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Gold Distribution on the Sea Floor off the Klamath Mountains California

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By George W. Moore and Eli A. Silver

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ABSTRACT

Analyses of 82 samples collected from the surface of the continental shelf between the Oregon-California border and Eureka, Calif., indicate that the background gold content on this shelf is about 0.1 ppb (part per billion). Four anomalous tracts, which range in extent from 10 to 30 square kilometers, have gold values above 10 ppb, and the richest sample contains 390 ppb. The anomalous areas seem to lack a close correlation with water depth, but they are related to areas underlain by soft Cenozoic strata that contain small quantities of dispersed gold originally derived from lodes in the Klamath Mountains. This relationship suggests that the offshore gold accumulations are lag concentrates produced from the Cenozoic deposits by wave erosion during the postglacial rise in sea level. Gold contents at the surface are too low for economic recovery, and drilling will be required to determine whether the anomalous areas are underlain by higher grade material.

INTRODUCTION

As part of the U.S. Geological Survey's Heavy Metals program, resource appraisals have been undertaken on areas of the continental shelf that lie offshore from mining districts on land that in the past have produced significant quantities of metals, such as gold and platinum. The shelf off northernmost California adjacent to the gold districts of the Klamath Mountains is one such area selected for study (fig. 1). To perform the investigation, a joint research contract was entered into with Scripps Institution of Oceanography. This report summarizes the results of the first year's work.

The initial phase of the investigation has provided a fair understanding of the areal distribution of gold in the surface layer of sediment for a distance of about 150 kilometers along the northern California continental shelf. The sample spacing is close enough to define approximately shapes of areas with high gold values and to permit consideration of the significance of their relationship to other aspects of the geology.

A companion project dealing with the continental shelf off southern Oregon, directly north of this project area, is in progress through a joint research contract with Oregon State University. Preliminary reports have recently been issued on the first findings of that study (Clifton, 1968; Kulm and others, 1968).

Sampling was done from Scripps Institution of Oceanography's research vessel Oconostota in August and September 1967, and we are indebted to the officers, crew, and graduate students aboard the ship, who made the project a success. After the cruise, Norman Schumacher, of Scripps Institution of Oceanography, prepared the samples for chemical analysis and was responsible for determining the physical properties of the sediment.

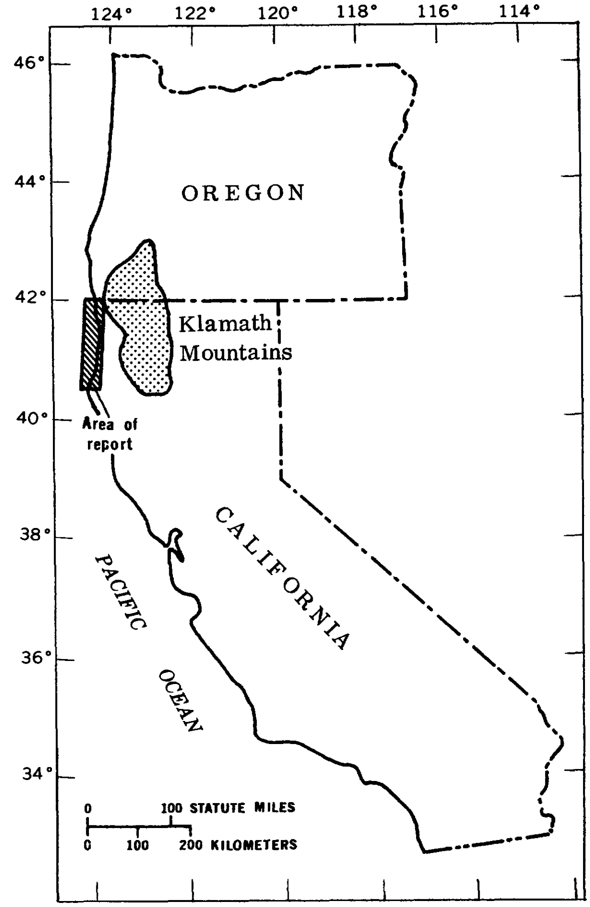

Figure 1.--Index map showing location of the project area and the Klamath Mountains gold districts.

FIELD AND LABORATORY METHODS

Most of the 82 samples considered in this report were taken with a sediment dredge developed by André M. Rosfelder, of Scripps Institution of Oceanography. Material enters the dredge through a cone-shaped scoop, from which it passes into a watertight bag that holds about 15 kilograms of sediment. The dredge was particularly effective on the homogeneous and firmly compacted sand of the shelf, which commonly resists penetration by samplers of the snapper type. During dredging operations, the device remained on the bottom for about 1 minute, while the ship drifted at 1–3 kilometers per hour. Sample locations are based on radar ranges and bearings to headlands, recorded at the time the dredge touched the bottom.

The median diameter of the grains in the offshore samples ranges from 0.06 to 0.15 mm (millimeter). Inasmuch as a single grain of gold of these grain sizes is detectable by chemical analysis, a fairly large fraction from an original sample is required for an analysis to be representative, and the coarsest samples require the largest fractions. For each sample, we endeavored to select a weight for analysis according to grain size such that if the sample were to contain 10 ppb (parts per billion) gold, the number of gold grains theoretically expected would be 1.8, a value that provides an optimum 72.6 percent chance that the fraction will contain between 1 and 3 grains of gold (Dixon and Massey, 1957, table A–15) and hence will give an analysis between 5 and 15 ppb. The calculations, which assume that the gold grains are the size of the median diameter of the whole sample, were based on the relation

$$\underline{n} = 1/6\, \pi\, \underline{D}^3\, \rho\, \delta^{-1} \lambda,$$

where

$\underline{n}$ = weight in grams,

$\underline{D}$ = the median diameter in centimeters,

ρ = the density of native gold in grams per cubic centimer,

δ = the grade in parts per billion, and

λ = the expected number of gold grains.

When $\rho = 17$ g/cm^3, $\delta = 10$ ppb, $\lambda = 1.8$, and D is replaced by $\underline{d}$ in millimeters, this relation reduces to

$$\underline{n} = 1.6 \cdot 10^6\, \underline{d}^3.$$

As an example, 2100-g fractions were used for samples with a median diameter of 0.11 mm. The precision of analysis would be greater for a sample with a gold content higher than 10 ppb, or with a median diameter for gold grains smaller than that of its other grains, as in these cases the analyzed fraction would contain more than the 1–3 grains of gold called for in the equation.

The chemical analyses were made by atomic-absorption spectrophotometry according to the method developed by VanSickle and Lakin (1968). The digestion and extraction procedures used in this method require that the sample not exceed a weight of 100 g; hence, the heavy minerals in the fractions were first concentrated to less than 100 g by separation with heavy liquids. Bromoform, with a specific gravity of 2.85, was used in a first stage of separation, followed by methylene iodide, with a specific gravity of 3.3. Fractions from sand samples were separated in 100-g batches in steep-walled glass funnels 15 centimeters in diameter; two silt samples were separated in 40-g batches in a centrifuge.

Gold values for 61 of the samples studied are given in table 1 and contoured in figure 2. The values reported are the calculated gold content of the samples before concentration. Gold analyses were not obtained for the 21 remaining samples, but comparison of figure 2 with figure 3, which is a plot of the percent of each sample that is heavier than methylene iodide, shows that in areas for which both percent heavier than methylene iodide and gold analyses are available, the two show a fairly close correlation. Therefore, the methylene iodide percentages can be used to estimate the probable gold content.

GOLD DISTRIBUTION

Surface sediment in four areas on the northernmost California continental shelf contain gold values greater than 10 ppb.[1/] These areas are north of Point St. George, west of Crescent City, south of the mouth of the Klamath River, and north of Trinidad Head. The highest value obtained in this investigation, 390 ppb, was in a sample from the area north of Trinidad Head. Background gold content is about 0.1 ppb. No clear-cut relationship appears to exist between water depth and gold content. The four samples that define the gold anomaly north of Trinidad Head were all collected at depths ranging from 20 to 22 m (meters), but no other samples collected at other depths in this area were analyzed. The anomalous samples south of the Klamath River came from depths ranging from 16 to 27 m, those north of Point St. George, from depths of 18 to 29 m, and the sample west of Crescent City, from 42 m depth. Samples with only background gold values occur at similar depths near each of these anomalously rich areas.

The absolute ratio between gold and other heavy minerals changes systematically toward the south. For samples of similar gold content, the percent heavier than methylene iodide decreases by a factor of about 4 from the north end of the project area to the south end (table 1). Chromium content (table 1) similarly is much greater north than south of Point St. George, which lies at 41°47' N. The analyses also show a poor correlation between chromium and gold. The available evidence indicates mixing of a chromium-bearing

1/ Based on a price of $35 per ounce for gold, 10 ppb is equivalent to 1 cent per ton, or 1.6 cents per cubic yard.

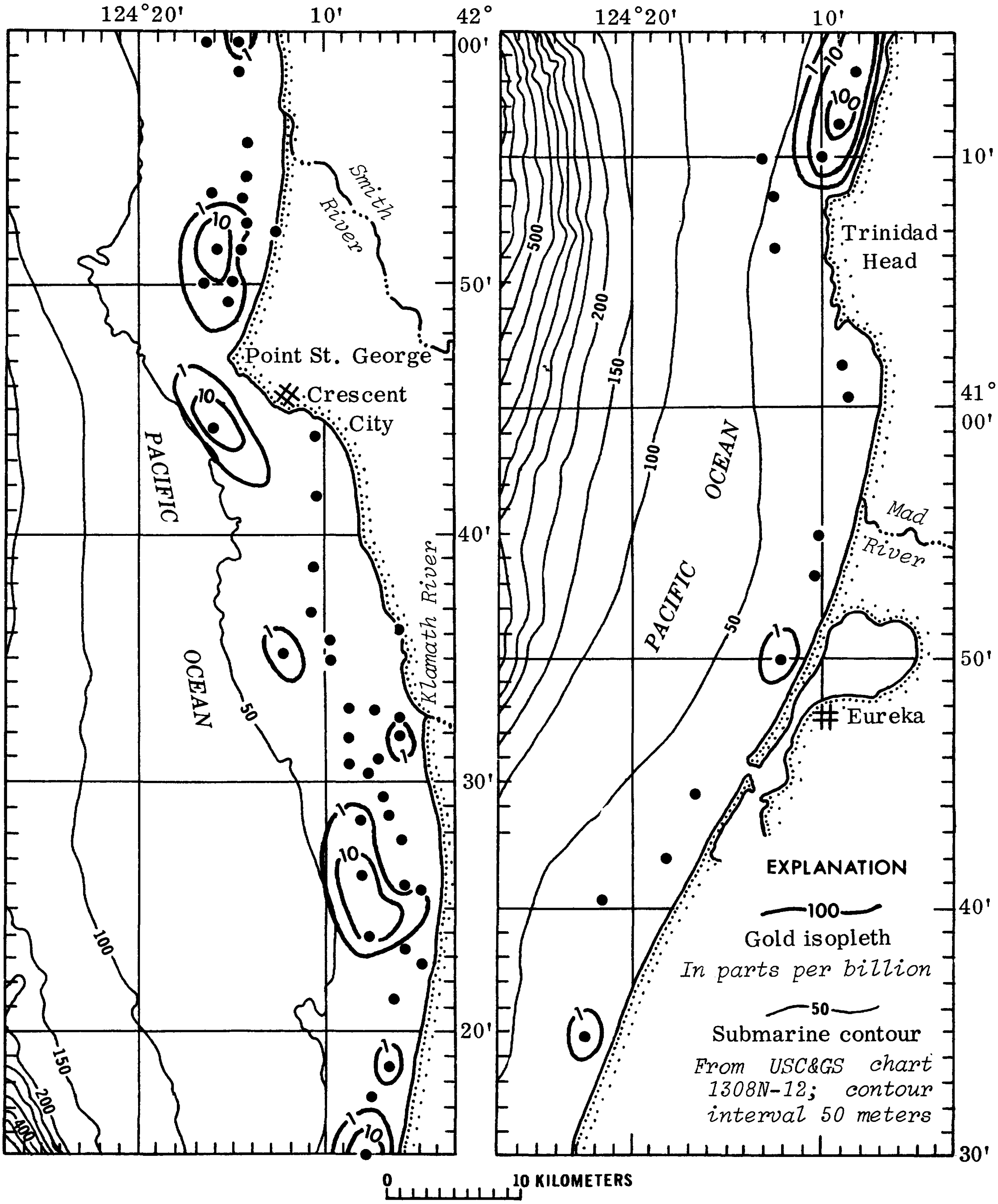

Figure 2.--Map showing location and gold content of the samples.

heavy-mineral suite from the north with a gold-bearing heavy-mineral suite derived from the Klamath Mountains to the east.

ORIGIN OF THE ANOMALOUSLY HIGH GOLD VALUES

The rather broad depth range within which the gold anomalies occur and their discontinuous nature along the coast suggest to us that they do not occur on relict beaches, in the sense of being at stillstands of Pleistocene sea level. The gold anomalies do bear a relationship to the bedrock geology, however, and this may be genetically significant. The offshore geology of part of the project area has been reported on earlier (Moore and Silver, 1968), and mapping by acoustic-

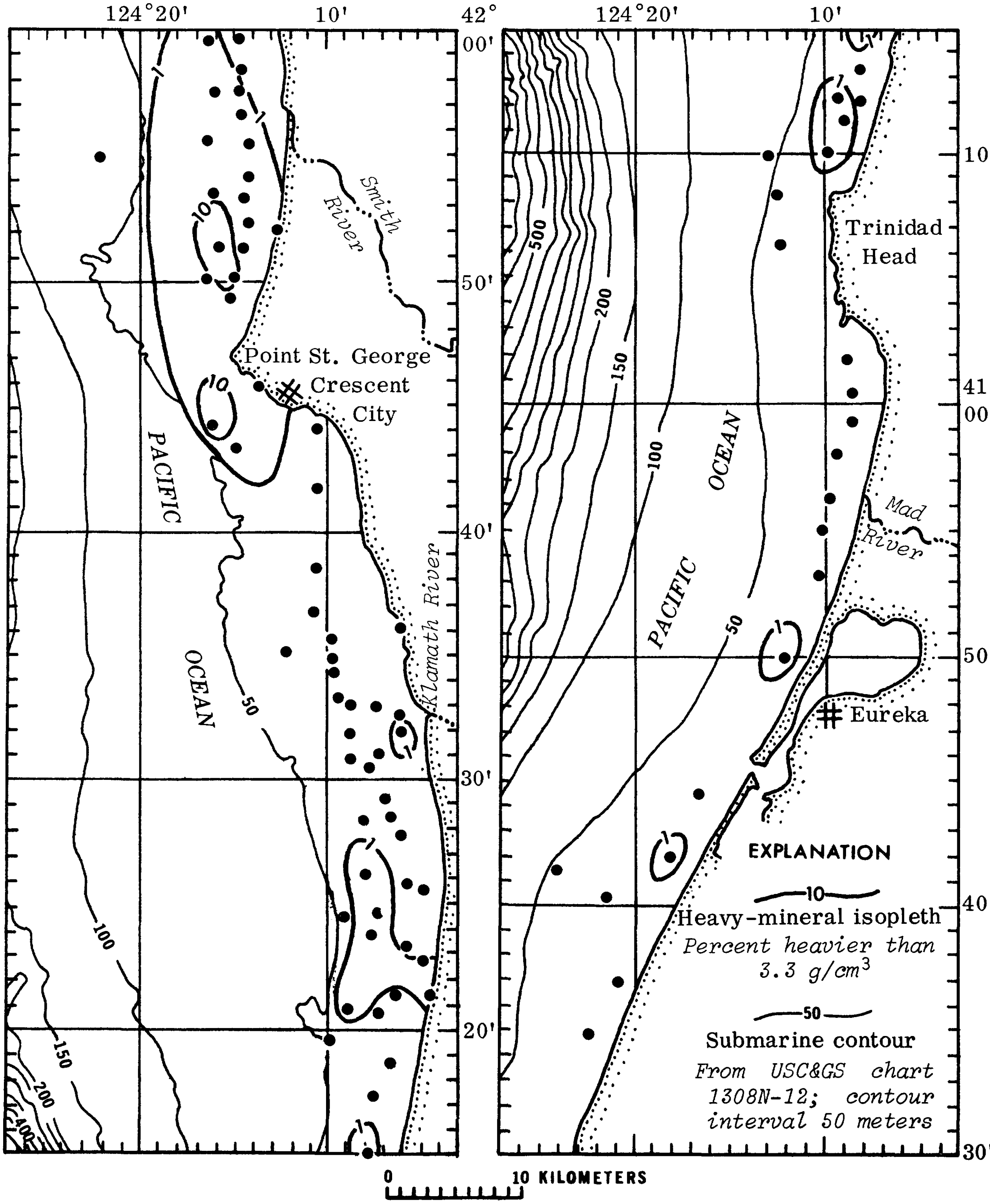

Figure 3.--Map showing weight percent of minerals heavier than methylene iodide in the samples.

reflection profiling methods of the remainder of the area sampled for gold has now been completed. This mapping shows that a single common denominator relates all the areas of anomalously high gold content to the bedrock geology. Each such area overlies a northwest-trending syncline containing upper Cenozoic deposits that carry small quantities of dispersed gold, originally derived from lodes in the Klamath Mountains (fig. 4). This relationship is true also of two minor anomalies at the south end of the area near Eureka (fig. 2).

To explain the gold anomalies, we offer the following hypothesis: During the Holocene rise of sea level that

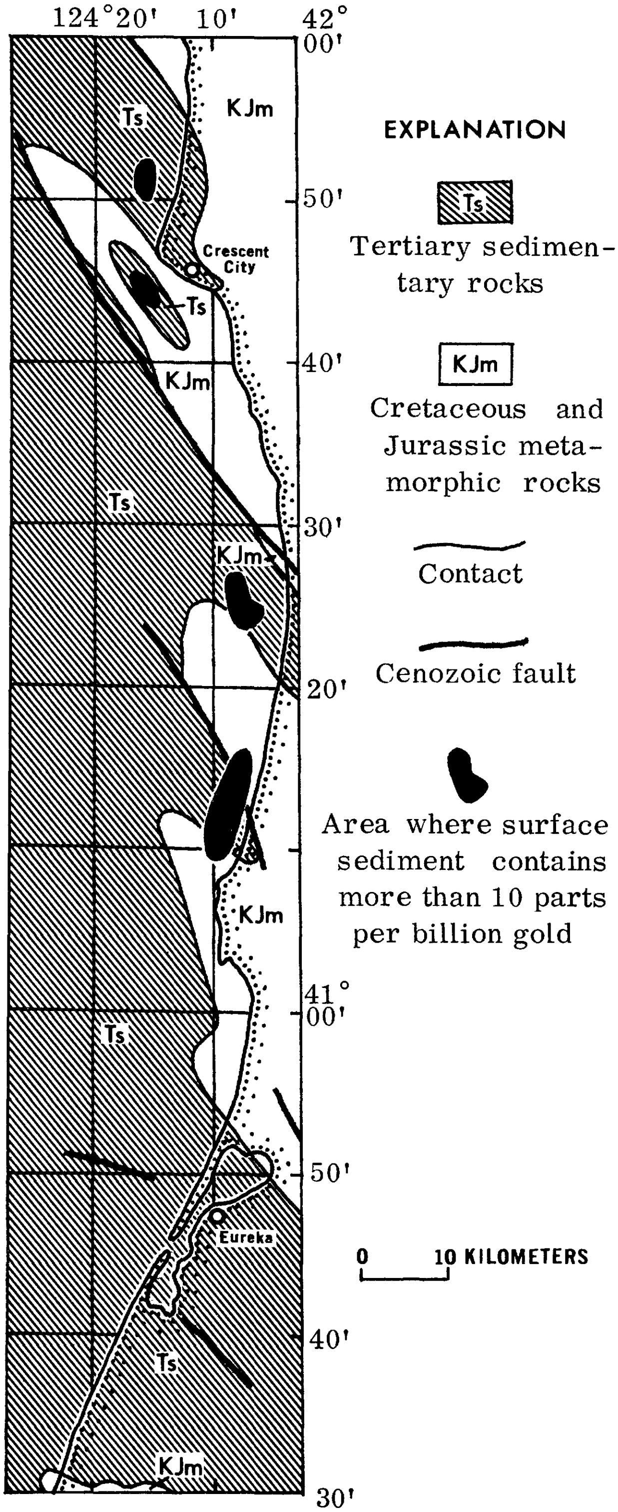

Figure 4.--Map showing relationship between gold anomalies and bedrock geology.

followed the Wisconsin Glaciation, encroaching waves attacked and reworked the soft gold-bearing Cenozoic deposits. Other constituents of the deposits were transported away by the attacking waves, and the gold accumulated offshore as a lag concentrate. Acoustic-reflection profiles indicate that the postglacial deposits in the areas of the anomalies are as thick as 10 meters.

CONCLUSIONS

Surface sediment in localized areas on the northern California continental shelf contains gold that occurs as probable lag accumulations above synclinal bodies of soft upper Cenozoic material that was eroded by waves along the shore of the rising postglacial sea. Each of four anomalies in which the gold content exceeds 10 ppb covers an area of more than 10 square kilometers, and the richest individual sample contains 390 ppb gold. The gold content of the surface sediment is too low to be of economic significance, and drilling will be necessary to provide information on the distribution of gold at depth within the deposits and on the possible occurrence of minable gold resources below the anomalies.

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Table 1.--Location, depth, and analyses of the samples

[Altitude of beach samples above mean lower low water indicated by + in depth column; heavy-liquid separations by N. Schumacher; gold analyses by W. L. Campbell, T. G. Ging, R. F. Hansen, R. Leinz, M. S. Rickard, T. M. Stein, and Z. C. Stephenson; chromium analyses by J. P. Cahill, C. Huffman, V. E. Shaw, and J. A. Thomas]

Location		Depth (meters)	Median diameter (millimeters)	Heavier than bromoform (percent)	Heavier than methylene iodide (percent)	Gold (parts per billion)	Chromium (percent)
Lat N	Long W						
41°59.6'	124°16.3'	27	0.11	12.7	1.5	0.1	0.080
41°59.5'	124°14.8'	20	.12	5.6	.8	1.0	.070
41°58.5'	124°14.6'	18	.12	6.8	.8	.1	.068
41°57.6'	124°14.9'	18	.12	15.0	2.1	--	.15
41°57.5'	124°16.0'	22	.12	21.1	4.6	--	.15
41°56.6'	124°14.7'	18	.12	23.9	2.0	--	.24
41°55.7'	124°16.4'	27	.11	33.0	7.2	--	.41
41°55.5'	124°14.4'	22	.11	25.0	4.4	.7	.31
41°55.0'	124°21.9'	59	.06	6.6	.8	--	--
41°54.3'	124°14.4'	18	.12	41.0	1.8	.7	.43
41°53.6'	124°16.0'	27	.11	38.4	9.2	.4	.62
41°53.4'	124°14.7'	18	.11	42.0	5.3	.1	.31
41°52.3'	124°14.4'	18	.11	30.5	7.4	1.6	.22
41°52.1'	124°12.8'	+2	.43	16.4	1.7	.2	.047
41°51.5'	124°15.8'	29	.11	34.7	11.5	13.	.80
41°51.4'	124°14.6'	18	.12	30.6	2.3	.2	.45
41°50.3'	124°16.3'	29	.12	29.5	8.4	7.1	.68
41°50.2'	124°15.0'	18	.12	37.8	12.8	4.0	.68
41°49.4'	124°15.3'	18	.13	28.5	5.7	2.6	.57
41°45.9'	124°13.8'	+1	1.06	24.2	2.9	--	--

Table 1.--Location, depth, and analyses of the samples--Continued

Location		Depth (meters)	Median diameter (millimeters)	Heavier than bromoform (percent)	Heavier than methylene iodide (percent)	Gold (parts per billion)	Chromium (percent)
Lat N	Long W						
41°44.2'	124°15.8'	42	0.13	41.6	11.9	15.	--
41°44.1'	124°10.7'	5	.14	13.1	.6	<.1	--
41°43.2'	124°14.6'	37	.12	16.9	1.9	--	--
41°41.6'	124°10.7'	18	--	8.0	.1	<.1	--
41°38.6'	124°10.7'	32	--	6.0	<.1	<.1	--
41°36.8'	124°10.8'	33	.08	2.4	.2	.6	.024
41°36.2'	124°06.0'	+1	--	2.7	.1	.3	--
41°35.8'	124°10.0'	33	.09	10.8	.4	.5	.049
41°35.2'	124°12.4'	41	.09	12.9	.4	1.2	--
41°35.0'	124°10.0'	33	.08	2.6	.1	.3	.030
41°34.2'	124°09.5'	31	.09	4.1	.8	--	.058
41°33.5'	124°09.0'	31	.10	5.6	.2	--	.031
41°33.1'	124°07.8'	20	.11	2.2	.2	.1	.030
41°32.9'	124°09.0'	31	.12	11.6	.8	.7	.038
41°32.8'	124°06.3'	18	.09	9.3	.9	.9	.060
41°32.0'	124°06.3'	16	.11	13.4	1.6	5.3	.055
41°31.9'	124°09.0'	27	.12	15.0	.8	.7	.046
41°31.2'	124°07.5'	18	.12	12.5	.9	.7	.047
41°30.9'	124°08.6'	27	.12	11.0	.8	.5	.048
41°30.4'	124°08.6'	29	.12	3.8	.4	.2	.030
41°29.3'	124°07.2'	18	.12	9.6	.7	.8	.045
41°28.6'	124°06.7'	18	--	17.3	.2	<.1	--
41°28.5'	124°08.3'	18	.12	6.3	.7	1.2	.054
41°27.6'	124°06.0'	16	.12	3.0	.8	.4	.038

Table 1.--Location, depth, and analyses of the samples--Continued

Location		Depth (meters)	Median diameter (millimeters)	Heavier than bromoform (percent)	Heavier than methylene iodide (percent)	Gold (parts per billion)	Chromium (percent)
Lat N	Long W						
41°26.0'	124°08.1'	27	0.12	12.0	1.4	55.	0.065
41°25.7'	124°05.8'	17	--	12.4	.4	<.1	--
41°25.7'	124°05.1'	16	.13	12.9	1.5	9.4	.040
41°24.8'	124°09.0'	46	.09	6.2	.3	--	--
41°24.6'	124°06.9'	24	.13	35.5	3.6	--	--
41°23.8'	124°08.0'	27	.13	17.1	1.6	22.	.077
41°23.4'	124°05.8'	16	--	--	.5	<.1	--
41°22.9'	124°05.5'	15	.13	6.7	1.0	<.1	.024
41°21.4'	124°06.7	15	.13	8.8	.4	<.1	.044
41°21.4'	124°04.5'	+3	.34	41.4	5.1	--	--
41°20.9'	124°09.0'	38	.12	9.4	1.4	--	.060
41°20.7'	124°07.4'	18	.12	1.2	.1	--	.022
41°19.6'	124°09.9'	42	.09	1.4	.7	--	.025
41°18.7'	124°07.3'	22	.13	10.0	.7	1.2	.060
41°17.4'	124°07.6'	22	.11	6.9	.5	<.1	.065
41°15.2'	124°08.0'	22	.12	21.3	4.1	11.	.20
41°13.4'	124°08.3'	20	.13	4.6	.5	13.	.044
41°12.1'	124°09.2'	22	.13	19.3	1.7	--	--
41°12.0'	124°08.2'	15	.13	12.6	.6	--	--
41°11.4'	124°09.0'	20	.13	14.4	1.1	390.	.098
41°10.1'	124°09.9'	20	.13	14.1	1.4	11.	.10
41°09.8'	124°13.1'	53	.06	1.9	.1	<.1	.018
41°08.2'	124°12.6'	22	.13	2.3	.1	<.1	.015
41°06.3'	124°12.5'	38	.13	4.6	.5	<.1	.041

Table 1.--Location, depth, and analyses of the samples--Continued

Location		Depth (meters)	Median diameter (millimeters)	Heavier than bromoform (percent)	Heavier than methylene iodide (percent)	Gold (parts per billion)	Chromium (percent)
Lat N	Long W						
41°01.4'	124°09.1'	15	0.13	1.1	0.1	<0.1	.10
41°00.4'	124°08.8'	15	.13	.8	.2	.1	.015
40°59.2'	124°08.8'	15	.13	1.2	.1	.1	.011
40°57.9'	124°09.5'	22	.13	1.6	.1	--	.018
40°56.3'	124°09.8'	27	.14	3.7	.4	--	.033
40°54.9'	124°10.6'	29	.14	7.4	.4	.5	.053
40°53.2'	124°10.6'	20	.15	7.6	.7	<.1	.060
40°49.9'	124°12.3'	18	.15	13.6	3.8	8.1	.22
40°44.4'	124°16.8'	27	.14	2.2	.2	<.1	.011
40°41.9'	124°18.4'	31	.10	.7	.1	<.1	.016
40°41.4'	124°24.0'	60	.10	.7	.2	--	.018
40°40.3'	124°21.7'	27	.12	1.5	.3	.3	.020
40°37.0'	124°20.9'	18	.13	2.0	.2	--	.037
40°34.8'	124°22.4'	18	.13	2.4	.4	1.2	.042

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