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The Influence of Grain Morphology on Reservoir Quality of Some Athabasca Oil Sands Samples

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Abstract

This study focused on the determination of detailed grain morphology using SEM technology on some Athabasca oil sands samples obtained from the Upper McMurray Formation in the Manville Group which occurs in the Western Canada Sedimentary Basin. The research was carried out using scientific techniques to understand grain morphology—being a major effect in discerning reservoir quality—a factor which is essential for in-situ bitumen recovery. After studying various grain size and shape parameters, results showed that Sample B is poorly sorted medium sand of relatively low porosity but high permeability. Sample C on the other hand is moderately sorted fine sand of relatively high porosity but low permeability. It was also found out that although both oil sand samples contain heavy oil which is essentially recoverable in-situ; Sample B proved to be more promising due to its higher permeability values. At the end of the study, it was recommended that further research be carried out on the oil sands samples by use of core analysis techniques; computer-based simulation for heavy oil recovery; and a general study of structural effects on oil sands such as weathering and fracturing, all of which are important in better-quality in-situ bitumen recovery.

Keywords: SEM technology; McMurray Formation; Oil sands

Introduction

This study was carried out on the oil sands of Canada, found in Athabasca, within the province of Alberta, where in lies the estuarine McMurray Formation. It is important to note that a lot of studies have been carried out previously on the Athabasca oil sands of Canada, but only a limited amount of work is available on the grains—its characteristics and morphology—of these sands. It is hoped that a study as this one will succeed in studying sufficiently the morphology of the oil sands grains using Scanning Electron Microscope (SEM) technology. The SEM is beneficial in that it could produce images of very high resolution, which could then be analysed with the aid of software for image analysis. Bell et al., [1] noted that recent advances in petrographic image analysis have established an avenue for obtaining correct and accurate information about reservoir qualities in oil sands (Figure 1).

Geology of the Study Area

The Athabasca oil sands belong to the McMurray Formation which is a member of the Lower Cretaceous rocks called the Manville Group. Manville Group occurs in a sedimentary basin called the Western Canada Sedimentary (WCS) Basin. Authors like Price [3] believe that the evolution of the WCS is similar and most likely associated to the evolution and formation of the Cordillera. More so, Price [3] attributed the evolution of the WCS basin to two major geologic events. The first event is that of continental rifting and drifting which took place in the Late Proterozoic to Late Jurassic; hallmarking the evolution of the Cordilleran margin at the initial stage, as well as the displacement of the North American cratonic body which eventually lead to the conception of a terrace wedge on the continent. The second event equally attributed to the evolution of the WCS basin began from the Late Jurassic to Early Eocene and is characterized by the collision of the Pacific and the North American plates. These collisions gave rise to the disconnection of the wedge from the basement; hence the north-eastward transposition.

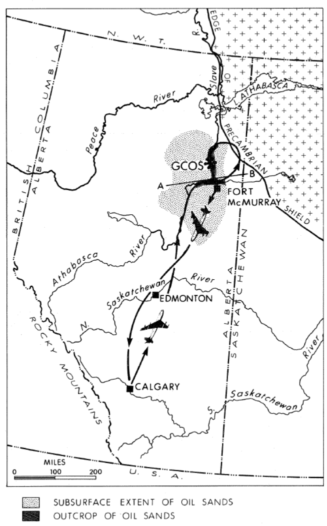

Figure 1: Athabasca oil sands location map (Carrigy) [2].

The eventual compression and thickening of the wedge so transposed led to the formation of the Western Canada Sedimentary

Basin. Successive geologic events that followed e.g. exposures, uplifts, and erosions, resulted in the building up of rock sediments in the basin. Hein et al., [4] attributed the deposition of the Manville Group to various events of sea transgressions and regressions, and equally inferring that the environments of deposition vary between fluvial, estuarine, and marine.

Methodology

Pre analysis treatment

This study was based on two oil sand samples. The samples were taken from the estuarine Upper McMurray Formation in Canada's Athabasca oil sand province. The samples for the study were taken at two different points in the Formation. Samples were labelled B and C for the purpose of clarity and specification. The aim was to analyse 1000 grains each from sample B and C, making the sum of 2000 grains in total. But the first step in the methodology, i.e. after samples were collected from the field, was to carry out a pre-analysis treatment. This treatment involved cleaning the bituminous oil sands with toluene in the laboratory using a special apparatus called the Soxhlet apparatus (Figure 2). The essence of carrying out the cleaning is to get rid of the bitumen content from the sand, so that very clean sand is obtained, and grain studies carried out.

Sample mounting and coating

Sample mounting is the first step in the image acquisition process. The mounting procedure is in such that the grains are mounted to one side of a rounded adhesive scotch tape. The other side of the scotch tape also contains adhesive, and is affixed to an aluminium stub specially designed for use in the SEM chamber. When that is done, the side of the adhesive scotch that contains the grains is then divided into four quadrants. The division is done so that different quadrants (and different areas of grains) can be outlined, thereby preventing the risk of photographing same grains multiple times.

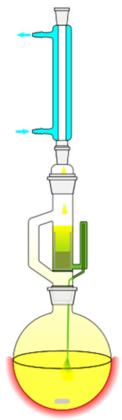

Figure 2: Soxhlet apparatus used for sample cleaning.

Sample mounting and coating

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Figure 3: Gold coating machine at London South Bank University SEM laboratory.

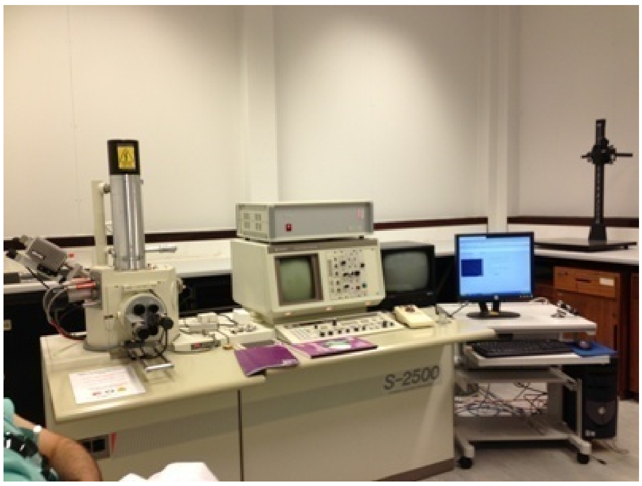

Figure 4: The Scanning Electron Microscope and its constituent components.

SEM image acquisition

The overall setup for the SEM consists of the following four basic components:

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Scanning Electron Microscope (Hitachi S2500) consisting of Energy Disperse X-Ray, and Back-Scattered Electron for sample composition, and digital imaging, respectively.

TV Screen for observing SEM chamber through the help of inbuilt cameras in the chamber. SEM monitor for observing scanned samples.

A desktop computer connected to the SEM machine, installed with Rontec Quantax software for scanning and saving images to computer (Figures 4 and 5).

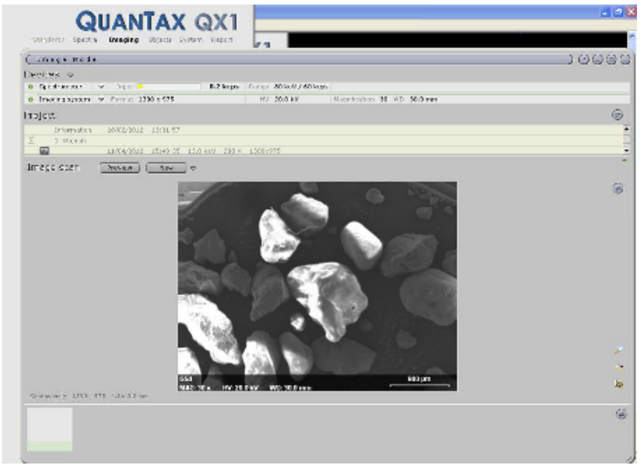


Figure 5: Quantax software after scanning of image from SEM.

Image J® Analysis

Image J® is Java-programmed image analysis software which is built solely for use in analyzing various image-based samples (Figures 6 and 7). The Image J® is available for free download from: http://rsbweb.nih.gov/ij/download.html. The layout of the downloaded software is shown below:

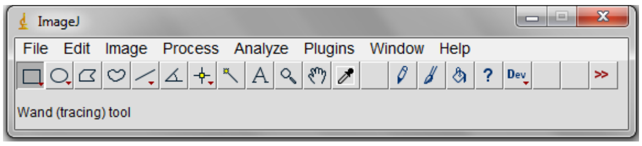
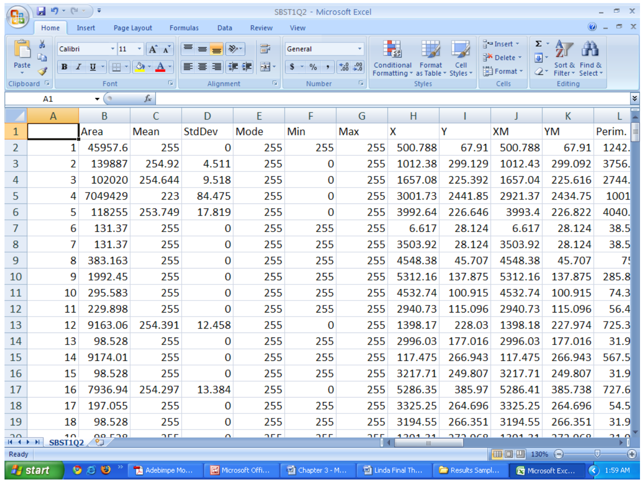


Figure 6: Image J® software layout.



	A	B	C	D	E	F	G	H	I	J	K	L
1		Area	Mean	StdDev	Mode	Min	Max	X	Y	XM	YM	Perim.
2	1	45957.6	255	0	255	255	255	500.788	67.91	500.788	67.91	1242.
3	2	139887	254.92	4.511	255	0	255	1012.38	299.129	1012.43	299.092	3756.
4	3	102020	254.644	9.518	255	0	255	1657.08	225.392	1657.04	225.616	2744.
5	4	7049429	223	84.475	255	0	255	3001.73	2441.85	2921.37	2434.75	1001
6	5	118255	253.749	17.819	255	0	255	3992.64	226.646	3993.4	226.822	4040.
7	6	131.37	255	0	255	255	255	6.617	28.124	6.617	28.124	38.5
8	7	131.37	255	0	255	255	255	3503.92	28.124	3503.92	28.124	38.5
9	8	383.163	255	0	255	255	255	4548.38	45.707	4548.38	45.707	75
10	9	1992.45	255	0	255	255	255	5312.16	137.875	5312.16	137.875	285.8
11	10	295.583	255	0	255	255	255	4532.74	100.915	4532.74	100.915	74.3
12	11	229.898	255	0	255	255	255	2940.73	115.096	2940.73	115.096	56.4
13	12	9163.06	254.391	12.458	255	0	255	1398.17	228.03	1398.18	227.974	725.3
14	13	98.528	255	0	255	255	255	2996.03	177.016	2996.03	177.016	31.9
15	14	9174.01	255	0	255	255	255	117.475	266.943	117.475	266.943	567.5
16	15	98.528	255	0	255	255	255	3217.71	249.807	3217.71	249.807	31.9
17	16	7936.94	254.297	13.384	255	0	255	5286.35	385.97	5286.41	385.738	727.6
18	17	197.055	255	0	255	255	255	3325.25	264.696	3325.25	264.696	54.5
19	18	98.528	255	0	255	255	255	3194.55	266.351	3194.55	266.351	31.9

Figure 7: Image J® generated results on a spreadsheet.

Data Analysis and Results

Grain size distribution

Sample B was analysed based on Phi (ø) values, and a frequency and percentage frequency values were computed, where it was noticed that more grains fall between Phi (ø) values of 1.1 and 1.2, representing 4.3 and 4.4 percent of all grains within the sample respectively. From the Udden-Wentworth Scale [5,6], these Phi (ø) values correspond to values within Medium Sand category. Sample B is therefore classified as Medium Sand (Figure 8).

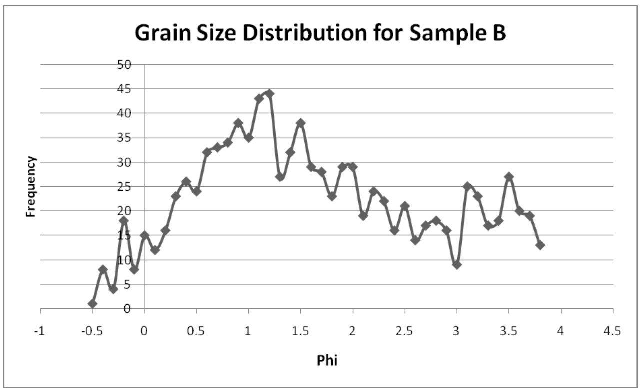


Figure 8: Grain Size Distribution plot for Sample B.

For sample C, Phi (ø) values, and a frequency and percentage frequency values were computed, where it was noticed that more grains fall between Phi (ø) values of 2.5 and 3.0, representing 19 and 17.8 percent of all grains within the sample respectively. From the Udden-Wentworth Scale, these Phi (ø) values correspond to values within Fine Sand category (Figure 9). Sample C is therefore classified as Fine Sand [5,6].

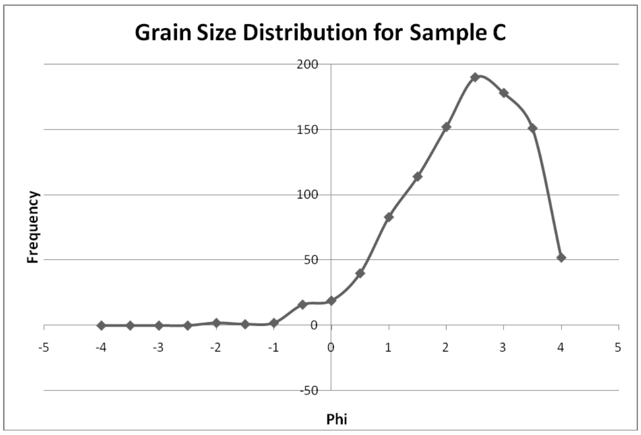


Figure 9: Grain Size Distribution plot for Sample C.

Grain sorting

To calculate the grain sorting, the Folk and Ward [7] formula for deriving standard deviation of grains is used. Standard deviation value of Sample B was calculated at 3.20, implying that Sample B is poorly sorted since its value falls between 2.0 – 4.0 on the sorting scale. For Sample C, Standard deviation value was calculated at 1.90 implying that Sample C is moderately sorted since its value falls between 1.62 – 2.0 on the sorting scale.

Discussion, Conclusion and Recommendations

Grain size (distribution, sorting, skewness, and kurtosis) and grain shape (roundness, circularity, aspect ratio, and solidity) are all essential factors that influence and control the quality of the reservoir. As an exception, because of the fact that Athabasca oil sands have minimal cementation with a very low level of compaction, it became necessary to limit the factors that influence and control reservoir quality to the grain textural properties only.

Grain size implications

Porosity

Porosity is the storage capacity of a rock, and this storage capacity is not very much affected by size of grains but mostly by grain sorting. Therefore when sorting is increased, it is sure that porosity increases because of the fact that fines which could have filled available voids will be greatly reduced, or even not present. With respect to samples of oil sands in this study, it is reported in the previous chapter that Sample B is poorly sorted, and Sample C is moderately sorted. It therefore imply that Sample C is more porous than Sample B, and saturation of fluids will be higher in Sample C than it will be in Sample B, and that fines or clay content will be more present in Sample B than in Sample C.

Permeability

Permeability is the ability of a rock to transmit fluids, which is usually affected by size of grains as is especially true in the case of the category in which the Athabasca oil sands belong being unconsolidated sands. Thus, permeability can be said to be high when there is large pores or voids within rock fabric or grains. But then, chances are that when there are large grain sizes, there is the possibility of having larger pores or voids which will then effectively enhance permeability. Another factor that will effectively enhance permeability is the contact between individual grains. It is very important to note that there is lesser contact in the case of larger or coarse grains than in the case of fine grains. In the case of the two samples studied here, Sample B is poorly sorted medium sand, while sample C is moderately sorted fine sand. To graphically ascertain permeability, from Figure 10 [8] below, Sample B, which is poorly sorted medium is bound to possess more permeability values than sample C.

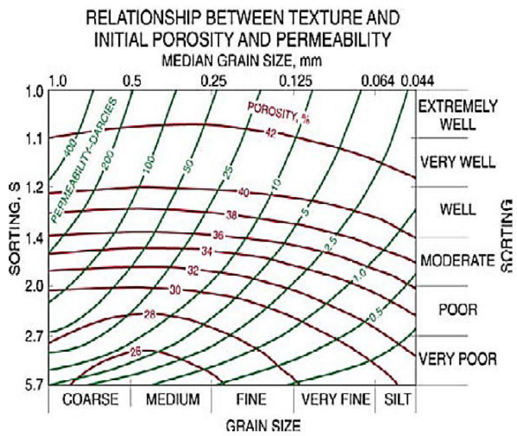


Figure 10: Relationship between texture and initial porosity and permeability [8].

Grain shape implications

Grain shape parameters which include roundness, circularity, aspect ratio, and solidity are all significant in affecting overall reservoir quality. Roundness values computed for Sample B showed that majority of grains fall within roundness scale of between 0.5 and 0.7 with highest amount at 0.5. Sample C also showed that grain roundness fall between 0.45 and 0.55 with highest amount at 0.55. Thus, for both samples B and C, it is can be said that average roundness value is given at 0.525, which going by Table 1 below, samples can be said to be rounded [9].

Classification	Class Intervals
Very angular	0.12 – 0.17
Angular	0.17 – 0.25
Subangular	0.25 – 0.35
Subrounded	0.35 – 0.49
Rounded	0.49 – 0.70
Well rounded	0.70 – 1.0

Table 1: Roundness classification [9].

In addition to other grain shape values (circularity, aspect ratio, and solidity) obtained as reported in previous chapter, porosity and permeability of both samples will not be greatly affected by these grain shape parameters especially since we are dealing with Athabasca oil sands which lack cementation, and thus unconsolidated, as opposed to consolidated sandstones.

Conclusions and Recommendations

From this study, we know that both Samples B and C, obtained from the Upper McMurray Formation in Athabasca, Canada, contain heavy oil, and going by the results presented in this study, it is found that from both samples, heavy oil is recoverable, in-situ. Sample B is poorly sorted medium sand of relatively low porosity but high permeability while Sample C is moderately sorted fine sand of relatively high porosity but low permeability. Although both are recoverable, Sample B seems to be more promising—in-situ recovery wise—due to its high permeability.

In order to determine further, the detailed grain morphology of the Athabasca oil sands, it is necessary to suggest—but not limiting—recommendations on the following:

Porosity and permeability, both of which are key reservoir quality factors, should be studied using core plugs to give better and more accurate results and to ascertain other petrophysical parameters like capillary pressure, wettability, and saturation.

Computer-based simulators such as the Eclipse Thermal for Heavy Oil Recovery should be employed to study heavy oil flow around and within the sand grains while taking into consideration the effects of such flow with respect to grain size (distribution, sorting, skewness, and kurtosis) and, if any, grain shape (roundness, circularity, aspect ratio, and solidity). This is a promising procedure for understanding reservoir heterogeneity as well as the potentially viable procedures for recovery.

There is an insistent need to study weathering, fracturing, and other structural effects in the Athabasca oil sands, plus its influence on general oil sand morphology, as well as its impending effect in in-situ thermal recovery.

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