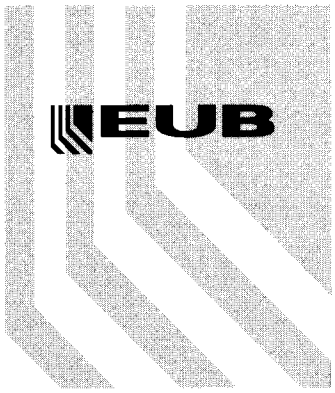

Bulk Densities, Porosities, and Liquid Saturations of Good Grade Athabasca Oil Sands

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BULK DENSITIES, POROSITIES, AND LIQUID SATURATIONS OF GOOD GRADE ATHABASCA OIL SANDS

by

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BULK DENSITIES, POROSITIES, AND LIQUID SATURATIONS OF GOOD GRADE ATHABASCA OIL SANDS

The porosities, and the saturations with oil and with water, of Athabasca oil sands are of interest and importance. A considerable volume of data on these properties is becoming available from the reports of oil companies holding exploration permit areas along the Athabasca river. A perusal of the values reported for bulk densities and porosities indicates that many of them are grossly erroneous. The object of the study herein presented was to devise a method for testing the accuracy of porosity data to the end of eliminating useless data from reported values. The remaining material could then be used for deducing the ranges of variations of bulk densities, porosities and saturations with oil and with water.

The writer has found it useful to divide the material making up the McMurray-oil-sand formation into three categories, namely: good grade oil sand containing 10% by weight of oil or more; shale containing 4% or less of oil; and interbedded oil sand and shale containing between 4% and 10% of oil. The present study is concerned only with good grade oil sand.

It so happened that the analyses of good grade oil sand available for study were from cores cut from sections of the McMurray formation that were predominantly shale and interbedded oil sand and shale. As a consequence, the mechanical analyses of the oil-sand aggregates show many examples of high silt content. In large masses

of good grade oil sand, such as would be suitable for mining operations, silt contents will correspond to the lower, rather than the higher, values shown in the tables of analyses.

The direct method for determining the porosity and the percent saturation with oil and with water is to measure the volume and the weight of a suitable sample of oil sand, and then to determine its composition in terms of water, oil and mineral matter. Oil sand is an unconsolidated material. It is held together by the content of viscous oil. The natural packing is easily disturbed by handling. The analysis for composition should be made on the sample used for the bulk density determination or at least on material that is strictly comparable to this sample. It can be realized that unless real care is exercised, large errors can occur.

An indirect method of determining porosity is to use the sieve analysis of the mineral aggregate of the sample. This method cannot be regarded as accurate, but it can be made precise enough to test whether the directly determined porosity is reasonably accurate. A large number of direct analyses, from which wrong data have been rejected, provides a basis for calculating the range of variations of porosities and saturations.

Average Mechanical Analyses of the Mineral Aggregates of Good Grade Oil Sands from Various Areas along the Athabasca River

The mineral aggregates of Athabasca oil sands vary over a considerable range of coarseness to fineness. Many mechanical analyses are reported in "Drilling and Sampling of Bituminous Sands of Northern Alberta", Report 826, Bureau of Mines, Department of Mines and

Technical Surveys, Ottawa. A perusal of these analyses indicates that the percentage of particles retained on the 80-mesh sieve is a useful criterion for gauging the coarseness of an oil-sand aggregate. Using this criterion and the data of Report 826, Table 1 was compiled.

Average Mechanical Analyses of -200 Mesh Material in Shales and in Good Grade Oil Sand

The -200 mesh material from a number of shale samples and from good grade oil sands was separated into size ranges of particles by use of a Roller Particle Size Analyser -- an air elutriator. One shale sample was collected from a shale seam exposed by the cutting of a road down into the valley of Horse river to the plant of Abasand Oils Ltd. The other shale samples came from a core cut by Socony-Vacuum Exploration Co. in Tp. 91, Rge. 10, W. 4th Meridian. Oil present in samples was extracted by benzene in a Soxhlet apparatus. The oil-free samples were dispersed in distilled water and washed on a 200-mesh sieve; the material passing the sieve was recovered from the water by settling and evaporation. The results of the air elutriation analyses are given in Table 2.

The various fractions of -200 mesh particles that were separated by air elutriation were examined visually under a binocular microscope. The particles in the 74 - 64, 64 - 32 and 32 - 16 micron fractions could be seen clearly. They appeared no different from particles caught on sieves. They were mainly sub-angular quartz particles. There were some particles of minerals other than quartz. Mica flakes were generally present. Also, there were black particles of

woody material. The 16 - 8 micron material was too fine to be seen properly under the binocular microscope; viewing under higher power was awkward. The indication was that the nature of this fraction was the same as that of the coarser fractions.

An examination of the 8 - 0 micron fraction was made by X-ray diffraction by Dr. P. J. S. Byrne. His results are given in Table 3.

Stock Samples

A supply of oil-sand mineral aggregate, freed from oil, was separated by sieving into 30 - 50 mesh, 50 - 80 mesh, 80 - 100 mesh and 100 - 200 mesh fractions. Portions of these fractions were recombined to produce stocks of coarse, medium-coarse, medium-fine and fine sands (cf. Table 1). Mechanical analyses of the four stocks are given in Table 4.

A stock of -200 mesh material comparable to that present in good grade oil sand, was prepared. Its particle size distribution is given in Table 5.

Porosity Measurements

The porosities of the four stock sands, and of these sands with increasing proportions of the stock -200 mesh material added to them, were measured. Samples of 50 to 75 grams of aggregate were packed into a cylindrical cell by applying 800 p.s.i. pressure, transmitted by a loose-fitting piston. The sample was put into the cell in four "lifts", pressure being applied each time. The resulting column of aggregate was 9.4 cm^2 in cross section and from 3 to 5 cm. long.

Porosities were calculated using the value 2.65 for the specific gravity of the mineral grains (quartz). The specific gravity of the oil was taken as unity -- the same as for water. Actually the specific gravity of oil-sand oils varies over the range of 1.005 to 1.020. The results of the porosity measurements are reported in Table 6 and in Figures 1 to 4.

Criterion for Spotting and Rejecting Erroneous Bulk Density and Porosity Data

The Socony-Vacuum Exploration Co. (now Mobil Oil of Canada Ltd.) explored its oil-sands permit area by core drilling during the season of 1953. This area was in townships 91 and 92 on the west bank of the Athabasca river. A technical officer of the company took charge of cores as they came from the borehole. Samples for analyses were promptly frozen, using solid carbon dioxide, and were kept frozen until analyzed. The samples were flown to Edmonton in the frozen state and delivered to Core Laboratories, where they were stored, still frozen. The bulk density measurement was the first analytical operation performed when a sample analysis was started. It is a fair assumption that the analysis of the Socony-Vacuum Exploration Co. core samples are as reliable as it is practicable to get data from routine field and laboratory procedures.

The Socony-Vacuum Exploration Co. core analyses of samples of good grade oil sands are given in Table 7. The reported data consisted of the composition of the sample in terms of percent by weight of oil, water and mineral matter, and the bulk density and sieve analysis of the mineral aggregate. From these data the porosity and the percent saturations with oil and water have been calculated in two ways. One

method uses the bulk density as the starting point; the other uses the sieve analysis and the relationship between sieve analysis and porosity presented in Figs. 1 to 4. The calculated values are included in Table 7.

Porosities determined from the bulk density and from the sieve analysis of a sample approximate each other to a varying degree. The mean of the differences between the 70 pairs of porosity values given in Table 7 is 2.9, and the standard deviation of these differences is 2.3. One may assume, somewhat arbitrarily, that porosities calculated from the bulk density and from the sieve analysis should be within 5 of each other if the sample analysis is to be regarded as reasonably reliable; if one applies this criterion to the data of Table 7, the analyses thus rejected are mostly those which are obviously out of line. This criterion for rejecting data was adopted.

Further available core analyses for good grade oil sand that included both the bulk density and the sieve analysis, are given in Table 8.

Ranges of Variation of Porosities and Liquid Saturations

The data of Tables 7 and 8, after rejecting unreliable data according to the adopted criterion, were used to calculate the ranges of variations of bulk densities, porosities, and liquid saturations of good grade oil sands. The range of variation of a property was taken as the mean value plus and minus twice the standard deviation. The ranges so calculated are presented in Table 9.

It will be noted that, on the average, good grade oil sand is far from completely saturated with oil. This may be of significance

in connection with "in situ" methods of development involving the permeability of oil sand as it lies in the formation with its content of viscous oil at low temperature. However, it should be mentioned that the oil in the formation is not dry. Part of the water content of the oil sand is present in dispersed form in the oil. It is hoped that an opportunity will occur for determining and compiling a body of data on the distribution of water in oil sands.

Table 1.

Average Mechanical Analyses of Good Grade Oil-Sand Mineral Aggregates from Various Areas

Number of Analyses Averaged	Accumulative Percent Retained on Mesh 20	40	60	80	100	150	200	Passing 200	Area
	Coarse Sand (80 mesh 50%+)								
27	35	42	56	78	84	93	100	14	Wheeler
60	11	43	58	78	83	92	100	11	Muskeg
82	5	18	32	71	85	92	100	4	Steepbank
56	7	32	46	71	81	92	100	6	M.R. Lakes
7	1	16	20	70	85	89	100	7	Horse River
	Medium-Coarse Sand (80 mesh 25-50%)								
11	13	15	21	46	65	84	100	21	Wheeler
15	7	15	21	38	51	70	100	13	Muskeg
69	6	11	16	35	63	85	100	8	Steepbank
32	3	7	10	36	57	87	100	6	M.R. Lakes
17	2	5	5	34	62	77	100	11	Horse River
	Medium-Fine Sand (80 mesh 10 - 25%)								
7	2	3	6	16	44	76	100	19	Wheeler
13	4	7	9	16	26	62	100	13	Muskeg
69	3	5	7	16	37	68	100	9	Steepbank
29	4	6	7	15	32	72	100	9	M.R. Lakes
29	2	4	4	17	45	61	100	11	Horse River
	Fine Sand (80 mesh 0 - 10%)								
25	1	1	2	9	26	70	100	18	Wheeler
15	1	3	4	8	14	56	100	13	Muskeg
48	3	5	5	7	31	70	100	10	Steepbank
22	2	3	3	6	18	70	100	10	M.R. Lakes
69	1	2	2	4	26	52	100	9	Horse River

Table 2.

Mechanical Analysis by Air Elutriation, of Passing 200-Mesh Material in Shales and in Good Grade Oil Sands

Sample	Particle Size Range in Microns 74-64	64-32	32-16	16-8	8-0
		Shales			
Abasand Road	3	32	17	6	42
Socony core					
Sample 18	6	26	18	18	32
" 22	9	19	19	21	32
" 26	10	14	21	26	29
" 34	5	9	25	26	35
" 36	13	20	23	20	24
" 40	8	21	29	19	23
" 44	10	19	25	22	24
" 48	2	14	30	29	25
" 54	7	17	28	23	25
" 58	5	9	22	31	33
" 74	10	10	35	26	19
" 82	12	18	22	20	28
" 86	20	23	17	15	25
		Good Grade Oil Sands			
Socony core	67	18	7	3	5
Abasand Quarry	69	14	9	4	4
Bitumount	27	25	25	14	9
"	42	25	20	8	5
"	26	23	28	13	10
"	19	24	30	14	13
"	39	22	21	11	7

Table 3.

X-ray Diffraction Determinations of the Quartz and Clay (Illite + Kaolin) Contents of 0-8 Micron Fractions of -200 Mesh Material

Sample	Quartz Approx. %	Clay, Approx. % by difference
	Shales	
Socony core		
22	30	70
26	30	70
34	25	75
36	35	65
40	30	70
44	30	70
48	30	70
54	30	70
58	25	75
66	35	65
74	30	70
86	35	65
	Good Grade Oil Sands	
Bitumount	20	80
	25	75
	20	80
	20	80
	25	75

Table 4.

Mechanical Analysis of Stocks of Coarse, Medium-Coarse, Medium-Fine and Fine Oil-Sand Mineral Aggregates

Stock	Accumulative Percent on Mesh 50	80	100	200	Passing %
Coarse	26	71	86	100	-
Medium-coarse	10	30	54	97	3
Medium-fine	9	17	37	98	2
Fine	3	5	30	97	3

Table 5.

Particle Size Distribution of Stock -200 Mesh Material

74 - 64 microns	42%
64 - 32 microns	28%
32 - 16 microns	13%
16 - 8 microns	7%
8 - 0 microns	10%

Table 6.

Porosities of Repacked Oil-Sand Mineral Aggregates

Sample	Porosity %
Coarse Sand	
0% -200 mesh	40.8
10% " "	38.1
20% " "	34.6
30% " "	32.1
50% " "	31.2
75% " "	34.6
100% " "	38.5
Medium-Coarse	
0% -200 mesh	41.4
10% " "	39.5
20% " "	37.0
30% " "	35.3
50% " "	32.8
75% " "	35.7
Medium-Fine	
0% -200 mesh	42.8
10% " "	40.8
20% " "	38.8
30% " "	36.8
40% " "	35.3
50% " "	34.7
75% " "	36.2
100% " "	38.7
Fine Sand	
0% -200 mesh	44.2
10% " "	42.2
20% " "	39.2
30% " "	37.4
50% " "	35.5
75% " "	36.2

Table 7.

Core Analyses by Socony-Vacuum Exploration Co. and Calculations Based Thereon

Sample	Composition Oil Wt.%	Composition Water Wt. %	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	From Bulk Densities: Bulk Density	Porosity %	Saturations Oil %	Water %	Total %	From Sieve Analyses: Porosity %	Saturations Oil %	Water %	Total %
Socony Exploration Co. Hole 1 - Sec. 35, Tp. 91, Rge. 10, W. 4th																	
62C	10.6	2.5	1	9	69	95	100	12	1.88	38.2	52	12	64	38.0	53	12	65
65C	13.6	1.5	-	1	4	29	100	57	1.99	36.2	75	8	83	35.6	77	9	86
75C	12.5	1.2	-	1	6	70	100	21	1.97	35.8	69	7	76	39.0	60	6	66
76C	16.4	0.7	-	-	10	85	100	11	1.85	42.2	73	3	76	42.1	72	3	75
77C	14.5	1.2	-	2	12	85	100	18	1.92	38.8	72	6	78	39.0	72	4	76
78C	17.3	0.6	-	-	8	93	100	5	1.85	42.7	75	3	78	43.4	73	3	76
79C	10.6	0.6	1	4	38	93	100	19	1.88	37.0	54	3	57	37.2	53	3	56
82C	15.7	1.1	-	2	90	98	100	7	1.94	39.0	78	5	83	39.2	77	5	82
Socony Exploration Co. Hole 3 - Sec. 2, Tp. 91, Rge. 10, W. 4th																	
3C	13.0	2.8	-	-	1	57	100	17	2.08	33.9	80	17	97	40.4	61	13	74
5C	10.1	1.2	1	4	9	33	100	49	2.09	30.2	70	8	78	35.6	55	6	61
12C	13.7	2.0	-	-	1	40	100	28	2.03	35.5	78	12	90	37.5	72	10	82
14C	11.0	4.4	-	1	3	68	100	16	2.04	35.0	64	26	90	40.5	51	20	71
15C	11.1	1.2	2	4	8	80	100	21	2.11	32.8	71	28	99	39.0	55	22	77
17C	15.4	1.5	-	-	2	82	100	18	2.03	36.5	86	9	95	39.3	76	7	84
18C	14.2	2.7	-	1	7	89	100	9	1.90	40.4	67	13	80	42.3	62	12	74
19C	15.3	2.6	-	-	7	94	100	5	1.79	44.5	62	11	73	43.4	64	11	75
20C	15.0	0.2	-	-	14	92	100	6	1.82	41.8	65	1	66	41.8	65	1	66
21C	10.8	0.9	-	1	14	86	100	20	1.90	36.5	56	5	61	38.8	51	4	55
22C	15.8	0.3	-	-	16	96	100	3	1.85	41.5	70	1	71	42.0	69	1	70
24C	15.4	0.2	-	-	13	90	100	11	1.90	39.7	74	1	75	40.8	70	1	71
25C	16.7	2.0	-	-	2	77	100	14	1.86	43.0	72	9	81	40.8	79	10	89
26C	15.0	7.9	-	-	32	95	100	9	1.71	50.2	51	27	78	39.8	78	42	120

Table 7 (continued)

Sample	Composition Oil Wt.%	Composition Water Wt.%	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	Bulk Density	From Bulk Densities Porosity %	Saturations Oil %	Water %	Total %	From Sieve Analyses Porosity %	Saturations Oil %	Water %	Total %
Socony Exploration Co. Hole 5 - Sec. 32, Tp. 91, Rge. 10, W. 4th																	
9C	11.7	4.0	-	-	4	68	100	19	1.97	37.2	62	21	83	39.2	57	20	77
35C	14.8	6.1	-	1	29	95	100	8	1.88	43.8	64	24	88	40.0	74	31	105
38C	10.7	5.1	1	3	28	93	100	22	2.24	28.5	84	37	121	36.9	58	27	85
39C	15.1	2.5	5	22	84	98	100	3	1.96	38.5	73	12	85	40.5	71	12	83
40C	12.8	3.9	14	45	90	99	100	2	2.01	37.3	69	21	90	40.2	61	19	80
42C	15.9	1.7	5	16	83	98	100	4	1.92	40.3	76	8	84	40.1	77	4	81
43C	10.7	4.0	7	20	48	87	100	26	2.12	31.7	72	27	99	36.1	59	22	81
Socony Exploration Co. Hole 35 - Sec. 26, Tp. 91, Rge. 10, W. 4th																	
7C	12.7	2.6	-	-	4	84	100	13	2.08	33.5	79	16	95	41.5	56	12	78
8C	14.8	0.4	-	6	21	81	100	35	2.09	33.2	92	2	94	36.0	82	2	84
9C	10.1	4.4	-	1	23	87	100	7	2.09	32.5	65	28	93	41.7	44	19	63
15C	11.8	5.0	-	3	8	31	100	51	2.03	36.1	67	28	95	35.5	68	29	97
17C	16.6	0.9	-	2	16	90	100	9	2.01	43.3	77	4	81	42.3	73	4	77
18C	15.9	1.2	-	1	16	93	100	6	1.86	41.8	71	5	76	42.8	68	5	73
Socony Exploration Co. Hole 35-2																	
8C	11.8	2.6	3	11	21	56	100	25	2.15	30.5	83	18	101	37.8	60	14	74
9C	13.7	3.9	-	1	4	34	100	21	2.03	37.0	75	21	96	39.1	69	19	88
10C	14.0	3.9	-	1	3	70	100	7	2.04	36.7	78	22	100	43.1	60	16	76
11C	14.3	2.3	2	5	9	76	100	7	2.08	34.4	87	14	101	43.1	64	10	74
23C	15.1	2.5	1	5	26	93	100	6	2.04	36.6	84	14	98	40.5	72	12	84
25C	13.9	5.6	1	4	14	64	100	31	1.98	40.0	69	28	97	36.8	79	32	111
26C	14.1	3.6	1	4	9	35	100	37	1.91	40.7	66	17	83	36.7	79	20	99
30C	10.6	8.7	1	6	20	50	100	54	1.92	41.5	49	40	89	34.8	66	54	120
31C	17.0	4.9	-	1	8	75	100	13	1.91	43.7	74	22	96	41.3	82	24	106
32C	17.0	4.3	-	-	13	84	100	9	1.88	44.1	73	18	91	42.0	79	20	99

Table 7 (continued)

Sample	Composition Oil Wt.%	Composition Water Wt. %	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	Bulk Density	From Bulk Densities Porosity %	Saturations Oil %	Saturations Water %	Saturations Total %	From Sieve Analyses Porosity %	Saturations Oil %	Saturations Water %	Saturations Total %
34C	17.5	5.2	-	1	9	80	100	12	1.89	44.9	74	22	96	42.0	83	25	108
35C	15.7	4.1	-	1	8	79	100	10	1.91	42.2	71	18	89	42.2	71	18	89
36C	16.3	3.8	-	-	5	81	100	7	1.98	40.2	80	19	99	43.1	72	17	87
37C	18.0	5.0	-	-	7	89	100	3	1.84	46.4	71	20	91	43.8	79	22	101
38C	17.0	4.2	-	-	5	90	100	5	1.82	46.1	67	17	84	43.5	75	18	93
39C	15.6	3.7	-	1	6	38	100	34	1.96	40.3	76	18	94	36.8	88	21	109
40C	19.4	2.3	-	-	5	90	100	5	1.91	43.6	85	10	95	43.5	86	10	96
41C	18.9	2.2	-	1	11	91	100	14	1.92	42.8	85	10	95	39.8	96	11	107
42C	17.7	2.8	-	1	29	89	100	10	1.91	42.6	79	13	92	39.5	91	14	105
Socony Exploration Co. Hole 25-2 - Sec. 26, Tp. 91, Rge. 10, W. 4th																	
25C	15.3	1.4	-	-	2	41	100	46	1.88	40.9	70	6	76	35.9	87	8	95
27C	16.9	0.6	-	1	8	89	100	12	1.99	38.1	88	3	91	42.0	75	3	78
28C	15.2	1.5	2	8	21	83	100	7	2.00	37.1	82	8	90	41.6	68	7	75
29C	15.0	0.8	2	9	17	77	100	13	2.04	35.0	87	5	92	40.1	71	4	75
30C	14.0	2.5	1	4	13	70	100	67	1.95	38.4	71	13	84	36.8	77	14	91
43C	13.5	6.2	-	1	11	91	100	10	1.96	40.5	65	30	95	40.8	65	29	94
44C	14.4	5.2	-	1	24	95	100	9	1.85	43.7	61	22	83	41.9	66	23	89
45C	16.8	2.7	-	-	8	86	100	5	1.89	42.7	74	12	86	43.4	73	12	85
46C	15.3	3.3	-	3	43	92	100	5	1.87	42.7	67	14	81	40.6	73	16	89
47C	16.6	1.6	-	-	28	93	100	4	1.86	42.7	72	7	79	40.8	78	8	86
48C	14.0	3.7	10	22	46	87	100	7	1.93	40.0	67	18	85	40.3	66	18	84
50C	15.7	1.6	9	33	96	97	100	3	1.81	43.4	65	7	72	40.0	75	8	83
51C	13.6	4.9	12	27	95	98	100	4	1.90	41.5	62	22	84	39.8	67	24	91
Socony Exploration Co. Hole 27 - Sec. 27, Tp. 91, Rge. 10, W. 4th																	
21C	13.2	4.2	-	1	6	71	100	20	1.97	42.2	62	20	82	39.2	66	21	87
39C	12.2	2.7	3	6	13	83	100	22	2.26	27.5	100	22	122	38.6	60	13	73
41C	10.9	4.4	1	4	10	72	100	35	2.04	34.7	64	26	90	36.8	58	24	82

Table 8.

Porosities and Saturations of Good Grade Oil-Sand Samples from Cores

Sample	Composition Oil Wt.%	Composition Water Wt.%	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	Bulk Density	From Bulk Densities Porosity %	Saturations Oil %	Water %	Total %	From Sieve Analyses Porosity %	Saturations Oil %	Water %	Total %
Sun Oil Co. Hole 1 - Lsd.4, Sec.3, Tp.98, Rge.10, W. 4th																	
3	12.5	6.1	-	-	1	54	100	34	1.95	40.2	61	30	91	36.8	70	33	103
7	13.1	3.7	-	-	4	59	100	32	1.96	38.5	67	19	86	37.3	70	20	90
11	11.5	9.2	-	-	1	48	100	25	1.78	46.8	43	35	78	38.2	62	50	112
12	11.4	5.6	-	-	7	75	100	16	1.81	47.7	47	27	74	40.5	54	27	81
13	12.3	5.5	-	-	19	68	100	7	1.93	40.2	59	26	85	41.7	56	25	81
14	13.6	4.0	-	-	36	92	100	12	1.71	46.8	50	15	65	40.5	64	19	83
15	13.2	7.5	3	13	78	95	100	18	1.86	44.3	56	32	88	34.8	82	47	129
Sun Oil Co. Hole 2 - Lsd. 4, Sec. 15, Tp. 97, Rge. 10, W. 4th																	
2	11.8	7.0	-	-	5	75	100	29	1.86	43.0	51	30	81	37.5	64	38	102
6	10.4	3.5	-	-	5	50	100	53	1.86	39.6	49	16	65	35.7	57	19	76
7	12.1	2.6	-	-	2	18	100	66	1.77	43.0	50	11	61	35.7	68	5	73
8	13.5	2.1	-	-	1	33	100	44	1.80	41.1	59	9	68	35.9	76	12	88
10	11.3	4.7	-	-	5	43	100	40	1.78	43.8	46	19	65	36.2	63	26	89
13	11.0	5.9	-	-	3	37	100	55	1.95	38.8	55	30	85	35.6	59	31	90
14	11.8	5.0	-	-	2	50	100	51	1.79	40.0	53	22	75	35.6	68	29	97
16	12.1	5.5	-	-	5	64	100	39	1.81	43.7	50	23	73	36.2	69	31	100
17	10.5	6.1	20	21	24	71	100	40	2.02	36.4	58	34	92	35.3	61	35	96
21	10.4	5.8	12	13	17	60	100	33	1.97	37.2	55	28	83	36.2	58	32	90
22	11.6	6.8	-	-	8	75	100	30	1.93	40.8	63	32	95	37.3	63	37	100
25	15.4	2.4	-	-	20	88	100	14	1.71	48.7	54	8	62	39.8	75	12	87
26	11.4	4.8	-	4	37	84	100	23	1.74	44.5	45	19	64	36.5	63	26	89
27	14.2	4.7	2	7	81	97	100	14	-	-	-	-	-	36.3	81	27	108
40	13.9	4.8	-	16	86	96	100	8	2.17	33.5	90	31	121	38.2	73	25	98
41	11.1	3.6	4	33	86	96	100	8	1.91	38.5	55	18	73	38.2	56	18	74

Table 3 (continued)

Sample	Composition Oil Wt.%	Composition Water Wt.%	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	Bulk Density	From Bulk Densities Porosity %	Saturations Oil %	Saturations Water %	Saturations Total %	From Sieve Analyses Porosity %	Saturations Oil %	Saturations Water %	Saturations Total %
Sun Oil Co. Hole 3 - Lsd. 4, Sec. 13, Tp. 97, Rge. 10, W. 4th																	
1	11.7	6.2	-	-	3	45	100	36	1.64	49.2	39	21	60	36.8	65	35	100
2	10.1	6.7	-	-	4	76	100	29	1.85	42.0	45	30	75	37.4	54	36	90
7	14.0	1.8	-	-	2	40	100	28	1.78	43.4	57	7	64	37.6	73	9	82
11	14.3	4.1	-	-	71	94	100	13	1.86	42.7	62	18	80	36.8	80	23	103
12	12.8	3.8	-	4	55	92	100	11	1.82	42.7	55	16	71	38.0	66	20	86
14	13.9	3.0	2	11	58	92	100	9	1.88	41.0	64	14	78	38.2	72	15	87
15	14.2	4.2	4	28	78	94	100	12	1.76	44.8	56	16	72	37.8	76	22	98
Sun Oil Co. Hole 3A - Lsd. 12, Sec. 13, Tp. 96, Rge. 10, W. 4th																	
45-50'	11.3	5.6	-	-	2	10	100	87	1.94	39.2	56	28	84	37.2	61	30	91
100-105'	15.8	2.1	-	-	2	58	100	45	1.82	43.0	66	9	75	35.9	91	12	103
120-125'	16.5	1.8	-	-	6	70	100	12	1.83	43.6	69	8	77	41.9	74	8	82
135-140'	15.1	3.0	-	-	1	65	100	12	1.81	44.0	62	12	74	41.9	68	13	81
160-165'	16.9	1.5	15	50	88	96	100	6	1.69	47.9	60	5	65	39.5	84	8	92
180-185'	17.3	1.2	-	-	84	98	100	3	1.84	43.3	74	5	79	40.0	85	6	91
200-205'	13.5	1.3	39	79	93	98	100	4	1.88	39.7	64	6	70	39.8	64	6	70
225-230'	13.4	1.6	21	53	89	97	100	3	1.74	44.2	53	6	59	39.9	63	8	71
240-245'	17.0	1.5	-	6	87	96	100	6	1.89	41.9	77	7	84	39.4	85	8	93
Shell McClelland - Lsd. 1, Sec. 22, Tp. 98, Rge. 10, W. 4th																	
143-144'	11.8	6.6	7	23	38	76	100	20	1.97	39.2	59	33	92	37.0	65	37	102
174-179'	11.8	7.6	4	8	32	90	100	22	1.90	42.2	53	34	87	36.9	66	42	108
Shell - Muskeg - Lsd.6, Sec. 27, Tp. 95, Rge. 10, W. 4th																	
227'	14.5	3.7	-	5	79	98	100	1	1.92	40.7	68	18	86	40.7	69	17	86
228'	15.3	4.6	-	1	77	97	100	2	1.87	43.5	66	20	86	40.6	74	22	96
231'	14.7	3.0	-	10	89	98	100	1	1.92	40.4	70	14	84	40.7	69	14	83

Table 8 (continued)

Sample	Composition Oil Wt.%	Composition Water Wt.%	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	Bulk Density	From Bulk Densities Porosity %	Saturations Oil %	Water %	Total %	From Sieve Analyses Porosity %	Saturations Oil %	Water %	Total %
233'	10.0	6.8	-	1	54	94	100	6	1.96	38.5	51	35	86	39.3	49	34	83
236'	11.4	6.0	-	35	86	99	100	3	1.92	40.2	55	29	84	39.8	55	29	84
237'	14.2	3.6	-	24	89	98	100	2	1.89	41.3	65	16	81	40.6	67	17	84
239'	13.5	4.7	-	2	49	96	100	4	1.95	40.2	66	23	89	40.7	64	22	86
249'	14.2	3.9	-	34	99	100	100	1	1.90	41.3	65	18	83	40.7	67	18	85
250'	15.1	2.9	-	33	94	99	100	2	1.92	40.5	72	14	86	40.6	70	14	84
252'	10.6	4.6	-	40	76	95	100	5	2.04	34.7	62	27	89	39.6	51	22	73
253'	13.7	4.1	-	40	93	99	100	1	1.95	39.4	68	20	88	40.7	65	19	84
Shell-Muskeg - Lsd. 11, Sec. 11, Tp. 95, Rge. 10, W. 4th																	
60'	14.0	2.6	-	15	65	97	100	1	1.98	37.8	73	10	83	40.7	65	12	77
170'	13.5	5.7	-	1	64	95	100	5	1.88	42.7	59	25	84	39.6	67	29	96
171'	12.1	4.1	-	51	90	99	100	2	1.92	39.3	59	20	79	40.6	56	19	75
175'	15.9	2.9	-	20	87	99	100	5	1.71	47.5	57	11	68	39.6	79	14	93
180'	14.4	3.1	-	41	88	99	100	4	1.84	42.7	62	13	75	39.8	70	15	85
196'	15.9	5.0	-	62	89	98	100	5	1.81	46.0	63	20	83	39.6	81	26	107
199'	12.0	9.5	-	3	75	97	100	6	1.81	46.4	47	37	84	39.4	63	50	113
200'	11.9	9.8	-	1	57	96	100	5	1.85	45.2	49	40	89	39.6	61	51	112
Shell-Muskeg - Lsd. 6, Sec. 26, Tp. 95, Rge. 10, W. 4th																	
41'	14.0	4.4	-	1	5	87	100	9	1.93	39.3	63	20	83	42.3	62	20	82
42'	10.3	15.0	-	3	7	80	100	14	1.84	48.2	39	50	97	40.9	53	77	130
46'	9.9	10.4	-	1	2	90	100	14	1.91	42.7	44	47	91	40.9	48	50	98
47'	14.3	6.0	-	-	1	90	100	7	1.76	47.1	54	23	77	43.0	63	27	90
48'	15.0	2.8	-	1	56	90	100	5	1.91	42.9	67	13	80	39.7	74	14	88
49'	13.7	9.9	-	2	5	84	100	7	1.78	48.7	50	36	86	43.0	63	46	109
51'	14.1	6.0	-	1	3	79	100	9	1.89	43.0	62	26	88	42.3	64	27	91
53'	15.5	6.4	-	-	1	88	100	6	1.79	45.2	62	25	87	43.2	69	29	98

Table 8 (continued)

Sample	Composition Oil Wt.%	Composition Water Wt.%	Accum. Percent Retained 20 mesh	40 mesh	80 mesh	140 mesh	200 mesh	Passing 200 mesh	Bulk Density	From Bulk Densities Porosity %	Saturations Oil %	Saturations Water %	Saturations Total %	From Sieve Analyses Porosity %	Saturations Oil %	Saturations Water %	Saturations Total %
54'	15.5	6.7	-	-	1	88	100	9	1.78	44.0	63	27	90	42.3	72	31	103
55'	14.9	7.9	-	-	6	86	100	8	1.72	49.8	51	27	78	42.4	70	37	107
57'	14.7	6.8	-	-	-	78	100	20	1.76	47.9	54	25	79	39.2	77	36	113
58'	14.6	7.0	-	1	6	93	100	4	1.75	48.2	53	26	79	43.5	64	31	95
60'	10.2	6.4	-	15	27	94	100	11	1.88	40.7	47	30	77	39.4	50	32	82
77'	12.4	5.2	-	20	51	72	100	53	2.01	37.5	67	28	95	32.5	83	35	118
151'	14.0	6.3	-	1	82	99	100	8	1.82	44.9	57	23	80	38.3	75	34	109
152'	14.9	6.1	-	1	53	98	100	10	1.81	46.0	59	24	83	38.1	81	33	114
159'	16.1	3.0	-	1	87	99	100	1	1.87	43.0	70	13	83	40.8	77	14	91
160'	16.2	3.8	-	1	88	99	100	1	1.87	43.5	70	16	86	40.8	78	18	96
162'	17.0	2.9	-	1	84	100	100	1	1.88	43.2	74	13	87	40.8	82	14	96
169'	13.9	3.5	-	7	84	98	100	2	1.94	39.6	68	17	85	40.7	65	16	81
170'	16.9	4.1	-	2	95	99	100	1	1.84	45.1	69	17	86	40.8	82	20	102
175'	13.1	5.5	-	25	88	98	100	2	1.89	41.9	59	25	84	40.7	62	26	88
176'	13.2	5.1	-	13	90	99	100	1	1.86	42.7	58	22	80	40.8	62	24	86
184'	9.9	8.9	-	47	87	99	100	1	1.89	41.3	42	39	81	40.8	47	42	89
186'	11.8	11.2	-	54	96	99	100	3	1.76	48.9	43	40	83	40.5	60	57	117
189'	12.4	6.2	-	47	93	99	100	1	1.84	43.0	53	24	77	40.8	59	29	88
192'	13.2	5.1	-	44	95	99	100	1	1.86	42.6	58	22	80	40.8	62	24	86
195'	10.0	7.3	-	35	93	99	100	1	1.90	40.7	47	34	81	40.8	47	34	81
197'	12.8	5.3	-	34	91	98	100	2	1.87	42.2	57	23	80	40.7	60	25	85
198'	15.6	4.1	-	9	92	99	100	2	1.87	43.4	67	18	85	40.7	75	20	95
200'	15.2	3.5	-	28	91	98	100	5	1.89	42.0	69	16	85	39.6	76	17	93

Table 9.

Ranges of Variations for Bulk Densities, Porosities and Liquid Saturations of Good Grade Athabasca Oil Sands

Borehole Samples	Socony-Vacuum Exploration Co.	Sun Oil Co.	Shell Oil Co.
Number of Samples	57	20	38
Silt Content			
Mean Percentage	16	26	16
Standard deviation	14	22	14
From Bulk Densities			
Mean bulk density	1.93	1.89	1.89
Standard deviation	0.08	0.07	0.05
Range of variation	1.77 to 2.09	1.75 - 2.03	1.79 - 1.99
Mean Porosity %	40	40.6	41.6
Standard deviation	3.1	2.2	2.3
Range of variation %	34 to 46	36 to 45	37 to 46
Mean Oil Saturation %	72	60	61
Standard deviation	8.4	8.0	8.1
Range of variation %	55 to 89	44 to 78	45 to 78
Mean Water Saturation %	14	19	23
Standard deviation	8.0	10	8.1
Range of variation %	1 to 30	1 to 39	6 to 39
Mean Total Saturation %	85	79	84
Standard deviation	10.0	9.0	4.0
Range of variation %	65 to 100	61 to 97	76 to 92
From Sieve Analyses			
Mean Porosity %	40	38	41
Standard deviation	2.4	2.2	1.2
Range of variation	35 to 45	34 to 42	38 to 42
Mean Oil Saturation %	72	66	65
Standard deviation	9.4	9.0	9.3
Range of variation	53 to 91	48 to 84	46 to 83
Mean Water Saturation %	13	25	24
Standard deviation	8.4	9.7	9.0
Range of variation %	1 to 30	6 to 44	6 to 42
Mean Total Saturation %	85	87	89
Standard deviation	12.9	9.0	7.9
Range of variation %	59 to 100	69 to 100	73 to 100

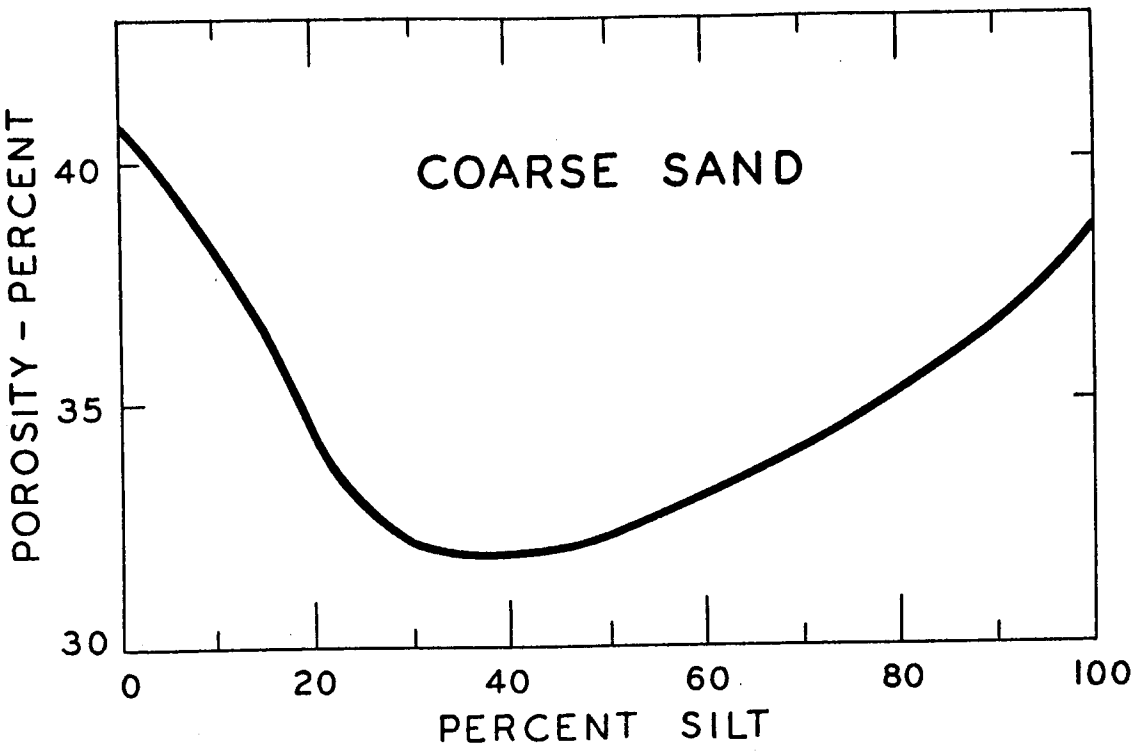

Fig. 1 – Relationship of porosity to silt content for coarse sand.

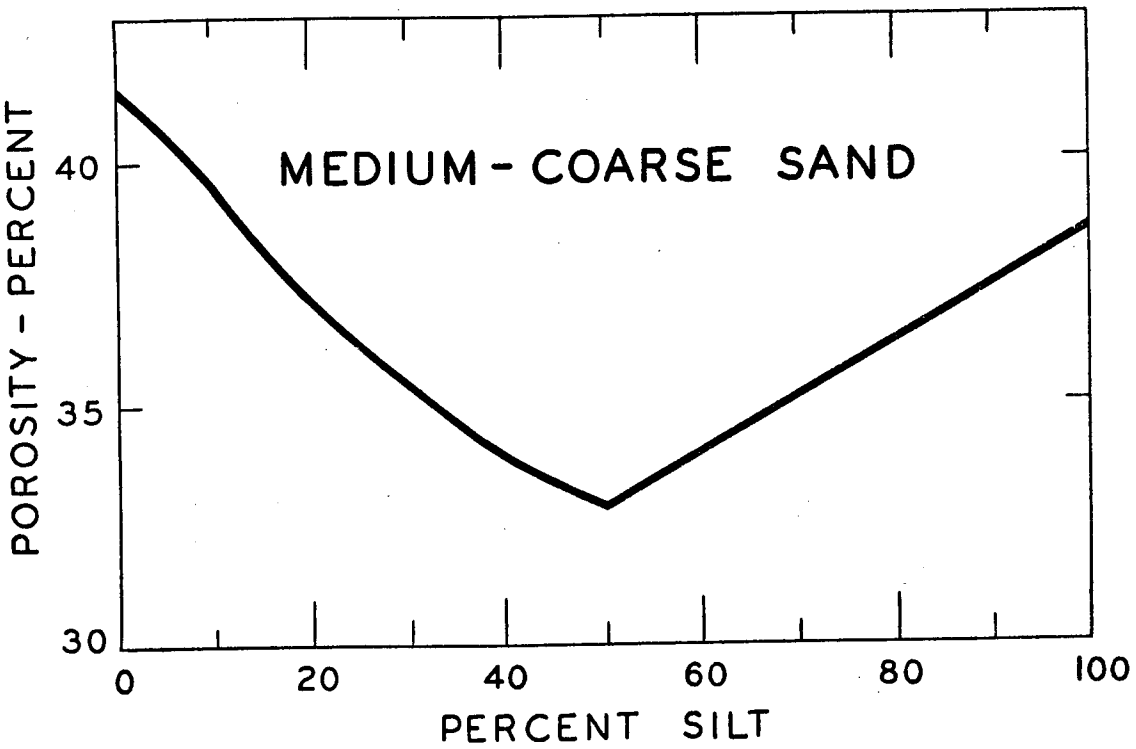

Fig. 2 – Relationship of porosity to silt content for medium - coarse sand.

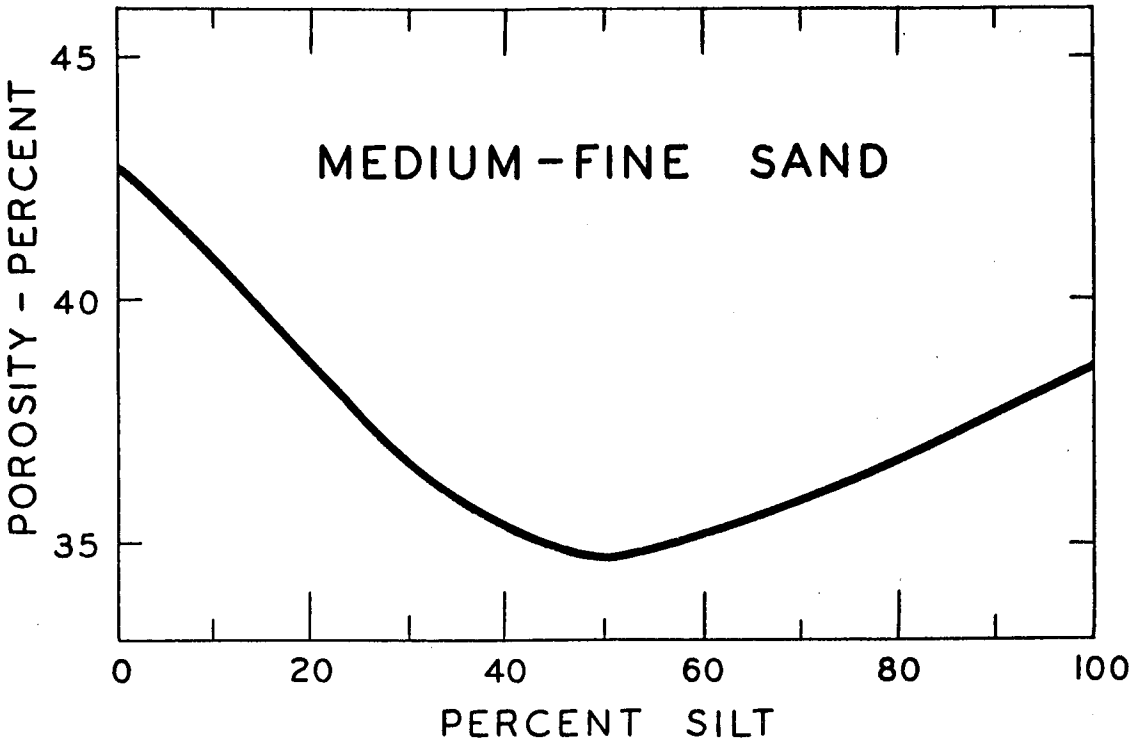

Fig. 3 - Relationship of porosity to silt content for medium-fine sand.

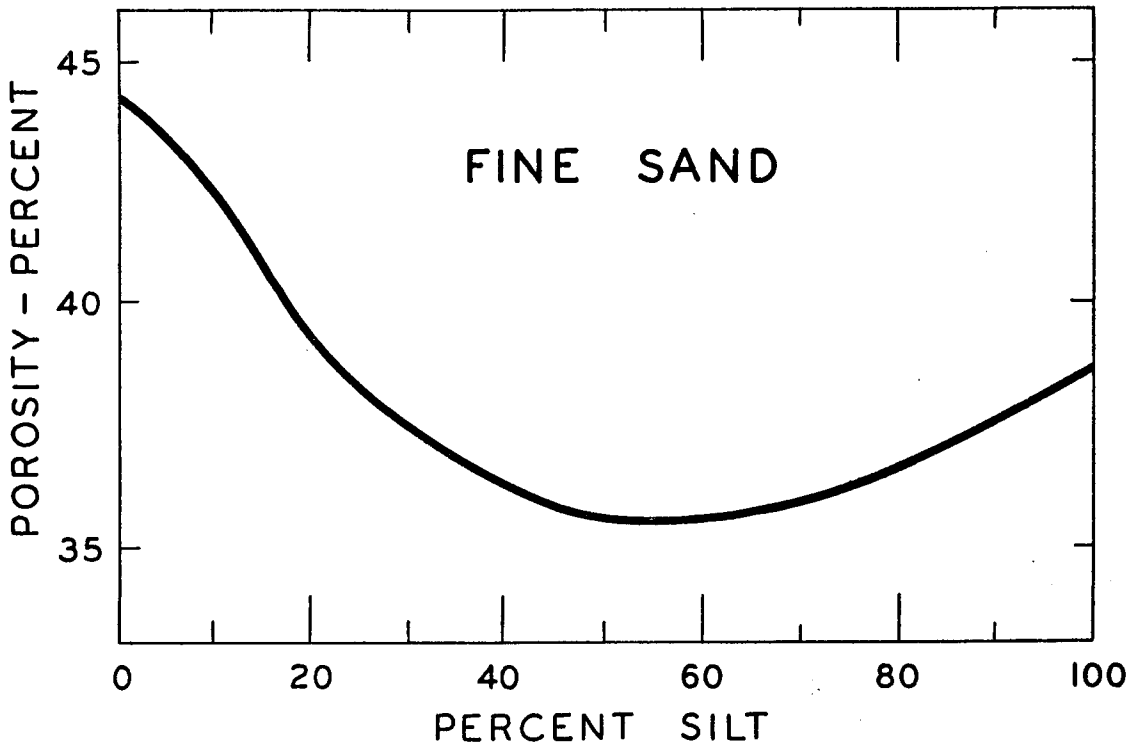

Fig. 4 - Relationship of porosity to silt content for fine sand.