UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mass Properties of Conventional Core Samples from the Sisquoc, Monterey, and Point Sal Formations, Unocal Newlove 51 Well, Orcutt Oil Field, Santa Maria Basin, California

by

Larry A. Beyer
Caroline M. Isaacs

Open-File Report

90-14

This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U. S. Government.

U. S. Geological Survey, 345 Middlefield Rd., MS 999, Menlo Park, California 94025

INTRODUCTION

This report presents data on grain density, dry and saturated bulk densities, and porosity of selected samples of conventional cores taken from the Unocal Newlove 51 well, Orcutt oil field, California. Discussions of laboratory measurement procedures with helium and mercury pycnometers and measurement errors also are included.

Mass Properties

Mass properties include grain density, dry and saturated bulk density, porosity, pore-fluid density and permeability. Mass properties of subsurface sedimentary rocks are the result of many factors: (1) Composition of source sediments; (2) depositional environment which controls original texture and bedding; (3) burial, temperature, pressure and pore-fluid histories including fluid chemistry and circulation which, together with sediment composition and texture, control diagenesis; (4) deformational history; and (5) associated rocks.

Description of mass properties is an important step to understanding the history of a buried rock sequence. Also, mass properties contribute significantly to, or dominantly influence gravity, temperature, seismic and other geophysical measurements and, thus, are important to the interpretation of geophysical data. Lastly, mass properties are crucial to the practical evaluation of porous rocks that act as economic reservoirs of petroleum.

Grain density, dry bulk density, total porosity and saturated bulk density are reported here. These properties are defined in this study as follows.

grain density	ρ_g = dry weight / grain volume
dry bulk density	ρ_b = dry weight / bulk volume
total porosity	$\phi = 100\ (1 - \rho_b / \rho_g)$
saturated bulk density	$\rho_s = \rho_b + \phi / 100$

The units of density and total porosity are g/cm^3 and percent, respectively. Saturated bulk density assumes a pore-fluid density of 1.00 g/cm^3. Permeability and other physical properties such as magnetic, elastic, thermal, and electrical characteristics were not measured in this study.

Unocal Newlove 51 Well

The Unocal Newlove 51 well is located in the Orcutt oil field in the onshore Santa Maria basin (Figure 1). This extensively cored well was drilled in 1932 to a depth of 4,114 feet and is located on the south side of the Orcutt fault, which borders the north side of the field (Figure 2). As originally reported by the operator, the drilled sequence includes the Careaga Formation (0-90 ft), Foxen Mudstone (90-462 ft), Sisquoc Formation (462-1884 ft), Monterey Formation (1,884-4,014 ft), and Lospe Formation (4,014-4,114 ft). Within the Monterey Formation, the original operator reports identified the arenaceous zone (1,884-1,918 ft), cherty zone (1,918-2,154 ft), bentonitic brown zone (2,154-2,309 ft), buff and brown zone (2,309-2,515 ft), dark brown zone (2,515-2,841 ft), oil sand zone (2,841-3,132 ft) and siltstone and shell zone (3,132-4,014 ft). Subsequently, Canfield (1939) proposed the name "Point Sal Formation" for the siltstone and shell zone, and Woodring and Bramlette (1950) formally adopted the proposal. Common current usage includes the oil sand zone in the Point Sal Formation as well, and this usage is followed here.

METHODS

Sample Selection, Preparation and Weighing

Core materials were gathered from spot-sampled collections to represent the various lithologies and the maximum, mean and minimum bulk densities. Core samples that showed evidence of alteration by drilling fluids were not collected.

Core samples were cut, either with a dry saw or a saw lubricated with free flowing water, to (1) remove surfaces previously exposed to drilling fluids or long exposed to the atmosphere, (2) remove rough surfaces capable of trapping bubbles during immersion in mercury, and (3) size samples for the helium and mercury pycnometers. At the same time, matched pieces were cut for geochemical analyses as reported by Isaacs and others (1989). Samples cut for mass property determinations were dried in a pre-heated oven for 24 hours at about 105 °C to drive off H_2O^- (adsorbed water)(e. g., Breger and Chandler, 1969). Amounts of H_2O^- probably range from less than 1 weight percent to as much as about 5 weight percent in some clay-rich Sisquoc samples (Isaacs, 1980, Appendix A).

Samples were cooled in a dessicator after drying, weighed to the nearest .001 g and stored in the dessicator until measurement of grain volume in a helium pycnometer. Weights of the Newlove 51 samples ranged from 16.4 to 50.8 g with a mean of 28.4 g.

Grain Volume Measurements

Grain volume was determined by the gas displacement-Boyle's law method with a Beckman Model B5 Air Comparison Pycnometer operated with helium (e.g., McIntyre and others, 1965). Helium injection pressure into sample pores was 4 psi.

Repeated zero or reference readings without a sample in the pycnometer to within .02 cm^3, before and after sample measurements, was the criterion for acceptance of a sample volume measurement. Also, sample volume measurements were made until values repeated to within +.02 cm^3. Measured grain volumes of Newlove 51 samples ranged from 6.1 to 18.8 cm^3 with a mean of 11.1 cm^3. The Beckman pycnometer was calibrated with volume standards provided by the manufacturer.

Bulk Volume Measurements

Bulk volumes of core samples were measured by the mercury displacement method using a mercury pycnometer slightly modified from that described and illustrated by McCulloh (1965). This vacuum-equipped mercury immersion bulk-volume pycnometer is designed to minimize bubble entrapment against the sample and to minimize and permit evaluation of the amount of mercury lost to pore spaces during immersion. All measured volumes of samples were corrected for mercury lost to pore spaces or artificial cracks.

The accuracy and precision of these bulk volume measurements depended on the reading accuracy and the precision of the mercury pycnometer, and on the accuracy of its calibration. A skilled operator can read the burette tube to .02 cm^3 and repeat volume measurements of non-porous test samples to .05 cm^3 or better. Measured bulk volumes of Newlove 51 samples ranged from 7.3 to 21.4 cm^3 with a mean of 14.7 cm^3. The pycnometer was calibrated by adding known weights of mercury at known temperatures to the burette tube. Calculated mercury volume was compared to observed burette volume. The calibration was checked by determining the bulk density of transparent quartz crystals; these measured bulk densities were within .002 g/cm^3 of accepted values after correction for temperature.

RESULTS

Values of grain density, dry bulk density, porosity and saturated bulk density for 65 core samples are given together with error estimates in Table 1. Table 1 is constructed to correspond to Table 2 of Isaacs and others (1989), which gives approximate mineral abundances of the samples. Error estimates that appear in parentheses in Table 1 are due to the uncertainties of the pycnometer measurements. Equations for these error estimates are given in the appendix.

The range, mean, standard deviation, and sample size of measured mass properties grouped by formation are given in Table 2. Grain density, dry bulk density, porosity, and saturated bulk density versus depth are given in Figures 3 through 6. The relationship between grain density, dry bulk density, and porosity is shown in Figure 7.

Table 1. Grain density, dry bulk density, porosity, and saturated bulk density of selected samples of conventional cores from the Unocal Newlove 51 well, Orcutt oil field, Santa Maria basin, California. Sample numbers are average depth of individual core from which sample was taken followed (in parentheses) by tray number and a letter to designate various samples from the same tray. Values in parentheses are error estimates based on the equations given in the appendix.

Sample Number	Core Depth Interval (feet)	Grain Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Porosity (%)	Saturated Bulk Density (g/cm^3)
	SISQUOC:				
910 (2A)	897 - 923	2.473 (.006)	1.514 (.006)	38.78 (0.40)	1.902 (.010)
961 (A)	948 - 974	2.490 (.005)	1.516 (.004)	39.11 (0.28)	1.907 (.007)
1060 (1A)	1049 - 1070	2.574 (.006)	1.512 (.005)	41.27 (0.33)	1.924 (.008)
1118 (2A)	1113 - 1123	2.556 (.006)	1.511 (.005)	40.89 (0.35)	1.919 (.009)
1180 (5A)	1168 - 1191	2.540 (.005)	1.581 (.005)	37.74 (0.32)	1.959 (.008)
1229 (7A)	1216 - 1241	2.445 (.004)	1.426 (.003)	41.68 (0.23)	1.843 (.006)
1254 (7A)	1241 - 1266	2.531 (.005)	1.496 (.004)	40.92 (0.30)	1.905 (.007)
1341 (A)	1328 - 1354	2.590 (.004)	1.554 (.004)	40.00 (0.26)	1.954 (.007)
1453 (5A)	1444 - 1462		1.449 (.005)		
1497 (4A)	1487 - 1506	2.579 (.006)	1.657 (.006)	35.74 (0.36)	2.015 (.009)
	MONTEREY FORMATION, cherty zone:				
1925* (A)	1913 - 1937	2.392 (.005)	1.441 (.004)	39.74 (0.31)	1.839 (.007)
1968 (1A)	1955 - 1980	2.314 (.006)	1.305 (.005)	43.61 (0.35)	1.741 (.008)
1968 (2A)	1955 - 1980	2.337 (.004)	1.280 (.003)	45.25 (0.25)	1.732 (.006)
1968 (2B)	1955 - 1980	2.420 (.006)	1.663 (.007)	31.27 (0.46)	1.976 (.012)
1991 (2A)	1980 - 2002	2.370 (.007)	1.354 (.005)	42.89 (0.39)	1.783 (.009)
2010 (2A)	2002 - 2018		2.151 (.007)		
2010 (6A)	2002 - 2018	2.487 (.004)	1.737 (.005)	30.15 (0.31)	2.039 (.008)
2026 (A)	2018 - 2033	2.465 (.004)	1.656 (.005)	32.79 (0.31)	1.984 (.008)
2037 (5A)	2033 - 2041	2.350 (.005)	1.635 (.006)	30.42 (0.42)	1.939 (.011)
	MONTEREY FORMATION, bentonitic brown zone:				
2178 (6A)	2165 - 2190	2.264 (.004)	1.748 (.006)	22.80 (0.41)	1.976 (.010)
2202 (1A)	2190 - 2213	2.470 (.006)	1.898 (.008)	23.17 (0.51)	2.130 (.013)
2227 (6A)	2213 - 2240	2.450 (.003)	2.030 (.005)	17.14 (0.29)	2.201 (.008)
2254 (2A)	2240 - 2267	2.459 (.006)	1.822 (.008)	25.88 (0.53)	2.081 (.014)
	MONTEREY FORMATION, buff and brown zone:				
2395 (A)	2387 - 2404	2.357 (.004)	1.911 (.007)	18.89 (0.42)	2.100 (.011)
2408 (A)	2404 - 2413	2.304 (.004)	2.230 (.008)	3.22 (0.51)	2.262 (.013)
2439 (A)	2435 - 2443	2.228 (.006)	1.983 (.011)	10.97 (0.72)	2.093 (.018)
2487 (A)	2480 - 2495	2.494 (.005)	1.914 (.007)	23.27 (0.43)	2.147 (.011)
2487 (B)	2480 - 2495	2.557 (.004)	2.073 (.006)	18.95 (0.35)	2.262 (.009)
	MONTEREY FORMATION, dark brown zone:				
2634 (A)	2625 - 2641	2.579 (.003)	2.175 (.006)	15.68 (0.35)	2.332 (.010)
2667 (A)	2667 - 2667	2.467 (.005)	1.850 (.007)	25.00 (0.43)	2.100 (.011)
2669 (1A)	2660 - 2677	2.517 (.006)	1.948 (.008)	22.62 (0.50)	2.174 (.013)
2669 (4A)	2660 - 2677	2.635 (.008)	2.020 (.012)	23.34 (0.67)	2.254 (.018)
2669 (6A)	2660 - 2677	2.569 (.006)	1.950 (.009)	24.12 (0.51)	2.191 (.014)
2687 (2A)	2677 - 2696	2.564 (.004)	1.979 (.007)	22.81 (0.39)	2.207 (.011)

2687 (3A)	2677 - 2696	2.571 (.006)	2.038 (.009)	20.71 (0.53)	2.246 (.014)
2687 (4A)	2677 - 2696	2.554 (.004)	1.990 (.006)	22.08 (0.35)	2.211 (.009)
2687 (5A)	2677 - 2696	2.538 (.004)	1.987 (.005)	21.71 (0.32)	2.204 (.009)
2687 (6A)	2677 - 2696	2.554 (.004)	1.984 (.007)	22.31 (0.39)	2.208 (.011)
2687 (7A)	2677 - 2696	2.677 (.004)	2.164 (.006)	19.18 (0.34)	2.355 (.010)
2705 (2A)	2696 - 2714	2.589 (.005)	2.028 (.008)	21.67 (0.46)	2.245 (.013)
2705 (2B)	2696 - 2714		2.030 (.006)		
2705 (4A)	2696 - 2714	2.760 (.005)	2.255 (.008)	18.30 (0.43)	2.438 (.012)
2705 (5A)	2696 - 2714	2.600 (.006)	2.035 (.009)	21.72 (0.54)	2.252 (.015)
2722 (2A)	2714 - 2730	2.763 (.003)	2.568 (.007)	7.05 (0.36)	2.639 (.010)
2722 (3A)	2714 - 2730	2.514 (.005)	1.938 (.008)	22.92 (0.49)	2.167 (.013)
2722 (6A)	2714 - 2730	2.566 (.004)	2.024 (.007)	21.14 (0.40)	2.235 (.011)
2743 (2A)	2736 - 2750	2.709 (.004)	2.226 (.008)	17.83 (0.41)	2.404 (.012)
2758 (2A)	2750 - 2766	2.607 (.005)	2.085 (.008)	20.02 (0.47)	2.286 (.013)
2788 (2A)	2785 - 2790	2.659 (.004)	2.073 (.006)	22.06 (0.33)	2.293 (.009)
2810 (A)	2804 - 2816	2.625 (.004)	2.120 (.007)	19.24 (0.37)	2.312 (.010)
2824 (A)	2816 - 2832	2.685 (.005)	2.296 (.010)	14.50 (0.52)	2.441 (.015)
2824 (B)	2816 - 2832	2.792 (.003)	2.676 (.007)	4.16 (0.36)	2.718 (.011)
2824 (C)	2816 - 2832	2.683 (.009)	2.242 (.015)	16.44 (0.85)	2.407 (.024)
2824 (5A)	2816 - 2832	2.511 (.004)	2.130 (.007)	15.16 (0.43)	2.282 (.012)
2837 (2A)	2832 - 2841	2.568 (.005)	1.985 (.007)	22.71 (0.43)	2.212 (.011)
	POINT SAL FORMATION, oil sand zone:				
2850 (3A)	2841 - 2859	2.617 (.005)	2.191 (.009)	16.29 (0.50)	2.353 (.014)
2867 (2A)	2859 - 2875	2.717 (.004)	2.287 (.007)	15.82 (0.38)	2.445 (.011)
3040 (3A)	3030 - 3050	2.606 (.005)	2.117 (.009)	18.74 (0.50)	2.305 (.014)
3040 (4A)	3030 - 3050	2.566 (.005)	2.110 (.008)	17.77 (0.47)	2.287 (.013)
3057 (3A)	3050 - 3064	2.686 (.003)	2.352 (.007)	12.42 (0.36)	2.477 (.010)
	POINT SAL FORMATION, siltstone and shell zone:				
3137 (3A)	3129 - 3146	2.642 (.005)	2.177 (.009)	17.59 (0.52)	2.353 (.014)
3156 (B)	3146 - 3165	2.571 (.004)	2.069 (.006)	19.53 (0.37)	2.264 (.010)
3256 (4A)	3247 - 3265	2.689 (.003)	2.446 (.006)	9.03 (0.32)	2.537 (.009)
3383 (2A)	3373 - 3393	2.663 (.004)	2.063 (.007)	22.52 (0.38)	2.288 (.010)
3383 (2B)	3373 - 3393	2.625 (.008)	2.192 (.014)	16.48 (0.78)	2.357 (.022)

* Reported as 1921 in Isaacs and others (1989).

Table 2. Range, mean, standard deviation, and sample size for mass properties of core samples grouped by formation.

	Grain Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Porosity (%)	Saturated Bulk Density (g/cm^3)
SISQUOC FORMATION				
range	2.44 - 2.59	1.43 - 1.66	35.7 - 41.77	1.84 - 2.02
mean	2.53	1.52	39.6	1.92
standard deviation	0.05	0.06	1.9	0.05
population size	9	10	9	9
MONTEREY FORMATION				
range	2.23 - 2.79	1.28 - 2.68	3.2 - 45.2	1.73 - 2.72
mean	2.52	1.97	22.4	2.19
standard deviation	0.14	0.28	9.0	0.21
population size	43	45	43	43
POINT SAL FORMATION				
range	2.57 - 2.72	2.06 - 2.45	9.0 - 22.5	2.26 - 2.54
mean	2.64	2.20	16.6	2.37
standard deviation	0.05	0.13	3.7	0.09
population size	10	10	10	10

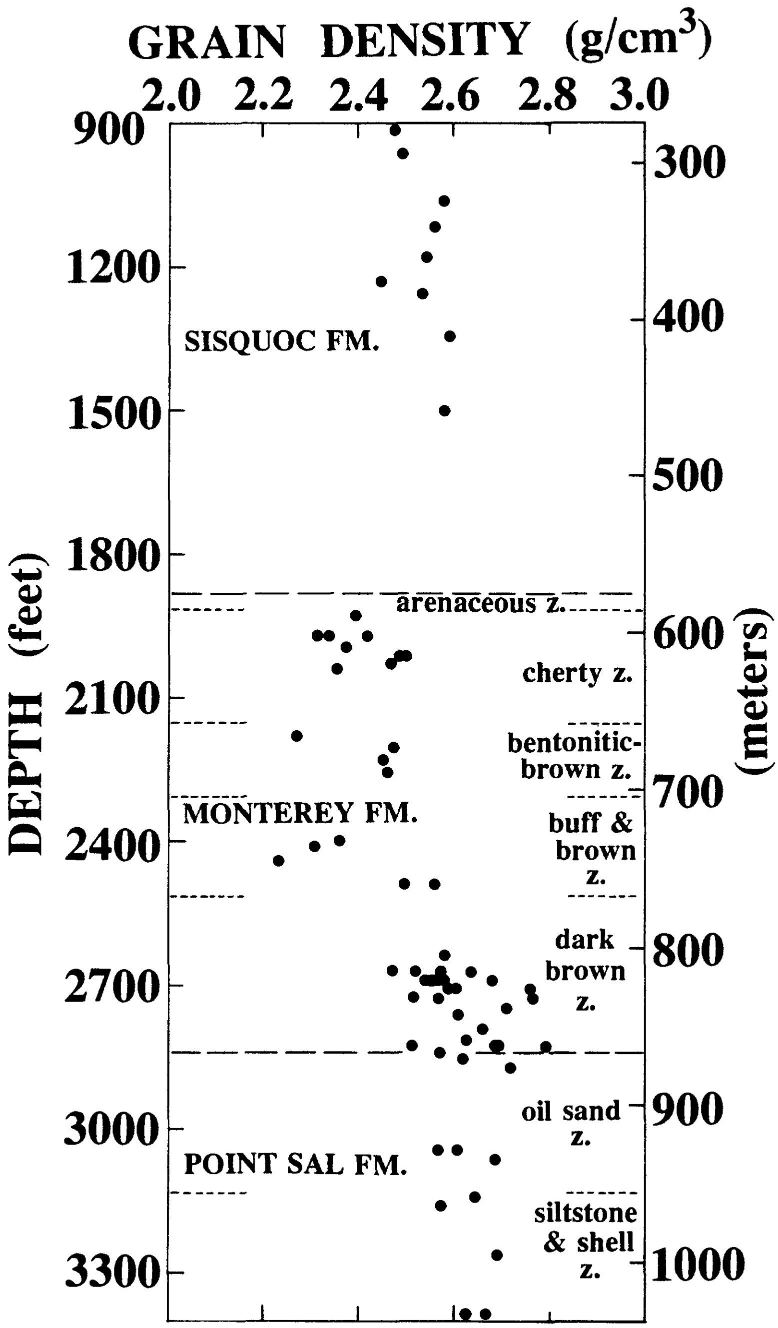

Figure 3. Grain density of 62 core samples from the Unocal Newlove 51 well versus depth. Informal zones of Canfield (1939) as identified in original well reports and formation names are shown here and in Figures 4 through 6.

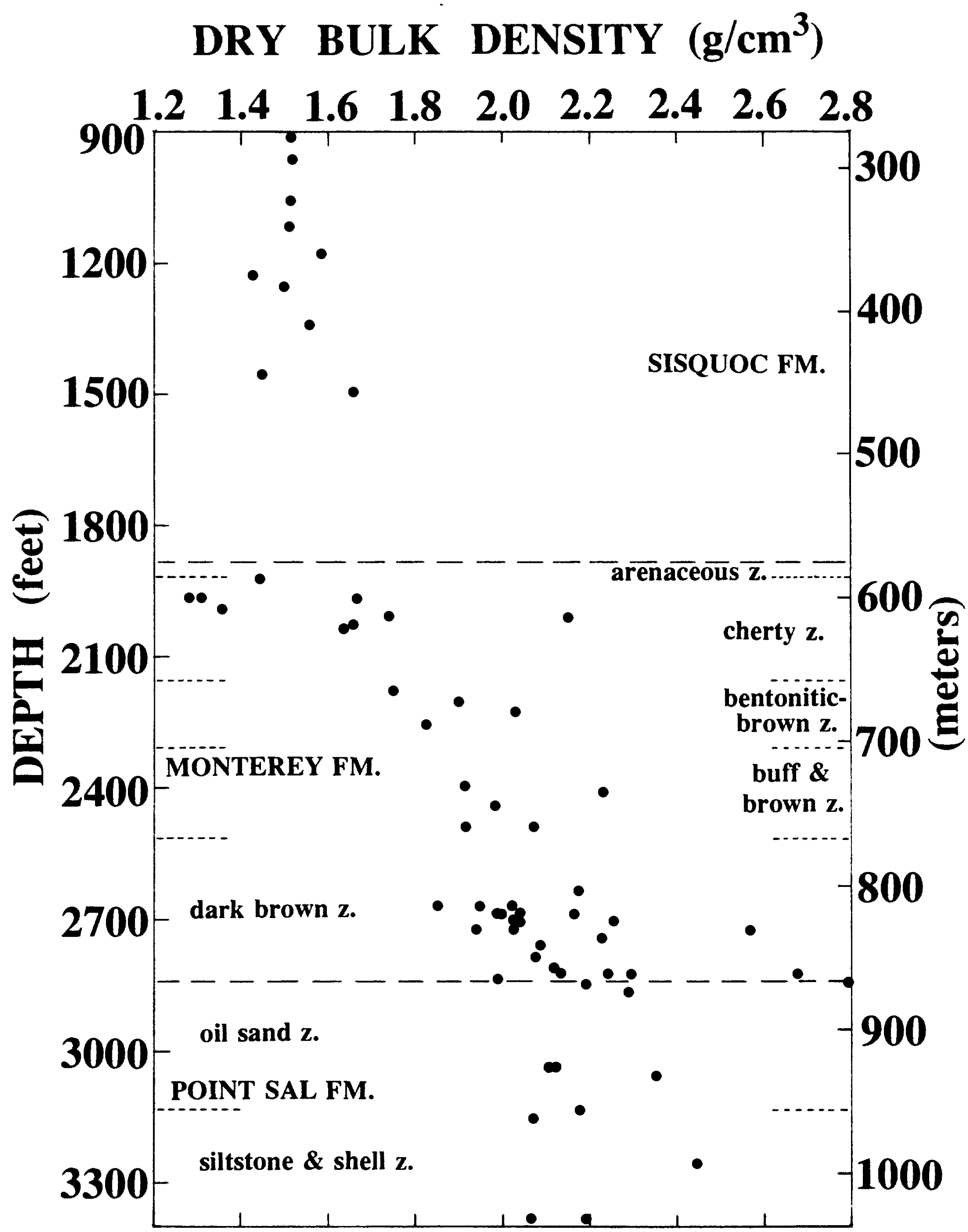

Figure 4. Dry bulk density of 65 core samples from the Unocal Newlove 51 well versus depth.

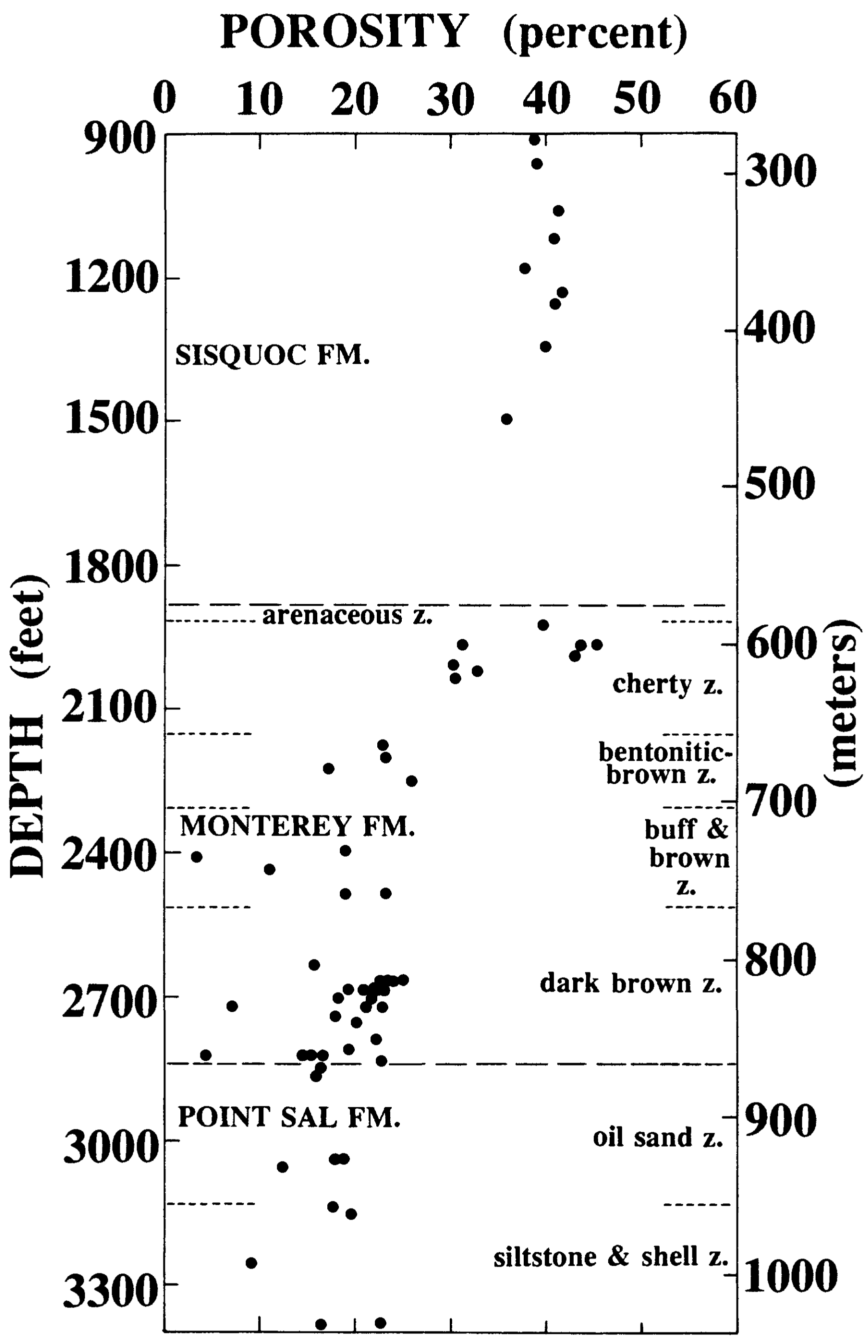

Figure 5 Porosity of 62 core samples from the Unocal Newlove 51 well versus depth.

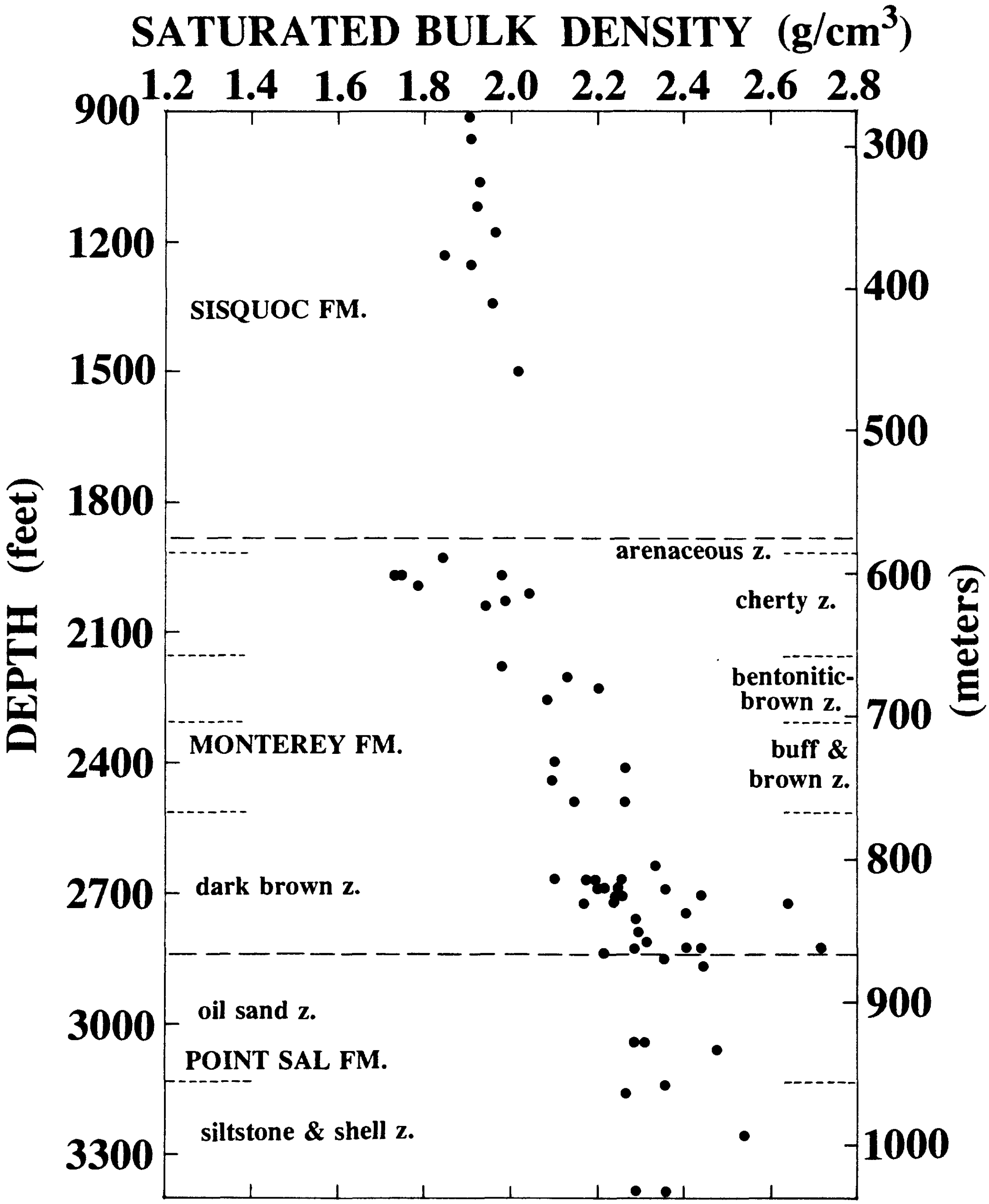

Figure 6. Saturated bulk density of 62 core samples from the Unocal Newlove 51 well versus depth. Saturated bulk density is calculated by assuming a pore-fluid density of 1.00 g/cm³.

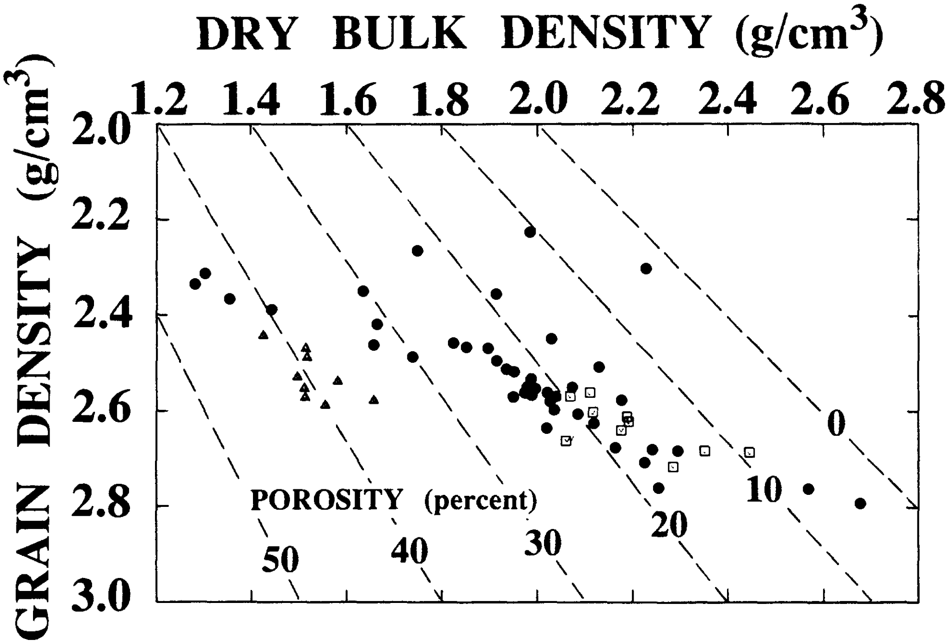

Figure 7. Grain density, dry bulk density and porosity of 62 core samples from Unocal Newlove 51 well. Solid circles represent 43 samples from the Monterey Formation. Triangles and open rectangles represent 9 and 10 samples from the Sisquoc and Point Sal Formations, respectively.

ACKNOWLEDGMENTS

We are grateful to William J. M. Bazeley, William K. Dahleen, Robert A. Fellows, and Kenneth A. Pisciotto for access to core samples. We also thank Margaret A. Keller for cutting core samples for measurements and especially Vicki A. Gennai who operated the helium pycnometer with great patience and perseverance. Gregg H. Blake and Mary Lou Thornton of Unocal Corporation provided information from original well reports and paleontological evaluation.

REFERENCES

Blake, M. C., Jr., Campbell, R. H., Dibblee, T. W., Howell, D. G., Nilsen, T. H., Normark, W. R., Vedder, J. G., and Silver, E. A., 1978, Neogene basin formation in relation to plate-tectonic evolution of the San Andreas Fault System, California: American Association of Petroleum Geologists Bulletin, v. 62, p. 344-372.

Breger, I. A., and Chandler, J. C., 1969, Determination of fixed water in rocks by infrared absorption: Analytical Chemistry, v. 41, no. 3, p. 506-510.

California Division of Oil and Gas, 1974, California oil and gas fields, south, central coast, and offshore California: State of California, Sacramento, California, v. 2, unpaginated.

Canfield, C. R., 1939, Subsurface stratigraphy of Santa Maria Valley oil field and adjacent parts of Santa Maria Valley, California: American Association of Petroleum Geologists Bulletin, v. 23, p. 45-81.

Isaacs, C. M., 1980, Diagenesis in the Monterey Formation examined laterally along the coast near Santa Barbara, California: Stanford University unpublished Ph.D thesis, 329 p.

Isaacs, C. M., Taggart, J. E., Jr., Jackson, L. L., and Scott, Norman III, 1989, Analytical reproducibility and abundances of major elements and sedimentary components in cores from the Sisquoc, Monterey, and Point Sal Formations, Union Newlove 51 well, Orcutt oil field, onshore Santa Maria basin, California: U.S. Geological Survey Open-File Report 89-459, 23 p.

McCulloh, T. H., 1965, A confirmation by gravity measurements of an underground density profile based on core densities: Geophysics, v. 30, p. 1108-1132.

McIntyre, D. B., Welday, E. E., and Baird, A. K., 1965, Geologic application of the air pycnometer: A study of the precision of measurements: Geological Society of America Bulletin, v. 76, p. 1055-1060.

Woodring, W. P., and Bramlette, M. N., 1950, Geology and paleontology of the Santa

Maria district, California: U.S. Geological Survey Professional Paper 222, 142 p.

APPENDIX

The error equation for grain density assumes negligible errors in weight measurements and an uncertainty in the helium pycnometer grain volume measurement of 0.02 cm^3:

$$\rho_{g\,error} = .02[\text{dry weight}/(\text{grain volume}^2)]$$

The error equation for dry bulk density also assumes negligible errors in weight measurements and an uncertainty in the mercury pycnometer bulk volume measurement of 0.05 cm^3:

$$\rho_{b\,error} = .05[\text{dry weight}/(\text{bulk volume}^2)]$$

Errors in calculated porosity and saturated bulk density are given by the following equations:

$$\phi_{error} = 100/\rho_g[\rho_{b\,error} + (\rho_b/\rho_g)/\rho_{g\,error}]$$

$$\rho_{s\,error} = \rho_{b\,error} + \phi_{error}/100$$