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Mass Properties of Conventional Core Samples from the Monterey Formation, Union-Humble Bell Fee 156, West Cat Canyon Oil Field, Santa Maria Basin, California

by

Larry A. Beyer[1]
Caroline M. Isaacs[1]

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[1]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 Union-Humble Bell Fee 156 well, West Cat Canyon oil field, California. Discussions of laboratory measurement procedures using helium and mercury pycnometers and of 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 that, 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 / dry grain volume
dry bulk density	ρ_b = dry weight / dry bulk volume
total porosity	$\phi = 100\ (1 - \frac{\rho_b}{\rho_g})$
saturated bulk density	$\rho_s = \rho_b + \phi /100$

Density and total porosity are reported in 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.

Union-Humble Bell Fee 156 Well

The Union-Humble Bell Fee 156 well is located in the West Cat Canyon oil field in the onshore Santa Maria basin (Figure 1). This extensively cored well was drilled in 1971 to a depth of 6,000 feet and is located in the crestal region on the anticlinal structure near the southeast end of the field (Figure 2). As originally reported by the operator, the drilled sequence includes the top of the Sisquoc sands (2,761 ft), Monterey Formation (4,231-6,000 ft), top of Monterey "siliceous zone" (4,928 ft) and top of Monterey "massive chert" (5,340 ft). Roehl (1981) identified the "arenaceous" zone from about 4,231 to 4,610 ft, the top of the "cherty" zone at about 4,610 feet, the top of the "buff and brown" zone at about 4,930 feet, and the top of the "dark brown" zone at about 5,760 feet. All cores were cut in the "buff and brown" zone and the "dark brown" zone. Relative abundances of "chert" and dolomite, fractures and oil staining observed in recovered cores are given in Figure 3 with percent core recovery. Conventional open-hole well logs corresponding to the cored interval are shown in Figure 4.

METHODS

Sample Selection, Preparation, and Weighing

Core materials were gathered from spot-sampled collections to characterize 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; in preparation). 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^- remaining probably are less than 1 weight percent.

Samples were cooled in a desiccator after drying, weighed to the nearest 0.001 g and stored in the desiccator until measurement of grain volume in a helium pycnometer. Weights of the Bell 156 samples ranged from 23.5 to 65.7 g with a mean of 41.0 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 0.02

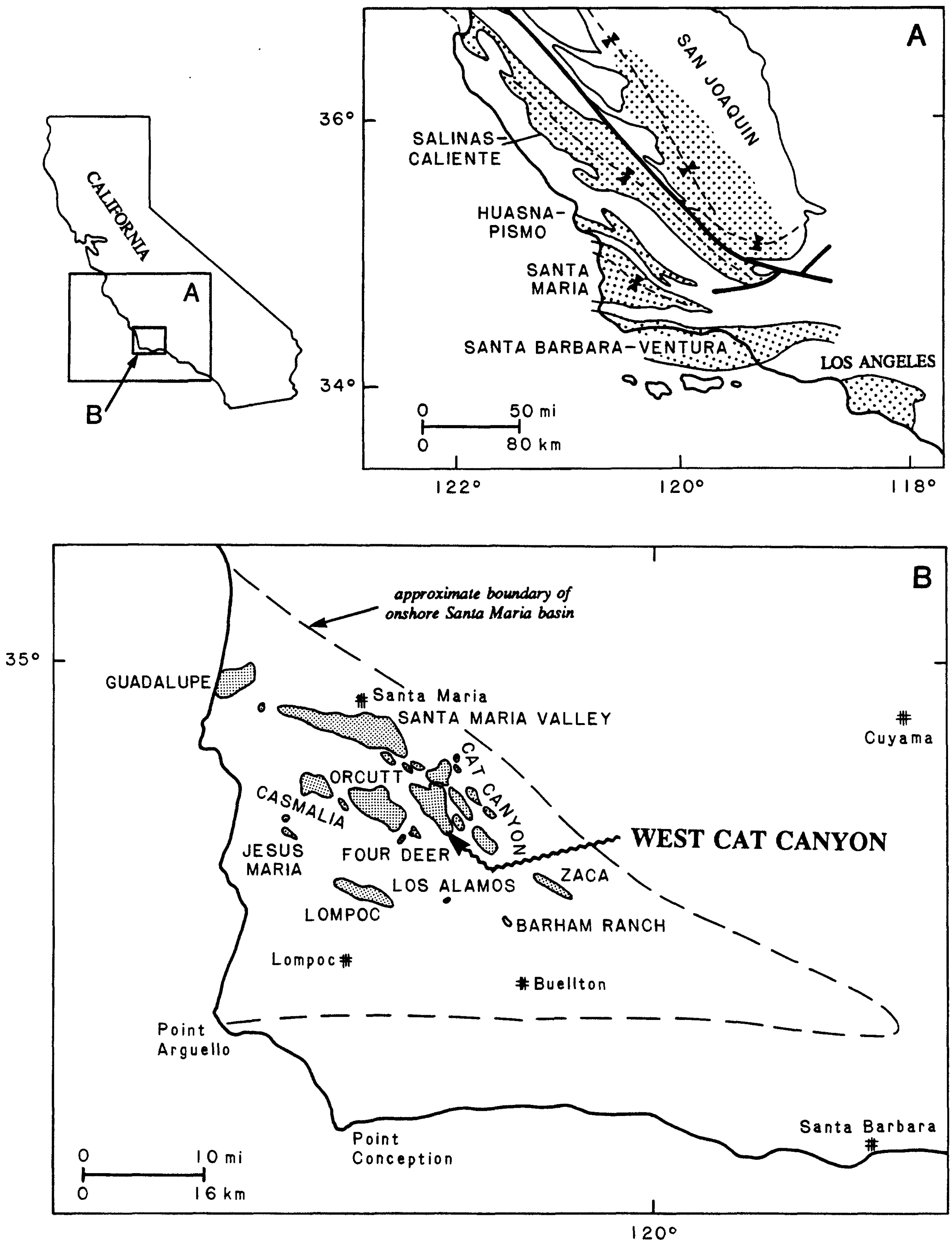

Figure 1. (A) Locality map showing Neogene basins of south-central California with dotted pattern indicating original distribution of Monterey deposits (from Blake and others, 1978). (B) Index map showing oil fields in the onshore Santa Maria basin (from California Division of Oil and Gas, 1974).

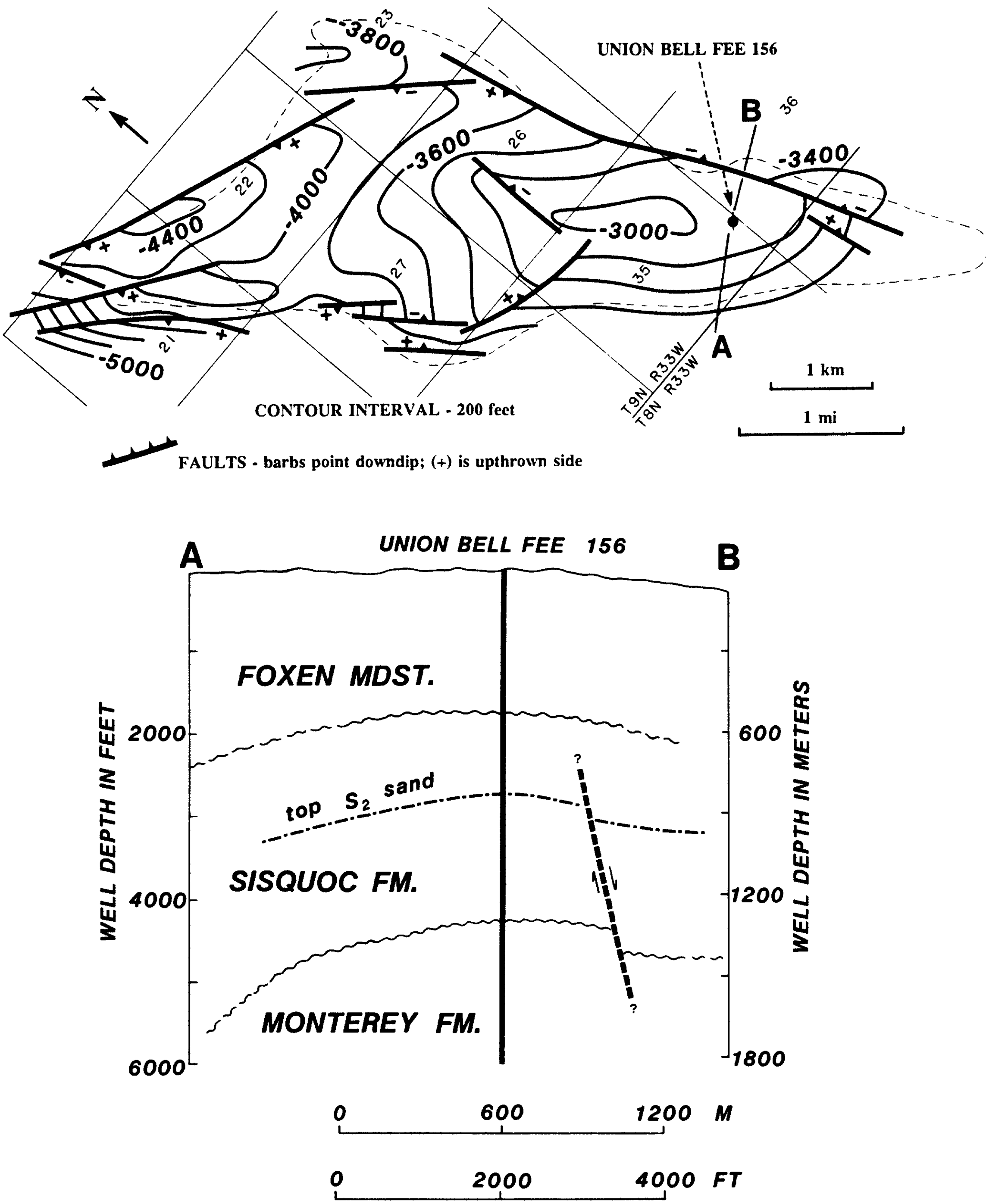

Figure 2. Structure contour map on top of S_2 sand (top) and cross section (bottom) showing location of Bell 156 well, West Cat Canyon oil field (from California Division of Oil and Gas, 1974).

Figure 3. Percent core recovery, observed abundances of "chert" and dolomite, fractures, and oil staining in recovered conventional cores from the Union Bell Fee 156 well, West Cat Canyon oil field (from Roehl, 1981).

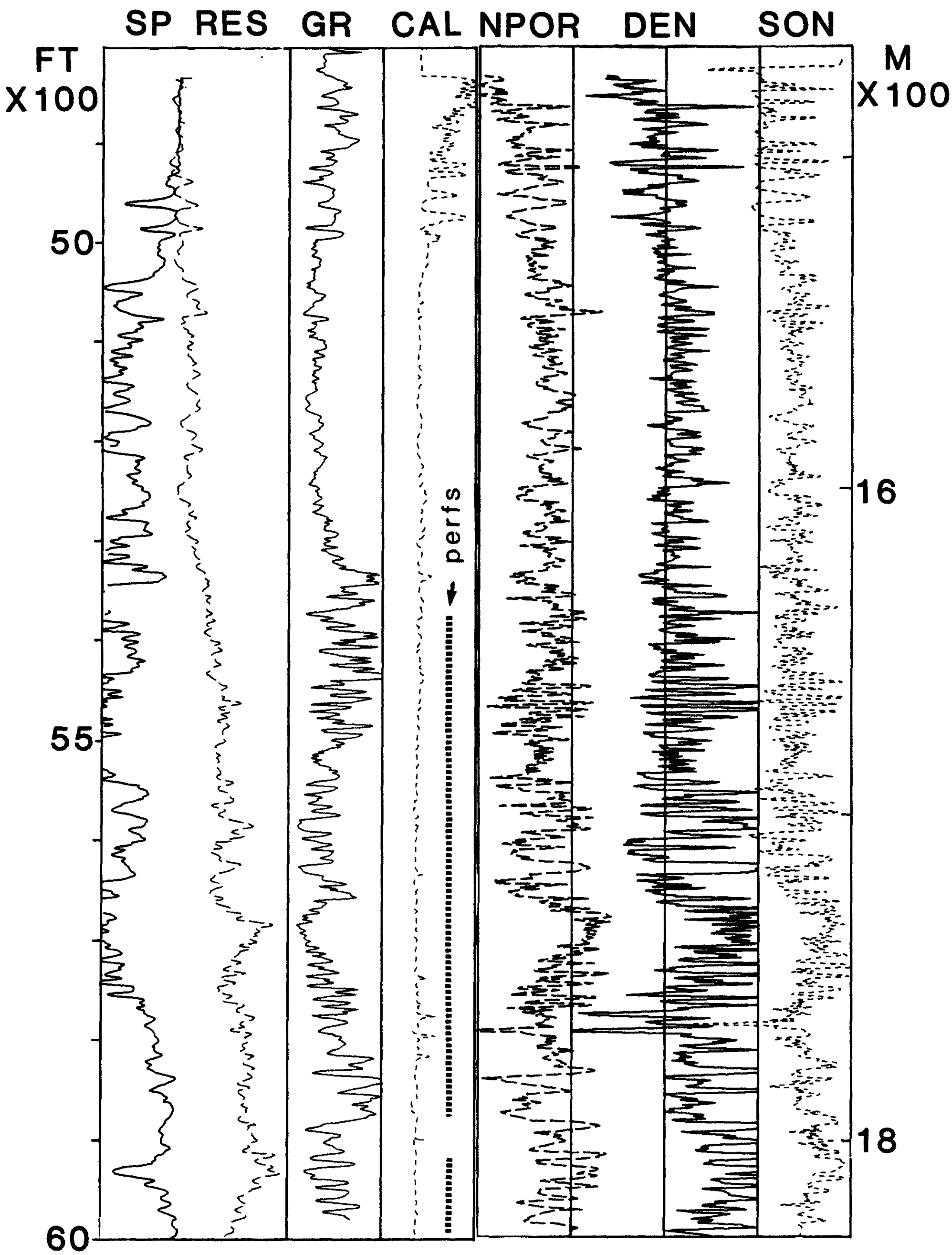

Figure 4. Spontaneous potential, resistivity, gamma-ray, caliper, neutron porosity, gamma-gamma density, and sonic logs (left to right) from the cored portion of the Union Bell Fee 156 well, West Cat Canyon oil field (Beyer, 1987). Perforated interval shown by dashed line on caliper plot.

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 0.02 cm^3. Measured grain volumes of Bell 156 samples ranged from 10.1 to 25.9 cm^3 with a mean of 16.4 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 0.02 cm^3 and repeat volume measurements of non-porous test samples to 0.05 cm^3 or better. Measured bulk volumes of Union Bell 156 samples ranged from 10.4 to 28.9 cm^3 with a mean of 18.0 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 0.002 g/cm^3 of accepted values after correction for temperature.

RESULTS

Values of grain density, dry bulk density, porosity, and saturated bulk density for core samples are given together with error estimates in Table 1. 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.

Grain density, porosity, and saturated bulk density versus depth are plotted in Figure 5. Saturated bulk densities and grain densities range from about 2.2 to 2.75 g/cm^3, and porosities from near 0 to 20 percent. No systematic variation of these properties with depth is evident. The relationship between grain density, saturated bulk density, and porosity is shown in Figure 6. Generally, grain and saturated bulk densities are lowest for organic-rich rocks and highest for dolomite-rich rocks. Rocks rich in diagenetic silica and detrital minerals, and with lesser abundances of organic matter or dolomite, tend to have higher intergranular porosities.

Table 1. Grain density, dry bulk density, porosity, and saturated bulk density of selected samples of conventional cores from the Union Bell Fee 156 well, West Cat Canyon 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)
	MONTEREY FORMATION, buff and brown zone:				
4954	4954 - 4954	2.499 (.004)	2.190 (.007)	12.37 (0.40)	2.314 (.011)
5064	5064 - 5064	2.619 (.002)	2.451 (.005)	6.42 (0.25)	2.515 (.007)
5072	5072 - 5072	2.699 (.005)	2.219 (.009)	17.79 (0.50)	2.397 (.014)
5077(A)	5077 - 5077	2.711 (.002)	2.231 (.004)	17.70 (0.23)	2.408 (.006)
5134	5132 - 5136	2.549 (.004)	2.120 (.007)	16.86 (0.39)	2.288 (.011)
5140	5140 - 5140	2.552 (.003)	2.480 (.008)	2.81 (0.45)	2.508 (.013)
5154(A)	5154 - 5154	2.653 (.005)	2.175 (.009)	18.00 (0.49)	2.355 (.014)
5159(A)	5159 - 5159	2.538 (.004)	2.332 (.008)	8.14 (0.47)	2.413 (.013)
5175	5175 - 5175	2.561 (.002)	2.122 (.004)	17.15 (0.22)	2.293 (.006)
5178	5178 - 5178	2.534 (.003)	2.306 (.007)	8.99 (0.39)	2.396 (.011)
5236	5236 - 5236	2.529 (.004)	2.035 (.007)	19.54 (0.39)	2.230 (.011)
5246	5246 - 5246	2.533 (.003)	2.170 (.006)	14.32 (0.37)	2.313 (.010)
5253	5253 - 5253	2.540 (.003)	2.265 (.005)	10.84 (0.28)	2.373 (.008)
5345	5345 - 5345	2.280 (.004)	2.254 (.011)	1.15 (0.67)	2.266 (.017)
5345(A)	5345 - 5345	2.277 (.004)	2.197 (.009)	3.51 (0.55)	2.232 (.014)
5345(A&B)	5345 - 5345	2.470 (.002)	2.198 (.005)	11.02 (0.27)	2.308 (.007)
5422	5422 - 5422	2.741 (.004)	2.732 (.009)	0.32 (0.45)	2.735 (.013)
5435	5435 - 5435	2.301 (.002)	2.251 (.006)	2.17 (0.36)	2.273 (.009)
5446	5446 - 5446	2.611 (.004)	2.255 (.008)	13.64 (0.45)	2.391 (.013)
5456	5456 - 5456	2.218 (.002)	2.102 (.004)	5.23 (0.29)	2.154 (.007)
5463(A)	5463 - 5463	2.454 (.004)	2.223 (.008)	9.39 (0.44)	2.317 (.012)
5463(B)	5463 - 5463	2.741 (.003)	2.738 (.008)	0.11 (0.38)	2.739 (.011)
5465	5465 - 5465	2.265 (.003)	2.209 (.006)	2.49 (0.39)	2.233 (.010)
5472	5472 - 5472	2.471 (.002)	2.217 (.004)	10.29 (0.22)	2.320 (.006)
5475	5475 - 5475	2.267 (.002)	2.251 (.005)	0.71 (0.33)	2.258 (.009)
5476(B)	5476 - 5476	2.166 (.002)	2.160 (.005)	0.25 (0.34)	2.163 (.009)
5478	5478 - 5478	2.203 (.002)	2.060 (.004)	6.48 (0.27)	2.125 (.007)
5484	5484 - 5484	2.214 (.003)	2.200 (.007)	0.62 (0.43)	2.207 (.011)
5494	5494 - 5494	2.227 (.002)	2.219 (.005)	0.37 (0.29)	2.223 (.007)
5496	5496 - 5496	2.695 (.002)	2.668 (.006)	1.01 (0.29)	2.678 (.009)
5498	5498 - 5498	2.424 (.003)	2.226 (.006)	8.17 (0.34)	2.307 (.009)
5504	5503 - 5506	2.461 (.004)	2.118 (.007)	13.93 (0.42)	2.257 (.011)
5505	5505 - 5505	2.427 (.003)	2.098 (.005)	13.54 (0.32)	2.234 (.008)
5515	5515 - 5515	2.573 (.003)	2.431 (.007)	5.52 (0.40)	2.486 (.011)
5534	5532 - 5537	2.382 (.005)	2.191 (.010)	8.03 (0.58)	2.271 (.015)
5565	5565 - 5565	2.423 (.003)	2.268 (.007)	6.40 (0.40)	2.332 (.011)
5648	5648 - 5648	2.669 (.005)	2.177 (.008)	18.45 (0.45)	2.361 (.013)
5652	5652 - 5652	2.391 (.002)	2.152 (.005)	10.00 (0.27)	2.252 (.007)

5703(A)	5703 - 5703	2.730 (.005)	2.686 (.013)	1.60 (0.65)	2.702 (.019)
5745	5745 - 5745	2.466 (.004)	2.213 (.008)	10.24 (0.45)	2.316 (.012)
	MONTEREY FORMATION, dark brown zone:				
5771	5771 - 5771	2.400 (.004)	2.362 (.009)	1.57 (0.54)	2.378 (.015)

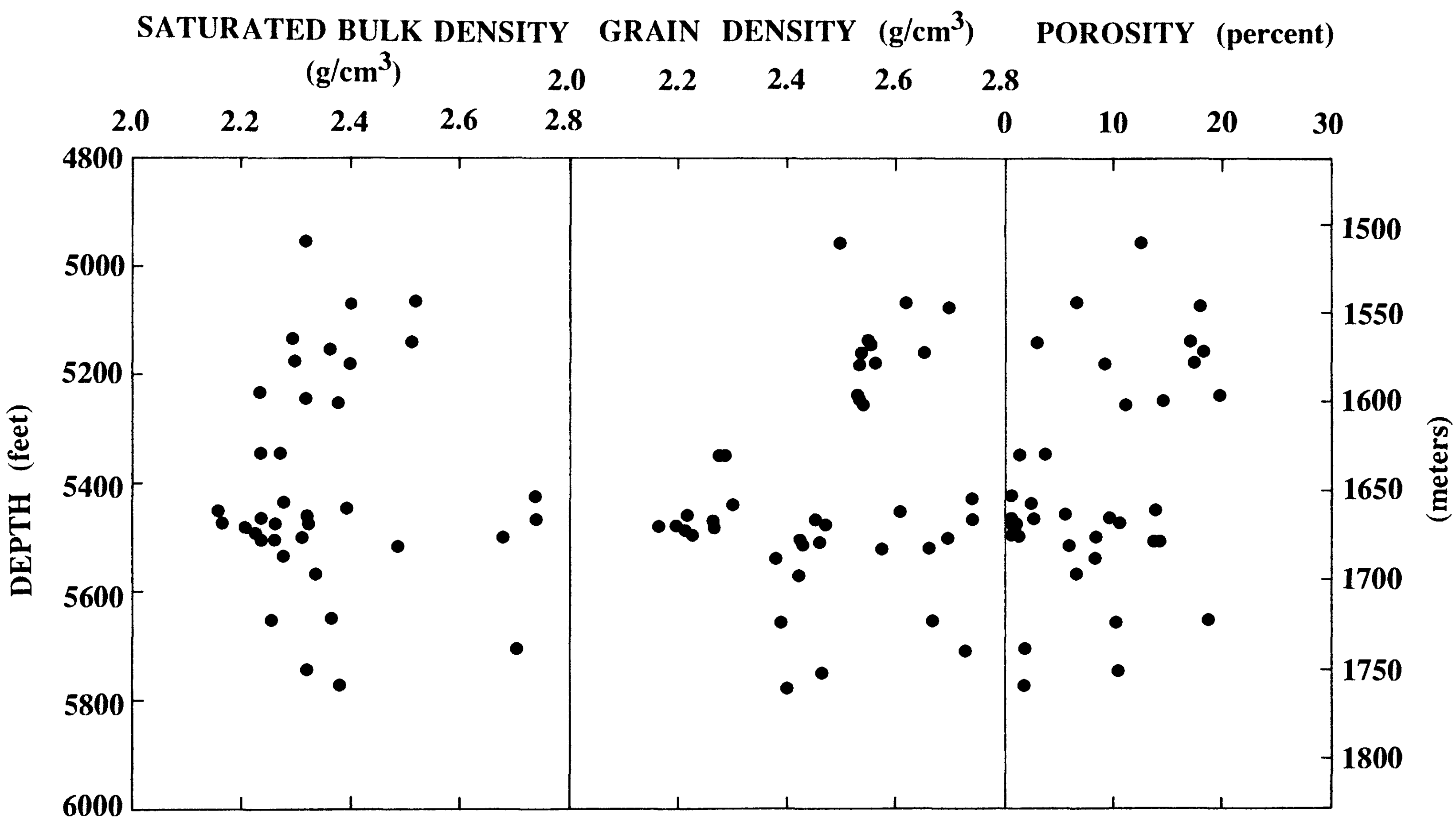

Figure 5. Saturated bulk density, grain density, and porosity of core samples from the Union Bell 156 well versus depth. Saturated bulk density is calculated by assuming a pore-fluid density of 1.00 g/cm^3.

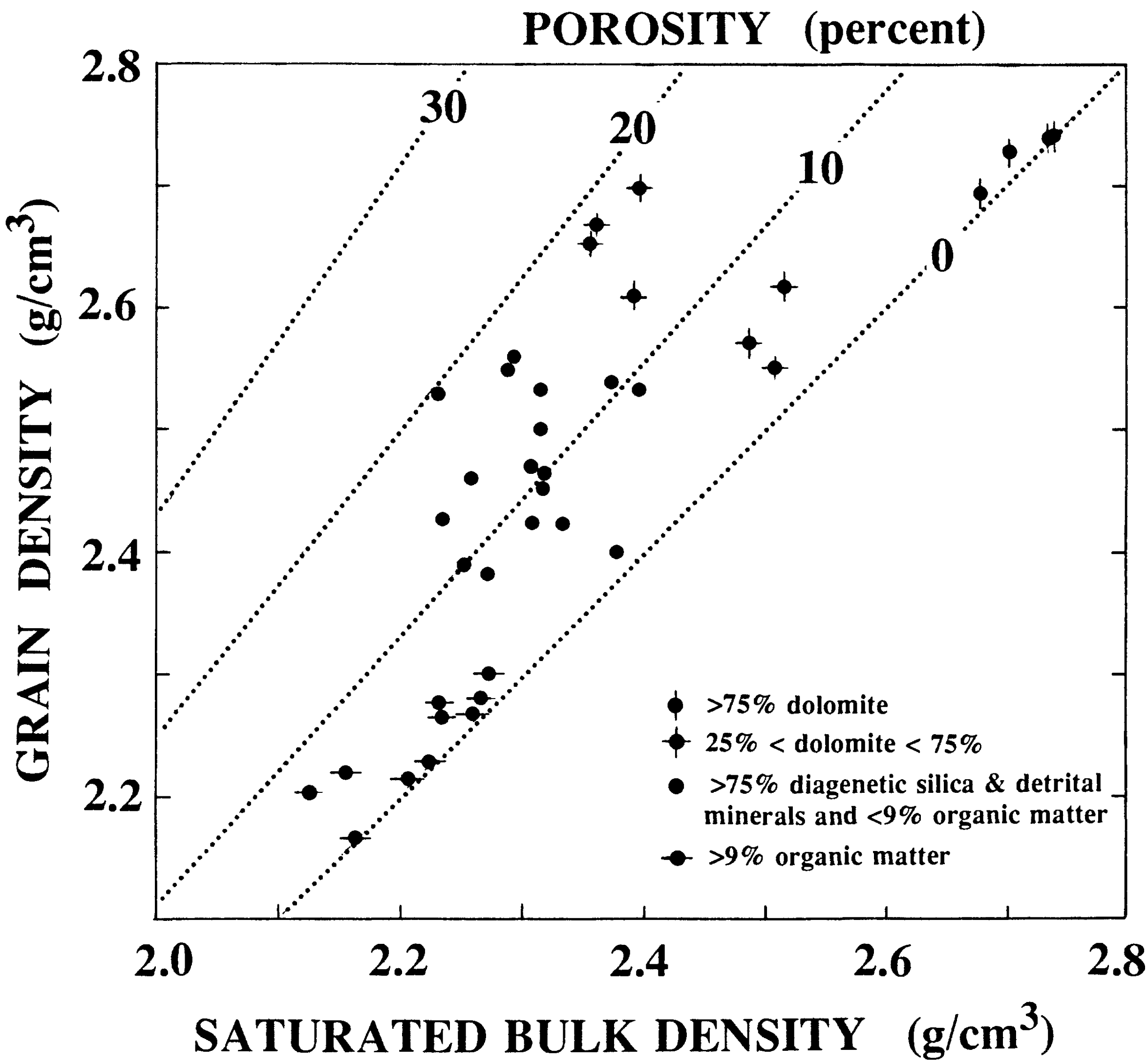

Figure 6. Grain density, saturated bulk density, and porosity of core samples from Union Bell Fee 156 well, based on a pore-fluid density of 1.00 g/cm^3. Groupings are based on chemical analyses of samples by Isaacs and others (unpublished data).

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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:

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

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