SECTION 4

DENSITY OF ROCKS

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Handbook of Physical Constants—*Revised Edition*
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TABLE 4-1. AVERAGE DENSITIES OF HOLOCRYSTALLINE IGNEOUS ROCKS
(R. A. Daly)

Rock	Number of samples	Mean density	Range of density
Granite	155	2.667	2.516–2.809
Granodiorite	11	2.716	2.668–2.785
Syenite	24	2.757	2.630–2.899
Quartz diorite	21	2.806	2.680–2.960
Diorite	13	2.839	2.721–2.960
Norite	11	2.984	2.720–3.020
Gabbro, including olivine gabbro	27	2.976	2.850–3.120
Diabase, fresh	40	2.965	2.804–3.110
Peridotite, fresh	3	3.234	3.152–3.276
Dunite*	15	3.277	3.204–3.314
Pyroxenite	8	3.231	3.10 –3.318
Anorthosite	12	2.734	2.640–2.920

* From Birch, Jour. Geophys. Res., **65**, 1083, 1960

TABLE 4-2. AVERAGE DENSITIES OF NATURAL GLASSES
(R. A. Daly)

Glass	No. of determinations	Range of density	Mean density	Ref.
Rhyolite obsidian	15	2.330–2.413	2.370	2
Trachyte obsidian	3	2.435–2.467	2.450	2
Pitchstone	4	2.321–2.37	2.338	1
Andesite glass	3	2.40 –2.573	2.474	1
Leucite tephrite glass	2	2.52 –2.58	2.55	1
Basalt glass	11	2.704–2.851	2.772	2

REFERENCES FOR TABLE 4-2

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2. Tilley, Min. Mag., **19**, 275, 1922

Table 4-1 was taken by Daly from a slightly longer compilation in his *Igneous rocks and the depths of the earth* (New York, McGraw-Hill Book Co., 598 p., 1933). It is virtually the same as the list in the first edition of the Handbook of Physical Constants, but with more extensive data for dunites. For further data on the densities of igneous rocks *see* Tables 9-2, 21-2, and 21-4.

Table 4-4 lists a selection of values of porosity and density of sedimentary rocks. The selection illustrates porosity and density variations in relationship to rock type, and to age, locality, and depth of sample.

Porosity is expressed as either total or apparent porosity. Total porosity is a measure of the total void volume and includes those pores which may be sealed off, as well as those which are connected with the surface of the test specimens. It is based on differences in measurement between total or bulk volume (V_B) and grain volume (V_G). The total porosity (P_T) by per cent is

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

TABLE 4-3. DENSITY OF CRYSTALLINE ROCK AND CORRESPONDING GLASS (ARTIFICIALLY PREPARED) (R. A. Daly)

	Density		Difference per cent of rock density	Ref.
	Rock	Glass		
Granite, Shap Fells	2.656	2.446	7.90	3
Granite, Peterhead	2.630	2.376	9.66	3
Syenite, Plauen'scher Grund	2.724	2.560	6.02	3
Tonalite, New Zealand	2.765	2.575	6.87	3
Diorite, Guernsey	2.833	2.680	5.40	3
Diorite, Markfield	2.880	2.710	5.90	3
Gabbro, Carrock Fell	2.940	2.791	5.07	3
Olivine dolerite, Clee Hills	2.889	2.775	3.95	3
Dolerite, Rowley Rag	2.800	2.640	5.71	3
Dolerite, Whin Sill	2.925	2.800	4.27	3
Diabase, Palisades	2.975	2.761	7.19	1
Diabase, Vinal Haven	2.96	2.76	6.8	2
Eclogite	3.415·	2.746 (?)	19.6	4

REFERENCES FOR TABLE 4-3

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Alternatively, and more usually, grain density (D_G) is substituted for grain volume, and bulk density (D_B) for bulk volume. Total porosity by per cent correspondingly is

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

Apparent porosity, otherwise called effective or net porosity, excludes sealed-off or occluded pores. It is based on a measurement of the pore volume (V_P) which intercommunicates and is connected with the surface of the test specimen. Apparent porosity (P_A) by per cent is

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

The method of determining porosity may affect porosity values more than true differences between total and apparent porosity. For 10 specimens of fire brick Hartmann (13) found that the average total porosity, determined by the grain density–bulk density relationship, was 25.5 per cent where bulk volume was obtained by the displacement of water by a previously wetted specimen, but 24.6 per cent where bulk volume was obtained by mercury displacement. Nutting (25) 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 per cent in the determination of grain density. Apparently, however, such large errors due to the adsorption of water do not commonly occur in practice. Hirschwald (17) showed that an erroneous large deficiency of apparent porosity may result from obtaining pore volume by the 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 apply a pressure of 50–150 atmospheres to obtain the optimum saturation of the pores.

Among the earlier publications which give extensive data on porosity and bulk density is that of Buckley (5), 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 specimens for 36 hours. Gary (9) listed the bulk density of numerous building stones, and the total porosity as determined by the grain density–bulk density relationship. Moore (22) 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 (8) 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. Sorby (33) 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. Hirschwald (17) determined the porosity of many sandstone, limestone, and slate specimens of building stone by saturating the specimens under a partial vacuum and then applying a pressure of 150 atmospheres. Grubenmann, Niggli, and others (11) have presented extensive data on the total porosity and bulk density of the building and roofing stones of Switzerland. Kessler (18) determined the bulk density of commercial marbles of the United States and derived total porosity by the grain density–bulk density relationship.

More recently Melcher (21) 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 relationship. Hedberg (14, 15) and Athy (1) determined the total porosity and bulk density of subsurface samples of shale with particular reference to the relationship of compaction to the thickness of overburden. Stearns (34) determined the bulk density and total porosity of many samples of water-bearing rock. Fancher, Lewis, and Barnes (6) 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 porosity determinations. A recent extensive list of porosity determinations of oil sands is given by Rall, Hamontre, and Taliaferro (29). 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 (2) as: shale, 8.2 per cent; sandstone, 14.8 per cent; limestone, 5.3 per cent; and all sedimentary rocks, 8.5 per cent. Additional data since the publication of Barrell's summary indicate that the average value of 8.2 per cent porosity for shale may be low. Athy's graph (1) for Pennsylvanian and Permian shales from structurally disturbed areas show an average of 8.8 per cent for a depth range from 1000 feet to 5000 feet, but Hedberg's data (15) for undisturbed Tertiary shale show an average porosity of 19.8 per cent for a depth range from 219 feet to 7994 feet.

For further data on the density of sediments and sedimentary rocks, *see* Tables 21-5 and 21-11.

TABLE 4-4. POROSITY AND BULK DENSITY, DRY AND SATURATED, OF SEDIMENTARY ROCKS*
(G. Edward Manger)

Formation	Age	Locality	Depth of sample, feet	Number of samples	Porosity, per cent Aver.	Min.	Max.	Sat'd. bulk density (average) g per cm^{-3}	Ref.	Porosity method: T (Total) A (Apparent)
			SANDSTONE							
"Mount Simon" ss.	Cambrian	W. Va., Wood County	13,005–13,065	9	.7	.2	2.5	2.70	30	A
Southern "Potsdam" ss.	Cambrian	Wis.	quarry	14	11.4	4.8	28.3	2.41	5	A
Northern "Potsdam" ss.	Cambrian	Wis.	quarry	16	19.4	10.4	22.6	2.32	5	A
St. Peter Ss.	Ordovician	Ark., Ozark Plateau	outcrop	12	8.8	3.6	14.1	2.50	4	T
Bradford ss.	Devonian	Pa.	≈600–≈2300	297	15.0	6.0	23.3	2.40	7	T
					(assumed grain density, 2.65 g cm^{-3})					
Chemung Formation (ss's.)	Devonian	Pa.	≈1700–≈2300	49	9.5	4.5	22.2	2.51	20, 21	T
Berea Ss.	Mississippian	Ohio, W. Va.	0–2160	18	14.1	4.7	19.5	2.39	20, 21 3, 36	T, A
Atoka Formation (and other ss's.)	Pennsylvanian	Ark.:								
		Ozark Plat.	outcrop	17	12.3	4.7	19.8	2.44	4	T
		Ark. Valley	outcrop	35	7.8	0	20.6	2.51	4	T
		Ouachita Mts.	outcrop	25	5.1	0	10.4	2.56	4	T
Bartlesville sand	Pennsylvanian	Okla.	1570–2680	26	18.3	7.6	32.0	2.40	20	T
Bunter Ss.	Triassic	Gt. Britain	outcrop	18	20.4	5.8	30.8	2.29	22	A
Keuper Ss.	Triassic	Gt. Britain	outcrop	16	22.6	16.5	28.6	2.25	22	A
Woodbine sand	Cretaceous	Tex.	2436–3701	10	24.7	19.0	32.0	2.25	28	A
Sandstones and siltstones	Cretaceous	Montana, eastern	outcrop	22	33.7	22.6	38.3	2.17	34	T
Sandstones	Cretaceous	Wyo.	0–3187	38	19.7	8.8	27.0	2.32	20, 21	T
Sandstones	Miocene	Switzerland	quarry	15	18.7	13.3	22.1	2.37	11	T
					(dips 7° or less)					
			LIMESTONE, DOLOMITE, CHALK, AND MARBLE							
Ellenburger Group (ls. and dol.)	Ordovician	Tex., Llano County	outcrop	57	3.0	.1	12.6	2.75	10	T
Beekmantown Group (dol.)	Ordovician	W. Va., Wood County	10,531–11,945	56	.4	.1	1.1	2.80	30	A
Black River Ls.	Ordovician	Ontario	quarry	11	.46	.07	1.67	2.72	26	A
Niagara Dolomite	Silurian	Wis.	quarry	14	2.9	.5	6.7	2.77	5	A

TABLE 4-4. *Continued*

Formation	Age	Locality	Depth of sample, feet	Number of samples	Porosity, per cent Aver.	Min.	Max.	Sat'd. bulk density (average) g per cm^{-3}	Ref.	Porosity method: T (Total) A (Apparent)
LIMESTONE, DOLOMITE, CHALK, AND MARBLE *Continued*										
Limestone	Carboniferous	Gt. Britain, Midlands	outcrop	24	5.7	2.2	14.9	2.58	27	T
Marl	Carboniferous	Russia	subsurface	19	8.2	..	..	2.63	24	T
Oolites	Jurassic	Gt. Britain	outcrop	5	14.6	5.5	24.0	2.44	22	A
Limestones	Jurassic	Switzerland	quarry	114	3.6 (dips 8° or more)	.4	25.6	2.66	11	T
Glen Rose Ls.	Cretaceous	Tex.	20.5–30.5	10	16.8	16.0	18.8	2.37	28	A
Chalk	Cretaceous	Gt. Britain	outcrop	3	28.8	17.6	42.8	2.23	22	A
Limestone	Cretaceous	Switzerland	quarry	29	4.3 (dips 10° or more)	.4	18.3	2.65	11	T
Green River Fm. (marlstone)	Eocene	Colo.	mine	11	2.9	.2	12.0	2.26	36	A
SHALE, CLAYSTONE, AND SLATE										
Shale	Pennsylvanian	Okla.	1000	..	17	..	..	2.42	1	graph
			3000	..	7	..	..	2.59	1	graph
			5000	..	4	..	..	2.66	1	graph
Shales	Cretaceous	Wyo., Mont.	outcrop	9	29.5	23.8	37.6	2.17	31	T
Shale, nearly horizontal and undisturbed	Oligocene and Miocene	Venezuela	≈600	6	33.5	31.3	35.8	2.06	15	T
			≈2500	9	25.4	22.9	28.9	2.25	15	T
			≈3500	9	21.1	17.8	25.6	2.35	15	T
			≈6100	3	9.6	9.1	10.6	2.52	15	T
			≈7850	2	10.4	10.3	10.4	..	15	T
SAND, CLAY, GRAVEL, ALLUVIUM, AND SOILS										
Cape May Fm. (sd.)	Pleistocene	N.J.	mostly pits	12	38.9	30.8	45.3	1.93	34	T
Loess soil	Quaternary	Idaho	surface	3	61.2	53.2	69.4	1.61	34	T
Fine sand	Quaternary	Calif.	sea-floor sediments,	54	46.2	..	..	1.93	12	†
Very fine sand			0–1 inch below the	15	47.7	..	..	1.92	12	†
Sand-silt-clay			depositional surface	3	74.7	..	..	1.44	12	†
Mud	Quaternary	Hudson River	submerged crate	..	88.2	..	..	..	19	†

		SAND, CLAY, GRAVEL, ALLUVIUM, AND SOILS *Continued*								
Silt	Quaternary	Hudson River	50 ft below river	..	55	..	..	..	16	†
Newly deposited material	Quaternary	Mississippi River Delta	..	..	80–90	..	..	..	32	A
Soft mud	Quaternary	Clyde Sea	0–2.5 cm in mud	9	82	80	87	..	23	A
			22.5–25 cm in mud	9	75	72	80	..	23	A
			MISCELLANEOUS							
Marble	?	U.S.A., Great Britain	quarry	112	.7 (43+ localities)	.4	2.1	2.75	18, 22	T, A

* Publication authorized by the Director, U.S. Geological Survey.
† Pore volume by volume of natural-state water.

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There appear to be few systematic studies of the densities of metamorphic rocks; most of the entries in Table 4-5 refer to rocks from New England. Compilation of such a table is complicated by the fact that geologists tend to classify metasedimentary rocks on a stratigraphic basis, rather than on mineralogy. The mineralogy, and hence the density, of a given formation depends in part on the grade of metamorphism, which differs from place to place. The situation may be further complicated by banding and layering, which can cause heterogeneity in the rock on a scale of a few inches to many feet. This makes it difficult to sample adequately and accurately.

For further data on the densities of metamorphic rocks *see* Tables 9-2, 21-2, and 21-4.

TABLE 4-5. AVERAGE DENSITIES OF METAMORPHIC ROCKS
(Sydney P. Clark, Jr.)

Rock	Number of samples	Mean density	Range of density	Ref.
Gneiss, Chester, Vt.	7	2.69	2.66 –2.73	1
Granite gneiss, Hohe Tauern, Austria	19	2.61	2.59 –2.63	3
Gneiss, Grenville, Adirondack Mtns., N.Y.	25	2.84	2.70 –3.06	1
Oligoclase gneiss, Middle Haddam area, Conn.	28	2.67	..	4
Quartz-mica schists, Littleton Fm., N.H. (high-grade metamorphism)	76	2.82	2.70 –2.96	1
Muscovite-biotite schist, Middle Haddam area, Conn.	32	2.76	..	4
Staurolite-garnet and biotite-muscovite schists, Middle Haddam Area, Conn.	22	2.76	..	4
Chlorite-sericite schists, Vt.	50	2.82	2.73 –3.03	1
Slate, Taconic sequence, Vt.	17	2.81	2.72 –2.84	1
Amphibolite, N.H. and Vt.	13	2.99	2.79 –3.14	1
Granulite, Lapland				
hypersthene-bearing	7	2.93	2.67 –3.10	5
hypersthene-free	5	2.73	2.63 –2.85	5
Eclogite	10	3.392	3.338–3.452	2

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