(200)
R290
no. 79-1652

U.S. Geological Survey
Reports-Open file series

USGS LIBRARY-RESTON
3 1818 00074822 6

TM
cmc
tharal

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRELIMINARY POROSITY ESTIMATES OF SOUTH-FLORIDA CENOZOIC CARBONATE ROCKS BASED ON BOREHOLE GRAVITY MEASUREMENTS

by

James W. Schmoker, Robert B. Halley, Frederick W. Meyer,
and Stephen L. Robbins

U.S. GEOLOGICAL SURVEY
RESTON, VA.
NOV 13 1979
LIBRARY

Open-File Report 79-1652

1979

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

300024

Porosity is one of the fundamental properties of carbonate rocks affecting the production characteristics of aquifers and hydrocarbon reservoirs. It is measured by a variety of methods, both in rock samples and in boreholes, but all routine methods of porosity measurement examine relatively small volumes of rock. One must assume that the distribution of pore space in the small measured sample is characteristic of the rock as a whole. Such an assumption works well if pores are evenly distributed and are small relative to sample size, but carbonate rocks often are heterogeneous, containing irregularly distributed pore space in the form of fractures, vugs, channels, and caverns (using the nomenclature of Choquette and Pray, 1970). Porosity measurement in heterogeneous carbonate rocks is thus a common problem, and is of economic significance to both petroleum geologists and hydrologists.

The borehole gravity meter, with a radius of investigation comparable to the largest pore spaces (caverns), offers advantages in the evaluation of porosity in vuggy, channeled, and cavernous carbonate rocks. It is a density logging tool that is not significantly influenced by casing, borehole rugosity, or formation damage caused by drilling. Variations in heterogeneous rocks are averaged into the density determination.

Fundamentals of borehole gravity logging and data interpretation, considerations of the effective radius of investigation, and applications to geologic problems have been discussed in the literature by Smith (1950), Goodell and Fay (1964), Howell, Heintz, and Barry (1966), McCulloh (1966), Healey (1970), Beyer (1971), Jageler (1976), Hearst and McKague (1976), and Schmoker (1977a,b; 1978). In the absence of complicating structural factors, the relationship between formation density and measurements of gravity in a borehole is given by (McCulloh, 1966):

$$\rho = 39.124(F-\Delta g/\Delta z) \quad (1)$$

where ρ is the average formation density between two vertically separated points in the borehole (g/cm^3), F is the free-air vertical gradient of gravity (mgals/ft), Δg is the measured difference in gravity between the vertically separated points (mgals), and Δz is the vertical separation (ft). In evaluating equation 1, a value for the free-air gradient of 0.09409 mgals/ft, appropriate for the latitudes of south Florida, was used.

The U.S. Geological Survey - LaCoste and Romberg[1/] borehole gravity meter (described by McCulloh and others, 1967a, b) was used to carry out borehole gravity surveys in five wells penetrating the Cenozoic sediments and rocks of peninsular Florida (fig. 1). The strata investigated are primarily limestone and dolomite with lesser amounts of quartz sand, clay, chert, gypsum, and anhydrite. Rock units logged, in approximate descending order, include the Miami Oolite, Key Largo Limestone, and Fort Thompson Formation (Pleistocene); Tamiami Formation (Pliocene); Hawthorn Formation and Tampa Limestone (Miocene); Suwannee Limestone (Oligocene); Ocala Limestone, Avon Park Limestone, Lake City Limestone, and Oldsmar Limestone (Eocene); and the Cedar Keys Formation (Paleocene). Figure 2 relates stratigraphy to the zones in the five wells logged with the borehole gravity meter. (A summary of the geology of the area is given by Puri and Vernon [1964]).

Prior to each borehole gravity survey, a natural-gamma-ray log was run for stratigraphic correlation. Gravity stations were located where the gamma-ray log or driller's log indicated variations in formation properties. Additional intervals were located between formation breaks to establish

---

1/Use of brand names in this report is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

density variability throughout the investigated section. Drift control was established by station reoccupations; tidal corrections, terrain corrections, and drift corrections were applied to the borehole gravity data. Terrain effects were minimal, although small corrections for the influence of man-made features upon near-surface stations were applied.

Previous work (Schmoker, 1978) indicates that the random error in densities computed from borehole gravity data does not exceed ± 0.02 g/cm^3 for intervals greater than 20 ft (6.5 m). However, mechanical difficulties with the gravity meter at well no. 4 increased this error to about ± 0.10 g/cm^3, and probably account for the greater scatter observed in results from this well.

Porosity, ϕ, was computed from the borehole-gravity density, ρ, using the equation:

$$\phi = 100x(\rho_G - \rho)/(\rho_G - \rho_F) \tag{2}$$

where ρ_G is the estimated average grain density and ρ_F is the pore-fluid density. Pores were assumed to be 100 percent water saturated, with water density ranging between 1.00 and 1.02 g/cm^3 depending upon salinity. Grain density was estimated from lithologic logs prepared from well cuttings, with the assumption that such logs are representative of rocks within the radius of investigation of the borehole gravity meter. Mineral densities were taken from Deer and others (1966).

Results are tabulated in tables 1-5 of the Appendix. Porosity estimates of monomineralic intervals are given as a single number. Where two or more minerals are present in the well samples, maximum and minimum porosities are given based on the most-and least-dense minerals, respectively. A "best estimate" of porosity calculated using a weighted-average grain density reflecting the sample composition, is also shown. Figure 3 plots "best estimate" porosity as a function of depth.

The porosity values of tables 1-5 are measurements of total porosity, which is always greater than effective porosity. The average total porosity of the Cenozoic carbonates of peninsular Florida logged in this study is about 38 percent. The lowest porosity values occur in the Cedar Keys Formation (the four deepest intervals of well no. 1) where carbonate porosity is plugged by gypsum and anhydrite, and carbonate strata are interbedded with evaporites containing almost no porosity.

There is a slight porosity decrease in quartz-sand units. This may reflect the lack of intragranular pore space in the quartz grains, in contrast to the carbonate rocks which may contain considerable intragranular porosity (Halley, 1978). A general decrease of porosity with depth is evident in each of the wells. Although this trend is irregular it may indicate increased cementation at greater depths. Aquifers, which are defined by permeability changes and secondary porosity, as well as total porosity, are not well delineated by the data shown here.

REFERENCES

Beyer, L. A., 1971, The vertical gradient of gravity in vertical and near-vertical boreholes: Palo Alto, Stanford Univ., Ph.D. thesis, 217 p.

Choquette, P. W., and Pray, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: American Association Petroleum Geologists Bulletin, v. 54, no. 2, pp. 207-250.

Deer, W. A., Howie, R. A., and Zussman, J., 1966, An introduction to the rock forming minerals: New York, John Wiley and Sons, 528 p.

Goodell, R. R., and Fay, C. H., 1964, Borehole gravity meter and its application: Geophysics, v. 29, no. 5, p. 774-782.

Halley, R. B., 1978, Estimating pore and cement volume in thin section: Journal of Sedimentary Petrology, v. 48, p. 642-650.

Healey, D. L., 1970, Calculated in situ bulk densities from subsurface gravity observations and density logs, Nevada Test Site and Hot Creek Valley, Nye County, Nevada, in Geological Survey research 1970: U.S. Geological Survey Professional Paper 700-B, p. B52-B62.

Hearst, J. R., and McKague, H. L., 1976, Structure elucidation with borehole gravimetry: Geophysics, v. 41, no. 3, p. 491-505.

Howell, L. G., Heintz K. O., and Barry, A., 1966, The development and use of a high-precision downhole gravity meter: Geophysics, v. 31, no. 4, p. 764-772.

Jageler, A. H., 1976, Improved hydrocarbon reservoir evaluation through use of borehole gravimeter data: Journal Petroleum Technology, v. 28, no. 6, p. 709-718.

McCulloh, T. H., 1966, The promise of precise borehole gravimetry in petroleum exploration and exploitation: U.S. Geological Survey Circular 531, 12 p.

McCulloh, T. H., LaCoste, L. J. B., Schoellhamer, J. E., and Pampeyan, E. H., 1967a, The U.S. Geological Survey-LaCoste and Romberg precise borehole gravimeter system--Instrumentation and support equipment, in Geological Survey research 1967: U.S. Geological Survey Professional Paper 575-D, p. D92-D100.

McCulloh, T. H., Schoellhamer, J. E.. Pampeyan, E. H., and Parks, H. B., 1967b, The U.S. Geological Survey-LaCoste and Romberg precise borehole gravimeter system--Test results, in Geological Survey research 1967: U.S. Geological Survey Professional Paper 575-D, p. D101-D112.

Puri, H. S., and Vernon, R. O., 1964, (Revised) - Summary of the geology of Florida and a guidebook to the classic exposures: Florida Bureau of Geology, Special Publication 5, 312 p.

Schmoker, J. W., 1977a, Density variations in a quartz diorite determined from borehole gravity measurements, San Benito County, California: The Log Analyst, v. 18, no. 2, p. 32-38.

_______1977b, A borehole gravity survey to determine density variations in the Devonian shale sequence of Lincoln County, West Virginia: U.S. Dept. of Energy, Morgantown Energy Res. Center MERC/CR-77/7, 15 p.

_______1978, Accuracy of borehole gravity data: Geophysics, v. 43, no. 3, p. 538-542.

Smith, N. J., 1950, The case for gravity data from boreholes: Geophysics, v. 15, no. 4, p. 605-636.

APPENDIX

The data associated with each subsurface gravity interval in the five wells logged are given in tables 1-5. Column headings are explained in the following list:

Depth Interval:	Depths of gravity stations relative to the wellhead (ft).
Corrected Density:	In situ formation density computed from corrected borehole gravity measurements using equation 1 (g/cm^3).
Lithology:	Mineral identification and volume percent of each mineral (rounded to the nearest 10 percent), obtained from visual inspection of well samples. Abbreviations are: Q - quartz Ls - calcite D - dolomite Ch - chert A - anhydrite G - gypsum C - clay (undifferentiated)
Estimated Average Grain Density:	Weighted-average grain density reflecting sample composition (g/cm^3).
Porosity:	In situ formation porosity in percent computed from equation 2. "Best Estimate" is based on the estimated average grain density. "Minimum" and "Maximum" are based on the lightest and heaviest minerals in the interval.

TABLE 1 WELL #1

Owner: Orange County Public Utilities
Location: Orange County, Florida, T.23S., R.29E., Sec. 32, NW¼, NW¼, NW¼.
Florida State #: W13287

Depth Interval (ft.)	Corrected Density	Lithology	Estimated Average Grain Density	Porosity Minimum	Porosity Best Estimate	Porosity Maximum
7.4 - 25	2.090	Q	2.65		34	
25 - 60.1	1.821	C,Q (80,20)	2.69	50	51	52
60.1 - 105	1.951	Ls,Q (80,20)	2.71	42	44	45
105 - 115	2.065	D,Q (90,10)	2.84	35	42	43
115 - 135	2.103	D,Q (80,20)	2.82	33	39	41
135 - 155	1.983	Cavity	--	40(Q)	43	47(D)
155 - 225	1.970	Ls	2.72		44	
225 - 300	1.966	Ls	2.72		44	
300 - 370	2.093	Ls	2.72		36	
370 - 399.9	2.246	D	2.86		33	
399.9 - 539.9	2.180	D,Ls (60,40)	2.80	31	34	37
539.9 - 679.9	2.064	D	2.86		43	
679.9 - 700	2.106	D	2.86		41	
700 - 900	2.127	D	2.86		39	
900 - 1050	2.152	D	2.86		38	
1050 - 1060	2.167	D	2.86		37	
1060 - 1290	2.338	D	2.86		28	
1290 - 1310	2.395	Ch	2.61		13	
1310 - 1450	2.410	D	2.86		24	
1450 - 1460	2.414	D,Ls (70,30)	2.82	18	22	24
1460 - 1600	2.376	D	2.86		26	
1600 - 1750	2.287	D,Ls (50,50)	2.79	25	28	31
1750 - 1760	2.324	Ls	2.72		23	
1760 - 1900	2.369	Ls,D (60,40)	2.78	20	23	26
1900 - 1910	2.504	D	2.86		19	
1910 - 2120	2.427	D	2.86		23	
2120 - 2366	2.306	Ls,D (60,40)	2.78	24	27	30
2366 - 2376.1	2.662	D,G (75,25)	2.73	0	4	11
2376.1 - 2386	2.650	D	2.86		11	
2386 - 2396	2.746	A,D (75,25)	2.93	6	10	10
2396 - 2405.1	2.757	A,D,G (50,25,25)	2.77	0	1	10

Table 2 WELL #2

Owner: Hercules, Inc., Wilmington, Delaware
Location: Indian River County, Florida, T.33S., R.28E., Sec. 25, NE¼, NE¼, NE¼.
Florida State #: W14167

Depth Interval (ft.)	Corrected Density	Lithology	Estimated Average Grain Density	Porosity Minimum	Porosity Best Estimate	Porosity Maximum
6.8 - 49.9	1.937	Q	2.65		43	
49.9 - 100	2.021	Q,Ls (80,20)	2.66	38	38	41
100 - 200	1.845	C,Q,Ls (50,20,30)	2.69	49	50	51
200 - 330	1.881	C,Ls,Q (50,30,20)	2.69	47	48	49
330 - 369.9	1.905	Ch,C (50,50)	2.66	44	46	47
369.9 - 470	1.771	Ch,C,Ls (50,40,10)	2.66	52	54	55
470 - 574.9	1.945	Ls,D (75,25)	2.76	45	46	49
574.9 - 690	2.039	Ls,D (75,25)	2.76	40	41	44
690 - 821	2.016	Ls,D (75,25)	2.76	41	42	45
821 - 870.1	2.329	Ls,D (75,25)	2.76	23	25	29
870.1 - 950	2.270	D,Ls (90,10)	2.85	26	31	32
950 - 1010	2.162	D	2.86		38	
1010 - 1079.9	2.230	D,Ls (80,20)	2.83	28	33	34
1079.9 - 1099.9	2.106	D,Ls (60,40)	2.80	36	39	41
1099.9 - 1200	2.264	D,Ls (90,10)	2.85	27	32	32
1200 - 1300	2.282	D	2.86		31	
1300 - 1320	2.257	D,Ls (75,25)	2.83	27	31	32
1320 - 1400	2.372	D	2.86		26	
1400 - 1520	2.202	D,Ls (85,15)	2.84	30	35	35
1520 - 1600	2.097	Ls	2.72		36	
1600 - 1675	2.171	Ls	2.72		32	
1675 - 1710	2.181	Ls	2.72		31	
1710 - 1800	2.240	Ls,D (50,50)	2.79	28	29	33
1800 - 1820	2.349	D	2.86		28	
1820 - 1900	2.244	D,Ls (80,20)	2.83	28	32	33
1900 - 1998.1	2.453	D,Ls,C,Ch (70,20,5,5)	2.81	10	20	22
1998.1 - 2130	2.421	D,Ch (60,40)	2.74	12	18	24
2130 - 2200	2.294	Ls	2.72		25	
2200 - 2295	2.222	Ls	2.72		29	
2295 - 2350	2.270	D,Ls (80,20)	2.83	26	31	32

Table 3 WELL #3

Owner: Miami-Dade Water and Sewer Authority
Location: Dade County, Florida, T.56S., R.40E., Sec. 21, NE¼.
Florida State #: W13768

Depth Interval (ft.)	Corrected Density	Lithology	Estimated Average Grain Density	Porosity Minimum	Porosity Best Estimate	Porosity Maximum
20 - 30	1.768	Ls	2.72		55	
30 - 40	1.924	Ls	2.72		46	
40 - 60	2.312	Ls,Q (50,50)	2.69	20	22	24
60 - 80	2.069	Ls	2.72		38	
80 - 110	2.193	Ls	2.72		31	
110 - 120	1.768	Q,Ls (80,20)	2.66	53	54	55
120 - 150	1.922	Q	2.65		44	
150 - 175	1.906	C	2.70		47	
175 - 200	2.019	C	2.70		40	
200 - 225	2.000	C	2.70		41	
225 - 250	1.935	C,Q (80,20)	2.69	43	45	45
250 - 300.1	2.043	C,Ls (80,20)	2.70	39	39	39
300.1 - 365	1.954	C,Ls (90,10)	2.70		44	
365 - 405	2.107	C,Ls (70,30)	2.71	35	35	36
405 - 415	2.026	Ls	2.72		40	
415 - 465	1.985	Ls	2.72		43	
465 - 515	2.007	Ls	2.72		41	
515 - 565	2.053	Ls	2.72		39	
565 - 615	2.028	Ls	2.72		40	
615 - 665	2.027	Ls,C (80,20)	2.72	40	40	40
665 - 715	2.007	Ls	2.72		41	
715 - 765	2.065	Ls	2.72		38	
765 - 815	2.155	Ls	2.72		33	
815 - 865	2.154	Ls	2.72		33	
865 - 915	2.113	Ls,C (60,40)	2.71	35	35	35
915 - 935	2.165	Ls	2.71		32	
935 - 965	2.012	Ls	2.72		41	
965 - 1015.1	2.033	Ls	2.72		40	
1015.1 - 1040	2.031	Ls,D (70,30)	2.76	40	41	45
1040 - 1065.1	2.060	Ls,D (70,30)	2.76	38	40	43

WELL #3 (continued)

Depth Interval (ft.)	Corrected Density	Lithology	Estimated Average Grain Density	Porosity Minimum	Porosity Best Estimate	Porosity Maximum
1065.1 - 1090	1.998	Ls	2.72		42	
1090 - 1115	2.041	Ls	2.72		39	
1115 - 1165	2.094	Ls	2.72		36	
1165 - 1215	2.007	Ls	2.72		41	
1215 - 1245	1.965	Ls,Q (60,40)	2.69	42	43	44
1245 - 1265	2.173	Ls,Q (70,30)	2.70	29	31	32
1265 - 1315	2.002	Ls	2.72		42	
1315 - 1365	2.009	Ls	2.72		41	
1365 - 1415	2.028	Ls	2.72		40	
1415 - 1465.1	1.966	Ls	2.72		44	
1465.1 - 1495	1.977	Ls	2.72		43	
1495 - 1515.1	2.015	Ls	2.72		41	
1515.1 - 1565	2.137	Ls	2.72		34	
1565 - 1590	2.158	Ls	2.72		33	
1590 - 1615	2.121	Ls	2.72		35	
1615 - 1665	1.988	Ls	2.72		43	
1665 - 1695.1	2.025	Ls	2.72		40	
1695.1 - 1715	2.053	Ls	2.72		39	
1715 - 1765	2.023	Ls	2.72		41	
1765 - 1815	2.011	Ls	2.72		41	
1815 - 1915.1	2.082	Ls	2.72		37	
1915.1 - 2015	2.050	Ls	2.72		39	
2015 - 2115	2.063	Ls	2.72		38	
2115 - 2140.1	2.132	Ls	2.72		34	
2140.1 - 2175.1	2.031	Ls,D (80,20)	2.75	40	41	45
2175.1 - 2215	2.093	Ls,D (80,20)	2.75	37	38	42
2215 - 2315.1	2.090	Ls,D (80,20)	2.75	37	38	42
2315.1 - 2415.1	2.080	Ls	2.72		37	
2415.1 - 2475	2.143	Ls	2.72		34	
2475 - 2515	2.248	Ls,D (80,20)	2.75	28	29	33
2515 - 2535	2.296	Ls,D (80,20)	2.75	25	26	30
2535 - 2550	2.249	Ls,D (80,20)	2.75	27	29	33
2550 - 2615	2.215	Ls,D (80,20)	2.75	29	31	35
2615 - 2715	2.131	Ls	2.72		34	
2715 - 2730	2.234	Ls,D (80,20)	2.75	28	30	34

TABLE 4   WELL #4

Owner: Florida Keys Aqueduct Authority
Location: Monroe County, Florida, T.64S., R.35E., Sec. 26 (Fiesta Key)
Florida State #: W13752

Depth Interval (ft.)	Corrected Density	Lithology	Estimated Average Grain Density	Porosity Minimum	Porosity Best Estimate	Porosity Maximum
7.2 - 20	1.248	Ls	2.72		86	
20 - 40	2.236	Ls	2.72		28	
40 - 60	1.831	Ls	2.72		52	
60 - 80	1.836	Ls	2.72		52	
80 - 100	1.999	Ls	2.72		42	
100 - 120	1.596	Q,Ls (60,40)	2.69	64	65	66
120 - 140	2.079	Q,Ls (60,40)	2.69	35	36	37
140 - 160	2.069	Q,Ls (60,40)	2.69	35	37	38
160 - 180	2.020	Q,Ls (60,40)	2.69	38	40	41
180 - 200	2.063	Q,Ls (60,40)	2.69	36	37	38
200 - 225	2.086	Q,Ls (60,40)	2.69	34	36	37
225 - 245	1.946	Q,Ls (60,40)	2.69	43	44	45
245 - 269.8	2.115	Q,Ls (60,40)	2.69	33	34	35
269.8 - 300	1.853	Q,Ls (60,40)	2.69	48	50	51
300 - 336	2.096	Q,Ls (60,40)	2.69	34	35	36
336 - 370	2.020	Q,Ls (60,40)	2.69	38	40	41
370 - 405	1.936	Q,Ls (60,40)	2.69	44	45	46
405 - 439.9	1.966	Q,Ls (60,40)	2.69	42	43	44
439.9 - 470	2.080	Q	2.65		35	
470 - 500	1.926	Q	2.65		44	
500 - 540	1.969	Q	2.65		42	
540 - 588	1.959	Q	2.65		42	
588 - 640	2.178	Q	2.65		29	
640 - 669.9	2.004	Q,Ls (50,50)	2.69	39	41	42
669.9 - 702	1.993	Q,Ls (50,50)	2.69	40	41	42
702 - 736	2.077	Ls,Q (70,30)	2.70	35	37	38
736 - 762	2.011	Ls	2.72		41	
762 - 804	1.938	Ls	2.72		46	
804 - 832	2.111	Ls	2.72		36	
832 - 862	2.028	Ls	2.72		40	
862 - 896	2.185	Ls	2.72		31	
896 - 934	1.943	Ls	2.72		45	
934 - 970.1	2.105	Ls	2.72		36	

TABLE 5 WELL #5

Owner: Florida Keys Aqueduct Authority
Location: Monroe County, Florida, T.66S., R.32E., Sec. 11 (Marathon)
Florida State #: 12799

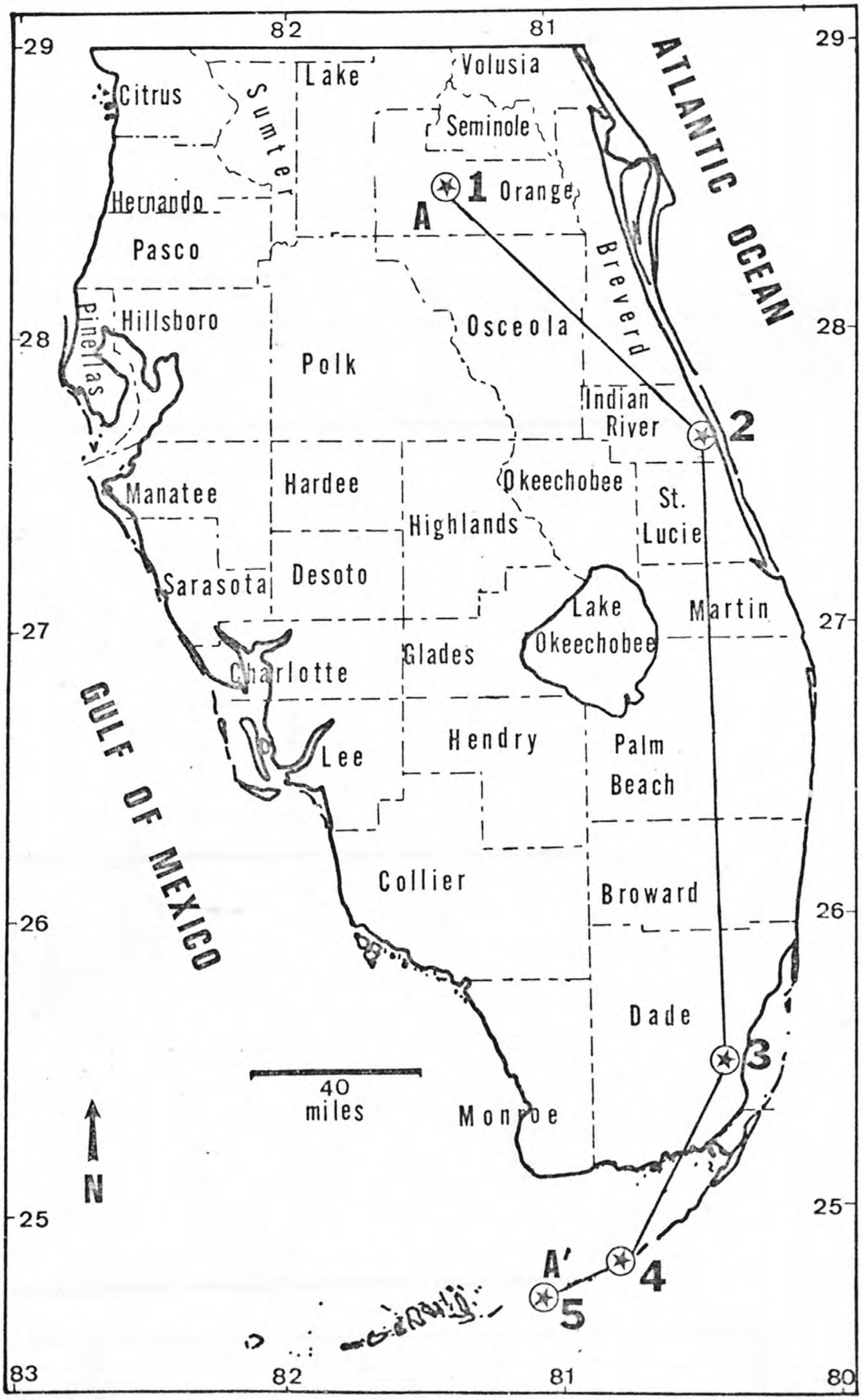
Depth Interval (ft.)	Corrected Density	Lithology	Estimated Average Grain Density	Porosity Minimum	Porosity Best Estimate	Porosity Maximum
7.8 - 20.0	1.773	Ls	2.72		55	
20.0 - 40.1	1.824	Ls	2.72		52	
40.1 - 60.0	1.943	Ls	2.72		45	
60.0 - 80.0	1.842	Ls	2.72		51	
80.0 - 100.0	1.883	Ls,Q (80,20)	2.71	47	49	49
100.0 - 120.0	1.917	Ls,Q (75,25)	2.70	45	46	47
120.0 - 140.0	1.989	Ls,Q (80,20)	2.71	40	42	43
140.0 - 160.1	2.052	Ls,Q (50,50)	2.69	36	38	39
160.1 - 180.0	1.994	Q	2.65		40	
180.0 - 202.0	2.006	Ls,Q (50,50)	2.69	39	41	42
202.0 - 224.0	2.011	Ls,Q (60,40)	2.69	39	41	42
224.0 - 245.0	1.986	Ls,Q (50,50)	2.69	40	42	43
245.0 - 270.0	1.921	Ls,Q (60,40)	2.69	44	46	47
270.0 - 294.0	1.948	Ls,Q (60,40)	2.69	43	44	45
294.0 - 310.1	1.893	Q,Ls (60,40)	2.68	46	47	48
310.1 - 336.0	1.971	Q,Ls (60,40)	2.68	41	42	44
336.0 - 360.0	1.914	Q,Ls (60,40)	2.68	45	46	47
360.0 - 388.0	1.969	Q,Ls (50,50)	2.69	41	43	44
388.0 - 408.0	1.997	Ls,Q (60,40)	2.69	40	41	42
408.0 - 428.0	2.118	Q	2.65		32	
428.0 - 452.0	2.069	Q	2.65		35	
452.0 - 468.0	2.075	Q	2.65		35	
468.0 - 484.0	2.043	Q	2.65		37	
484.0 - 502.0	2.062	Q	2.65		36	
502.0 - 522.0	2.026	Q	2.65		38	
522.0 - 541.9	2.022	Q	2.65		38	
541.9 - 562.1	2.095	Q	2.65		34	
562.1 - 585.6	2.011	Q	2.65		39	

FIGURE CAPTIONS

Figure 1. Map of peninsular Florida showing locations of wells logged with the borehole gravity meter and the line of cross section A-A′.

Figure 2. Diagrammatic cross section A-A′ showing wells and formations logged with the borehole gravity meter. Formation boundaries are compiled from unpublished sources and are approximate. Horizontal distances are not to scale.

Figure 3. Graphs showing "best estimate" porosity computed from borehole gravity measurements versus depth for the five wells located on A-A′ of Figure 1. Data are plotted at interval bottoms.



ATLANTIC OCEAN
GULF OF MEXICO
Citrus
Sumter
Lake
Volusia
Seminole
Orange
Hernando
Pasco
Brevard
Hillsboro
Pinellas
Polk
Osceola
Indian River
Manatee
Hardee
Highlands
Okeechobee
St. Lucie
Sarasota
Desoto
Martin
Lake Okeechobee
Charlotte
Glades
Lee
Hendry
Palm Beach
Collier
Broward
Dade
Monroe
40 miles
N
A
A'
1
2
3
4
5

Figure 1.

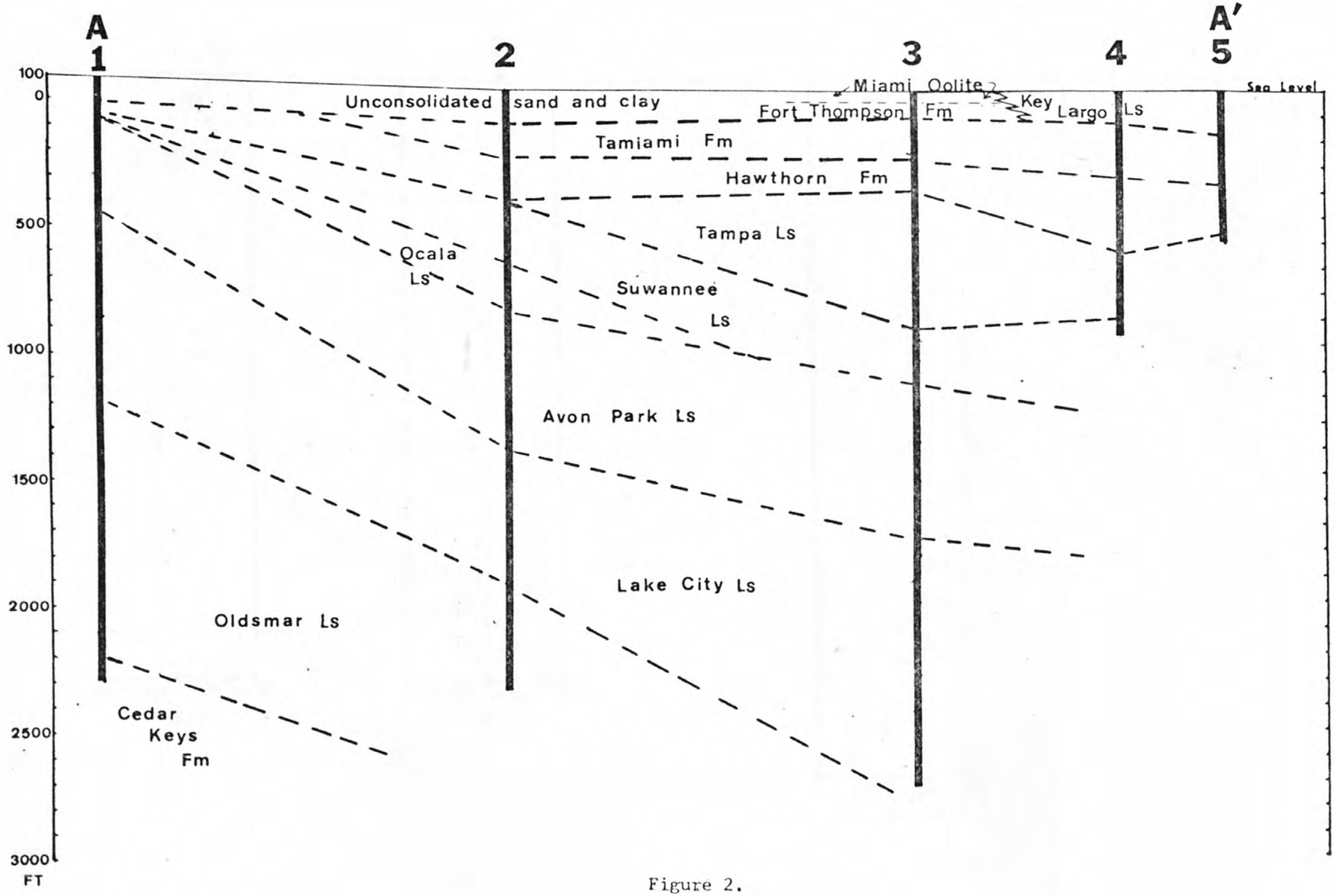
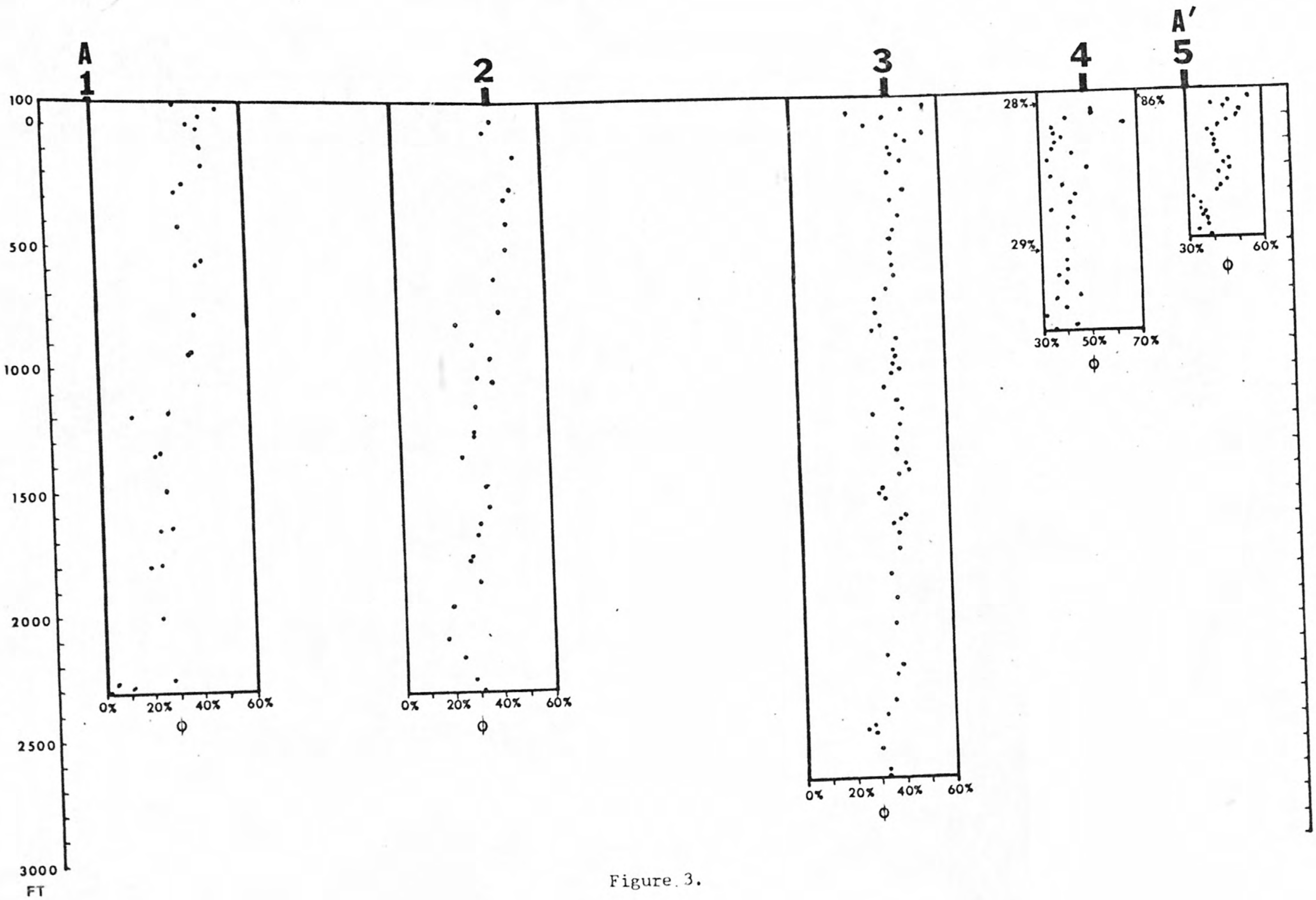

A
1
2
3
4
A′
5
100
0
500
1000
1500
2000
2500
3000
FT
Sea Level
Unconsolidated sand and clay
Miami Oolite
Key Largo Ls
Fort Thompson Fm
Tamiami Fm
Hawthorn Fm
Tampa Ls
Ocala Ls
Suwannee Ls
Avon Park Ls
Lake City Ls
Oldsmar Ls
Cedar Keys Fm

Figure 2.



A
1
2
3
4
A′
5
100
0
500
1000
1500
2000
2500
3000
FT
0%
20%
40%
60%
φ
28%
86%
29%
30%
50%
70%
60%

Figure 3.

USGS LIBRARY-RESTON
3 1818 00074822 6