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COMPLETE BOUGUER GRAVITY MAP OF THE NORTHERN PART OF THE SAN FRANCISCO BAY AREA AND ITS GEOLOGIC INTERPRETATION

By
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Introduction

This report represents the results of gravity measurements in an area in the Coast Ranges of California extending north from San Francisco 36 miles and east from the Pacific Ocean 41 miles. The gravity measurements were undertaken to ascertain possible gravitational expressions of the San Andreas fault, the San Pablo Bay basin, and the Tolay fault. Other objectives were to investigate the possibility that the Tolay fault may represent the northern extension of the Hayward-Wildcat fault zone, and to search for unknown major geologic structures.

A general interpretation of the complete Bouguer anomaly map relates the major anomalies to known geologic structures and in addition brings out the following points: 1) there is no characteristic gravity expression of the San Andreas fault; 2) the gravity anomalies associated with the Tolay fault indicate it may represent the northern extension of the Hayward-Wildcat fault zone; 3) the negative gravity anomaly associated with the San Pablo Bay basin is primarily due to the presence of a downfaulted and folded block of Tertiary rocks rather than to Quaternary deposits in the bay basin.

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Geology

In order to provide a background for interpretation of the gravity map, a generalized geologic map and a summary of the geology of the area are included in this report. The generalized geologic map is a compilation from Weaver (1949), Lawson (1914), Schlocker, Bonilla, and Radbruch (1958), Travis (1952), and Galloway (1962). A detailed account of the structure and stratigraphy can be found in the literature cited in the bibliography.

Structure: The area covered by the gravity survey is divided into three structural blocks by two faults trending northwest-southeast, the San Andreas fault and the Tolay fault. The San Andreas fault separates the central block, mostly of rocks of the Franciscan Formation considered to be of Jurassic and Cretaceous age, from the western block consisting of a Cretaceous quartz diorite body partially covered by Tertiary sedimentary rocks. The Tolay fault separates the central block from the eastern block consisting primarily of a thick section of Tertiary rocks. These blocks correspond to those described by Lawson (1914) immediately to the south: the Montara block, the San Francisco-Marin block, and the Berkeley Hills block. Within the individual blocks there are numerous folds and faults which are the results of repeated diastrophism that has occurred during and since Cretaceous time.

The San Andreas fault, which separates the central and western blocks, is a major structural feature in California. Within the area of the gravity survey it is not a single distinct fault, but a fault zone which is expressed topographically from Bolinas Bay northwestward as a valley. Right-lateral displacement on the order of 300 to 500 miles has been proposed by Hill and Dibblee (1953), Crowell (1962), and by Curtis and others (1958). Higgins (1961) and Rose (1959) believe this amount of lateral displacement is not supported by the distribution of Cretaceous rocks or by paleontological evidence.

Although the Tolay fault is not a major regional structure, within the area covered by the gravity measurements it compares in importance with the San Andreas fault. Upper-Tertiary and Quaternary rocks conceal the location of the Tolay fault along most of its length. A post-Miocene vertical displacement of thousands of feet is indicated by the penetration of approximately 6,000 feet of Miocene(?) and Pliocene rocks in gas and oil wells east of the fault without reaching older rock.

The rock units that appear on the geologic map can be grouped into three major divisions on the basis of age, density (table 1), and, to a certain extent, location. These divisions are the Jurassic and Cretaceous rocks, the Tertiary rocks, and the unconsolidated Quaternary deposits. The central block consists of rocks of Jurassic and Cretaceous age partly covered by Tertiary sedimentary and volcanic rocks and Quaternary sedimentary deposits. The western block contains a Cretaceous granitic body partially covered by Tertiary and Quaternary rocks. The eastern block is primarily a thick section of Tertiary rocks partially covered by Quaternary rocks.

Jurassic and Cretaceous rocks: The majority of the rocks exposed in the northern Coast Ranges are Late Jurassic to early Late Cretaceous in age. Two facies of this stratigraphic section are present (Irwin, 1957, 1961). One, the Franciscan Formation, reflects a eugeosynclinal depositional environment. The second, reflecting a shelf or slope environment, is represented in the area of this report by the Knoxville Formation (Upper Jurassic), Novato Conglomerate (Cretaceous?), Horsetown(?) Formation (Lower Cretaceous), and the Chico Formation (Lower? and Upper Cretaceous).

Table 1. Densities of rocks in the San Francisco Bay Area.[1]

System	Rock unit	Investigator	Rock type	Density range (gm/cc)	Average density (gm/cc)
Quaternary	Sediments of San Francisco Bay	Meade[2]	Sand and silt		1.90
		Trask and Ralston (1951)	Mud, sand and silt	1.57-2.10	
		Schlocker and others (1958) dry densities	Alluvium	1.61-2.25	
			bay mud and clay	0.69-1.61	
		Bonilla (1959)	Alluvium	1.56-2.19	
	Sediments of San Pablo Bay	Calif. Dept. Public Works	Mud, salt, and clay	1.53-1.96	
			sand and gravel	1.96-2.42	
Tertiary and Quaternary	Merced Formation	Bonilla (1959)	Sand, silt, and clay	1.35-2.36	1.90
Tertiary	Sonoma Volcanics	Clement	Rhyolite	2.63-2.64	2.63
	Petaluma Formation	Clement[3]			2.30
	Orinda Formation	No measurement	Sandstone		[4]2.3
	San Pablo Group	No measurement	Sandstone		[4]2.3
	Monterey Group	Greve (1962)		2.19-2.31	2.23
		Clement		1.60-2.51	2.30
Cretaceous	Quartz diorite of Point Reyes	Clement	Quartz diorite	2.67-2.70	2.68
Jurassic	Franciscan Formation	Irwin (1961), dry densities	Sandstone	2.30-3.10	2.65
		Clement	Sandstone	2.45-3.06	2.66
			greenstone	2.38-2.89	2.78
			serpentine	1.80-2.60	2.53
		Greve (1962)	Sandstone	2.49-2.70	2.66
			greenstone	2.63-2.99	2.80
			serpentine	1.96-2.79	2.56
		Schlocker and others (1958) dry densities	Serpentine	1.25-2.53	
	Knoxville Formation	Irwin (1961), dry densities	Sandstone	2.45-2.68	2.59

1 Saturated densities unless otherwise noted.
2 Personal communication from Robert Meade, U. S. Geological Survey.
3 Density profile.
4 Assumed.

The Franciscan Formation is generally considered to be the basement rock of the Coast Ranges. Although the base is not exposed, the thickness is believed to be in excess of 35,000 feet (Irwin, 1961). The Franciscan Formation is an assemblage of rocks which consists predominately of graywackes, shale, and volcanic rocks which are primarily basaltic lavas and pyroclastics. Smaller amounts of radiolarian cherts, conglomerate, foraminiferal limestone, and metamorphic rocks are also present. During and after deposition the Franciscan rocks were intruded by mafic and ultramafic igneous rocks. The mafic intrusive igneous rocks and the volcanic rocks are difficult to distinguish in the field and are generally mapped together as greenstone. The ultramafic rocks are peridotite and serpentinized peridotite.

The Knoxville Formation and the Novato Conglomerate, Horsetown(?) and Chico Formations are exposed mostly along the eastern side of the area and probably extend under the Quaternary sediments in and north of San Pablo Bay. Exposed thicknesses of 10,000 feet and 7,500 feet of the Knoxville and Horsetown(?) Formations and the Chico Formation respectively are present.

The basement rock of the western block is a granitic plutonic rock mostly of quartz diorite composition. Rocks of similar composition outcrop at the Farallon Islands 20 miles southwest of Point Reyes and at Bodega Head about three miles west of the northwest corner of the map area. Samples of quartz diorite have also been dredged from the edge of the continental shelf northwest of the Farallon Islands (Hanna, 1952). The quartz diorite body of the western block, the Farallon Islands, Bodega Head, and other granitic bodies of the Coast Ranges are probably part of the same general episode of plutonic action, but not necessarily the same intrusion. Potassium-argon age dating indicates the intrusions are Late Cretaceous in age (Curtis, Everndon, and Lipson, 1958).

Tertiary rocks: Of the exposed Tertiary rocks, only the Monterey Shale, the San Pablo Group, the Orinda, Petaluma and Merced Formations, and the Sonoma Volcanics contribute significantly to the gravity anomalies. An unexposed section of Tertiary volcanic and sedimentary rocks, revealed in drilling a gas well as lying beneath the Petaluma Formation, also contributes to the gravity anomalies.

The Monterey Shale on this map includes all Miocene sedimentary rocks underlying the San Pablo Group, which are represented on the map along with undifferentiated Paleocene through Miocene sedimentary rocks by the symbol Tsu. The largest exposure of the Monterey Shale is in the western block where it rests upon the quartz diorite and attains a thickness of 8,400 feet near Bolinas Bay. Adjacent to the San Andreas fault, where it is in fault contact with the Franciscan Formation, the Monterey Shale is middle Miocene in age and is predominately a siliceous shale. To the west and northwest, under Drakes Bay and on the Point Reyes Peninsula, upper Miocene siltstones and sandstones with subordinate amounts of siliceous shale rest upon the quartz diorite and a Paleocene conglomerate.

The Monterey Shale is exposed in the eastern block both north and south of San Pablo Bay. North of the bay a small exposure averaging 500 feet in thickness is found west of the Carneros fault. Along the southern shore of San Pablo Bay, Monterey Shale up to 6,700 feet thick is exposed in the limbs of a synclinal fold.

The center of the synclinal fold south of San Pablo Bay is occupied by the San Pablo Group. The San Pablo Group, at this location consisting of sandstone and minor amounts of shale, comprising the Briones, Cierbo and Neroly Sandstones is approximately 4,600 feet thick.

The Orinda Formation of Pliocene age is found south of San Pablo Bay in a shallow northwest-trending syncline. Near the shore of the bay the formation consists of 2,500 feet of sandstone, shale, conglomerate, and lenses of limestone and carbonaceous material. Weaver (1949) believes this formation is in part contemporaneous with the Petaluma Formation exposed north of San Pablo Bay.

The Petaluma Formation of Pliocene age is composed of continental sedimentary rocks ranging from clay shales through sandstones to conglomerates. The formation is exposed only in the eastern block north of San Pablo Bay and at one location is in fault contact with the Franciscan Formation along the Tolay fault. Although the base of the Petaluma Formation and the underlying rocks are not exposed, a gas well east of the town of Petaluma, drilled to 5,061 feet, penetrated approximately 2,200 feet of the Petaluma Formation before entering a thick section of Tertiary volcanic and sedimentary rocks. The thickness of this Tertiary section and the type of rock below it are unknown.

The Sonoma Volcanics of Pliocene age are exposed in the central and eastern blocks. The scattered exposures are remnants of a widespread series of flows and tuff beds interbedded with sandstones, gravel and conglomerates.

The Merced Formation of Pliocene and Pleistocene(?) age extends across the northern part of the area. Up to 300 feet of marine sandstone and sandy shales rest unconformably upon the Franciscan Formation and at one location are interbedded with the Sonoma Volcanics. The Merced Formation is also exposed west of the San Andreas fault near Bolinas Bay where it is in fault contact with both the Franciscan Formation and the Monterey Shale.

Quaternary rocks: Quaternary sediments are scattered throughout the area, but their contribution to the Bouguer gravity anomaly is appreciable only in the vicinity of San Pablo Bay. North of San Pablo Bay over 500 feet of gravels, clays, sands, reworked tuffs, and conglomerates of the Huichica Formation of Pleistocene age lie upon the Sonoma Volcanics. Deposits of mud, silt, clay, sand, and gravel up to 290 feet thick are present in the southern end of the bay at the site of the San Rafael-Richmond Bridge. At the head of San Pablo Bay in Carquinez Strait, the sediments are 167 feet thick. The thickness and disposition of the Quaternary sediments throughout the rest of the bay basin are unknown.

Gravity measurements

The gravity measurements were made during 1961 and 1962 with gravimeters of the U. S. Geological Survey and Stanford University. Five hundred and nineteen gravity stations were established at bench marks and points of checked elevation appearing on 7½-minute topographic sheets. An attempt was made to have a gravity station density of one station every 1½ square miles. This density was in general achieved except in areas where the necessary elevation control was absent.

The base net of 24 stations is tied to the gravity station established by Woollard (1958) at gate 23 of the San Francisco International Airport. The value reported by Woollard for this station is 979988.0 mgal.

Secondary stations were established during traverses up to 2 hours in length, beginning and ending at a base station. During a traverse the combined effect of any instrument drift and tidal variations was assumed to be linear. The instrument readings were adjusted by interpolation and converted to values of observed gravity using the instrument scale constant.

The calibration of the two gravimeters used for the measurements were compared over a calibration loop. The maximum difference between the instruments was 0.2 mgal and occurred at the extreme limits of the instruments.

Reduction of data

The presentation of the results for interpretation is in the form of a complete Bouguer gravity anomaly map. The complete Bouguer anomaly as used in this report is: observed gravity minus theoretical gravity plus free air adjustment minus Bouguer adjustment plus terrain adjustment plus curvature adjustment. This anomaly includes the effect of all density variations beneath the surface of the earth. The effect of differences between the actual density of surface material and the value of 2.67 gm/cc used in the Bouguer and terrain adjustment is considered to be part of the complete Bouguer anomaly.

Before any attempt is made to interpret the anomaly map, the magnitude of the probable error in the complete Bouguer anomaly should be examined. The main source of error is the station location. The free air adjustment and the theoretical gravity depend only on the station location. The largest probable error in station elevation occurs for stations established at checked elevation points appearing on 7½-minute topographic sheets. These elevations, according to U. S. Geological Survey standards, are correct to within two feet. An error in elevation of 2 feet results in an error of 0.19 mgal in the free air adjustment.

The latitude of each station was estimated to the nearest 0.01 minute from 7½-minute topographic sheets using a scale with 0.05 minute divisions. At the latitude of the area, an error of 0.01 minute corresponds to approximately 60 feet which would result in a change of theoretical gravity of 0.015 mgal.

The Bouguer adjustment also depends on the elevation of the station. For the assumed density of 2.67 gm/cc, an elevation error of 2 feet results in an error of 0.068 mgal in the Bouguer adjustment. The maximum probable error in the complete Bouguer anomaly due to station location error may be $\pm$ 0.19 mgal, $\pm$ 0.015 mgal, $\mp$ 0.068 mgal, or an absolute value of 0.14 mgal.

In the analysis of the probable error the terrain adjustments are neglected. Terrain adjustments and adjustment errors due to station location are opposite in sign to the Bouguer adjustments and adjustment errors. Any terrain adjustment errors would increase or decrease the maximum probable error slightly. Since the terrain adjustments are included in the complete Bouguer anomaly some discussion of their computation and reliability is necessary. The effect of the terrain around each station out to a distance of 14 miles was computed following the method described by Hammer (1939). The accuracy of the terrain adjustments is difficult to judge since they depend upon the computer's subjective evaluation of average elevations. Six stations were recomputed and the maximum difference between any set of terrain adjustments is 0.1 mgal. This indicates the adjustments are reasonably consistent although they may be consistently high or low.

General interpretation

The complete Bouguer gravity anomaly map is composed of local anomalies superimposed upon a regional gravity gradient of approximately 0.5 mgal/mile increasing toward the west. The total range of the complete Bouguer anomaly is 63.9 mgal with a high of 28.6 mgal and a low of -35.3 mgal.

The largest anomaly in the area is the elongated gravity low found in the vicinity of San Pablo Bay. The striking features of this anomaly are: 1) the location of its axis east of the center of San Pablo Bay and, 2) the large gradients along the east and west sides of the anomaly. The large gradient along the west side of the gravity low probably indicates a major fault zone. This long narrow gravity feature extends across the map in a northwest-southeast direction. To the northwest it coincides with the Tolay fault which is the contact between the eastern and central blocks. To the southeast it more or less coincides with the surface traces of the Hayward-Wildcat fault zone. This correlation supports the hypothesis that the Tolay fault may be the northwest continuation of the Hayward-Wildcat fault zone (Weaver, 1949).

The large gradient along the east side of the elongated gravity low indicates a monoclinal fold or fault that may form the contact between the Jurassic and Cretaceous rocks and the Tertiary rocks beneath the Quaternary sediments of the bay. These major features of the gravity low, the large gradients and the easterly offset from the axis of the bay, indicate the anomaly is primarily a reflection of a thick section of downfaulted and folded Tertiary rocks. The gravitational effect of the Quaternary rocks is secondary.

A minor feature of the anomaly map is the distortion of the long narrow gravity anomaly along the west side of the gravity low. This distortion immediately north of San Pablo Bay is due to the gravitational effect of an anticlinal ridge of Franciscan rocks along the Sears Point anticline. This structure, which plunges southeast and is surrounded by Pliocene and

Quaternary rocks, produces a nose and a high in the Bouguer gravity surface.

Another minor gravity feature is the gradient found 2 to 3 miles west of Sonoma which extends southward and joins the long narrow anomaly associated with the Tolay fault. This gradient may indicate a possible branch of the Tolay fault.

Gravity highs associated with the central block, mostly of Franciscan rocks, generally coincide with belts of exposed mafic and ultramafic igneous rocks. The largest of the highs, having a maximum value of 28.6 mgal, is just east of the San Andreas fault. Smaller highs also associated with exposures of mafic and ultramafic rocks lie west and south of Petaluma. The Sonoma Volcanics of Burdell Mountain, consisting of 400 feet of andesite flows and 800 feet of tuffaceous beds, produce a small gravity low southwest of Sonoma.

The gravity high southwest of Sausalito is due to the density contrast between Franciscan volcanic rocks and closely associated cherts and Franciscan sandstones to the northwest.

The gravity high with a maximum value of 12 mgal found southeast of Petaluma is an especially interesting anomaly. Samples of sandstone from this area have densities up to 3.06 gm/cc. These high densities are the result of metamorphism that formed jadeite, lawsonite, and other minerals (Bloxam, 1956). Detailed gravity measurements should be useful in outlining the areal extent of metamorphism of graywackes, as this metamorphism is difficult to recognize in hand specimens.

The somewhat elongated gravity high with a maximum value of 14 mgal found northwest of Petaluma indicates the presence of excess mass associated with the Franciscan Formation. Since the Franciscan Formation in this area is almost completely covered by Pliocene to Recent rocks the material comprising the mass is unknown. The mass may be either mafic igneous rocks interbedded with or intruding the Franciscan Formation or metamorphosed Franciscan sandstone.

The major structural feature in the area, the San Andreas fault, has no characteristic gravity anomaly associated with it. In the vicinity of Tomales Bay where there are no local gravity anomalies of note to distort the smooth gravity surface, the gradual increase toward the west can be attributed to the regional gradient.

Although a rapid change in the Bouguer gravity in the vicinity of the San Andreas fault occurs near Bolinas Bay, this anomaly is clearly due to the low density of the Miocene sedimentary rocks, the high density of the mafic igneous rocks in the central block, and the intermediate density of the quartz diorite and the Franciscan sedimentary rocks. The gravity high with a maximum of 28.6 mgal, as previously mentioned, centers along the belt of mafic and ultramafic igneous rocks. The decrease toward the south within the western block reflects a thickening of the Miocene sedimentary rocks toward the south and southwest. Thus all of the gravity variation near Bolinas Bay can be accounted for by local rock masses that are only accidentally associated with the San Andreas fault.

Other small highs and lows in the Bouguer gravity surface in the western block reflect the undulations of the quartz diorite basement beneath the Miocene strata.

Summary

The larger features of the complete Bouguer gravity anomaly map are produced by density contrasts between rocks of Jurassic and Cretaceous age and rocks of Tertiary age. Exceptions are the gravity highs associated with the mafic igneous rocks interbedded with and intruding the Franciscan Formation.

The elongated gravity low in the vicinity of San Pablo Bay is primarily the effect of a downfaulted and folded block of Tertiary rocks bounded by rocks of Jurassic and Cretaceous age on the east and west. The contribution of the Quaternary sediments is minor. The large gradient along the west side of the gravity low coincides with the Tolay fault northwest of San Pablo Bay and appears to coincide with the Hayward-Wildcat fault zone south of the bay. This correlation supports the hypothesis that the Tolay fault represents the northern extension of the Hayward-Wildcat fault zone. The gradient along the east side of the gravity low may indicate the location of a fault or a rapid thinning of Tertiary rocks at the eastern boundary of the Tertiary block.

The San Andreas fault appears to have no characteristic local gravity anomaly associated with it. Along Tomales Bay, where rocks of similar density are in fault contact, there is a small increase in the Bouguer gravity surface toward the west.

Between Tomales Bay and Bolinas Bay the Bouguer gravity surface decreases rapidly in the vicinity of the San Andreas fault. This feature is a combination of a gravity high east of the fault and gravity low west of the fault. The gravity high is associated with mafic igneous rocks in the Franciscan Formation. The gravity low is produced by the low-density Tertiary sedimentary rocks (2.3 gm/cc).

References

Bloxam, T. W., 1956, Jadeite-bearing metagraywackes in California: Am. Mineralogist, v. 41, nos. 5-6, p. 488-496.

Bonilla, M. G., 1959, Geologic observations in the epicentral area of the San Francisco earthquake of March 22, 1957: California Div. Mines Spec. Rept. 57, p. 30.

Crowell, J. C., 1962, Displacement along the San Andreas Fault, California: Geol. Soc. America Spec. Paper 71, 61 p.

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

Galloway, A. J., 1962, Point Reyes Peninsula and San Andreas Fault zone, in Geologic guide to the gas and oil fields of northern California: California Div. Mines and Geology Bull. 181, p. 391-398.

Greve, G. M., 1962, An investigation of the earth's gravitational and magnetic fields on the San Francisco Peninsula, California: Stanford Univ., Stanford, Calif., unpub. Ph. D. Thesis.

Hammer, Sigmund, 1939, Terrain corrections for gravimeter stations: Geophysics, v. 4, no. 3, p. 184-194.

Hanna, G. D., 1952, Geology of the continental slope off central California: California Acad. Sci. Proc., 4th ser., v. 27, no. 9, p. 325-358.

Higgins, C. G., 1961, San Andreas fault north of San Francisco, California: Geol. Soc. America Bull., v. 72, no. 1, p. 51-68.

Hill, M. L., and Dibblee, T. W., Jr., 1953, San Andreas, Garlock, and Big Pine Faults, California--a study of the character, history, and tectonic significance of their displacement: Geol. Soc. America Bull., v. 64, p. 443-458.

Irwin, W. P., 1957, Franciscan group in Coast Ranges and its equivalents in Sacramento Valley, California: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, p. 2284-2297.

____1961, Specific gravity of sandstones in the Franciscan and related upper Mesozoic formations of California: Art. 78 in U. S. Geol. Survey Prof. Paper 424-B, p. B189-B191.

Lawson, A. C., 1914, Description of the San Francisco district; Tamalpais, San Francisco, Concord, San Mateo, and Hayward quadrangles: U. S. Geol. Survey Geol. Atlas, Folio 193.

Richmond-San Rafael Bridge, 4th Annual Report, 1956, California Dept. of Public Works, Div. of San Francisco Bay Toll Crossings.

Rose, R. L., 1959, California Upper Cretaceous conglomerates and the lateral displacement on the San Andreas fault north of San Francisco [abs.]: Geol. Soc. America Bull., v. 70, no. 12, pt. 2, p. 1745.

Schlocker, J., Bonilla, M. G., and Radbruch, D. H., 1958, Geology of the San Francisco North quadrangle, California: U. S. Geol. Survey Misc. Geol. Inv. Map I-272.

Trask, P. D., and Ralston, J. W., 1951, Engineering geology of San Francisco Bay, California: Geol. Soc. America Bull., v. 62, no. 9, p. 1079-1110.

Travis, R. B., 1952, Geology of the Sebastopol quadrangle, California: Calif. Div. Mines Bull. 162, 32 p.

Weaver, C. E., 1949, Geology of the Coast Ranges immediately north of the San Francisco Bay Region, California: Geol. Soc. America Mem. 35, 242 p.

Woollard, G. P., 1958, Results for a gravity control network at airports in the United States: Geophysics, v. 23, no. 3, p. 520-535.