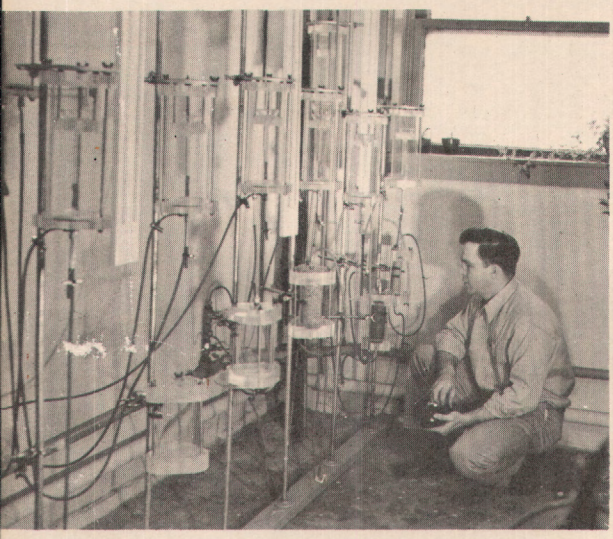


UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARY OF HYDROLOGIC AND PHYSICAL PROPERTIES OF ROCK AND SOIL MATERIALS, AS ANALYZED BY THE HYDROLOGIC LABORATORY OF THE U. S. GEOLOGICAL SURVEY, 1948–60

HYDROLOGIC LABORATORY

DENVER, COLORADO

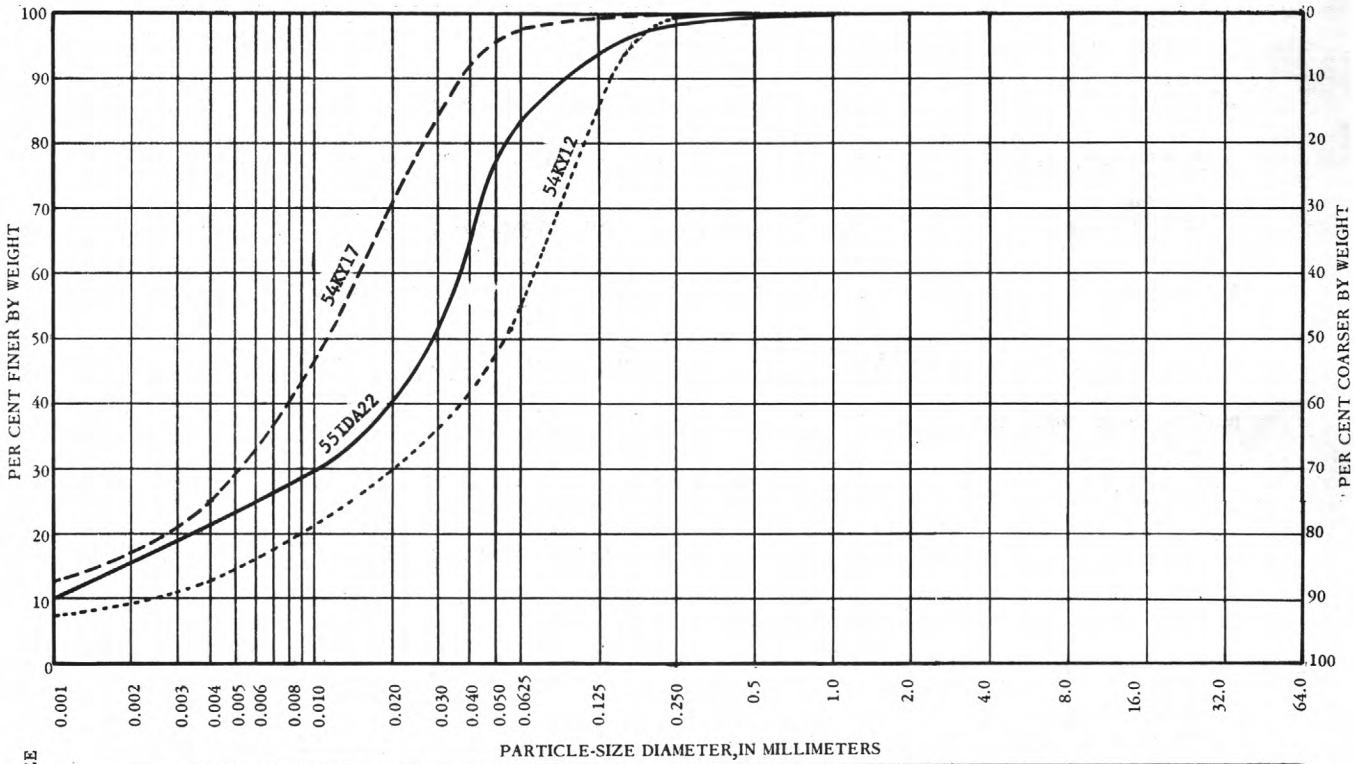
Table 8.--Properties of loess and eolian sand

Test	Loess			Eolian sand		
	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses
Permeability, vertical (gpd per sq ft)	0.1 - 4	2	6	22 -1,500	500	6
Dry unit weight (g per cc)	1.25- 1.62	1.45	18	1.33- 1.70	1.58	15
Specific gravity of solids	2.64- 2.74	2.67	36	2.63- 2.70	2.66	13
Porosity, undisturbed (percent)	44.0 -57.2	49	5	39.9 - 50.7	45	6
Porosity, repacked (percent)	43.0 -53.0	46	6	35.8 - 41.5	38	9
Centrifuge moisture equivalent (percent)	13.2 - 28.7	22	13	.1 - 1.8	0.7	14
Specific retention (percent)	21.8 -29.8	27	5	.5 - 5.8	3	14
Specific yield (percent)	14.1 -22.0	18	5	32.3 - 46.7	38	14

Tuff.--Tuff is a fine-textured volcanic rock formed by the compaction of volcanic dust after it settles from the air. The formation of tuff is usually aided by the action of percolating water. Tuff is generally light in weight and color and composed of angular particles of quartz, feldspar, and other minerals. Table 9 summarizes properties of tuff.

Water-bearing properties of wind-laid deposits.--Wind-blown materials ordinarily are not very coarse. Fine material is usually blown from sites of aqueous deposition by the wind and deposited as dunes or sheets. The coarser deposits of sand, therefore, have irregular stratification and extreme irregularity of crossbedding and other structure owing to the variability of wind direction and alternation of scouring and deposition. However, for any particular sand sample taken from one section of a dune, the degree of sorting is usually good. The hydrologic properties may, therefore, be somewhat different than that of water-laid sand of the same texture. The data here presented indicate that both porosity and permeability are somewhat higher for eolian sand than for water-laid material of the same particle size.

Silt transported by the wind may lack all stratification. Loess is loosely cemented and usually has interstices of such size that it has a high water-retaining capacity and a low permeability.



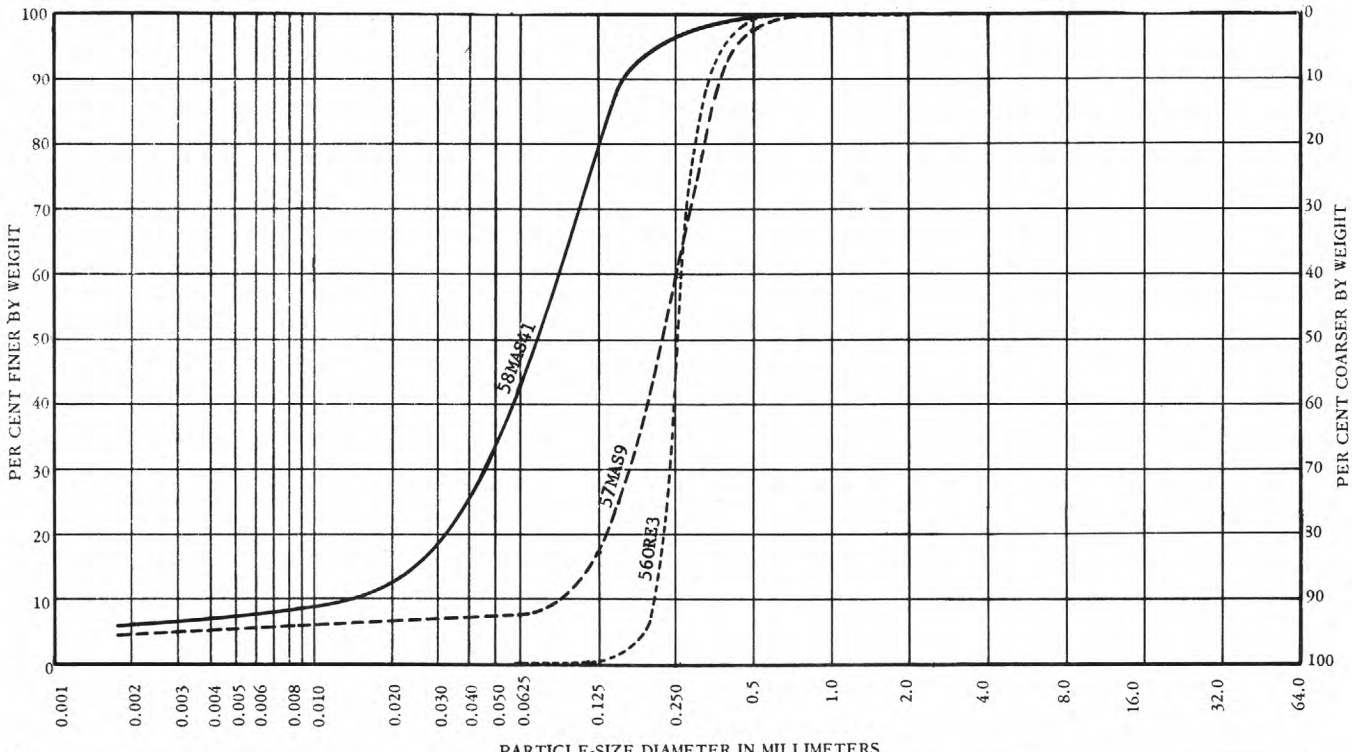
PERCENT OF SIZE

	CLAY SIZES	SILT SIZES	SAND SIZES					GRAVEL SIZES				
	< 0.004 mm	0.004 – 0.0625 mm	V. fine .0625-.125	Fine .125-.25	Medium .25-.5	Coarse .5-1	V.Coarse 1-2	V. fine 2-4	Fine 4-8	Medium 8-16	Coarse 16-32	V.Coarse 32-64
---- 25.0	72.8	1.7	0.5									
—— 21.0	62.5	10.5	4.5	1.3	0.4							
····· 13.1	41.6	30.3	14.8	0.2								

HYDROLOGIC AND PHYSICAL PROPERTIES

Laboratory sample number	Location	Depth of sample (feet)	Specific gravity of solids	Dry unit weight (g per cc)	Specific retention (percent of volume)	Total porosity (percent of volume)	Specific yield (percent of volume)	Coefficient of permeability (gpd per sq ft)
54KY17	Henderson County, Ky.	----	2.74	1.54	29.7	43.8	14.1	0.02
55IDA22	National Reactor Testing Station, Ida.	----	2.73	1.53	----	44.0	----	1
54KY12	Henderson County, Ky.	----	2.67	1.44	13.0	46.1	33.1	4

Figure 9.--Typical data on particle-size distribution, and hydrologic and physical properties of loess.



PERCENT OF SIZE

	CLAY SIZES	SILT SIZES	SAND SIZES					GRAVEL SIZES				
	< 0.004 mm	0.004 – 0.0625 mm	V. fine .0625-.125	Fine .125-.25	Medium .25-.5	Coarse .5-1	V.Coarse 1-2	V. fine 2-4	Fine 4-8	Medium 8-16	Coarse 16-32	V.Coarse 32-64
———	7.1	36.1	36.4	17.2	2.8	0.4						
– – –	5.3	2.5	10.0	51.8	28.4	2.0						
-----	0.1		0.2	44.9	54.6	0.1	0.1					

HYDROLOGIC AND PHYSICAL PROPERTIES

Laboratory sample number	Location	Depth of sample (feet)	Specific gravity of solids	Dry unit weight (g per cc)	Specific retention (percent of volume)	Total porosity (percent of volume)	Specific yield (percent of volume)	Coefficient of permeability (gpd per sq ft)
58MAS41	Ipswich River Valley, Mass.	2.0	2.70	1.33	4.0	50.7	46.7	22
57MAS9	Middlesex County, Mass.	2.5	2.68	1.61	1.0	39.9	38.9	250
56ORE3	Florence, Oreg.	----	2.65	1.63	1.5	38.5	37.0	630

Figure 10.--Typical data and particle-size distribution, and hydrologic and physical properties of eolian sand.

Table 9.--Properties of tuff

Tests	Range of properties	Arithmetic mean	Number of analyses
Permeability, vertical (gpd per sq ft)	0.0001 - 17	4	44
Permeability, horizontal (gpd per sq ft)	.0001 - 17	5	44
Dry unit weight (g per cc)	1.17 - 2.31	1.48	230
Specific gravity of solids	2.30 - 2.64	2.50	174
Porosity, undisturbed (percent)	7.2 - 54.7	41	180
Centrifuge moisture equivalent (percent)	2.5 - 30.0	13	76
Specific retention (percent)	5.6 - 38.2	21	90
Specific yield (percent)	2.0 - 47.0	21	90

Tuff may be sorted somewhat by water after deposition, but ordinarily the original deposits are loosely packed and poorly sorted. After consolidation, tuff may still exhibit, in a reduced degree, a high porosity. Because the heavier and coarser particles fall first, tuff generally grades from coarse at the bottom of the deposit to fine at the top. However, within the range of any one sample the material can be considered to be fairly homogeneous. The data indicate a wide range of hydrologic and physical properties. One relation shown by the data indicates that porosity is fairly high even though permeability is low.

Ice-laid deposits

Rock debris transported by glacial ice, and deposited either directly or in bodies of glacial melt water, is called glacial drift. Drift is separated into nonstratified drift, or till, and stratified drift, sometimes referred to as washed drift.

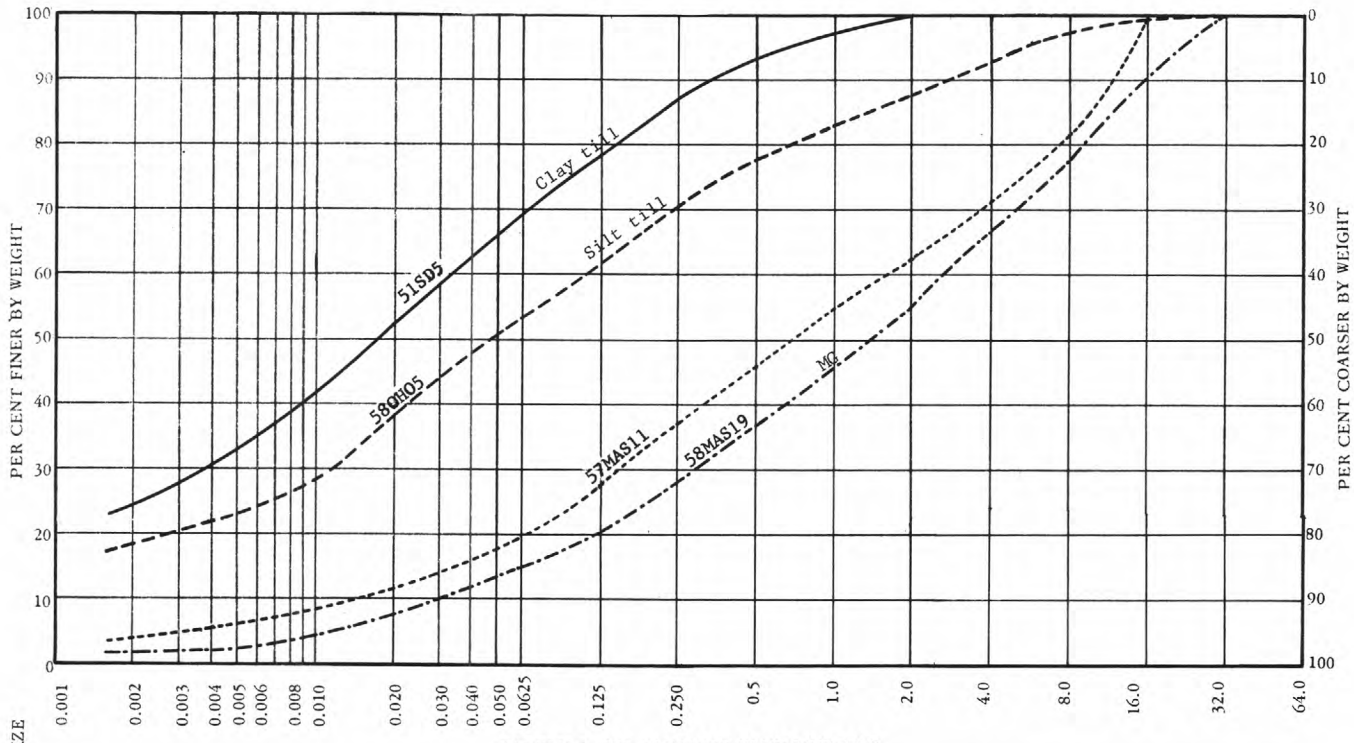
Till, washed drift.--Because some melt water is associated with most glacial deposition, the dividing line between till and washed drift is not sharp. However, till is regarded in this report as being primarily unsorted drift, and washed drift is considered as being those deposits that have been sorted by the action of melt water.

Till is rock debris deposited directly by glacial ice and has a wide range of particle sizes. Till differs widely in composition and textures in different places. Most till contains considerable clay, and, therefore, is sometimes called boulder clay.

Washed drift can be divided into two classes: the proglacial, or deposits made beyond the limits of the glacier (outwash); and ice-contact deposits, which include eskers, kame terraces, kames, and features marked by numerous kettles. These two classes grade directly into each other, and for this study, no distinction will be made between the two.

Tables 10 and 11 summarize the properties of ice-laid deposits, and figures 11 and 12 present the typical hydrologic and physical properties as related to particle-size distribution for such deposits.

Water-bearing properties of ice-laid deposits.--Glacial drift has a tremendous range in size of materials, containing debris of all sizes from clay to boulders. The materials directly deposited by the ice are a heterogeneous mixture of these particles and are called till. Till differs greatly in compostion in different places, depending on the source materials. Because it is unsorted, it usually exhibits low porosity and permeability and is a poor producer of water. Particularly is this true of compact clay till. However, more sandy till, even though of lower porosity, is more permeable and may be a fair producer of water.

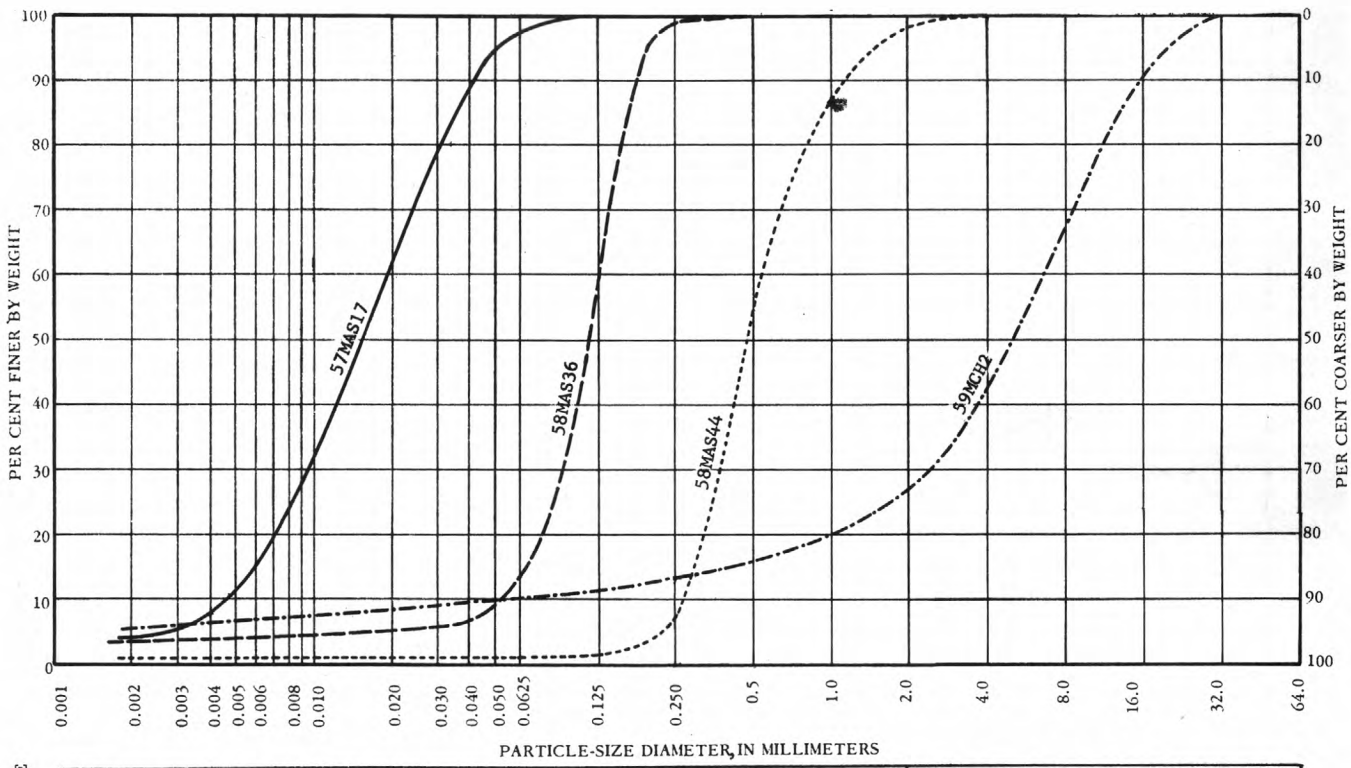


CLAY SIZES	SILT SIZES	SAND SIZES					GRAVEL SIZES				
< 0.004 mm	0.004 – 0.0625 mm	V. fine .0625-.125	Fine .125-.25	Medium .25-.5	Coarse .5-1	V.Coarse 1-2	V. fine 2-4	Fine 4-8	Medium 8-16	Coarse 16-32	V.Coarse 32-64
30.5	38.9	9.0	8.8	6.2	3.8	2.8					
21.9	31.7	7.7	9.1	7.4	5.3	4.7	4.9	4.5	2.2	0.6	
5.4	14.6	6.8	9.3	9.0	8.7	8.0	9.2	10.5	18.5		
2.1	12.8	5.1	7.6	8.9	9.3	9.2	12.0	10.1	13.1	9.8	

HYDROLOGIC AND PHYSICAL PROPERTIES

Laboratory sample number	Location	Depth of sample (feet)	Specific gravity of solids	Dry unit weight (g per cc)	Specific retention (percent of volume)	Total porosity (percent of volume)	Specific yield (percent of volume)	Coefficient of permeability (gpd per sq ft)
51SD5	Hand County, S. D.	97.0-98.0	2.69	1.62	33.4	39.8	6.4	0.1
58OH05	Montgomery County, Ohio	----	2.71	1.78	----	33.9	----	.08
57MAS11	Middlesex County, Mass.	2.5	2.72	2.12	2.5	22.1	19.6	2
58MAS19	Brockton, Mass.	----	2.73	1.78	0.6	34.8	34.2	97

Figure 11.--Typical data on particle-size distribution, and hydrologic and physical properties of till.



PERCENT OF SIZE

CLAY SIZES < 0.004 mm	SILT SIZES 0.004 – 0.0625 mm	SAND SIZES					GRAVEL SIZES				
		V. fine .0625-.125	Fine .125-.25	Medium .25-.5	Coarse .5-1	V.Coarse 1-2	V. fine 2-4	Fine 4-8	Medium 8-16	Coarse 16-32	V.Coarse 32-64
7.6	89.0	3.2	0.2								
3.8	9.4	46.0	39.6	1.2							
1.2	0.0	0.4	6.3	46.3	32.1	11.8	1.6	0.3			
6.3	4.0	1.0	2.1	2.3	4.2	7.2	15.4	25.3	22.5	9.7	

HYDROLOGIC AND PHYSICAL PROPERTIES

Laboratory sample number	Location	Depth of sample (feet)	Specific gravity of solids	Dry unit weight (g per cc)	Specific retention (percent of volume)	Total porosity (percent of volume)	Specific yield (percent of volume)	Coefficient of permeability (gpd per sq ft)
57MAS17	Middlesex County, Mass.	15	2.72	1.12	13.3	58.8	45.5	2
58MAS36	Ipswich River Valley, Mass.	2	2.69	1.41	2.8	47.6	44.8	71
58MAS44	do	2	2.67	1.47	0.9	44.9	44.0	1,400
59MCH2	Kalamazoo, Mich.	1-2	2.72	1.78	26.5	34.6	8.1	-----

Figure 12.--Typical data on particle-size distribution, and hydrologic and physical properties of washed drift.

Table 10.--Properties of till

[Classified by predominant particle size]

Test	Clay			Silt			Sand			Gravel		
	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses
Permeability, repack (gpd per sq ft)	----------	-----	--	----------	-----	--	0.5 - 80	12	18	2 -2,600	730	8
Permeability, vertical (gpd per sq ft)	0.00008-0.009	0.002	7	0.0003- 0.4	0.06	12	.06-220	24	10	----------	-----	--
Dry unit weight (g per cc)	----------	-----	--	1.61 - 1.91	1.78	15	1.69- 2.12	1.88	11	1.72- 2.12	1.91	4
Specific gravity of solids	2.61 -2.69	2.65	8	2.64 - 2.77	2.70	15	2.66- 2.73	2.69	13	2.67- 2.78	2.72	8
Porosity, undisturbed (percent)	----------	-----	--	29.5 -40.6	34	15	22.1 - 36.7	31	10	----------	-----	--
Porosity, repacked (percent)	----------	-----	--	----------	-----	--	----------	------	--	22.1 - 30.3	26	3
Centrifuge moisture equivalent (percent)	----------	-----	--	11.7 -21.2	15	11	0.4 - 15.0	6	10	0.1 - 17.4	7	4
Specific retention (percent)	----------	-----	--	22.6 -33.4	28	11	2.5 - 28.8	14	10	.6 - 24.6	12	4
Specific yield (percent)	----------	-----	--	0.5 -13.0	6	11	1.9 - 31.2	16	10	5.1 - 34.2	16	4

Table 11.--Properties of washed drift

[Classified by predominant particle size]

Test	Silt			Sand			Gravel		
	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses
Permeability, repack (gpd per sq ft)	----------	-----	--	250 -3,750	940	13	500 -12,700	5,000	9
Permeability, vertical (gpd per sq ft)	1 -12	5	5	24 -1,400	340	27	----------	-------	--
Dry unit weight (g per cc)	1.11- 1.66	1.38	5	1.36- 1.83	1.55	36	1.47- 1.78	1.60	6
Specific gravity of solids	2.70- 2.73	2.72	5	2.65- 2.75	2.69	38	2.65- 2.75	2.68	8
Porosity, undisturbed (percent)	38.4--59.3	49	5	36.2 - 47.6	44	31	34.6 - 41.5	39	3
Porosity, repacked (percent)	----------	-----	--	31.6 - 41.9	36	5	37.0 - 44.5	41	3
Centrifuge moisture equivalent (percent)	1.3 -10.8	5	5	0.1 - 1.4	0.4	34	----------	--------	--
Specific retention (percent)	4.7 -13.3	9	5	.5 - 5.7	3	35	----------	--------	--
Specific yield (percent)	33.2 -48.1	40	5	29.0 - 48.2	41	35	----------	--------	--

Washed drift contains sorted sand and gravel, usually intermingled and interbedded with till. Such deposits differ greatly--even in the same locality--in thickness, coarseness of material, depth, and areal extent--rarely extending over a few miles. Laboratory data indicate that their water-bearing properties compare favorably with that of water-laid sand, having fairly high porosity and permeability, especially in comparison to clay till.

Chemical and Organic Origin

Chemical Origin

Chemically formed rocks are those derived when mineral material that has been in solution becomes insoluble and is precipitated. These deposits usually are produced by concentration when bodies of sea water are isolated and allowed to evaporate. One such rock, chert, is formed when silica derived from organisms dissolves and precipitates from solution around certain nuclei in places where conditions are favorable for crystallization. Chert was the only rock of this type tested.

Chert

Chert is composed of light-colored rocks, usually white to gray, made up of extremely fine-grained silica. It occurs in masses that range from small nodules to formations of wide areal extent. No samples of this rock type have been tested to date.

Organic Origin

Rocks of organic origin are formed from remains of living organisms that accumulate calcium carbonate from solution or from the decay of plant and animal life that produces carbonaceous materials. Limestone, dolomite, and peat are the only materials of organic origin considered in this report.

Limestone, dolomite, peat

Limestone is a common and widely distributed calcium-carbonate rock. It is fine textured, usually of gray color, and effervesces freely with dilute cold hydrochloric acid. Dolomite differs from limestone in that it contains magnesium, and effervesces only slightly in cold hydrochloric acid. Peat is a soft, dark brown to black deposit produced by the partial decomposition of plant and animal life under aqueous conditions. Table 12 summarizes the properties of materials of organic origin. Only a limited number of samples of peat and dolomite have been tested to date.

Water-Bearing Properties of Rocks of Chemical and Organic Origin

No rocks differ more radically in their water-bearing character than those of chemical and organic origin. Limestones and dolomites are generally dense and massive and their ability to carry and yield water is dependent, not on their original texture, but on the secondary structures such as fractures, solution cavities, and joints, which exist or are produced or enlarged by the solvent action of water.

Table 12.--Properties of limestone, dolomite, and peat

Test	Limestone			Dolomite			Peat		
	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses
Permeability, vertical (gpd per sq ft)	0.0003-160	23	28	0.00008- 0.07	0.03	3	3 -280	140	2
Permeability, horizontal (gpd per sq ft)	.0006-540	44	28	------	----	---	------	------	---
Dry unit weight (g per cc)	1.21 - 2.69	1.94	66	1.83 - 2.20	2.02	2	0.12- 0.14	0.13	4
Specific gravity of solids	2.68 - 2.88	2.75	74	2.64 - 2.72	2.69	3	1.54	1.54	4
Porosity, undisturbed (percent)	6.6 - 55.7	30	74	19.1 -32.7	26	2	92.2	92	2
Centrifuge moisture equivalent (percent)	.7 - 17.7	5	34	------	----	---	404.3	404	2
Specific retention (percent)	4.9 - 29.1	13	32	------	----	---	48.5	49	2
Specific yield (percent)	.2 - 35.8	14	32	------	----	---	43.7	44	2

Limestone and dolomite may, when newly formed, contain abundant interstices. However, during compaction or as the calcareous materials are dissolved and again precipitated, these pores are filled. For this reason, older limestone is generally compact, and the passages for water storage and transport develop along fractures, joints, and bedding planes or by solution, usually along bedding planes and joints. If the limestone or dolomite originally occupied a position where water circulated actively and subsequently was moved below the water table, a good water-bearing formation resulted. However, dolomite differs from limestone in that it is somewhat less soluble than limestone. The hydrologic properties determined for limestone and dolomite in the laboratory generally indicate the properties of the original structure of the rock and they are consequently very low.

Peat, because of its fibrous nature, is extremely absorbent and has a high water-retention property. Peat has an exceptionally high porosity but, in spite of this, has poor water-producing characteristics.

Metamorphic Rocks

Rocks that have been so changed by heat and pressure--usually in the presence of liquids and gases--that rocks of new characteristics are formed, are called metamorphic. The change occurs either in the mineral composition, in the texture, or both. Only a few representatives of this rock class have been analyzed in the Hydrologic Laboratory.

Slate, Schist

Slate is a very fine-textured rock resulting usually from the deep-seated deformation of clay and shale. The cleaved surfaces tend to be very smooth because of the fineness of the mineral grains.

Schist is a crystalline rock with a secondary foliation but it is somewhat coarser textured than slate. It has a strong tendency to split along the foliation in irregular plates. Mica schist, the common type, results from the recrystallization of sandstone, shale, clay, or excessive shearing of granitoid and porphyritic igneous rocks.

Table 13 summarizes the properties for slate and schist. The highest permeabilities, porosities, and specific yields, and lowest specific retentions were obtained for samples of weathered schist.

Quartzite

Quartzite is a compact rock composed of interlocking quartz grains. It is derived from the metamorphism of sandstone and is distinguished from it by the fact that fractures in quartzite pass through the grains of quartz, thereby producing an uneven surface. Data on the properties of quartzite are not available in the Laboratory at present.

Table 13.--Properties of slate and schist

Test	Slate			Schist		
	Range of properties	Arithmetic mean	Number of analyses	Range of properties	Arithmetic mean	Number of analyses
Permeability, vertical (gpd per sq ft)	0.000004-0.001	0.0002	8	0.00004-24	4	17
Dry unit weight (g per cc)	-------	----	---	1.42 - 2.69	1.76	21
Specific gravity of solids	2.85 -3.05	2.94	10	2.70 - 2.84	2.79	21
Porosity, undisturbed (percent)	-------	----	---	4.4 -49.3	38	18
Centrifuge moisture equivalent (percent)	-------	----	---	4.5 -15.8	10	12
Specific retention (percent)	-------	----	---	10.3 -23.6	17	11
Specific yield (percent)	-------	----	---	21.9 -33.2	26	11

Water-Bearing Properties of Metamorphic Rocks

Metamorphic rocks usually are dense and compact and depend on fractures, joints, cleavage planes, or solution passages for storage and transport of water. Some weathered rocks of this class at the surface contain water, but, because of their fine texture, do not yield it readily. The more crystalline rocks of this class are similar in their water-bearing properties to the crystalline igneous rocks. Schist, for example, carries water in small openings that develop parallel to the planes of foliation, but the horizontal joint patterns prevalent in granite are scarce. Slate, schist, quartzite, and marble exhibit low porosity and permeability when tested in their original state. However, slate yields water through joints and cleavage planes, quartzite through joints, and marble along bedding or joint planes or through solution passages developed in them. The results of physical and hydrologic analyses obtained in the laboratory refer to the matrix of the rock and not the secondary structures.

SUMMARY

Laboratory data presented in this report must be used with caution. Use depends greatly on the source of the data, its range, and the number of samples or analyses upon which results or conclusions are based. The larger the sampling population the more meaningful and useful the data. To allow the reader to asses the realiability of the data in this report, the physical and hydrologic data have been tabulated for each rock type, giving both the number of samples and the range of the data. Furthermore, for comparative use, the arithmetic mean has been calculated for each of the same groups.

Arkin, Herbert, and Colton (1956, p. 17) state that the arithmetic mean is the most commonly used, most easily understood, and most generally recognized average, that its computation is relatively simple, and that it may be treated algebraically. However, these authors also point out that the arithmetic mean has the disadvantage that it may be greatly distorted by extreme values and therefore it may not be typical. Because of the ease of computation and the widespread usage, the arithmetic mean has been used in this report.

In addition to the detailed data presented in tables for individual rocks, the arithmetic means have been summarized in one comprehensive table wherein the relation of the rocks to one another can be studied (table 14). Here again, caution should be used in relating data concerning one type of rock or test to another. For example, the reader might assume that both repacked permeability and undisturbed vertical permeability were determined for the same sample. This is incorrect. With medium sand, for example, the data indicate only that for 255 samples the repacked permeability averaged about 300, and for 112 samples the vertical permeability averaged about 340. Similarly, data on a particular texture of sandstone cannot be compared directly to that of an unconsolidated sand of the same texture. This again would assume that the samples were comparable except for cementation, and the assumption would be incorrect. It should be remembered that the data were obtained from samples taken from the rock matrix and thus are not representative necessarily of the properties of the geologic formation as a whole.

Table 14.--Summary of the arithmetic mean of properties for all rock types

Test	Sedimentary rocks																									Igneous rocks			Metamorphic rocks		
	Water-laid deposits													Wind-laid deposits			Ice-laid deposits							Chemical and organic deposits								
	Sandstone		Siltstone	Claystone	Shale	Clay	Silt	Sand			Gravel			Loess	Eolian sand	Tuff	Till				Washed drift			Limestone	Dolomite	Peat	Weathered granite	Weathered gabbro	Basalt	Schist	Slate	
	Fine	Medium						Fine	Medium	Coarse	Fine	Medium	Coarse				Clay	Silt	Sand	Gravel	Silt	Sand	Gravel									
(1) Permeability, repack (gpd per sq ft)	-----	-----	-------	-------	-----	------	------	61	300	1,100	11,000	6,700	3,700	-----	--------	-------	-----	-----	12	730	-----	940	5,000	--------	--------	------	----------	---------	------	------	-------	(1)
(2) Permeability, vertical (gpd per sq ft)	5	77	0.004	0.002	-----	0.002	0.6	94	340	680	------	--------	--------	2	500	4	0.002	0.06	24	------	5	340	--------	23	0.03	140	35	4	0.2	4	0.0002	(2)
(3) Permeability, horizontal (gpd per sq ft)	7	-----	-------	-------	-----	.005	2	------	------	-------	-------	--------	--------	-----	--------	5	-----	-----	-----	------	-----	------	--------	44	--------	------	----------	---------	------	------	-------	(3)
(4) Dry unit weight (g per cc)	1.76	1.68	1.61	1.51	2.53	1.49	1.38	1.55	1.69	1.73	1.76	1.85	1.93	1.45	1.58	1.48	-----	1.78	1.88	1.91	1.38	1.55	1.60	1.94	2.02	0.13	1.50	1.73	2.53	1.76	-------	(4)
(5) Specific gravity of solids	2.65	2.66	2.65	2.66	2.73	2.67	2.66	2.67	2.66	2.65	2.68	2.71	2.69	2.67	2.66	2.50	2.65	2.70	2.69	2.72	2.72	2.69	2.68	2.75	2.69	1.54	2.74	3.02	3.07	2.79	2.94	(5)
(6) Porosity, undisturbed (percent)	33	37	35	43	6	42	46	43	39	39	------	--------	--------	49	45	41	-----	34	31	------	49	44	39	30	26	92	45	43	17	38	-------	(6)
(7) Porosity, repacked (percent)	-----	-----	43	-------	-----	48	46	32	35	34	34	32	28	46	38	-------	-----	-----	-----	26	-----	36	41	--------	--------	------	----------	---------	------	------	-------	(7)
(8) Centrifuge moisture equivalent (percent)	6	4	14	-------	------	30	13	4	1	1	2	3	3	22	1	13	-----	15	6	7	5	1	--------	5	--------	404	----------	---------	------	10	-------	(8)
(9) Specific retention (percent)	13	10	29	-------	------	38	28	8	4	5	7	7	9	27	3	21	-----	28	14	12	9	3	--------	13	--------	49	----------	---------	------	17	-------	(9)
(10) Specific yield (percent)	21	27	12	-------	------	6	20	33	32	30	29	24	21	18	38	21	-----	6	16	16	40	41	--------	14	--------	44	----------	---------	------	26	-------	(10)

Ordinarily, the arithmetic mean could be used in the field to describe rock for which a laboratory analysis is not available. Ideally, the field man should have some idea of the reliability of the value applied to the rock in question. Figure 13 is a graph of the distribution of repacked

Figure 13.--Distribution of permeability for repacked samples of water-laid medium sand.

permeabilities for medium sand samples and shows that about 76 percent of the samples tested fall within the permeability class of 100 to 1,000 gpd per sq ft. The arithmetic mean of permeability for these samples was found to be about 300 gpd per sq ft. However, when the distribution of values for a particular property (such as the graph in figure 13) are known, the field man still is unable to definitely use any particular value from the graph for his rock because that particular rock could have a value at either extreme of the full range of values.

Because a hydrologic or physical property of a rock in the field may fall at the extreme limits of the range of values, precise data for various properties must depend upon laboratory analysis of a sample. Thus, the advisability of providing graphs for all data would be in doubt and such illustrations are not provided in this report. If only comparative values for a particular property are required and laboratory testing is not possible, the data contained in the tables of this report should be useful in the analysis of many engineering and geologic problems.

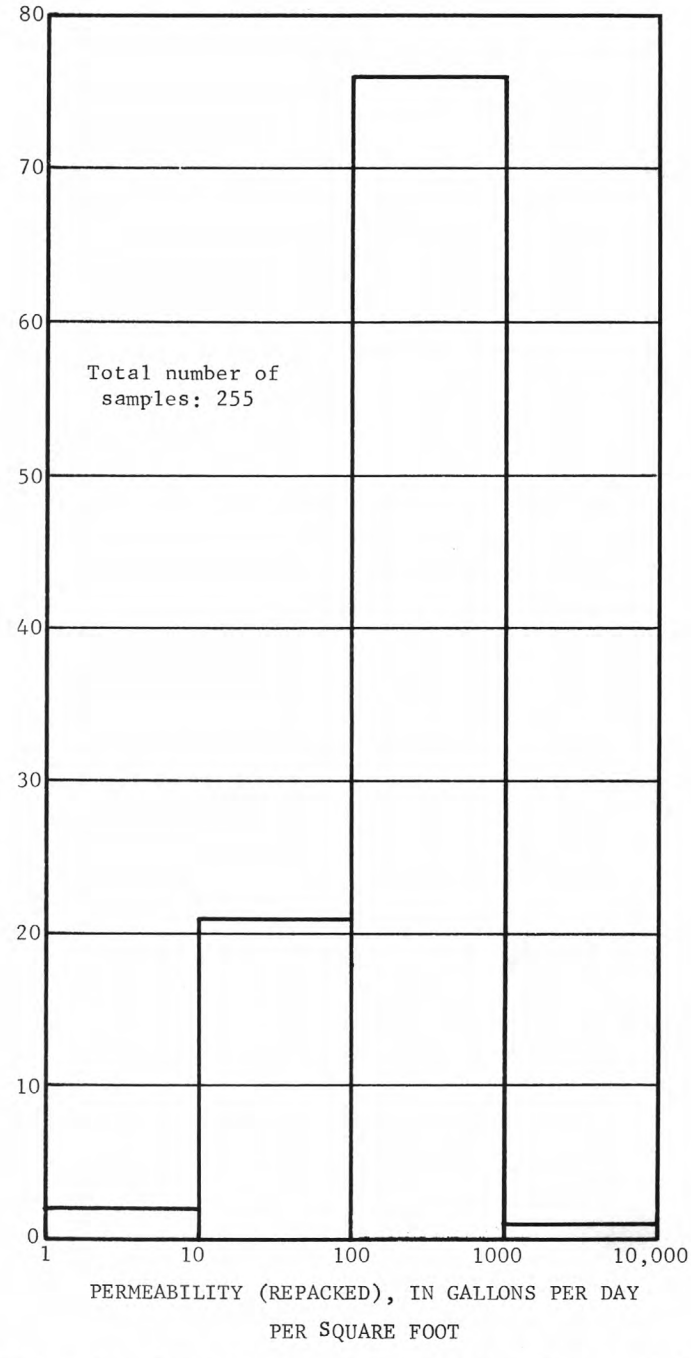


Figure 13.--Distribution of permeability for repacked samples of water-laid medium sand.

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