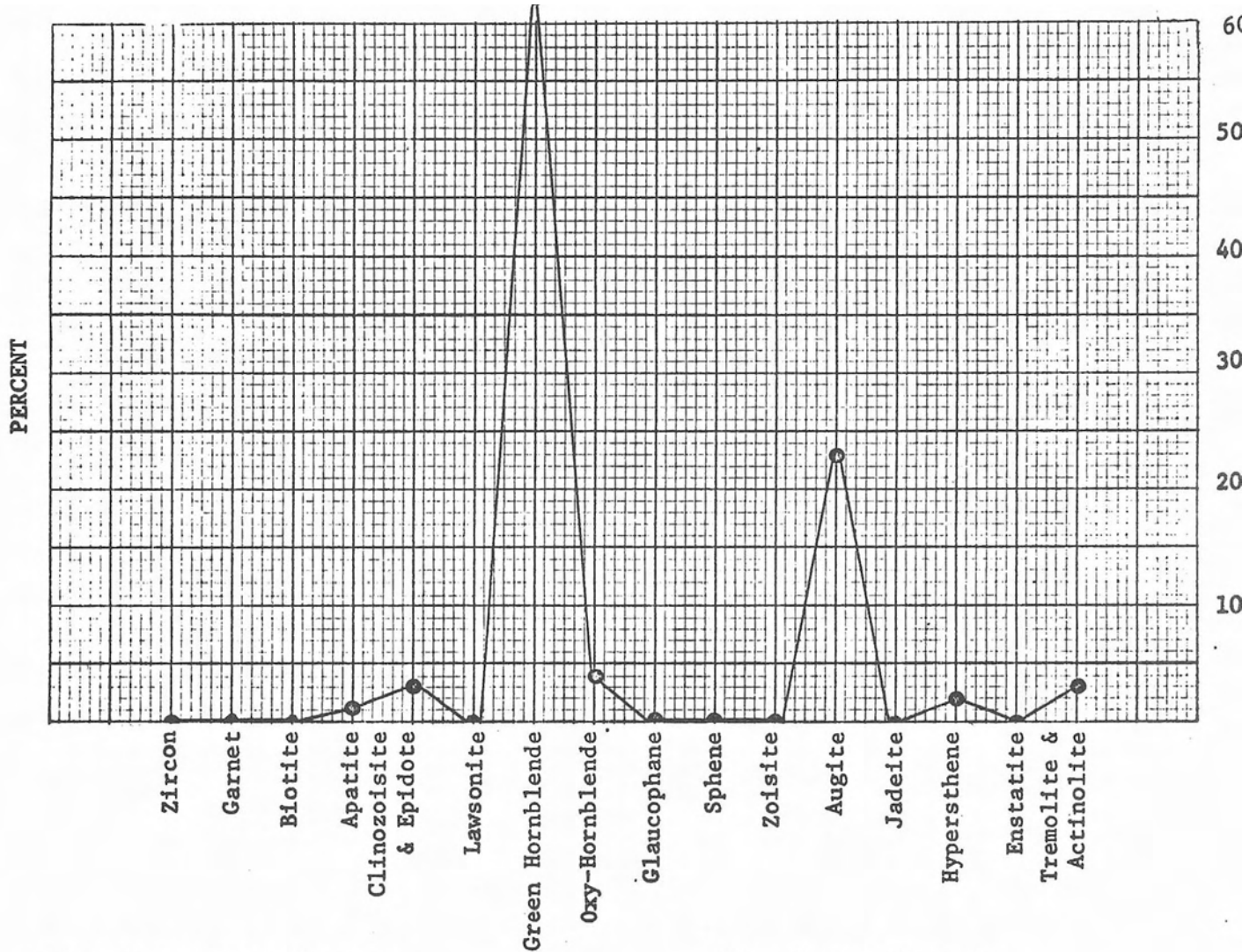
Size Fraction (SF) .124 - .175 mm

% Opaques 5.34

Graph % = Total % of Each Mineral

% Composite Gr. and Unknowns 18.32

Total % of Transparent Grains
Wt. % of SF/Total Sample 72.00



Other Transparent Minerals

<u>Mineral</u>	<u>No. Grains Counted</u>
Carbonate	1
Pumpellyite	1
Composites - Alterites	22

Other Opaque Minerals

<u>Mineral</u>	<u>No. Grains Counted</u>
Hematite	6
Magnetite	1

Analyst J. Lee

SAMPLE 2137

Fig. 31

Wt. % of HM/SF 4.06 55

Location 37°24.6' 122'32.4'

Total Grains Counted 164

Depth 54.9 meters 30.0 fathoms

% Transparent Grains 60.90

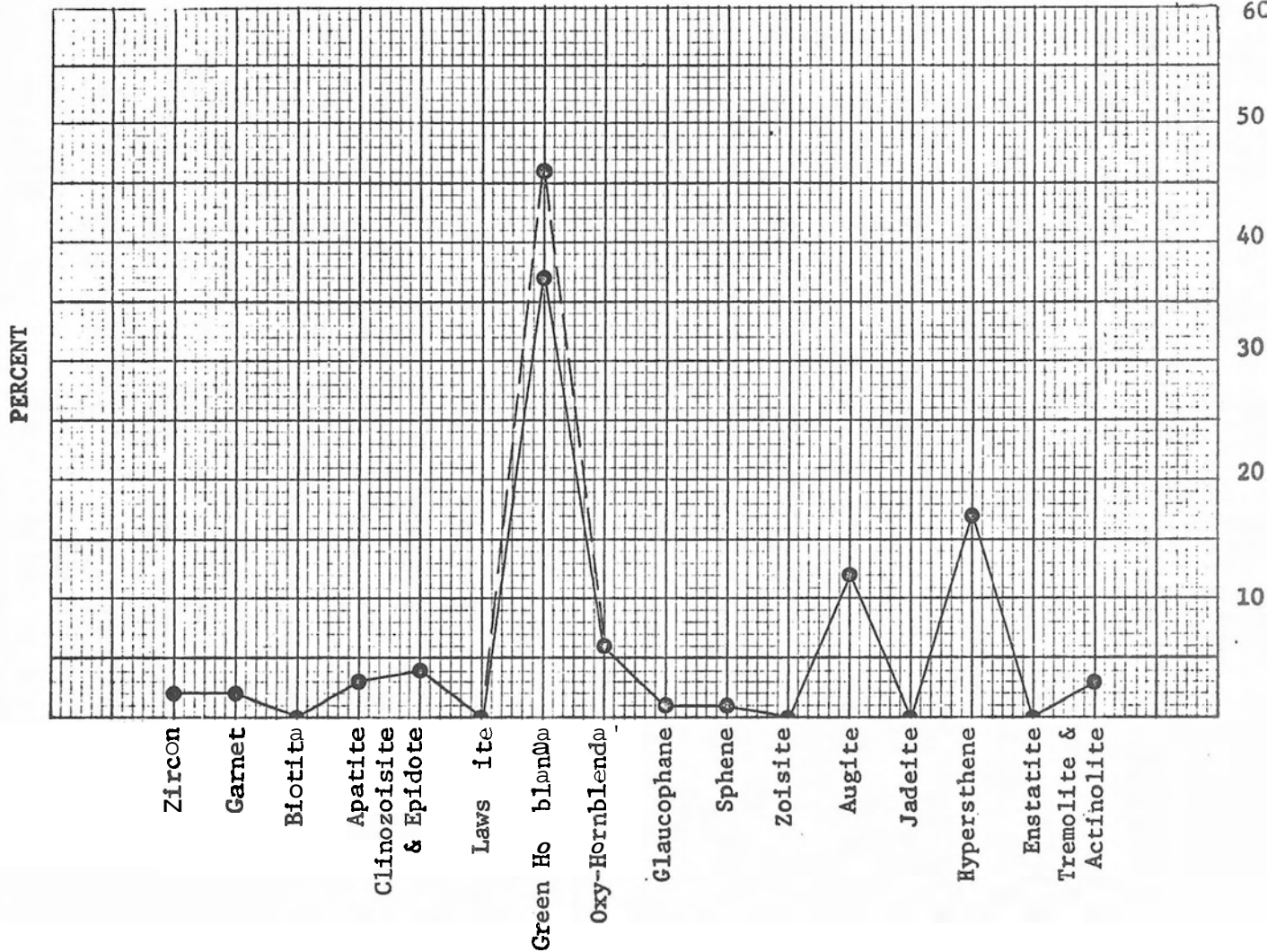
Size Fraction (SF) .061 - .351 mm

% Opaques 1.77

Graph % = Total % of Each Mineral

% Composite Gr. and Unknowns 21.4

Total % of Transparent Grains
Wt. % of SF/Total Sample 91.01



Other Transparent Minerals

<u>Mineral</u>	<u>No. Grains Counted</u>
Picotite	1
Allanite	1
Composites - Alterites	31
Unknowns	4
Zoisite	1

Other Opaque Minerals

<u>Mineral</u>	<u>No. Grains Counted</u>
Magnetite	22
Hematite	5
Leucoxene	1

Analyst J. Lee

SAMPLE 2138

Fig. 32

Wt. % of HM/SF 11.04

Location 37°23.5' 122°34.7'

Total Grains Counted 158

Depth 60.4 meters 33 fathoms.

% Transparent Grains 64.0

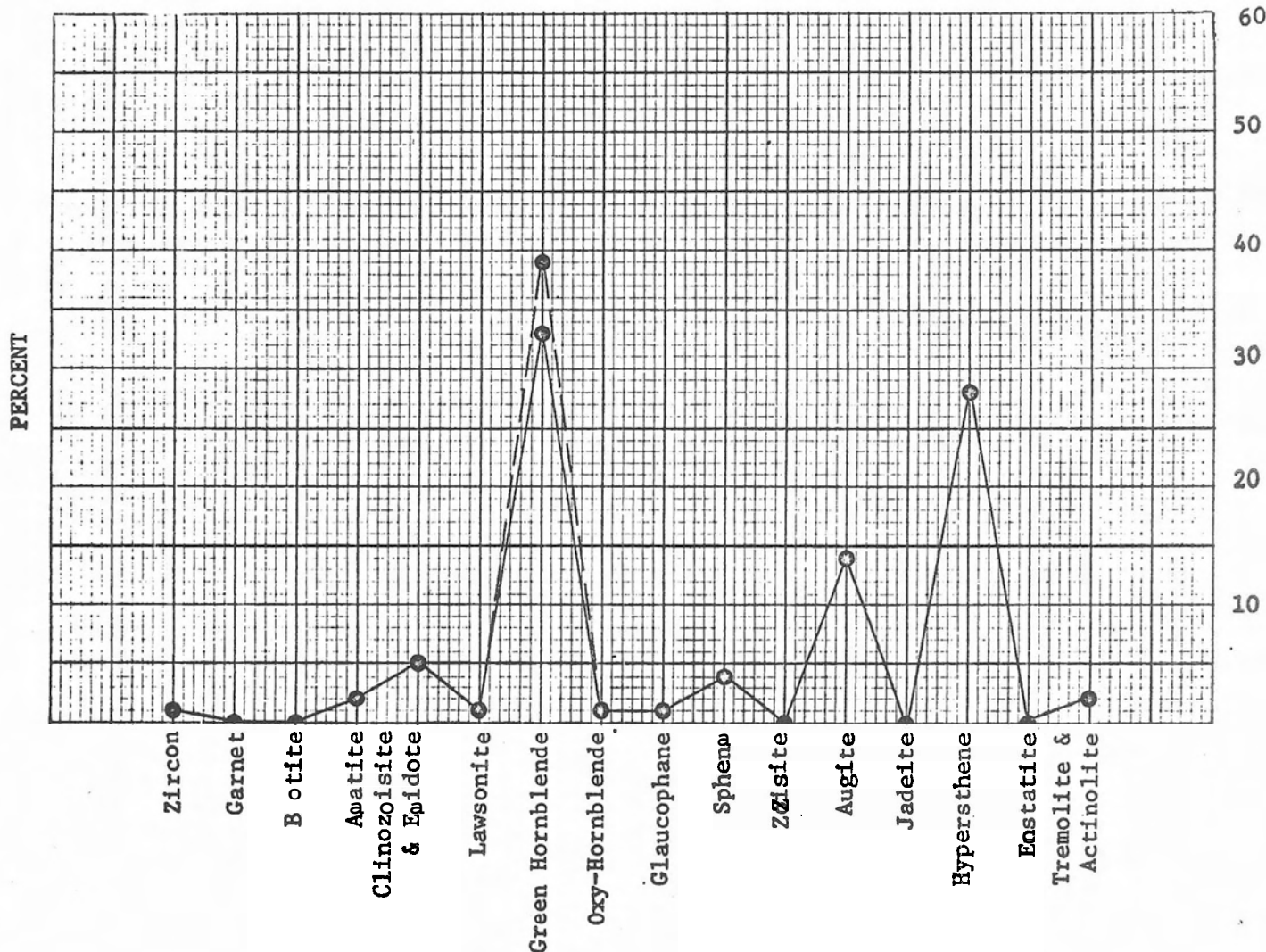
Size Fraction (SF) .061 - .351 mm

% Opaques 15.8

Graph % = Total % of Each Mineral

% Composite Gr. and Unknowns 20.2

Total % of Transparent Grains
Wt. % of SF/Total Sample 88.43



Other Transparent Minerals

<u>Mineral</u>	<u>No. Grains Counted</u>
Picotite	1
Lawsonite	1
Composites - Alterites	31
Unknowns	1
Pumpellyite	1

Other Opaque Minerals

<u>Mineral</u>	<u>No Grains Counted</u>
Magnetite	24
Leucoxene	1

Analyst J. Lee

IV. PROVENANCE

The potential sources of sand-size sediment now on the Continental Shelf characterized by the mineralogic studies of this report are:

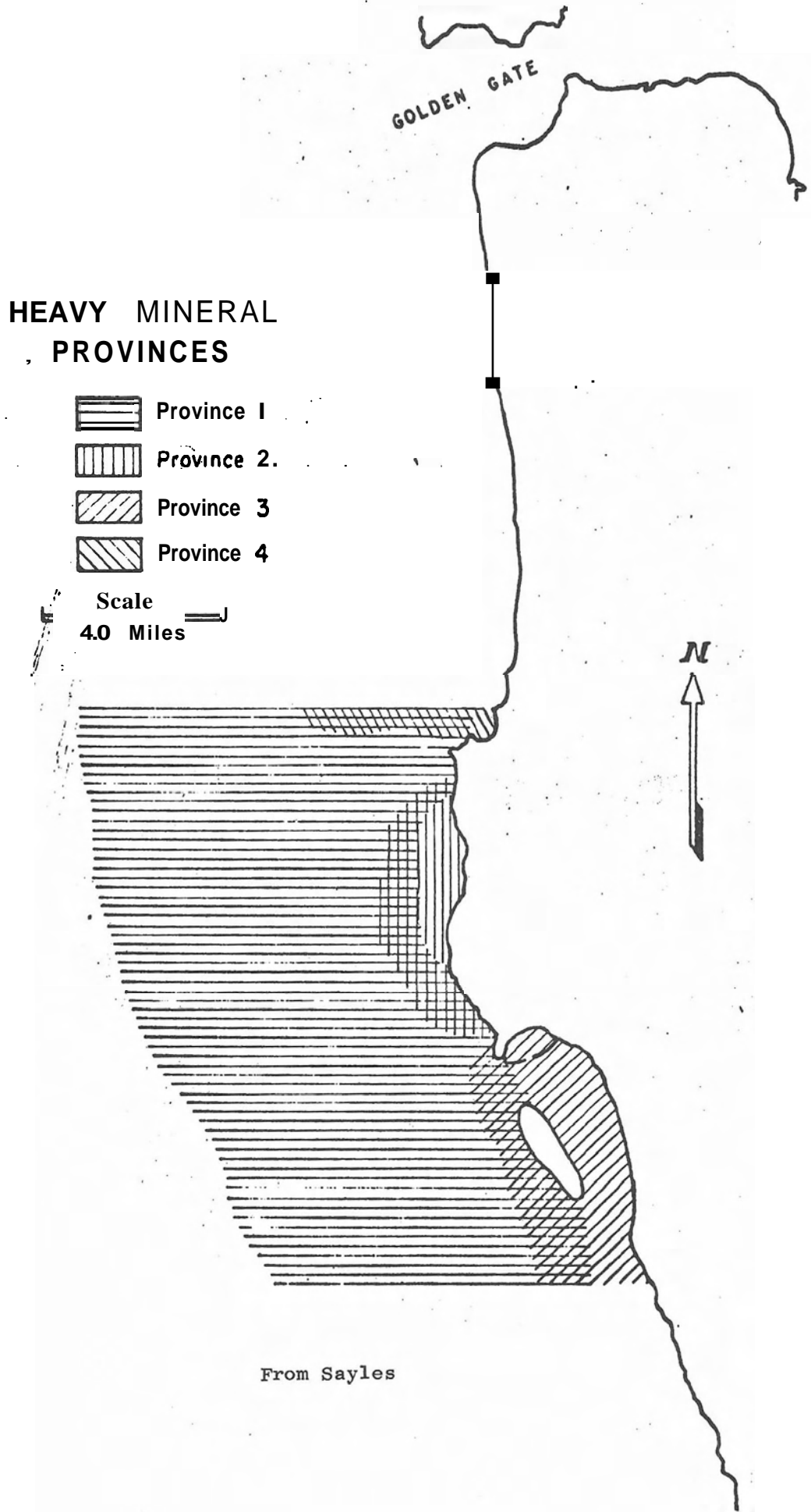
- (1) Subaerial stream drainage areas with unique lithologies such as:
 - (a) North of Pillar Point - Granitic terrain
 - (b) Half Moon Bay to the San Gregorio Fault - Granitic and Tertiary sedimentary terrain including Pilarcitos, Pursima, and Tunitas Creeks.
 - (c) San Gregorio Fault to Pigeon Point - Tertiary sedimentary and volcanic terrain drained by San Gregorio, Pomponio, and Pescadero Creek, plus Cretaceous marine sediments drained by Butano Creek a tributary to Pescadero Creek at its mouth.
- (2) Cliff erosion of Pleistocene and Tertiary sediments in the north and middle and Cretaceous marine sediments in the south.
- (3) Recent longshore drift chiefly from areas to the north.
- (4) Relict longshore drift again chiefly from the north.
- (5) In place relict sediments deposited subaerially by wind and streams on the shelf during lower stands of sea level.
- (6) Transgressive relict sediments produced by reworking of offshore sediments in the surf zone and transported progressively shoreward with rising sea level.
- (7) Submerged outcrops eroded by submarine erosion.
- (8) Recent shelf sediments reworked and transported by contour currents.

A quantitative assignment of actual volumes to each of the above

SEDIMENTARY PROVINCES

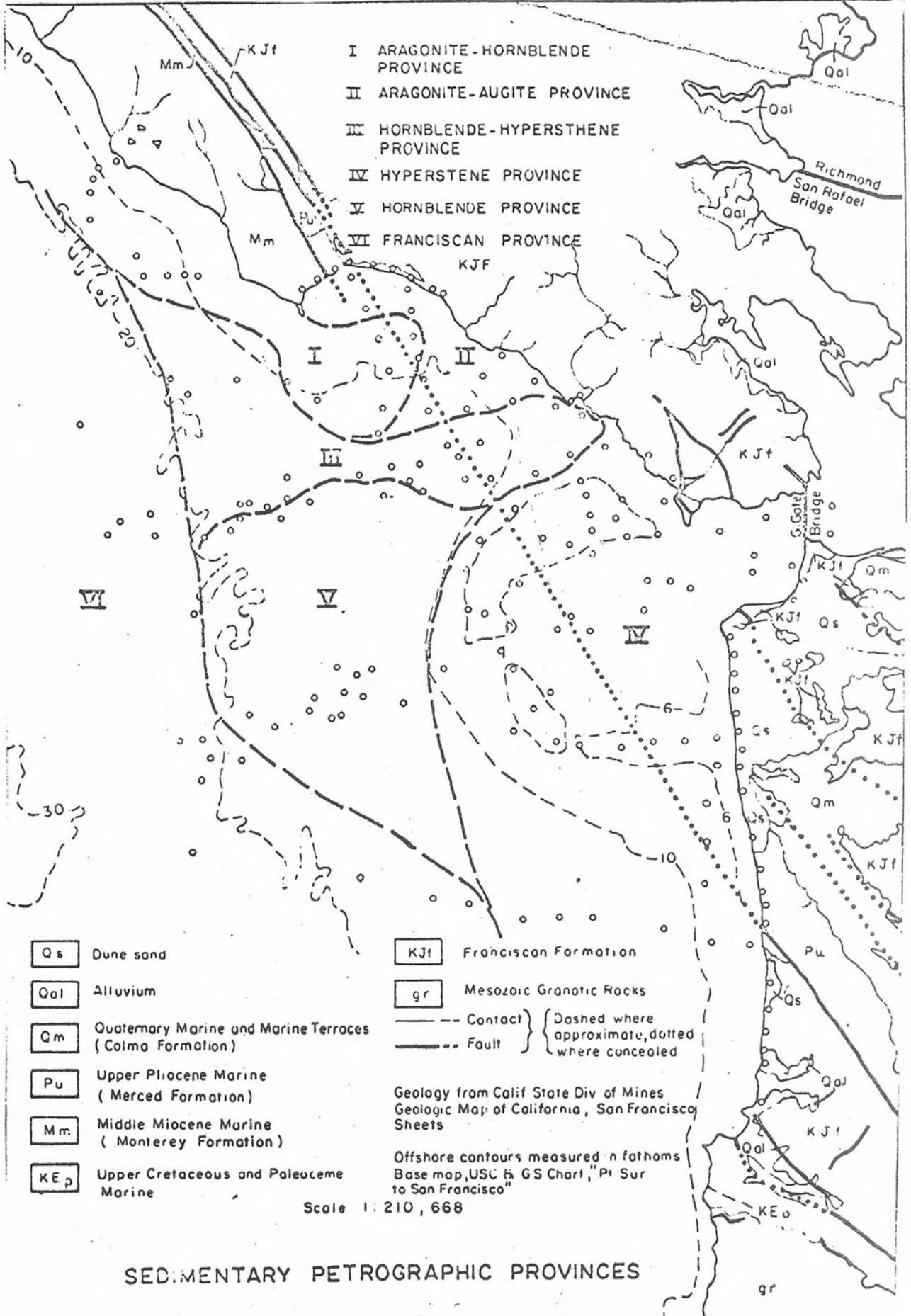
Sayles (1965) using samples from the near-shore around Half Moon Bay and north described several heavy mineral provinces, depicted in Fig. 33, based on a vector-mixing concept. Sayles picked several samples and used their mineralogical composition as end members or vectors and then compared the rest of the samples to each vector. The mean values and standard deviation of the samples of Sayles' provinces shown in Table 4. A summary of Sayles' findings indicate three basic zones: (A) Off-shore zone of hornblende-augite-actinolite-hypersthene which is the predominate areal province (Sayles province (1)) and (B) a high hornblende province inside Half Moon Bay and between Point Montana and Pillar Point (Sayles Province 3 and 2 respectively) and (C) a hornblende-hypersthene-augite zone in the north-west along the coast (Sayles Province (4)).

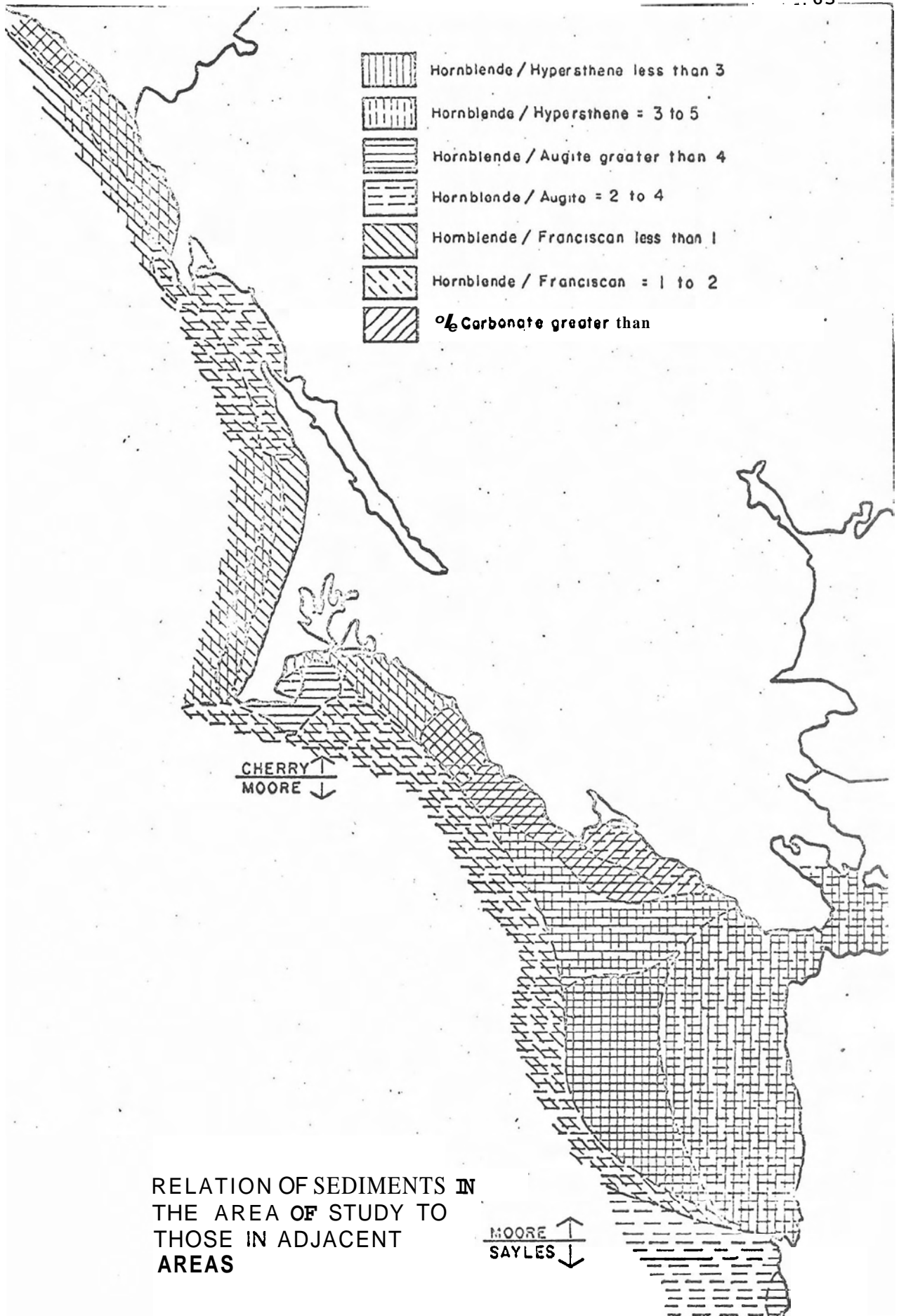
Moore (1965) working in the area just west of the Golden Gate in the Gulf of Farallons and north of the region studied by Sayles (1965) described five mineralogic provinces (Fig. 34) two of which continue into the area of this report. Moore reported an offshore zone (Moore's Province VI) with Franciscan affinities and an inshore zone (Moore's Province IV) related to the San Francisco offshore bar with a distinctive hypersthene content. A regional interpretation north of the area of interest is shown in Fig. 35 with the provinces divided on various mineralogic ratios.



		HORNBLende	HYPERSTHENE	AUGITE	OXYHORNBLende	CARBONATE	SPHENE	TREMOLITE - ACTINOLITE	EPIDOTE	GARNET	ZOISITE	ZIRCON	ENSTATITE	GLAUCOPHANE	LAWSONITE	APATITE	CLINOZOISITE	ANDALUSITE
1	\bar{x}	57.5	8.98	15.8	2.00	0	2.34	4.36	2.09	1.82	0.52	0.96	2.12	0.32	0.27	0.48	0.34	0
	σ	6.13	2.78	3.92	1.85	0	2.31	2.40	1.72	2.19	0.84	1.61	2.34	0.51	0.69	0.78	0.67	0
2	\bar{x}	83.7	3.33	3.75	0.08	0	3.25	1.41	1.67	1.33	0.25	0.75	0.33	0	0	0.08	0	0.08
	σ	6.30	1.25	2.59	0.28	0	3.65	1.98	1.60	1.11	0.60	1.30	0.47	0	0	0.28	0	0.28
3	\bar{x}	74.4	3.86	6.14	0.99	0	4.26	1.91	2.17	0.77	0.37	3.60	0.20	0.17	0	0.51	0.54	0
	σ	10.4	2.15	2.57	1.34	0	3.54	1.75	1.50	1.04	0.72	9.48	0.40	0.38	0	0.81	0.81	0
4	\bar{x}	44.3	25.9	18.6	0.43	0	4.43	1.00	2.43	1.43	0.57	0.29	0.14	0	0	0	0.29	0.29
	σ	3.69	2.03	4.27	0.73	0	2.32	1.41	1.29	0.73	0.73	0.43	0.34	0	0	0	0.70	0.45
1-2	\bar{x}	69.0	5.89	9.33	1.37	0	3.00	2.44	3.22	1.44	0.78	2.22	0.67	0.11	0	0	0.33	0
	σ	7.35	2.38	3.71	1.94	0	1.94	1.83	1.31	1.77	1.03	2.78	0.94	0.31	0	0	0.67	0
1-3	\bar{x}	64.6	7.35	12.89	1.30	0	3.88	3.50	1.00	0.88	0.38	1.63	0.13	0.63	0	0.38	1.00	0
	σ	7.58	3.46	4.04	1.12	0	1.36	1.87	1.00	0.93	0.70	1.11	0.33	1.32	0	0.48	1.11	0
1-4	\bar{x}	55.3	14.5	12.8	1.66	0	1.33	6.33	2.19	0.67	0.83	0.33	1.33	1.33	0	0.33	1.67	0
	σ	5.15	4.07	2.11	1.11	0	0.75	1.97	0.69	0.47	0.46	0.47	0.49	0.94	0.10	0.47	0.37	0

MEAN AND STANDARD DEVIATION OF MINERAL CONTENT
OF THE PROVINCES AND MIXING ZONES

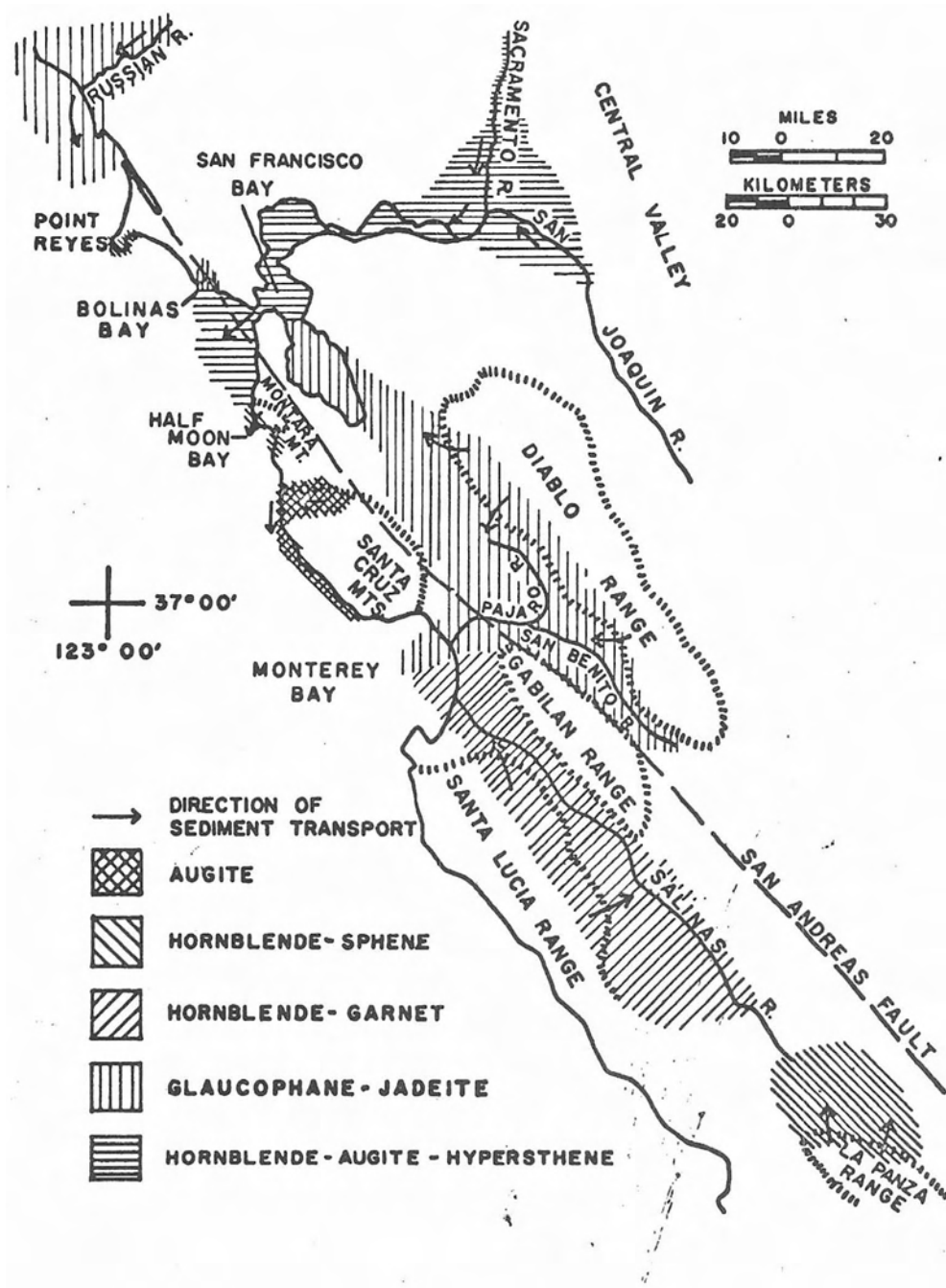




RELATION OF SEDIMENTS IN THE AREA OF STUDY TO THOSE IN ADJACENT AREAS

From Moore (1965)

Fig. 36



Recent heavy mineral provinces of central California.

From Yancey and Lee (1972)

The shelf **south** of Pigeon Point is the subject of study by this group (see Lee and others, 1970) and a report similar to this one will be issued eventually. However at this time no zonal interpretations have been made.

Yancey and Lee (1972) (Fig. 36) in a more regional study of the heavy mineral provinces identify (I) **Sayles' hornblende-augite-hypersthene** zone as the mixture of Sierran-Great Valley-Franciscan sediments coming out the Golden Gate and deposited on the San Francisco off-shore bar and (II) Sayles hornblende zone as a hornblende-sphene province. They also report a coastal augite rich zone extending south from **Tunitas** Creek.

From our data we recognize five provinces (see also Fig. 37)

TABLE 5

LOCAL SEDIMENTARY PROVINCES

1. A near shore zone in Half Moon Bay of high hornblende content = Sayles Province 3.
2. An offshore zone of a mixture of high to moderate amounts of **hornblende-augite-hypersthene** and with traces of Franciscan material = Sayles Province 1 = Moore's Province VI.
3. High hypersthene **offshore** = Moore's Province IV?
4. Tongues of material extending from stream mouths consisting of (a) higher hornblende and augite, and (b) lower hypersthene than number 3.
5. A near shore zone trending offshore near province number 4 and related to it with somewhat less hornblende,

Fig. 37

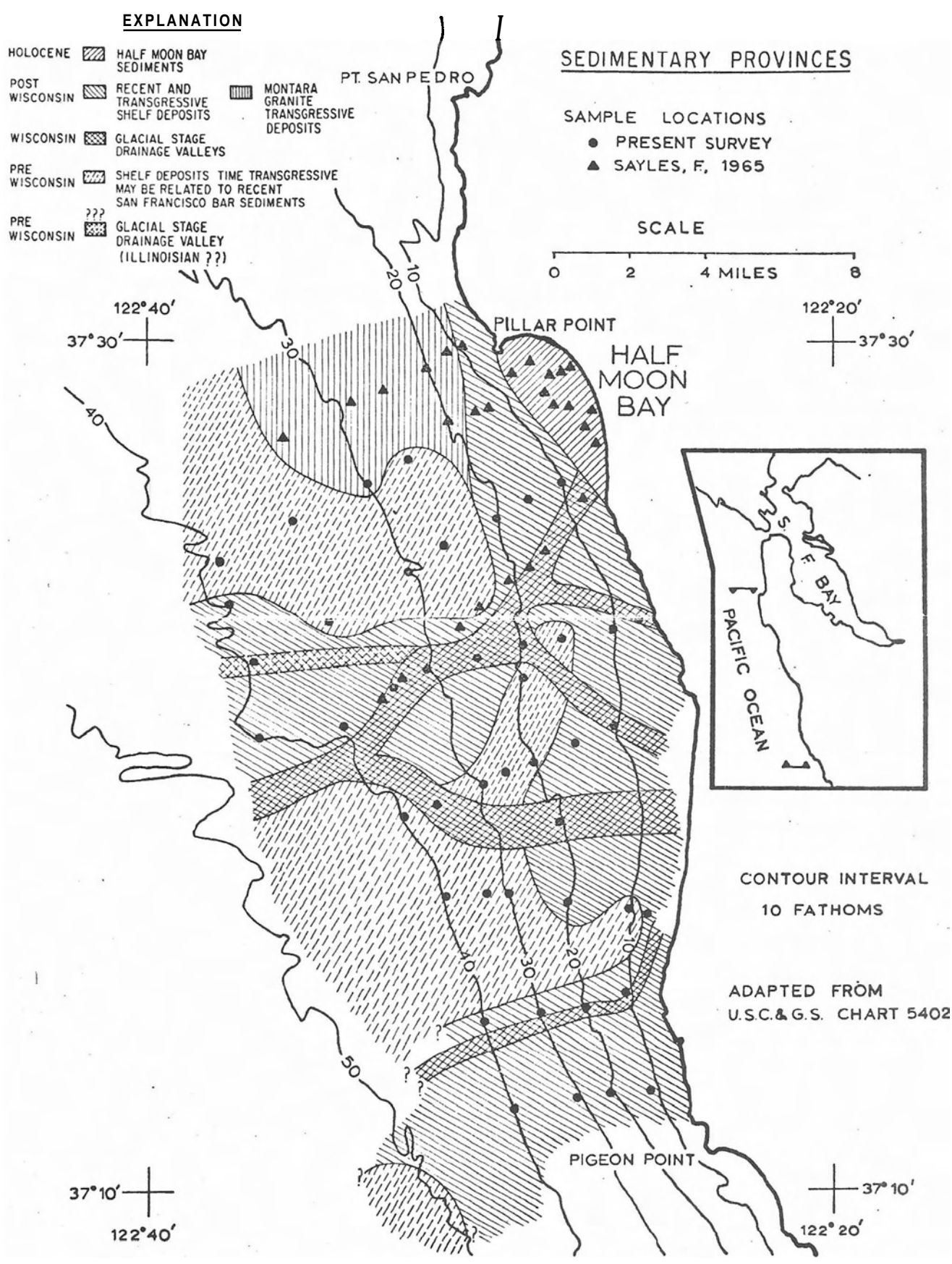
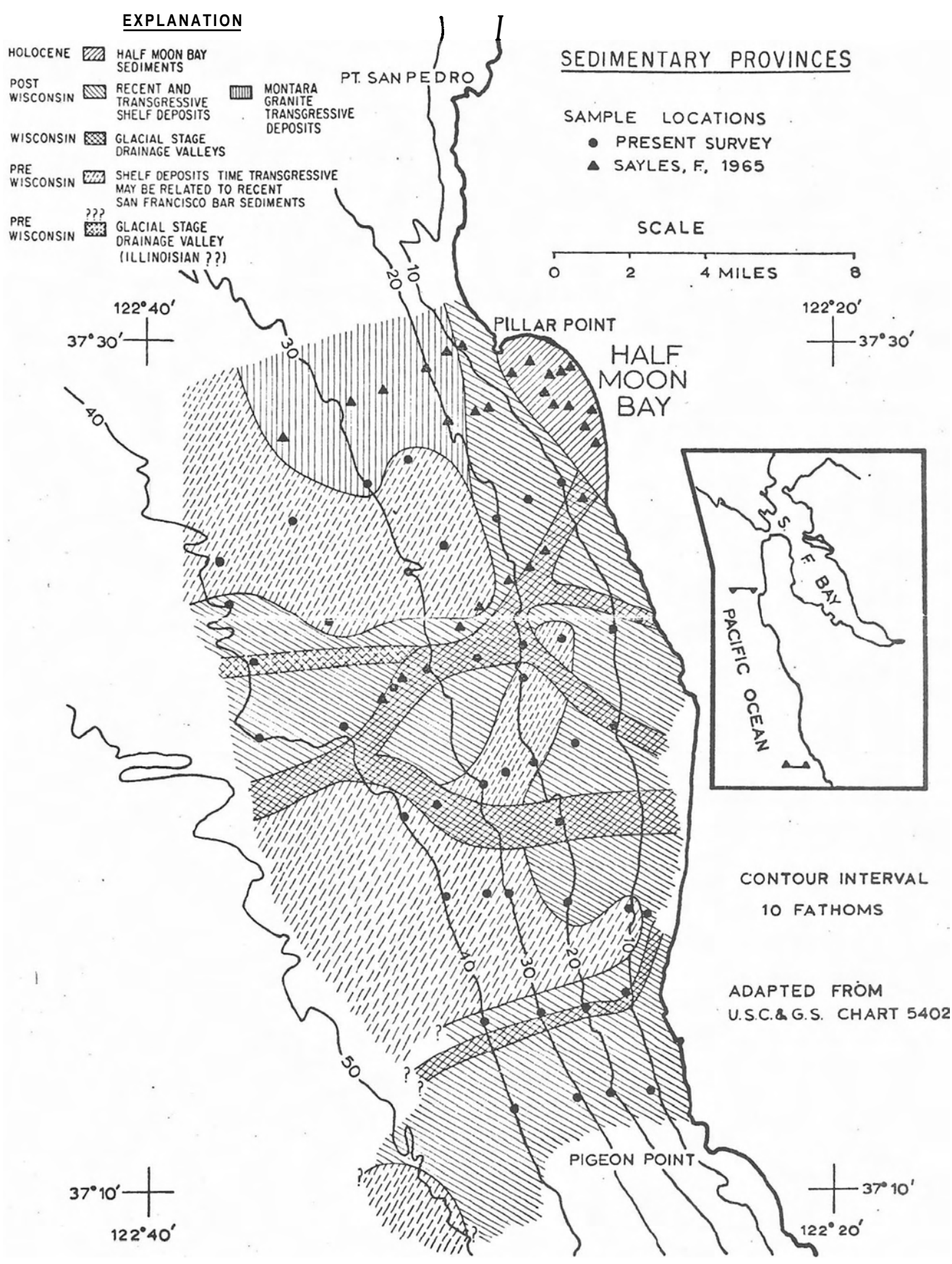


Fig. 37



another possible alternative would be to store the sample in a refrigerator to retard the oxidation. Comparison of the results of the organic content study with other parameters, such as the grain size distribution, might reveal relationships between the variables. Trask (Sverdrup, et al, 1942), in the Southern California area resulted in an increased correlation between organic content and median grain size, and similar relationships might be demonstrated through further comparisons.

The organic content of sediments can be a good indicator of oceanographic conditions when used with studies of other parameters. Continued studies of this type may be helpful in furthering the knowledge of the ocean environment.

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