Complete Bouguer Gravity and General Geology of the Bradley, San Miguel, Adelaida, and Paso Robles Quadrangles, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 646-B

Complete Bouguer Gravity and General Geology of the Bradley, San Miguel, Adelaida, and Paso Robles Quadrangles, California

By STEPHEN H. BURCH *and* DAVID L. DURHAM

GEOPHYSICAL FIELD INVESTIGATIONS

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Gravity data indicate the major structures of the Salinian basement in this region

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COMPLETE BOUGUER GRAVITY AND GENERAL GEOLOGY OF THE BRADLEY, SAN MIGUEL, ADELAIDA, AND PASO ROBLES QUADRANGLES, CALIFORNIA

By Stephen H. Burch and David L. Durham

ABSTRACT

Complete Bouguer gravity coverage of 313 stations and generalized geological mapping were compiled for the Bradley, San Miguel, Adelaida, and Paso Robles quadrangles, California. These quadrangles constitute a 30- by 30-minute rectangle covering nearly 1,000 square miles in the southern Salinas Valley, an oil-producing and potential oil-producing area. The granitic and metamorphic Salinian block constitutes the basement of the central, and by far the greatest, part of the map area. The Salinian basement block is separated from the adjacent Franciscan basement by the San Andreas fault in the northeast corner of the area and by the Nacimiento fault zone in the southwest corner. Overlying both basement blocks is a sequence of Cretaceous and Tertiary marine deposits and the nonmarine Paso Robles Formation.

The major gravity features of the Salinian block include (1) the Hames Valley low, which covers much of the Bradley quadrangle and represents a structural-depositional basin 10,000–15,000 feet deep, (2) the San Ardo oil-field high to the northeast, where basement rises to within 2,500 feet of the surface, (3) the Vineyard Canyon low, which covers much of the San Miguel quadrangle and represents a basin approximately 10,000 feet deep, (4) the Cholame Hills high to the northeast, where depth to basement is less than 2,000 feet, and (5) the transverse Indian Valley fault, a pre-late Miocene basement fault whose presence is deduced from the mutual truncation of the four previously mentioned gravity features. Inferred basement structures suggest three unexplored areas favorable to oil accumulation.

The gravity data suggest that in the area of Paso Robles the Jolon fault, rather than the Nacimiento fault, marks the contact of the Franciscan and granitic basement blocks and, furthermore, that the Jolon fault probably joins the Rinconada fault to the south.

INTRODUCTION

A 2-mgal (milligal) gravity map of the Bradley, San Miguel, Adelaida, and Paso Robles quadrangles, California, was prepared by S. H. Burch as part of a regional survey for the San Luis Obispo 1:250,000 gravity sheet. This map is overprinted on a generalized geologic map compiled by D. L. Durham. (See source map on pl. 1.) The geology of most of the area (fig. 1)

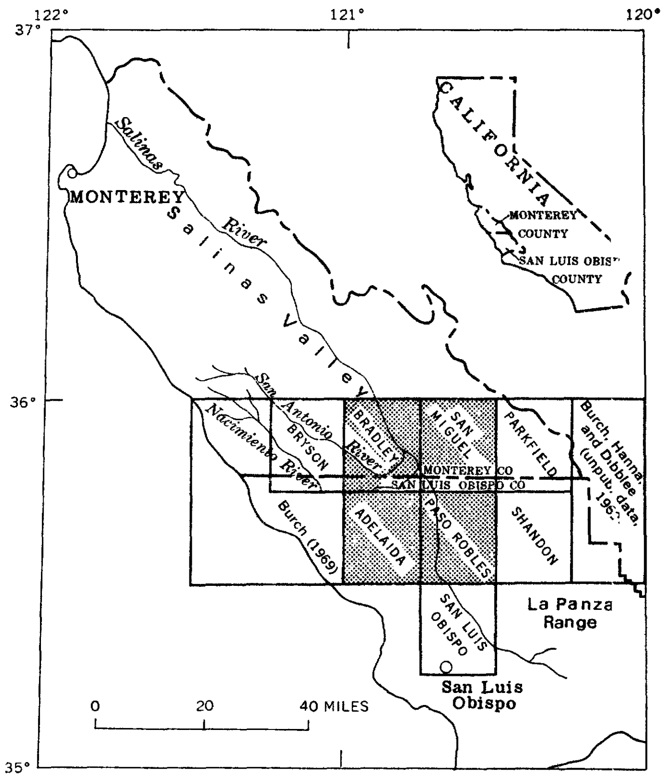

FIGURE 1.—Map showing location of the quadrangles forming area of study.

was mapped by Durham on a scale of 1:24,000 during an investigation of the southern Salinas Valley area. Mutual consultation between the authors on their respective fields lead to the joint preparation of this paper.

The four quadrangles constituting the map area form a 30- by 30-minute block which covers nearly 1,000 square miles in the oil-producing and potential oil-producing region in the Salinas Valley. The map area extends from the San Andreas fault in the northeast corner, across the entire Salinian basement block, and beyond the Nacimiento fault in the southwest corner.

GENERAL GEOLOGY

The geologic map (pl. 1) consists principally of D. L. Durham's mapping but is supplemented by data from the San Luis Obispo geologic sheet (Jennings, 1958). Rock units are lumped to provide continuity with companion maps to the west and east (Burch, 1969; S. H. Burch, W. F. Hanna, and T. W. Dibblee, Jr., unpub. data, 1969).

The map area is divided by the northwest-trending San Andreas and Nacimiento fault zones into three major basement blocks: (1) the Franciscan block of eugeosynclinal rocks southwest of the Nacimiento fault, (2) the granitic and metamorphic Salinian block (Compton, 1966, p. 277; also Reed, 1933, p. 12) between the Nacimiento and San Andreas faults, and (3) the Franciscan block of eugeosynclinal rocks northeast of the San Andreas fault. The Salinian block covers by far the greatest area and hence receives greatest attention in this report. The geology of the Franciscan block northeast of the San Andreas fault is not discussed here because of its small area and the complexity of geologic problems involved.

BASEMENT ROCKS

ULTRAMAFIC ROCKS

The ultramafic rocks are emplaced only in the Franciscan Formation, and most are serpentinites typical of those found throughout the Franciscan (Bailey and Everhart, 1964, p. 47). The smaller bodies are thoroughly serpentinized, and intense shearing has destroyed original textures in all but an occasional 2–3-inch remnant block. The centers of the larger bodies consist of blocky serpentinite, but invariably this grades outward to the usual sheared material. These serpentinite bodies crop out as elongate pods and lenses concordant with the regional structure. They commonly form discontinuous trains which extend for miles along zones of apparent slippage.

FRANCISCAN FORMATION

The eugeosynclinal Franciscan Formation crops out in the southwestern and northeastern parts of the map area, southwest of the Nacimiento fault and northeast of the San Andreas fault. Although this unit was not studied in detail in the map area, it is presumed to be similar to Franciscan rocks elsewhere in the Coast Ranges. It consists of graywacke, siltstone and shale, conglomerate, greenstone, chert, and glaucophane schist and related metamorphic rocks. The rocks are moderately to highly deformed, principally by faulting.

The Franciscan northeast of the San Andreas presumably ranges in age from Late Jurassic to Late Cretaceous (Bailey, Irwin, and Jones, 1964, fig. 23). Palynomorphs recently collected by B. M. Page from the tract southwest of the Nacimiento are of Early and possibly Late Cretaceous age (W. R. Evitt, written commun., 1969).

GRANITIC ROCKS

Granitic rocks crop out in the map area northeast of the Jolon fault zone near Paso Robles and just west of the San Andreas fault zone in the San Miguel quadrangle. Many wells drilled between the two zones reach the granitic basement (table 1). Direct evidence of basement lithology between the Jolon and Nacimiento fault zones is lacking.

The granitic rocks cropping out near Paso Robles are cut by aplite dikes and are similar in appearance to adamellite described by Compton (1966, p. 277–278) from the La Panza Range, just south of the map area. Christensen (1963, p. 111) described coarse-grained biotite granite outcrops in the San Miguel quadrangle.

The granitic rocks are presumably of Cretaceous age like other granitic rocks of the Salinian block (Compton, 1966, p. 287).

SUPERBASEMENT SEDIMENTARY ROCKS

PALEOCENE AND UPPER CRETACEOUS DEPOSITS

The unit designated as Paleocene and Upper Cretaceous deposits which crops out only southwest of the Jolon fault zone, includes all sedimentary rocks older than the lower Miocene Vaquerors Formation, exclusive of the Franciscan Formation. It is apparently absent in the subsurface northeast of the Jolon fault zone, for well data there indicate that Miocene or younger beds directly overlie the basement complex. This unit, some of which presumably belongs to Taliaferro's (1943) Asuncion Group, consists mainly of sandstone and conglomerate, but mudstone is locally abundant. Since the base of the unit is concealed in the map area, its thickness and the underlying unit are unknown. The Reserve Oil and Gas DeVries 37–25 (pl. 1, exploratory well 42), drilled in the northeastern part of the Adelaida quadrangle, reportedly penetrated the unit for 5,200 feet without reaching the base (table 1). This information and nearby surface data suggest that the unit is at least 7,000–10,000 feet thick.

Marine fossils of both Late Cretaceous and Paleocene age have been collected from the unit at different locations in the area; however, there appears to be no consistent lithologic difference between the Paleocene and Cretaceous beds.

TABLE 1.—*Selected exploratory wells between the Jolon and San Andreas fault zones*

[Elevation: kb, kelly bushing; gr, ground; df, derrick floor; t, from topographic map]

Map No. (pl. 1)	Operator	Well	Location			Year drilled	Elevation (ft)	Total depth (ft.)	Reported geologic data (depths in feet)
			Sec.	T.(S.)	R.(E.)				
1	Amerada Petroleum Corp	Creston Community 1-5	4	28	13	1952	1,208 kb	1,643	Top basement complex, 1,385.
2	do	McWilliams 1	32	27	13	1952	1,157 kb	2,180	Top basement complex, 2,175.
3	Barnsdall Oil Co	Harper 1		27	12	1949	892	4,182	Weathered granite, 3,995; hard granite, 4,080.
4	do	Kelch 1	23	23	12	1948	1,900 gr	2,407	Bottom in basement complex (?).
5	do	P. W. & P. 1	29	23	11	1948	851 kb	4,151	Basement complex, 4,088; hard basement complex, 4,139.
6	do	R. and W. 1	21	23	12	1948	1,050 gr	4,100	Bottom in basement complex (?).
7	Bishop Oil Co	Alexander B-1	8	23	11	1953	751 gr	2,468	Granite, 2,462-2,468.
8	Bishop Oil Co. and Cuyama Oil Co	O'Reilly 1	32	22	11	1948	769 kb	2,483	Bottom in basement complex.
9	Buttes Gas and Oil Co	Buttes-Work 1	31	24	12	1957	834 kb	5,050	Bottom in Miocene beds.
10	Canon Drilling Co	Heilman 1	7	28	13	1951	1,340 t	1,707	Granite, 1,677.
11	Chanslor-Canfield Midway Oil Co	Mahoney 1	3	25	12	1949	1,600 gr	4,772	Top Vaqueros Formation, 4,651.
12	do	Patterson 1	11	27	13	1949	1,000 gr	3,374	Top Vaqueros Formation, 3,146.
13	do	San Ardo 6-G-1	6	23	10	1946	1,099	8,062	Bottom in basement complex.
14	do	Silva 1	23	24	12	1949	1,030 df	5,134	Vaqueros Formation, 4,715.
15	Continental Oil Co	Hellman 1	26	25	11	1930	1,050	5,095	Vaqueros Formation, 4,629-5,095.
16	do	Nacimiento 1	32	24	11	1929	889	5,955	Vaqueros Formation, 5,746-5,955.
17	Cuyama Oil Co	O'Reilly 2	28	22	11	1948	855 t	2,962	Top basement complex, 2,923.
18	Davis and Thompson	Firanzi 44X	5	24	12	1955	913 kb	4,419	Bottom in granite.
19	Douglas, James M	Smith 1	36	22	9	1934	1,380 t	4,158	Bottom in Vaqueros Formation.
20	Epco Inc	Epco 1	27	26	13	1938	1,026	6,157	Granitic basement complex, 6,020.
21	Estrella Partnership	Kirchenmann 1	28	25	12	1949	660 gr	5,178	Top basement complex, 5,040.
22	Franco Western Oil Co	Ed Preszler 45A-3	3	26	12	1958	742 kb	5,313	Top basement complex, 5,210.
23	General Petroleum Corp	Garrissere 67X-30	30	22	10	1953	835 t	3,367	Bottom in basement complex.
24	Hamilton and Sherman	Lenhoff 1	26	27	12	1953	971 kb	5,003	Bottom in beds of Relizian Stage.
25	Hamilton Dome Oil Co	Benjamin 1	9	23	12	1958	1,128 kb	2,448	Bottom in basement complex(?).
26	Humble Oil & Refining Co	A. Orradre et ux. 1	25	22	10	1956	660 t	2,072	Bottom in pre-Cretaceous rocks.
27	do	Edwin Borchert et al. 1	2	25	13	1956	1,417 kb	6,230	Bottom in Miocene rocks.
28	Jergins Oil Co	Lanigan 249-35	35	22	10	1951	620 t	2,804	Bottom in granite.
29	do	USL South 1	26	22	11	1949	1,200 t	3,302	Granite at 3,293.
30	Jergins Oil Co.-North American Consolidated Oil Co.	McCool 1	27	22	10	1948	480 t	2,110	Bottom in granite.
31	Kimble, Joseph C	Garelli 1	17	24	12	1952	812 kb	5,135	Miocene red beds, 5,022-5,135.
32	Macson Oil Co	Linn 1	5	26	12	1951	775 gr	2,669	Top Vaqueros Formation, 2,615.
33	M.J.M. & M. Oil Co	Stanford-Johnson 1	11	27	12	1955	860 t	3,455	Bottom in granite.
34	Norris Stamping and Manufacturing Co.	Clark 1	3	27	13	1945	1,025	3,336	Bottom in middle Miocene beds.
35	North American Consolidated & Jergins Oil Co.	Rosenberg 1	34	22	10	1947	500	2,500	Top granite, 2,452.
36	Northern Oil Co	Sinclair 1	26	22	10	1962	704 kb	2,234	Basement complex at 2,224.
37	Ohio Oil Co	Araujo C. H. 1	12	27	11	1956	1,200 gr	2,152	Bottom in Cretaceous beds.
38	do	Ohio-Humble-Smith 1	35	25	12	1958	760	5,365	Basement complex at 5,340.
39	Petroleum Securities Co	White 1	27	23	13	1926	1,844	3,205	Granitic basement complex at 3,185.
40	Porter, B. F., Estate	Porter 1	36	23	10	1949	509 gr	3,354	Bottom in basement complex.
41	Reid, Gene, Drilling, Inc	Heilman 1	35	27	12	1951	1,018 kb	4,239	Middle Miocene beds, 4,100-4,105.
42	Reserve Oil and Gas Co	DeVries 37-25	25	25	10	1960	1,130 t	5,200	Bottom in Cretaceous beds.
43	Royalty Service Corp	Federal 1	21	24	10	1943	1,362	7,673	Bottom in Miocene beds.
44	Shell Oil Co	Branch 1	34	24	10	1937	661	8,994	Granitic basement complex, 8,974
45	do	D.G. & J. Unit 1	19	22	10	1948	740 gr	2,721	Granite, 2,571.
46	do	Flint 1	32	24	12	1921	974	4,665	Vaqueros Formation, 4,450-4,465.
47	do	Labarere 27-X	21	23	10	1959	1,088 df	10,957	Bottom in basement complex.
48	do	Mahoney 1	4	25	12	1933	742	5,972	Bottom in granite(?).
49	Standard Oil Co	Alexander 85-9	9	23	11	1951	932 df	2,812	Top granite, 2,811.
50	do	Alexander B-6-5	5	23	11	1951	1,096 df	3,050	Top basement complex, 3,043.
51	do	Ruth Hillman 45-19	19	25	14	1955	1,180 df	7,395	Bottom in Miocene beds.
52	Starr, E. G	No. 1	9	27	13	1926	925	3,576	Vaqueros Formation, 3,440-3,576.
53	Sunray Oil Corp	Sinclair 47-10	10	25	12	1952	933 kb	6,048	Top basement complex, 6,013.
54	Sunray Oil Corp. and Parkford, E. A	Klever 1	23	27	12	1951	1,000 gr	2,791	Granodiorite, 2,771-2,791.
55	Taylor, Frank M., and Associates	Estrella Creek 18-20	20	25	13	1964	930 kb	6,943	Basement complex, 6,882.
56	do	Estrella Creek 85-30	30	25	13	1963	860 kb	7,100	Basement complex, 6,930.
57	Texaco Inc	Adrian Orradre 1	19	22	11	1955	813 kb	2,225	Granite, 2,147.
58	do	Aurignac 1-28	5	23	10	1957	758 gr	6,735	Bottom in granite.
59	do	Aurignac 1-30	33	22	10	1957	720 t	4,018	Basement complex, 4,004.
60	do	Aurignac B-1	9	23	10	1952	730 gr	3,749	Granite, 3,741.
61	do	G. G. Martin 1	1	26	11	1954	855	2,029	Top basement complex, 1,988.
62	do	Hall 1	26	23	9	1955	1,259 kb	5,940	Weathered granite at 3,012.
63	do	Jensen 1-1	19	25	12	1952	831	4,909	Bottom in granite.
64	do	Koch 1	20	22	10	1960	616 kb	3,451	Bottom in basement complex.
65	do	Labarere 3-1	15	23	10	1952	591 gr	3,402	Granite at 3,266.
66	do	Laloli 1	28	25	12	1953	626 gr	4,587	Granitic basement complex, 4,540
67	do	M. Garrissere 3	29	22	10	1962	810 kb	4,534	Granite at 4,480.
68	do	Nichols 1	13	23	11	1952	1,300 t	3,404	Bottom in granite.
69	do	Powell 1	11	23	11	1964	1,041 gr	2,546	Granite at 2,540.
70	do	Rosenberg 1-174	28	22	10	1958	425 t	2,781	Bottom in granite.
71	do	Sesnon 1	3	24	11	1956	772 gr	3,761	Top basement complex, 3,758.
72	do	Sesnon Core Hole 1	34	23	11	1964	784 kb	3,529	Basement complex at bottom.
73	do	Shell 1-1	6	24	10	1956	1,671 gr	11,994	Bottom in Miocene beds.
74	do	Signal 1	28	24	10	1952	1,572 kb	10,480	Bottom in lower Miocene beds.
75	do	Wood 1	25	23	11	1954	1,140 t	3,824	Fresh basement complex, 3,780.
76	do	Wood-Maher 1	23	23	11	1949	1,159 gr	3,178	Top granite at 3,114.
77	Thornbury, Geis, and Robinson	Konekamp 1-3	3	25	10	1959	1,201 kb	8,009	Bottom in Miocene beds.
78	Tresaden and Reynolds	Tres-Rey & Assoc. 1	31	22	12	1959	1,280 t	3,000	Bottom in basement complex.
79	Union Oil Co	Union-Texaco-Connell 1	2	25	10	1961	1,090 gr	6,869	Bottom in Miocene beds.
80	Wilshire Oil Co., Inc	Hunter-Dryden 71-26	26	23	10	1951	775 gr	5,052	Bottom in basement complex.

TIERRA REDONDA AND VAQUEROS FORMATIONS

In the map area the unit designated as Tierra Redonda and Vaqueros Formations crops out southwest of the Jolon fault zone. It has reportedly been penetrated by numerous exploratory wells northeast of the Jolon fault, but is absent in the subsurface near the San Ardo oil field, where younger beds lie directly on basement complex.

Both the Vaqueros and Tierra Redonda Formations are sandy and locally conglomeratic. Although each has considerable variation in lithologic character, the Vaqueros is generally darker colored, finer grained, and less massive than the Tierra Redonda.

The Vaqueros Formation unconformably overlies Cretaceous and Paleocene strata in the southwestern part of the map area and reportedly lies on granitic basement in the subsurface northeast of the Jolon fault zone (table 1). The Tierra Redonda Formation lies either conformably on the Vaqueros or unconformably on older strata; in places it intertongues with the lower part of the Monterey Shale.

The Vaqueros Formation is about 1,300 feet thick in the southwest corner of the Bradley quadrangle but apparently thins southeastward and lenses out completely in the northeastern part of the Adelaida quadrangle. The Vaqueros is probably about 1,650 feet thick in the subsurface northeast of the Jolon fault zone near the San Antonio River, where it was penetrated by the Shell Oil Branch 1 (exploratory well 44, pl. 1 and table 1). The formation presumably thins to the northeast, disappearing near the San Ardo oil field. The Tierra Redonda Formation is probably about 1,650 feet thick in the southwest quarter of the Bradley quadrangle but is only about 700 feet thick to the southeast in the Adelaida quadrangle.

The Vaqueros Formation in the map area contains early Miocene marine fossils. The Tierra Redonda Formation lacks fossils in the map area, but stratigraphic relations with the Vaqueros Formation and Monterey Shale restrict it to an early and middle Miocene age. A marine origin for the Tierra Redonda is probable since it intertongues with the marine Monterey Shale, is overlain and underlain by marine strata, and lacks features characteristic of nonmarine deposits.

VOLCANIC ROCKS

Basaltic volcanic rocks associated with the Monterey Shale crop out locally southwest of the Jolon fault zone. At least some are submarine flows contemporaneous with Monterey Shale deposition. Rhyolitic volcanic rocks crop out near the San Andreas fault zone in the northeastern part of the San Miguel quadrangle (Jennings, 1958).

MONTEREY SHALE

Monterey Shale forms many of the hills west of the Salinas River and crops out in the upper reaches of larger streams in the San Miguel quadrangle. It also crops out southwest of the Nacimiento fault zone. The Monterey underlies younger units in most areas of their occurrence, except northwest of Paso Robles, where the younger Paso Robles Formation lies directly on granite.

The lower part of the Monterey Shale, the Sandholdt Member, is chiefly calcereous mudstone but includes porcelaneous rocks, chert, and dolomitic carbonate rock. The upper part is mainly porcelaneous rocks and noncalcereous mudstone with some chert and dolomitic carbonate rock. The uppermost part of the Monterey, the Buttle Member, is exposed north of Hames Valley and consists of diatomite and diatomaceous mudstone.

The Monterey Shale conformably overlies the Vaqueros Formation in most of the area, but to the northeast, in the subsurface, it overlaps the Vaqueros to lie directly on basement rock. It conformably overlies or intertongues with the Tierra Redonda Formation.

The Sandholdt Member of the Monterey Shale reaches 4,000 feet in thickness in the southern Bradley quadrangle northeast of the Jolon fault. The upper part of the Monterey, exclusive of the Buttle Member, is about 9,000 feet thick in the same area. The Buttle Member is about 600–700 feet thick on the flanks of Hames Valley. These figures indicate that the total thickness of the Monterey reaches a maximum of 13,000 feet in the northwestern part of the map area. The unit thins considerably to the northeast, however, and is only about 1,500 feet thick in the San Ardo oil field. It is even thinner near the center of the San Miguel quadrangle, where the Monterey intertongues with the Santa Margarita Formation.

Foraminifera indicative of middle Miocene age are abundant in the Sandholdt Member of the Monterey Shale. The overlying siliceous rocks of the Monterey are generally lacking in fossils useful in age determination; however, stratigraphic relations with the Santa Margarita and Pancho Rico Formations indicate that these siliceous strata are probably of late Miocene age but could include beds of latest middle Miocene and early Pliocene age.

PANCHO RICO AND SANTA MARGARITA FORMATIONS

The Santa Margarita Formation crops out in a belt just southwest of the Jolon fault and in the eastern part of the San Miguel quadrangle. The Pancho Rico Formation crops out along the margin of the hills southwest of the Salinas River, around Hames Valley, in patches just northeast of the Jolon fault, and in a broad belt from the northeastern part of the Bradley quadrangle across the San Miguel quadrangle. Only in the central San Miguel quadrangle are the two units exposed in the same stratigraphic sequence.

The Santa Margarita is a light-gray to white, medium- to coarse-grained, massive to thick-bedded calcareous sandstone. Fossils are abundant in most of the unit. The Pancho Rico Formation, although characteristically sandstone, also contains mudstone, conglomerate, and siliceous rocks similar to those in the Monterey Shale. Fine-grained sandstone is the most common lithology west of the Salinas River, whereas coarser grained sandstone and conglomerate are common east of the river.

The Santa Margarita Formation conformably overlies the Monterey Shale southwest of the Jolon fault, and northeast of the fault intertongues with it as well. In most of the map area the Pancho Rico Formation conformably overlies and probably locally intertongues with the Monterey, but in the Vineyard Canyon area, it lies with apparent conformity on the Santa Margarita.

The Santa Margarita is about 500 feet thick near the Nacimiento River in the southern part of the Bradley quadrangle and thins northwestward. The Pancho Rico is 450–650 feet thick in the northeastern part of the map area and thins southeastward; it is 100–200 feet thick northeast of Hames Valley and thins southward to 20 feet or less near the Nacimiento River. The Pancho Rico is absent in the map area southwest of the Jolon fault.

The Santa Margarita Formation contains marine fossils indicative of late Miocene age. The Pancho Rico Formation contains marine fossils characteristic of Pliocene age, generally early Pliocene.

PASO ROBLES FORMATION

The Paso Robles Formation blankets much of the low-lying central and southeastern part of the map area. It also caps hills and occupies small structural depressions near the San Antonio River in the Bradley quadrangle. It is a predominantly nonmarine unit consisting chiefly of conglomerate and sandstone in units a few feet to scores of feet thick, but mudstone is also common in the formation. Limestone and, more rarely, lignite occur sparingly. In some places, northeast of Hames Valley for example, the Paso Robles Formation conformably overlies the Pancho Rico Formation; in others, near the Nacimiento River for example, it conformably overlies the Santa Margarita Formation. The Paso Robles and Pancho Rico locally intertongue in the northeastern part of the map area. Elsewhere the Paso Robles unconformably overlies older units with varying degrees of discordance.

The total thickness of the Paso Robles Formation in the map area is unknown since the upper part of the formation is so commonly eroded. The formation is at least 1,000 feet thick east of the San Ardo oil field, however, and is probably even thicker to the south.

The Paso Robles Formation is generally considered to be Pliocene and possibly early Pleistocene in age since it overlies and may intertongue with the Pancho Rico Formation and since it unconformably underlies older alluvium of Pleistocene and Holocene(?) age.

SURFICIAL DEPOSITS

Surficial deposits are made up of older alluvium and alluvium. Older alluvium covers the floors of the larger valleys and forms terraces along their sides. Alluvium occurs along the beds of most streams. The older alluvium is mainly semiconsolidated sand and gravel, and the alluvium is similar but unindurated. The older alluvium lies with angular discordance on older rocks, and the alluvium commonly occurs along streams that cut older alluvium or other units. The older alluvium and alluvium combined are probably no thicker than a few score feet in most places, but their thickness is uncertain, partly because of difficulty in distinguishing older alluvium from Paso Robles Formation in wells. The older alluvium is considered to be of Pleistocene and possibly Holocene age because it unconformably overlies the Paso Robles Formation of Pliocene and possibly Pleistocene age. The alluvium is Holocene.

STRUCTURE

The gross basement structure and the general structural condition of the Franciscan Formation were described under "Basement rocks." This section is concerned principally with structural features of the Salinian block.

FAULTS

The most obvious structural feature in the map area is the Jolon fault zone (pl. 1), which begins near Paso Robles, continues northwest through the San Antonio River valley, and extends at least 15 miles beyond the map area. It is generally ½–1 mile wide at the surface and comprises several traces. The principal trace is the Jolon fault itself, along which stratigraphic relations give evidence of at least 11 miles of right-lateral strike-slip displacement (Durham, 1965). Another element of the zone is the San Marcos fault, which at the surface separates the middle Miocene from the upper Miocene part of the Monterey Shale along much of its length. The Jolon fault zone northwest of the San Antonio River presumably is concealed by alluvium and rocks thrust over it along the San Antonio fault. The zone is obscure southeast of Paso Robles, but its trend suggests that it continues southward to join the Rinconada fault zone. (See section on "Gravity anomalies".)

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The Los Lobos fault (Kilkenny and others, 1952) is a thrust fault located southwest of the Salinas River in the northern Bradley quadrangle. The principal fault trace is apparently concealed by alluvium in the map area (pl. 1). Well data (table 1), however, define the fault as a southwest-dipping feature separating severely deformed beds in the upper plate from little-deformed beds in the lower plate. It apparently dies out to the southeast.

The San Antonio fault (pl. 1) is a thrust fault exposed along the northeast side of the San Antonio River. It dips northeastward and separates deformed upper plate beds from relatively undeformed lower plate beds.

The Los Lobos and San Antonio faults are believed to have a common origin. They are on opposite sides of the very thick sedimentary sequence of Hames Valley and dip toward the center of the valley. On both faults, the material of the upper plate is thrust from the valley center toward its margins, and on both faults the underformed sediments of the lower plate rest on structural basement highs on opposite sides of the thick sedimentary sequence. For the Los Lobos fault, the depth to basement northeast of the Salinas River is locally less than 2,500 feet, but southwest of the river the basement surface locally slopes over 3,000 feet per mile toward Hames Valley, where it is deeper than 10,000 feet (Durham, 1966, pl. 5). The southwest edge of the platform-like basement high trends northwest beneath the river and roughly parallels the Los Lobos fault. For the San Antonio fault, subsurface information is lacking in the map area, but 1–5 miles to the northwest, just southeast of the fault, the depth to basement is only 1,000–1,500 feet.

To explain the observed relations, a northeast-southwest crustal shortening is postulated. The basement highs on opposite sides of the basin thus served as buttresses compressing the thick sedimentary section of Hames Valley, and some of the section was forced out over the basement highs via the thrust faults. The strata riding directly on the basement highs were not subject to the compression and thus were not so highly deformed. The evidence seems to indicate, therefore, that the Los Lobos and San Antonio faults are probably related to (1) crustal shortening and (2) the configuration of the basement surface.

The Espinosa fault zone (pl. 1) branches north-northwest from the Jolon fault zone in the Bradley quadrangle. It is confined at the surface to the Monterey Shale, where it forms a series of en echelon belts of crushed and contorted rock across which structural features are discontinuous. Well data suggest that the basement surface is considerably deeper on the northeast side of the fault zone than on the southwest side. The feature may be a simple basement offset at depth having a complex expression at the surface because of the intervening thousands of feet of Monterey Shale.

FOLDS

The Monterey Shale is generally deformed into broad folds where it is thick, but near faults it is commonly tightly folded, contorted, and overturned. Sandy and conglomerate units, in contrast, are in general simply tilted or warped into broad folds.

AGE OF DEFORMATION

The Paso Robles Formation is, in many places, deformed to the same extent as the underlying units. This indicates faulting and folding after deposition of the Paso Robles (post-Pliocene and Pleistocene?); however, because the Paso Robles also lies unconformably or disconformably on the Monterey Shale, deformation probably also occurred before or during deposition of the Paso Robles (late or post-late Miocene). The Vaqueros Formation lies unconformably on Cretaceous and lower Tertiary rocks, and the Tierra Redonda Formation overlaps the Vaqueros to lie unconformably on these older strata; thus, deformation probably occurred before, and perhaps during, Miocene time. Similarly, Miocene strata in the subsurface near the San Ardo oil field apparently pinch out against and lap up onto a basement-complex surface. This slope in the basement surface must result from deformation that occurred in Miocene or pre-Miocene time.

GRAVITY DATA

GRAVITY SURVEY

The map area contains 313 gravity stations tied to seven gravity bases. The principal facts for the bases are given in table 2, and those for the 313 stations in table 3. All the data are tied to base 173 (Chapman, 1966, p. 36) at the U.S. Geological Survey office in Menlo Park, Calif. The observed gravity at this base, determined by numerous ties to North American Gravity Standardization Stations at the San Francisco Airport, is taken to be 979,958.74 mgal.

TABLE 2.—*Principal facts for bases used in gravity survey*

Base	Lat N.	Long W.	Elevation (ft)	Observed gravity[1] (mgal)	Description
SLUKB	36 7.73	121 1.12	405.8	979793.04	USC&GS BM G154 at San Lucas.
BRADB	35 51.81	120 47.73	552.0	979737.30	USGS BM 553 at Bradley.
JOLNB	35 58.47	121 10.47	979.0	979722.66	USGS BM 979 at Jolon.
CAMBB	35 33.55	121 5.33	81.0	979801.24	USC&GS BM A694 at Cambria.
PSROB	35 37.55	120 41.28	720.0	979717.17	USC&GS BM L24 at Paso Robles.
PARKB	35 53.98	120 25.92	1535.0	979687.69	USC&GS BM F79 at Parkfield.
SHANB	35 39.33	120 22.71	1038.0	979686.02	USC&GS BM W559 at Shandon.

[1] The amount of scatter among numerous ties between these bases suggests that the relative observed gravity of each is known to ±0.02 mgal.

TABLE 3.—*Principal facts for gravity stations*

Station	Lat N.	Long W.	Elevation (ft)	Observed gravity (mgal)	Terrain correction (mgal)	Free air anomaly (mgal)	Complete Bouguer anomaly (mgal)
20	35 54. 23	120 58. 02	1159	979702. 35	1. 41	−11. 16	−49. 76
21	35 53. 93	120 56. 99	936	979712. 38	2. 51	−21. 68	−51. 48
22	35 53. 87	120 56. 26	851	979711. 16	1. 78	−30. 86	−58. 44
23	35 52. 07	120 51. 09	594	979726. 53	. 88	−37. 04	−58. 68
24	35 52. 33	120 52. 17	611	979724. 61	1. 04	−37. 74	−57. 80
25	35 52. 59	120 53. 33	649	979721. 61	1. 13	−37. 53	−38. 81
26	35 52. 91	120 54. 22	763	979709. 73	1. 12	−39. 15	−64. 37
27	35 53. 23	120 55. 16	786	979708. 24	1. 37	−38. 93	−64. 70
28	35 50. 18	120 50. 61	684	979719. 07	. 92	−33. 34	−56. 04
29	35 47. 78	120 51. 27	593	979726. 31	1. 28	−31. 24	−50. 44
30	35 47. 42	120 54. 76	796	979734. 48	2. 61	−3. 46	−28. 34
31	35 47. 23	120 57. 19	1055	979729. 53	1. 43	16. 22	−18. 77
32	35 46. 99	120 58. 49	1199	979719. 71	1. 67	20. 28	−19. 43
33	35 48. 29	120 58. 70	1005	979732. 14	1. 33	12. 61	−20. 75
34	35 48. 89	120 58. 79	914	979736. 20	1. 38	7. 26	−22. 91
35	35 50. 13	120 58. 68	1056	979723. 98	1. 29	8. 63	−28. 53
36	35 51. 20	120 58. 85	748	979746. 12	1. 44	−1. 73	−26. 11
228	35 59. 92	120 53. 14	439	979766. 83	1. 19	−22. 53	−36. 50
229	35 58. 72	120 52. 64	470	979763. 97	1. 23	−20. 76	−35. 76
230	35 57. 89	120 52. 13	460	979764. 70	1. 28	−19. 79	−34. 39
231	35 55. 56	120 51. 56	501	979752. 68	1. 54	−24. 62	−40. 39
232	35 54. 90	120 50. 48	494	979750. 98	1. 95	−26. 04	−41. 15
233	35 52. 23	120 48. 79	525	979736. 94	1. 27	−33. 35	−50. 21
234	35 51. 72	120 46. 14	551	979741. 28	1. 20	−25. 84	−43. 67
BRADB	35 51. 81	120 47. 73	552	979737. 30	. 98	−29. 85	−47. 94
236	35 50. 76	120 45. 14	554	979738. 58	1. 20	−26. 89	−44. 82
237	35 49. 54	120 44. 95	558	979736. 63	1. 11	−26. 72	−44. 88
238	35 47. 33	120 43. 66	584	979735. 08	. 90	−22. 67	−41. 94
239	35 44. 17	120 41. 98	632	979727. 92	. 92	−20. 82	−41. 72
240	35 43. 21	120 41. 69	620	979726. 93	. 78	−21. 57	−42. 20
241	35 39. 69	120 41. 72	716	979730. 76	1. 13	−3. 70	−27. 29
242	35 40. 54	120 41. 58	680	979724. 29	. 82	−14. 76	−37. 42
243	35 41. 75	120 41. 47	675	979722. 41	. 72	−18. 88	−41. 47
PSROB	35 37. 55	120 41. 28	720	979717. 16	. 93	−13. 86	−37. 79
245	35 35. 12	120 41. 38	730	979710. 87	. 87	−15. 77	−40. 10
246	35 34. 42	120 41. 45	758	979712. 58	. 84	−10. 43	−35. 76
247	35 33. 57	120 41. 67	766	979719. 81	. 86	−1. 24	−26. 83
248	35 33. 02	120 42. 04	772	979720. 74	. 90	1. 04	−24. 72
249	35 32. 67	120 42. 39	779	979717. 68	. 98	−. 87	−26. 78
250	35 35. 02	120 42. 82	872	979711. 75	. 97	−1. 39	−30. 52
251	35 34. 47	120 43. 78	923	979709. 01	1. 03	1. 45	−29. 38
252	35 33. 99	120 44. 75	929	979708. 03	1. 18	1. 72	−29. 18
253	35 33. 08	120 46. 50	894	979720. 21	1. 59	11. 90	−17. 38
254	35 32. 96	120 47. 48	925	979717. 24	1. 97	12. 01	−17. 95
255	35 32. 50	120 48. 05	979	979714. 18	2. 95	14. 69	−16. 16
256	35 32. 55	120 49. 07	1065	979710. 22	2. 63	18. 74	−15. 39
257	35 32. 46	120 49. 69	1620	979683. 29	2. 67	34. 74	−15. 04
258	35 32. 34	120 50. 17	1207	979704. 10	2. 06	26. 28	−13. 32
259	35 32. 05	120 50. 78	1189	979705. 22	2. 28	26. 12	−12. 64
260	35 32. 06	120 51. 48	1273	979700. 60	2. 29	29. 38	−12. 26
261	35 30. 64	120 50. 68	1413	979687. 12	2. 75	31. 09	−14. 92
262	35 32. 93	120 52. 63	1386	979697. 46	2. 88	35. 64	−9. 31
263	35 33. 44	120 53. 43	1455	979693. 84	2. 88	37. 78	−9. 54
264	35 33. 84	120 54. 37	1853	979668. 90	3. 97	49. 70	−10. 24
265	35 34. 21	120 54. 74	1588	979686. 33	4. 17	41. 68	−8. 93
266	35 34. 15	120 55. 38	1033	979718. 49	5. 11	21. 73	−8. 82
267	35 34. 12	120 56. 19	673	979737. 18	7. 45	6. 60	−9. 19
268	35 33. 63	120 57. 28	530	979752. 33	4. 88	9. 00	−4. 43
269	35 34. 29	120 58. 73	367	979763. 70	5. 23	4. 10	−3. 35
270	35 34. 51	120 59. 47	342	979767. 08	4. 59	4. 81	−2. 41
293	35 34. 58	120 46. 99	1265	979693. 85	1. 97	18. 30	−23. 39
294	35 35. 74	120 48. 10	1550	979676. 63	3. 01	26. 23	−24. 23
295	25 35. 86	120 49. 68	1288	979698. 30	1. 69	23. 09	−19. 67
296	35 37. 69	120 52. 92	1141	979713. 15	2. 45	21. 51	−15. 42
297	35 39. 48	120 50. 30	2032	979656. 19	5. 84	45. 80	−18. 43
298	35 40. 12	120 50. 82	1732	979677. 10	3. 03	37. 59	−19. 13
299	35 38. 63	120 47. 59	2323	979632. 99	6. 80	51. 18	−22. 11
300	35 39. 63	120 45. 90	1574	979683. 17	2. 11	29. 50	−22. 70
301	35 38. 98	120 43. 18	1016	979718. 81	1. 42	13. 58	−20. 07
302	35 40. 70	120 42. 37	916	979717. 36	1. 13	. 28	−30. 22
303	35 40. 37	120 49. 21	1116	979718. 67	2. 18	20. 87	−15. 47
304	35 36. 73	120 55. 08	1235	979711. 41	3. 99	29. 98	−8. 65
305	35 44. 48	120 53. 74	973	979729. 37	2. 03	12. 27	−19. 29

TABLE 3.—*Principal facts for gravity stations*—Continued

Station	Lat N.	Long W.	Elevation (ft)	Observed gravity (mgal)	Terrain correction (mgal)	Free air anomaly (mgal)	Complete Bouguer anomaly (mgal)
306	35 43. 14	120 52. 72	965	979731. 66	1. 46	15. 71	−16. 14
307	35 43. 35	120 54. 86	1205	979716. 26	2. 65	22. 59	−16. 35
308	35 42. 99	120 55. 99	851	979740. 91	1. 53	14. 45	−13. 40
309	35 40. 56	120 58. 46	1775	979675. 21	6. 48	39. 12	−15. 63
310	35 38. 53	120 56. 54	1905	979663. 18	8. 97	42. 20	−14. 53
311	35 39. 89	120 56. 64	1605	979685. 44	5. 16	34. 31	−15. 90
343	35 46. 07	120 53. 93	771	979739. 88	3. 74	1. 51	−21. 37
344	35 45. 04	120 54. 51	785	979743. 47	1. 38	7. 88	−17. 84
345	35 45. 00	120 55. 24	773	979745. 26	1. 53	8. 60	−16. 56
346	35 45. 53	120 55. 72	773	979744. 90	2. 30	7. 49	−16. 90
347	35 45. 43	120 56. 43	776	979746. 37	1. 66	9. 38	−15. 75
348	35 45. 00	120 57. 37	778	979748. 06	1. 70	11. 87	−13. 29
349	35 44. 66	120 57. 74	778	979746. 10	1. 68	12. 40	−12. 73
350	35 44. 55	120 58. 68	778	979747. 95	1. 64	12. 40	−12. 82
351	35 44. 85	120 59. 25	777	979747. 90	1. 88	11. 83	−13. 11
360	35 44. 18	120 59. 93	773	979748. 92	2. 55	13. 43	−10. 71
361	35 43. 92	120 58. 93	776	979747. 46	2. 44	12. 62	−11. 73
362	35 43. 87	120 57. 25	778	979745. 97	1. 70	11. 39	−13. 77
363	35 43. 09	120 57. 55	775	979745. 73	1. 75	11. 98	−13. 03
364	35 42. 57	120 58. 38	776	979746. 61	2. 39	13. 70	−10. 71
365	35 42. 86	120 56. 81	775	979745. 00	1. 73	11. 58	−13. 45
366	35 41. 96	120 57. 15	810	979741. 95	3. 01	13. 10	−11. 85
367	35 41. 23	120 56. 86	772	979742. 24	2. 80	10. 86	−13. 00
368	35 44. 66	120 56. 09	774	979746. 56	1. 66	10. 48	−14. 58
369	35 44. 35	120 55. 20	772	979745. 91	1. 39	10. 09	−15. 18
370	35 42. 95	120 55. 70	776	979745. 33	1. 82	11. 88	−13. 10
371	35 43. 88	120 53. 76	771	979744. 66	1. 92	9. 41	−15. 29
372	35 45. 38	120 54. 18	771	979743. 47	1. 53	6. 08	−19. 01
384	35 59. 05	120 59. 14	1189	979720. 41	3. 32	2. 83	−34. 88
385	35 59. 50	120 57. 56	916	979738. 55	3. 33	−5. 35	−33. 64
387	35 57. 63	120 59. 74	2543	979624. 93	8. 89	36. 72	−42. 05
389	35 55. 85	120 58. 98	1953	979655. 09	4. 94	13. 94	−48. 48
390	35 55. 14	120 57. 64	1107	979700. 11	2. 32	−19. 59	−55. 48
391	35 56. 08	120 56. 84	1075	979704. 59	2. 36	−19. 47	−54. 21
392	35 57. 07	120 56. 53	1866	979655. 70	5. 45	4. 62	−54. 29
393	35 57. 73	120 56. 70	1912	979662. 04	5. 74	14. 35	−45. 86
394	35 57. 45	120 55. 63	1488	979688. 29	4. 18	1. 12	−46. 04
395	35 56. 33	120 55. 00	1715	979658. 93	4. 12	−5. 29	−60. 33
396	35 55. 48	120 53. 67	1678	979658. 00	4. 11	−8. 49	−62. 26
397	35 53. 91	120 50. 83	1055	979700. 94	3. 02	−21. 90	−55. 30
398	35 53. 42	120 51. 68	1070	979695. 99	2. 04	−24. 74	−59. 63
399	35 54. 34	120 53. 62	877	979705. 81	1. 56	−34. 39	−63. 10
400	35 53. 63	120 53. 71	768	979714. 44	1. 07	−34. 99	−60. 44
401	35 46. 08	120 44. 40	796	979718. 93	. 85	−17. 10	−43. 74
402	35 45. 95	120 45. 12	713	979724. 52	. 73	−19. 13	−43. 02
403	35 46. 67	120 46. 08	886	979711. 58	1. 37	−16. 83	−46. 05
404	35 45. 01	120 46. 02	953	979706. 17	1. 07	−13. 57	−45. 40
405	35 45. 56	120 47. 92	650	979723. 74	1. 01	−25. 28	−46. 72
406	35 46. 70	120 48. 24	584	979730. 14	. 87	−26. 72	−46. 01
407	35 45. 65	120 49. 35	673	979722. 93	1. 05	−24. 06	−46. 25
408	35 46. 43	120 51. 24	1317	979675. 90	4. 34	−11. 63	−52. 74
409	35 47. 28	120 49. 96	670	979723. 17	1. 15	−26. 42	−48. 41
410	35 47. 96	120 48. 91	995	979703. 05	1. 42	−16. 95	−49. 87
411	35 48. 75	120 49. 93	621	979725. 14	. 98	−31. 16	−51. 62
412	35 48. 78	120 48. 36	973	979704. 91	1. 53	−18. 32	−50. 38
413	35 49. 06	120 47. 12	893	979712. 22	. 86	−18. 94	−48. 91
414	35 50. 20	120 48. 22	545	979732. 43	1. 01	−33. 09	−50. 90
415	35 50. 79	120 47. 12	827	979716. 64	1. 61	−23. 19	−50. 14
416	35 51. 26	120 47. 67	528	979736. 51	. 99	−32. 12	−49. 36
417	35 49. 85	120 46. 30	992	979706. 14	1. 65	−16. 83	−49. 43
418	35 48. 75	120 45. 37	556	979736. 45	. 91	−25. 96	−44. 25
419	35 46. 21	120 42. 89	766	979721. 06	. 89	−17. 98	−43. 54
420	35 44. 48	120 44. 12	889	979709. 56	. 95	−15. 45	−45. 19
421	35 43. 60	120 43. 97	1033	979701. 48	1. 68	−8. 73	−42. 71
422	35 44. 62	120 45. 76	1064	979698. 34	1. 58	−10. 41	−45. 55
423	35 43. 70	120 45. 76	1142	979696. 39	1. 30	−3. 71	−41. 82
424	35 43. 82	120 47. 21	1063	979702. 29	1. 45	−5. 41	−40. 65
425	35 42. 68	120 46. 30	945	979715. 76	1. 04	−1. 41	−33. 00
426	35 41. 79	120 46. 31	1058	979717. 06	1. 47	11. 78	−23. 27
427	35 42. 85	120 47. 50	1219	979693. 19	2. 42	1. 54	−38. 11
428	35 41. 84	120 47. 70	1353	979694. 50	1. 90	16. 90	−27. 89
429	35 42. 28	120 48. 34	1708	979668. 94	5. 07	24. 10	−29. 75
430	35 43. 14	120 49. 62	1643	979675. 96	4. 20	23. 78	−28. 70
431	35 43. 69	120 48. 77	1368	979678. 43	4. 09	−. 40	−43. 52

TABLE 3.—*Principal facts for gravity stations*—Continued

Station	Lat N.	Long W.	Elevation (ft)	Observed gravity (mgal)	Terrain correction (mgal)	Free air anomaly (mgal)	Complete Bouguer anomaly (mgal)
432	35 44. 62	120 50. 08	1336	979682. 65	4. 98	—0. 51	−41. 64
433	35 44. 78	120 51. 40	1462	979681. 94	3. 28	10. 40	−36. 77
434	35 51. 01	120 51. 55	685	979718. 52	1. 06	−34. 98	−57. 58
435	35 49. 69	120 52. 02	1484	979656. 12	4. 05	−20. 35	−67. 50
436	35 49. 24	120 50. 91	1016	979694. 35	2. 66	−25. 50	−57. 91
437	35 47. 35	120 52. 41	978	979702. 19	1. 93	−18. 53	−50. 37
438	35 46. 32	120 52. 52	1338	979690. 34	2. 77	4. 94	−38. 46
439	35 47. 01	120 55. 75	1344	979704. 57	2. 07	18. 75	−25. 56
440	35 46. 40	120 54. 99	1576	979689. 56	4. 64	26. 43	−23. 30
441	35 47. 46	120 53. 60	1217	979697. 81	2. 53	−. 59	−40. 06
442	35 46. 78	120 56. 43	1000	979732. 01	1. 78	14. 17	−18. 57
443	35 46. 35	120 57. 77	1473	979701. 82	2. 91	29. 08	−18. 84
445	35 46. 88	120 59. 37	1232	979718. 30	1. 63	22. 14	−18. 75
446	35 48. 00	120 57. 30	1212	979714. 81	2. 85	15. 17	−23. 81
447	35 48. 05	120 55. 79	1134	979711. 62	2. 07	4. 57	−32. 50
448	35 48. 02	120 54. 55	1130	979706. 23	1. 94	−1. 15	−38. 22
449	35 48. 98	120 57. 48	968	979727. 70	1. 49	3. 71	−28. 22
510	35 49. 55	120 59. 83	1197	979715. 44	2. 09	12. 18	−27. 05
517	35 54. 23	120 59. 33	1189	979702. 20	1. 64	−8. 49	−47. 89
518	35 53. 37	120 58. 01	1384	979686. 51	2. 74	−4. 62	−49. 63
519	35 52. 35	120 58. 50	1018	979720. 85	1. 96	−3. 24	−36. 42
520	35 53. 09	120 59. 18	1139	979713. 75	2. 46	−. 02	−36. 87
521	35 51. 86	120 57. 13	918	979720. 74	1. 56	−12. 06	−42. 19
522	35 51. 17	120 57. 85	689	979746. 45	1. 59	−6. 90	−29. 11
523	35 50. 27	120 56. 27	890	979731. 40	2. 04	−1. 77	−30. 45
524	35 51. 27	120 56. 48	1535	979676. 11	3. 94	2. 18	−46. 84
525	35 50. 96	120 55. 02	1659	979659. 60	3. 59	−2. 22	−55. 87
551	35 36. 44	120 58. 72	1447	979699. 25	4. 31	38. 17	−7. 45
552	35 36. 12	120 57. 22	2930	979600. 27	12. 50	79. 11	−9. 35
592	35 38. 42	120 39. 41	835	979705. 55	. 65	−15. 91	−44. 08
593	35 38. 00	120 37. 67	768	979707. 37	. 71	−19. 79	−45. 60
594	35 38. 25	120 35. 55	961	979691. 49	. 69	−17. 87	−50. 36
595	35 38. 25	120 33. 58	1019	979686. 96	. 70	−16. 95	−51. 42
596	35 37. 45	120 32. 73	1026	979687. 97	. 75	−14. 14	−48. 81
597	35 36. 65	120 33. 04	1200	979677. 23	. 86	−7. 38	−47. 93
598	35 35. 62	120 33. 69	922	979698. 98	. 91	−10. 31	−41. 23
599	35 34. 29	120 32. 68	1014	979693. 31	. 73	−5. 44	−39. 71
600	35 33. 03	120 31. 92	1062	979689. 55	. 74	−2. 89	−38. 81
601	35 31. 07	120 31. 27	1114	979687. 29	. 78	2. 53	−35. 14
602	35 31. 99	120 33. 48	1104	979692. 60	. 90	5. 59	−31. 62
603	35 30. 44	120 37. 25	1478	979658. 73	1. 75	9. 10	−40. 15
604	35 30. 11	120 38. 92	848	979705. 27	1. 05	−3. 15	−31. 38
605	35 31. 55	120 37. 94	1334	979667. 06	1. 98	2. 31	−41. 75
606	35 32. 44	120 36. 76	1249	979677. 67	1. 18	3. 66	−38. 27
607	35 33. 07	120 35. 38	1129	979687. 44	1. 24	1. 25	−36. 48
608	35 32. 85	120 33. 58	1052	979693. 50	. 80	. 38	−35. 14
609	35 31. 24	120 33. 11	1327	979679. 76	1. 22	14. 79	−29. 79
610	35 31. 08	120 34. 54	1200	979689. 86	1. 33	13. 17	−26. 92
611	35 32. 50	120 39. 42	1004	979695. 42	1. 21	−1. 72	−35. 17
612	35 32. 10	120 41. 53	922	979708. 01	1. 23	3. 72	−26. 88
613	35 33. 84	120 40. 04	870	979699. 35	. 87	−12. 30	−41. 47
614	35 34. 49	120 36. 57	915	979698. 75	. 77	−9. 59	−40. 41
615	35 35. 80	120 37. 28	925	979695. 82	. 74	−13. 44	−44. 64
616	35 35. 72	120 39. 21	846	979700. 92	. 73	−15. 66	−44. 14
617	35 36. 94	120 39. 48	807	979703. 88	. 70	−18. 10	−45. 27
618	35 36. 48	120 36. 52	820	979704. 22	. 83	−15. 89	−43. 37
619	35 35. 65	120 34. 83	1063	979689. 24	1. 14	−6. 83	−42. 38
620	35 34. 19	120 31. 19	1211	979674. 19	. 90	−5. 88	−46. 78
621	35 35. 43	120 30. 66	1385	979665. 13	1. 08	−. 34	−47. 06
624	35 36. 52	120 30. 29	1335	979669. 80	1. 03	−1. 93	−46. 97
625	35 39. 26	120 31. 97	998	979687. 23	. 76	−20. 09	−53. 78
626	35 39. 18	120 30. 43	855	979697. 58	. 90	−23. 08	−51. 70
679	35 55. 63	120 30. 12	1861	979671. 46	1. 37	21. 97	−40. 85
680	35 55. 31	120 32. 03	2601	979625. 11	3. 14	45. 66	−40. 85
681	35 30. 24	120 43. 68	1636	979665. 74	3. 94	31. 25	−21. 25
682	35 30. 11	120 45. 59	1979	979649. 00	5. 72	46. 95	−15. 58
683	35 30. 92	120 47. 11	1880	979654. 23	5. 44	41. 72	−17. 68
684	35 30. 85	120 44. 46	1591	979669. 78	3. 02	30. 19	−21. 68
685	35 32. 30	120 43. 29	871	979707. 33	1. 11	−2. 04	−31. 00
686	35 33. 26	120 43. 53	876	979708. 37	1. 05	−1. 89	−31. 08
687	35 35. 46	120 44. 48	1078	979703. 23	1. 33	8. 84	−27. 04
688	35 36. 77	120 42. 37	1286	979673. 45	2. 69	−3. 24	−44. 93
689	35 36. 72	120 45. 22	1624	979669. 18	2. 63	24. 35	−29. 05

TABLE 3.—*Principal facts for gravity stations*—Continued

Station	Lat N.	Long W.	Elevation (ft)	Observed gravity (mgal)	Terrain correction (mgal)	Free air anomaly (mgal)	Complete Bouguer anomaly (mgal)
690	35 38. 88	120 45. 33	1721	979668. 99	2. 69	30. 21	−26. 47
691	35 38. 23	120 42. 44	1125	979701. 90	1. 94	7. 99	−28. 90
692	35 39. 67	120 43. 33	1127	979713. 00	2. 05	17. 23	−19. 62
693	35 40. 44	120 44. 12	1108	979716. 20	1. 96	17. 55	−18. 74
694	35 41. 44	120 43. 23	895	979719. 26	1. 09	−. 85	−30. 66
695	35 42. 87	120 42. 63	838	979713. 40	1. 35	−14. 11	−41. 69
696	35 44. 14	120 40. 12	677	979725. 31	. 84	−19. 15	−41. 69
697	35 43. 07	120 38. 36	678	979723. 30	. 71	−19. 54	−42. 24
698	35 43. 94	120 36. 23	918	979708. 12	. 69	−13. 39	−44. 39
699	35 44. 92	120 38. 10	977	979707. 37	. 96	−9. 99	−42. 75
700	35 41. 30	120 38. 38	783	979712. 65	. 60	−17. 80	−44. 23
701	35 42. 39	120 40. 24	836	979711. 02	. 88	−15. 99	−43. 98
702	35 39. 56	120 40. 26	768	979714. 48	. 66	−14. 90	−40. 76
703	35 40. 43	120 39. 45	769	979712. 38	. 61	−18. 14	−44. 09
704	35 39. 46	120 37. 88	783	979707. 39	. 62	−20. 44	−46. 85
705	35 39. 57	120 36. 28	891	979696. 69	. 68	−21. 14	−51. 22
706	35 40. 45	120 36. 27	832	979702. 99	. 60	−21. 64	−49. 76
707	35 39. 57	120 34. 67	898	979695. 06	. 62	−22. 11	−52. 49
708	35 40. 99	120 32. 98	805	979701. 36	. 69	−26. 58	−53. 68
709	35 41. 80	120 31. 00	1113	979681. 77	. 93	−18. 35	−55. 84
710	35 43. 26	120 30. 28	1393	979667. 87	1. 18	−7. 99	−54. 88
711	35 45. 74	120 30. 70	1819	979646. 36	3. 30	7. 03	−52. 42
712	35 44. 34	120 31. 89	1511	979662. 77	1. 77	−3. 54	−53. 90
713	35 42. 64	120 32. 65	1132	979684. 06	1. 10	−15. 47	−53. 44
714	35 41. 46	120 34. 88	750	979708. 67	. 70	−25. 11	−50. 30
715	35 42. 21	120 36. 09	728	979714. 55	. 74	−22. 37	−46. 76
716	35 43. 90	120 34. 12	933	979704. 12	. 95	−15. 92	−47. 18
717	35 53. 25	120 45. 86	798	979730. 34	1. 35	−15. 73	−41. 93
718	35 55. 01	120 46. 90	997	979722. 98	1. 54	−6. 88	−39. 76
719	35 55. 38	120 48. 39	1159	979712. 75	1. 53	−2. 41	−40. 88
720	35 56. 15	120 49. 31	1089	979720. 61	1. 53	−2. 23	−38. 29
721	35 56. 13	120 50. 36	894	979733. 23	1. 08	−7. 92	−37. 71
779	35 48. 97	120 31. 28	1474	979673. 31	1. 46	−3. 07	−52. 47
782	35 46. 39	120 32. 76	1194	979691. 64	1. 23	−7. 40	−47. 38
783	35 53. 31	120 48. 11	974	979714. 04	1. 10	−15. 56	−48. 08
784	35 57. 68	120 49. 89	607	979754. 74	1. 26	−15. 62	−35. 32
785	35 56. 56	120 45. 65	1008	979727. 17	1. 76	−3. 87	−36. 91
786	35 57. 84	120 46. 82	1074	979722. 59	1. 52	−4. 07	−39. 63
787	35 59. 15	120 45. 25	1626	979681. 75	3. 34	5. 13	−47. 63
788	35 58. 85	120 48. 46	1202	979713. 53	1. 92	−2. 54	−42. 10
789	35 59. 18	120 50. 80	672	979752. 28	1. 20	−14. 11	−36. 11
790	35 58. 43	120 54. 61	898	979729. 83	2. 33	−14. 23	−42. 90
791	35 54. 44	120 41. 77	1001	979718. 04	1. 43	−10. 63	−43. 76
792	35 52. 31	120 42. 04	909	979718. 37	1. 37	−15. 92	−45. 93
793	35 49. 78	120 42. 23	754	979723. 85	1. 17	−21. 41	−46. 27
794	35 48. 82	120 43. 45	1256	979688. 25	2. 95	−8. 42	−48. 82
795	35 50. 92	120 43. 58	1129	979699. 66	1. 49	−11. 95	−49. 43
796	35 55. 28	120 44. 74	1506	979690. 75	2. 05	8. 37	−41. 54
797	35 56. 69	120 42. 75	1819	979668. 60	2. 67	13. 64	−46. 43
798	35 57. 30	120 40. 86	1961	979659. 84	4. 77	17. 37	−45. 49
799	35 58. 53	120 41. 15	2254	979636. 59	5. 26	19. 91	−52. 54
800	35 57. 05	120 44. 03	1410	979698. 86	1. 66	4. 93	−42. 07
801	35 58. 19	120 44. 05	1225	979709. 95	1. 74	−3. 01	−43. 55
802	35 56. 16	120 40. 42	1124	979714. 66	2. 35	−4. 90	−41. 35
803	35 57. 42	120 38. 89	1232	979714. 38	1. 74	3. 18	−37. 60
804	35 59. 20	120 38. 10	1754	979681. 87	2. 00	17. 22	−41. 29
805	35 59. 47	120 39. 92	2179	979647. 74	3. 36	22. 67	−49. 11
806	35 53. 15	120 39. 50	1476	979678. 90	1. 11	−3. 26	−53. 08
807	35 54. 98	120 38. 24	2039	979646. 15	3. 08	14. 33	−52. 91
808	35 56. 49	120 36. 87	2079	979659. 41	1. 72	29. 19	−40. 78
809	35 59. 94	120 36. 66	1837	979677. 93	1. 49	20. 02	−41. 85
811	35 59. 88	120 34. 03	2235	979647. 74	2. 07	27. 35	−47. 64
812	35 57. 04	120 31. 79	2066	979658. 74	1. 45	26. 51	−43. 28
813	35 53. 25	120 33. 47	1665	979678. 04	2. 08	13. 51	−41. 85
814	35 51. 36	120 35. 52	1315	979684. 78	1. 52	−9. 97	−53. 83
899	35 46. 14	120 40. 52	1147	979697. 11	1. 69	−5. 99	−43. 89
900	35 46. 98	120 38. 88	1421	979676. 90	1. 44	−1. 63	−49. 23
901	35 48. 29	120 39. 17	1462	979674. 53	1. 64	−2. 01	−50. 82
902	35 48. 25	120 41. 21	1406	979678. 26	3. 29	−3. 49	−48. 72
903	35 50. 07	120 39. 77	1371	979682. 80	1. 65	−4. 84	−50. 59
904	35 51. 41	120 40. 90	1311	979693. 74	1. 25	−1. 45	−45. 45
905	35 51. 42	120 39. 01	1427	979679. 83	1. 36	−4. 47	−52. 35
906	35 49. 59	120 37. 78	1615	979663. 64	2. 46	−. 37	−53. 63

TABLE 3.—*Principal facts for gravity stations*—Continued

Station	Lat N.	Long W.	Elevation (ft)	Observed gravity (mgal)	Terrain correction (mgal)	Free air anomaly (mgal)	Complete Bouguer anomaly (mgal)
907	35 46. 96	120 36. 77	1418	979677. 04	1. 49	−1. 75	−49. 19
908	35 49. 70	120 36. 48	1555	979666. 95	1. 99	−2. 86	−54. 52
909	35 52. 01	120 36. 87	1510	979673. 59	1. 25	−3. 74	−54. 59
910	35 53. 46	120 36. 15	2305	979621. 35	5. 28	16. 71	−57. 48
911	35 54. 72	120 35. 96	2053	979655. 48	2. 08	25. 34	−43. 38
912	35 55. 84	120 34. 83	2540	979626. 53	4. 38	40. 59	−42. 58
915	35 53. 04	120 30. 12	2652	979614. 69	3. 79	43. 28	−44. 33
947	35 53. 86	120 44. 15	1025	979719. 97	1. 44	−5. 62	−39. 56
948	35 55. 22	120 42. 56	1654	979678. 04	2. 06	9. 67	−45. 33
951	35 54. 04	120 54. 75	816	979708. 62	1. 13	−36. 88	−63. 93
952	35 54. 46	120 56. 07	862	979707. 45	1. 45	−34. 33	−62. 64
953	35 55. 70	120 55. 39	1290	979685. 80	2. 06	−17. 49	−59. 95
954	35 55. 23	120 56. 47	968	979704. 28	1. 84	−28. 63	−60. 20
955	35 55. 69	120 55. 39	1092	979692. 14	1. 60	−29. 76	−65. 85
956	35 57. 15	120 51. 63	495	979762. 12	1. 32	−18. 02	−33. 79
1033	35 48. 89	120 33. 77	1585	979664. 11	1. 72	−1. 72	−54. 68
1034	35 50. 34	120 33. 67	1653	979661. 22	1. 15	−. 28	−56. 16
1035	35 51. 72	120 33. 06	1785	979652. 69	1. 46	1. 63	−58. 48
1036	35 51. 74	120 52. 91	810	979711. 22	2. 80	−31. 57	−56. 74
1037	35 50. 88	120 53. 19	885	979700. 68	1. 71	−33. 82	−62. 67

The accuracy of the gravity data undoubtedly varies from station to station. The observed gravity values for the 298 stations read with a LaCoste-Romberg gravity meter are probably accurate to 0.02 mgal after correcting for tidal effects. The values for the 15 stations read with a Worden meter (scale constant about 0.5 mgal) are probably accurate to 0.1–0.2 mgal after correcting for drift. Latitude and longitude were measured to ±0.01 minute. Elevation accuracy depends critically on type of source data. Roughly 30 percent of the stations were read at bench marks, and elevation errors for these should be less than 0.5 feet. Ten percent are field-checked spot elevations probably accurate to within 1 foot; 55 percent are unchecked spot elevations accurate to within 5 feet. Twenty-four stations were established on the shore of Lake Nacimiento and are estimated to have an elevation accuracy of ±1 foot.

All gravity data were corrected for terrain effects (at density 2.67 g/cm³) out to a radius of 166.7 km. For the inner zones terrain corrections were made by hand using Hayford-Bowie templates and dividing each compartment into four subcompartments where corrections were large. For the outer zones the corrections were made by computer using a program developed by Don Plouff. The boundary between inner and outer zone corrections was either 5.24 or 2.29 km; 1-minute and 3-minute terrain digitization grids were employed.

All basic measurements were reduced to anomaly values using a gravity reduction program developed by S. H. Burch. The basic procedures and formulas of the reduction are as follows:

1. The gravity difference (ΔG) between the base and a given station is calculated in one of six ways depending on the reduction option selected. It is then corrected for tide and drift.
2. Observed gravity (OG) = Gravity base value $\pm \Delta G$.
3. Theoretical gravity (THG) = $978049\ [1 + 0.005228 \sin^2\theta - 0.0000059 \sin^2 (2\theta)]$, where θ = latitude.
4. Free air anomaly (FAA) = $OG - THG + (0.09411549 - 0.000137789 \sin^2\theta)E - 0.0000000067E^2$, Where E = elevation.
5. Simple Bouger anomaly (BA) = $FAA - 0.012774\ \rho E$, where ρ = reduction density.
6. Curvature correction (CC) = $0.0004462 \times E - 3.28 \times 10^{-8} \times E^2 + 1.27 \times 10^{-15} \times E^3$.
7. Complete Bouguer anomaly (CBA) = $BA + TC - CC$, where TC = terrain correction.

GRAVITY INTERPRETATION

Quantitative interpretation of gravity anomalies here relies largely on a two-dimensional two-layer basement-sediment model. Density contrasts of 0.3 and 0.5 grams per cubic centimeter are commonly used to arrive at maximum and minimum dimensions for various anomalous features. The following estimates are used for unit densities:

	g/cm^3
Surficial deposits	<2.2
Paso Robles Formation	2.2
Pancho Rico and Santa Margarita Formations	2.3
Monterey Shale	2.3
Tierra Redonda and Vaqueros Formations	2.4
Paleocene and Upper Cretaceous deposits	2.5
Basement rocks	2.67

Based on these values, the density contrasts of 0.3 and 0.5 furnish good approximations to common sediment-basement combinations. A mixed sequence of Cretaceous and Tertiary rocks on basement will have a density contrast close to 0.3. Quaternary deposits on basement, however, have a density difference of close to 0.5.

In arriving at subsurface mass distribution, graticule and various simple mathematical calculations, and interpretations using a U.S. Geological Survey modification of Bott's (1960) interpretation program, were fitted to outcrop and well data.

GRAVITY ANOMALIES

The important features of the gravity map (pl. 1) are associated with basement features east of the Jolon and Rinconada fault zones or with the faults themselves. No major anomalies occur west of the faults, owing in part, perhaps, to the lower station density in this area. Discussion here will treat first the area east of the faults, then the fault zones themselves, and finally the area west of the faults.

AREA EAST OF JOLON AND RINCONADA FAULTS

The anomalies of the area east of the Jolon and Rinconada faults are assumed to reflect depth to basement rather than changes in basement density. The largest anomaly is the Hames Valley low, which covers much of the Bradley quadrangle. This feature, representing a deep basement depression, is bounded by the steep gradients of the Jolon fault on the west and by the steep basement slope paralleling the Los Lobos fault on the northeast. The data indicate two closed lows 7 miles apart. Analyses of the northern low (fig. 2) using Gauss's theorem and Bott's interpretation program suggest a depth to basement at the bottom of the depression of slightly more than 15,000 feet. The sharpness of the southern low may be due to near-surface low-density diatomite deposits as well as to the large depth to basement. Just east of the Hames Valley low is a northwest-trending gravity high associated with the San Ardo oil field, where basement rises to within 2,500 feet of the surface (Durham, 1966, pl. 5).

In the San Miguel quadrangle, a similar gravity pattern obtains. A broad gravity low, called the Vineyard Canyon low, is separated on the northeast by a steep gradient from another northwest-trending gravity high, called the Cholame Hills high. Here, however, the gradient on the northeast is not associated with any known major fault, dips in the surface are gentle, revealing no major syncline, and the gradient on the southwest is extremely gentle. Both the Cholame Hills high and the Vineyard Canyon low extend southeastward into the adjoining Parkfield and Shandon quadrangles (S. H. Burch, W. F. Hanna, and T. W. Dibblee, Jr., unpub. data, 1969). A Bott profile indicates that the depth to basement at the bottom of the Vineyard Canyon low is approximately 10,000 feet and at the top of the Cholame Hills high is less than 2,000 feet.

The existence of a large northeast-trending basement fault, here called the Indian Valley fault, is indicated by the mutual truncation of all the previously discussed northwest-trending anomalies along a line extending from upper Indian Valley to the lower San Antonio River valley (pl. 1). The significance of this fault is

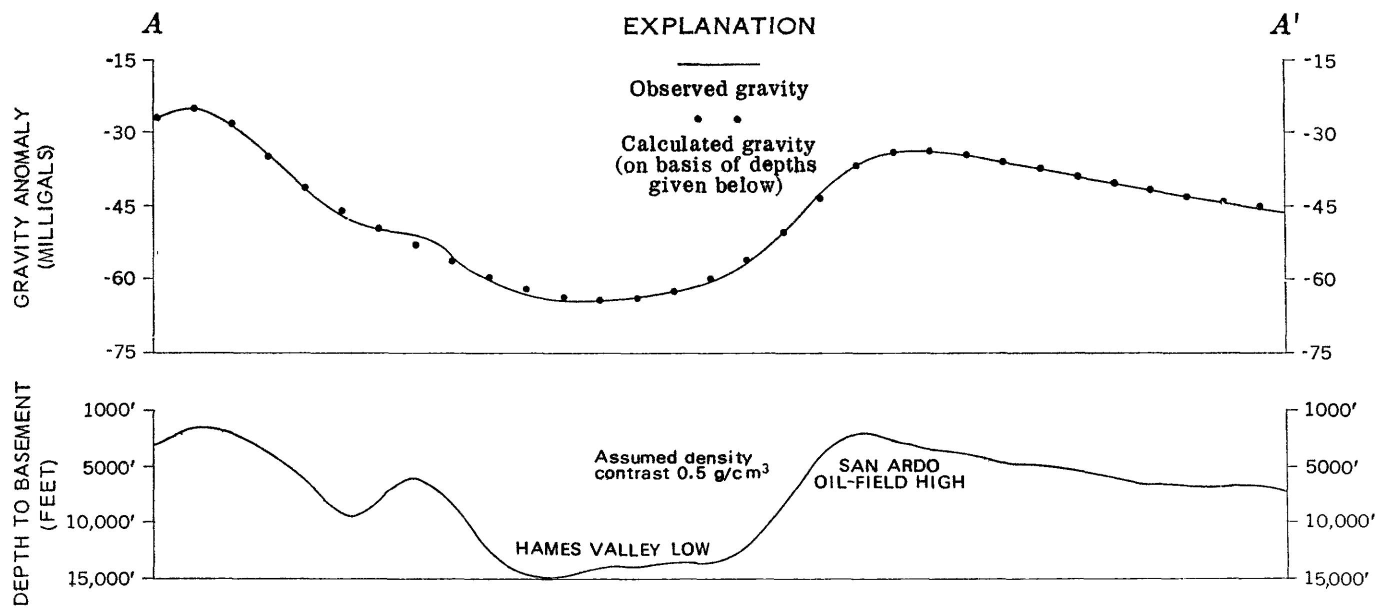

FIGURE 2.—Gravity and structure profiles through the Hames Valley low and San Ardo oil-field high, Bradley quadrangle. Structure profile calculated by the U.S. Geological Survey's modified version of Bott's (1960) program.

that a similar transverse fault appears 19–20 miles northwest on the opposite side of the Espinosa fault, and the similarity of the two suggests that the Espinosa is a strike-slip fault with a right-lateral offset of approximately 16 miles (Burch, 1969). Apparently undisturbed overlying upper Miocene formations date the fault as pre-late Miocene.

The broad gravity high extending northeast from Wellsona (north of Paso Robles) to Ranchito and Hog Canyons may reflect a slight basement rise in this area. The steep gravity nose in the southeast corner of the map is caused by the large granite mass of the La Panza Range that crops out about 1 mile to the south. The gravity low separating the latter two features intersects the Vineyard Canyon low near Shandon (S. H. Burch, W. F. Hanna, and T. W. Dibblee, Jr., unpub. data, 1969).

Apparent positive gravity anomalies of 2–3 mgal are associated with topographic valleys in the center of the map area. This is illustrated by the high gravity values in the Salinas River valley and its main tributaries (where data are available) from Hames Valley to Estrella Creek. These highs do not reflect basement features, but rather are relative highs contrasting with the normally low values caused by the extensive low-density topographic plateaus of Quaternary sedimentary deposits. Failure to remove these highs before using the Bott program will result in sharp basement ridges coincident with the topographic valleys.

The gravity data reveal three unexplored areas where basement structure might result in conditions favorable to accumulation of oil.

1. The steep gravity gradient on the west side of Hames Valley is interrupted by a gently sloping bench about 1 mile wide. The depth to basement suggested by the low gravity values requires a basement ridge of moderate size. Figure 2 shows a Bott program interpretation of the feature. The half width of the anomaly (regional removed) suggests a maximum depth of 7,000 feet to the center of the ridge.
2. The southeast extension of the San Ardo oil-field high indicates a basement high that has not been fully explored. This high may rise to within 2,500 feet of the surface.
3. The Cholame Hills high indicates a major basement high, also little explored.

AREA NEAR JOLON AND RINCONADA FAULTS

The alinement of the steep linear gravity gradients northwest and southeast of the Paso Robles granite body indicates that the Jolon and Rinconada fault zones probably join. The Rinconada is of major importance since in the San Luis Obispo quadrangle immediately to the south, it probably separates granitic basement on the east from Franciscan basement on the west (E. W. Hart, oral commun., 1967). Thus the Jolon fault may bear the same relation to these major basement units within the map area. Evidence from the Bryson quadrangle to the west (Burch, 1969), however, suggests that the basement contact branches westward from the Jolon fault and roughly follows the thrust fault east and north of Lake Nacimiento.

Despite the deflection of the gravity gradient around the east side of the Paso Robles granite body, the fault passes west of the body and, at the surface, defines its western contact. The deflection is caused by the greater density contrast against the Paso Robles Formation on the east than against the Miocene strata to the west.

AREA WEST OF JOLON AND RINCONADA FAULTS

The area west of the Jolon and Rinconada faults apparently contains no major gravity anomalies. Proceeding northeast from the southwest corner of the map, a rather even gravity gradient of about −2 mgal per mile bottoms out in a syncline where Monterey Shale is exposed, then reverses and ascends an anticline of Cretaceous and lower Tertiary beds, and finally drops off over the Jolon fault. Both the syncline and anticline are long, broad features without much gravity relief.

Perhaps the most significant aspect of the gravity data in this area is the lack of gravity expression of the Nacimiento fault. This fault is generally considered to be the boundary between the eugeosynclinal Franciscan basement on the southwest and the granitic and metamorphic basement of the Salinian block on the northeast, and thus it is thought to have a significance similar to that of the San Andreas fault. Yet, the following evidence suggests that in the map area the Jolon, rather than the Nacimiento, separates the major basement units:

1. The dips are low and gravity expression negligible on the Nacimiento fault.
2. The dips are steep and gravity expression sharp on the Jolon fault.
3. The steep gravity gradient associated with the Rinconada fault, which marks the contact of the granitic and Franciscan basement blocks to the south, joins the Jolon fault rather than the Nacimiento fault.

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