Recent Coastal Sediments,
Double Point to Point San Pedro, California

By

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THESIS

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Date

ABSTRACT

This study seeks to examine patterns of longterm sediment movement along a portion of the California coast centering around the mouth of San Francisco Bay. Naturally-occurring heavy minerals were used to trace the influence of the several sources of sediments. Surface samples were collected from beaches and from the adjacent portion of the shelf under less than 130 feet of water. The samples obtained were analyzed mechanically and petrographically. Six petrographic provinces were differentiated on the basis of physical and mineralogical properties.

It was found that sands south and west of the Golden Gate in less than 60 to 100 feet of water reflect the mineralogy of San Francisco Bay sediments, and samples from the mollusk-rich Bolinas Bay and adjacent areas to the north and west contained large amounts of aragonite. Sediments in 60 to 100 feet of water west of the Golden Gate are unusually high in hornblende and sediments in more than 100 feet of water are somewhat higher in minerals of the Franciscan Formation than sediments closer to the coast.

It is concluded from this information that the San Francisco Bay Bar and adjacent sediments south and west of the Golden Gate have been derived principally from San Francisco Bay, and that sediments in the Bolinas Bay area are derived in large part from the decomposition of shells of modern marine organisms. The areas in 60 to 100 feet of water and greater than 100 feet of water do not appear to have any modern sources of sediment and are interpreted as relicts of features developed during lower stands of sea level.

Similarities between sediments in more than 100 feet of water in this area and sediments in the same environment to the north of the area studied suggest a less complicated distribution of sediments and perhaps extensive longshore transport of sediments during this lower stand of sea level. The distribution of recent sediments near the coast in the area studied indicates that longshore transport is now only of limited, local importance.

ACKNOWLEDGEMENTS

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INTRODUCTION

Purpose of the Study

In the past decade, much interest has been generated in the study of the long term movement of Recent sediments. The present study continues this work, concentrating on the coastal shelf sediments west of Marin and San Francisco Counties, California (see Fig. 1).

One of the earliest studies concerned with long term sediment movement in this area was done by G. K. Gilbert in 1917[1]. Gilbert (1917) suggested that the "bay bar" outside the Golden Gate was in part the product of deposition of large amounts of sand produced by hydraulic mining in the Sierras and in part from cliff erosion south of San Francisco. Work by Trask and others in the mid- and late- 1950's suggested that longshore movement along the beaches west of San Francisco is to the north. Other later authors (e.g., Howard, 1963) have also suggested the bay bar may have been formed from this northward moving sediment. In 1962 Kamel studied the distribution of radioactive thorium and postulated littoral movement generally to the south along the Marin and San Francisco coasts. In 1963 Cherry studied sediments immediately north of the present area of study and determined that littoral movement is to the south, but is very slow.

The study of long term sediment movement along coastlines has been of interest to geologists because of its bearing upon local and regional geologic history and its bearing upon sedimentary processes. Engineers are interested

[1] See references, pp. 57-66.

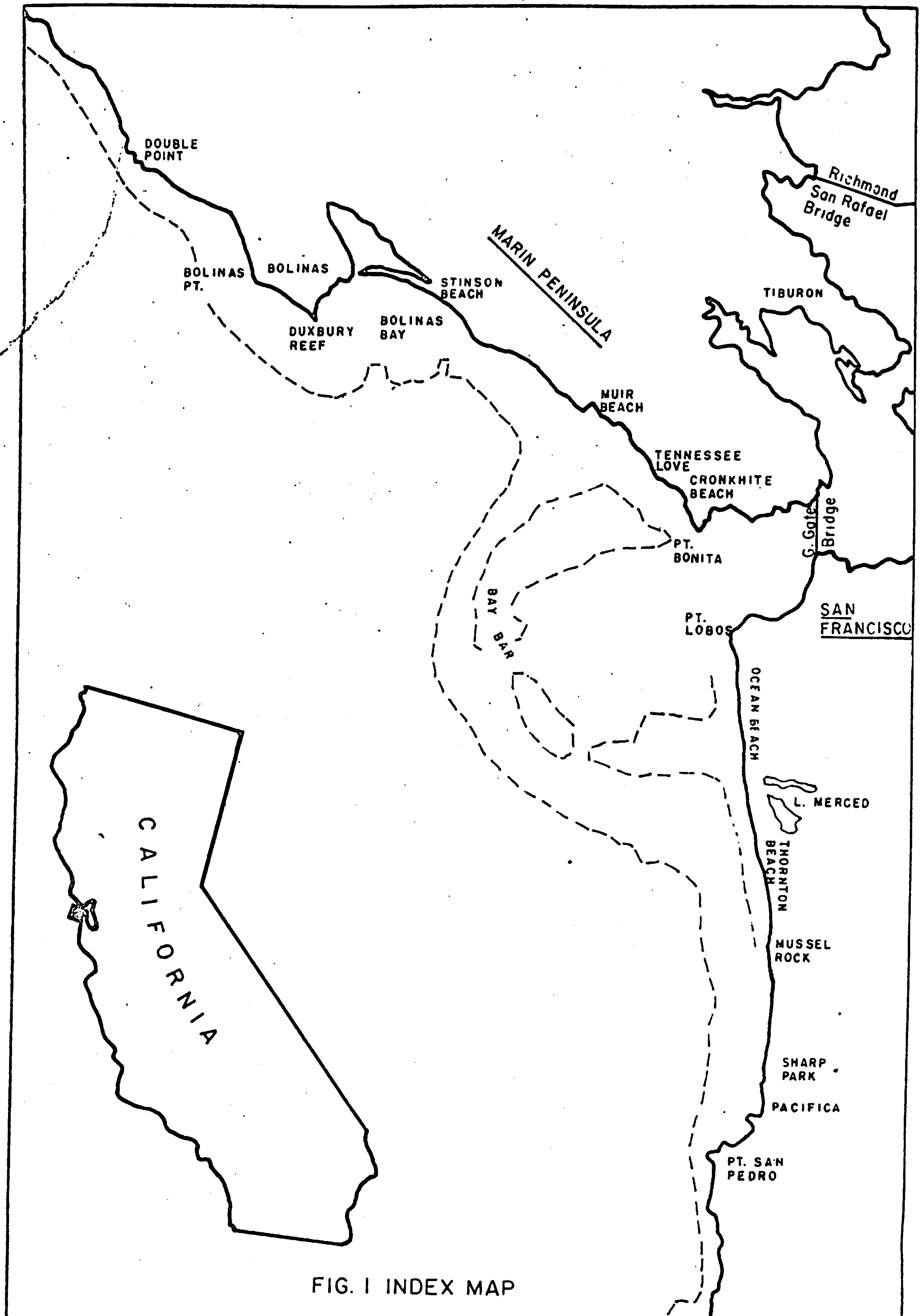


FIG. I INDEX MAP

in sediment movement not so much because of its historical implications, but because of its effect on the future of coastal structures such as breakwaters, groins and jetties.

The present study relies primarily on the distribution of heavy minerals to derive patterns of littoral transport. This method has been used locally by Bailey (1921), Cherry (1964) and Minard (1964); and is currently being used by Sayles (personal communication, 1964). Minerals with densities greater than bromoform (ρ = 2.85 gm/cc.) are called "heavy minerals" and usually make up less than 5% of the total sediment. In spite of their lack of concentration, heavy minerals are often much more indicative of source rocks than are the more abundant light minerals. Criticisms of heavy minerals studies, generally based on supposed density sorting, have been answered well by Van Andel (1959).

Distribution of heavy minerals from nearly 200 beach and offshore sediments has been determined. From these data, areas of sediments with similar properties (sedimentary petrographic provinces) are differentiated and an interpretation of long term movement causing this differentiation is developed. The interpretation presented here is consistent with most earlier studies and clarifies some previous anomalies.

Geologic History

The most recent interpretation of the geologic history of the San Francisco bay area has been prepared by Howard (1963). Only the late Cenozoic history of the bay area is important to this study. Howard states that the

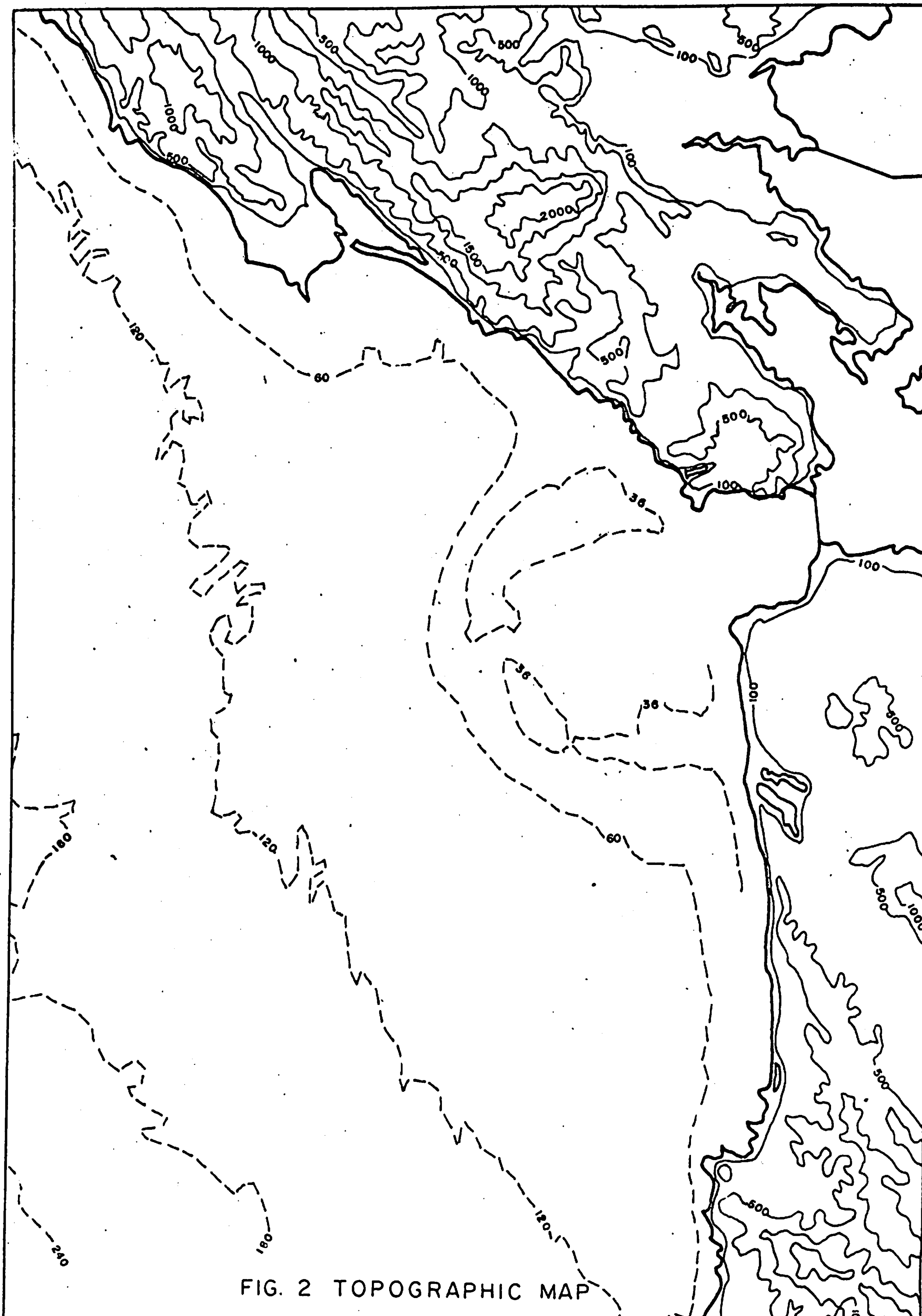


FIG. 2 TOPOGRAPHIC MAP

SCALE: 1:210,688. ALL CONTOURS MEASURED IN FEET rivers of the great valley began draining through the bay area in late Pliocene time. Glaciation in the Pleistocene epoch caused sea level to drop several times. During these glacial stages, deep channels were cut in the bottom of the bay. Cores taken from various parts of the bay indicate the deepest channel was 167 feet below present sea level at Carquinez and 240 feet below sea level in San Pablo Strait (Louderback, 1952, p. 83). The deepest sounding recorded in the Golden Gate Channel, also bedrock-bottomed, is 381 feet. Louderback (1952) states that this depth approximates the upper Pleistocene river bottom.

The ice caps melted and sea level rose, pausing several times, and finally the sea invaded the lower valley of the Sacramento River, forming San Francisco Bay. The presence of Indian shell-mounds below sea level in the bay is cited by several authors as evidence that the bay did not fill to its present level until quite recently. Studies by Moore (1949), and Moore and Shumway (1950) indicate that the recent sediment cover on the coastal shelf south of San Francisco is relatively thin. If this is also the case west of San Francisco, the Upper Pleistocene coastline must have been much farther west than it is now - perhaps as far west as the Farallon Islands.

Physiography

The area of study can be divided into three physiographic units (see Figure 2). The coastal shelf is an area of minor relief. Two troughs extend

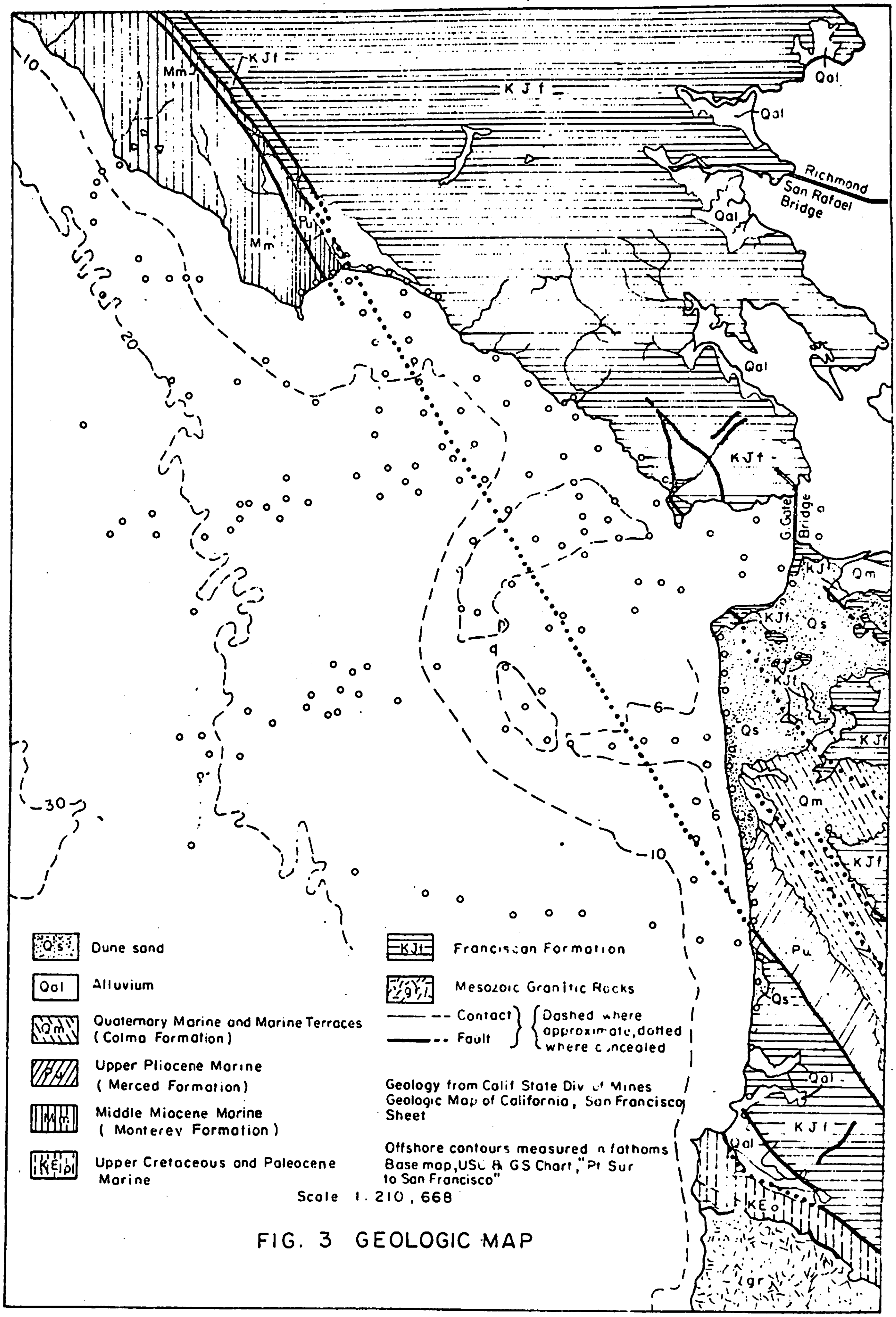


FIG. 3 GEOLOGIC MAP

northwest and southwest from the Golden Gate and are separated from each other by a low ridge, perhaps a tombolo, extending to the Farallon Islands. Each of the troughs leads to a submarine canyon, one of which may have been the mouth of the Upper Pleistocene Sacramento River. Except for a few patches, all of the coastal shelf is covered by recent sediment. A series of granodiorite mounds, of which the Farallons are the largest, are exposed along the western edge of the shelf. Portions of the bottom west of Duxbury and Double Points are apparently swept clear of all sediments except shale pebbles. (See Figure 1 for location of all geographic features).

The character of the coast itself is a reflection of the local geology (see Figure 3). The Monterey and Franciscan formations form cliffs along almost all of the coast north of the Golden Gate. The only exceptions to this occur at drowned stream valleys, where Cronkhite Beach, Tennessee Cove, Muir Beach and Stinson Beach have formed. Landslides of all sizes have occurred along much of this cliff-lined coast.

South of the Golden Gate, Franciscan cliffs give way to unconsolidated or slightly consolidated dune sands. These sands are in turn replaced by sediments of the Colma formation near Lake Merced (T. Hall, personal communication, 1965). South of Lake Merced, cliffs of the Merced group (of Hall, 1965) as high as 500 feet line the coast to Mussel Rock. Broad beaches extend from Point Lobos, just south of the Golden Gate, to Mussel Rock. South of Mussel Rock, cliffs of the Franciscan formation extend to the water's edge. At Point San Pedro the coast line is displaced westward, with the apparently very resistant Montara granite forming seacliffs from just south of Pt. San Pedro almost as far south as Half Moon Bay.

Sediment is provided to the littoral zone by landslides, sheetwash and a few small, intermittent streams. The only large stream entering the area of study passes through the Golden Gate.

The third physiographic unit includes San Francisco Bay. The bay presently receives water and sediment from the Sacramento River through Suisun Bay and from numerous other creeks and rivers around its perimeter. The Sacramento River, draining 40 percent of the state of California, provides 85 percent of the total sediment to the bay (Porterfield, et al, 1961). The presence of a sand channel extending from Carquinez Strait to the Golden Gate (Trask, et al, 1954) suggests that sediment of sand size is presently moving through the bay and through the Golden Gate.

Hydraulic Conditions

The frequency of swell in the area of study has been tabulated by National Marine Consultants (1960). Swell frequencies are tabulated in hours per month from each of eight compass directions. From these data it was determined that the most frequent and persistent swell comes from west-northwest with a period of about 10 seconds. Figure 4 is a wave diffraction diagram for these conditions in the area of study.

From this diagram one can see that energy is concentrated on the northern and southern parts of the bay bar (energy concentration is inversely pro-

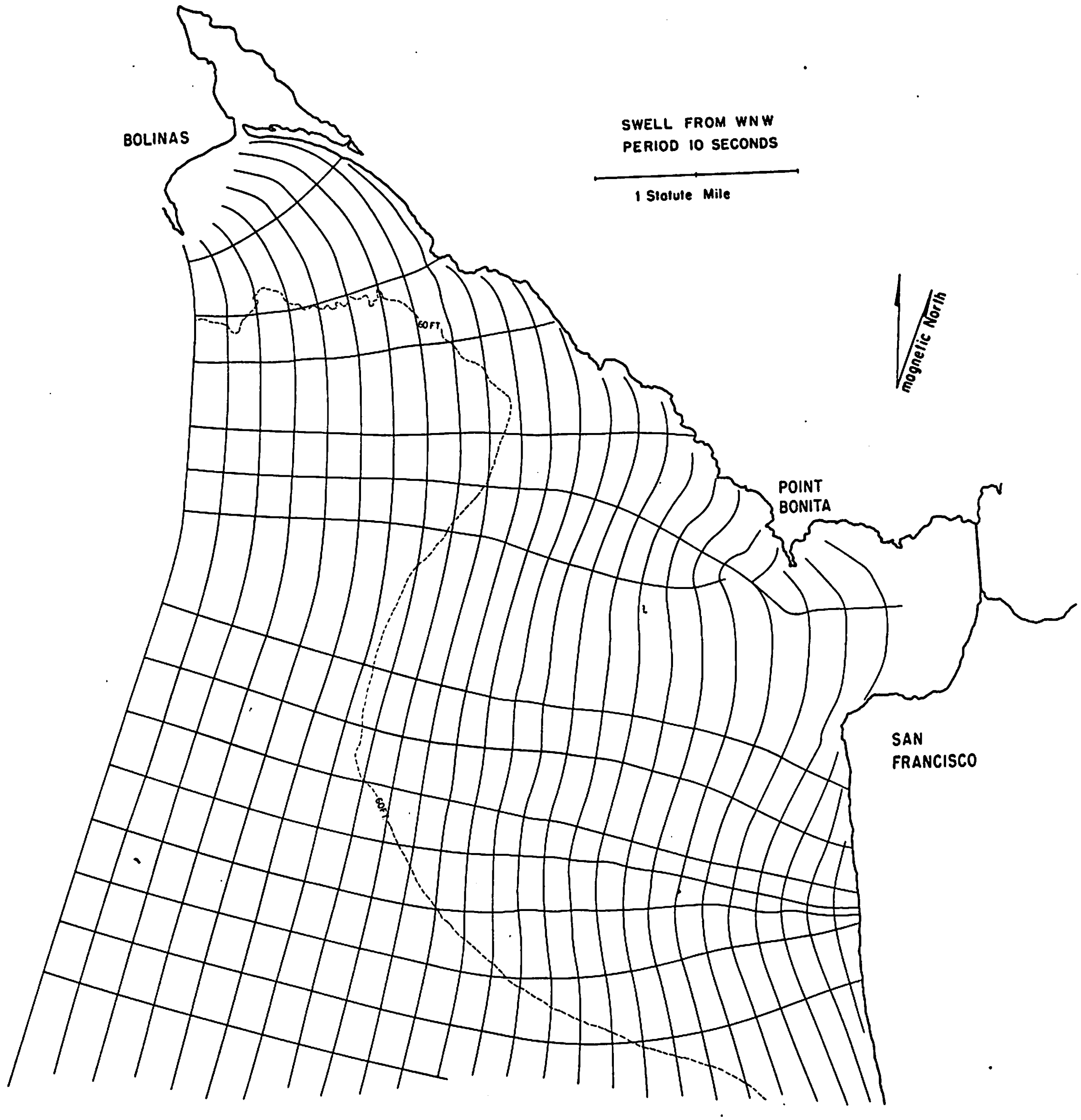


FIG. 4 WAVE REFRACTION DIAGRAM (WNW, 10 SEC) FOR MARIN-SAN FRANCISCO AREA

portional to the perpendicular distance between orthogonals). One zone of low energy exists west of the Golden Gate and another is found in Bolinas Bay.

This distribution of energy suggests a number of things. Bolinas Bay is an area of low energy in which apparently little sediment movement is going on. Any longshore movement in this area probably will be to the southeast under these conditions. Hydraulic conditions closer to the Golden Gate are more vigorous. In fact Tennessee Cove Beach and Cronkhite Beach are composed mainly of pebbles. The bedrock-bottomed Bonita Channel, probably carved by tidal currents, is 182 feet deep less than a half-mile offshore.

South of the Golden Gate, energy concentration increases to the middle of the bay bar (about one-half mile north of Fleishhacker Zoo) and then gradually dissipates to the south. Trask's studies and the present study of this beach all show steep beach profiles, large grain sizes and high sorting coefficients at the southern terminus of the bay bar. These characteristics give way to those more indicative of calmer conditions both to the north and south.

PREPARATION OF DATA

Collection of Samples

Field work was done during the summer of 1964 to augment and expand the collection of sediments available from Trask and others' 1954 study. Most of these samples were studied before the field work commenced to indicate where more samples should be taken. Offshore samples were collected on June 10 and 11, 1964. To obtain samples a 3-foot long, 6-inch diameter cylindrical steel bucket with a serrated lip was lowered from a fishing boat. The sampler was allowed to rest on the bottom while more line was paid out and the boat moved 100-200 yards away. The sampler was then dragged across the bottom and pulled to the surface with a power winch. Sample positions were located by fathometer, radiocompass and ship's compass and recorded on available U.S.C. and G.S. coastal charts. Samples 1683 to 1745 were taken for Trask's 1954 study by the U.S.C. and G.S. ship BOWIE between May 1952 and October 1954. The samples were stored intact by the Institute of Engineering Research after the Trask *et. al.* study was completed.

Samples were collected from all the beaches in the area of study on July 22, 1964. Where beaches were long enough, samples were taken at half mile intervals. Small beaches were sampled at both ends and/or the middle. Samples of approximately one half gallon were taken from the mid-tide level and locations recorded on 7-1/2 minute quadrange maps.

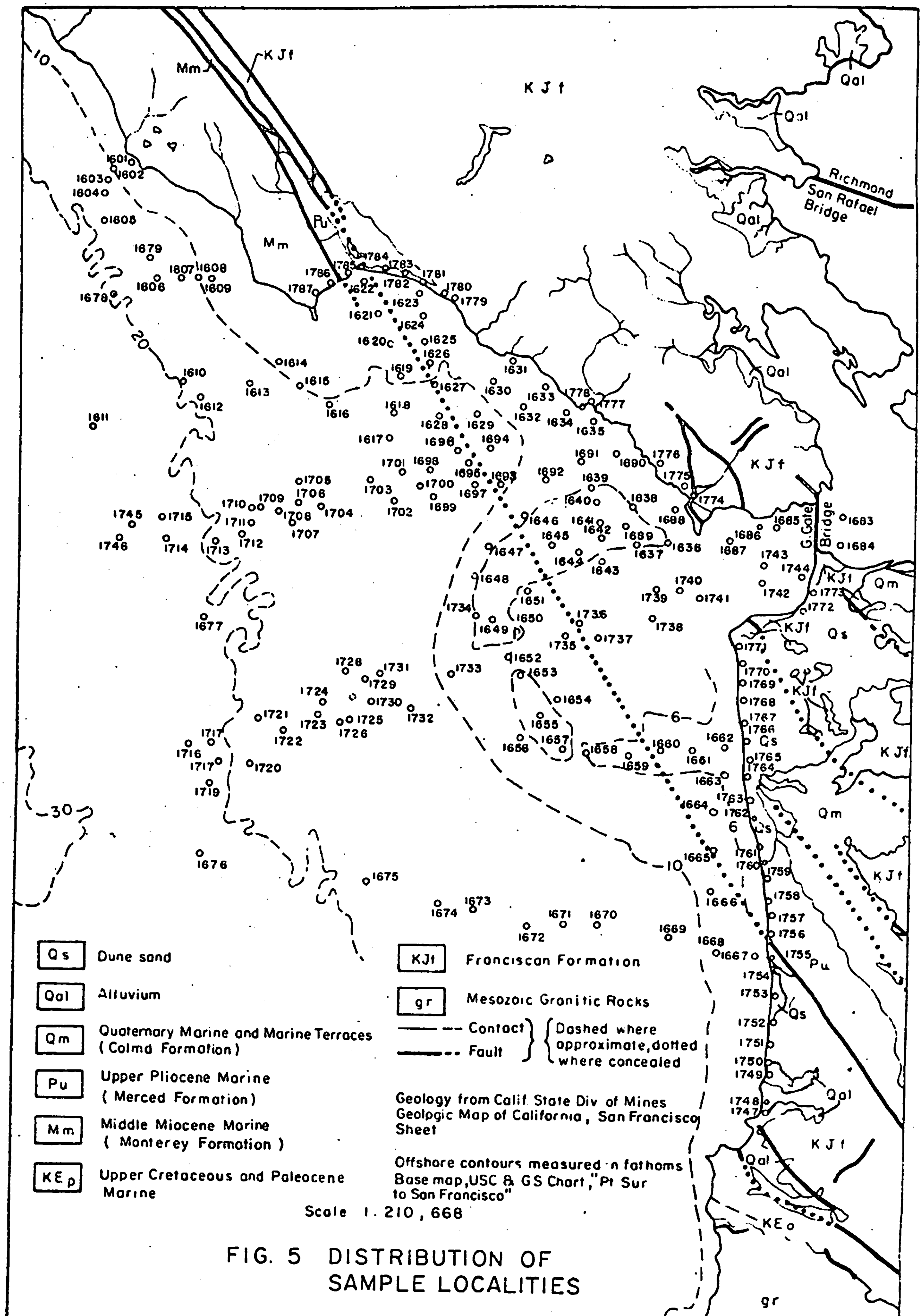


FIG. 5 DISTRIBUTION OF SAMPLE LOCALITIES

Methods of Investigation

All samples, including Trask's, were studied identically. About 250 grams of each sample were split off, washed to remove clay, salt and organic matter, and sieved. Usually seven sieve sizes were used: 53- and 247-micron sieves were always used, and five other sizes were chosen according to the appearance of the sediment. The size fractions were weighed and a grain size curve was constructed for each sample.

Approximately one half gram of the 53- to 247-μ fraction of each sample was split off, and separated into low- and high- density fractions in bromoform. The heavy portion was immediately dried and mounted on a microscope slide. A petrographic microscope was fitted with a mechanical stage with which the slides could be traversed in regular fashion. Traverses were spaced evenly across the slide in such a way that at least 100 grains would be identified. Some samples were so highly altered that several hundred grains had to be traversed in order to identify 100 grains. Another 20 to 25 gram portion of the 53- to 247-micron fraction was split off and separated in bromoform. The light and heavy separates were weighted for a precise measurement of the percent of heavy minerals in the size fraction studied.

Several methods of studying the light fraction were attempted. Some samples were studied petrographically, like the heavy fraction, some were mounted on lucite brickets and stained, and some were studied by x-ray diffraction and in oils. This study of the light fraction was undertaken to determine whether a correlation could be established between changes in heavy mineralogy and changes in the light minerals. Results of the study of the light minerals will be presented in this fashion.

PRESENTATION OF DATA

Physical Properties

The results of the studies of physical properties - grain size, sorting and percent heavy minerals-are recorded on Figures 6, 7 and 8. The general pattern of grain size distribution (Figure 6) is what might be expected in such an area (see Shepard, 1963; and Rector, 1954): relatively high median grain sizes near the coast give away to progressively smaller grain sizes in deeper water. Heavy wave action and steep offshore slopes are probably the cause of the inversion of this pattern in the Double Point area. The tongue of coarse sediment extending westward from the Golden Gate suggests that the influence of the bay and river sediments extends at least as far as the bay bar.

Grain sizes reach minimum values along a line approximately coincident with the 120-ft. depth contour. To the west of this contour, grain sizes rise again. (The five median grain sizes included in parentheses at the left edge of Figure 6 correspond to values published by Trask, et. al. in 1954, but for which no sediment samples could be found. Sorting coefficients for the same samples appear in Figure 7). This information immediately suggests that more than one source, physical environment or period of deposition has been operating. Cherry (1964) felt that wave action at a lower stand of sea level might be responsible for similar grain-size phenomena in the Point Reyes area.

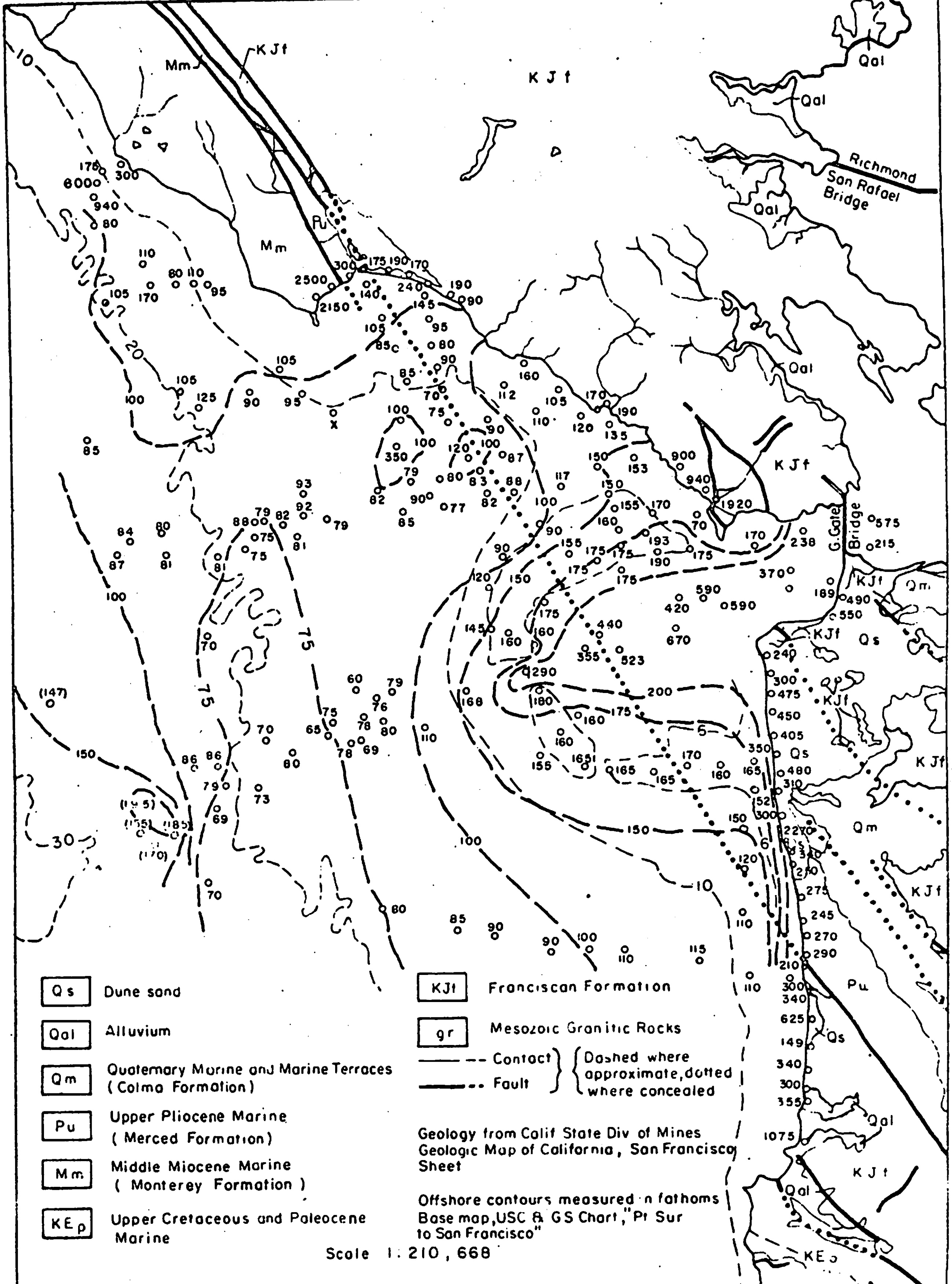


FIG. 6 DISTRIBUTION OF MEDIAN GRAIN SIZES

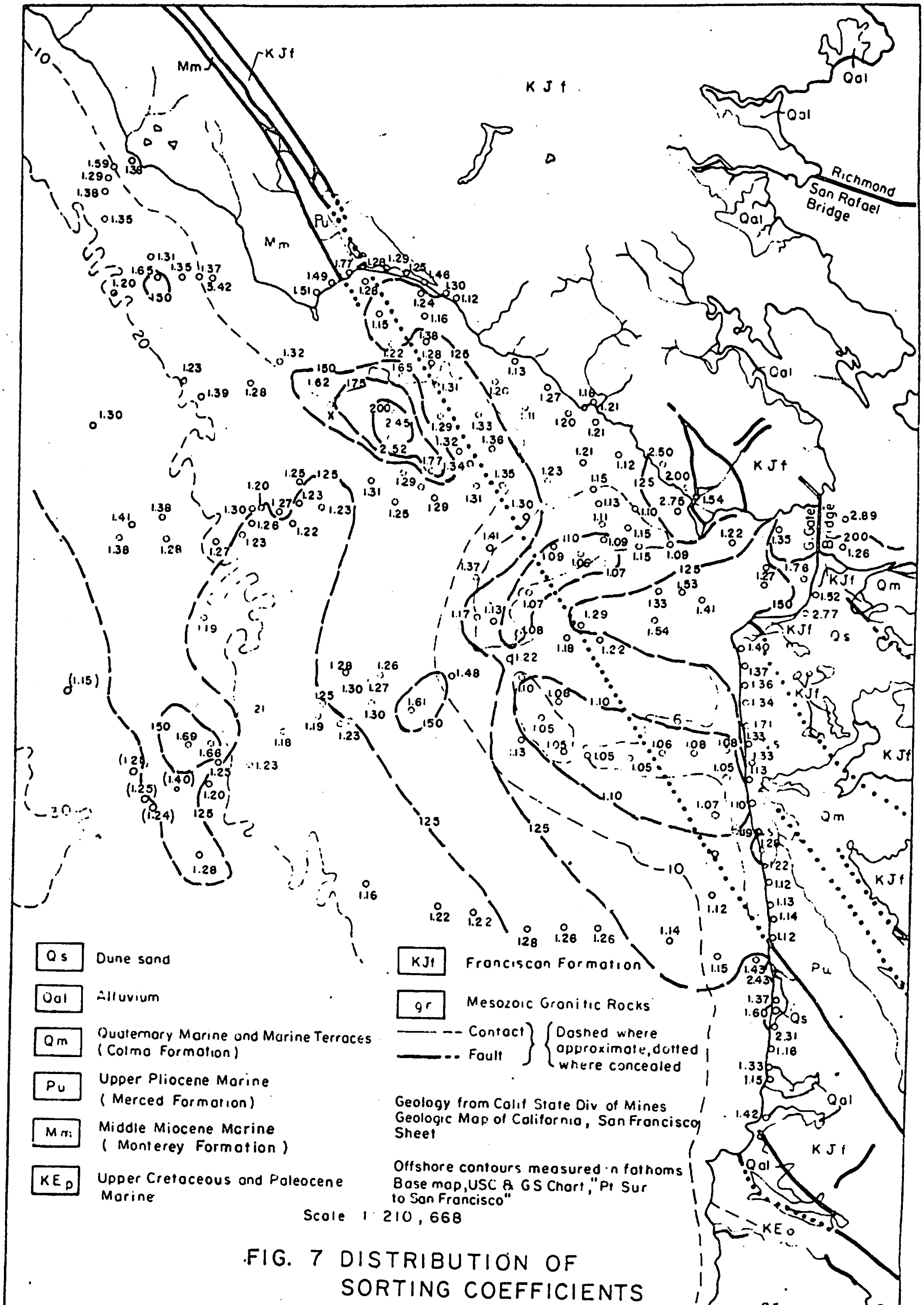


FIG. 7 DISTRIBUTION OF SORTING COEFFICIENTS

Figure 7 shows a rather complex distribution of sorting coefficients (S_o). Values for S_o are high near the Golden Gate, but drop to their lowest values on the bay bar. Sorting coefficients rise and fall twice in zones west of the bay bar; once in less than 120 feet of water and once at greater depths. The well sorted areas on the bay bar and west of the 120-ft. depth contour have median grain sizes between 150 and 200 microns. Inman (1949) has advanced a theoretical justification for sands of this size being better sorted than sands of either coarser or finer grain sizes. Some other reason must be found, however, to explain the presence of the very fine-grained, well-sorted sediments found between the bay bar and the 120-ft. depth contour.

Very high S_o values for a few samples south of Stinson Beach are related to sudden changes in grain size and are probably caused by interaction of coastal and tidal currents. Lack of good sorting from Bolinas to Double Point is probably caused by heavy wave attack and steep slopes. Beach sands along a part of Ocean Beach are somewhat less well sorted than nearby offshore samples, but are generally better sorted than Stetson's (quoted by Hough, 1942) average S_o for beach sands of 1.45.

Percent of heavy minerals decreases in all directions from the southern part of the bay bar. This pattern suggests that the percentage of heavy minerals is in some way associated with proximity to the Golden Gate. It is quite likely that higher percentages of heavies would be found in a coarser sand fraction closer to the Golden Gate and in a finer fraction southwest of the bay bar (see Fig. 8).

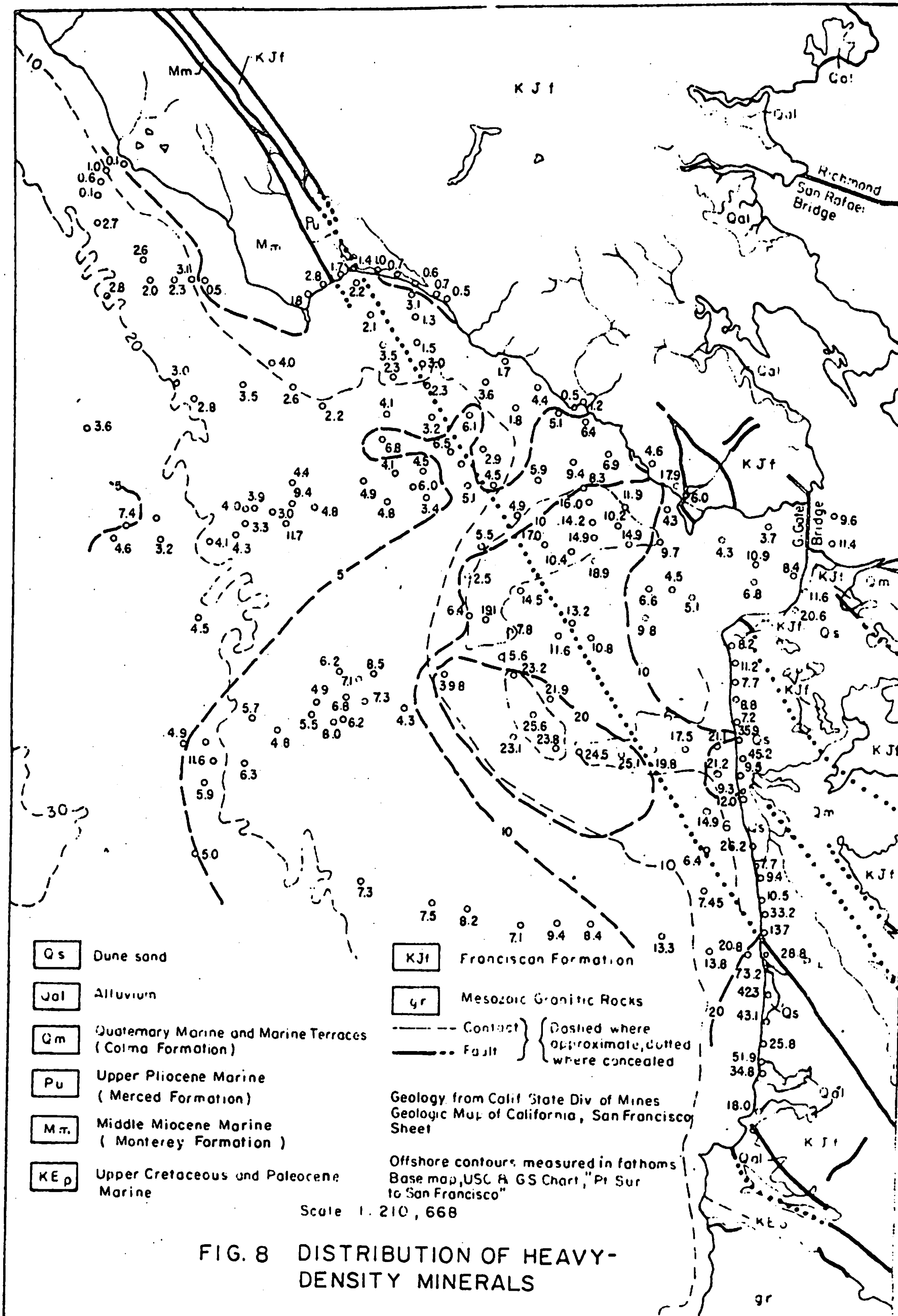


FIG. 8 DISTRIBUTION OF HEAVY-DENSITY MINERALS

Much can be deduced from the physical properties just considered. A change in physical properties coinciding with the 120 ft. depth contour is apparent from the first two maps. Another change in properties may occur just west of the bay bar, based on the sorting coefficient. Finally, the influence of the Golden Gate appears to extend to the south and southwest beyond the bay bar.

Light Minerals

Light minerals from the 53- to 247-μ size fraction of twenty-one samples approximately evenly distributed throughout the area of study were crushed and x-rayed. The purpose of the light-mineral study is to determine whether patterns of distribution found in heavy minerals are reflected in the distribution of the light minerals. Although the light minerals (quartz, mica, and feldspar) are much more abundant than the heavy minerals, the same few light minerals are found in nearly all rocks, making the determination of sources very difficult.

Several prominant intensity peaks appeared on x-rays of most samples. Four of these peaks were identified from standard patterns provided by Dr. R. L. Hay and compared with equivalent peaks from all twenty-one samples. All samples were prepared identically and exposed to the same radiation. Figure 9 shows the intensities of the four peaks studied and the intensity of the background radiation. In some cases, no peak appeared at the appropriate place, and only the background radiation was recorded. The

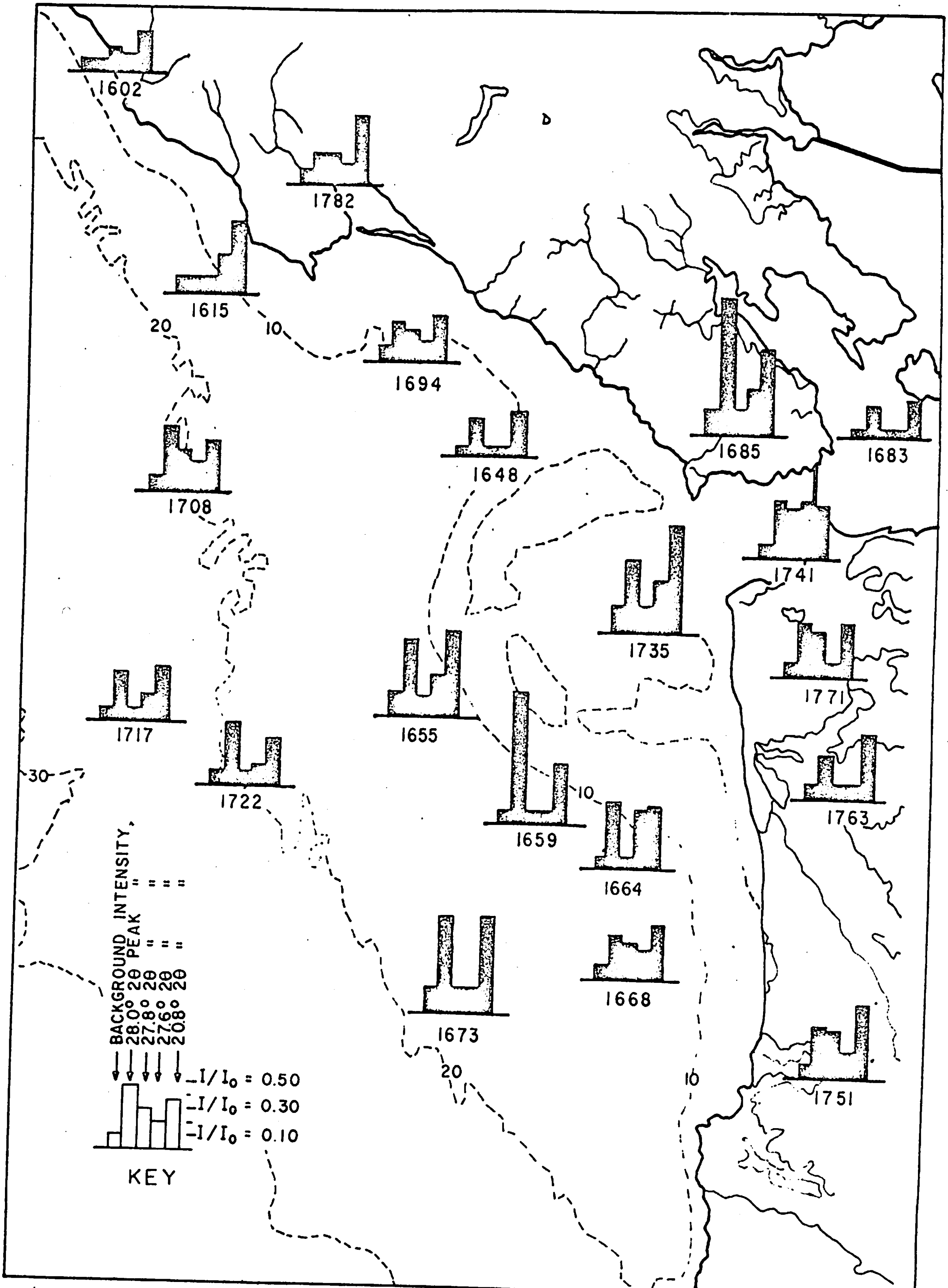


FIG. 9 DISTRIBUTION OF LIGHT DENSITY MINERALS

four peaks studied are those found at 20.8° 2θ (quartz), 27.6° 2θ (orthoclase), and 27.8° and 28.0° 2θ (plagioclase).

It would not be wise to draw conclusions about the distribution of light minerals from such a small study. Figure 8 does show, however, that certain differences in light mineral concentration do occur in the area studied, and some regularities can be found. For example, the ratio of the 28.0° 2θ to 20 8 2θ peak intensities (plagioclase: quartz) is greater than 0.5 north and west of Bolinas; the 27.8° 2θ peak (plagioclase) is found only in samples north of the bar bar and in two samples south of Mussel Rock; and the ratio of the 27.6° 2θ to 20.8° 2θ peak intensities (orthoclase: quartz) is less than 0.5 on and east of the bay bar and in Bolinas Bay, and is higher everywhere else.

It is concluded from these data that differences in light mineral distribution do exist and, with very careful study, would probably be found to reflect quite closely the distribution of heavy minerals.

Heavy Minerals

This study has concentrated principally on the occurrence and distribution of heavy minerals. Although heavy minerals make up only a small part of the total sediment, they are generally easy to identify and are often indicative of restricted source areas. Wherever a diversity of heavy minerals exists and it is possible to place restrictions on heavy mineral sources, much can be said about the history, influence of sources, and long term movement of sediments. The heavy minerals found in this area will now be discussed in the order of their abundance. Besides petrographic descriptions, distribution of each species and inferences of possible sources will be outlined.

Hornblende. Several varieties of hornblende were observed. The most abundant variety is dark-green, highly pleochroic, and prismatic. This variety was found in outcrops of the dioritic Coast Range Batholith at Point Reyes and Bodega Head, and in offshore sands by Cherry (1964). Dark green hornblende is generally subangular to subrounded in outline with prominent cleavage. Typical grains show off-center bisectrix figures, suggesting that the 110 face is parallel to the slide. The larger grains of dark green hornblende are often opaque in the center but thinner and transluscent around all edges. Dark green hornblende occurred in all sizes within the 53- to 247-micron fraction, but tended to be less than 150μ in diameter. The prismatic habit, pleochroism and extinction angle serve to identify this mineral at even the smallest sizes found.

A very highly pleochroic, light brown-to-black variety of hornblende was also recorded. It is generally found in small grains, has less distinct cleavage than the dark green variety and is often more angular. This variety is not common and has been included with dark green hornblende in all grain counts.

Figure 10 shows the distribution of dark-green and brown hornblende. Hornblende is common in nearly every source of the local sediments. For this

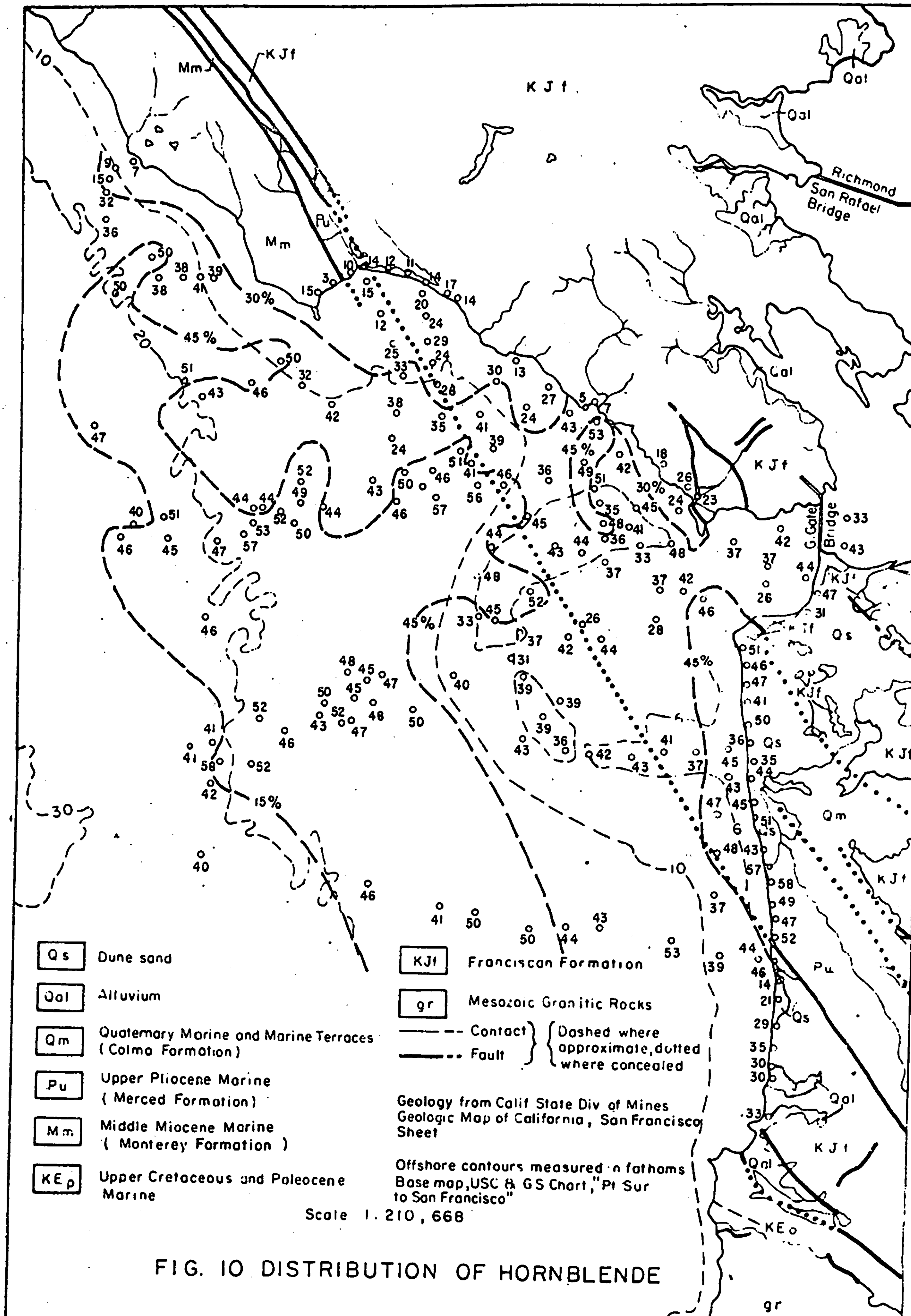


FIG. 10 DISTRIBUTION OF HORNBLENDE

reason it may be expected to make up an appreciable portion of the heavy concentrates throughout the entire area of study. High concentrations of hornblende are shown in Figure 10 along Ocean Beach, in a few samples west of Muir Beach and in a zone trending parallel to the coast under 60 to 120 ft. of water. Hornblende is not concentrated on beaches north of the Golden Gate, however, so the primary source of this mineral does not appear to be the Franciscan formation of the Marin Coast. Hornblende concentration is also low in San Francisco Bay.

Hypersthene. The second most abundant heavy mineral is hypersthene. This mineral has high relief, low birefringence and a striking green-to-orange pleochroism, making it one of the minerals most easily identified. Grains with the 010 face nearly parallel to the slide are not pleochroic, but they do exhibit nearly centered acute bisectrix interference figures. Cleavages are quite distinct on some grains, but nearly absent on others. The typical form of hypersthene is subrounded and prismatic. Most hypersthene grains are in the coarser portions of the sand studied. They are seldom less than 150 microns in diameter.

Many hypersthene grains, particularly those in offshore samples, have serrate terminations parallel to the c axis. Three types of termination could be separated: rounded, showing no evidence of etching; serrate, showing sharp, needlelike terminations parallel to the c axis; and worn, appearing much the same as the etched grains, but having the ends of the terminations rounded off.

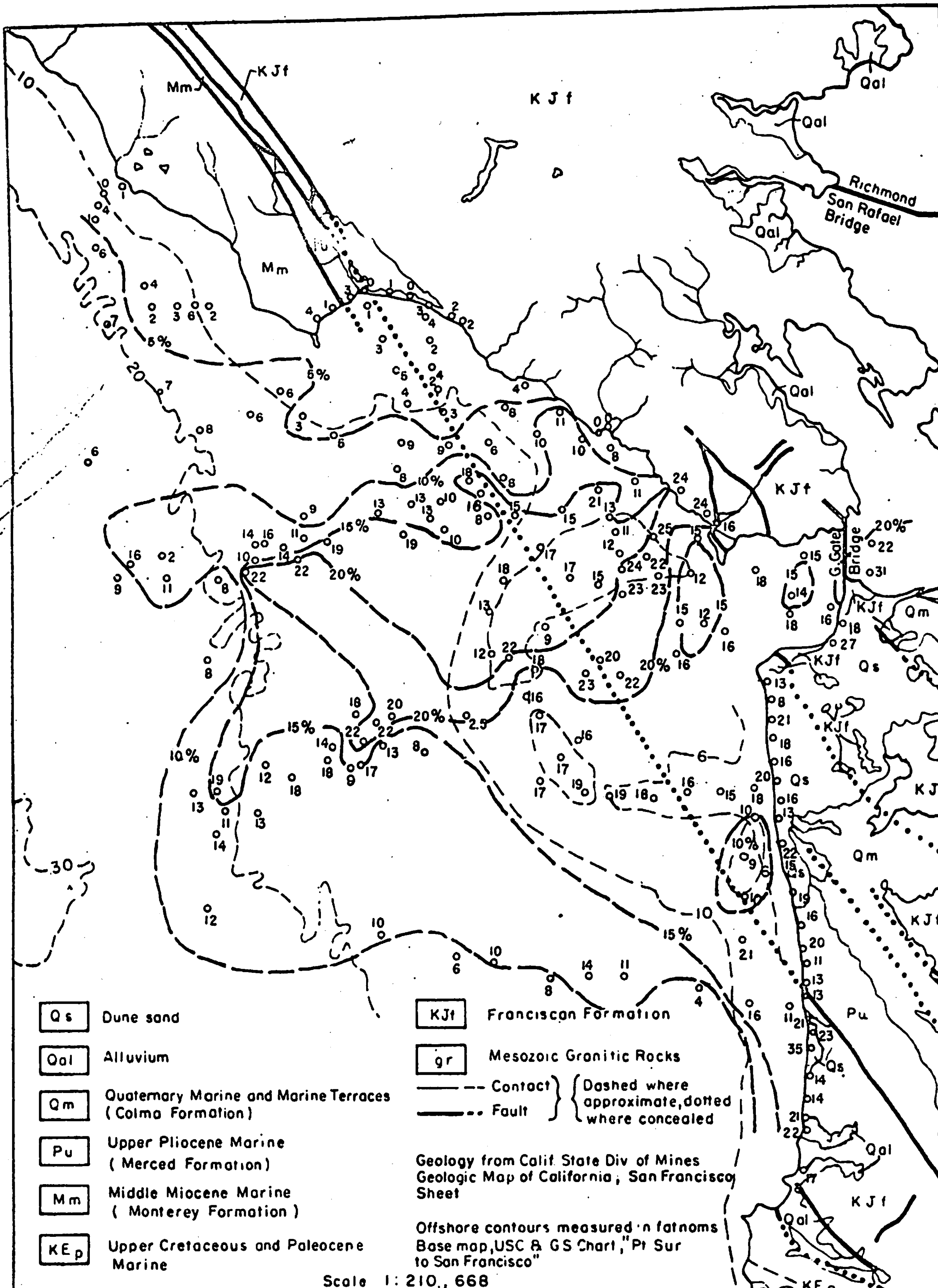
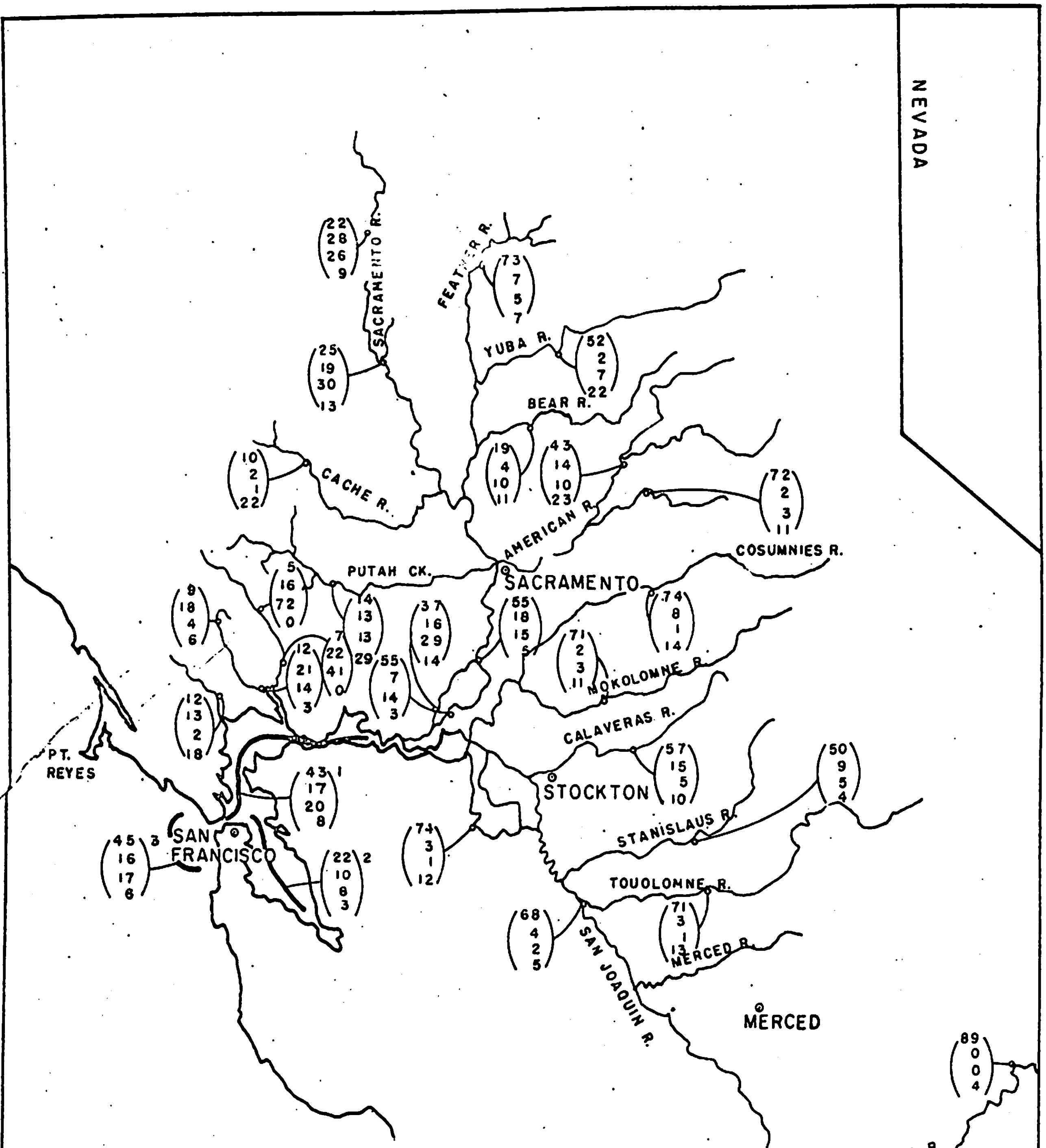


FIG. 11 DISTRIBUTION OF HYPERSTHENE

A careful study of these terminations showed that less than 30% of the hypersthene grains on beaches were freshly etched, but many were worn. In the offshore samples 30 to 100% of the hypersthenes were freshly etched. Hypersthene found in seacliffs south of the Golden Gate is almost always etched and grains found within San Francisco Bay are seldom etched (T. Hall, personal communication, 1965).

Thus, hypersthene which is being deposited west of the Golden Gate is generally etched, but is derived from sources where etching is not common. (Although hypersthenes in the seacliffs are etched, this etching is quickly worn off as the grains work their way seaward across the beach). Thus etching of hypersthene grains may now be occurring under marine conditions in the area of study.

The distribution of hypersthene is shown in Figure 11. Highest concentrations of hypersthene are within San Francisco Bay, on and immediately west of the bay bar, and along the southern beaches. Concentrations decrease regularly to the north, west and south of the bay bar. A few anomalously low concentrations appear between the Golden Gate and the bay bar, but the general pattern of distribution seems to be quite closely related to the Golden Gate. It is quite likely that hypersthene has been selectively sorted around the Golden Gate. Thus, hypersthenes larger than the sizes counted may be concentrated just west of the Golden Gate, and the area only appears to be deficient in hypersthene.



HEAVY MINERALS IN CALIFORNIA RIVERS

DATA COLLECTED BY N. T. HALL, 1964

KEY:
(% Hornblende
% Augite
% Hyperstene
% Epidote)

1. Average of 20 North Bay Samples
2. Average of 3 South Bay Samples
3. Average of 26 Bay Bar Samples (by D. Moore)

FIG. 12 DISTRIBUTION OF HEAVY MINERALS IN CALIFORNIA RIVERS

Table 1. Daily Sediment Contribution to San Francisco Bay[1]

Stream Group	1957-1959 Average Suspended Sediment (Tons) Measured	Estimated Additional	Bed Load (Tons)	Total Sediment (Tons)	1909-1959 Average Adjusted to 1957-1959 Conditions Total Sediment (Tons)
Delta System (Sacramento and San Joaquin Rivers East of Antioch)	12,200	50	1960	14,200	13,800
Suisun Bay (Including Walnut Creek)	320	320	60	700	500
San Pablo Bay (Including Petaluma and Sonoma Creeks and Napa River)	218	580	80	900	1000
San Francisco Bay (Including Alameda, Coyote, San Lorenzo and Stevens Creeks and Guadalupe River)	983	410	140	1,500	800
Total (Rounded)	13,700	1,400	2,200	17,000	16,000

1. From Porterfielt, G. N., et al. (1961) Fluvial Sediments Transported by Streams Tributary to San Francisco Bay Area., Table 12.

Concentrations of hypersthene along the southern beaches could be caused by littoral transport from the Golden Gate or by erosion of the hypersthene-bearing cliffs of the Colma and Merced formations. In an effort to locate the original source of the hypersthene in the Merced Formation, Hall (personal communication, 1964) has sampled channel sands from most of the rivers in the Great Valley. A summary of his findings is recorded on Figure 12. The two rivers supplying noteworthy amounts of hypersthene are the Napa, draining the Sonoma volcanics, and the upper Sacramento, draining the basalts of the Modoc Plateau. A comparison of sediment volume supplied by the Napa and Sacramento Rivers may be seen in Table 1. This information suggests that the latter source is the principle supplier of hypersthene.

Augite. Two types of augite are found in this area. The more common variety is pale green, slightly pleochroic, subround to round, and has moderate cleavage. The other type is purplish-brown to brown, pleochroic, generally angular and has moderate to poor cleavage. Both varities have high positive relief, high extinction angles, and rather high birefringence.

Augite distribution is shown in Figure 13. Combined concentration of brown and green augite increases progressively from north to south. The Bolinas-Marin Coast area north of Muir Beach is characterized by low augite concentration. Augite seems to be highest around the Golden Gate and to the south, but its distribution is somewhat different from that of hypersthene.

When the ratio of brown to green augite is plotted (Figure 14), a distribution pattern very similar to that of hornblende appears. Since brown

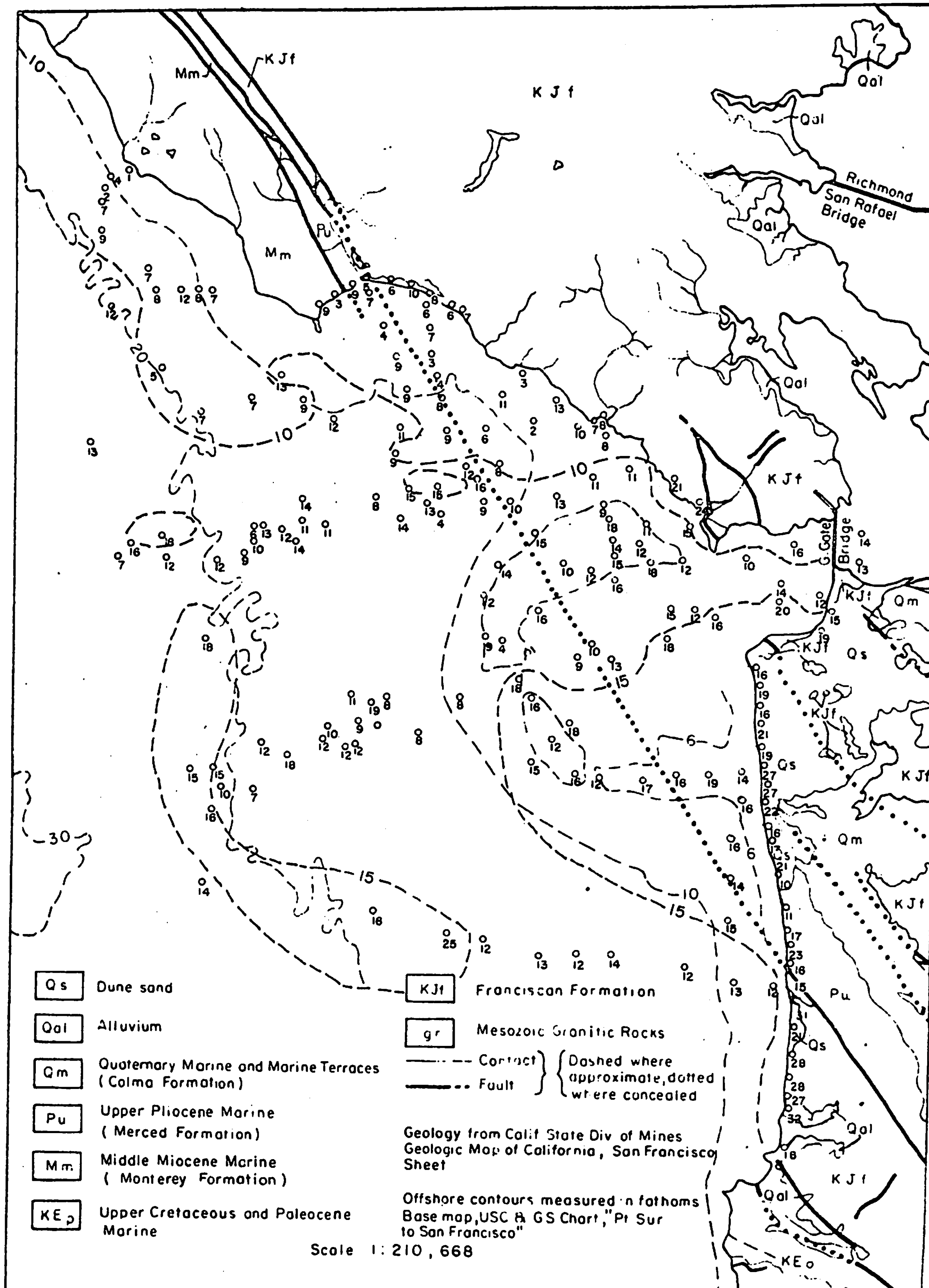


FIG. 13 DISTRIBUTION OF AUGITE

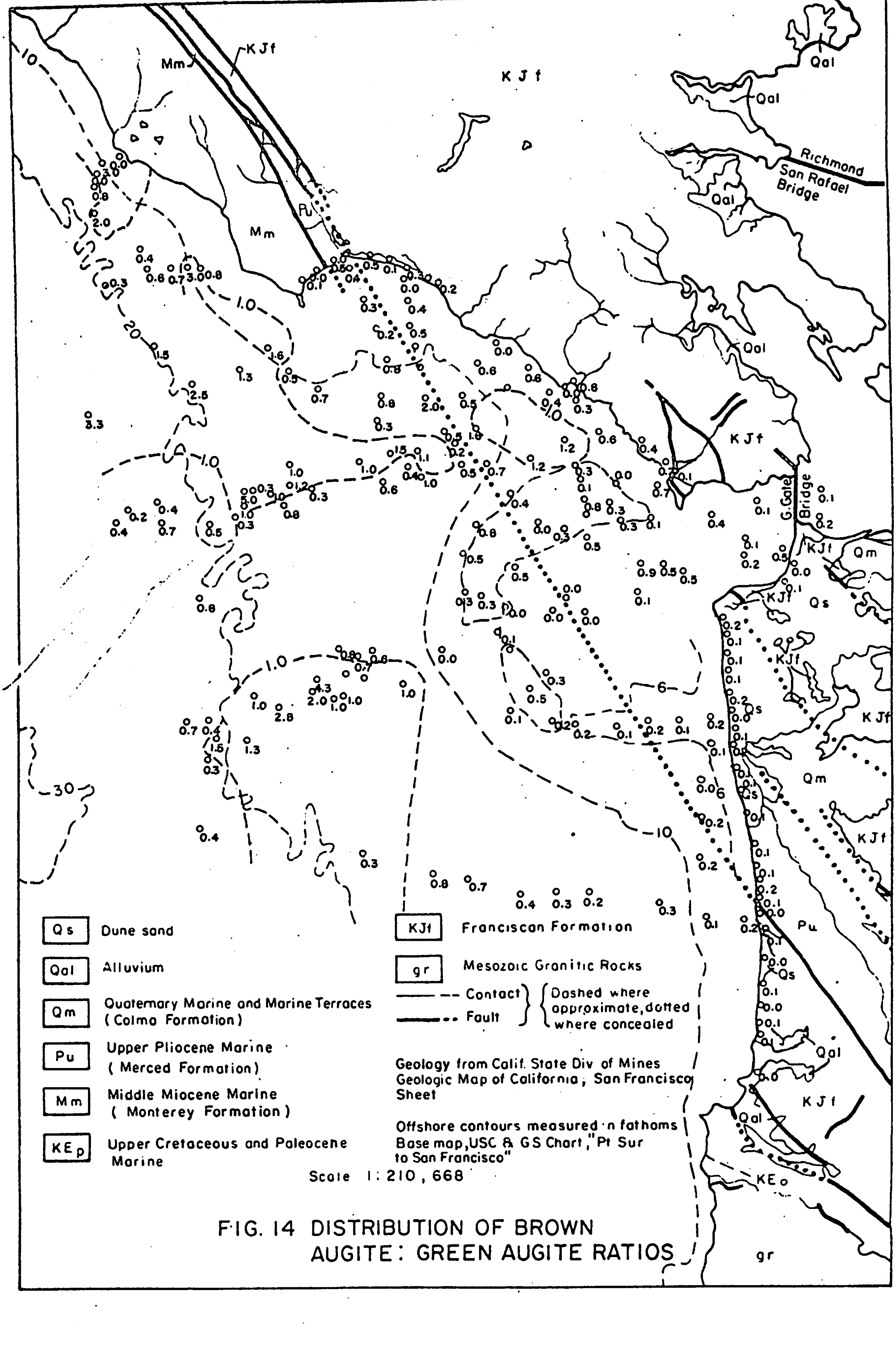


FIG. 14 DISTRIBUTION OF BROWN AUGITE: GREEN AUGITE RATIOS

augite is generally sparse, however, no correlation will be attempted between hornblende and brown augite. The distribution of green augite, when mapped alone, indicates the Marin Coast and the bay as probable sources.

Franciscan minerals. Because they individually occur in relatively small quantities, minerals common to the Franciscan Formation will be considered as a group. The minerals included in this group are karinthine, epidote, glaucophane and actinolite.

Karinthine is blue-green, prismatic and moderately pleochroic. It has a prominent cleavage and is often moderately altered. Murgoci described karinthine in glaucophane schists of the Franciscan Formation in 1908. Bailey (1921) and Johnson (1934) have also noted karinthine in sediments associated with the Franciscan Formation. Chemically, karinthine is an intermediate between hornblende and glaucophane, and was listed as "pale green hornblende" by Cherry (1964).

Epidote is bright yellow-green and usually has about the same shape as green augite. However, epidote has higher relief and is more pleochroic than augite and is straight-extinguishing. Cleavage is slightly better on epidote than augite. The few grains of zoisite and clinozoisite that were observed were counted with epidote.

Glaucophane is distinguished easily by its purple-to-blue pleochroism, low relief, low extinction angle and low birefringence. It has the single cleavage and tabular shape of most of the other amphiboles. Actinolite shares the characteristics of the other amphiboles, but it has green-to-

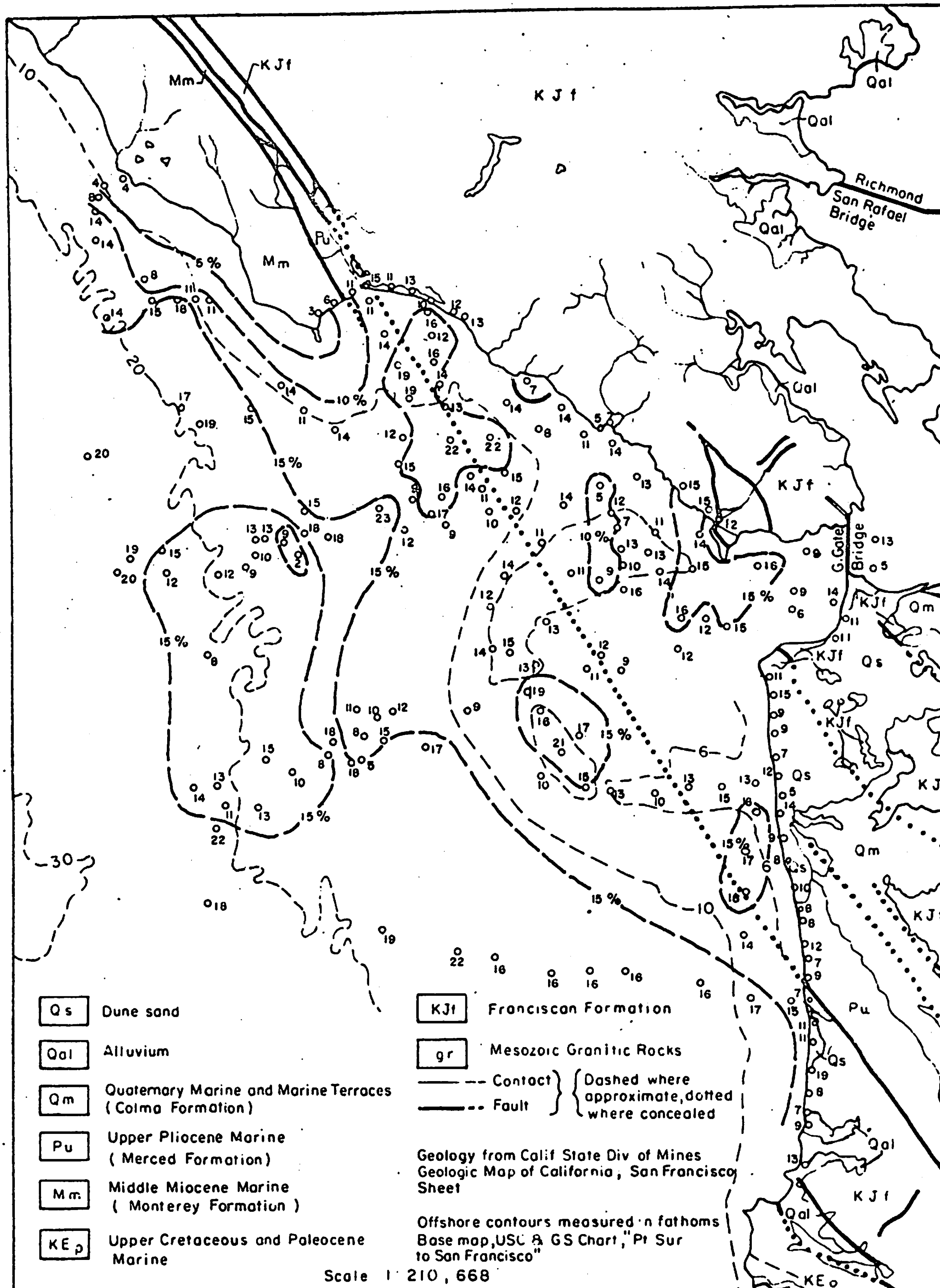


FIG. 15 DISTRIBUTION OF FRANCISCAN MINERALS

colorless pleochroism.

Figure 15 shows the distribution of the Franciscan minerals. This group is quite sparse around Duxbury Point and the Golden Gate. It reaches its maximum concentration in Bolinas Bay, and along the southern and western borders of the area of study. Since these minerals are not particularly concentrated along the Franciscan cliffs of the coast south of Mussel Rock or Marin County, it must be assumed that these areas are not now contributing significant quantities of sediment to the beach or littoral zone.

Aragonite. Aragonite was found in the Double Point and Bolinas Bay areas, just south of Cherry's (1964) "carbonate zone". Carbonate fragments are distinguished by their high birefringence and extreme change of relief. Grains are buff to colorless and occasionally are stained dark brown. All stages of rounding were observed. Some grains, up to 200 microns in diameter, are optically continuous. Another common type of grain is composed of several 25- to 50-μ diameter pathces of optically homogeneous carbonate, and a third type is microcrystalline. Interference figures, when observed, are uniaxial or biaxial with a low 2V. All of these textures were also seen in slides of fragments of mollusk shells from the Bolinas area.

Aragonite is practically restricted to Bolinas Bay and the Bolinas Coast (Figure 16). Since no important source of heavy carbonate is known in the coastal formations (Weaver, 1949; Galloway, 1962) an organic origin was theorized. (Shells and shell fragments make up much of the larger size fractions of Bolinas Coast and Bay samples). A portion of the heavy carbonate

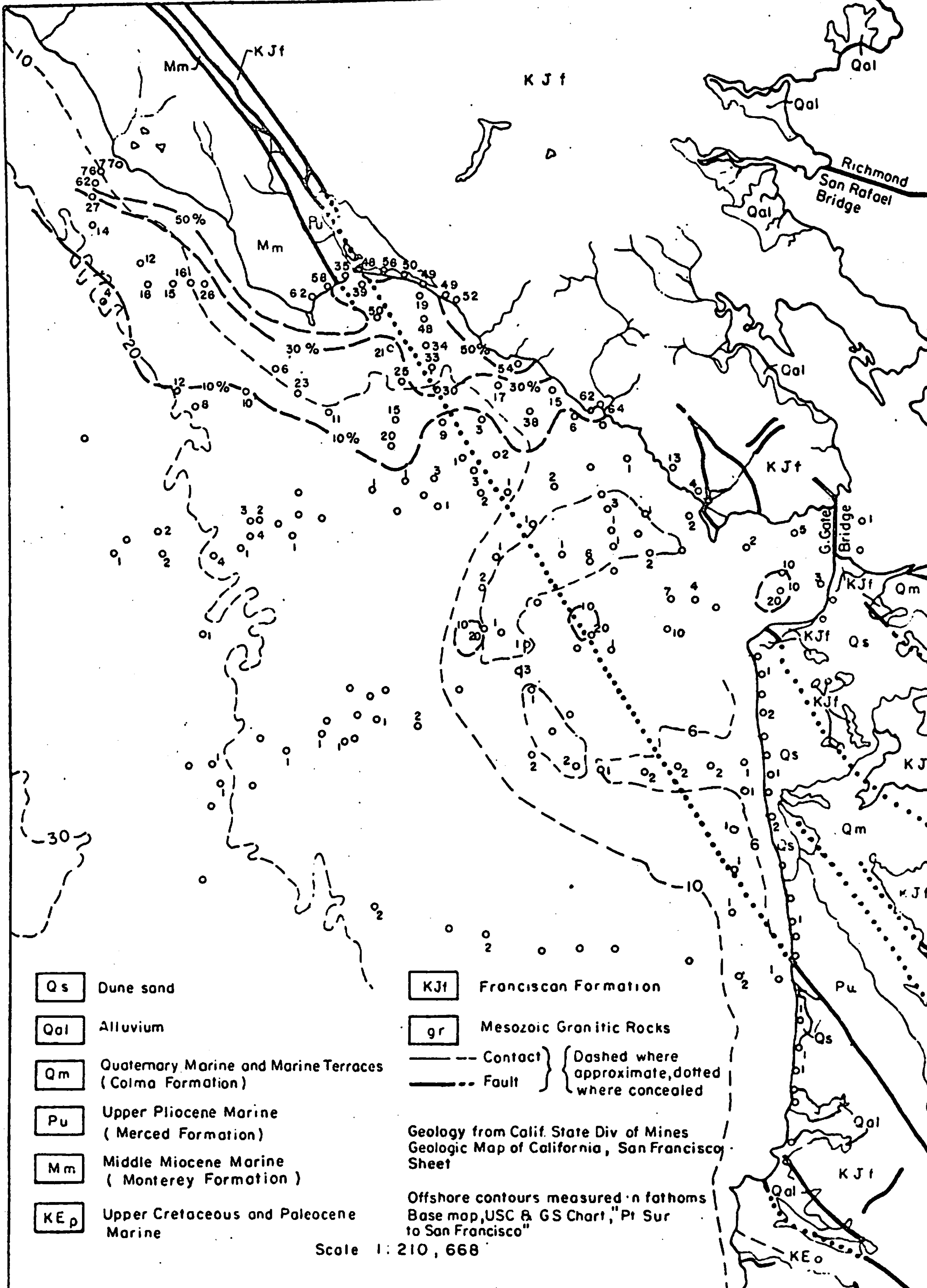


FIG. 16 DISTRIBUTION OF ARAGONITE

from the 53- to 247-μ size fraction was crushed and x-rayed. It was found to contain only aragonite. Following this, shells of several species of mollusks and a brachiopod were extracted from field samples, identified and x-rayed. The gastropods *Crepidula nummaria* (Gould), *Nassarius mendicus* (Gould) and *Olivella pedroana* (Conrad) were found to have pure aragonite shells. A gastropod, *Tegula*, sp., and a brachiopod *Tetrabratalia transversa* (Sowerby) were found to have pure calcite shells.

No effort was made to insure that the species x-rayed were in any way representative of the entire invertebrate population. The primary purpose of the x-ray study was to demonstrate the presence of organisms capable of producing the types of carbonate found in the sands of this area. From this study it would appear that local modern invertebrates are an adequate source of the calcareous sands.

Minor and accessory minerals. For the purposes of this study, minor minerals are those making up one to six percent of the total sediment. Accessory minerals are those that make up less than one percent of the total. The four minor heavy minerals observed are biotite, sphene, zircon and garnet. Biotite typically occurs in large (150- to 250-μ), dark brown plates. These plates are thin and rounded and show uniaxial interference figures. Biotite makes up about six percent of the total sediment but does not appear to have a systematic distribution indicative of any particular source.

Sphene occurs in subround to subangular grains and makes up about two from the 53- to 247-μ size fraction was crushed and x-rayed. It was found to contain only aragonite. Following this, shells of several species of mollusks and a brachiopod were extracted from field samples, identified and x-rayed. The gastropods Crepidula nummaria (Gould), Nassarius mendicus (Gould) and Olivella pedroana (Conrad) were found to have pure aragonite shells. A gastropod, Tegula, sp., and a brachiopod Tetrabratalia transversa (Sowerby) were found to have pure calcite shells.

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Sphene occurs in subround to subangular grains and makes up about two percent of the total sediment. It has approximately the same color as argonite, but has much higher relief. Sphene is found most regularly and in largest amounts near the Golden Gate. Its major sources are probably drained by tributaries of San Francisco Bay.

Zircon is usually found in small, pitted or abraded subhedral grains. It is most common in northern parts of the area of study and is probably derived from Point Reyes as suggested by Cherry (1964). The amount of abrasion is much greater than that seen by this writer in Cherry's samples from the Pt. Reyes area. Garnets are found in all parts of the area of study and make up about one percent of the total sediment. They are typically round and pink or orange in color. Garnets are easily identified by their color, relief and isotropism.

Apatite, oxyhornblende, diopside, jadeite, lawsonite, pumpellyite and tourmaline are the accessory minerals found in this area. Cherry (1964) ascribed a plutonic origin to the apatite found just north of this area. Hall (personal communication, 1964) has found tourmaline in rivers draining the Sierras. All the other accessories are probably derived entirely from the Franciscan Formation. Some species were originally tabulated separately, but they are all included as "other minerals" in the final tabulation. Distributions of the accessory minerals were studied, but no meaningful patterns could be developed.

Selective Sorting

In 1953, Van Andel described the effects of four parameters on the distribution of heavy minerals. Of these four - abrasion, weathering, solution, and sorting - only the latter two are likely to have any effect upon the sediments studied. Cherry's work (1964) in the Drake's Bay area indicates little movement of sediments along the coast by littoral currents, suggesting that abrasion must be minimal. Since sediments introduced through the Golden Gate are compared only with those sediments inside the bay, abrasion taking place in the inland rivers would not influence this study. The youth of the sediments involved suggests that weathering or solution (except on hypersthenes) should be minimal in the marine environment. Etching of hypersthene, apparently the effect of solution in this environment, occurs more or less regularly throughout the offshore area, effecting the absolute concentration of that mineral, but not the relative concentrations considered in this study.

Because hydraulic conditions are so diverse in this area, the effects of hydraulic sorting have to be carefully considered. The heavy minerals studied vary considerably in size (53 to 247 μ), shape (spherical to platey) and density (ρ = 2.9 - 4.3 gm/cc). The ability of flowing water to transport sand grains depends largely on these properties.

Tests were devised to determine whether any important mineral is restricted to a particular size range within the 53- to 247-micron fraction. All samples were plotted on a graph of median grain size (D_m) against sorting coefficient (S_o) on Figure 17. Samples are identified only by the petrographic

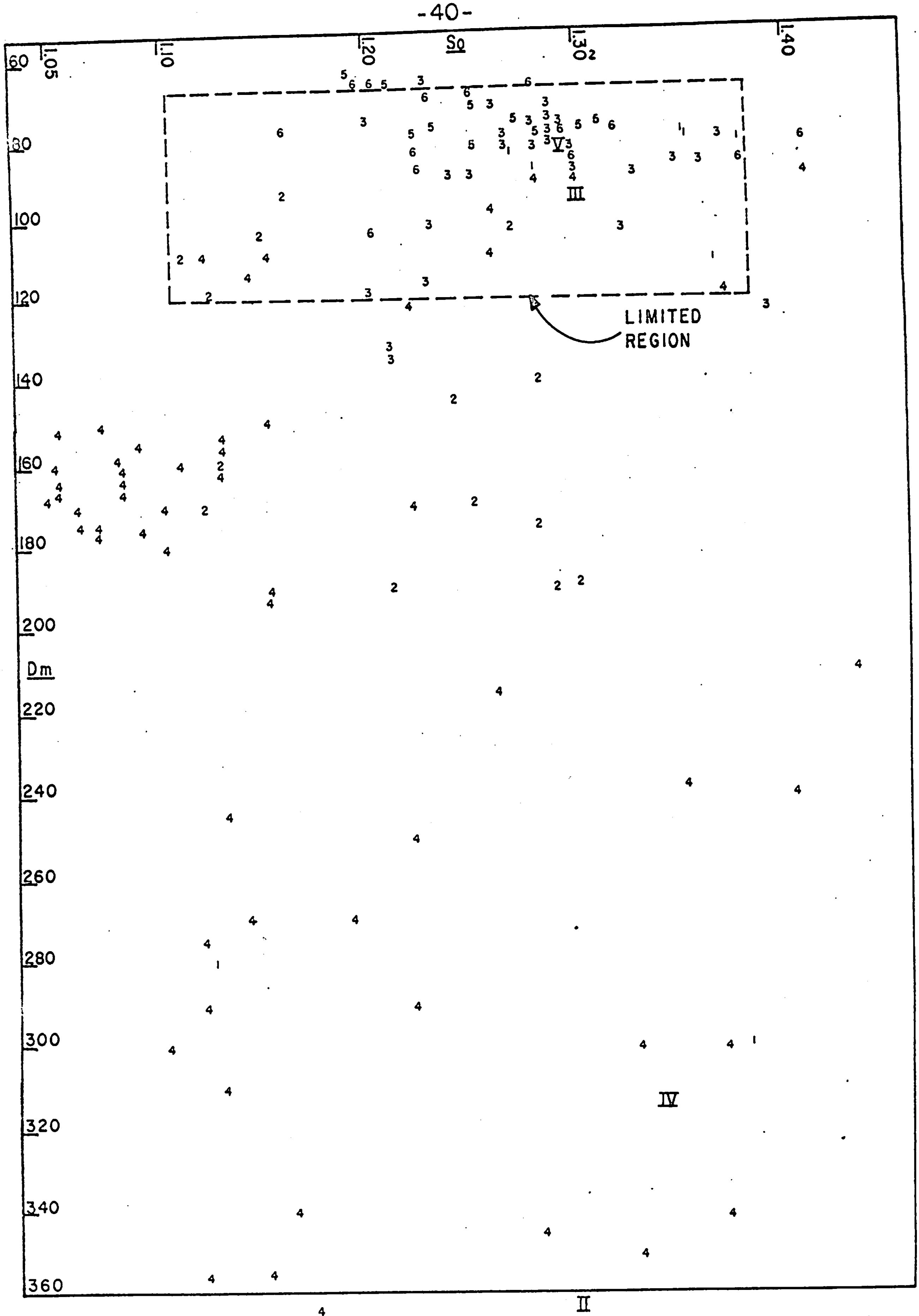

FIG. 17 MEDIAN GRAIN SIZE (Dm, IN MICRONS) vs SORTING COEFFICIENT (So). NUMBER 1 TO 6 INDICATE PETROGRAPHIC PROVINCES TO WHICH SAMPLES HAVE BEEN ASSIGNED. ROMAN NUMERALS INDICATE PROVINCE AVERAGES NOT ALL SAMPLES ARE SHOWN

provinces into which they were placed on the basis of mineralogic and physical similarities (see Figure 21). A small area on the graph was outlined and the characteristics of mineral species in a "limited area" were compared with the characteristics of all samples from each province.

The results of this test are shown on Figure 18. The range bounded by median grain sizes of 70 and 120 microns and by sorting coefficients of 1.11 and 1.30 was chosen to be the "limited area" because a significant number of samples from each petrographic province is included. Similar tests were made on other limited areas. Although the range of grain sizes included makes up less than 5% of the total, and only 13% of all sorting coefficients are included, about 30% of all samples are represented.

The range and average percent concentration of each heavy mineral species were computed for the samples from each province. Subsequently, the same characteristics were determined for the samples from each province which are found within the limited area shown on Figure 17. Close agreement between characteristics of any mineral species in samples from any province found within the limited area and all samples from that province indicates that concentration of the species studied is not dependent upon grain size or degree of sorting. That is, the heavy mineral species studied is not selectively sorted in that province.

Each symbol on the graphs in Figure 18 may be described as follows: The range of percents of the given mineral species for the entire province is represented by the longer vertical line on the left side of the rectangle,

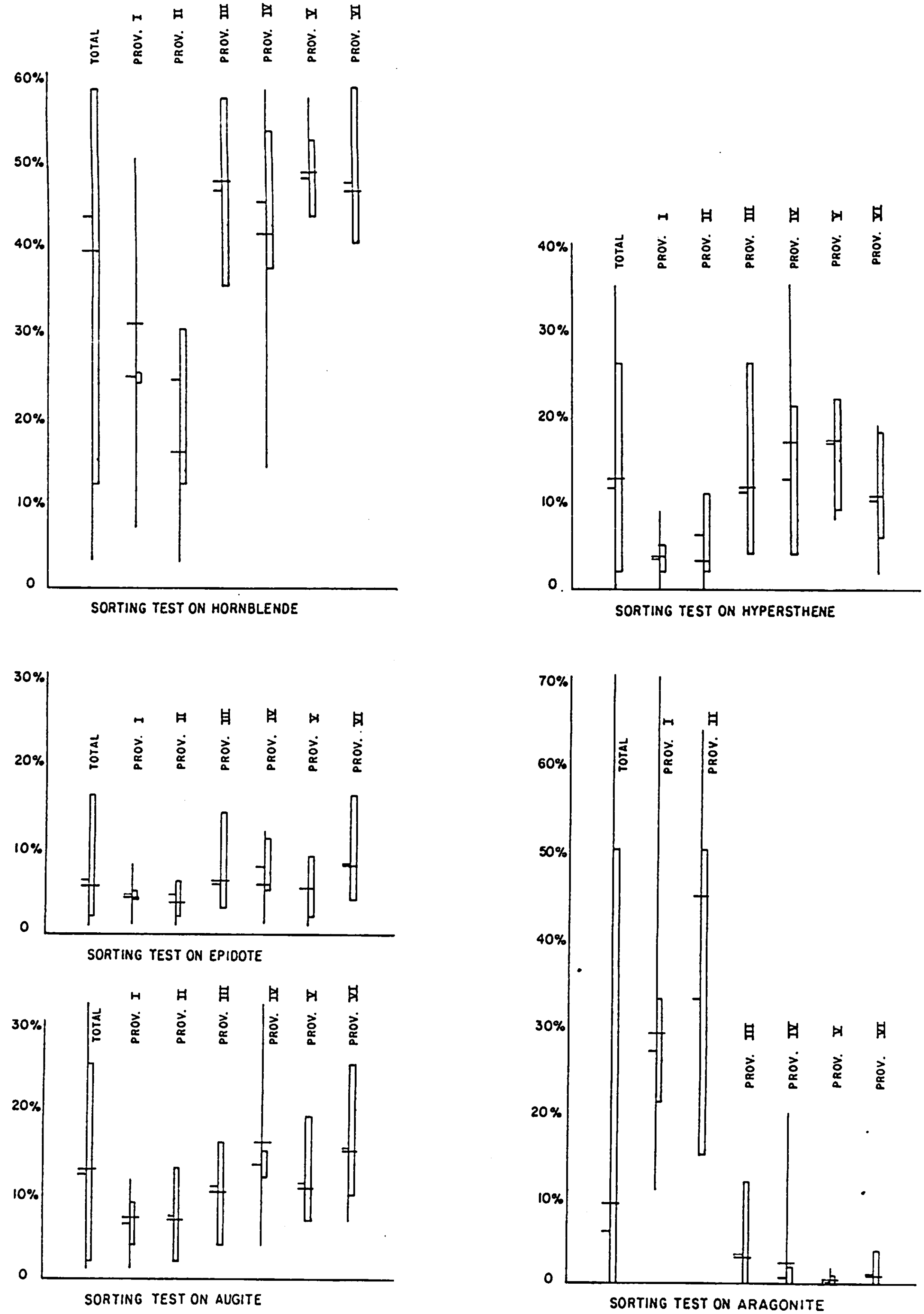

FIG. 18 SORTING TEST: RELATIONSHIP OF HEAVY MINERAL ABUNDANCES IN SAMPES WITH D_m = 70-120μ AND S_o = 1.11-1.30 TO ABUNDANCES ALL SAMPLES

and the average percent for the entire province is represented by the longer horizontal line. The vertical line on the right side of the rectangle and the shorter horizontal line represent corresponding values for those samples from the province included in the limited area shown on Figure 17.

Only in provinces II and IV (see Figure 21) is there significant variation between mineralogies of the limited group of samples and the whole province. Most of the variance in province II is due to characteristics of a few samples at the southern edge of this province. Samples 1630, 1632 and 1633 reflect influences of both provinces II and III. There are not enough of these "transitional" samples to form a separate province, so these three must be included in the province they most closely resembel. If these transitional samples are removed and the sorting test is again applied, there is very little divergence between the limited sample and the entire province.

Nearly all heavy minerals in the province closest to the Golden Gate exhibit some degree of selective sorting. In view of the rapid dispersal of energy in the relatively open area west of the very constricted Golden Gate channel, this is not surprising. Since no evidence of selective sorting is found west of province IV, it must be assumed that the effects of selective sorting produced by the tidal currents through the Golden Gate do not extend more than six or seven miles away.

Since average D_m and S_o vary considerably between provinces, and the limited samples still reflect the compositions of the entire provinces (with exception of province IV), no important heavy mineral must be restricted to a

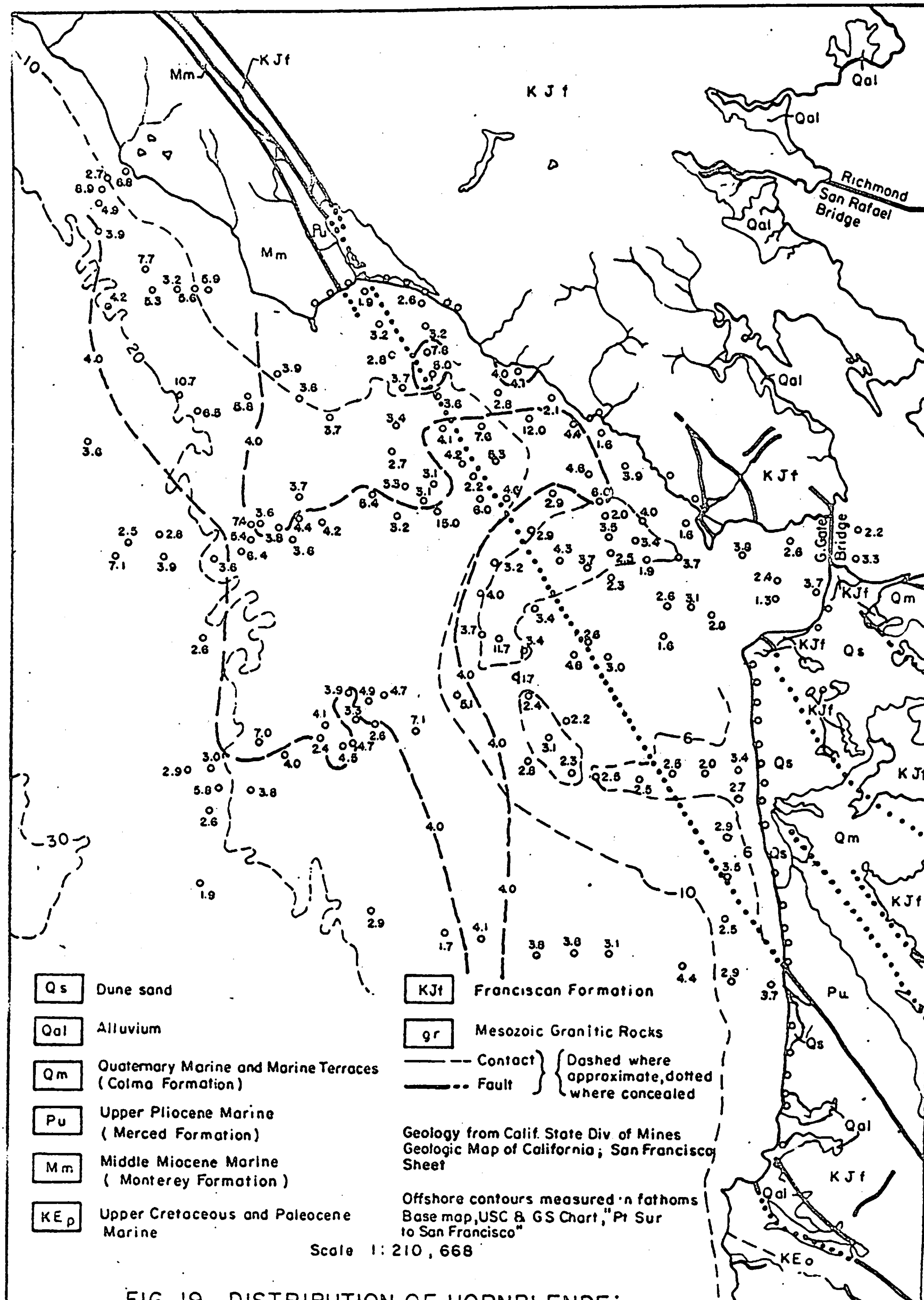

FIG. 19 DISTRIBUTION OF HORNBLENDE: AUGITE RATIOS

size range within the 53- to 247-micron fraction.

Mineral Ratios

It is important to remember in all of the above discussions of mineral distribution that the percent concentration of any one mineral species is dependent upon the concentrations of all other species. However, it has been shown that the Golden Gate and the adjacent coastline supply combinations of minerals to the littoral zone. Because of this, it is necessary to investigate changes in ratios of minerals as well as changes of individual species. If two minerals are being supplied by some source and respond the same way to different hydraulic conditions, their ratio should remain approximately constant anywhere they are transported unless another source is providing a different ratio of these minerals to the same area.

The three most abundant minerals in the area of study - hornblende, hypersthene and augite - are approximately equal in density, size and shape, and should therefore respond quite similarly to any given hydraulic conditions. The ratios of hornblende to augite are distributed in much the same way as the percentages of hornblende (Figure 19). A zone of high hornblende:augite ratios is confined by the 120-ft. depth contour on the west and extends to the coast at Muir Beach. The bay bar and all beaches except Muir Beach are areas of low hornblende:augite ratio. . One may assume then, that sediments being supplied by San Francisco Bay and most of the coastal cliffs have relatively low hornblende-to-augite ratios.

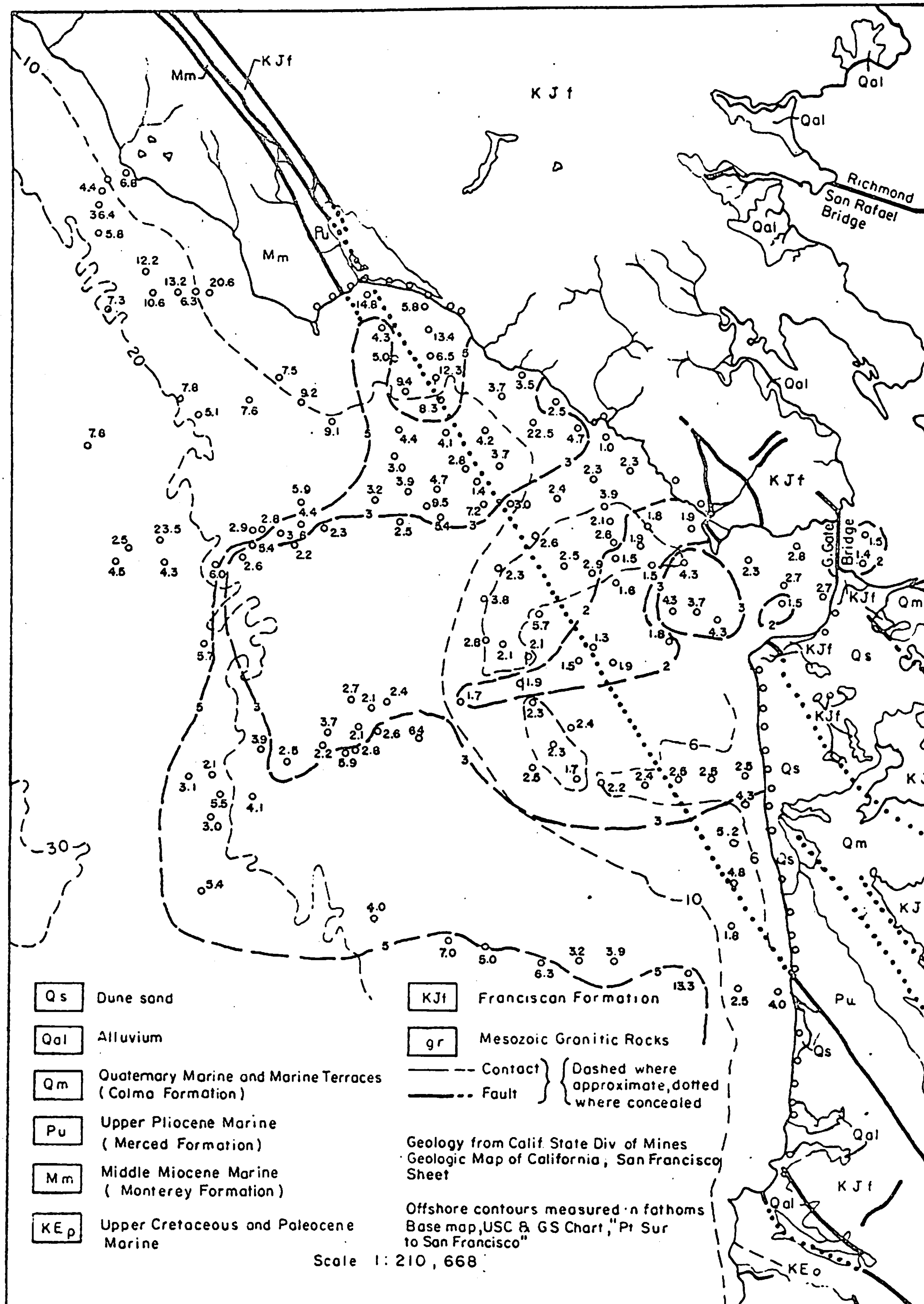

FIG. 20 DISTRIBUTION OF HORNBLENDE: HYPERSTHENE RATIOS

The ratios of hornblende to hypersthene further serves to relate hypersthene to San Francisco Bay. Figure 20 shows moderate to low hornblende: hypersthene ratios extending westward from the Golden Gate to the 120-ft. depth contour. A portion of the high hornblende: augite ratio area shown in Figure 18 is overlapped by this zone of low hornblende: hypersthene ratios.

Several other mineral ratio diagrams have been drawn comparing hornblende and hypersthene with green augite only and with the sum of the Franciscan minerals, and the latter two with each other. Patterns of distribution in these diagrams reflected essentially the same changes shown in Figures 18 and 19. If the heavy mineral distribution in the area of study is a reflection of the interaction of only a few sources, some of which have been shown to be relatively minor, such a simple, repeated pattern as this should appear.

INTERPRETATION

Petrographic Provinces

From the data presented above, it is now possible to outline areas of petrographic and physical similarity. Such areas will be interpreted as corresponding to Edelman's sedimentary petrologic provinces (see Cherry, 1964), p. 43, footnote). Edelman defined his provinces as groups of sediments which constitute natural units by age, origin and distribution. Since boundaries based on any one criterion cross those based on any other, divisions are made when any major characteristic changes significantly.

The area north of Duxbury Point, and Bolinas Bay, form a natural unit by virtue of the high concentration of aragonite in that area. A limit has been drawn around this area bounded by the coast and the fifteen-percent aragonite contour. This high carbonate area is split into two provinces, one with a high hornblende:augite ratio (province I) and one with a low ratio (province II). Aragonite concentration is higher in province II than in Province I (see Figure 21).

Another area, rich in hornblende and having a high hornblende:augite ratio, is bounded by the carbonate-rich provinces on the north, the bay bar on the east, and by the 120-ft. depth contour on the south and west. This area is split into two provinces on the basis of the hornblende:hypersthene ratio. This ratio is moderate in province III and quite low in province V.

Province IV includes all the southern beaches and the bay bar. This

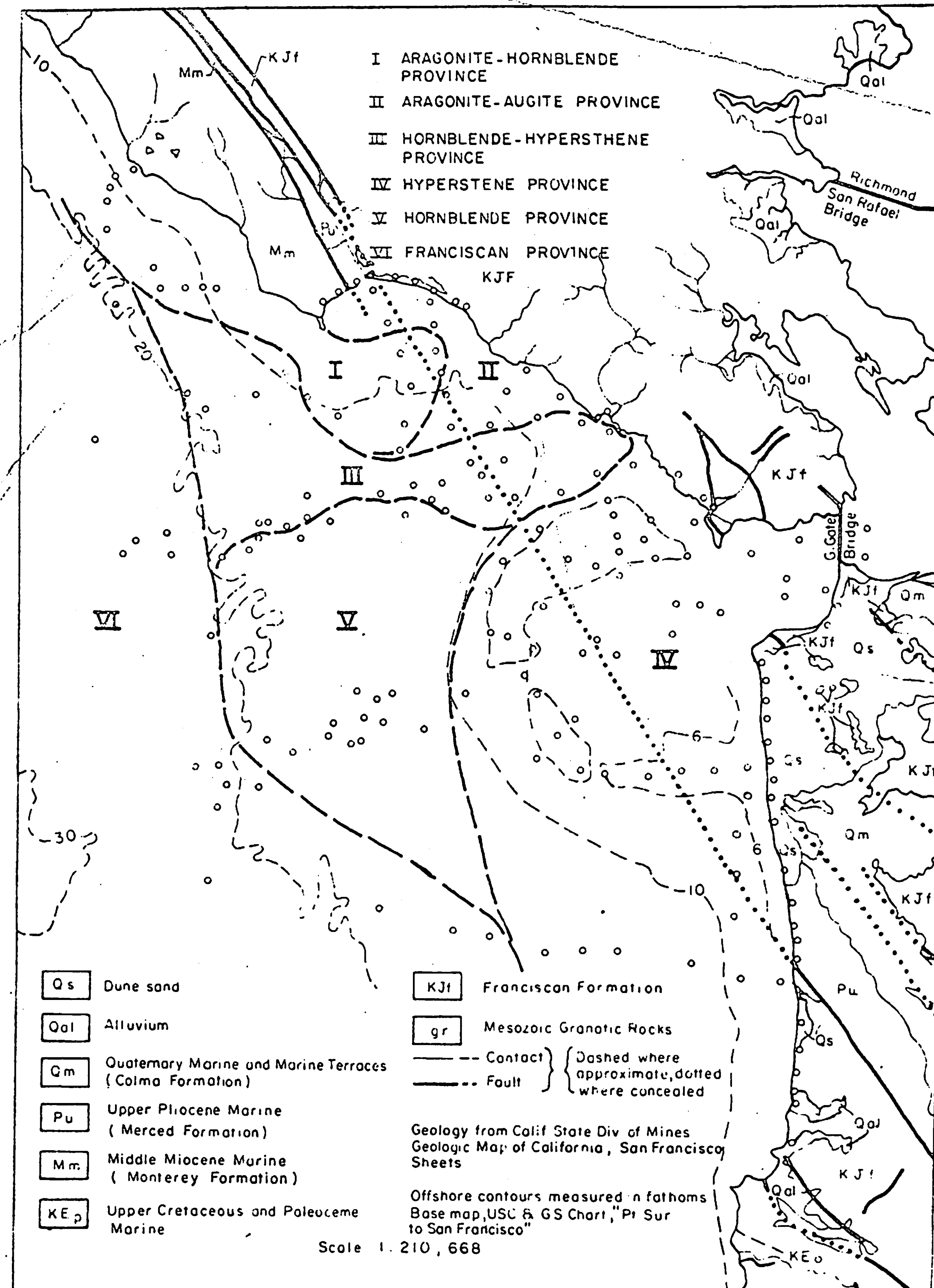

FIG. 21 SEDIMENTARY PETROGRAPHIC PROVINCES

province could be divided into two parts where the hornblende:hypersthene ratio equals 3, but sufficient similarity exists throughout the entire area that it will remain one province. What changes do occur in this province are more gradual than those upon which province boundaries are drawn.

Province VI, lying almost wholly in water more than 120 feet deep, is characterized by low hornblende, hypersthene and carbonate concentrations. In comparison with the other provinces, this one is rich in Franciscan minerals. Like province V, province VI has no connection with the modern coast.

For the most part, the distribution of sediments in the area of study appears straightforward. Most of the heavy minerals of the Bolinas area are apparently derived from local aragonite-producing organisms. The sediments on the bay bar are very similar to those in San Francisco Bay's channels, and must have been derived in large part from the bay. Although contributions from the Colma Formation and later sands may also be present, movement of these sands has been inland much of the time. Movement of what little sand is contributed by cliffs south of the bay bar is mostly to the south.

The areas of high hornblende concentration (provinces I, III and V) are not apparently related to any single source, except along the Bolinas coast. Sandy shales of the Bolinas area Monterey Formation contain considerable quantities of small hornblende grains. If the source of these sands were the Monterey shale, the well sorted zone with an unusually low median grain size discussed on page 8 could also be explained. Since Recent and Pleistocene sediments on the California shelf are generally thin, and terraces below the present sea level are well known along other parts of this coast, it is proposed that this area of high hornblende concentration represents the erosional products of a terract cut by wave action in hornblende-rich sediments of the Monterey Formation. Weaver (1949) and other authors have derived the Monterey shale from the underlying, hornblende-bearing, Coast Range Batholith, and the present writer has observed many small (50-100 μ) hornblende grains in shales from the Bolinas area.

The mineralogy of province VI closely approximates the "deep water" sediments described by Cherry (1964) just north of the area of study. Since aragonite in province I and hypersthene in provinces III and V decrease in abundance rather quickly near the 120-ft. depth contour, it is proposed that sediment transport is not now taking place in water more than 120 feet deep. Thus, as Cherry proposed for such sediments in the area to the north, the sediments of province VI represent an earlier stage of deposition when the sea was at a lower level.

In November, 1964, Imbrie and Van Andel published information concerning the use of vector analysis on heavy mineral data. The authors believe this method will be very helpful in determining influences of sedimentary sources in areas of complex mineralogy. The methods obtained by Imbrie and Van Andel are essentially those used in this study. That is, "end-member mineralogies" are determined for all sediment sources and all samples in the area of study are related to these end members. Had a formal vector analysis been made of the data obtained in this study, probably very few changes would be made in the outlines of petrographic studies.

Recent Geologic History

The data and interpretation presented thus far provide a basis upon which a sedimentary history of this area may be constructed. This history is necessarily sketchy because only the surface sediments were examined. The following sequence of events is suggested by the information derived from local surface sediments and inferred from these sediments and from data published on other nearby areas.

1. During the last major ice age (15,000-25,000 years ago), the level of the sea dropped more than 300 feet (Shepard, 1963). The coastline moved westward, possibly beyond the Farallons. Stream gradients all along the coast range were steepened, facilitating transport of eroded material from the Franciscan and other formations. Large amounts of sediment poured into the Sacramento River and were carried out onto the broad coastal plain and into the ocean. Extensive dune fields developed along much of the coastal plain.

2. The sea rose to within 50 to 80 feet of the present level. This is suggested by local features described by Bauer (1952) and Cherry (1964) and probably occurred between eight and fifteen thousand years ago (Shepard, 1964). The dunes were buried and, because of aggradation in all of the major streams, very little sediment was supplied to the coast. Few of the modern headlands were yet within reach of the waves (Howard, 1964), and little longshore transport was occurring. During this period, a terrace was cut in the soft Monterey Formation sediments west of the Golden Gate.

These sediments were deposited in relatively shallow water, mixing in part with the older, predominantly Franciscan-derived material.

3. Five to seven thousand years ago, the sea rose approximately to the present level. Sediments were then supplied to the coast by 1) coastal headlands exposed once again to wave attack, 2) local colonies of marine organisms, and 3) formations drained by rivers emptying into San Francisco Bay, as this river system adjusted to its new base level. This period has continued to the present, when the headlands contribute only minor quantities of sediment, the marine organisms are effective only around Bolinas, and San Francisco Bay and its tribularies contribute most of the sediment to the area.

Relation to Other Studies

Work was completed in 1964 by Cherry on a portion of the coast immediately north of the present area of study. A study is now in progress by F. Sayles on the area immediately to the south. Both of these projects have employed heavy mineral studies to determine patterns of long term sediment movement. A summary of characteristics of Cherry's and a few of Sayles' sediments are shown with those of the present study on Figure 22.

This figure clearly shows that sediments from the various headlands, cliffs, rivers and bays along this hundred-mile length of coastline determine almost entirely the mineralogy of the nearby littoral zone. Wherever physiographic boundaries occur or the composition of local source rocks changes, however, the littoral-zone mineralogy usually changes also. Along

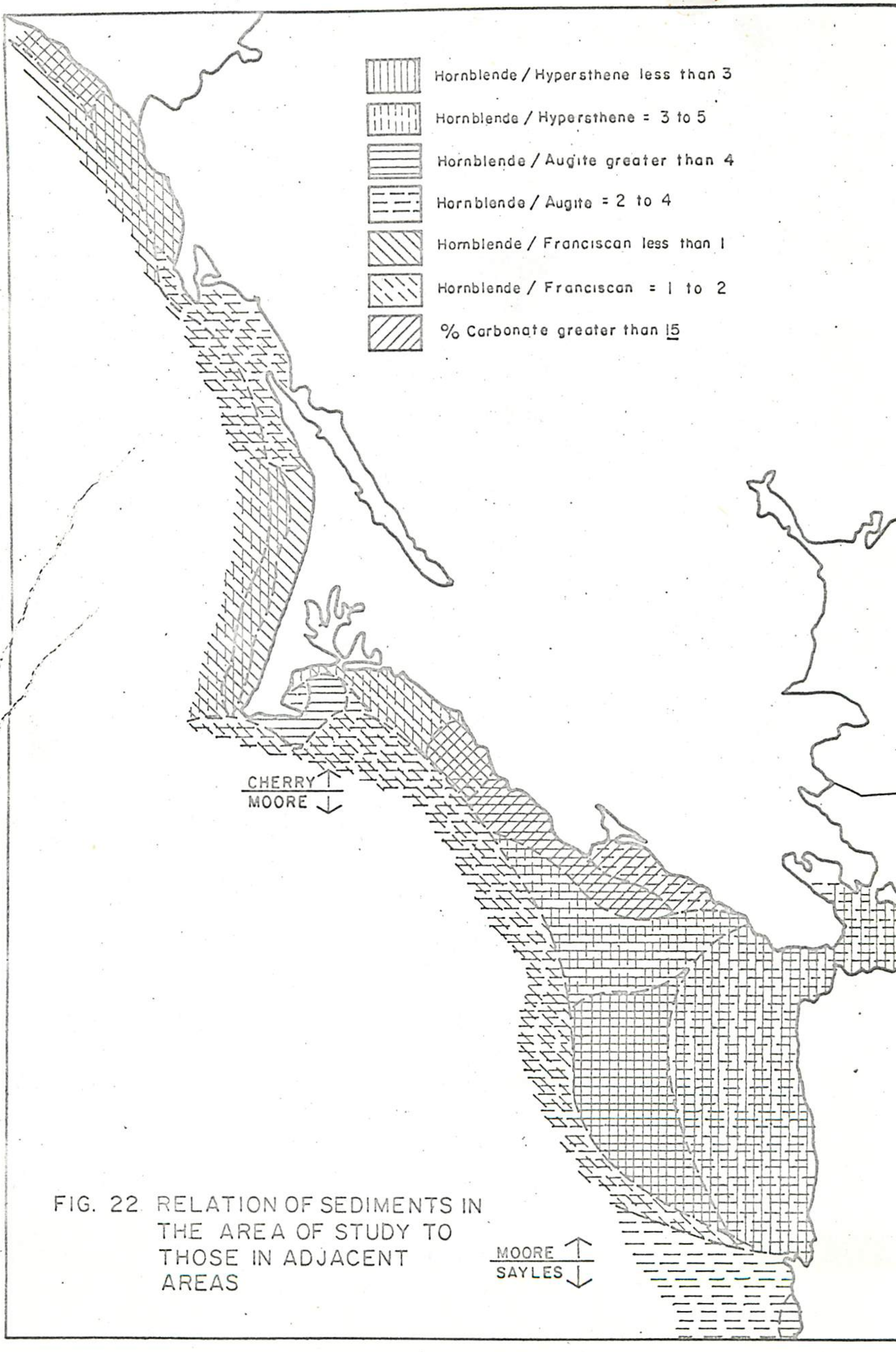

FIG. 22 RELATION OF SEDIMENTS IN THE AREA OF STUDY TO THOSE IN ADJACENT AREAS

this entire length of coast, a change of mineralogy occurs in 90 to 120 feet of water. Beyond this depth, mineralogies change less often and Franciscan-derived sediments are common.

Summary and Conclusions

The long term movement of sediments in the San Francisco Bay area has been of interest to geologists and engineers for some time, and has been the subject of a number of studies in the past decade. The results of these studies have been incomplete and at times contradictory.

The present project has employed the study of heavy minerals found in beach and offshore sediments west of San Francisco to aid in the determination of long term movement. Sufficient differences in heavy mineralogy have been found to delineate several major areas of petrographic similarity and assign sources to them. The relation of the petrographic "provinces" to their sources is an indication of the long term sediment movements taking place in this area now and in the past.

Although the sedimentary history of this part of the California coast is not yet completely known, some statements can now be made.

1. Longshore transport along this portion of the California coast is only of local importance at the present time.

2. Sand-sized sediments in more than 90 to 120 feet of water tend to lack physical connection to mineralogically similar sediments on the modern coast, and therefore must be products of an earlier period of sedimentation.

3. The bay bar has essentially the same mineralogy as the sand channel in San Francisco Bay west of Carquinez, and must be derived from this channel.

4. The composition of sediments on beaches south of the Golden Gate is much less variable than the composition of the cliffs behind it. For this reason, these cliffs must be eroding rather slowly and the beaches owe their composition at least in part to offshore sands mixed with local sediments by the surf.

5. Sediment movement between the Golden Gate and the bay bar is to the north or south, depending on the direction of tidal currents.

6. Longshore movement south of the bay bar is to the south.

Much more information could be gained by considering cores of the Pleistocene and Recent sediments in this area. Some of this information would certainly bear strongly upon the interpretations and conclusions made in this study. It is also possible that a more detailed study of the light-density minerals would supply new and different information.

It is the hope of this writer that the above projects be undertaken so that they and this study may supply the greatest possible amount of information about this area of modern sedimentation. Understanding of such areas can be invaluable assistance in interpreting the circumstances surrounding past periods and other areas of sedimentation.

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Physical and Minerallogical Properties of All Samples by Province

<u>Province 1</u>

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1601	20	300	1.38	0.73	7	1	0	1	1	2	1	0
1602	60	125	1.59	1.82	9	0	1	3	4	1	1	2
1603	80	600	1.29	0.63	15	4	0	2	2	4	1	1
1604	100	940	1.38	0	32	1	4	3	7	5	4	1
1605	90	80	1.35	2.72	36	6	3	6	9	5	4	3
1606	60	170	1.65	2.00	38	2	5	3	8	4	6	3
1607	30	80	1.35	2.32	38	3	7	5	12	8	9	1
1608	60	110	1.37	3.05	41	6	2	6	8	5	5	1
1609	30	95	3.42	0.46	39	2	4	3	7	2	4	3
1615	60	95	1.62	2.59	32	3	6	3	9	3	5	2
1616	60	*	*	2.15	42	5	7	5	12	7	4	3
1618	60	100	2.45	4.14	38	9	6	5	11	7	4	0
1619	60	85	1.65	2.25	33	4	5	4	9	5	8	2
1620	48	85	1.27	3.45	25	5	5	1	6	4	5	2
1625	54	80	1.38	1.46	29	4	2	1	3	2	6	6
1626	60	90	1.28	3.02	24	2	2	2	4	5	6	0
1627	66	70	1.31	2.03	28	3	6	2	8	6	3	3
1679	100	110	1.31	2.66	50	4	5	2	7	2	2	2
$\overline{X}$	-	178	1.59	2.08	30.9	3.6	3.9	3.2	7.1	4.3	4.3	1.9
s	-	98	.55	1.21	12.0	2.1	2.3	1.6	2.3	2.0	2.3	1.5

*Not determined

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende / Hypersthene	Hornblende / Augite	Hypersthene / Augite
1	4	77	7	0	2	1	3	0	57	7.0	>7.0	>1.0
0	4	76	4	0	2	0	2	1	413	>9.0	9.0	0
2	8	62	6	0	1	2	3	0	97	3.8	>15.0	>4.0
4	14	27	9	1	3	2	6	4	192	32.0	8.0	0.3
2	14	14	14	1	2	0	3	4	203	6.0	12.0	2.0
2	15	16	7	1	5	0	6	8	150	19.0	7.6	0.4
0	18	15	7	0	1	1	2	5	192	12.7	5.4	0.4
0	11	16	12	0	3	0	3	3	330	6.8	20.5	3.0
2	11	26	13	0	0	0	0	2	132	19.5	9.8	0.5
1	11	23	17	1	2	0	3	2	278	10.7	5.3	0.5
0	14	11	9	2	0	0	2	5	69	8.4	6.0	0.7
1	12	15	14	0	0	1	1	0	54	4.2	6.3	1.5
4	19	25	7	2	1	1	4	0	161	8.3	6.6	0.8
3	19	21	8	3	4	4	11	2	179	5.0	5.0	1.0
2	16	34	12	0	1	1	2	0	243	7.3	15.5	2.0
3	14	33	9	2	7	1	10	4	228	12.0	12.0	1.0
1	13	33	9	2	7	1	10	4	228	12.0	12.0	1.0
2	8	12	11	2	2	0	4	4	38	12.5	10.0	0.8
1.7	12.5	29.6	9.8	0.9	2.2	0.8	3.9	2.6	182.0	>10.7	>9.2	>1.2
1.3	4.4	20.8	3.4	1.0	1.6	1.0	2.9	2.3	101.1	>6.9	>4.3	>0.7

Province 2

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1621	36	105	1.15	2.11	12	3	3	1	4	5	4	3
1622	24	140	1.28	2.17	15	1	5	2	7	5	0	1
1623	24	145	1.24	3.08	20	4	6	0	6	6	2	3
1624	48	95	1.16	1.25	24	2	5	2	7	3	5	1
1630	50	112	1.20	3.62	30	8	7	4	11	5	5	2
1631	40	160	1.13	1.73	13	4	3	0	3	1	4	0
1632	36	110	1.11	1.80	24	10	1	1	2	2	3	1
1633	50	105	1.27	4.41	27	11	8	5	13	5	6	3
1777	0	190	1.21	1.23	7	0	5	3	8	1	2	2
1778	30	170	1.18	0.47	5	0	7	0	7	1	2	1
1779	0	170	1.12	0.52	14	2	7	0	7	6	3	1
1780	0	190	1.30	0.67	17	2	5	1	6	4	2	4
1781	0	240	1.46	0.60	14	3	6	2	8	4	1	3
1782	0	170	1.25	0.65	11	0	9	1	10	2	3	4
1783	0	190	1.29	1.02	12	1	4	2	6	3	2	3
1784	0	175	1.28	1.39	15	0	5	0	5	2	4	4
1785	0	300	1.77	1.70	10	3	6	3	9	4	2	1
1786	0	2500	1.49	2.76	3	1	3	0	3	4	1	1
1787	0	1900	1.61	1.77	15	4	8	1	9	2	1	0
$\overline{X}$	-	162	1.29	1.73	15.2	3.1	5.4	1.5	6.9	3.4	2.7	2.0
s	-	53	0.17	1.09	7.2	3.3	2.0	1.5	2.8	1.7	1.6	1.3

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende/Hypersthene	Hornblende/Augite	Hypersthene/Augite
2	14	50	10	3	4	0	7	9	296	4.0	4.0	1.0
5	11	39	8	5	9	2	16	3	250	15.0	3.0	0.2
5	16	19	4	7	10	4	21	10	101	5.0	3.3	0.7
3	12	48	7	0	0	0	0	0	358	12.0	4.8	0.4
2	14	17	14	2	1	0	3	3	358	3.8	4.3	1.3
2	7	54	10	0	4	1	5	4	395	4.3	4.3	10.0
2	8	38	7	1	0	0	1	10	283	2.4	24.0	1.4
0	14	15	16	0	1	0	1	3	403	3.4	3.4	0
2	7	64	10	0	1	0	1	3	111	77.0	1.4	0
1	5	62	20	0	1	0	1	0	189	75.0	0.7	0.3
-3	13	52	8	0	0	2	2	2	122	7.0	2.0	0.4
2	12	49	9	6	0	0	6	0	93	8.5	3.4	0.5
2	10	49	13	0	1	0	1	2	102	4.7	2.3	0
5	14	50	12	0	0	0	0	3	89	>11.0	1.2	0.3
3	11	56	11	0	1	0	1	2	111	12.0	3.0	0.3
7	17	48	9	0	2	1	3	3	111	>15.0	3.0	0
4	11	35	8	2	13	7	22	2	122	3.3	1.7	0.5
0	6	58	6	1	20	1	22	1	118	3.0	1.0	0.3
0	3	62	5	0	0	0	0	1	77	3.8	1.9	0.5
2.6	10.7	45.5	9.8	1.4	3.6	0.9	5.9	3.2	194.2	>6.9	3.8	1.0
1.9	3.9	14.9	3.9	2.3	5.5	1.8	7.9	3.1	117.4	>4.2	5.0	2.2

Province 3

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1610	120	105	1.23	3.03	51	7	2	3	5	5	4	5
1612	120	125	1.39	2.80	43	8	2	5	7	7	5	4
1613	90	90	1.28	3.52	46	6	3	4	7	7	2	4
1614	60	105	1.32	3.95	50	6	8	5	13	5	7	1
1617	70	350	2.52	6.78	24	8	7	2	9	5	4	3
1628	70	75	1.29	3.18	35	9	3	6	9	14	5	2
1629	65	90	1.33	6.07	41	10	4	2	6	13	6	3
1634	50	120	1.20	5.19	42	9	7	3	10	3	5	2
1635	40	135	1.21	6.43	53	14	6	2	8	5	7	1
1691	40	134	1.21	9.37	44	21	5	6	11	4	0	1
1692	40	117	1.23	5.87	36	15	6	7	13	9	4	1
1693	60	88	1.35	4.53	46	15	6	4	10	5	3	3
1694	65	87	1.36	2.91	39	11	3	5	8	5	5	4
1695	65	80	1.29	4.72	40	26	13	3	16	5	3	0
1696	70	92	1.77	6.46	51	18	8	4	12	7	3	4
1697	65	82	1.37	5.13	56	8	6	3	9	3	2	4
1698	70	80	1.29	4.52	46	10	7	8	15	5	0	5
1699	70	77	1.29	3.43	57	10	2	2	4	4	7	4
1700	75	85	1.30	5.95	41	4	9	4	13	4	3	7
1701	80	79	1.28	4.08	50	13	6	9	15	3	2	3
1703	85	82	1.31	4.93	43	13	4	4	8	12	6	3
1705	95	93	1.25	4.39	52	9	7	7	14	8	4	2
1706	100	92	1.27	9.40	49	11	5	6	11	9	4	3

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende / Hypersthene	Hornblende / Augite	Hypersthene / Augite
3	17	12	4	0	0	0	0	4	253	7.3	25.5	3.5
3	19	8	11	0	0	0	0	4	369	5.4	21.5	4.0
3	16	10	7	0	3	2	5	4	232	7.3	15.3	2.0
8	23	6	6	2	3	0	5	0	324	8.3	6.3	0.8
3	15	20	15	2	1	1	4	5	243	3.0	3.4	1.1
3	24	9	10	1	1	0	2	4	262	3.9	11.7	3.0
4	26	3	9	1	0	0	1	8	230	4.1	10.3	2.5
1	11	6	15	2	1	0	3	3	401	4.7	6.0	1.3
1	14	0	5	1	0	0	1	5	56	3.8	8.8	2.3
0	5	0	8	2	1	0	3	3	103	2.3	9.8	4.2
0	14	2	8	1	1	0	2	10	112	2.4	6.0	2.5
1	12	1	9	0	0	0	0	7	116	3.1	3.1	2.5
1	15	2	20	0	0	0	0	5	74	3.5	13.0	3.7
3	11	0	1	5	0	0	5	1	101	1.5	3.1	2.0
0	14	1	1	2	0	0	2	1	145	2.8	6.4	2.3
1	10	2	7	1	0	0	1	2	113	7.0	9.3	1.3
0	10	3	9	0	0	0	0	7	84	5.6	6.6	1.2
1	16	1	7	0	0	0	0	5	161	5.7	28.5	5.0
3	17	3	16	0	0	0	0	6	226	10.3	3.6	0.3
1	9	1	5	2	0	0	2	5	171	3.8	8.3	2.2
2	23	1	4	2	0	0	2	6	82	3.3	10.8	3.3
1	15	0	4	0	0	0	0	6	14	5.8	7.4	1.3
2	18	0	3	1	0	1	2	6	97	4.5	9.8	2.2

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1708	100	82	1.27	3.04	52	14	6	6	12	3	3	3
1709	110	78	1.20	3.90	44	16	10	3	13	6	4	1
1710	110	88	1.30	4.02	44	14	1	5	6	6	4	3
1711	110	75	1.26	3.31	53	10	5	5	10	5	4	1
1713	120	81	1.27	4.12	47	8	8	4	12	3	5	4
$\overline{X}$	-	93.2	1.30	4.72	47.3	11.7	5.6	4.4	10.0	6.1	4.0	2.9
s	-	20.2	0.11	1.73	6.8	4.8	2.7	2.3	3.0	3.1	1.4	1.6

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende / Hypersthene	Hornblende / Augite	Hypersthene / Augite
0	9	0	4	1	3	0	4	5	177	3.8	8.7	2.3
2	13	2	6	0	1	0	1	5	356	2.8	4.4	1.6
0	13	3	10	1	0	1	2	8	150	3.1	3.1	14.0
2	12	4	7	1	1	1	3	3	180	5.3	10.6	2.0
1	13	4	10	2	0	1	3	4	115	5.9	5.9	1.0
1.2	14.2	3.1	7.6	1.0	0.6	0.2	1.8	4.7	174.2	4.7	9.8	2.7
1.0	6.0	3.1	4.4	1.1	1.0	0.5	0.8	2.5	101.2	2.0	6.4	5.0

Province 4

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1636	40	175	1.65	9.67	48	11	11	1	12	4	7	4
1637	30	190	1.15	14.93	33	23	14	4	18	7	4	2
1638	30	170	1.10	11.89	45	25	11	0	11	2	5	2
1639	30	150	1.15	8.31	51	13	7	2	9	3	5	4
1640	25	155	1.13	16.00	35	17	17	1	18	2	4	1
1641	25	160	1.11	14.23	48	18	8	6	14	7	2	3
1642	30	175	1.09	14.92	36	24	12	3	15	5	2	2
1643	35	175	1.07	18.94	37	23	11	5	16	6	7	1
1644	30	175	1.06	10.43	44	15	9	3	12	3	3	3
1645	30	155	1.09	16.98	43	17	10	0	10	3	5	3
1646	60	90	1.30	4.88	45	17	11	4	15	5	5	0
1647	50	90	1.41	5.95	44	18	8	6	14	5	5	4
1648	36	120	1.37	12.05	48	13	8	4	12	6	4	2
1649	35	160	1.13	19.08	45	22	3	1	4	7	3	2
1650	33	160	1.08	14.51	52	9	11	5	16	5	4	4
1651	40	175	1.07	7.82	37	18	8	0	8	4	6	3
1652	50	290	1.22	5.64	31	16	17	1	18	9	5	4
1653	35	180	1.10	23.20	39	17	13	3	16	8	6	1
1654	40	160	1.08	21.23	39	16	14	4	18	7	8	2
1655	30	160	1.05	25.63	39	17	8	4	12	8	10	2
1656	40	155	1.13	23.09	43	17	14	1	15	5	1	3
1657	33	165	1.05	23.77	36	19	13	3	16	9	3	3

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende/Hypersthene	Hornblende/Augite	Hypersthene/Augite
0	15	3	4	2	0	0	2	5	92	4.9	4.4	1.0
1	14	2	3	2	0	2	4	3	76	1.4	2.4	1.6
2	11	1	5	1	0	2	3	0	58	1.8	4.1	2.3
0	12	0	6	1	2	1	4	5	73	3.9	7.3	1.9
0	7	3	8	4	2	2	8	4	182	2.1	2.1	1.0
1	13	1	2	1	2	1	4	0	53	2.7	6.0	2.3
1	10	1	6	2	1	0	3	5	53	1.5	3.0	2.0
2	16	0	3	1	1	1	3	2	59	1.6	3.4	2.1
0	9	6	7	2	2	0	4	3	188	2.9	4.9	1.7
0	11	1	3	4	8	1	13	2	53	2.5	4.3	1.7
1	11	1	2	1	1	1	3	6	61	2.6	4.1	1.5
0	14	1	2	3	0	0	3	4	70	2.4	5.5	2.3
0	12	2	3	3	2	1	6	4	59	3.6	6.0	1.6
2	15	1	4	4	2	1	7	2	43	2.0	15.0	7.3
0	13	1	5	2	1	2	5	0	55	5.8	4.7	0.8
0	13	0	12	4	1	2	7	5	44	2.1	4.6	2.3
1	19	3	8	1	0	1	2	7	48	1.9	1.8	0.9
1	16	1	3	3	2	2	7	1	54	2.4	3.0	1.3
0	17	0	3	0	2	2	4	3	53	2.4	2.8	1.1
1	21	0	4	3	3	0	6	1	61	2.4	4.9	2.1
1	10	2	4	3	5	0	8	1	50	2.5	3.1	1.2
0	15	2	1	3	2	5	10	1	53	1.9	2.8	1.5

Province 4 (Con't)

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1658	33	165	1.05	24.45	42	19	10	2	12	6	5	1
1659	33	165	1.05	24.10	43	18	15	2	17	5	3	1
1660	33	170	1.06	19.81	41	16	14	2	16	7	4	1
1661	33	160	1.08	17.49	37	15	18	1	19	8	2	2
1662	18	165	1.08	21.11	35	18	12	2	14	7	4	2
1663	30	152	1.05	21.15	43	10	14	2	16	10	4	1
1664	40	150	1.07	14.90	47	9	16	0	16	8	4	5
1665	45	122	1.22	6.35	48	10	12	2	14	9	3	2
1666	50	110	1.12	7.46	37	21	13	2	15	9	3	2
1667	55	210	1.43	20.78	44	11	10	2	12	7	3	4
1668	60	110	1.15	13.81	39	16	12	1	13	7	5	3
1669	70	115	1.14	13.26	53	4	9	3	12	5	7	1
1670	75	110	1.26	8.36	43	11	12	2	14	6	6	2
1671	80	100	1.26	9.38	44	14	9	3	12	10	4	1
1672	90	90	1.28	7.14	50	8	9	4	13	11	3	2
1683	80	226	2.06	9.61	33	22	13	1	14	4	1	6
1684	70	215	1.26	11.40	43	31	11	2	13	3	0	1
1685	70	238	1.35	5.31	42	15	14	2	16	1	0	6
1687	70	170	1.22	3.66	37	17	7	3	10	7	4	2
1688	69	70	2.73	4.28	24	12	9	6	15	8	3	3
1689	36	193	1.15	10.23	41	22	9	3	12	8	2	3
1690	70			6.86	42	18	7	4	11	4	4	4

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende / Hypersthene	Hornblende / Augite	Hypersthene / Augite
1	13	1	2	5	2	3	10	1	66	2.2	4.2	1.9
1	10	2	3	2	2	1	5	2	57	2.4	2.9	1.2
1	13	2	2	3	2	1	6	3	50	2.5	2.9	1.1
3	15	2	1	6	1	2	9	2	27	2.5	2.1	0.8
0	13	1	6	2	0	1	3	0	58	2.5	3.8	1.5
1	16	1	7	5	0	2	7	0	36	4.3	3.1	0.7
0	17	1	6	1	1	1	3	1	38	5.2	2.9	0.6
2	16	1	9	1	0	2	3	0	45	4.8	4.0	0.8
0	14	1	6	0	0	1	1	5	63	1.7	2.8	1.6
1	15	1	5	4	3	1	8	4	74	4.0	4.4	1.1
2	17	2	3	2	2	3	7	3	75	2.4	3.3	1.3
3	16	0	4	2	1	2	5	6	56	13.3	5.9	0.4
2	16	0	5	2	2	0	4	7	38	3.9	3.6	0.9
1	16	1	4	6	1	0	7	2	53	3.1	4.9	1.6
0	16	0	1	0	3	1	4	8	63	6.2	5.6	0.9
2	13	1	7	4	1	0	5	5	141	1.5	2.5	1.8
1	5	0	3	2	0	1	3	2	90	1.4	3.9	2.7
2	9	5	9	0	1	0	1	3	136	2.8	3.0	1.1
3	16	2	10	1	0	1	2	6	200	2.2	5.3	2.4
2	16	2	21	3	0	0	3	7	126	2.0	2.7	1.3
0	13	0	3	3	0	1	4	5	91	1.4	4.6	2.4
1	13	1	8	0	4	1	5	2	108	2.4	6.0	2.6

Province 4 (Con't)

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1733	60	116	1.48	39.78	40	25	8	0	8	4	0	2
1734	40	440	1.44	6.39	33	14	7	2	9	8	2	3
1735	50	355	1.12	11.58	52	28	9	0	9	6	3	0
1736	50	440	1.29	13.22	26	20	10	0	10	10	1	1
1737	55	523	1.22	10.80	41	22	13	0	13	4	3	0
1738	75	670	1.51	9.82	28	16	16	2	18	4	4	2
1739	90	420	1.49	6.59	37	9	8	7	15	7	3	3
1740	120	590	1.41	4.45	42	11	8	4	12	5	4	2
1741	140	590	1.39	5.11	46	11	11	5	16	5	4	3
1742	70	370	1.17	6.82	26	18	17	3	20	2	3	1
1743	100	173	1.27	10.93	37	14	13	1	14	3	3	3
1744	60	310	1.76	8.37	44	16	8	4	12	3	5	4
1747	0	1075	1.42	17.95	33	17	18	0	18	4	6	2
1749	0	355	1.15	34.81	30	22	30	2	32	6	2	1
1750	0	380	1.33	51.72	30	21	26	1	27	3	4	0
1751	0	340	1.16	25.83	35	14	28	0	28	4	2	2
1752	0	1490	2.31	43.12	29	14	26	2	28	11	6	2
1753	0	625	1.60	42.31	21	35	21	0	21	7	2	1
1754	0	340	1.37	73.17	14	23	28	3	31	7	3	0
1755	0	300	2.43	28.79	46	21	15	0	15	4	1	2
1756	0	290	1.12	13.72	52	13	15	1	16	3	4	1
1757	0	270	1.14	33.19	47	13	20	3	23	5	1	1

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende/Hypersthene	Hornblende/Augite	Hypersthene/Augite
3	9	0	3	9	3	4	16	0	100	1.6	5.0	3.1
1	14	20	7	1	0	0	1	4	82	2.8	4.7	1.7
2	11	0	3	3	0	2	5	2	90	1.5	4.7	3.1
0	12	20	7	3	1	1	5	0	116	1.3	2.6	2.0
2	9	1	5	4	2	2	8	1	78	1.9	2.3	1.7
2	12	10	13	2	0	0	2	0	92	1.8	1.8	1.0
3	16	7	11	0	1	1	2	3	143	4.1	4.6	1.1
1	12	4	12	2	0	0	2	5	146	3.8	5.3	1.4
3	15	0	5	0	0	2	2	5	120	4.2	4.2	1.0
0	6	20	6	2	0	1	3	1	108	1.4	1.6	1.1
0	9	10	6	4	1	0	5	5	114	2.6	2.8	1.1
2	14	3	2	4	1	1	6	3	125	2.8	5.5	2.0
1	13	0	9	2	1	2	5	5	121	1.9	1.8	0.9
0	9	1	2	2	2	0	4	0	123	1.4	1.0	0.7
0	7	1	4	4	0	1	5	5	96	1.4	1.2	0.8
0	8	1	4	5	2	2	9	1	111	2.5	1.3	0.5
0	19	0	2	6	0	1	7	1	123	2.1	1.1	0.5
1	11	0	1	8	0	1	9	2	108	0.6	1.0	1.7
1	11	0	2	5	0	2	7	12	84	0.6	0.5	0.8
0	7	0	4	3	0	3	6	1	112	2.2	3.1	1.4
1	9	0	3	2	1	1	4	3	104	4.0	3.5	0.9
0	7	0	3	2	1	0	3	4	86	3.6	2.3	0.7

Province 4 (Con't)

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1758	0	245	1.13	10.52	49	11	16	1	17	7	5	0
1759	0	275	1.12	9.38	58	20	10	1	11	2	2	4
1760	0	250	1.22	7.72	57	16	9	1	10	3	1	3
1761	0	345	1.28	26.18	43	19	20	1	21	5	3	2
1762	0	270	1.19	12.01	51	15	15	2	17	6	2	0
1763	0	300	1.10	9.34	45	22	15	1	16	3	4	2
1764	0	310	1.13	9.56	44	13	20	2	22	6	2	4
1765	0	480	1.33	45.20	35	16	27	0	27	3	1	1
1766	0	350	1.33	35.92	36	20	27	0	27	3	3	4
1767	0	405	1.71	7.24	50	16	16	3	19	3	3	1
1768	0	450	1.39	8.80	41	18	20	1	21	3	2	2
1769	0	475	1.36	7.68	47	21	14	2	16	5	2	1
1770	0	300	1.37	11.16	46	8	17	2	19	7	5	1
1771	0	240	1.40	8.15	51	13	13	3	16	4	6	1
1772	0	550	2.77	20.62	31	27	17	2	19	7	3	1
1773	0	490	1.52	11.57	47	18	15	0	15	4	4	1
1774	0	1920	1.54	6.02	23	20	15	1	16	7	3	1
1775	0	940	2.00	17.93	26	12	20	4	24	10	3	1
1776	0	900	2.50	4.56	18	11	17	7	24	12	1	2
$\overline{X}$	-	314	1.34	16.55	41.0	16.9	13.8	2.2	16.0	5.7	3.5	3.0
s	-	295	0.37	11.70	8.6	5.3	5.6	1.7	5.3	2.5	1.8	1.3

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende / Hypersthene	Hornblende / Augite	Hypersthene / Augite
0	12	0	5	0	1	0	1	3	98	4.5	3.1	0.7
0	8	1	1	2	0	0	2	1	112	2.9	5.8	2.0
1	8	0	3	2	0	1	3	3	98	3.6	6.3	1.8
0	10	0	1	4	0	2	6	0	98	2.3	2.2	1.0
0	8	0	5	1	0	0	1	3	90	3.4	3.4	1.0
0	9	2	3	2	0	0	2	1	111	2.0	3.0	1.5
2	14	0	6	2	0	0	2	0	65	3.4	2.2	0.7
0	5	1	9	2	1	2	5	0	87	2.2	1.3	0.6
2	12	0	1	3	0	1	4	0	76	1.8	1.3	0.7
0	7	0	4	2	0	2	5	0	121	3.1	3.1	1.0
2	9	2	4	4	0	1	5	0	118	2.3	2.1	0.9
1	9	0	5	1	1	0	2	0	77	2.2	3.4	1.5
2	15	0	6	3	0	1	4	2	82	5.8	2.7	0.5
0	11	1	3	3	0	1	4	1	106	3.9	3.9	1.0
0	11	0	3	3	1	3	7	2	81	1.1	1.8	1.6
2	11	0	2	5	1	0	6	1	97	2.6	3.1	1.2
1	12	0	6	3	0	6	9	14	158	1.2	1.5	1.3
1	15	4	5	4	1	0	5	9	280	2.2	1.3	0.6
0	15	13	6	1	4	4	9	4	294	1.6	1.1	0.6
0.9	12.1	2.3	4.9	2.6	1.1	1.2	4.9	2.9	92.5	2.8	3.5	1.4
0.9	3.9	4.1	3.2	1.8	1.3	1.2	1.7	2.7	46.8	1.6	1.9	0.9

Province 5

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1702	80	85	1.25	4.76	46	19	9	5	14	5	2	3
1704	90	79	1.23	4.79	44	19	8	3	11	9	2	5
1707	95	81	1.22	14.69	50	22	8	6	14	5	1	1
1712	115	77	1.34	4.25	57	22	7	2	9	2	2	4
1721	110	70	1.21	5.71	52	12	3	4	7	7	3	3
1722	100	70	1.18	4.83	46	18	6	6	12	2	3	3
1723	95	65	1.19	5.50	43	18	4	14	18	4	0	3
1724	95	75	1.25	4.92	50	14	4	8	12	7	3	6
1725	95	69	1.23	6.17	47	17	3	7	10	5	2	8
1726	95	78	1.29	8.04	52	9	6	6	12	8	4	4
1727	90	78	1.30	6.76	45	22	6	6	12	3	2	3
1728	90	80	1.28	6.18	48	18	6	5	11	6	0	4
1729	80	76	1.27	7.11	45	22	3	6	9	1	1	7
1730	80	80	1.30	7.32	48	13	11	8	19	5	4	5
1731	80	155	1.52	8.53	47	20	5	3	8	7	2	1
1732	75	110	1.61	4.27	50	8	4	4	8	8	2	4
$\overline{X}$	-	83.3	1.29	6.49	48.1	17.1	5.8	5.8	11.6	5.3	2.1	5.3
s	-	31.1	0.09	2.82	3.6	4.6	2.4	2.8	3.4	2.4	1.2	1.9

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende / Hypersthene	Hornblende / Augite	Hypersthene / Augite
2	15	0	2	0	1	1	2	5	83	2.4	5.1	2.1
2	18	0	1	3	2	1	6	1	107	2.3	5.5	2.4
1	8	1	1	1	1	1	3	1	93	2.3	6.3	2.8
1	9	1	1	1	2	0	3	0	68	2.5	8.1	3.1
2	15	0	6	4	0	2	6	2	148	4.3	17.3	4.0
2	10	1	6	1	0	0	1	6	149	2.6	7.7	3.0
1	8	1	5	0	3	1	4	3	134	2.3	10.8	4.5
2	18	0	3	0	0	0	0	3	123	3.6	12.5	3.5
0	15	0	4	0	0	0	0	7	113	2.8	15.7	5.7
2	18	1	0	0	0	1	1	7	173	5.8	8.7	1.5
0	8	0	5	0	1	0	1	7	184	2.0	7.5	3.7
1	11	0	4	1	0	1	2	6	128	2.7	8.0	3.0
1	10	0	5	0	0	0	0	9	143	2.0	15.0	7.3
1	15	1	0	1	0	0	1	3	124	3.7	4.4	1.2
2	12	0	5	1	2	0	3	5	145	2.4	9.4	4.0
3	17	2	11	0	0	1	1	3	97	6.3	12.5	2.0
1.4	12.8	0.5	3.7	0.8	0.8	0.6	2.2	4.3	125.8	3.1	9.7	3.4
0.8	3.8	0.6	2.9	1.2	1.0	0.6	0.9	4.3	31.6	1.3	3.9	1.6

Province 6

Sample	Depth	Median Grain Size	Sorting Coefficient	Percent Heavy Minerals	Hornblende	Hypersthene	Green Augite	Brown Augite	Total Augite	Epidote	Karinthine	Actinolite
1611	150	85	1.30	3.64	47	6	3	10	13	10	7	2
1673	100	90	1.22	8.22	50	10	7	5	12	8	7	1
1674	110	85	1.22	7.53	41	6	14	11	25	16	4	2
1675	120	80	1.16	7.28	46	10	7	9	16	8	6	4
1676	125	70	1.28	5.04	40	12	16	6	22	9	3	5
1677	120	70	1.19	4.52	46	8	10	8	18	4	1	2
1678	120	105	1.20	2.79	50	7	9	3	12	6	3	3
1714	120	81	1.29	3.22	45	11	5	7	12	4	5	3
1715	125	80	1.32	*	51	2	5	13	18	5	3	3
1716	125	86	1.69	4.85	41	13	9	6	15	6	2	3
1717	125	81	1.66	*	41	19	11	4	15	6	2	2
1718	120	71	1.25	11.57	58	11	4	6	10	6	2	2
1719	125	69	1.20	5.92	42	14	12	4	16	12	2	5
1720	115	73	1.23	6.27	52	18	10	4	14	6	5	1
1745	130	84	1.41	7.37	40	16	13	3	16	12	4	3
1746	130	87	1.38	4.60	46	9	5	2	7	10	2	4
$\overline{X}$	-	81.1	1.31	5.92	46.0	10.8	8,8	6.3	15.1	8.0	3.6	2.8
s	-	9.4	0.16	2.34	5.1	4.6	3.9	3.2	4.4	3.4	1.9	1.2

*Not determined

Glaucophane	Total Franciscan Minerals	Carbonate	Biotite	Sphene	Zircon	Garnet	Sphene + Zircon + Garnet	Other Minerals	Unidentifiable Grains/100 Identifiable	Hornblende/Hypersthene	Hornblende/Augite	Hypersthene/Augite
1	20	0	7	1	0	0	1	6	363	7.8	15.7	2.0
0	16	2	4	0	1	2	3	3	34	5.0	7.1	1.4
0	22	0	3	2	0	0	2	1	40	6.9	2.9	0.4
1	19	2	3	1	0	0	1	3	76	4.6	6.6	1.4
1	18	0	6	1	0	0	1	1	51	3.3	2.5	0.8
1	8	1	14	2	1	1	4	1	76	5.8	4.6	0.8
2	14	4	9	3	0	0	3	1	70	7.1	5.5	0.8
0	12	2	8	1	0	1	2	8	175	4.1	9.0	2.2
4	15	2	2	2	1	1	4	6	175	25.5	10.2	0.4
3	14	0	9	0	0	1	1	7	388	3.2	4.6	1.4
3	13	1	6	2	2	0	4	9	126	2.2	3.7	1.7
1	11	1	1	2	0	0	2	6	103	5.3	14.5	2.8
3	22	0	1	1	0	1	2	3	181	3.0	3.5	1.2
1	13	0	5	1	0	0	1	2	101	4.0	5.2	1.3
0	19	0	1	1	1	1	3	5	151	2.5	3.1	1.2
4	20	1	10	1	0	0	1	6	135	5.1	9.2	1.8
1.6	16.0	1.0	5.6	1.3	0.4	0.5	2.2	4.3	140.3	6.0	6.7	1.4
1.4	4.1	1.1	3.6	0.8	0.6	0.6	0.7	2.8	103.5	5.2	16.9	0.1