

Porosity and Bulk Density of Sedimentary Rocks

By G. EDWARD MANGER

CONTRIBUTIONS TO GEOCHEMISTRY

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ABSTRACT

More than 900 items of porosity and bulk density data for sedimentary rocks have been tabulated. Most of the data are from the more accessible American, British, German, and Swiss literature. The number of porosity determinations per item ranges from 1 to 2,109. The tabulation reflects the fact that more porosity than bulk density data are available for sedimentary rocks.

INTRODUCTION

Data on the porosity and bulk or lump density of sedimentary rocks have been assembled for the Division of Reactor Development of the U.S. Atomic Energy Commission. Most of the data are from the more accessible American, British, German, and Swiss literature. They are tabulated under headings according to rock type and geologic age, and grouped according to geographic locality. To the extent that information is available, the following items are included: The name of the stratigraphic unit, the source of the material or depth below the surface, the number of samples, the average and range of porosity, the average dry and saturated bulk density, the source of the data, and the method of porosity determination. The tabulation reflects the fact that more porosity than density data for sedimentary rocks are available in the literature. The stratigraphic nomenclature in this report is from various sources and does not necessarily follow that of the U.S. Geological Survey.

Total porosity is a measure of all the void space of porous material. It includes the sealed-off pores as well as those which are connected with the surface of the test specimen. The equation for total porosity (P_T) by percent is

$$P_T = 100 \left(1 - \frac{V_G}{V_B} \right), \quad (1)$$

where (V_B) is bulk volume and (V_G) is grain volume. Alternatively and more usually, grain density is substituted for grain volume, and

bulk density for bulk volume. Total porosity by percent correspondingly is

$$P_T=100\left(1-\frac{D_B}{D_G}\right). \quad (2)$$

Apparent porosity, otherwise called effective or net porosity, is a measure of the interconnected void space which communicates with the surface of the test specimen. It therefore does not include the sealed-off or occluded pores. Apparent porosity is obtained by determining the fluid capacity of the interconnected pores, that is, the pore volume (V_P), and by dividing this volume by the bulk volume (V_B). The equation for apparent porosity (P_A) by percent is

$$P_A=100\left(\frac{V_P}{V_B}\right). \quad (3)$$

The method of determining bulk volume may result in greater differences in porosity than the usually small differences between total and apparent porosity that are recorded in the literature. For 10 specimens of fire brick Hartmann (1926) found that bulk volume by immersion in water was consistently slightly more than by mercury displacement. The average total porosity by the grain density-bulk density relation was 25.5 percent where bulk volume was determined by the displacement of water by a previously wetted specimen, but 24.6 percent where bulk volume was determined by mercury displacement. Steinhoff and Mell (1924), using 73 cubes of porous refractory material 2 cm along the edges, found that the bulk volume obtained by micrometer measurement was significantly greater than by mercury displacement. The average total porosity, determined by the grain density-bulk density relation, was 25.0 percent where the bulk volume was obtained by micrometer measurement, but the total porosity was 23.6 percent where the bulk volume was obtained by mercury displacement. These results indicate that mercury displacement determinations of bulk volume tend toward minimum values. A comparison of equations (1) and (3) shows that a decrease in bulk volume due to the method of measurement will decrease the computed total porosity but will increase the computed apparent porosity. That mercury displacement determinations of bulk volume may at times be less than true values of bulk volume is shown by the fact that the computed apparent porosity occasionally exceeds the computed total porosity where bulk volume is obtained by mercury displacement, and where there is no evidence that adsorptive effects have resulted in erroneously large determinations of pore volume.

Nutting (1930) stated that in the determination of grain density by pycnometry the adsorption of water by very finely powdered quartz grains (or other material) may cause an error of 1 or 2 percent in the grain density. Apparently, however, such large errors due to the adsorption of water do not commonly occur in practice. Hirschwald (1912) showed that an erroneously large deficiency of porosity may result from obtaining pore volume by imbibition of water under atmospheric pressure. He obtained better results by letting the specimens imbibe water for 3 hours under a partial vacuum equal to the vapor pressure of water at room temperature, but he had to supplement this process by applying a pressure of 50 to 150 atmospheres to obtain the optimum saturation of the pores.

Among the more important earlier publications which give extensive data on porosity and bulk density is that of Buckley (1898), who determined the porosity of building stones of Wisconsin by slowly immersing the specimens in boiling water and then maintaining a reduced pressure of one twelfth of an atmosphere on the specimen for 36 hours. Gary (1898) listed the bulk density of numerous building stones, and the total porosity as determined by the grain density-bulk density relation, but his specimens are usually not identified according to the geologic formation. Moore (1904) determined the porosity of specimens of sedimentary rocks by saturating them with water under a vacuum of 29 inches of mercury and listed many determinations. Fuller (1906) calculated the porosity of some sedimentary and other rocks by using the data of Geikie, Delesse and Merrill, but the original data were obtained from the imbibition of water under atmospheric pressure, and it is not clear whether Fuller used an arbitrary value of 2.65 gcm^{-3} for bulk density in his calculations. Sorby (1908) gave the porosity of sandstone, shale, and slate obtained by imbibition of water for several days under a partial vacuum resulting from the condensation of steam. Sorby used almond oil or benzol to saturate specimens of clay. Hirschwald (1912) determined the porosity of many sandstone, limestone, and slate specimens of building stone by saturating the specimens under a partial vacuum followed by applying a pressure of 150 atmospheres. Grubenmann, Niggli, and others (1915) have presented extensive data on the total porosity and bulk density of the building and roofing stones of Switzerland. Kessler (1919) determined the bulk density of commercial marbles of the United States and derived total porosity by the grain density-bulk density relation.

More recently Melcher (1924) gave a critical discussion of previous methods of porosity determination and presented many determinations of bulk density and total porosity of oil sands obtained by the

grain density-bulk density relation. Hedberg (1926) and Athy (1930) determined the total porosity and bulk density of subsurface samples of shale with particular reference to the relation of compaction to the thickness of overburden. Stearns (1927) determined the bulk density and total porosity of many samples of water-bearing rock. Fancher, Lewis, and Barnes (1933) gave extensive references to the various methods of porosity determination, summarized many of the methods and techniques evolved up to the year 1933, and presented many original apparent porosity determinations. A recent extensive list of porosity determinations of oil sands is given by Rall, Hamontre, and Taliaferro (1954). In their method pore volume is determined by the pressure and volume relationships of a gas system with and without a rock specimen.

Average values for the porosity of sedimentary rocks have been given by Barrell (1914) as: shale, 8.2 percent; sandstone, 14.8 percent; limestone, 5.3 percent; and all sedimentary rocks, 8.5 percent. Additional data since the publication of Barrell's summary indicate that the average value of 8.2 percent for the porosity of shale may be low. Athy's graph (1930) for Pennsylvanian and Permian shales from structurally disturbed areas shows an average porosity of 8.8 percent for a depth range from 1,000 to 5,000 feet, but Hedberg's data (1936) for undisturbed Tertiary shale show an average porosity of 19.8 percent for a depth range from 219 to 7,994 feet.

Tabulations of the assembled data on porosity and bulk density follow (tables 1-5). Nearly all the measurements were made at room temperature and 1 atmosphere. Numbers in parentheses following bulk density entries are the number of determinations on which the averages are based. Methods of porosity determination and sources of data are keyed in the tabulations to lists that appear on pages E45 to E47 and E47 to E55, respectively. A "Remarks" column contains miscellaneous notes from the cited sources that may be useful in evaluating the porosity and bulk density data.

The tabulations indicate that the porosity of sandstone generally but not invariably decreases and the bulk density increases with depth of burial, age, degree of tectonic disturbance, and departure from homogeneous texture. The carbonate rocks show a much less sensitive variation in porosity and bulk density in relation to these factors. Pure shales show the most sensitive decrease in porosity and increase in bulk density with depth of burial and degree of tectonic disturbance.

TABLE 1.—Sandstone, siltstone, quartzite, chert, and conglomerate

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Precambrian											
Goodrich Quartzite.....	Ishpeming, Mich.....	Mine.....	-----	-----	-----	-----	3.24	-----	17	A-16	
Nonesuch Shale (calcareous sandstone).	White Pine, Mich.....	do.....	-----	-----	-----	5.3	2.60	2.65	16	A-16	
Cambrian											
Antietam Quartzite.....	Martinsville, Pa.....	Outcrop (?).....	1	-----	-----	1.7	3.05	3.07	17	A-16	
Chickies Quartzite.....	Pennsylvania.....	Outcrop.....	5	3.8	7.8	5.4	-----	-----	43	T-1	
"Mt. Simon" sandstone (dolomitic).	Sand Hill well, Wood County, W. Va.	13,005-13,165.....	9	.2	2.5	.7	2.69	2.70	(1)	A-15	
Southern "Potsdam" sandstone.	Wisconsin.....	Quarry.....	14	4.8	28.3	11.4	2.30	2.41	22	A-1	
Northern "Potsdam" sandstone.	do.....	do.....	16	10.4	22.6	19.4	2.13	2.32	22	A-1	
Reagan Sandstone.....	Otis and Penny-Wann fields, Kans.	3,449-3,683.....	24	5.5	17.8	11.2	-----	-----	123	A-9	
Sandstone.....	Conley, Great Britain.....	Quarry.....	1	-----	-----	6.1	2.45	2.51	105	A-2	
Upper Cambrian and Lower Ordovician											
Potsdam and Beekmantown Groups (sandstone).	Ontario, Canada.....	Quarry.....	6	5.0	12.4	8.0	2.44	2.52	112	A-2	5 localities.

TABLE 1.—*Sandstone, siltstone, quartzite, chert, and conglomerate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Ordovician											
Juniata Formation.....	Sand Hill well, Wood County, W. Va.	7,833.....	1	-----	-----	1.2	2.67	2.68	(¹)	A-15	Clean, uniform.
St. Peter Sandstone.....	Wisconsin.....	Quarry.....	2	18.1	20.0	19.1	2.15	2.34	22	A-1	
Do.....	Ozark Plateau, Ark.	Outcrop.....	12	3.6	14.1	8.8	2.41	2.50	20	T-2	
Crystal Mountain Sandstone.	Ouachita Mountains, Ark.	do.....	1	-----	-----	17.5	2.19	2.37	20	T-2	
Simpson Group (sandstone).	Cunningham pool, Kansas.	4,051-4,117....	36	5.7	22.7	13.3	-----	-----	123	A-9	
Wilcox sand.....	Bowlegs field, Oklahoma.	-----	2	12.1	12.8	12.5	-----	-----	9	A-6	
Do.....	Oklahoma City field, Oklahoma.	≈6,300.....	12	16.9	23.3	20.7	-----	-----	123	A-9	
Do.....	do.....	≈6,300.....	2	8.0	16.9	12.5	-----	-----	9	A-6	
Do.....	Ramsay pool, Oklahoma.	≈4,800.....	-----	-----	-----	20	-----	-----	52	N-1	
Do.....	Seminole field, Oklahoma.	≈4,300.....	2	15.6	15.6	15.6	-----	-----	9	A-6	
Second Wilcox sandstone..	Arcadia-Coon Creek pool, Oklahoma.	≈6,000.....	-----	9	18	-----	-----	-----	25	N-1	
Second Simpson sand.....	West Edmond field, Oklahoma.	7,000+.....	2	14.9	15.1	15.0	-----	-----	123	A-9	
First Bromide sand.....	Fitts pool, Oklahoma.	≈4,150.....	1	-----	-----	7.7	-----	-----	123	A-9	
Bromide Formation (sandstone).	Lindsay area, Oklahoma.	9,500-11,300..	-----	1	24	14	-----	-----	148	N-1	
Do.....	Maysville pool, Oklahoma.	7,400.....	1	-----	-----	14.1	-----	-----	148	N-1	
Hammar-Haindl sand.....	Oklahoma City field, Oklahoma.	≈6,600.....	12	7.1	26.5	15.0	-----	-----	123	A-9	
Do.....	do.....	≈6,600.....	2	-----	-----	14.1	-----	-----	9	A-6	
Johnson sand.....	do.....	≈6,600.....	5	18.2	30.3	24.3	-----	-----	123	A-9	
Do.....	do.....	≈6,600.....	32	5.3	21.3	14.1	-----	-----	9	A-6	
Mollman sand.....	do.....	≈6,600.....	2	12.5	15.7	14.1	-----	-----	123	A-9	
School Land sand.....	do.....	≈6,600.....	4	11.4	14.8	13.1	-----	-----	9	A-6	
McKee sand.....	Hare field, New Mexico.	7,795.....	2	-----	-----	8.5	2.51	2.60	76	A-5	
Swan Peak quartzite.....	Afton quadrangle, Wyoming.	-----	-----	-----	-----	2.0	2.56	2.58	110	T-2	
Chazy Group.....	Ontario, Canada.....	Quarry.....	1	-----	-----	17.5	2.19	2.37	114	A-2	

Clean, uniform.

Silurian

Clinch Sandstone.....	Lee County, Va.....					9.6				84	N	
Tuscarora Sandstone.....	Sand Hill well, Wood County, West Virginia.	7,668-7,763.....	5	0.9	1.5	1.1	2.59	2.60	(1)	A-15		
Tuscarora Sandstone, do- lomite.	do.....	7,777-7,803.....	2	.5	1.1	.8	2.64	2.65	(1)	A-15		
Red Mountain Formation.	Bessemer, Alabama.....	Mine, 1,400.....				3.1	3.14	3.17		172	A-16	Ferruginous sandstones.
Do.....	do.....	do.....				2.9	3.26	3.29		172	A-16	Red sandstones.
Do.....	do.....	do.....				.8	2.76	2.77		172	A-16	Siltstone and shale.
Blaylock Sandstone.....	Ouachita Mountains, Ar- kansas.	Outcrop.....	4	2.3	17.4	7.3	2.42	2.49		20	T-2	
Medina group.....	Ontario, Canada.....	Quarry.....	2	12.0	14.9	13.5	2.30	2.44		112	A-2	2 localities.

Devonian

Oriskany Sandstone.....	Wayne-Dundee field, New York.	≈1,924.....	4	7.1	9.0	8.3				47	T	1 well.
Do.....	State Line field, New York.	≈4,700.....	18	7.9	12.2	10.3				47	T	5.7 ft of core.
Bradford sand.....	Bradford field, Pennsyl- vania.	≈600-≈2,300.....	297	6.0	23.3	15.0	2.25	2.40		46	T-6	Estimated grain density, 2.65.
Do.....	do.....	≈600-≈2,300.....	1			13.1				123	A-9	
Do.....	do.....	≈600-≈2,300.....	1			18.6	2.17	2.36		98	T-2	
Do.....	do.....	≈600-≈2,300.....	75	3.8	26.0	12.9				43	A-6	
Do.....	do.....	≈600-≈2,300.....	40	4.5	22.7	12.5				9	A-6	
Do.....	do.....	≈600-≈2,300.....	17	2.0	14.4	11.9				43	A-6	
Do.....	Kane field, Pennsylvania.	Subsurface.....	69	3.0	16.4	10.6				9	A-6	
Do.....	do.....	do.....	2	14.5	15.1	14.8				123	A-9	
Chipmunk sand.....	Cattaraugus County, N.Y.	do.....	2	11.5	13.4	12.5				9	A-6	
Clarendon sand.....	Saybrook field, Pennsyl- vania.	do.....	5	8.8	18.5	14.4				9	A-6	
Do.....	Warren field, Pennsylva- nia.	do.....	13	2.6	25.6	10.6				43	A-6	
Do.....	do.....	do.....	7	14.2	22.2	18.9				9	A-6	
Kane sand.....	Kane field, Pennsylvania.	do.....	65	2.9	11.8					47	T	19 wells.
Oriskany Group (sand- stone).	Tioga field, Pennsylvania.	≈4,000.....	1			9.9				47	T	
Do.....	Sabinsville pool, Penn- sylvania.	≈4,350.....	6	9.1	10.1	9.4				47	T	2 wells.
Do.....	Hebron field, Pennsylva- nia.	≈5,130.....		9	14					125	N-1	
Do.....	Hebron gas field, Penn- sylvania.	5,174-5,179.....				10				49	N	
Do.....	Hebron-Ellisville field, Pennsylvania.	≈5,500.....										

Footnotes on p. E25.

TABLE 1.—Sandstone, siltstone, quartzite, chert, and conglomerate—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Devonian—Continued											
Sandstone.....	Butler and Zelenople, quadrangle, Pennsylvania.	Subsurface....	8	4.5	22.2	10.1	2.39	2.49	99	T-2	Calcareous.
Do.....	Dorseyville field, Pennsylvania.	1,910.....	11			8.6	2.42	2.51	98	T-2	
Speechley sand.....	Oil City field, Pennsylvania.	Subsurface....	11	3.7	15.7	11.4			43	A-6	
Do.....	Butler County, Pa.	2,032 to 2,049..	3	4.3	15.4	10.9	2.42	2.53	98	T-2	
Third Bradford sand.....	Bradford field, Pennsylvania.	Subsurface....	10	13.1	16.9	14.6			43	T-1	
Do.....	do.	do.	5	14.9	18.5	16.2	2.25	2.41	98	T-2	
Third sandstone.....	Allegheny and Butler Counties, Pa.	1,700-1,800....	13	4.6	9.1	6.7	2.46	2.53	98	T-2	
Fourth and Top sand.....	Butler County, Pa.	Subsurface....	3	10.6	15.9	12.7	2.31	2.44	98	T-2	
Fifth sandstone.....	New Kensington quadrangle, Pennsylvania.	2,300.....	3	6.2	13.2	10.5	2.43	2.54	98	T-2	
Thirty-foot sand.....	Glenshaw field, Pennsylvania.	1,850.....	7	7.2	9.8	9.0	2.41	2.50	98	T-2	
Oriskany Group (sandstone).	Kanawha County, W. Va.			6.8	11				85	N-1	
Huntersville chert.....	Sand Hill well, Wood County, W. Va.	3,455.....	1			.7	2.58	2.59	(1)	A-15	
Sandstone.....	Ravenna, Ky.	Mine.....	2	10.4	11.9	11.2	2.55(1)	2.65(1)	98	T-2	
Williamsburg sand.....	Williamsburg, Ky.	800(?).....	1			12.4			98	T-2	
Hoing sand.....	Colmar-Plymouth pool, Illinois.	415-500.....	137	5.7	23.9	18.6			118	A-6	
Oriskany sandstone.....	Ontario, Canada.	Quarry.....	1			6.6	2.48	2.55	112	A-2	
Old Red sandstone.....	Cradley, Great Britain.	Outcrop.....	1			2.5	2.57	2.60	105	A-2	
Graywacke.....	Germany.	Quarry.....	3	.5	9.1	3.6			72	A-3	
Do.....	do.	do.	3	.7	7.2	4.3			72	A-3	
Sandstone.....	do.	do.	2	7.7	18.7	13.2			72	A-3	
Upper Old Red sandstone.	Micheldean, Great Britain.	Outcrop.....	1			16.0	2.18	2.34	105	A-2	
Do.....	do.	do.	1			9.1	2.40	2.49	105	A-2	

Upper Devonian and Lower Mississippian

Three Forks shale, (red sandstone).	Afton quadrangle, Wyoming.					6.4	2.62	2.68	110	T-2	Average grain density, 2.664.
First Venango sand	Franklin Heavy field, Pennsylvania.	Subsurface	12	11.2	18.5	13.9			123	A-9	
Do	Pleasantville field, Pennsylvania.	do	2	12.4	20.7	16.5			43	A-6	
Second Venango sand	Oil City field, Pennsylvania.	do	30	5.8	20.1	15.0			9	A-6	
Do	Pleasantville field, Pennsylvania.	do	1			17.2			43	A-6	
Second sand, Venango oil sand group.	Oil City area, Pennsylvania.	618-873	115	2.0	28.2	14.6	2.28	2.43	45	T-2	
Third Venango sand	do	Subsurface	2	10.2	10.2	10.2			9	A-6	
Do	do	do	17	3.4	22.3	13.7			43	A-6	
Boulder sand	Allegheny County, Pa.		4	4.4	12.6	7.9	2.45	2.53	98	T-2	

Mississippian

Berea sandstone	Hancock County, W. Va.	Subsurface	2	16.7	22.2	19.5			9	A-6	Quartzite cap.
Do	Cabin Creek field, West Virginia.	≈2,500				4			161	T-2	
Do	do	≈2,500				16			161	T-2	
Sandstone, well-sorted	Tucker County, W. Va.		1			4.4			131	T-1	Pay sand. Carbon ratio, 72.5-77.5 percent.
Berea Sandstone	Harrison County, Ohio	Subsurface	3	15.4	17.2	16.6	2.24	2.40	98	T-2	Building stone.
Do	Monroe, Noble, and Belmont Counties, Ohio.	1,440-2,160	8	4.7	17.1	11.1	2.37	2.48	99	T-2	
Do	Monroe County, Ohio	Subsurface	1			11.7			9	A-6	
Do	S. Amherst, West View, and Berea, Ohio.	Quarry	6	15.9	17.8	16.6	2.12	2.29	19	A-1	Mississippian(?).
Berea (?) Sandstone	Berea, Ohio	Outcrop	2	10.2	13.2	11.7			100	A-13	
Do	Amherst, Ohio	Quarry				16	2.06	2.22	172	A-16	
Keener sand	Monroe County, Ohio	1,220-1,570	5	11.3	18.4	14.9	2.25	2.40	98	T-2	Do. Clayey and limy.
Maxville Limestone (siltstone).	Muskingum County, Ohio.	≈200	2				2.67		17	A-16	
Sandstones	Monroe County, Ohio	1,350-1,500	3	11.3	13.1	12.5	2.35	2.48	99	T-2	
Mooretown Formation (sandstone).	Tri-County oil field, Indiana.	≈1,300				5			42	N	Clean, fine sandstone.
Sample sand	Francisco pool, Indiana.	1,400				17			107	N	
Waltersburg Sandstone	Lower Wabash area, Illinois and Indiana.	1,900				19.5			146	N-1	
Do	Powell's Lake oil field, Kentucky.	1,810-1,820		14	21	18.5			79	N-1	
Fort Payne Chert	Near Smithville, Tenn.	Subsurface	2	3.8	4.8	4.2	2.65	2.69	17	A-16	

Footnotes on p. E25.

TABLE 1.—Sandstone, siltstone, quartzite, chert, and conglomerate—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gem ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Mississippian—Continued											
Aux Vases Sandstone.....	Salem pool, Illinois.....	1,760-1,794.....	28	7.9	19.2	14.7			118	A-6	Well sorted.
Do.....	do.....	≈1,800.....				16.1			5	N-1	
Benoist sand.....	do.....	≈1,725.....				17.5			5	N-1	
Do.....	Hoodville field, Illinois.....	2,999-3,003.....	6	15.3	17.0	16.1			123	A-6	
Bethel Sandstone.....	Louden, Centralia, Patoka, and Salem pools, Illinois.....	1,360-1,853.....	102	10.0	24.9	18.3			118	A-6	
Do.....	South-central Illinois.....	1,363-1,724.....	33	10.0	22.2	18.2			122	N-1	
Cypress Sandstone.....	Bartelso, Carlyle, Lawrence County, Louden, Noble, and Patoka pools, Illinois.....	1,009-2,024.....	126	5.7	23.8	18.6			118	A-6	
Paint Creek Shale (stray sand).....	Fayette County, Ill.....	1,363-1,724.....	33	10.0	22.2	18.2			122	N-1	
Tar Springs Sandstone.....	Benton field, Illinois.....	2,000-2,100.....		13	25	20			74	N-1	
Carlyle sand.....	Carlyle, Ill.....	1,026.....	3	20.6	27.6	23.4	2.02	2.26	98	T-2	
Michigan stray sand.....	Millbrook field, Illinois.....	1,235-1,282.....	7	9.7	20.7	19.1			123	A-9	
Sandstones.....	Ozark Plateau, Ark.....	Outcrop.....	4	8.6	17.3	13.3	2.30	2.43	20	T-2	
Boone Formation (chert).....	Near Picher, Okla.....	Mine.....				5.0	2.56	2.61	16	A-16	
Boone Formation (quartzite).....	do.....	do.....				2.0	2.72	2.74	16	A-16	
Boone Formation (calcareous chert).....	do.....	do.....				8.9	2.39	2.48	16	A-16	
Mississippian or Pennsylvanian											
Deaner sand.....	Deaner field, Oklahoma.....	2,522.....	1			12.5	2.35	2.47	98	T-2	
Kingwood sand.....	do.....	2,659.....	2	15.7	16.0	15.9	2.27	2.43	98	T-2	
Red sand.....	Osage County, Okla.....	Subsurface.....	5	7.5	18.4	14.0	2.36	2.50	98	T-2	

Pennsylvanian

Olean Formation (sandstone).	Rock City, N.Y.-----	Outcrop(?)-----	2	14.4	15.8	15.1	-----	-----	9	A-6	Carbon ratio, 52.5-57.5 per- cent. Carbon ratio, 57.5-62.5 per- cent. Carbon ratio, 72.5-77.5 per- cent. Carbon ratio, 80-82.5 per- cent. Now "Burbank" sand. Do.
Allegheny Formation (sandstone).	Bakerton, Pa.-----	≈ 500-----	-----	-----	-----	1.4	2.70	2.71	17	A-16	
Allegheny Formation (siltstone).	do-----	≈ 500-----	-----	-----	-----	1.8	2.76	2.78	17	A-16	
Do-----	Colver, Pa.-----	Mine-----	-----	-----	-----	-----	2.66	-----	17	A-16	
Kanawha Formation (sandstone).	Near Franklin, Pa.-----	5-140-----	3	7.8	12.0	10.3	2.29	2.39	17	A-16	
Do-----	do-----	0-20-----	2	-----	-----	-----	2.46	-----	16	A-16	
Do-----	do-----	0-20-----	-----	-----	-----	11.0	2.16	2.27	16	A-16	
Do-----	do-----	0-20-----	-----	-----	-----	-----	2.15	-----	16	A-16	
Kanawha Formation (sandstone).	Dehuc, W. Va.-----	-----	-----	-----	-----	-----	2.70	-----	16	A-16	
Monongahela Formation (sandstone).	Scotts Run, W. Va.-----	Mine-----	3	3.1	4.8	4.1	2.5	-----	173	A-16	
Sandstones, well-sorted-----	West Virginia, Ohio-----	Outcrop-----	7	16.5	25.3	21.5	-----	-----	131	T-1	
Do-----	do-----	do-----	8	6.8	20.1	16.2	-----	-----	131	T-1	
Do-----	West Virginia-----	do-----	10	3.0	9.5	5.4	-----	-----	131	T-1	
Do-----	do-----	do-----	4	1.9	3.9	2.7	-----	-----	131	T-1	
Mansfield Formation (sandstone).	Powell's Lake oil field, Kentucky.-----	1,200-----	-----	15	23	18.7	-----	-----	79	N-1	
Biehl sand-----	Allendale pool, Illinois-----	1,416-1,555-----	93	6.2	20.3	13.3	-----	-----	118	A-6	
Makanda sand-----	Boskey Dell, Ill.-----	Outcrop-----	4	16.2	19.6	18.3	-----	-----	123	A-9	
Robinson sand-----	Crawford-Main pool, Illinois.-----	905-1,014-----	289	3.4	27.1	18.6	-----	-----	118	A-6	
Do-----	Flat Rock, Lawrence County, New Hebron, and Parker pools, Illinois.-----	880-1,030-----	47	6.3	24.3	16.8	-----	-----	118	A-6	
Upper Partlow sand-----	North Johnson pool, Illinois.-----	504-561-----	15	15.5	23.4	20.8	-----	-----	118	A-6	
Bartlesville sand-----	Anderson County, Kans.-----	-----	-----	-----	-----	17.5	-----	-----	84	N	
Do-----	Various fields, Kansas.-----	695-1,183-----	82	7.0	24.8	20.4	-----	-----	123	A-9	
Peru sand-----	Sedan and Cunningham fields, Kansas.-----	197-208-----	14	14.4	22.4	17.5	-----	-----	123	A-9	
Wayside sand-----	Montgomery County, Kans.-----	586-631-----	-----	-----	-----	9.7	2.47	2.56	98	T-2	
Do-----	Jefferson field, Kansas.-----	243-424-----	16	15.7	23.0	20.0	-----	-----	123	A-9	

TABLE 1.—*Sandstone, siltstone, quartzite, chert, and conglomerate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Pennsylvanian—Continued											
Atoka Formation (sandstone).	Ozark Plateau, Ark.	Outcrop	15	4.7	19.8	11.5	2.32	2.44	20	T-2	11 wells.
Do.	Arkansas Valley, Ark.	do	23	0	20.6	7.6	2.43	2.51	20	T-2	
Do.	Ouachita Mountains, Ark.	do	13	0	10.4	5.5	2.50	2.55	20	T-2	
Sandstones	Ozark Plateau, Ark.	do	2	13.8	18.1	16.0	2.26	2.42	20	T-2	
Do.	Arkansas Valley, Ark.	do	12	5.4	10.7	8.2	2.42	2.51	20	T-2	
Do.	Ouachita Mountains, Ark.	do	12	.9	9.6	4.6	2.52	2.57	20	T-2	
Armstrong sand.	W. Duncan field, Oklahoma.	≈2,000	63			26.7			121	N-1	
Bartlesville sand.	Creek and Osage Counties, Oklahoma.	1,570-2,267	14	13.5	38.7	20.1	2.17	2.37	98	T-2	
Do.	Cushing field, Oklahoma.	2,639-2,680	2	28.9	32.0	30.5	2.20(1)	2.49(1)	98	T-2	
Do.	Pershing field, Oklahoma.	1,988-2,132	10	7.6	16.0	13.3	2.31	2.44	98	T-2	
Do.	Various fields, Oklahoma.	813-6,592	587	3.3	33.7	17.4			123	A-9	
Basal Pennsylvanian sand.	Pauls Valley field, Oklahoma.	Subsurface	6	5.9	12.3	8.8			123	A-9	
Booch sand.	Various fields, Oklahoma.	2,913-(?)	5	17.5	25.4	22.1			123	A-9	
Burbank sand.	Burbank field, Oklahoma.	2,920-2,970	2	15.2	15.7	15.4			123	A-9	
Burgess sand.	S. Moore pool, Oklahoma.	7,791-7,795		1.8	35	17			104	N-1	
Do.	Washington County, Okla.	≈1,650	2	16.4	22.0	19.2	2.24(1)	2.40(1)	104	N-1	
Cisco Formation	West Red River field, Oklahoma.	≈1,550	6	22.6	26.1	24.6			123	A-9	
Cleveland sand.	Osage County, Okla.	Subsurface	1			17.7	2.21	2.39	98	T-2	
Coffeyville Formation (sandstone).	Turley, Okla.	do				16.8	2.14	2.31	17	A-16	
Cromwell sand.	Hughes County, Okla.	do	1			12.1			123	A-9	
Do.	Little River field, Oklahoma.	≈3,220	22	16.2	23.2	19.9			9	A-6	
Do.	Kanawa field, Oklahoma.	≈2,300	6	16.6	22.6	19.0			9	A-6	
Deese Formation (sandstone).	Southwest Antloch field, Oklahoma.	≈6,550	1			15			128	N-1	
Do.	Velma oil field, Oklahoma.	3,330-4,320				21			132	N-1	
Dutcher sand.	South Depew field, Oklahoma.	2,410	2	14.6	18.2	16.4			123	A-9	
Do.	Slack field, Oklahoma.	2,575-2,613	5	9.9	14.9	10.8			98	T-2	
Gilcrease sand.	Francis field, Oklahoma.	≈2,500	2	27.3	27.5	27.4			9	A-6	

Do.....	Holdenville field, Oklahoma.	≈3,200.....	2	16.8	16.8	16.8	-----	-----	9	A-6
Do.....	Saskaw, Okla.	≈2,830.....	2	18.1	18.3	18.2	-----	-----	9	A-6
Glenn sand.....	Creek County, Okla.	1,514-1,592.....	1	-----	-----	21.4	2.12	2.33	98	T-2
Healdton sand zone.....	Healdton field, Oklahoma.	849-1,356.....	92	2.3	35.8	23.8	-----	-----	123	A-9
Hewitt sand.....	Hewitt field, Oklahoma.	1,408-1,435.....	3	17.3	21.7	19.5	2.13(1)	2.32(1)	98	T-2
Hickman sand.....	Burbank field, Oklahoma.	2,782-3,005.....	84	6.1	32.7	20.4	2.15	2.35	98	T-2
Holdenville Shale (sandstone).....	Tulsa, Okla.	Subsurface.....	-----	-----	-----	17.0	2.50	2.67	17	A-16
Hoover sandstone.....	Laverne district, Okla.	≈4,200.....	-----	-----	-----	18	-----	-----	114	N-1
Hoxbar Formation.....	Superior well, Caddo County, Okla.	8,353-8,362.....	6	3.8	7.8	6.55	-----	-----	(2)	A
-----	-----	9,448-9,492.....	39	4.7	8.7	6.90	-----	-----	(2)	A
-----	-----	10,215-10,224.....	3	9.5	10.9	10.17	-----	-----	(2)	A
Deese Formation.....	do.....	13,083-13,095.....	7	2.1	6.3	4.36	-----	-----	(2)	A
-----	-----	15,075-15,085.....	8	7.2	9.2	8.20	-----	-----	(2)	A
-----	-----	16,953-16,956.....	1	-----	-----	28.2	-----	-----	(2)	A
Humphrey sand.....	Velma oil field, Oklahoma.	Subsurface.....	-----	-----	-----	17	-----	-----	132	N-1
Layton gas sand.....	Pawnee and Creek Counties, Okla.	853-1,525.....	2	22.1	26.3	24.2	2.02	2.26	98	T-2
Lower part of Dornick Hills Formation and Springer Formation.....	Velma pool, Oklahoma.....	≈5,000.....	-----	-----	-----	21	-----	-----	39	N-1
-----	-----	≈5,300.....	-----	-----	-----	19	-----	-----	39	N-1
-----	-----	≈6,100.....	3,500	-----	-----	16	-----	-----	39	N-1
-----	-----	≈6,600.....	-----	-----	-----	14	-----	-----	39	N-1
-----	-----	≈7,100.....	-----	-----	-----	12	-----	-----	39	N-1
Medrano sand.....	Caddo County, Okla.	4,596-5,823.....	242	2.2	25.5	17.3	-----	-----	123	A-9
Middle Rowe Formation.....	Cement field, Oklahoma.	3,346-3,354.....	17	3.4	28.9	22.9	-----	-----	123	A-9
Morrow Series (sandstone).....	Laverne district, Oklahoma.	Subsurface.....	-----	-----	-----	14	-----	-----	114	N-1
Olympic sand.....	Olympia pool, Oklahoma.	≈1,800.....	-----	11.9	21.7	18	-----	-----	150	N-1
Do.....	Hughes County, Okla.	-----	-----	-----	-----	20.5	-----	-----	84	N
Peru sand.....	Bartlesville field, Oklahoma.	710-720.....	17	14.7	20.2	18.6	-----	-----	123	A-9
Sandstone.....	Garber field, Oklahoma.	1,784-1,800.....	2	10.3	16.4	13.4	2.25(1)	2.41(1)	98	T-2
Do.....	Stone Bluff field, Oklahoma.	1,144-1,162.....	1	-----	-----	16.5	2.22	2.38	98	T-2
Seminole Formation (sandy zone).....	Tulsa, Okla.	Subsurface.....	-----	-----	-----	20.5	2.26	2.47	17	A-16
Sims sand.....	Velma field, Oklahoma.	do.....	-----	-----	-----	18-20	-----	-----	132	N-1
Skinner sand.....	West Chandler field, Oklahoma.	≈4,120.....	1	-----	-----	12.1	-----	-----	123	A-9
Stray sand.....	Osage County, Okla.	1,536 or deeper.....	-----	-----	-----	15.2	2.37	2.47	98	T-2
Third Deese sand.....	Southwest Antioch field, Oklahoma.	≈6,500.....	400	-----	-----	15.5	-----	-----	111	N-1
Thomas sandstone.....	Southwest Randlett field, Oklahoma.	≈1,600.....	-----	21.8	25.8	22.2	-----	-----	26	N-1
Tonkawa sandstone.....	Laverne district, Oklahoma.	Subsurface.....	-----	-----	-----	18	-----	-----	114	N-1
Tucker sand.....	Washington County, Okla.	1,355-1,371.....	16	5.3	20.6	16.5	-----	-----	123	A-9
Upper Rowe Formation.....	Cement field, Oklahoma.	3,379-3,393.....	22	15.7	26.2	23.3	-----	-----	123	A-9

Shaly, limy.

 Do.
Do.
Do.
Do.
Do.

Shaly.

TABLE 1.—*Sandstone, siltstone, quartzite, chert, and conglomerate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Pennsylvanian—Continued											
Wayside sand.....	Bartlesville field, Oklahoma.	525-530.....	4	15.7	19.4	18.0	-----	-----	9	A-9	9 wells.
Do.....	Keystone field, Oklahoma.	1,119-1,235.....	8	6.7	20.9	15.4	2.37(5)	2.49(5)	98	T-2	
Do.....	Muskogee and Pawnee Counties, Okla.	1,116-1,304(?).....	2	15.8	20.1	18.0	2.22	2.40	98	T-2	
Wilson sand.....	Stephens County, Okla.	1,380.....	1	-----	-----	20.0	2.16	2.36	98	T-2	
Cisco Group.....	Archer County oil fields, Texas.	900-1,750.....	-----	19.4	24.6	22.8	-----	-----	75	T-2	8 wells.
Cook sand.....	Cook Ranch field, Texas.	≈1,300.....	46	12.5	28.2	24.0	-----	-----	171	N-1	
Hickman(?) sand.....	Petrolia field, Texas.	Subsurface.....	4	18.5	26.6	22.9	2.08	2.31	99	T-2	
McClesky sand.....	Eastland County, Tex.	3,135-3,142.....	2	6.6	8.5	7.6	2.49(1)	2.55(1)	98	T-2	
Middle Strawn sandstone.....	Walnut Bend field, Texas	4,866-4,888.....	20	8.9	21.7	16.1	-----	-----	123	A-9	
Strawn Group (sandstone).....	Cooke County, Tex.	-----	-----	-----	22	-----	-----	-----	84	N	
Do.....	Coleman County, Tex.	1,950.....	10	23.6	24.6	24.2	-----	-----	119	A-11	
Strawn Group (sand).....	Langston-Kleiner field, Texas.	≈3,500.....	Many	-----	-----	15.2	-----	-----	126	N-1	
Weber Sandstone.....	Rangely field, Colorado.....	5,600-6,300.....	-----	6	19	-----	-----	-----	117	N-1	
Weber Sandstone (quartzite).....	do.....	≈5,800.....	10	11.1	13.6	12.2	-----	-----	128	N-1	
Weber Sandstone.....	do.....	5,943-6,429.....	36	0.4	15.6	9.8	-----	-----	57	A-9	Fine sandstone, hard. 2 wells.
Bell sand.....	Lance Creek field, Wyoming.	5,776-5,936.....	2	7.5	10.5	9.0	-----	-----	157	T-2	
Converse sand.....	do.....	4,615-4,625.....	1	-----	-----	13.5	-----	-----	157	T-2	
Leo sand.....	do.....	5,160-5,723.....	7	2.9	16.9	8.6	-----	-----	157	T-2	
Second Leo sand.....	do.....	5,244-5,275.....	1	-----	-----	5.9	-----	-----	157	T-2	
Tensleep Sandstone.....	Big Medicine Bow field, Wyoming.	7,016-7,474.....	3	9.8	19.5	15.0	-----	-----	157	T-2	
Do.....	Elk Basin field, Wyoming.	≈4,000.....	-----	-----	-----	10.7	-----	-----	145	N-1	
Do.....	Longs Creek, Wyo.	5,955-5,956.....	2	-----	-----	13.7	-----	-----	76	A-5	
Do.....	Salt Creek field, Wyoming.	3,992-4,039.....	2	10.9	18.7	14.8	-----	-----	157	T-2	
Do.....	Steamboat Butte oil field, Wyoming.	6,923-7,104.....	-----	-----	-----	12-13	-----	-----	11	N-1	

Pennsylvanian and Permian

Wells Formation (quartzite).	Afton quadrangle, Wyoming.	Outcrop-----	-----	-----	-----	15.1	2.27	2.42	110	T-2	
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Carboniferous

Lower Coal Measures-----	Great Britain-----	Quarry-----	1	-----	-----	20.5	2.16	2.37	105	A-2	
Millstone grit-----	Meanwood, Great Britain.	Outcrop-----	2	13.0	18.2	15.6	2.23	2.38	105	A-2	
Sandstone-----	Germany-----	do-----	3	2.7	13.8	6.9	2.47	2.54	56	T-3	
Do-----	do-----	Quarry-----	9	3.8	23.5	11.7	-----	-----	72	A-3	
Do-----	Aktyubin area, U.S.S.R.	1,150-4,430-----	9	-----	-----	11.8	2.41	2.53	108	T	
Do-----	do-----	7,610-8,510-----	14	-----	-----	3.9	2.50	2.54	108	T	

Permian

Washington(?) Formation (sandstone).	Waterford, Ohio-----	Quarry-----	3	-----	-----	16	2.17	2.33	172	A-16	
First sand-----	KMA field, Texas-----	3,769-3,787-----	21	7.0	22.3	16.2	-----	-----	123	A-9	Permian. Do. 2 localities.
KMA sand-----	do-----	3,687-3,824-----	156	.5	19.6	7.5	-----	-----	123	A-9	
Spraberry siltstone-----	Spraberry field, Texas-----	6,800-----	-----	-----	-----	8	-----	-----	169	N-1	
Sandstone-----	Great Britain-----	Outcrop(?)-----	2	12.1	24.8	18.5	2.22	2.41	105	A-2	
Dyas Sandstone-----	Germany-----	Quarry-----	7	9.1	20.7	15.9	-----	-----	72	A-3	
Zechstein conglomerate-----	do-----	Outcrop-----	1	-----	-----	2.8	2.55	2.58	56	T-3	
Sandstone-----	Aktyubin area, U.S.S.R.	Subsurface-----	45	-----	-----	10.1	2.42	2.52	108	T	
Do-----	do-----	do-----	98	-----	-----	10.5	2.43	2.54	108	T	
Conglomerate-----	do-----	do-----	1	-----	-----	10.9	2.59	2.70	108	T	

Permian and Triassic

Sandstone-----	Aktyubin area, U.S.S.R.	Subsurface-----	3	-----	-----	18.5	2.19	2.38	108	T	
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Triassic

Amherst sandstone-----	Connecticut Valley-----	Outcrop-----	1	-----	-----	23	1.92	2.15	18	A-12	
Stockton Formation (sandstone).	New Jersey-----	do-----	5	1.3	7.9	4.0	-----	-----	43	T-1	
Santa Rosa Sandstone-----	Guadalupe County, N. Mex.	Outcrop(?)-----	1	-----	-----	18.0	2.17	2.35	98	T-2	
Shublik Formation-----	Barrow, Alaska-----	2,651-2,766-----	2	9.3	16.0	12.7	-----	-----	175	A	

TABLE 1.—*Sandstone, siltstone, quartzite, chert, and conglomerate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Triassic—Continued											
Bunter Sandstone	Great Britain	Quarry, outcrop	18	5.8	30.8	20.4	2.09	2.29	105	A-2	
Do	Caldy Grange, Great Britain	Outcrop	1			14.8	2.22	2.37	105	A-2	3 in from fault.
Do	do	do	1			15.5	2.21	2.36	105	A-2	1 ft from fault.
Do	do	do	1			22.5	2.02	2.25	105	A-2	2 ft from fault.
Do	do	do	1			25.5	1.94	2.20	105	A-2	12 ft from fault.
Do	do	do	1			25.5	1.94	2.20	105	A-2	25 ft from fault.
Keuper Sandstone	Great Britain	do	16	16.5	28.6	22.6	2.02	2.25	105	A-2	
Do	Caldy Grange, Great Britain	do	1			16.5	2.18	2.35	105	A-2	3 in from fault.
Do	do	do	1			18.0	2.14	2.32	105	A-2	1 ft from fault.
Do	do	do	1			20.1	2.08	2.28	105	A-2	2 ft from fault.
Do	do	do	1			22.5	2.02	2.25	105	A-2	12 ft from fault.
Do	do	do	1			22.6	2.01	2.24	105	A-2	24 ft from fault.
Bunter Sandstone	Near Hanover, Germany	In place						2.25	14		Torsion balance.
Buntsandstein	Germany	Outcrop	1			20.5	2.09	2.30	56	T-3	
Do	do	Quarry	39	7.7	26.4	18.3			72	A-3	
Keuper Sandstone	do	do	11	12.1	28.3	19.9			72	A-3	
Sandstone	Cantons of Basel-Land, Basel-Stadt, Schwyz and St. Gallen, Switzerland	do	7	3.6	21.1	11.1	2.42	2.53	63	T-4	Dips 0°-20°.
Jurassic											
Jones sand	Schuler field, Arkansas	7,500-7,700		0	35	20.2			163	N-1	
Do	do	7,564-7,632	62	5.4	29.2	20.9			41	N-1	1 well.
Do	Various fields, Arkansas	7,530-7,664	53	8.1	27.3	15.3			123	A-9	
Morgan sands	Schuler field, Arkansas	5,300-5,850			26	16			163	N-1	
Morrison Formation (sandstone)	Long Park, Montrose County, Colo.	239-313	62	4.9	24.1	18.6			(3)	A-9	Well sorted.
Do	do	215-284	22	5.2	27.8	17.9			(3)	A-9	Moderately well sorted.
Do	do	229-267	3	11.7	16.7	14.5			(3)	A-9	Poorly sorted.

Morrison Formation (silt-stone).	-----do-----	200-247-----	22	7.1	27.3	15.6			(9)	A-9	Do.
Morrison Formation	Cisco dome, Utah-----	Outcrop-----	1			4.0			166	T-2	Very limy. 2 wells.
Do.	Two structures Wyoming.	8,255-8,400-----	6	1.9	11.1	6.0			157	T-2	
Nugget Sandstone.	Steamboat Butte oil field, Wyoming.	≈5,200-----		8.7	24.9				11	N-1	
Nugget Sandstone (quartzite).	Afton quadrangle, Wyoming.		1?			8.2	2.46	2.54	110	T-2	
Nugget Sandstone.	Fremont County, Wyo.					24.9			84	N	
Sundance Formation.	Big Medicine Bow field, Wyoming.	5,165-5,855-----	24	6.0	23.2	12.9			123	A-9	
Do.	do.	5,419-----	1			12.6			157	T-2	
Do.	Iles dome, Colorado.	≈3,250-----	1			16.8			123	A-9	
Do.	Iles dome and Lance Creek fields, Colorado and Wyoming.	3,316-3,955-----	11	2.3	22.1	11.8			157	T-2	5 wells.
Sundance Formation, basal part.	Lance Creek field, Wyoming.	3,200-4,400-----	Many	20	30	25			40	N-1	
Sundance Formation.	Quealy and Lance Creek fields, Wyoming.	4,051-4,300-----	3	19.1	24.9	22.5			157	T-2	2 wells.
Do.	Salt Creek field, Wyoming.	2,717-2,944-----	4	4.5	17.6	11.7			157	T-2	Do.
Preuss Sandstone.	Afton quadrangle, Wyoming.	Outcrop-----				3.4	2.59	2.62	110	T-2	
Stump Sandstone.	do.					5.0	2.58	2.63	110	T-2	
Kingsk Shale.	Barrow, Alaska.	1,739-2,430-----	20	8.5	25.0	15.8			175	A	
Do.	Simpson, Alaska.	6,153-6,269-----	3	17	23	19.0			175	A	
Dogger sandstone.	Wesendorf field, Germany.	Subsurface(?)-----				23			124	N	
Do.	do.			12	22				124	N	
Sandstone.	Oberg field, Germany.								72	A-3	
Do.	Germany.	Quarry-----	4	5.2	24.6	17.1			72	A-3	
Do.	Luxemburg.	Outcrop-----	1			15.0	2.28	2.43	56	T-3	Fine sandstone, uniform.

Cretaceous

Raritan Formation (gravel).	New Jersey-----	185-----	1			31.9	1.67	1.99	143	T-5	
Raritan Formation (sandstone).	do-----	Outcrop and water well.	4	41.7	48.4	45.6	1.43	1.89	143	T-5	Medium sand.
Do.	do-----	Pit-----	2	39.9	44.8	42.3	1.49	1.91	143	T-5	Fine sand.
Raritan(?) Formation (sandstone).	do-----	do-----	1			41.5	1.54	1.96	143	T-5	Very coarse sand.
Do.	do-----	do-----	1			35.7	1.75	2.11	143	T-5	Fine gravel.
Sands.	Dare County, N.C.	6,487-6,681-----	22	2.5	33.9	26.6			142	N-1	
Do.	do-----	7,021-7,201-----	15	12.8	32.6	25.5			142	N-1	
Eutaw Formation (sands).	do-----	3,657-4,285-----	8	15.9	41.2	32.1			142	N-1	
Do.	Gilbertown field, Alabama.	3,300-3,400-----				30			36	N-1	
Tuscaloosa Group.	Brookhaven oil field, Mississippi.	10,135-10,545-----				24			174	N-1	Pilot zone.
						26			174	N-1	Smith zone.
						26			174	N-1	Arrington zone.

Footnotes on p. E25.

TABLE 1.—Sandstone, siltstone, quartzite, chert, and conglomerate—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Cretaceous—Continued											
Sturgis zone sand	Fouke field, Arkansas	≈3,600	2	15	36	27.3			135	N-1	
Trinity Group	Miller County, Ark.	Subsurface	2	28.7	29.9	29.3			123	A-9	
Dees sand	Rodessa field Louisiana	do.	3	13.1	24.9	17.9			123	A-9	
Gas Sand	Monroe gas field, Louisiana	≈2,150	5	14.3	40.3	27.8	2.04(4)	2.29(4)	98	T-2	
Hill sand	Rodessa field, Louisiana	Subsurface	2	18.0	22.8	20.4			123	A-9	
Tokio sand	Claiborne Parish La.	do.	2	29.3	30.7	30.0			123	A-9	
Do	Pine Island field, Louisiana	do.	3	3.2	18.4	13.3			9	A-6	
Trinity Group sand	North Lisbon field, Louisiana	do.	2	20.3	26.4	23.4			123	A-9	
Elledge sand	New Hope field, Texas	≈8,200	Many			10.8			154	N-1	
Hill sand	Carthage and New Hope fields, Texas	7,352-7,533	83	5.4	26.1	15.6			123	A-9	
Do	New Hope field, Texas	≈7,400	Many			16.6			154	N-1	
Do	Ham Gossett field, Texas	≈6,500				20			168	N-1	
Lower Pettit sand	Carthage field, Texas	5,885-6,164	32	3.9	31.0	21.2			123	A-9	
Paluxy Sandstone	Talco field, Texas	≈4,000				25			165	N-1	
Pittsburg sand	New Hope field, Texas	7,888-8,140	315	1.7	20.6	11.5			123	A-9	
Do	do.	≈7,900	Many			13.4			154	N-1	
Travis Peak Formation	Limestone County, Tex.	729-731	2	13.5	14.3	13.9	2.08	2.22	119	A-11	
Upper Pettit sand	Carthage field, Texas	5,675-5,691	16	13.0	20.7	16.7			123	A-9	
Woodbine Formation (sand)	Rusk County, Tex.	2,436-3,701	10	19.0	32.0	24.7	2.00	2.25	119	A-11	
Do	Gregg County, Tex.	3,514-3,715	31	19.8	31.4	26.7			123	A-9	
Do	Tyler County, Tex.					22.1			84	N	
Do	E. Texas field, Texas	≈3,650	7	23.8	29.0	26.0			43	A-6	
Do	do.	3,504-3,513	1			17.5			103	N	
Do	do.	3,522	1			17.6			103	N	
Do	do.	3,537-3,546	1			5.5			103	N	
Do	do.	3,537-3,546	1			6.3			103	N	
Do	do.	3,774-3,778	1			11.0			103	N	
Do	do.	3,774-3,778	1			17.6			103	N	
Do	do.	3,774-3,778	1			22.2			103	N	
Do	do.	3,778-3,780	1			19.7			103	N	

Calcareous.

Stilty.
Conglomerate.
Chalk conglomerate.
Conglomerate, clayey.
Poor saturation.
Fair saturation.
Excellent saturation.
Good saturation.

Do.....	do.....	3,785-3,786	1			11.0			103	N	Slight saturation. 10 wells.
Do.....	do.....	≈3,650	25	0(?)	27.2	19.0			103	N	
Do.....	Ham Gossett field, Texas	3,400-4,100				23			169	N-1	
Lewisville Member	Hawkins field, Texas	≈4,850				26.4			166	N-1	
Dexter Member	do.....	≈4,850				27.4			166	N-1	Lignitic. Carbon ratio, 50- 55 percent. Acid solubles, 34- 38 percent. Acid solubles, 37 percent.
Woodbine Formation (sand).	Mexia-Groesbeck field, Texas.	≈3,000	8	10.7	37.7	24.4	2.05	2.29	99	T-2	
Do.....	Limestone County, Tex...	2,910-3,025	100	5.1	29.7	18.6			123	A-9	
Sandstone, well-sorted	Iowa, Nebraska		9	33.1	41.3	37.3			131	T-1	
Sandstone, well-sorted, coaly.	South Dakota		2	27.7	29.9	28.8			131	T-1	Top member.
Sandstone, cemented	Lincoln County, Kans...	Outerop	7	1.1	3.4	1.5			149	A-8	
Do.....	Ellsworth County, Kans.	do.....	1			1.5			149	A-8	
Dakota Sandstone (D sand).	Denver Basin, Colorado	Subsurface		8.6	29.5	21.6			93	N-1	
Dakota Sandstone (J sand).	do.....	do.....		8.9	32.7	19.6			93	N-1	Lower member.
Dakota Sandstone (D sand).	Little Beaver field, Colo- rado.	≈5,200				19.7			44	N-1	
Do.....	do.....	≈5,400				20.7			44	N-1	
Dakota Sandstone (J sand).	do.....	≈5,400				22.8			44	N-1	
Dakota Sandstone	Several structures, Wyo- ming and Colorado.	2,465-3,600	7	13.5	23.4	18.5			157	T-2	4 wells.
Do.....	Beaver Creek and Nieber domes Wyoming.	7,949-8,634	6	4.0	7.6	5.4			157	T-2	2 wells.
Bearpaw Shale (siltstone).	Rosebud County, Mont...	Outerop	1			41.1	1.57	1.98	143	T-5	Very fine sand- stone. Fine sandstone.
Claggett Formation (silt- stone).	do.....	do.....	1			36.3	1.81	2.17	143	T-5	
Cut Bank sand	Glacier County, Mont.					15.4			84	N	
First Cat Creek sand	Fergus County Mont.		1			22.6	2.07	2.30	143	T-5	
Hell Creek Formation	Rosebud County Mont.	Outerop	5	24.8	38.3	35.3	1.80	2.15	143	T-5	Very fine sand- stone. Fine sandstone. Do. Do. Siltstone.
Do.....	Yellowstone County, Mont.	do.....	1			26.8	1.97	2.24	143	T-5	
Judith River Formation	Rosebud County Mont.	do.....	2	32.3	44.8	38.5	1.66	2.05	143	T-5	
Do.....	do.....	do.....	2	33.2	51.2	42.2	1.82	2.24	143	T-5	
Lance Formation	do.....	do.....	3	36.7	43.0	39.4	1.66	2.05	143	T-5	Fine sandstone. Do. Do. Siltstone.
Do.....	do.....	do.....	1			30.8	1.87	2.18	143	T-5	
Do.....	do.....	do.....	1			27.4	2.01	2.28	143	T-5	
Do.....	do.....	do.....	1			5.1	2.52	2.57	99	T-2	
Peay sand	Big Horn Mountains	do.....	1			5.0	2.58	2.63	99	T-2	Fine sandstone. Do. Do. Do.
Do.....	Jack Creek, Mont.	do.....	1			23.2	2.06	2.29	143	T-5	
Second Cat Creek sand	Fergus County, Mont.	do.....	1			25.8	1.96	2.22	143	T-5	
Third Cat Creek sand	do.....	do.....	1			23.6	2.06	2.30	143	T-5	
Virgelle Sandstone Mem- ber of Eagle Sandstone.	Yellowstone County, Mont.	do.....	1			27.1	1.93	2.20	143	T-5	Do.
Do.....	Fergus County, Mont.	do.....	1								

TABLE 1.—Sandstone, siltstone, quartzite, chert, and conglomerate—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Cretaceous—Continued											
Adaville Formation (sandstone).	Sublette County, Wyo.	12, 726-12, 734	6	10.3	13.7	12.0			(4)	A	Quartzite. Conglomerate. Siltstone.
Do.	do.	13, 248-13, 874	36	7.7	16.5	12.2			(4)	A	
Do.	do.	14, 554-14, 767	11	8.1	11.9	10.1			(4)	A	
Blair Formation (sandstone).	do.	15, 764-15, 784	11	7.8	15.4	11.0			(4)	A	
Blair(?) Formation (sandstone).	do.	16, 683-16, 880	15	4.3	10.4	7.6			(4)	A	
Frontier Formation (sandstone).	do.	20, 384-20, 503	21	4.6	9.5	7.4			(4)	A	
Bear River Formation.	Afton quadrangle, Wyoming.		1			7.2	2.48	2.55	110	T-2	
Do.	do.		1			13.8	2.32	2.46	110	T-2	
Do.	do.		1			12.9	2.28	2.41	110	T-2	
Do.	do.		1			7.4	2.47	2.54	110	T-2	
Cody Formation.	Beaver Creek structure, Wyoming.	3,728				7.1			157	T-2	
Ephraim Conglomerate.	Afton quadrangle, Wyoming.	Outcrop	1			13.2	2.31	2.44	110	T-2	
Frontier Formation.	Grass Creek field, Wyoming.	Subsurface				27.0	1.93	2.20	98	T-2	
Do.	Afton quadrangle, Wyoming.					17.1	2.30	2.47	110	T-2	
Frontier Formation (sandstone).	Wyoming.	4,270-6,895	4	2.7	20.8	14.1			157	T-2	3 wells. Do. 2 wells.
Do.	do.	7,054-8,435	17	.7	25.9	10.7			157	T-2	
Lakota Formation (sandstone).	Quealy and Lance Creek structures, Woming.	3,715-3,966	4	12.7	23.2	17.6			157	T-2	
Do.	Nieber dome, Wyoming.	8,365	1			6.8			157	T-2	
Lower Muddy sand	S. Glen Rock field, Wyoming.	5,500-6,800				20			37	N-1	
Upper Muddy sand	do.	5,500-6,800				14			37	N-1	
Mesaverde Formation.	Beaver Creek structure, Wyoming.	2,025	1			20.2			157	T-2	
Newcastle Sandstone.	Lance Creek field, Wyoming.	2,900-2,915	2	14.9	20.7	17.8	2.29(1)	2.44(1)	98	T-2	
Do.	Osage field, Wyoming.	40(?)	12	11.3	26.0	16.7	2.15(5)	2.34(5)	98	T-2	
Do.	do.	1,415-1,450	3	21.3	23.6	22.7	2.04(1)	2.28(1)	98	T-2	

Do.....	Weston, Crook and Carbon Counties, Wyo.	Outcrop.....	9	8.8	24.8	21.2	2.17(4)	2.35(4)	98	T-2	
Do.....	Weston County, Wyo.	1,435.....	2	19.0	19.5	19.3	2.14	2.33	98	T-2	
Torchlight Sandstone Member of Frontier Formation.	Big Horn County, Wyo.	Outcrop.....	2			29.4			99	T-2	
First Wall Creek sand.	Carbon County, Wyo.	do.....	1			19.9			99	T-2	
Do.....	Lost Soldier field, Wyoming.	289-313.....	2	17.5	20.1	18.8	2.19(1)	2.37(1)	98	T-2	
Do.....	Salt Creek field, Wyoming.	1,235.....	1			19.8	2.18	2.38	98	T-2	
Do.....	Big Muddy field, Wyoming.	3,040-3,187.....	6	17.4	23.4	20.5	2.07	2.29	98	T-2	
Wall Creek Sandstone.	Salt Creek field, Wyoming.	1,033-1,454.....	4	12.1	20.8	15.3			157	T-2	2 wells.
Do.....	do.	≈1,500.....	1			25.8	1.96	2.22	99	T-2	
Do.....	Natrona County, Wyo.	Outcrop.....	1			7.6	2.47	2.55	99	T-2	Calcareous.
Wayan Formation.	Afton quadrangle, Wyoming.	do.....	1			7.7	2.45	2.53	110	T-2	
Ferron Sandstone Member of Mancos Shale.	Wasatch Plateau gas fields, Utah.	4,600-5,100.....		1	21	12-15			159	N-1	
Dakota Sandstone.	North of Chama, N. Mex.	Outcrop.....	27	3.9	24.5	17.0			158	T-2	
Okpikruak Formation.	Oumalik, Alaska.	9,278-10,468.....	10	2.8	10.0	4.8			175	A	Graywacke.
Seabee Formation.	Umiat, Alaska.	536-577.....	3	6.1	17	11			175	A	
Topagoruk Formation.	Barrow, Alaska.	200-1,916.....	10	24	29	25.9			175	A	
Do.....	Fish Creek, Alaska.	2,923-2,970.....	2	25	31	28.0			175	A	
Do.....	Oumalik, Alaska.	919-2,756.....	24	4	15.0	8.3			175	A	
Do.....	Simpson, Alaska.	133-683.....	22	30	38	35.0			175	A	
Do.....	Umiat, Alaska.	100-3,009.....	97	4	44	13.6			175	A	
Torok Formation.	Barrow, Alaska.	1,210-3,198.....	44	6.4	24.0	15.0			175	A	Do.
Tuktu Formation.	Fish Creek, Alaska.	5,481-6,010.....	8	6.0	10.0	7.8			175	A	Do.
Do.....	Oumalik, Alaska.	3,244-3,756.....	10	6.0	16.0	10.9			175	A	Do.
Do.....	Barrow, Alaska.	2,094-2,095.....	1			24.0			175	A	Do.
Tuluga Member (former usage) of Schrader Bluff Formation.	Fish Creek, Alaska.	1,633-1,640.....	2	28	33	30.5			175	A	
Basal quartz sand.....	Bellshill Lake field, Alberta, Canada.	≈3,100.....	25			26.6			130	N-1	
Ellerlie quartz sands.....	White Mud oil field, Alberta, Canada.	≈4,100.....				25.5			77	N-1	
Viking sandstone.....	Alberta, Canada.	Subsurface.....	2	17	22	20			128	N-1	
Guasare formation.....	La Paz field, Venezuela.	1,800-2,300.....				22			24	N-1	
Eudower sandstone.....	Germany.....	Outcrop.....	2	12.5	15.9	14.2	2.26	2.40	56	T-3	
Quadersandstein.....	do.....	Quarry.....	16	12.2	26.2	21.7			72	A-3	
Sandstone.....	do.....	do.....	13	8.8	23.6	18.9			72	A-3	
Valendis sand.....	Emlichheim field, Germany.	Subsurface.....		25	39				124	N	
Do.....	Lingen field, Germany.	do.....		12	15				124	N	
Wealden sands.....	Nienhagen and Hänigsen fields, Germany.			25	30				124	N	

Footnotes on p. E25.

TABLE 1.—*Sandstone, siltstone, quartzite, chert, and conglomerate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Paleocene											
Fort Union Formation	North of Buckley, Mont.	Outcrop	1			22.6	2.09	2.32	143	T-5	Fine sandstone. Do.
Lebo shale Member of Fort Union Formation (sandstone).	Rosebud County, Mont.	do	1			27.7	1.93	2.21	143	T-5	
Lebo shale Member of Fort Union Formation (siltstone).	do	do	1			40.1	1.65	2.05	143	T-5	Siltstone.
Tongue River Member of Fort Union Formation.	do	do	7	9.4	36.6	27.3	1.96	2.24	143	T-5	Fine stonestone.
Do	do	do	3	31.4	53.6	40.0	1.63	2.03	143	T-5	Very fine sandstone. Siltstone.
Do	do	do	1			26.2	1.91	2.17	143	T-5	
Tullock Member of Fort Union Formation.	do	do	2	26.7	36.6	31.7	1.87	2.19	143	T-5	Very fine sandstone. Siltstone. Medium sandstone.
Do	do	do	1			29.8	1.92	2.22	143	T-5	
Do	do	do	1			34.0	1.73	2.07	143	T-5	
Paleocene and Eocene											
Wasatch Formation	Powder Wash field, Colorado.	3,090-3,113	4	25.9	30.2	27.7			123	A-9	
Eocene											
Sparta Sand	Gulf coast, U.S.A.	359-736	13	33.7	46.5	42.2			81	N-2	From core graphs.
Do	Gulf coast oil fields, U.S.A.	≈9,000	Many			18-20			151	N-1	
Do	Nachitoches, La.	556-588	3	41.1	41.8	41.4			81	N-2	
Do	Ville Platte field, Louisiana.	9,075				26			151	N-1	
Wilcox Group (sands)	Gulf coast, U.S.A.	212-556	10	40.0	43.9	41.6			81	N-2	
Do	Gulf coast oil fields, U.S.A.	Subsurface	Many			20-22			151	N-1	
Do	Eola field, Louisiana.	≈8,500	68	9	23	22			13		
Do	do	8,559				24			151	N-1	

Morein (Wilcox) sand.....	Mamou field, Louisiana.....	≈11,500.....	200			19.7			32	N-1	
Cockfield sands.....	Conroe field, Texas.....	5,250 (av.).....				25-28			101	N-1	
Lower Pawelek (Wilcox) sand.....	Falls City field, Texas.....	≈6,300.....	45			24.5			34	N-1	
O'Hern sand.....	Duval County, Tex.....					28.4			84	N	
Wilcox Group (sands).....	Coastal fields, Louisiana, Texas.....	7,630-10,156.....	Many	7	23	18.4			35	N-1	14 fields.
Wilcox Group (massive sand).....	Slick-Wilcox field, Texas.....	≈8,000.....				22			137	N-1	
Yegua Formation (sands).....	Katy field, Texas.....	6,250-7,450.....				27			2	N-1	
Knight Conglomerate.....	Afton quadrangle, Wyoming.....		1(?)			7.4	2.47	2.54	110	T-2	Siltstone.
Lyre Formation.....	Olympic Peninsula, Wash.....	Outerop.....	4	7.4	9.7	8.7			21	A	
Gatchell sand.....	Pleasant Valley field, California.....	≈9,150.....	Many			15			162	N-1	
Chorro sands.....	Infantes field, Columbia.....	≈2,200-≈2,600.....		15	22				4	N	
Middle Pauji sandstone.....	Venezuela.....	Subsurface.....				12			24	N	
Misoca-Trujillo sandstone.....	do.....	do.....				10			24	N	
Ramillete sands.....	La Concepcion field, Venezuela.....	≈3,000.....				21			24	N	
Punta Gorda sands.....	do.....	≈4,000.....				18.5			24	N	
Upper sands.....	La Paz field, Venezuela.....	≈1,600.....				26			24	N	
Tabla sands.....	Los Manueles field, Venezuela.....	6,000-7,500.....			20	8-10			24	N	
Sandstone.....	Isle of Wight.....	Outerop.....	1			33.8	1.73	2.07	105	A-2	Banded sandstone.

Eocene and Oligocene

Merecure Formation.....	Anaco field, Venezuela.....	≈7,000-≈10,000.....	Many			15-20			54	N-1	
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Eocene to Miocene

Sandstone.....	Wasco field, California.....	10,500-15,004.....				15			156	N-1	
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Oligocene

Sands.....	Saxet field, Texas.....	≈5,800.....	Many	7	45	31			120	N-1	Medium to coarse.
Do.....	do.....	≈6,300.....	Many	20	31	23			120	N-1	Do.
Do.....	do.....	≈6,900.....	Many	21	34	28			120	N-1	Do.
B zone sands.....	La Cara field, Colombia.....	1,100-2,000.....				22			4	N	
Sandstone.....	Cantons of Freiburg, Luzern, Vaud, and Zug, Switzerland.....	Quarry.....	6	1.5	13.9	5.8	2.53	2.59	63	T-4	Dip low to 25°, in part calcareous.
Do.....	Cantons of Unterwalden, Vaud, and Wallis, Switzerland.....	do.....	4	.8	4.1	2.3	2.64	2.66	63	T-4	Dip 15°-50°, calcareous.

TABLE 1.—*Sandstone, siltstone, quartzite, chert, and conglomerate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Oligocene(?)											
Frio Clay (sand)-----	Amelia field, Texas-----	6,694-6,785-----	-----	-----	-----	30-----	-----	-----	65-----	N-1-----	
Do-----	Anahuac field-----	6,960-7,078-----	22-----	23.4-----	37.1-----	30.4-----	-----	-----	123-----	A-9-----	
Frio Clay (sand No. 1)-----	South Cotton Lake field, Texas-----	≈6,500-----	-----	-----	-----	30-35-----	-----	-----	170-----	N-1-----	
Frio Clay (sand No. 2)-----	do-----	≈6,500-----	-----	-----	-----	30-35-----	-----	-----	170-----	N-1-----	
Marginulina sand-----	do-----	≈6,500-----	-----	-----	-----	25-30-----	-----	-----	170-----	N-1-----	
Sand in Frio Clay-----	La Rosa field, Texas-----	≈5,900-----	-----	-----	-----	32-----	-----	-----	50-----	N-1-----	
Oligocene and Miocene											
Amarillo F sand-----	Guarido dome, Venezuela-----	≈6,500-----	-----	-----	-----	22-26-----	-----	-----	54-----	N-1-----	Average of averages, 26 percent.
Oficina formation (sands)-----	Anaco fields, Venezuela-----	≈4,500-≈9,500-----	Many-----	-----	-----	18-20-----	-----	-----	54-----	N-1-----	
Do-----	Greater Oficina area, Venezuela-----	3,000-7,700-----		-----	-----	21-30-----	-----	-----	69-----	N-1-----	
				-----	-----	-----	-----	-----			
Miocene											
Kirkwood Formation-----	New Jersey-----	≈800-----	5-----	30.2-----	44.3-----	38.0-----	1.63-----	2.01-----	143-----	T-5-----	Fine to gravelly.
Catahoula Sandstone-----	Gulf coast, U.S.A-----	232-248-----	2-----	40.0-----	40.9-----	40.5-----	-----	-----	81-----	N-2-----	
Do-----	Saxet field, Texas-----	≈4,400-----	Many-----	29-----	42-----	35-----	-----	-----	121-----	N-1-----	
Fleming Formation of former usage-----	Gulf coast, U.S.A-----	346-1,852-----	9-----	31.3-----	50.1-----	41.2-----	-----	-----	81-----	N-2-----	Medium to coarse.
Lombardi sand-----	San Ardo field, California-----	≈2,100-----	-----	40-----	45-----	-----	-----	-----	8-----	N-1-----	
Modelo Formation, lower part-----	Santa Monica Mountains, Calif-----	Outcrop-----	2-----	22.4-----	24.0-----	23.2-----	-----	-----	80-----	T-2-----	Graywacke.
Miocene A-2 sand-----	Wasco field, California-----	13,095-13,130-----	-----	12-----	24-----	-----	-----	-----	156-----	N-1-----	
Salinas Shale (sandstone)-----	Santa Barbara County, Calif-----	Outcrop-----	1-----	-----	-----	33.3-----	1.78-----	2.11-----	98-----	T-2-----	Dip 55°.
Stevens sand zone-----	Paloma field, California-----	10,008-10,178-----	-----	18-----	20-----	-----	-----	-----	28-----	N-1-----	
Stevens sand-----	do-----	≈10,000-----	2-----	-----	-----	21.9-----	2.08-----	2.30-----	76-----	A-5-----	Standard deviation, 4.1 percent.
Stevens sand, F-1 section-----	South Coles Levee field, Calif-----	9,294-9,438-----	103-----	3.8-----	24.9-----	18.9-----	-----	-----	57-----	A-9-----	
				-----	-----	-----	-----	-----			
Stevens sand-----	Ten Section field, California-----	≈8,100-----	Many-----	15-----	30-----	20-----	-----	-----	90-----	N-1-----	
Temblor Formation (sands)-----	Kettleman Hills field, California-----	6,250-9,332-----	Many-----	-----	-----	14-----	-----	-----	59-----	N-----	

Tembler Formation (sandy shales).	-----do-----	6,250-9,332	Many	-----	-----	7	-----	-----	59	N	300 ft of sand.
Upper Terminal zone	Wilmington oil field, California.	3,000-3,500	-----	-----	-----	25	-----	-----	12	N	
Conglomerate	Cantons of Appenzell and St. Gallen, Switzerland.	Quarry	2	1.1	1.1	1.1	2.72	2.73	63	T-4	Dips 16°-17°.
Sandstone	Cantons of Aargau, Schwyz, Solothurn, St. Gallen, Zug, Appenzell-A - Rh, Basel - Land, Bern, Freiburg, and Luzern, Switzerland.	-----do-----	15	13.3	22.1	18.7	2.19	2.37	63	T-4	Dips 7° or less.
			53	.4	17.3	6.5	2.52	2.59	63	T-4	Dips 10° or more.
Tipam series sand	Digboi field, Assam.	≈ 5,000	-----	3	27	12	-----	-----	30	N-1	

Pliocene

First grubb pool	San Miguelito field, California.	≈ 6,000	800	-----	-----	18	-----	-----	60	N-1	20 wells, poorly sorted sands.
First grubb zone	-----do-----	6,570-7,447	-----	-----	-----	20.6	-----	-----	96	N-1	
Second grubb zone	-----do-----	7,706-8,259	-----	-----	-----	19	-----	-----	96	N-1	
Third grubb zone	-----do-----	8,472-8,938	-----	-----	-----	14.2	-----	-----	96	N-1	

Pliocene and Pleistocene

Sands	Mamou, La.	510-957	4	36.2	38.7	37.8	-----	-----	81	N-2	
Do	Gulf coast, U.S.A.	2,062-2,135	3	40.0	40.6	40.3	-----	-----	81	N-2	

Tertiary

Sandstone	Germany	Quarry	1	-----	-----	29.1	-----	-----	72	A-3	
-----------	---------	--------	---	-------	-------	------	-------	-------	----	-----	--

Age not specified

Sandstone	Lancashire and Derby, England.	Outcrop(?)	2	12.8	13.7	13.3	2.27	2.40	73	T-2	
Sandstone (dolomitic)	Mansfield, England.	Outcrop	1	-----	-----	14.1	2.31	2.45	73	T-2	
Quartzite	Nuneaton, England.	-----do-----	1	-----	-----	6.4	2.48	2.54	73	T-2	
Do			-----	-----	-----	.21	-----	-----	58	A-14	
Conglomerate	St. Marcet anticline, France.	≈ 5,000	-----	2	18	-----	-----	-----	134	N	
Pechelbronn sand	Pechelbronn, France.	Subsurface	1	-----	-----	17.8	-----	-----	9	A-6	

¹ E. C. Robertson, written communication, 1962.

² Superior Oil Co., written communication, 1959; D. A. Beaudry, 1950, Pore space reduction in some deeply buried sandstones: Unpublished dissertation, Univ. Cincinnati.

³ R. A. Cadigan, W. H. Caraway, G. L. Gates, and F. C. Morris, written communication, 1955.

⁴ Superior Oil Co., written communication, 1959; F. R. Hays, 1951, A petrographic study of deeply buried sandstones from the Superior Pacific Creek unit No. 1 well, Sublette County, Wyoming: Unpublished dissertation, Univ. Cincinnati.

TABLE 2.—*Limestone, dolomite, chalk, and marble*

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gm-3)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Precambrian											
Grenville Marble.....	Ontario, Canada.....	Quarry.....	9	0.01	1.06	0.35	2.77	2.77	112	A-2	
Cambrian											
Bonneterre Dolomite.....	Near Bonne Terre, Mo...	Subsurface.....				3.3	2.66	2.69	16	A-16	Galena bearing.
Do.....	do.....	do.....					3.30		16	A-16	
Gallatin Limestone.....	Afton quadrangle, Wyo- ming.	Outcrop.....				8.6	2.61	2.70	110	T-2	
Gros Ventre Formation.....	do.....	do.....				11.0	2.40	2.51	110	T-2	
Ophir Formation (lime- stone).	Ophir, Utah.....	Mine.....				.26	2.78	2.78	173	A-16	
Upper Cambrian and Lower Ordovician											
Arbuckle Group (lime- stone).	Various fields, Kansas.....	2,887-4,202.....	26	1.2	19.8	10.3			123	A-9	
Do.....	Woodrow field, Oklahoma.	≈1,900.....				2-8			95	N-1	
Lower Ordovician											
Ellenburger Group (lime- stone).	Riley Mountain, Llano County, Tex.	Outcrop.....	12	0.1	0.7	0.5	2.69	2.70	62	T-2	Sublithographic.
Ellenburger Group (dolo- mite).	do.....	do.....	23	1.1	12.6	4.3	2.72	2.76	62	T-2	Micro- granular.
Do.....	do.....	do.....	11	1.3	7.1	3.6	2.73	2.77	62	T-2	Fine grained.
Do.....	do.....	do.....	6	1.7	4.3	2.6	2.75	2.78	62	T-2	Medium grained.
Do.....	do.....	do.....	2	2.6	5.0	3.8	2.73	2.77	62	T-2	Coarse grained.
Ellenburger Group (cherty limestone).	do.....	do.....	1			.4	2.69	2.69	62	T-2	
Ellenburger Group (cal- citic dolomite).	do.....	do.....	1			.8	2.74	2.75	62	T-2	
Ellenburger Group (dolo- mitic limestone).	do.....	do.....	1			1.5	2.75	2.77	62	T-2	

Do.....	Permian Basin, West Tex.	≈8,800.....	63	-----	-----	2.5	-----	-----	7	A-4	Matrix porosity.
Do.....	do.....	8,857-8,893.....	36	-----	-----	3.30	-----	-----	7	A-4	All porosity.
Do.....	do.....	8,857-8,893.....	36	-----	-----	1.51	-----	-----	7	A-4	Matrix porosity
Do.....	do.....	8,857-8,893.....	36	-----	-----	1.79	-----	-----	7	A-4	Fracture and vug porosity.

Ordovician

Trenton Limestone (medium crystalline).	Rose Hill field, Virginia.	Subsurface.....	-----	-----	-----	1.2	-----	-----	102	N-1	Producing, 2 wells.
Trenton Limestone (finer crystalline).	do.....	do.....	-----	-----	-----	.6	-----	-----	102	N-1	Producing, 1 well.
Kingsport Formation (dolomite).	Mascot, Tenn.	do.....	3	-----	-----	.7	2.84	2.85	172	A-16	
Do.....	Jefferson City, Tenn.	56-285.....	7	0.4	2.3	1.3	2.78	2.79	172	A-16	
Martinsburg Shale (limestone).	Sand Hill well, Wood County, W. Va.	9,416.....	1	-----	-----	.6	2.71	2.72	(1)	A-15	
Trenton Limestone (quartzitic).	do.....	9,577-9,664.....	6	.3	2.7	.9	2.67	2.68	(1)	A-15	
Black River Limestone.	do.....	9,791-10,511.....	35	.1	1.4	.4	2.70	2.70	(1)	A-15	
Beekmantown Group (dolomite).	do.....	10,531-11,945.....	56	.1	1.1	.4	2.80	2.80	(1)	A-15	
Prairie du Chien Group (dolomite).	Wisconsin.....	Quarry.....	4	11.1	13.4	12.4	2.43	2.55	22	A-1	
Trenton Limestone (dolomite).	do.....	do.....	2	.9	1.2	1.0	2.81	2.82	22	A-1	
Kimmswick Limestone.	Dupo pool, Illinois.	401-445.....	44	1.9	17.0	10.8	-----	-----	118	A-6	
Do.....	do.....	≈600.....	4	11.6	16.5	15.8	-----	-----	123	A-9	
Viola Limestone.	Cunningham field, Kansas.	4,048-4,051.....	3	2.9	3.1	3.0	-----	-----	123	A-9	
Simpson Group.	do.....	4,051-4,117.....	36	5.7	22.3	13.3	-----	-----	123	A-9	
Bighorn Dolomite.	Afton quadrangle, Wyoming.	Outcrop.....	-----	-----	-----	8.6	2.59	2.68	110	T-2	
Beekmantown Group (limestone, dolomite).	Ontario, Canada.....	Quarry.....	4	1.3	12.6	4.6	2.66	2.71	112	A-2	4 localities.
Black River Group (limestone).	do.....	do.....	11	.07	1.67	.46	2.72	2.72	112	A-2	10 localities.

Silurian

Brassfield Limestone.	Piqua, Ohio.....	Quarry.....	-----	-----	-----	1.3	2.8	-----	173	A-16	Dolomitic.
Do.....	do.....	do.....	-----	-----	-----	2.7	2.6	-----	173	A-16	
Niagara Group (dolomite).	Maple Grove, Ohio.	do.....	-----	-----	-----	8.6	2.4	-----	173	A-16	
Do.....	Gibsonburg, Ohio.	do.....	2	3.4	4.0	3.7	2.6	-----	173	A-16	
Do.....	Lucky, Ohio.	do.....	2	3.0	8.5	5.8	2.5	-----	173	A-16	
Red Mountain Formation (limestone).	Bessemer, Ala.	1,400.....	-----	-----	-----	.9	2.83	2.84	172	A-16	
Do.....	do.....	Mine.....	-----	-----	-----	.6	2.92	2.93	172	A-16	Limonitic.

Footnotes on p. E34.

TABLE 2.—*Limestone, dolomite, chalk, and marble—Continued*

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Silurian—Continued											
Niagara Dolomite.....	Wisconsin.....	Quarry.....	14	0.5	6.7	2.9	2.74	2.77	22	A-1	3 localities. 6 localities.
Guelph Dolomite.....	Ontario, Canada.....	do.....	3	14.6	15.9	15.4	2.41	2.56	112	A-2	
Niagara Group (limestone, dolomite).....	do.....	do.....	6	4.4	13.4	9.1	2.54	2.63	112	A-2	
Salina Dolomite.....	W. Becher pool, Ontario.....	1,850-1,925.....				10			127	N-1	
Limestone.....	Various localities, Great Britain.....		4	1.4	6.3	2.8	2.61	2.64	105	A-2	
Upper Silurian and Lower Devonian											
Hunton Group (limestone).....	Hollow pool, Kansas.....	Subsurface.....	1			23.6			123	A-9	8 wells.
Hunton Group, Bois d'Arc Limestone.....	W. Edmond field, Oklahoma.....	6,947-7,296.....	349	0.10	14				97	N-1	
Do.....	do.....	≈7,000.....	56	.5	18.2				97	N-1	
Hunton Group, Bois d'Arc, Harragan, and Henryhouse Limestone.....	do.....	≈7,000.....	545	1.9	16.7	7.3			91	N-1	
Devonian											
Columbus Limestone.....	Barberton, Ohio.....	Quarry.....	3			0.7	2.69	2.70	172	A-16	
Do.....	Columbus, Ohio.....	do.....				5.4	2.60	2.65	17	A-16	
Delaware Limestone.....	Spore, Ohio.....	do.....	4	5.2	6.4	5.8	2.5		173	A-16	
Devonian Limestone.....	Crawford-Main pool, Illinois.....	2,935-2,948.....	14	3.8	11.8	8.1			118	A-6	Matrix porosity.
Dundee Limestone (dolomite).....	Coldwater field, Michigan.....	≈3,750.....	16			2.5			33	N-1	
Rogers City Limestone (dolomite).....	do.....	≈3,750.....	39			4.2			33	N-1	Do.
Ouray Limestone.....	Rattlesnake field, San Juan County, N. Mex.	7,005-7,015.....	6	1.4	2.7	2.0			71	N-1	Porous zone.
Do.....	do.....	7,155-7,178.....	4	7.6	12.9	10.0			71	N-1	
Jefferson Dolomite.....	Afton quadrangle, Wyoming.....					6.2	2.65	2.71	110	T-2	

D-3 zone dolomite.....	Leduc field, Alberta, Canada.	4,850-5,400.....				13			86	N-1	
D-3 zone.....	do.....	5,150-5,300.....	25	2.5	3.5				160	N-1	Dense matrix.
Limestone.....	Various localities, Germany.		6	.6	2.7	6.8	1.9		160	N-1	Entire matrix.
									72	A-3	
Mississippian											
McClosky lime.....	Lawrence County, and Noble pools, Illinois.	1,739-2,970.....	60	2.3	25.9	14.2			118	A-6	Oolitic.
Do.....	Olney and Salem pools, Illinois.	1,900-3,004.....	18	5.1	14.1	10.7			118	A-6	Do.
Do.....	Salem pool, Illinois.	≈2,000				10.3			5	N-1	Do.
McClosky limestone.....	Hitesville Cons. field, Kentucky.	2,525-2,578.....				13.2			23	N-1	Do.
McClosky limestone (D zone).....	do.....	≈2,600				13.5			23	N-1	Do.
Maxville Limestone.....	Muskingum County, Ohio.	≈200	2	.9	2.0	1.5	2.77	2.79	17	A-16	
Maxville Limestone (marl).....	do.....	≈200	6				2.67		17	A-16	
Maxville Limestone (marl).....	do.....	≈200	3				2.19		17	A-16	
Spergen Limestone.....	Bedford, Ind.	Quarry	7	11	15.4	13	2.29	2.42	172	A-16	
Do.....	Ste. Genevieve, Mo.	≈100	15				2.59		172	A-16	
St. Louis Limestone.....	Prarie du Rocher, Ill.	250-350	3			.8	2.68	2.69	16	A-16	
Do.....	Ste. Genevieve, Mo.	≈50	6				2.62		17	A-16	
Boone Formation, siliceous.....	Near Picher, Okla.	Mine	2			1.2	2.67	2.68	16	A-16	
Do.....	do.....	do.....	2			8.9	2.39	2.48	16	A-16	
Brazer Limestone.....	Afton quadrangle, Wyoming.		2			4.0	2.64	2.68	110	T-2	
Madison Limestone.....	Beaver Lodge and Tioga fields, Montana.	≈8,400	Many			6			31	N-1	12 wells.
Do.....	Afton quadrangle, Wyoming.		1			3.6	2.61	2.65	110	T-2	
Rundle Formation: Upper porous zone.....	Turner Valley field, Alberta, Canada.	≈6,900	48	2.0	19.6	10.8			55	N-1	Dolomite, limestone.
Lower porous zone.....	do.....	≈7,100	84			10.4			55	N-1	Do.
Upper porous zone.....	do.....	4,570-6,730		1	20	10			92	T-2	Dolomitic.
Lower porous zone.....	do.....	5,020-6,970		1	20	10			92	T-2	Do.
Pennsylvanian											
Lansing and Kansas City Formations.....	Ellingwood field, Kansas.	≈3,340.....	5	6.2	25.3	12.6			123	A-9	
Canyon reef limestone.....	Scurry field, Texas.	≈6,800	2,109	0	31.6	6.3			123	A-9	
Crinoidal limestone.....	Todd Deep field, Texas.	≈5,800				11.7			78	N-1	
Marble Falls Limestone.....	Erath County, Tex.	3,363-3,461.....	3	7.3	20.7	15.3			119	A-11	

TABLE 2.—Limestone, dolomite, chalk, and marble—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Carboniferous											
Carboniferous limestone	Midlands, England	Outcrop	24	2.2	14.9	5.7	2.52	2.58	113	T-2	30 percent MgCO ₃ .
Limestone	Micheldean, Great Britain	do	2	9.0	9.4	9.2	2.45	2.53	105	A-2	
Do	Hilton, Great Britain	Outcrop	1			2.2	2.59	2.61	105	A-2	Under Whinsill, 2 localities.
Do	Germany	Quarry	2	.6	1.3	1.0			72		
Permian											
Brown dolomite	Moore County, Tex.	3,574-3,614	15	3.2	27.1	11.7			(2)	A-10	Permeable. Impermeable. Dolomite(?).
Limestone	do	3,614-3,644	8	6.3	12.2	8.5			(2)	A-10	
Permian limestone	Big Springs field, Texas	≈9,000	5	11.9	22.2	17.9			123	A-9	
Rex chert Member of Phosphoria Formation, Zechstein	Afton quadrangle, Wyoming					17.0	2.33	2.50	110	T-2	
Do	Germany	Outcrop	1			3.1	2.64	2.67	56	T-3	
Do	Various localities, Germany	Quarry	3	4.1	21.3	12.3			72	A-3	
Dolomite	Aktyubin area, U.S.S.R.	Subsurface	4			4.1	2.62	2.66	108	T	
Limestone	do	do	1			5.2	2.75	2.80	108	T	
Marl	Kungur salt basin, U.S.S.R.	do	5			7.6	2.62	2.70	108	T	
Do	Aktyubin area, U.S.S.R.	do	14			8.4	2.53	2.61	108	T	
Paleozoic(?)											
Cockeysville Marble	Cockeysville, Md.	Quarry				0.6	2.87	2.88	172	A-16	Dolomitic.
Triassic											
Dinwoody Formation (sandy limestone).	Afton quadrangle, Wyoming					12.9	2.42	2.55	110	T-2	
Thaynes Limestone	do			8.3	8.7				110	T-2	
Do	do		1			.7	2.65	2.66	110	T-2	
Ross Fork Limestone	do					7.0	2.52	2.59	110	T-2	

Limestone	Germany	Quarry	2	1.8	2.4	2.1			72	A-3	Oolitic.
Muschelkalk	Mutzig, Germany	Outcrop	1			1.0	2.68	2.69	56	T-3	
Do	Various localities, Germany.	Quarry	19	1.2	36.5	15.5			72	A-3	
Do	Gallcia, Poland	do	1			13.4	2.46	2.59	56	T-3	
Limestone	Cantons of Vaud, Aargau, and Basel-Stadt, Switzerland.	do	6	1.1	4.4	2.9	2.67	2.70	63	T-4	Dip 3°-65°; in part dolomitic.
Do	Canton Tessin, Switzerland.	do	7	.4	4.0	2.0	2.68	2.70	63	T-4	Dip about 25°.
Marble	Canton Graubünden, Switzerland.	do	2	2.1	2.9	2.5	2.64	2.67	63	T-4	
Jurassic											
Reynolds oolite	Cairo field, Arkansas	≈7,800				17			61	N-1	Porous.
Reynolds Oolitic, Member of Smackover Formation	Dorchest pool, Arkansas	9,018-9,093		2	20	12			152	N-1	
Reynolds oolite	Schuler field, Arkansas	7,650-7,750			23	16.7			163	N-1	
Reynolds oolitic limestone	Various fields, Arkansas	7,250-7,650	4	16.4	20.0	18.0			123	A-9	
Smackover Formation	do	≈7,850	150	0	23.9	14.5			123	A-9	
Do	McKamie-Patton pool, Arkansas	≈9,300	1,767			14.2			133	N-1	
Do	McKamie field, Arkansas	9,120-9,381	14	0	16.4	7.5			123	A-9	
Twin Creek Limestone	Afton quadrangle, Wyoming.					0.2	2.75	2.75	110	T-2	
Carmel formation (limestone).	Near Huntington Utah	5-20	6	.2	4.6	2.0	2.65	2.67	173	A-16	
Inferior oolite	Cotteswolds, England	Outcrop	3	5.5	24.0	13.4	2.33	2.46	105	A-2	
Oolite	Clove Hill and Lockhampton Hall, England	do	2	14.3	18.3	16.3	2.25	2.41	105	A-2	
New Red marl	Leamington, England	do	1	30.0	34.4	32.2			141	A-2	
Do	England	Deep boring	4	4.8	10.0	7.5			141	A-2	
Portland limestone	Great Britain	Outcrop	1			8.6	2.54	2.63	73	A-2	
White Lias	Tiverton, England	do	1			9.4	2.44	2.53	105	A-2	
Limestone	St. Marcet anticline, France.	≈6,000			18-20	10			134	N	
Do	Germany		1			5.0			72	A-3	Dip 8° or more, or not recorded.
Solenhofen Limestone	do	Outcrop(?)	23	1.2	5.7	3.9	2.57	2.61	(1) 63	A-15	
Limestone	Cantons of Aargau, Basel-Land, Bern, Freiburg, Neuenberg, Solothurn, St. Gallen, Tessin, Vaud, and Zurich, Switzerland.	Quarry	114	.4	25.6	3.6	2.63	2.66	63	T-4	
Do	Mostly from Canton Schaffhausen, Switzerland.	do	18	.9	10.7	5.4	2.57	2.63	63	T-4	
No. 3 limestone	Dukhan field, Qatar	5,600-6,600	Many			16			38	N-1	
No. 4 limestone	do	5,600-6,600	do			21			38	N-1	

Footnotes on p. E34.

TABLE 2.—Limestone, dolomite, chalk, and marble—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Cretaceous											
Dees oolitic limestone.....	Rodessa field, Louisiana.....	≈ 5,450.....	74.....	8.0.....	32.0.....	22.0.....	123.....	A-9.....	19 wells.
Dees Coquina limestone.....	do.....	≈ 5,450.....	20.....	7.0.....	29.7.....	20.2.....	.....	.....	123.....	A-9.....
Kilpatrick zone.....	Sugar Creek field, Louisiana.....	≈ 4,520.....	.....	14.....	23.....	18.....	.....	.....	27.....	N-1.....
Sligo Formation.....	Haynesville field, Louisiana, Arkansas.....	≈ 5,300.....	.....	.....	.....	19.0.....	.....	.....	1.....	N-1.....
Caddo limestone.....	Eastland County, Texas.....	2,913(?).....	2.....	4.2.....	4.4.....	4.3.....	2.58.....	2.62.....	99.....	T-2.....	
Glen Rose Limestone.....	Bell County Texas.....	20.5-33.5.....	10.....	16.0.....	18.8.....	16.8.....	2.21.....	2.37.....	119.....	A-11.....	
Do.....	Ham Gossett field, Texas.....	5,700-6,200.....	.....	.....	.....	18.....	.....	.....	168.....	N-1.....
Glen Rose ("Bacon") Limestone.....	do.....	6,400-6,500.....	.....	.....	.....	6.....	.....	.....	168.....	N-1.....
Do.....	New Hope field, Texas.....	7,237-7,426.....	61.....	1.2.....	23.3.....	12.9.....	.....	.....	123.....	A-9.....
Do.....	do.....	≈ 7,300.....	Many.....	.....	.....	18.9.....	.....	.....	154.....	N-1.....
Do.....	Pickton field, Texas.....	≈ 7,900.....	380.....	.....	.....	19.....	.....	.....	164.....	N-1.....
Rodessa Formation (limestone).....	Ham Gossett field, Texas.....	6,600-6,800.....	.....	.....	.....	16.....	.....	.....	168.....	N-1.....
Niobrara Formation (chalk).....	Pickston, S. Dak.....	Subsurface.....	15.....	.....	.....	.....	1.63.....	.....	16.....	A-16.....
Bear River Formation (sandy limestone).....	Afton quadrangle, Wyoming.....	.....	.....	.....	.....	4.6.....	2.61.....	2.66.....	110.....	T-2.....
Peterson Limestone.....	do.....	.....	.....	.....	.....	9.5.....	2.45.....	2.54.....	110.....	T-2.....
La Paz field, Venezuela.....	.....	≈ 4,000-≈ 8,000.....	.....	.....	.....	1 to 2.....	.....	.....	48.....	N-1.....
Chalk.....	Balmoral, Great Britain.....	Outcrop.....	1.....	.....	.....	9.1.....	2.44.....	2.53.....	105.....	A-2.....
Do.....	Various localities, Great Britain.....	do.....	3.....	17.6.....	42.8.....	28.8.....	1.94.....	2.23.....	105.....	A-2.....	
Do.....	Germany.....	Quarry.....	3.....	2.3.....	7.0.....	5.8.....	.....	.....	72.....	A-3.....
Senonian chalk.....	Reitbrook field, Germany.....	Subsurface.....	.....	.....	.....	25.....	.....	.....	124.....	N.....
Limestone.....	Cantons of Bern, Neuenberg, Schwyz, St. Gallen, Unterwalden, Vaud, and Wallis, Switzerland.....	Quarry.....	29.....	.4.....	18.3.....	4.3.....	2.60.....	2.65.....	63.....	T-4.....	
Globigerina (marly) limestone.....	Ain Zalah field, Iraq.....	Subsurface.....	.....	.....	.....	0-11.....	.....	.....	38.....	N-1.....

Eocene

Green River Formation (marlstone).	Rifle, Colo.....	Mine.....	11	0.2	12.0	2.9	2.23	2.26	172, 173	A-16	Dip 20°-80°.
Green River Formation (limestone).	.....do.....	.....do.....	3			1.6	2.10	2.12	16	A-16
Limestone, porous.....	Eniwetok Atoll, Marshall Islands.	≈4,000.....	4				1.84-1.89		17	A-16	
Limestone, hard.....	.....do.....	≈4,000.....	2				2.31		17	A-16
Limestone.....	Cantons of Bern, Schwyz, St. Gallen, and Vaud, Switzerland.	Quarry.....	4	.7	2.6	1.7	2.68	2.70	63	T-4	

Miocene

Limestone, sandy.....	Eniwetok Atoll, Marshall Island.	1,100-2,687.....	2				1.21		17	A-16	Well D.
Limestone, porous.....			2				1.83		17	A-16	
Limestone, semiporous.....							2.39		17	A-16	
Limestone, hard.....							2.25-2.51		17	A-16	
Limestone.....	Canton Schaffhausen, Switzerland.	Quarry.....	1			18.3	2.24	2.42	63	T-4	
Asmari limestone.....	Masjidi Sulaiman field, Iran.	Subsurface.....	140		22.8	5.6			88	A	Well H. Dolomite, 0-10 percent. Dolomite, 11-25 percent. Dolomite, 26-50 percent. Dolomite, 51-75 percent. Dolomite, 75 percent.
Do.....	.....do.....	.....do.....			19.3	6.6			88	A
Do.....	.....do.....	.....do.....	27	1.1	13.0				88	A
Do.....	.....do.....	.....do.....	12	1.5	12.0				88	A
Do.....	.....do.....	.....do.....	8	2.5	8.9				88	A
Do.....	.....do.....	.....do.....	2	13.0	15.8				88	A
Do.....	.....do.....	.....do.....	7	4.2	16.1				88	A

Quaternary

Calcareous tufa.....	Cantons of Freiburg, St. Gallen, and Unterwalden, Switzerland.	Outcrop.....	4	7.0	27.8	19.2	2.03	2.22	63	T-4	
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TABLE 2.—*Limestone, dolomite, chalk, and marble*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Age not specified											
Marble.....	Eastern U.S.A. (31 localities).	Mostly quarry.	100	0.4	0.8	0.6	2.74	2.75	82	T-2	
Do.....	Missouri.....	Quarry.....	4	-----	-----	2.1	2.66	2.68	82	T-2	
Do.....	California.....	do.....	4	-----	-----	.6	2.84	2.85	82	T-2	
Do.....	Tokeen, Alaska.....	do.....	3	-----	-----	.5	2.72	2.72	82	T-2	
Do.....	Tiree, Great Britain.....	Outcrop.....	1	-----	-----	1.0	2.65	2.66	105	A-2	
Oolitic limestone.....	Great Britain.....	Outcrop.....	1	-----	-----	20.3	2.16	2.36	73	T-2	
Dolomite.....	Micheldean, England.....	do.....	1	-----	-----	8.6	2.54	2.63	73	T-2	
Limestone.....	Buxton, Darby, England.....	do.....	1	-----	-----	14.1	2.31	2.45	73	T-2	

¹ E. C. Robertson, written communication, 1962.² Phillips Petroleum Co., written communication.TABLE 3.—*Shale, claystone, and slate*

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Precambrian											
Goodrich Quartzite (argillite).	Ishpeming, Michigan	Mine	3				2.85		17	A-16	
Negaunee Iron-Formation (white slate).	do	1,000	2			0.6	2.93	2.94	172	A-16	
Nonesuch Shale (siliceous).	White Pine, Michigan	Mine	6	1.5	1.7	1.6	2.76	2.78	16	A-16	

Cambrian

Gros Ventre Formation (shale).	Afton quadrangle, Wyoming.	Outcrop.....	-----	-----	-----	11.1	2.38	2.49	110	T-2	
Ophir Formation (shale)...	Ophir, Utah.....	Subsurface....	2	-----	-----	.9	2.81	2.82	173	A-16	
Ophir Formation (silicified shale).	do.....	do.....	1	-----	-----	.6	2.80	2.81	173	A-16	
Ophir Formation (limestone, shale).	do.....	do.....	1	-----	-----	.6	2.92	2.93	173	A-16	Mineralized.

Ordovician

Martinsburg Shale.....	Bangor, Pennsylvania....	Quarry.....	-----	-----	-----	1.0	2.74	2.75	172	A-16	Slate.
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Silurian

Shale.....	Various localities, Great Britain.	Outcrop.....	5	2.0	10.1	5.2	2.54	2.59	105	A-2	
Wenlock Shale:											
Weathered.....	Malvern, England.....	do.....	1	-----	-----	14.1	-----	-----	141	A-2	
Unweathered.....	do.....	do.....	1	-----	-----	5.8	-----	-----	141	A-2	

Devonian

Slate.....	Various localities, Germany.	Quarry.....	19	1.7	13.0	3.4	-----	-----	72	A-3	Roofing slate.
Do.....	Hele, Great Britain.....	Outcrop.....	2	1.3	3.5	2.4	-----	-----	141	A-2	

Devonian and Mississippian

Chattanooga Shale.....	Irvine field, Kentucky....	Subsurface....	2	7.4	7.6	7.5	2.38	2.45	99	T-2	
Do.....	Near Smithville, Tenn....	Mine.....	-----	-----	-----	-----	2.53	-----	17	A-16	
Chattanooga Shale, silty..	do.....	do.....	2	1.6	1.7	1.7	2.30	2.32	17	A-16	
Hamilton shale.....	Hannibal, Mo.....	Outcrop.....	1	-----	-----	11.3	2.32	2.43	67	T-2	

Mississippian

Maxville Limestone (shale).	Muskingum County, Ohio.	Subsurface....	3	-----	-----	-----	2.56	-----	17	A-16	
Shale overlying Keener sand.	Monroe County, Ohio.....	1,445-1,475....	2	9.7	11.0	10.4	2.43	2.54	98	T-2	
Ridgetop Shale (silty)....	Near Smithville, Tenn....	≈150.....	6	-----	-----	-----	2.71	-----	17	A-16	

TABLE 3.—*Shale, claystone, and slate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Pennsylvanian											
Allegheny Formation (silty shale).	Colver, Pa.	Mine.	3				2.67		17	A-16	
Allegheny Formation (shale, slate).	Bakerton, Pa.	≈500.	2			1.7	2.72	2.74	17	A-16	
Kanawha Formation (shale).	Dehue, W. Va.	Mine.	6				2.75		16	A-16	
Monongahela Formation.	Scotts Run, W. Va.	do.	5			6.1	2.5		173	A-16	
Upper Block underclay.	New Brazil, Ind.	Trench	1			19.1			3	T-2	
Cherokee Shale.	Fulton, Mo.	Outcrop.	2	17.0	17.2	17.1	2.29	2.46	67	T-2	
Flint clay.	do.	do.	2	10.1	10.1	10.1	2.37	2.47	67	T-2	
Weston Shale.	Bonner Springs, Kans.	do.	2	15.5	16.0	15.8	2.28	2.44	67	T-2	
Chanute Shale.	Independence, Kans.	do.	2	14.8	15.0	14.9	2.31	2.46	67	T-2	
Chanute(?) Shale.	Montgomery County, Kans.	500-975.	4	7.3	10.6	9.1	2.51	2.60	67	T-2	
Do.	do.	1,300-1,305.	3	7.1	8.5	7.7	2.53	2.61	67	T-2	
Burgess sandstone (shale).	S. Moore pool, Oklahoma.	7,813-7,820.				3-4			104	N-1	From graph.
Carboniferous											
Coal Measure clay.	Brightside and Darnall, England.	Outcrop.		12.8	14.3	13.5			141	A-2	
Do.	Near Nottingham, England.	510.				13.4			141	A-2	
do.	do.	829.				14.6			141	A-2	
do.	do.	1,190.				10.7			141	A-2	
Middle Coal Measure.	St. Helens, Great Britain.	Outcrop.	2	4.0	7.3	5.7	2.84	2.89	105	A-2	
Shale under basalt.	Edinburg Castle, Great Britain.	do.	1			1.6	2.58	2.60	105	A-2	
Slate.	Various localities, Germany.	Quarry.	4	1.2	3.8	2.5			72	A-3	Roofing slate.
Clay, nonplastic.	Near Dabrowa, Poland.	Mine, hanging wall.	1			.85	2.44	2.45	115	T-2	
Do.	do.	Sabatzlarer bed 8.	1			1.2	2.48	2.49	115	T-2	
Clay.	Aktyubin area, U.S.S.R.	1,150-4,430.	2			15.3	2.30	2.45	108	T	
do.	do.	7,610-8,510.	1			12.5	2.31	2.44	108	T	

Pennsylvanian and Permian

Shale.....	Ponca City and Garber areas, Oklahoma.	1,000.....				17	2.25	2.42	6	N	From graph.
Do.....		2,000.....				11	2.42	2.53	6	N	Do.
Do.....		3,000.....				7	2.52	2.59	6	N	Do.
Do.....		4,000.....				5	2.57	2.62	6	N	Do.
Do.....		5,000.....				4	2.62	2.66	6	N	Do.

Permian

Wellington Formation (shale).	Selma, Kans.....	Outcrop.....	2	15.3	15.5	15.4	2.40	2.55	67	T-2	
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Permian and Triassic

Clay.....	Aktyubin area, U.S.S.R..	Subsurface....	4			16.0	2.33	2.49	108	T	
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Triassic

Ankareh Shale.....	Afton quadrangle, Wyoming.	Outcrop.....				9.2	2.40	2.49	110	T-2	
Woodside Formation (shale).	do.....	do.....				16.1	2.24	2.40	110	T-2	
Clay, nonplastic (Bröckelschiefer).	Heidelberg, Germany.....		1			18.0	2.21	2.39	115	T-2	Weak folding.

Jurassic

Morrison Formation (claystone).	Long Park, Colo.....	203-245.....	6	8.8	20.3	16.5			(1)	A-9	
Kimmeridge clay.....	Oxford and Filey, England.	Outcrop.....	2	19.0	30.7	24.8			141	A-2	
Lias clay.....	Bath and Robin Hoods Bay, England.	do.....	3	22.5	27.7	24.4			141	A-2	

Footnotes on p. E40.

TABLE 3.—*Shale, claystone, and slate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Cretaceous											
Middendorf Formation (white clay).	Aiken and Richland Counties, S.C.	Outcrop-----	2	39.0	42.3	40.7	1.55	1.96	67	T-2	Not weathered. Ransom well. Do. Do.
Graneros shale-----	Hamilton County, Kans.	do-----	2	24.6	25.2	24.9	1.99	2.23	67	T-2	
Graneros(?) shale-----	do-----	3,029-3,950-----	3	9.2	11.6	10.6	2.37	2.47	67	T-2	
Do-----	do-----	4,485-5,006-----	3	8.7	9.6	9.1	2.46	2.55	67	T-2	
Pennsylvanian(?) shale-----	do-----	5,355-5,440-----	3	7.7	8.4	8.1	2.52	2.61	67	T-2	
Mentor Formation (shale).	Falun, Kans.	Outcrop-----	2	22.9	23.3	23.1	2.06	2.29	67	T-2	
Adaville Formation (mudstone).	Afton quadrangle, Wyoming.	do-----	-----	-----	-----	23.0	2.07	2.30	110	T-2	
Adaville Formation (shale).	do-----	do-----	-----	-----	-----	11.9	2.34	2.46	110	T-2	
Do-----	Sublette County, Wyo.	13,620-----	1	-----	-----	7.8	-----	-----	(?)	A	
Do-----	do-----	13,694-----	1	-----	-----	5.7	-----	-----	(?)	A	
Hillard Formation (shale).	Afton quadrangle, Wyoming.	Outcrop(?)-----	-----	13.9	26.8	-----	1.98-2.28	2.25-2.42	110	T-2	
Shale-----	Black Hills, Wyo., Mont.	-----	3	32.5	37.6	34.5	1.80	2.14	129	T-2	
Do-----	do-----	-----	3	25.4	26.0	25.6	1.99	2.24	129	T-2	
Do-----	do-----	-----	1	-----	-----	23.8	2.00	2.24	129	T-2	
Do-----	do-----	-----	1	-----	-----	35.8	1.56	1.92	129	T-2	
Do-----	do-----	-----	1	-----	-----	25.3	1.99	2.24	129	T-2	
Wayan Formation (clay).	Afton quadrangle, Wyoming.	-----	-----	-----	-----	25.3	1.80	2.05	110	T-2	
Wayan Formation (mudstone).	do-----	-----	-----	-----	-----	28.6	1.90	2.19	110	T-2	
Gault clay-----	Aylesford and Folkestone, England.	Outcrop-----	3	18.9	28.1	24.0	-----	-----	141	A-2	
Specton clay-----	do-----	do-----	1	-----	-----	13.6	-----	-----	141	A-2	
do-----	do-----	do-----	1	-----	-----	8	-----	-----	141	A-2	
Gosauschichten-----	Austria(?)-----	Outcrop(?)-----	3	.8	4.7	2.2	2.61	2.63	115	T-2	
Paleocene											
Fort Union Formation:	Rosebud County, Mont.	Lebo Shale Member-----	Outcrop(?)-----	1	-----	-----	21.2	2.07	2.28	143	T-5
Tongue River Member.		do-----	Outcrop-----	2	23.5	36.9	30.2	1.87	2.17	143	T-5

Eocene and Oligocene

Shales, sandy.....	Los Manueles field, Venezuela.	3,000-5,000	-----	-----	-----	20	-----	-----	24	N	
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Oligocene

Clay, plastic.....	Baden, Germany.....	Pit.....	1	-----	-----	26.0	1.90	2.16	115	T-2	
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Oligocene and Miocene

Shale, undisturbed and nearly horizontal.	Eastern Venezuela.....	291-922.....	6	31.3	35.8	33.5	1.73	2.06	68	T-2	Wells AB, CD, EF.
Do.....	do.....	1,637-1,920.....	3	27.4	28.7	28.0	1.63	2.21	68	T-2	Wells AB, EF.
Do.....	do.....	2,031-2,996.....	9	22.9	28.9	25.4	2.00	2.25	68	T-2	Well AB.
Do.....	do.....	3,015-3,973.....	9	17.8	25.6	21.1	2.14	2.35	68	T-2	Do.
Do.....	do.....	4,336-4,849.....	3	14.2	17.8	16.3	2.22	2.38	68	T-2	Do.
Do.....	do.....	5,007-5,502.....	4	12.8	14.6	13.5	2.32	2.46	68	T-2	Do.
Do.....	do.....	6,013-6,175.....	3	9.1	10.6	9.6	2.42	2.52	68	T-2	Do.
Do.....	do.....	6,523.....	1	-----	-----	12.1	-----	-----	68	T-2	Well GH.
Do.....	do.....	7,749-7,994.....	2	10.3	10.4	10.4	-----	-----	68	T-2	Do.

Miocene

Kirkwood Formation.....	Yorktown, N.J.....	4.....	1	-----	-----	51.9	1.30	1.86	67	T-2	Yellow clay.
Do.....	do.....	11.....	1	-----	-----	40.3	1.62	2.02	67	T-2	Yellowish clay.
		13.....	1	-----	-----	38.6	1.70	2.08	67	T-2	Blue clay.
Shale in Stevens sand.....	S. Coles Levee field, Calif.....	9,437-9,439.....	1	-----	-----	8.0	-----	-----	57	A-9	
Tembler Formation.....	Kettleman Hills, Calif.....	6,250-9,332.....	Many	-----	-----	≅3	-----	-----	59	N	
Clay, nonplastic.....	Austria.....	Mine.....	1	-----	-----	7.0	2.69	2.76	115	T-2	Slight folding.
Do.....	do.....	Subsurface.....	1	-----	-----	22.5	2.01	2.24	115	T-2	Above coal.
Clay (plastic).....	do.....	Pit.....	1(?)	-----	-----	24.0	1.90	2.14	115	T-2	Miocene(?)
Do.....	Near Egger, Austria.....	-----	2	42.0	45.0	43.5	1.43	1.87	115	T-2	Do.

Miocene(?) and Pliocene(?)

Cohansey sand (clay).....	Crossley, N.J.....	Outerop.....	2	36.6	37.4	37.0	1.67	2.04	68	T-2	
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Footnotes on p. E40.

TABLE 3.—*Shale, claystone, and slate*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Pliocene											
Clay (plastic in Congeria beds).	Austria.....	Pit.....	2	26.0	26.1	26.1	1.80	2.06	115	T-2	Impure.
Tertiary											
Clays.....	Missouri.....	Pit or bank.....	3	28.3	29.8	28.8		1.96-2.13	167	A-2	Natural state(?).
Clay.....	Various localities, England.	Outcrop.....							141		
Age not specified											
Clay.....	49 localities, New Jersey...	Outcrop.....	49				1.83		29		Range 1.53-2.17 gcm ⁻³ air dried. Natural state(?). Do. Do. Do. Do.
Kaolins.....	Missouri.....	Pit or bank.....					1.90	167			
Loess clays.....	do.....	do.....					2.05	167			
Gumbo clays.....	do.....	do.....					2.01	167			
Fire clay.....	do.....	Subsurface.....					2.40	167			
Shales.....	do.....	Pit or bank.....					2.38	167			
Shale.....	Phillips well, Russell County, Kans.	1,400-1,485.....	4	22.0	23.3	22.5	2.15	2.37	67	T-2	Moist.
Do.....	do.....	2,575.....	2	16.5	17.6	17.1	2.31	2.48	67	T-2	
Shale, weathered.....	Near Ponca City, Okla.	37.....		48			1.52-1.85	6	N-2		
Clay.....						53		58	A-14		
Slate.....	Cornwall, Great Britain.....	Outcrop.....	1			5.9		141	A-2		
Slate, black.....	Moffat, Great Britain.....	do.....		3.8	5.2	4.5		141	A-2		
Slate, red.....	do.....	do.....				3.4		141	A-2		
Slate, green.....	do.....	do.....				2.1		141	A-2		
Slate, black.....	Westmorland, Great Britain.....	do.....	3	.40	.50	.49		141	A-2		
Slate, purple.....	Penrhyn, Great Britain.....	do.....				.24		141	A-2		
Slate.....	Great Britain.....	do.....	6	1.3	5.2	3.2		141	A-2		
Do.....	Settle, Great Britain.....		1			.9	2.73	2.74	105	A-2	
Slate, ordinary.....	Great Britain.....		2	.6	.6	.6	2.83	2.84	105	A-2	
Slate.....	Cornwall, Great Britain.....		2	4.0	6.0	5.0	2.60	2.65	105	A-2	
Schist.....	Great Britain.....		2	1.2	2.3	1.8	2.73	2.75	105	A-2	
Do.....	Tasmania.....		1			6.0	2.64	2.70	105	A-2	

¹ R. A. Cadigan, W. H. Caraway, G. L. Gates, and F. C. Morris, written communication, 1955.² Superior Oil Co., written communication, 1959; F. R. Hays, 1951, A petrographic study of deeply buried sandstones from the Superior Pacific Creek unit No. 1 well, Sublette County, Wyoming: Unpublished dissertation, Univ. Cincinnati.

TABLE 4.—Unconsolidated materials

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Sand, clay, gravel, and alluvium of Quaternary age											
Beach sand, well-sorted.....	Revere Beach, Mass.....	Surface.....	3	39.2	39.4	39.3	-----	-----	51	T-7	1 mm in diameter.
Do.....	do.....	do.....	3	40.1	40.2	40.1	-----	-----	51	T-7	0.5 mm in diameter.
Beach sand.....	do.....	do.....	9	38.7	44.8	42.9	-----	-----	51	T-7	Adjacent to boulders.
Do.....	Lynn Beach, Mass.....	do.....	4	41.1	43.6	42.9	-----	-----	51	T-7	Fine, wet. Fine, dry. Coarse, damp. Coarser, damp. Wet. Dry.
Do.....	Marblehead Beach, Mass.....	do.....	1	-----	-----	42.1	-----	-----	51	T-7	
Do.....	do.....	do.....	1	-----	-----	42.9	-----	-----	51	T-7	
Do.....	do.....	do.....	1	-----	-----	39.0	-----	-----	51	T-7	
Do.....	do.....	do.....	1	-----	-----	34.0	-----	-----	51	T-7	
Sand, artificially packed.....	do.....	do.....	1	-----	-----	37.9	-----	-----	51	T-7	Fine to medium grained. Poorly sorted. Medium grained. Loose.
Do.....	do.....	do.....	1	-----	-----	37.0	-----	-----	51	T-7	
Cape May Formation (sand).	Runyon, N.J.....	Mostly pits.....	8	30.8	45.3	40.1	1.50	1.90	143	T-5	
Do.....	Pleasantville, N.J.....	≈1.....	4	25.5	30.0	27.7	1.74	2.02	143	T-5	
Do.....	Absecon, N.J.....	0-3½.....	4	30.8	39.9	36.6	1.63	2.00	143	T-5	
Cape May Formation (gravel).	do.....	0-2.....	2	23.4	27.4	25.4	1.83	2.08	143	T-5	Recent(?) Do.
Silt.....	Princeton, N.J.....	1.....	1	-----	-----	53.2	1.25	1.78	143	T-5	
Sand.....	Old Bridge, N.J.....	2-6.....	4	43.6	46.6	45.0	1.47	1.92	143	T-5	
Sand and gravel.....	Pine Island, La.....	122-692.....	19	24.9	40.1	32.4	-----	-----	81	N-2	
Sands.....	Gulf coast, U.S.A.....	63-84.....	2	36.4	40.8	38.6	-----	-----	81	N-2	
Terrace gravel.....	Various localities, Montana.....	Surface.....	4	23.6	27.1	25.0	2.03	2.28	143	T-5	Above gravel bank. Below gravel bank.
Gravel.....	Yellowstone River, Rosebud County, Mont.....	do.....	1	-----	-----	20.2	2.19	2.39	143	T-5	
Gravel (clinkered shale and sandstone).	Tongue River, Mont.....	do.....	1	-----	-----	29.3	1.36	1.65	143	T-5	
Sand, very fine.....	do.....	do.....	1	-----	-----	49.9	1.36	1.86	143	T-5	
Gravel.....	Fergus County, Mont.....	do.....	1	-----	-----	25.1	1.89	2.14	143	T-5	
Clay.....	Clark County, Idaho.....	56½.....	1	-----	-----	42.4	1.51	1.93	143	T-2	Above gravel bank. Below gravel bank.
Do.....	Jefferson County, Idaho.....	2½.....	1	-----	-----	62.9	1.00	1.63	143	T-2	
Surface material.....	Rogers Dry Lake, Calif.....	Surface.....	2	37.8	38.3	38.1	-----	-----	98	T-2	
Upper clay member.....	Mojave River, Calif.....	Outcrop.....	1	-----	-----	43.1	1.55	1.98	98	T-2	
Lower clay member.....	do.....	do.....	1	-----	-----	35.7	1.73	2.09	98	T-2	

TABLE 4.—*Unconsolidated materials*—Continued

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gcm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Sand, clay, gravel, and alluvium of Quaternary age—Continued											
Coarse sand.....	San Diego County, Calif.	do.		39	41				87	T-5	Valley fill.
Medium sand.....	do.	do.		41	48				87	T-5	Do.
Fine sand.....	do.	do.		44	49				87	T-5	Do.
Fine sandy loam.....	do.	do.		50	54				87	T-5	Do.
Clay.....	Old lakebed, Sewerby, England.	do.	1			49.5			141	A-2	
Boulder clay.....	Bridlington, England.	do.	3	23.4	25.5	24.8			141	A-2	Pleistocene.
Do.....	Balby, England.	do.	2	23.9	24.1	24.0			141	A-2	Do.
Alluvial clay.....	Orgreave, England.	do.	1			30.2			141	A-2	Do.
Glacial clay.....	Mecklenburg, Germany.	Railroad cut.	4	37	51	45			116	A	Porosity by water content.
Glacial fine sand.....	Pomerania, Germany.	12-13.	1			42	1.52	1.94	116	T-2	
		18-19.	1			45	1.46	1.91	116	T-2	
		25.	1			39	1.63	2.02	116	T-2	
		42-44.	1			41	1.58	1.99	116	T-2	
Soils of Recent age											
Black Gumbo.....	Carbon County, Idaho.	Surface.	1			54.1	1.19	1.73	143	T-5	
Gravelly loam.....	Fremont County, Idaho.	do.	1			53.7	1.19	1.73	143	T-5	
Loess soil.....	Caribou, Fremont, and Jerome Counties, Idaho.	do.	3	53.2	69.4	61.2	1.00	1.61	143	T-5	
Soils.....	U.S.A.	do.		45	65	55			155	N	Common range.
Arable soil.....	Near Hamburg, Germany.	0-2.1.	13					1.73	83	N	Natural state(?).
Loamy sand.....	do.	0.6-8.7.	16				1.88		83	N	Do.
Marshy loam.....	do.	Surface(?)				84.0			136	T	82 percent organic material.
Sandy loam.....	Near Hamburg, Germany.	2.1-10.2.	3				2.00		83	N	Natural state(?).
Wet sandy loam.....	do.	4.9-8.2.	2				2.08		83	N	Do.

Subaqueous materials of Recent age

Coarse sand.....	San Diego, Calif.....	Sea floor sedi- ments, from 0-1 in. below depositional surface.	3			38.3		2.08	64	A-7	83 percent through No. 200 sieve.
Medium sand.....	do.....	do.....	3			40.9		2.00	64	A-7	
Fine sand.....	do.....	do.....	54			46.2		1.93	64	A-7	
Very fine sand.....	do.....	do.....	15			47.7		1.92	64	A-7	
Sandy coarse silt.....	do.....	do.....	7			51.2		1.86	64	A-7	
Silty very fine sand.....	do.....	do.....	7			61.3		1.68	64	A-7	
Medium silt.....	do.....	do.....	2			60.9		1.69	64	A-7	
Clayey fine silt.....	do.....	do.....	4			65.6		1.60	64	A-7	
Sand, silt, and clay.....	do.....	do.....	3			74.7		1.44	64	A-7	
Fine sand.....	Channel Islands region, California.	Sea bottom.....				29.5			153	N	
Fine silt.....	do.....	do.....				66			153	N	
Mud.....	Hudson River, near Canal Street, New York City, N.Y.	River bottom.....		77.2	88.4				89	A-7	
Do.....	Hudson River at Jersey City, N.J.	Mud on a submerged crate.				88.2			89	A-7	
Silt.....	Hudson River.....	50 ft below riverbed.				55			70	A-7	
Newly deposited material.....	Mississippi River Delta.....					80-90			140	A	
Mud.....	Seacoasts, U.S.A.....			40	>90				139	A	
Soft mud.....	Clyde Sea, Great Britain.....	0-2.5 cm in mud.	9	80	87	82			106	A	
		22.5-25 cm in mud.	9	72	80	75			106	A	

TABLE 5.—Other rock types

Stratigraphic unit	Locality	Source of material or depth (feet)	Number of samples	Porosity (percent)			Average bulk density (gm ⁻³)		Reference	Method of porosity determination	Remarks
				Min-imum	Max-imum	Average	Dry	Water-saturated			
Phosphoria Formation.....	Idaho, Utah, and Wyoming.	-----	9	-----	-----	-----	2.91	-----	94	-----	Permian.
Negaunee Iron-Formation (ore).	Ishpeming, Mich.....	Mine.....	12	-----	-----	-----	4.53	-----	17	A-16	Precambrian.
Negaunee Iron-Formation (hematitic).	do.....	do.....	3	-----	-----	-----	4.07	-----	17	A-16	Do.
Wabana series (ore).....	Wabana, Newfoundland..	300 ft. sea water plus 1,000 ft. rock.	3	-----	-----	-----	3.46	-----	17	A-16	Ordovician.
		≈1,400	3	-----	-----	-----	4.26	-----	17	A-16	Do.
Red Mountain Formation (ore).	Bessemer, Ala.....	-----	2	2.3	3.0	2.7	3.73	3.76	172	A-16	Silurian.
Biwabik Iron-Formation "Granite".....	Virginia, Minn.....	Subsurface.....	1	-----	-----	.3	2.75	2.75	16	A-16	Precambrian.
	Sand Hill well, Wood County, W. Va.	13,314-13,318..	2	.2	.4	.3	2.78	2.78	(1)	A-15	
Younger rock salt.....	Near Hanover, Germany..	In place.....	-----	-----	-----	-----	-----	2.1	14	-----	Torsion balance.
Older rock salt.....	do.....	do.....	-----	-----	-----	-----	-----	2.1	14	-----	Do.
Anhydrite.....	do.....	do.....	-----	-----	-----	-----	-----	2.9	14	-----	Do.
Potash bed.....	do.....	do.....	-----	-----	-----	-----	-----	1.6	14	-----	Do.
Gypsum and anhydrite.....	do.....	do.....	-----	-----	-----	-----	-----	2.6	14	-----	Do.
Gypsum.....	do.....	do.....	-----	-----	-----	-----	-----	2.2	14	-----	Do.
Borax, Ricardo Formation (Pliocene).	Boron, Calif.....	300-1,000.....	-----	-----	-----	-----	2.14	-----	17	A-16	33 percent ore.
Do.....	do.....	300-1,000.....	-----	-----	-----	-----	1.74	-----	17	A-16	80 percent ore.
Do.....	do.....	300-1,000.....	-----	-----	-----	-----	1.72	-----	17	A-16	92 percent ore.
Serpentine.....	Hilbig oil field, Texas.	≈2,500.....	-----	2.2	25.7	22	-----	-----	15	N	Productive.
Altered basalt.....	Oil fields, Texas.....	Subsurface.....	-----	21.7	35.6	-----	-----	-----	138	N	

¹ E. C. Robertson, written communication, 1962.

METHODS OF POROSITY DETERMINATIONS

TOTAL POROSITY

- T. Total porosity is determined but the method is not stated.
- T-1. Russell's method. Bulk volume (V_B) and grain volume are measured by the displacement of an organic liquid in a volumeter (Russell tube). Percent porosity is $100 (1 - V_G/V_B)$.
- T-2. Bulk density-grain density method. Bulk density (D_B) is obtained from the dry weight and the loss of weight in water. Grain density (D_G) is obtained by pycnometry. Percent porosity is $100 (1 - D_B/D_G)$.
- T-3. Bulk density-grain density method. D_B is obtained from the dry weight and micrometer measurement for volume. D_G is obtained by pycnometry.
- T-4. Bulk volume-grain volume method. V_B is determined by loss of weight in water. V_G is determined by the displacement of liquid as in method T-1.
- T-5. Bulk density-grain density method. D_B is determined from the dry weight and the volume of unconsolidated rock in a sampling tube. D_G is determined by pycnometry.
- T-6. Bulk density-grain density method. D_B is determined from the dry weight and by liquid displacement. D_G is assumed to be constant at 2.65 gm^{-3} .
- T-7. Bulk volume-grain volume method. V_B is determined by loss of weight in water. V_G is determined by pycnometry.

APPARENT OR EFFECTIVE POROSITY

- A. Apparent porosity is determined but the method is not stated.

The following methods are all based on the determination of pore volume (V_P) and bulk volume (V_B). Percent porosity is $100 V_P/V_B$.

- A-1. V_P is determined by water absorption by immersion in hot or boiling water, followed by evacuation to the vapor pressure of water at room temperature for about 1 day. V_B is determined by the loss of weight in water.
- A-2. V_P is determined by water absorption by immersion in water at room temperature while evacuated at the vapor pressure of water at room temperature. V_B is determined from pore volume and grain density.
- A-3. V_P is determined as in method A-2, but water absorption is followed by the application of pressure from 750 to 2,250 psi. V_B is determined by the displacement of water.

- A-4. V_P is determined by water absorption under high vacuum. V_B is determined by the displacement of water. Large openings are covered with rubber sheeting to include fracture and vuggy porosity with matrix porosity.
- A-5. V_P is determined by water absorption under high vacuum (0.002 mm Hg), followed by application of pressure of 1000 bars. Method of determining (V_B) is not stated.
- A-6. Barnes' method. V_P is determined by the volume of organic liquid absorbed under vacuum. V_B is determined by the volume of organic liquid displaced in a volumeter.
- A-7. V_P is determined as the volume of natural-state water. V_B is determined as the volume of a sampling chamber or by loss of weight in water. Where A-7 is enclosed in parentheses, method of determining bulk volume is not stated.
- A-8. A.S.T.M. method C127-42 V_P is determined by water absorption during boiling for 2 hours. V_B is determined by water displacement.
- A-9. U.S. Bureau of Mines method. V_P is determined by the pressure and volume relationships of a gas system with and without a rock specimen. V_B is determined by mercury displacement.
- A-10. V_P is determined by the volume of mercury injected at 1,000 psi. V_B is determined by mercury displacement.
- A-11. V_P is determined by the volume of liquid injected by fluid flow. V_B is determined by the loss of weight in liquid.
- A-12. V_P is determined as the volume of water absorbed after evacuation. V_B is determined from the bulk density of the dry specimen.
- A-13. V_P is determined as the volume of water imbibed at room temperature and pressure. V_B is determined by the loss of weight in water.
- A-14. V_P is obtained by Fuller's conversion of Geikie's values of water absorbed at atmospheric pressure. V_B is obtained from an assumed natural-state bulk density of 2.65 (?) gcm⁻³.
- A-15. V_P is determined by the volume of water absorbed after evacuation to 0.1 mm Hg at 80° C. V_B is determined from the loss of weight in water.
- A-16. V_P is determined by the volume of water imbibed for one week at room temperature and pressure by a specimen previously oven dried. V_B is determined by dimensional measurement.

POROSITY METHOD NOT CERTAIN

- N. Method is not specified.
- N-1. Very likely apparent porosity.

N-2. Probably apparent porosity. V_P probably is determined by water displacement. V_B is determined by the volume of a containing cell.

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