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

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

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

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

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

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

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 disburbance, 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.

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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
				Minimum	Maximum	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	Marticville, 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	Quarrry	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
				Minimum	Maximum	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	
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	Clean, uniform.
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	

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, dolomitic.	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, Arkansas.	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, Pennsylvania.	≈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.	Kane field, Pennsylvania	Subsurface	17	2.0	14.4	11.9			43	A-6	
Do.	do.	do.	69	3.0	16.4	10.6			9	A-6	
Chipmunk sand	Cattaraugus County, N.Y.	do.	2	14.5	15.1	14.8			123	A-9	
Clarendon sand	Saybrook field, Pennsylvania.	do.	2	11.5	13.4	12.5			9	A-6	
Do.	Warren field, Pennsylvania.	do.	5	8.8	18.5	14.4			9	A-6	
Do.	do.	do.	13	2.6	25.6	10.6			43	A-6	
Kane sand	Kane field, Pennsylvania	do.	7	14.2	22.2	18.9			9	A-6	
Oriskany Group (sandstone).	Tioga field, Pennsylvania	≈4,000	65	2.9	11.8				47	T	19 wells.
Do.	Sabinsville pool, Pennsylvania.	≈4,350	1			9.9			47	T	
Do.	Hebron field, Pennsylvania.	≈5,130	6	9.1	10.1	9.4			47	T	2 wells.
Do.	Hebron gas field, Pennsylvania.	5,174–5,179		9	14				125	N-1	
Do.	Hebron-Ellisville field, Pennsylvania.	≈5,500				10			49	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
				Minimum	Maximum	Average	Dry	Water-saturated			
Devonian—Continued											
Sandstone	Butler and Zelienople, quadrangle, Pennsylvania.	Subsurface	8	4.5	22.2	10.1	2.39	2.49	99	T-2	
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	Calcareous.
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	Granular.
Do	do	do	3	.7	7.2	4.3			72	A-3	Slaty.
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	Coarse.
Do	do	do	1			9.1	2.40	2.49	105	A-2	Fine.

Upper Devonian and Lower Mississippian

Three Forks shale, (red sandstone).	Afton quadrangle, Wyoming.					6.4	2.62	2.68	110	T-2	
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	Average grain density, 2.664.
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	
Bowlder 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	
Do	Cabin Creek field, West Virginia.	≈2,500				4			161	T-2	Quartzite cap.
Do	do	≈2,500				16			161	T-2	Pay sand.
Sandstone, well-sorted	Tucker County, W. Va		1			4.4			131	T-1	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	
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	
Berea(?) Sandstone	Berea, Ohio	Outcrop	2	10.2	13.2	11.7			100	A-13	Building stone.
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	Mississippian(?).
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	Do.
Mooretown Formation (sandstone).	Tri-County oil field, Indiana.	≈1,300				5			42	N	Clayey and limy.
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	Clean, fine sandstone.
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 (gcm⁻³)		Reference	Method of porosity determination	Remarks
				Minimum	Maximum	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	
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	Well sorted.
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	Do.
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	
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).	Dehue, 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	Carbon ratio, 52.5–57.5 percent.
Do	do	do	8	6.8	20.1	16.2			131	T-1	Carbon ratio, 57.5–62.5 percent.
Do	West Virginia	do	10	3.0	9.5	5.4			131	T-1	Carbon ratio, 72.5–77.5 percent.
Do	do	do	4	1.9	3.9	2.7			131	T-1	Carbon ratio, 80–82.5 percent.
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	Now "Burbank" sand.
Do	Various fields, Kansas	695–1,183	82	7.0	24.8	20.4			123	A-9	Do.
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
				Minimum	Maximum	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	
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	11 wells.
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 Antioch 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	

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Do	Holdenville field, Oklahoma.	≈3,200	2	16.8	16.8	16.8			9	A-6	
Do	Sasakwa, 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	Shaly, limy.
		9,448-9,492	39	4.7	8.7	6.90			[2]	A	Do.
		10,215-10,224	3	9.5	10.9	10.17			[2]	A	Do.
Deese Formation	do	13,083-13,095	7	2.1	6.3	4.36			[2]	A	Do.
		15,075-15,085	8	7.2	9.2	8.20			[2]	A	Do.
		16,953-16,956	1			28.2			[2]	A	Do.
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	Shaly.
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	

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
				Minimum	Maximum	Average	Dry	Water-saturated			
Pennsylvanian—Continued											
Wayside sand	Bartlesville field, Oklahoma.	525–530	4	15.7	19.4	18.0			9	A-9	
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	9 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	8 wells.
Weber Sandstone	Rangely field, Colorado	5,600–6,300		6	19				117	N-1	Calcareous.
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.
Bell sand	Lance Creek field, Wyoming.	5,776–5,936	2	7.5	10.5	9.0			157	T-2	2 wells.
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	

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.
KMA sand	do	3,687-3,824	156	.5	19.6	7.5			123	A-9	Do.
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	2 localities.
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	

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
				Minimum	Maximum	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 (siltstone).	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.
Do.	Two structures Wyoming	8,255–8,400	6	1.9	11.1	6.0			157	T–2	2 wells.
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.	do.				5.0	2.58	2.63	110	T–2	
Kingak 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.	Oberg field, Germany	do.		12	22				124	N	
Sandstone	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.	6,487–6,581	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
				Minimum	Maximum	Average	Dry	Water-saturated			
Cretaceous—Continued											
Sturgis zone sand	Fouke field, Arkansas	≈3,600		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	Calcareous.
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	Silty.
Do	do	3,522	1			17.6			103	N	Conglomerate.
Do	do	3,537-3,546	1			5.5			103	N	Chalk conglomerate.
Do	do	3,537-3,546	1			6.3			103	N	Conglomerate, clayey.
Do	do	3,774-3,778	1			11.0			103	N	Poor saturation.
Do	do	3,774-3,778	1			17.6			103	N	Fair saturation.
Do	do	3,774-3,778	1			22.2			103	N	Excellent saturation.
Do	do	3,778-3,780	1			19.7			103	N	Good saturation.

Do.	do.	3,785-3,786	1			11.0			103	N	Slight saturation.
Do.	do.	≈3,650	25	0(?)	27.2	19.0			103	N	10 wells.
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	
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	Lignitic.
Sandstone, well-sorted, coaly.	South Dakota		2	27.7	29.9	28.8			131	T-1	Carbon ratio, 50–55 percent.
Sandstone, cemented	Lincoln County, Kans.	Outcrop	7	1.1	3.4	1.5			149	A-8	Acid solubles, 34–38 percent.
Do.	Ellsworth County, Kans.	do.	1			1.5			149	A-8	Acid solubles, 37 percent.
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	
Dakota Sandstone (D sand).	Little Beaver field, Colorado.	≈5,200				19.7			44	N-1	Top member.
Do.	do.	≈5,400				20.7			44	N-1	Lower member.
Dakota Sandstone (J sand).	do.	≈5,400				22.8			44	N-1	
Dakota Sandstone	Several structures, Wyoming 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.	Outcrop	1			41.1	1.57	1.98	143	T-5	
Claggett Formation (siltstone).	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	Very fine sandstone.
Hell Creek Formation	Rosebud County Mont.	Outcrop	5	24.8	38.3	35.3	1.80	2.15	143	T-5	Fine sandstone.
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	Very fine sandstone.
Do.	do.	do.	2	33.2	51.2	42.2	1.82	2.24	143	T-5	Fine sandstone.
Lance Formation	do.	do.	3	36.7	43.0	39.4	1.66	2.05	143	T-5	Do.
Do.	do.	do.	1			30.8	1.87	2.18	143	T-5	Do.
Do.	do.	do.	1			27.4	2.01	2.28	143	T-5	Siltstone.
Peay sand	Big Horn Mountains	do.	1			5.1	2.52	2.57	99	T-2	
Do.	Jack Creek, Mont.	do.	1			5.0	2.58	2.63	99	T-2	
Second Cat Creek sand	Fergus County, Mont.	do.	1			23.2	2.06	2.29	143	T-5	Fine sandstone.
Third Cat Creek sand	do.	do.	1			25.8	1.96	2.22	143	T-5	Do.
Virgelle Sandstone Member of Eagle Sandstone.	Yellowstone County, Mont.	do.	1			23.6	2.06	2.30	143	T-5	Do.
Do.	Fergus County, Mont.	do.	1			27.1	1.93	2.20	143	T-5	Do.

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
				Minimum	Maximum	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	
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	Quartzite.
Do.	do.		1			13.8	2.32	2.46	110	T-2	
Do.	do.		1			12.9	2.28	2.41	110	T-2	Conglomerate.
Do.	do.		1			7.4	2.47	2.54	110	T-2	Siltstone.
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.	do.	7,054–8,435	17	.7	25.9	10.7			157	T-2	Do.
Lakota Formation (sandstone).	Quealy and Lance Creek structures, Woming.	3,715–3,966	4	12.7	23.2	17.6			157	T-2	2 wells.
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	133-983	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
				Minimum	Maximum	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.
Lebo shale Member of Fort Union Formation (sandstone).	Rosebud County, Mont.	do	1			27.7	1.93	2.21	143	T-5	Do.
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.
Do	do	do	1			26.2	1.91	2.17	143	T-5	Siltstone.
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.
Do	do	do	1			29.8	1.92	2.22	143	T-5	Siltstone.
Do	do	do	1			34.0	1.73	2.07	143	T-5	Medium sandstone.
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	
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	28	22			13		From core graphs.
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	Silstone.
Lyre Formation	Olympic Peninsula, Wash.	Outcrop	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	
Misoa-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	Outcrop	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	
Eocene to Miocene											
Sandstone	Wasco field, California	10,500-15,004				15			156	N-1	
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
				Minimum	Maximum	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	Guario dome, Venezuela	≈6,500				22–26			54	N-1	
Oficina formation (sands)	Anaco fields, Venezuela	≈4,500–≈9,500				18–20			54	N-1	
Do	Greater Oficina area, Venezuela.	3,000–7,700	Many			21–30			69	N-1	Average of averages, 26 percent.
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	Medium to coarse.
Fleming Formation of former usage.	Gulf coast, U.S.A	346–1,852	9	31.3	50.1	41.2			81	N-2	
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	
Stevens sand, F-1 section	South Coles Levee field, Calif.	9,294–9,438	103	3.8	24.9	18.9			57	A-9	Standard deviation, 4.1 percent.
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	

Temblor Formation (sandy shales).	do	6,250–9,332	Many			7			59	N	
Upper Terminal zone	Wilmington oil field, California.	3,000–3,500				25			12	N	300 ft of sand.
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 (gcm^{-3})		Reference	Method of porosity determination	Remarks
				Minimum	Maximum	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	
Do	do	do	----------	----------	----------	----------	3.30	----------	16	A-16	Galena bearing.
Gallatin Limestone	Afton quadrangle, Wyoming.	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 (limestone).	Ophir, Utah	Mine	----------	----------	----------	.26	2.78	2.78	173	A-16	
Upper Cambrian and Lower Ordovician											
Arbuckle Group (limestone).	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 (limestone).	Riley Mountain, Llano County, Tex.	Outcrop	12	0.1	0.7	0.5	2.69	2.70	62	T-2	Sublithographic.
Ellenburger Group (dolomite).	do	do	23	1.1	12.6	4.3	2.72	2.76	62	T-2	Microgranular.
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 (calcitic dolomite).	do	do	1	----------	----------	.8	2.74	2.75	62	T-2	
Ellenburger Group (dolomitic limestone).	do	do	1	----------	----------	1.5	2.75	2.77	62	T-2	

Do	Permain 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, dolomote).	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
				Minimum	Maximum	Average	Dry	Water-saturated			
Silurian—Continued											
Niagara Dolomite	Wisconsin	Quarry	14	0.5	6.7	2.9	2.74	2.77	22	A-1	
Guelph Dolomite	Ontario, Canada	do	3	14.6	15.9	15.4	2.41	2.56	112	A-2	3 localities.
Niagara Group (limestone, dolomite).	do	do	6	4.4	13.4	9.1	2.54	2.63	112	A-2	6 localities.
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	
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	8 wells.
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	
Dundee Limestone (dolomite).	Coldwater field, Michigan	≈3,750	16			2.5			33	N-1	Matrix porosity.
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	
Do	do	7,155–7,178	4	7.6	12.9	10.0			71	N-1	Porous zone.
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.
						6.8			160	N-1	Entire matrix.
Limestone	Various localities, Germany.		6	.6	2.7	1.9			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 13.5			23	N-1	Do.
McClosky limestone (D zone).	do	≈2,600				15.4 18.5			23	N-1	Do.
Maxville Limestone	Muskingum County, Ohio.	≈200	2	.9	2.0	1.5	2.77	2.79	17	A-16	
		≈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
				Minimum	Maximum	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.
Do	Germany	Quarry	2	.6	1.3	1.0			72		2 localities.
				Permian							
Brown dolomite	Moore County, Tex.	3,574–3,614	15	3.2	27.1	11.7			(2)	A-10	Permeable.
Limestone	do	3,614–3,644	8	6.3	12.2	8.5			(2)	A-10	Impermeable.
Permian limestone	Big Springs field, Texas	≈9,000	5	11.9	22.2	17.9			123	A-9	Dolomite(?).
Rex chert Member of Phosphoria Formation.	Afton quadrangle, Wyoming.					17.0	2.33	2.50	110	T-2	
Zechstein	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	Galicia, 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.	Dorcheat 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	
Solenhofen Limestone	do	Outcrop(?)	23	1.2	5.7	3.9	2.57	2.61	(1)	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	Dip 8° or more, or not recorded.
Do	Mostly from Canton Schaffhausen, Switzerland.	do	18	.9	10.7	5.4	2.57	2.63	63	T-4	Dip 7° or less.
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
				Minimum	Maximum	Average	Dry	Water-saturated			
Cretaceous											
Dees oolitic limestone	Rodessa field, Louisiana	≈5,450	74	8.0	32.0	22.0			123	A-9	
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	19 wells.
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	
Limestone	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	Altered by basalt.
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	Folded rocks; dip 10° or more.
Globigerina limestone (marly).	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	
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	Dip 20°-80°.
Miocene											
Limestone, sandy	Eniwetok Atoll, Marshall Island.	1,100-2,687	2				1.21		17	A-16	
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 D.
Do		do			19.3	6.6			88	A	Well H.
Do		do	27	1.1	13.0				88	A	Dolomite, 0-10 percent.
Do		do	12	1.5	12.0				88	A	Dolomite, 11-25 percent.
Do		do	8	2.5	8.9				88	A	Dolomite, 26-50 percent.
Do		do	2	13.0	15.8				88	A	Dolomite, 51-75 percent.
Do		do	7	4.2	16.1				88	A	Dolomite, 75 percent.
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	

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
				Minimum	Maximum	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
				Minimum	Maximum	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.
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
				Minimum	Maximum	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, Olkahoma	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	829				14.6			141	A-2	
	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	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	
Permian and Triassic											
Clay	Aktyubin area, U.S.S.R.	Subsurface	4			16.0	2.33	2.49	108	T	
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
				Minimum	Maximum	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	
Graneros shale	Hamilton County, Kans.	do	2	24.6	25.2	24.9	1.99	2.23	67	T-2	Not weathered.
Graneros(?) shale	do	3,029-3,950	3	9.2	11.6	10.6	2.37	2.47	67	T-2	Ransom well.
Do	do	4,485-5,006	3	8.7	9.6	9.1	2.46	2.55	67	T-2	Do.
Pennsylvanian(?) shale	do	5,355-5,440	3	7.7	8.4	8.1	2.52	2.61	67	T-2	Do.
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			(2)	A	Permeability, 0.1 md.
		13,694	1			5.7			(2)	A	Permeability, <0.1 md.
Hilliard 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	Dip 1°-5°.
Do	do		3	25.4	26.0	25.6	1.99	2.24	129	T-2	Dip 5°-10°.
Do	do		1			23.8	2.00	2.24	129	T-2	Dip 33°.
Do	do		1			35.8	1.56	1.92	129	T-2	Dip 45°.
Do	do		1			25.3	1.99	2.24	129	T-2	Dip 50°.
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	England	do	1			13.6			141	A-2	Weathered.
		do	1			8			141	A-2	Unweathered.
Gosauschichten	Austria(?)	Outcrop(?)	3	.8	4.7	2.2	2.61	2.63	115	T-2	Folded.
Paleocene											
Fort Union Formation:											
Lebo Shale Member	Rosebud County, Mont.	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	
Oligocene											
Clay, plastic	Baden, Germany	Pit	1			26.0	1.90	2.16	115	T-2	
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	1.93	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	
Temblor 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	Outcrop	2	36.6	37.4	37.0	1.67	2.04	68	T-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
				Minimum	Maximum	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						1.96–2.13	167		Natural state(?).
Clay	Various localities, England.	Outcrop	3	28.3	29.8	28.8			141	A-2	
Age not specified											
Clay	49 localities, New Jersey	Outcrop	49				1.83		29		Range 1.53–2.17 gcm^{-3} air dried.
Kaolins	Missouri	Pit or bank						1.90	167		Natural state(?).
Loess clays	do	do						2.05	167		Do.
Gumbo clays	do	do						2.01	167		Do.
Fire clay	do	Subsurface						2.40	167		Do.
Shales	do	Pit or bank						2.38	167		Do.
Shale	Phillips well, Russell County, Kans.	1,400–1,485	4	22.0	23.3	22.5	2.15	2.37	67	T-2	
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	Moist.
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
				Minimum	Maximum	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	
Do	Marblehead Beach, Mass	do	1			42.1			51	T-7	Fine, wet.
Do	do	do	1			42.9			51	T-7	Fine, dry.
Do	do	do	1			39.0			51	T-7	Coarse, damp.
Do	do	do	1			34.0			51	T-7	Coarser, damp.
Sand, artificially packed			1			37.9			51	T-7	Wet.
Do			1			37.0			51	T-7	Dry.
Cape May Formation (sand).	Runyon, N.J	Mostly pits	8	30.8	45.3	40.1	1.50	1.90	143	T-5	Fine to medium grained.
Do	Pleasantville, N.J	≈1	4	25.5	30.0	27.7	1.74	2.02	143	T-5	Poorly sorted.
Do	Absecon, N.J	0-3½	4	30.8	39.9	36.6	1.63	2.00	143	T-5	Medium grained.
Cape May Formation (gravel).	do	0-2	2	23.4	27.4	25.4	1.83	2.08	143	T-5	Loose.
Silt	Princeton, N.J	1	1			53.2	1.25	1.78	143	T-5	Recent(?)
Sand	Old Bridge, N.J	2-6	4	43.6	46.6	45.0	1.47	1.92	143	T-5	Do.
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	
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	
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	Above gravel bank.
Lower clay member	do	do	1			35.7	1.73	2.09	98	T-2	Below gravel bank.

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
				Minimum	Maximum	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		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 sediments, from 0–1 in. below depositional surface.	3			38.3		2.08	64	A-7	
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	83 percent through No. 200 sieve.
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 (gcm^{-3})		Reference	Method of porosity determination	Remarks
				Minimum	Maximum	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.
			3				4.26		17	A-16	Do.
Red Mountain Formation (ore).	Bessemer, Ala	≈1,400	2	2.3	3.0	2.7	3.73	3.76	172	A-16	Silurian.
Biwabik Iron-Formation	Virginia, Minn	Subsurface	1			.3	2.75	2.75	16	A-16	Precambrian.
"Granite"	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						2.6	14		Do.
Gypsum		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 gcm^{-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.

REFERENCES

[Numbers are used to simplify identification in tabulated material]

1. Akins, D. W., 1951, Primary high pressure water flooding in the Pettit lime Haynesville field: Am. Inst. Mining Metall. Engineers Trans., v. 192, p. 239–248.
2. Allison, A. P., Beckelhymer, R. L., Benson, D. G., Hutchins, R. M., Jr., Lake, C. L., Lewis, R. C., O'Bannon, P. H., Self, S. R., and Warner, C. A., 1946, Geology of Katy field, Waller, Harris, and Fort Bend Counties, Texas: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 157–180.
3. Altschaeffel, A. G., and Harrison, W., 1959, Estimation of a minimum depth of burial for a Pennsylvanian underclay: Jour. Sed. Petrology, v. 29, p. 178–185
4. Anderson, J. L., 1945, Petroleum geology of Colombia, South America: Am. Assoc. Petroleum Geologists Bull., v. 29, p. 1065–1142.
5. Arnold, H. H., Jr., 1939, Salem oil field, Marion County, Illinois: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1352–1373.
6. Athy, L. F., 1930, Density, porosity and compaction of sedimentary rocks: Am. Assoc. Petroluem Geologists Bull., v. 14, p. 1–24.
7. Atkinson, Burton, and Johnston, David, 1948, Core analysis of fractured dolomite in the Permian Basin: Am. Inst. Mining Metall. Engineers Trans., v. 179, p. 128–132.
8. Baldwin, T. A., 1950, San Ardo, A straitgraphic analysis of a California oil field: Am. Assoc. Petroluem Geologists Bull., v. 34, p. 1981–1989.
9. Barb, C. F. and Branson, E. R., 1931, Fluid flow through oil sands: International Petroleum Technology, v. 8, p. 325–334. Also quoted in Francher, G. H., Lewis, J. A., and Barnes, K. B., 1933, Some physical characteristics of oil sands *in* Third Pennsylvania Mineral Industries Conf., petroleum and natural gas sec., Proc.: Pennsylvania State Coll. Mineral Industries Expt. Sta. Bull. 12.
10. Barrell, Joseph, 1914, The strength of the earth's crust : Jour Geology, v. 22, p. 214.
11. Barton, H. E., 1948, Steamboat Butte oil field, Fremont county, Wyoming, *in* Howell, J. V., ed., Structure of typical American oil fields, v. 3: Am. Assoc. Petroleum Geologists, p. 480–513.
12. Bartosh, E. J., 1938, Wilmington oil field, Los Angeles County, California: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 1048–1079.
13. Bates, Fred W., 1941, Geology of Eola oil field, Avoyelles Parish, Louisiana: Am. Assoc. Petroleum Geoligists Bull., v 25, p. 1363–1395.
14. Birnbaum, A., 1924, Drehwagemessungen in Salzbergbau über und unter Tage: Kali, v. 18, p. 144–148.
15. Blackburn, W. C., 1935, Hilbig oil field, Bastrop, County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 1023–1037.
16. Blair, B. E., 1955, Physical properties of mine rock, Part III: U.S. Bur. Mines Rept. Inv. 5130, 69 p.
17. ——— 1956, Physical properties of mine rock, Part IV: U.S. Bur. Mines Rept. Inv. 5244, 69 p.

18. Born, W. T., and Owen, J. E., 1935, Effect of moisture upon velocity of elastic waves in Amherst sandstone: Am. Assoc. Petroleum Geologists Bull., v. 19, p. 9–18.
19. Bownocker, J. A., 1915, Building stones of Ohio: Geological Survey of Ohio, 4th ser., Bull. 18, 160 p.
20. Branner, G. C., 1937, Sandstone porosities in Paleozoic region in Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 21, p. 67–79.
21. Brown, R. D., Jr., Snavely, P. D., Jr., and Gower, H. D., 1956, Lyre formation (redefinition) Northern Olympic Peninsula, Washington: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 94–107.
22. Buckley, E. R., 1898, Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull., v. 4, p. 401–403.
23. Bybee, H. H., 1948, Hitesville consolidated field, Union County, Kentucky: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 2063–2082.
24. Caribbean Petroleum Company, staff, 1948, Oil fields of Royal Dutch-Shell group in Western Venezuela: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 517–628.
25. Carver, G. E., 1948, Arcadia-Coon Creek oil pool, Oklahoma and Logan Counties, Oklahoma, *in* Howell, J. V., ed., Structure of typical American oil fields, v. 3: Am. Assoc. Petroleum Geologists, p. 319–340.
26. Cipriani, D., Jr., 1956, Southwest Randlett field, Cotton County, Oklahoma, *in* Petroleum Geology of Southern Oklahoma, v. 1: Am. Assoc. Petroleum Geologists, p. 311–318.
27. Clark, C. C., 1938, Sugar Creek field, Claiborne Parish, Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 1504–1518.
28. Clark, R. W., 1940, Paloma oil field, Kern County, California: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 742–744.
29. Cook, G. H., 1878, Report on the clay deposits of Woodbridge, South Amboy and other places in New Jersey: Geol. Survey of New Jersey, p. 284–285.
30. Corps, E. V., 1949, Digboi oil field, Assam: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 1–21.
31. Cox, H. M., 1953, Williston Basin: Mississippian reservoir characteristics and proved reserves: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 2294–2302.
32. Crego, W. O., and Hanagan, J. M., 1951, Report on the Mamou field pressure maintenance project: Am. Inst. Mining Metall. Engineers Trans., v. 192, p. 263–268.
33. Criss, C. R., and McCormick, R. L., 1954, History and performance of the Coldwater oil field, Michigan: Am. Inst. Mining Metall. Engineers Trans., v. 201, p. 23–29.
34. Crutchfield, J. W., and Bowers, E. F., 1950, Performance of Lower Pawelek reservoir, Falls City field, Karnes County, Texas: Am. Inst. Mining Metall. Engineers Trans., v. 189, p. 335–344.
35. Culbertson, J. A., 1940, Downdip Wilcox Eocene of Coastal Texas a n. Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 1891–1922
36. Current, A. M., 1948, Gilbertown oil field, Choctaw County, Alabama, *in* Howell, J. V., ed., Structure of typical American oil fields, v. 3: Am. Assoc. Petroleum Geologists, p. 1–4.
37. Curry, W. H., Jr., and Curry, W. H., III, 1954, South Glenrock, a Wyoming stratigraphic oil field: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 2119–2156.
38. Daniel, E. J., 1954, Fractures reservoirs of Middle East: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 774–815.

39. Davis, W. B., 1951, A study of the Dornick Hills-Springer sand reservoir, Velma pool, Oklahoma: Am. Inst. Mining Metall. Engineers Trans., v. 192, p. 29–36.
40. Elkins, L. F., French, R. W., and Glenn, W. E., 1949, Lance Creek Sundance reservoir performance—a unitized pressure—maintenance project: Am. Inst. Mining Metall. Engineers Trans., v. 179, p. 222–248.
41. Elliott, G. R., 1944, Geologic factors in unitized pressure maintenance, Jones sand reservoir, Schuler field, Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 28, p. 217–230.
42. Esarey, R. E., 1927, Tri-County oil fields of southwestern Indiana: Am. Assoc. Petroleum Geologists Bull., v. 11, p. 601–610.
43. Fancher, G. H., Lewis, J. A., and Barnes, K. B., 1933, Some physical characteristics of oil sands, *in* Third Pennsylvania Mineral Industries Conference, petroleum and natural gas section, Proc: Pennsylvania State Coll. Mineral Industries Expt. Sta. Bull. 12, p. 65–171.
44. Fentress, G. H., 1955, Little Beaver field, Colorado, a stratigraphic, structural, and sedimentation problem: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 155–188.
45. Fettke, C. R., 1926, Core studies of the Second sand of the Venango group from Oil City, Pa., *in* Petroleum Development and Technology in 1926: Am. Inst. Mining Metall. Engineers, Petroleum Div., p. 219–234.
46. ——— 1934, Physcial characteristics of Bradford sand, Bradford field, Pennsylvania, and relation to production of oil: Am. Assoc. Petroleum Geologists Bull., v. 18, p. 191–211.
47. ———1938, Oriskany as a source of gas and oil in Pennsylvania and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 241–266.
48. Fichter, H. J., and Renz, H. H., *in* Mencher, E., and others, 1953, Geology of Venezuela and its oil fields: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 690–777.
49. Finn, F. H., 1949, Geology and occurrence of natural gas in Oriskany sandstone in Pennsylvania and New York: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 303–335.
50. Fisher, Barney, 1941, La Rosa field, Refugio County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 300–317.
51. Fraser, H. J., 1935, Experimental study of the porosity and permeability of clastic sediments: Jour. Geology, v. 43, p. 910–1010.
52. Frost, V. L., 1940, Ramsay oil pool, Payne County, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 1995–2005.
53. Fuller, M. L., 1906, Total amount of free water in the earth's crust: U.S. Geological Survey Water-Supply Paper 160, p. 59–72.
54. Funkhouser, H. J., Sass, L. C., and Hedberg, H. D., 1948, Santa Ana, San Joaquin, Guario, and Santa Rosa oil fields (Anaco fields) Central Anzoátegui, Venezuela: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 1851–1908.
55. Gallup, W. B., 1951, Geology of Turner Valley oil and gas field, Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 797–821.
56. Gary, N., 1898, Prüfung natürlicher Gesteine in den Betriebsjahren 1895/96 bis 1897/98: Königlichen technischen Versuchanstalten zu Berlin, Mitt., v. 5, p. 243–294.
57. Gates, G. L., Morris, F. C., and Caraway, W. H., 1950, Effect of oil-base drilling fluid filtrate on analysis of ores from South Coles Levee, Calif., and Rangely, Colo., fields: U.S. Bur. Mines Rept. Inv. 4716.
58. Geikie, A., 1903, quoted in Fuller, M. L., 1906, Total amount of free water in the earth's crust: U.S. Geol. Survey Water-Supply Paper 160, p. 59–72.

59. Gester, G. C., and Galloway, John, 1933, Geology of Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists Bull.,v. 17, p. 1161–1193.
60. Glenn, W. E., 1950, A study of reservoir performance of the First Grubb pool, San Miguelito field, Ventura County, California: Am. Inst. Mining Metall. Engineers Trans., v. 189, p. 243–260.
61. Goebel, L. A., 1950, Cairo field, Union County, Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1954–1980.
62. Goldich, S. S., and Parmelee, E. B., 1947, Physical and chemical properties of Ellenburger group Llano County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 1982–2020.
63. Grubenmann, U., and Niggli, P., and others, 1915, Die natürlichen Bausteine und Dachschiefer der Schweiz: Beitr. Geologie Schweiz, Geotechnische Serie, no. 5, 423 p.
64. Hamilton, E. L., and Menard, H. W., 1956, Density and porosity of sea-floor surface sediments off San Diego, California: Am. Assoc. Petroleum Geologists Bull., v. 40, p. 754–761.
65. Hamner, E. J., 1939, Amelia oil field, Jefferson County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1635–1665.
66. Hartmann, F., 1926, Die Bestimmung des Raugewichts und der Porosität feurefester Steine nach dem Quecksilber- und nach dem Wasser-Verdrängungsverfahren: Berichte der Fachausschüsse des Vereins deutscher Eisenhüttenleute, Ber. Nr. 82, 9 p.
67. Hedberg, H. D., 1926, The effect of gravitational compaction on the structure of sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., v. 10, p. 1035–1072.
68. Hedberg, H. D., 1936, Gravitational compaction of clays and shales: Am. Jour. Sci., 5th ser., v. 31, p. 241–287.
69. Hedberg, H. D., Sass, L. C., and Funkhouser, H. J., 1947, Oil fields of the Greater oficina area, Central Anzoátegui, Venezuela: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 2089–2169.
70. Hewett, B. H. M., and Johannesson, S., 1922, Shield and compressed air tunneling: New York, McGraw-Hill, p. 291–295.
71. Hinson, H. H., 1947, Reservoir characteristics of Rattlesnake oil and gas field, San Juan County, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 31, p. 731–771.
72. Hirschwald, J., 1912, Handbuch der bautechnischen Gesteinprüfung: Berlin, Borntraeger, 923 p.
73. Holmes, Arthur, 1930, Petrographic methods and calculation (revised ed.) London, Murby & Co., p. 52.
74. Howell, J. V., 1948, Geology of Benton field, Franklin County, Illinois: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 745–766.
75. Hubbard, W. E., and Thompson, W. C., 1926, The geology and oil fields of Archer County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 10, p. 457–481.
76. Hughes, D. S., and Kelly, J. L., 1952, Variation of elastic wave with saturation in sandstone: Geophysics, v. 17, p. 739–752.
77. Hunt, W. C., 1950, Preliminary report on Whitemud oil field, Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1795–1801.
78. Imbt, R. F., and McCollum, S. V., 1950, Todd Deep field, Crockett County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 239–262.
79. Ingham, W. I., 1948, Powell's Lake oil field, Union County, Kentucky: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 34–51.

80. Jakosky, J. J., and Hooper, R. H., 1937, The effect of moisture on the direct current resistivities of oil sands and rocks: Geophysics, v. 2, p. 33–35.
81. Jones, P. H., and Buford, T. B., 1951, Electric logging applied to ground water exploration: Geophysics, v. 16, p. 115–139.
82. Kessler, D. W., 1919, Physical and chemical tests on the commercial marbles of the United States: U.S. Bur. Standards Tech. Paper no. 123, 54 p.
83. Koch, E., in Königsberger, J., 1925, Über die heute mit der Drehwage von Eötvös bei Feldmessungen erreichbare Genauigkeit und über den Einflusz der geologischen Beschaffenheit des Terrains hierauf: Zeitschr. prakt. Geologie, v. 33, p. 169–175.
84. Krumbein, W. C., and Sloss, L. L., 1951, Stratigraphy and sedimentation: San Francisco, Freeman & Co., p. 91.
85. Lafferty, R. L., 1938, The Oriskany in West Virginia: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 175–188.
86. Layer, D. B., and Members of Staff, Imperial Oil Limited, 1949, Leduc oil field, Alberta, a Devonian coral-reef discovery: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 572–602.
87. Lee, C. H., 1919, Water in the major valleys *in* Ellis, A. J., and Lee, C. H., Geology and ground waters of the western part of San Diego County, California: U.S. Geol. Survey Water-Supply Paper 446, p. 121.
88. Lees, G. M., 1933, Reservoir rocks of Persian oil fields: Am. Assoc. Petroleum Geologists Bull., v. 17, p. 229–240.
89. Lewis, J. V., 1924, Fissility of shale and it relations to petroleum: Geol. Soc. America Bull., v. 35, p. 557–590.
90. Lietz, W. T., 1949, The performance of the Ten Section oil field: Am. Inst. Mining Metall. Engineers Trans., v. 186 p. 251–258.
91. Littlefield, Max, Gray, L. L., and Godbold, A. C., 1948, A reservoir study of the West Edmond Hunton pool, Oklahoma: Am. Inst. Mining Metall. Engineers Trans., v. 174, p. 131–164.
92. MacKenzie, W. D. C., 1940, Paleozoic limestone of Turner Valley, Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 1620–1640.
93. MacQuown, W. C., Jr., and Millikan, W. E., 1955, Little Beaver, Badger Creek, Middlemist field area, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 630–648.
94. Mansfield G. R., 1927, Geography, geology and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, p. 210.
95. McBee, William, Jr., and Vaughn, L. G., 1956, Oil fields of the central Muenster-Waurika arch, Jefferson County, Oklahoma and Montague County, Texas *in* Petroleum geology of Southern Oklahoma: Am. Assoc. Petroleum Geologists, v. 1, p. 355–372, 402 p.
96. McClellan, H. W., and Haines, R. B., 1951, San Miguelito oil field, Ventura County, California: Am. Assoc. Petroleum Geoligists Bull., v. 35, p. 2542–2560.
97. McGee, D. A., and Jenkins, H. D., 1946, West Edmond oil field, central Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1797–1829.
98. Melcher, A. F., 1921, Determination of pore space of oil and gas sands: Am. Inst. Mining Metall. Engineers Trans., v. 65 p. 469–497.
99. ——— 1924, Texture of oil sands with relations to the production of oil: Am. Assoc. Petroleum Geologists Bull., v. 8, p. 716–774.
100. Merrill, G. P., 1908, Stones for building and decoration: New York, John Wiley & Sons, 551 p.

101. Michaux, F. W., and Buch, E. O., 1936, Conroe oil field, Montgomery County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 20, p. 736-779.
102. Miller, R. L., 1948, Rose Hill oil field, Lee County, Virginia, *in* Howell, J. V., ed., Structure of typical American oil fields: Am. Assoc. Petroleum Geologists, v. 3, p. 452–479.
103. Minor, H. E., and Hanna, M. A., 1933, East Texas oil field: Am. Assoc. Petroleum Geologists Bull., v. 17, p. 757–792.
104. Moore, C. A., 1941, Coring the Burgess sandstone: World Oil, v. 126, June 16, p. 38–43.
105. Moore, C. C., 1904, The study of the volume composition of rocks, and its importance to the geologist: Geol. Soc. Liverpool Proc., v. 9 (1900–1904) p. 129–162.
106. Moore, H. B., 1931, The muds of the Clyde Sea area: Marine Biol. Assoc. [Great Britain] Jour., v. 17, new ser., p. 325–358.
107. Moulton, G. F., and Bell, A. H., 1929, Three typical oil fields of the Illinois region, *in* Structure of typical American oil fields: Am. Assoc. Petroleum Geologists, v. 2, p. 115–141.
108. Nevolin, N. V., Galakfionov, A. B., and Serova, A. D., 1959, Geologicheskoye stroyeniye aktyubinskogo priural'ya [Geology of the Aktyubin area adjacent to the Urals]: Prikladnaya Geofizika, no. 22, p. 129–156.
109. Nutting, P. G., 1930, Physical analysis of oil sands: Am. Assoc. Petroleum Geologists Bull., v. 14, p. 1337–1349.
110. Nutting, P. G., *quoted in* Birch, Francis, Schairer, J. F., and Spicer, H. C., eds., 1942, Handbook of Physical Constants: Geol. Soc. America Spec. Paper 36, p. 25–26.
111. Ockershauser, T. E., 1951, The Southwest Antioch Gibson sand unit: Am. Inst. Mining Metall. Engineers Trans., v. 192, p. 199–204.
112. Parks, W. A., 1912, Report on the building and ornamental stones of Canada, v. 1: Canada Dept. Mines, 376 p.
113. Parsons, L. M., 1922, Dolomitization of the Carboniferous limestone of the Midlands: Geol. Mag. [Great Britain], v. 59, p. 51–63.
114. Pate, J. D., 1959, Stratigraphic traps along north shelf of Anadarko Basin, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 39–59.
115. Petrascheck, W., and Wilser, B., 1926, Über den Wassergehalt und die Verfestigung von Tongesteinen: Berg und Hüttenm. Jahrb., v. 74, pt. 2, p. 57–65.
116. Pfeiffer, H., and Dienemann, W., 1928, Geologische, chemische und physikalische Untersuchungen von Erdrutschen durch die Preuszische Geologische Landesanstalt: Preusz. Geol. Landesanstalt Jahrb., v. 49, p. 304–319.
117. Pickering, W. Y., and Dorn, C. L., 1948, Rangely oil field, Rio Blanco County, Colorado, *in* Howell, J. V., ed., Structure of typical American oil fields: Am. Assoc. Petroleum Geologists, v. 3, p. 132–152.
118. Piersol, R. J., Workman, L. E., and Watson, M. C., 1940, Porosity, total liquid saturation and permeability of Illinois oil sands: Illinois Geol. Survey, Rept. Inv. no. 67, 72 p.
119. Plummer, F. B., and Tapp, P. F., 1943, Technique of testing large cores of oil sands: Am. Assoc. Petroleum Geologists Bull., v. 27, p. 64–84.
120. Poole, J. C., 1940, Saxet oil and gas fields, Nueces County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 1805–1835.
121. Putman, D. M., 1956, The West Duncan field, *in* Petroleum Geology of Southern Oklahoma: Am. Assoc. Petroleum Geologists, v. 1, p. 319–326.

122. Pye, W. D., 1944, Petrology of Bethel sandstone of south-central Illinois: Am. Assoc. Petroleum Geologists Bull., v. 28, p. 63–122.
123. Rall, C. G., Hamontre, H. C., and Taliaferro, D. B., 1954, Determination of porosity by a Bureau of Mines method: A list of porosities of oil sands: U.S. Bur. Mines Rept. Inv. 5025, 24 p.
124. Reeves, Frank, 1946, Status of German oil fields: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1546–1584.
125. Reeves, J. R., 1936, Hebron gas field, Potter County, Pennsylvania: Am. Assoc. Petroleum Geologists Bull., v. 20, p. 1019–1027.
126. Roark, G. E., and Lindner, J. D., 1955, Effects of extensive well fracturing on a water flood operation in the North Texas Strawn sand: Am. Inst. Mining and Metall. Engineers Trans., v. 204, p. 16–21.
127. Roliff, W. A., 1949, Salina-Guelph fields of southwestern Ontario: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 153–188.
128. Rose, Walter, and Bruce, W. A., 1949, Evaluation of capillary character in petroleum reservoir rock: Am. Inst. Mining Metall. Engineers Trans., v. 186, p. 127–142.
129. Rubey, W. W., 1930, Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U.S. Geol. Survey Prof. Paper 165–A, p. 1–54.
130. Rudolph, J. C., 1959, Bellshill Lake field, Alberta: Am. Assoc. Petroleum Geologists Bull., v. 43, p. 880–889.
131. Russell, W. L., 1926, Porosity and crushing strength as indices of regional alteration: Am. Assoc. Petroleum Geologists Bull., v. 10, p. 939–952.
132. Rutledge, R. B., 1956, The Velma oil field, Stephens County, Oklahoma, *in* Petroleum Geology of Southern Oklahoma: Am. Assoc. Petroleum Geologists, v. 1, p. 260–281, 402 p.
133. Schauer, P. E., Jr., 1957, Fractional balance evaluation of pressure maintenance, Smackover lime gas condensate reservoir, McKamie-Patton field, Arkansas: Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 210, p. 108–113.
134. Schneegans, Daniel, 1948, Gas-bearing structures of southern France: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 198–214.
135. Schwartz, C. B., 1948, Fouke oil and gas field, Miller County, Arkansas, *in* Howell, J. V., ed., Structure of typical American oil fields: Am. Assoc. Petroleum Geologists v. 3, p. 5–23.
136. Schwarz, 1870–71, *quoted in* Prinz, E., 1923, Handbuch der Hydrologie 2d ed.: Berlin, Julius Springer, p. 133.
137. Sebring, Louie, Jr., 1948, Slick-Wilcoxfield, Dewitt and Goliad Counties, Texas: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 228–251.
138. Sellards E. H., 1932, Oil fields in igneous rocks in Coastal Plain of Texas: Am. Assoc. Petroleum Geologists Bull., v. 16, p. 741–768.
139. Shaw, E. W., 1915, Discussion of "The role and fate of connate water in oil and gas sands," by Roswell H. Johnson: Am. Inst. Mining Metall. Engineers Bull. 103, p. 1449–1459.
140. Shaw, E. W., *quoted in* Meinzer, O. E., 1923, The occurrence of ground water in the United States: U.S. Geol. Survey Water-Supply Paper 489, p. 8.
141. Sorby, H. C., 1908, On the application of quantitative methods to the study of the structure and history of rocks: Geol. Soc. London Quart. Jour., v. 64, p. 171–233.
142. Spangler, W. B., 1950, Subsurface geology of Atlantic coastal plain of North Carolina: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 100–132.

143. Stearns, N. D., 1927, Laboratory tests on physical properties of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 596, p. 121–176.
144. Steinhoff, E., and Mell, Maria, 1924, Porositätsbestimmungen an feuersfesten Steinen: Berichte der Fachausschüsse des Vereins deutscher Eisenhüttenleute, Ber. Nr. 44, 6 p.
145. Stewart, F. M., Garthwaite, D. L., and Krebill, F. K., 1955, Pressure maintenance by inert gas injection in the high relief Elk Basin field: Am. Inst. Mining Metall. Engineers Trans., v. 204, p. 49–57.
146. Swann, D. H., 1951, Waltersburg sandstone oil pools of Lower Wabash area: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 2561–2581.
147. Swendenborg, E. A., 1949, Production of oil under unitization in Wertz dome field, Wyoming: Am. Inst. Mining Metall. Engineers Trans., v. 186, p. 163–170.
148. Swesnik, R. M., 1950, Golden Trend of south-central Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 386–422.
149. Swineford, Ada, 1947, Cemented sandstones of the Dakota and Kiowa formations in Kansas: Kansas Geol. Survey Bull. 70, p. 53–104.
150. Tillotson, A. W., 1938, Olympic pool, Hughes and Okfuskee Counties, Oklahoma: Am. Assoc. Petroleum Geologists Bull., v. 22, p. 1579–1587.
151. Todd, J. D., and Roper, F. C., 1940, Sparta-Wilcox Trend, Texas and Louisiana: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 701–715.
152. Trager, H. H., 1940, Dorcheat pool, Columbia County, deepest in Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 738–740.
153. Trask, P. D., 1931, Compaction of sediments: Am. Assoc. Petroleum Geologists Bull., v. 15, p. 271–276.
154. Trube, A. S., Jr., and DeWitt, S. W., 1950, High pressure water injection for maintaining reservoir pressures, New Hope field, Franklin County, Texas: Am. Inst. Mining Metall. Engineers Trans., v. 189, p. 325–334.
155. U.S. Dept. Agriculture, *quoted in* Fuller, Myron L., 1906, total amount of free water in the earth's crust: U.S. Geol. Survey Water-Supply Paper 160, p. 59–72.
156. Vallat, E. H., 1939, Wasco field, Kern County, California: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1564–1567.
157. Waldschmidt, W. A., 1941, Cementing materials in sandstones and their probable influence on migration and accumulation of oil and gas: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 1834–1879.
158. Waldschmidt, W. A., 1946, Gramp's field, Archuleta County, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 561–580.
159. Walton, P. T., 1955, Wasatch Plateau gas fields, Utah: Am. Assoc. Petroleum Geologists Bull., v. 39, p. 385–421.
160. Waring, W. W., and Layer, D. R., 1950, Devonian dolomitized reef D3 reservoir, Leduc field, Alberta, Canada: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 295–312.
161. Wasson, Theron, and Wasson, I. B., 1927, Cabin Creek field, West Virginia: Am. Assoc. Petroleum Geologists Bull., v. 11, p. 705–719.
162. Weddle, H. W., 1951, Pleasant Valley oil field, Fresno County, California: Am. Assoc. Petroleum Geologists Bull., v. 35, p. 619–623.
163. Weeks, W. B., and Alexander, C. W., 1942, Schuler field, Union County, Arkansas: Am. Assoc. Petroleum Geologists Bull., v. 26, p. 1467–1516.
164. Welsh, J. R., Simpson, R. E., Smith, J. W., and Yust, C. S., 1949, A study of oil and gas conservation in the Rickton field: Am. Inst. Mining Metall. Engineers Trans., v. 186, p. 55–65.

165. Wendlandt, E. A., and Shelby, T. H., Jr., 1948, Talco oil field, Franklin and Titus Counties, Texas, *in* Howell, J. V., ed., Structure of typical American oil fields: Am. Assoc. Petroleum Geologists, v. 3, p. 432–451.
166. Wendlandt, E. A., Shelby, T. H., and Bell, J. S., 1946, Hawkins field, Wood County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 30, p. 1830–1856.
167. Wheeler, H. A., 1896, Clay deposits: Missouri Geological Survey, v. 11, p. 90–91.
168. Wiggins, P. N., III, 1954, Geology of Ham Gossett oil field, Kaufman County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 306–318.
169. Wilkinson, W. M., 1953, Fracturing in Spraberry reservoir, West Texas: Am. Assoc. Petroleum Geologists Bull., v. 37, p. 250–265.
170. Wilson, J. M., 1941, South Cotton Lake field, Chambers County, Texas: Am. Assoc. Petroleum Geologists Bull., v. 25, p. 1898–1920.
171. Wilson, W. W., 1952, Engineering study of the Cook Ranch field, Shackelford County, Texas: Am. Inst. Mining Metall. Engineers Trans., v. 195, p. 77–84.
172. Windes, S. L., 1949, Physical properties of mine rock, Part I: U.S. Bur. Mines Rept. Inv. 4459, 79 p.
173. ——— 1950, Physical properties of mine rock, Part II: U.S. Bur. Mines Rept. Inv. 4727, 37 p.
174. Womack, Robert, Jr., 1950, Brookhaven oil field, Lincoln County, Mississippi: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 1517–1529.
175. Yuster, S. T., 1951, *in* Payne, T. G., and others, Geology of the Arctic slope of Alaska: U.S. Geol. Survey Oil and Gas Inv. Map OM 126, Sheet No. 2.

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