

**GEOCHEMICAL STUDIES - 4
PHYSICAL AND CHEMICAL
PROPERTIES OF SEDIMENTS AND
BITUMEN FROM SOME ALBERTA OIL
SAND DEPOSITS**

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"GEOCHEMICAL STUDIES"

This series of reports, under the general title "Geochemical Studies", makes available geochemical data on the formation fluids and rocks of Alberta, which would otherwise remain unpublished. Two types of data fall in this category. First, "Geochemical Studies" will act effectively as a document depository in cases where a formal publication is available, but without the raw data having been published; additional interpretations may be included if pertinent. Second, "Geochemical Studies" will include both the raw data and a minimal descriptive report in the case where no formal publication is planned.

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ABSTRACT

A suite of 33 oil sand samples was obtained from five oil sand deposits (Athabasca, Cold Lake, Loon River, Peace River, Wabasca). The samples came from 14 wells and sampling was designed to evaluate possible significant differences in the areal and vertical compositions of the oil sands. All samples were classed as 'good oil sand' on initial visual inspection. The bitumen was removed by Soxhlet extraction, and separated into major hydrocarbon fractions (saturates, aromatics, resins, asphaltenes) in which the elemental (CHONS) composition was determined. Specific gravity, viscosity (at three temperatures) and an elemental (CHONS) analysis were carried out on the clean bitumen, with 25 trace elements determined on 14 samples. The bitumen-free sands were analyzed for: major oxides; sand, silt and clay fractions; clay mineral composition; and composition (Cr, Fe, Mn, Ti, Zr) of the heavy mineral fraction from the clay sized ($< 2 \mu$) and heavy fraction ($\rho > 2.95$), respectively. Microfossils were identified in shales associated with some of the oil sand samples.

A Q-mode statistical factor analysis of the chemical, textural and heavy mineral data for the bitumen-free sand showed that although there are clearly differences among the samples, they appear sufficiently homogeneous that an R-mode analysis of the data was justified. The R-mode varimax solution of five factors (Eigenvalues > 0.5) showed that the chemical data should be factored separately from the textural and heavy mineral data. Chemical factors indicate three separate influences on the chemical composition of the sands: (1) quartz opposed by non-quartz minerals (feldspars and ferro-magnesian minerals) representing more than one-third of the variance among the variables; (2) an independent carbonate mineral factor; and (3) an independent TiO_2 mineral factor.

With respect to the composition of the bitumen and bitumen fractions, two main features were identified. First, the Loon River and Peace River bitumens are richer in S (mean 6.16%) and have higher mean contents of resins (46.0%) and asphaltenes (19.6%) and lower mean contents of saturates (15.2%) than bitumen from the other deposits. Cold Lake bitumen has the lowest mean S content (4.25%), highest mean saturates (23.7%), and lowest mean resins (38.8%). Bitumen from the other deposits occupies intermediate positions. Athabasca bitumen has the highest mean content of aromatics. With respect to vertical variations in composition, there is some evidence that the content of asphaltenes increases with depth, as sometimes does the content of total resins; there is a corresponding decrease in the content of saturates. The most important observation on the trace element content of the bitumens is the 5.74 ppm of Hg in the single sample from the Peace River oil sand deposit, a value which suggests contamination and which requires confirmation.

INTRODUCTION

Two decades ago, at a symposium titled Oil Sands Fuel of the Future held in Calgary, Alberta 1973-09-05/09, a talk was delivered with the rather long title Regional geochemistry of conventional and oil-sand oils, and their extracted asphaltenes in the Mannville Formation of Alberta, studied by neutron activation, NMR, EPR and X-ray techniques. It was authored by Brian Hitchon, J.G. Speight and K.F. Schulz of the Alberta Research Council, and R.H. Filby and K.R. Shah of the Nuclear Radiation Center, Washington State University, Pullman, Washington, USA. There is no abstract in the Program and Abstracts volume, only a cryptic note which states "Analytical work was still in progress at the time the abstracts had to go to the printer. The title of the paper largely describes its content". Just about the only paper not appearing in the symposium proceedings (Hills, 1974) is the above talk. By a strange irony, the senior author was chosen to review the symposium proceedings volume for Geoscience Canada (Hitchon, 1975).

The original objective of this study was to determine if there are significant vertical and lateral variations in the composition of bitumen from Alberta oil sand deposits. It was thought that such information might be of interest and value to those engaged in in situ recovery of the bitumen. Accordingly, samples of oil sand were taken from available cores at several locations in each of the major oil sand deposits. In the years since the study was completed, data from the analytical work appeared in only two publications. Eloffson et al. (1977) reported the elemental composition, molecular weight and ESR properties of asphaltenes from 12 of the samples, as well as ESR, S and API gravity of the crude bitumen. Hitchon (1978), in a paper on geochemical aspects of in situ recovery, cited the vertical variations of API gravity, S, N, asphaltenes, V and viscosity in crude bitumen from a core in the Athabasca oil sand deposit.

It is the intention of this Open File report to provide all the data collected during this study, with a minimum of interpretation.

ANALYTICAL PROCEDURES

SAMPLE COLLECTION AND PREPARATION

The majority of the 35 samples studied came from cores held by the Energy Resources Conservation Board (ERCB), although some samples were obtained directly from Shell Canada Limited and Esso Resources Ltd. These companies are duly thanked for their assistance and cooperation. In addition, Syncrude Canada Ltd. kindly made available two samples of surface-mined oil sand, one classed as having good processibility (Syncrude A) and one as having poor processibility (Syncrude B) with respect to Syncrude's hot water processing technology. The core samples were selected initially on the basis of being 'good oil sand' on visual inspection, but subsequent study indicates that a few are no more than medium grade oil sand. Table 1 shows the location of the wells from which the core samples were taken, together with the stratigraphic unit

Table 1. Location, stratigraphic unit and depth of core samples studied

Sample number	Location	Stratigraphic unit	Depth
<u>Athabasca deposit</u>			
BH-426A	6-6-103-12-W4M	McMurray Fm.	48.16-54.56
BH-426B	6-6-103-12-W4M	McMurray Fm.	71.63-75.90
BH-435A	6-25-95-16-W4M	McMurray Fm.	270.66-283.46
BH-435B	6-25-95-16-W4M	McMurray Fm.	283.46-295.66
BH-435C	6-25-95-16-W4M	McMurray Fm.	295.66-307.85
BH-435D	6-25-95-16-W4M	McMurray Fm.	307.85-320.04
BH-435E	6-25-95-16-W4M	McMurray Fm.	320.04-326.14
BH-425A	11-22-90-18-W4M	McMurray Fm.	195.07-200.86
BH-438A	10-23-80-13-W4M	McMurray Fm.	468.78-471.22
BH-438B	10-23-80-13-W4M	McMurray Fm.	480.21-485.62
<u>Cold Lake deposit</u>			
BH-433B	13-33-64-3-W4M	Clearwater Fm.	458.27-469.39
BH-433D	13-33-64-3-W4M	Clearwater Fm.	469.39-481.58
BH-433F	13-33-64-3-W4M	Clearwater Fm.	481.58-493.78
BH-433G	10-10-59-2-W4M	Clearwater Fm.	493.78-503.38
BH-434B	10-10-59-2-W4M	Mannville Fm. Sparky Ss.	482.19-484.63
BH-434C	10-10-59-2-W4M	Mannville Fm. Lloydminster Ss.	512.52-516.33
BH-434D	10-10-59-2-W4M	Mannville Fm. Lloydminster Ss.	521.21-527.30
BH-434E	10-25-58-5-W4M	Mannville Fm. Lloydminster Ss.	530.35-533.40
BH-439C	10-25-58-5-W4M	Mannville Fm. Sparky Ss.	489.66-492.71
BH-439D	10-25-58-5-W4M	Mannville Fm. Sparky Ss.	494.23-499.87
BH-439E	10-25-58-5-W4M	Mannville Fm. Lloydminster Ss.	502.77-524.86
<u>Loon River deposit</u>			
BH-427D	10-14-88-9-W5M	Wabiskaw Mbr.	379.48-383.44
<u>Peace River deposit</u>			
BH-429B	1-27-86-19-W5M	Bullhead Fm.	512.98-516.33
BH-429D	1-27-86-19-W5M	Bullhead Fm.	516.33-518.62
BH-428A	1-9-83-17-W5M	Bullhead Fm.	680.31-686.41
<u>Wabasca deposit</u>			
BH-437A	16-5-86-21-W4M	Wabiskaw Mbr.	339.85-342.90
BH-431B	10-25-81-22-W4M	Grand Rapids Fm.	228.30-239.27
BH-431C	10-25-81-22-W4M	Grand Rapids Fm.	259.08-262.13
BH-431F	10-25-81-22-W4M	Wabiskaw Mbr.	409.96-413.00
BH-436A	6-8-81-25-W4M	Grand Rapids Fm.	224.33
BH-430A	7-8-75-1-W5M	Grand Rapids Fm.	501.09-502.92
BH-430C	7-8-75-1-W5M	Grand Rapids Fm.	512.98-515.11
BH-430F	7-8-75-1-W5M	Wabiskaw Mbr.	671.47-679.70

and depths. Sample size varied, being based on about 'one cubic inch of sample per foot of core' (the standard ERCB guidelines for core sampling). Commonly, the core was fresh and so the composite material for each sample was homogenized in a plastic bag. An aliquot (usually about 150 gm) was then extracted in a Soxhlet thimble using reagent grade benzene (usually about 200 ml), cooled to room temperature without exposure to air, and the benzene-bitumen mixture then centrifuged at 8°C and 7000 rev/min for 15 min to remove clay minerals and water. The bitumen-free oil sand was then subject to a variety of analytical procedures, the results being given in Appendix A. The benzene was removed from the bitumen-benzene solution by evaporation at room temperature until the bulk of the benzene was removed. Residual benzene was removed in a desiccator under vacuum, to constant weight. Subsequent analytical determinations on the bitumen and bitumen fractions are given in Appendix B. A few of the bitumen samples were analyzed for trace elements (Appendix C).

BITUMEN-FREE OIL SAND

Standard dry sieving techniques were used to determine the textural fractions of the bitumen-free oil sand. Although data are available to construct grain-size distribution plots only the percent sand, silt and clay ($<2\mu$) are given in Appendix A. The percentage of the heavy fraction ($\rho > 2.95$; tetrabromoethane) was determined on the +325 mesh (>0.062 mm) portion of the sample. The clay mineral composition was determined by X-ray diffraction using the $<2\mu$ fraction and the following standard peaks: montmorillonite $17\text{\AA}-5^\circ 2\theta$, expanded by glycol; illite $10\text{\AA}-9^\circ 2\theta$; kaolinite $7\text{\AA}-12.4^\circ 2\theta$; chlorite $14\text{\AA}-6^\circ 2\theta$.

The chemical composition of the clean sand was determined using standard wet chemical silicate analysis methods (Rigg and Wagenbauer, 1964). Chemical analysis of the heavy mineral fraction followed the techniques by Kramers and Brown (1976).

BITUMEN AND BITUMEN FRACTIONS

Bitumen, free from clay minerals and water, and effectively free from benzene, was fractionated using a scheme similar to that outlined by Zarrella (1969), in which the bitumen was (re)dissolved in benzene, and the asphaltenes precipitated using n-pentane and determined gravimetrically. The hydrocarbons and resins were separated chromatographically, first into resins I and resins II, then into the saturates and aromatics fractions. The elemental composition of the bitumen and bitumen fractions was determined using a CHNS analyzer, with O determined directly by Alfred Bernhardt Laboratories of Germany.

Specific gravity was determined on the clean bitumen using the sink-float method (Mason, 1939) with a Berman torsion microbalance (Berman, 1939). The liquid was methanol, in which the bitumen is not soluble; a further advantage is the suitable density and low surface tension of methanol. Temperature corrections were made using data from the International Critical Tables. The specific gravity is reported to the third decimal place -- hence the small amount of benzene which was still present (maximum 2.7%; average 1.0%), as determined by gas-liquid chromatography, can be neglected because it only affects the fourth decimal place.

The viscosity was measured with a Wells-Brookfield microviscometer, Model HBT-5X, equipped with a 1.565° cone; three measurements were taken if sufficient sample was available. Plots (not shown) of the logarithm of the viscosity against temperature allow extrapolation of the viscosity to formation temperature or extrapolation to the viscosity at in situ recovery temperature, for example.

Trace elements in a few of the cleaned bitumen samples were determined by neutron activation analysis using techniques described briefly in Hitchon et al. (1975); the data are found in Appendix C.

RESULTS

The results reported here are based on work completed about a decade ago; no attempt has been made at a further synthesis of the data.

PROPERTIES OF TWO SURFACE-MINED OIL SANDS

Table 2 shows the results of the analysis of two surface-mined oil sand samples supplied by Syncrude Canada Ltd. As expected, the most obvious difference lies in the considerably higher contents of silt and clay in the sample designated as having poor processibility.

FACTOR ANALYSIS STUDY OF BITUMEN-FREE OIL SAND

A statistical factor analysis was carried out on the logarithmic transforms of the chemical, textural and heavy mineral data for the bitumen-free sand. There were 33 samples from the subsurface of the major oil sand deposits (data in Appendix A) and the two surface-mined oil sands (Table 2). The 14 variables were SiO_2 , TiO_2 , Al_2O_3 , ΣFe as Fe_2O_3 , CaO , MgO , Na_2O , K_2O , H_2O , LOI (loss on ignition), and the percentages of sand, silt, clay and heavy minerals.

The Q-mode varimax factor score matrix (Table 3) indicates that the first two factors explain about 84% of the information among the samples. Factor 1 has high positive scores for SiO_2 and percent sand, and a high negative score for MgO . Factor 2 has high positive scores for Na_2O , Al_2O_3 , SiO_2 and percent sand. Factor 3, which explains about 13% of the information among the samples, has high positive scores for percent silt, percent clay and LOI , and a high negative score for Na_2O . When the varimax factor components for these three factors are normalized and the data points plotted on a ternary diagram (Figure 1), all samples plot in the area with <50% factor 3. The factor 1 - factor 2 side of the diagram represents the well-sorted sand fraction comprising quartz sands without K-feldspar (factor 1) and quartz sands with K-feldspar (factor 2). An approach to factor 3 indicates an increase in the silt and clay content. Although the number of samples is small, there appear to be some differences among the oil sand deposits, at least with respect to the samples used in this study. For

Table 2. Properties of two surface-mined oil sands

Sample	Syncrude A (good processibility)	Syncrude B (poor processibility)
<u>Texture (%)</u>		
Sand	91.36	79.17
Silt	5.12	13.01
Clay	2.72	7.16
Heavy minerals	0.80	0.66
<u>Clay mineral composition (%)</u>		
Kaolinite	55	50
Illite	45	50
<u>Composition of clean sand (%)</u>		
SiO ₂	94.78	91.04
TiO ₂	0.32	0.52
Al ₂ O ₃	2.26	3.42
ΣFe as Fe ₂ O ₃	0.57	0.66
CaO	0.25	0.24
MgO	0.08	0.31
Na ₂ O	0.19	0.12
K ₂ O	0.56	0.80
H ₂ O	0.16	0.35
LOI	0.69	1.88
Σ	99.86	99.34
<u>Composition of heavy mineral fraction (%)</u>		
Fe	8.1	8.6
Ti	21.3	21.7
Zr	7.2	4.9
Mn	0.27	0.29
Cr	0.19	0.15
<u>Composition of crude bitumen</u>		
API gravity (60/60)	8.80(±0.05)	9.96
Viscosity (cps) 110°F (43°C)	6893	5321
150°F (66°C)	1113	810
186°F (86°C)	318	257
Saturates (wt.%)	20.0	20.7
Aromatics (wt.%)	28.3	29.5
Resins I (wt.%)	29.6	31.0
Resins II (wt.%)	6.8	5.3
Asphaltenes (wt.%)	15.3	13.5

Table 3. Q-mode varimax factor score matrix of chemical, textural and heavy mineral data for 35 oil sand samples

Variable	Factor		
	1	2	3
SiO ₂	0.380	0.449	0.187
TiO ₂	-0.143	-0.103	-0.009
Al ₂ O ₃	-0.128	0.377	0.088
ΣFe as Fe ₂ O ₃	-0.252	0.197	0.085
CaO	-0.321	0.146	0.180
MgO	-0.471	0.161	0.246
Na ₂ O	-0.331	0.490	-0.641
K ₂ O	-0.127	0.172	-0.058
H ₂ O	-0.333	-0.022	0.051
LOI	-0.160	0.114	0.332
Sand	0.364	0.489	0.159
Silt	-0.017	0.146	0.403
Clay	-0.099	0.020	0.296
Heavy minerals	-0.159	-0.175	0.233
Percent of information explained by factor	45.71	38.32	13.43
Cumulative percent of information	45.71	84.03	97.46

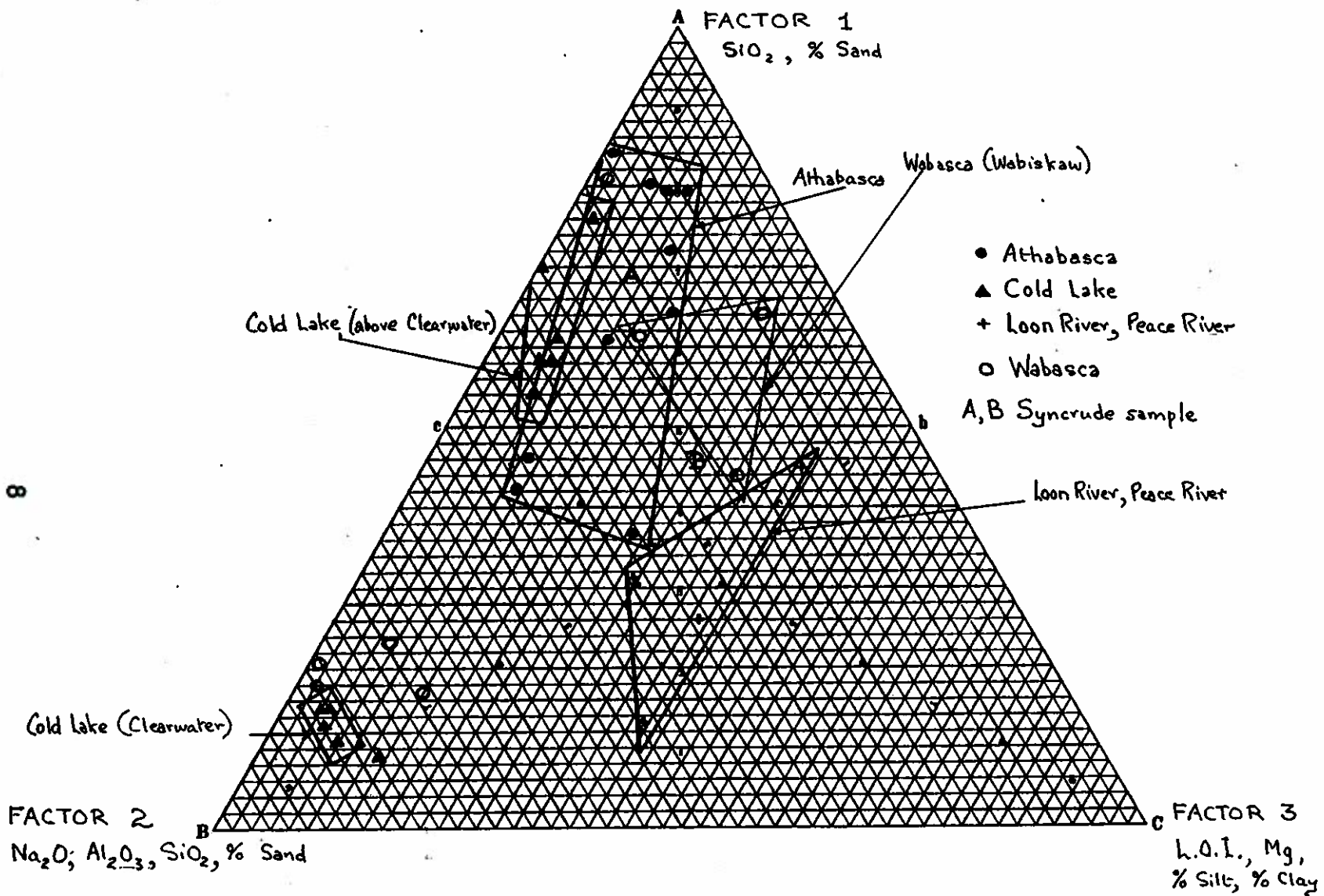


Figure 1. Ternary diagram of normalized varimax factor components for Q-mode on 35 bitumen-free sands from oil sand deposits in Alberta

example, K-feldspar appears to be important in all four samples from the Clearwater Formation at Cold Lake, as well as in some (but not all) samples from the Grand Rapids Formation in the Wabasca deposit. Samples exhibiting the strongest influence of factor 3 are from the Loon River and Peace River deposits. Although there are clearly differences among the samples they appear sufficiently homogeneous that an R-mode analysis of these data is therefore justified.

An R-mode factor analysis, using a varimax solution, was carried out on the logarithmic transforms of the same data used for the Q-mode. Table 4 shows the varimax factor matrix. Loadings <0.2 are omitted because they correspond, approximately, to $<5\%$ of a variable. The five factors extracted (Eigenvalues >0.5) account for nearly 92% of the variance of the variables, and the communalities, which measure the fraction of the variance of each variable explained by the factors that have been extracted, are generally >0.87 .

Most of the variance of the textural data (percent sand, silt, clay) is loaded on factor 2, with percent sand opposed by percent silt and percent clay. This suggests that the textural data should probably not be factored with the chemical data. Similarly, nearly 77% of the variance in the heavy minerals content is loaded onto factor 5, with minor positive loadings for TiO_2 and percent silt, and a minor negative loading for percent sand. This indicates that the percent heavy minerals content is independent of the overall chemical composition of the clean oil sands and should probably not be factored with the chemical data; further, TiO_2 minerals dominate the heavy mineral fraction, with most heavy minerals found in the silt-sized fraction (see similar characteristics found by Kramers and Brown (1976) in the surface-mineable area of the Athabasca oil sands deposit).

Factor 4 is a carbonate factor, with high positive loadings for Ca, Mg and LOI; the most important negatively loaded variable is SiO_2 . This suggests that the content of carbonates is independent of the rest of the sand components and that the LOI in this case represents CO_2 . This contrasts with the loading of LOI in factor 2, which is loaded with the percent silt and percent clay, suggesting that the LOI in factor 2 is mainly structural water removed from clay minerals. The content of TiO_2 in the clean sands is independent of the other components (a separate factor 3); the low positive loadings for CaO and the percent heavy minerals are not significant, because to speculate that most TiO_2 is found in the heavy mineral fraction as sphene ($\text{CaTi}(\text{SiO}_3)_2$) would be incorrect (see results of Kramers and Brown (1976) where the chief heavy minerals were shown to be rutile (TiO_2) and anatase (TiO_2)).

Factor 1, which represents more than one third of the variance among the variables, shows SiO_2 loaded against K_2O , Na_2O , Al_2O_3 , with lesser loadings for H_2O , MgO, CaO and LOI. This factor is interpreted to indicate that the dominant non-quartz components are the feldspars and ferro-magnesian minerals, and as the content of quartz decreases the contents of the non-quartz minerals increases. Independent of this relation is the content of carbonate minerals (factor 4) and TiO_2 minerals (factor 3).

Table 4. R-mode varimax factor matrix of chemical, textural and heavy mineral data for 35 oil sand samples

Variable	Factor					Communality
	1	2	3	4	5	
SiO ₂	-0.836			-0.455		0.943
TiO ₂	0.224		0.916		0.223	0.974
Al ₂ O ₃	0.857			0.359		0.947
ΣFe as Fe ₂ O ₃	0.853	-0.234		0.374		0.924
CaO	0.464		0.213	0.783		0.886
MgO	0.653	-0.307		0.611		0.897
Na ₂ O	0.910	0.224				0.885
K ₂ O	0.919					0.893
H ₂ O	0.755	-0.440		0.232		0.870
LOI	0.305	-0.549		0.731		0.959
Sand		0.881			-0.298	0.899
Silt		-0.905		0.259	0.223	0.941
Clay		-0.922				0.869
Heavy minerals		-0.342	0.237		0.876	0.947
Eigenvalue (Principal component)	7.280	3.102	1.236	0.676	0.539	
Percent of variance explained by factor	37.19	23.83	7.75	15.49	7.42	
Cumulative percent of variance	37.19	61.02	68.77	84.26	91.68	

Loadings < 0.2 omitted.

COMPOSITION OF BITUMEN AND BITUMEN FRACTIONS

In bitumen the atomic H/C ratio is in the narrow range 1.432-1.566, and S>O>N, with ranges and mean values as follows:

S	3.92-6.58; mean 4.72
O	0.86-1.63; mean 1.17
N	0.28-0.58; mean 0.41

There are differences in the bitumen among the oil sand deposits for the mean S and O contents but not for N, as can be seen in Table 5. Thus, the Loon River and Peace River bitumens have a higher mean S content, and there is a slightly enhanced mean content of O in bitumen from the Wabasca deposit. This is a reflection of the different mean contents of the major hydrocarbon fractions, as illustrated in Table 6. The Loon River and Peace River bitumens are characterized by the lowest amount of saturates (both range and mean), and the highest amounts of resins and asphaltenes, which together carry most of the S; there are also differences in the contents of S in the asphaltenes and resins among the different oil sand deposits. The mean content of S in asphaltenes are: Athabasca 8.1%; Cold Lake 7.6%; Loon River and Peace River 8.5%; Wabasca 8.0%. Corresponding mean contents for resins I are: Athabasca 5.9%; Cold Lake 5.2%; Loon River and Peace River 6.8%; Wabasca 5.9%. The bitumen from the Athabasca deposit has the highest range and mean contents for the aromatics (Table 6).

As expected, the saturates have the least amount of total heteroatoms, and the resins and asphaltenes the most. Nitrogen was <0.01% of the saturates in nearly two-thirds (n=20) of the samples, and <0.01% in five samples of aromatics. Oxygen was <0.01% in two samples of saturates. As a general observation, S is commonly >85% of the total heteroatoms in aromatics, and about half the total heteroatoms in asphaltenes. Oxygen is the dominant (60-70% of the total) heteroatom in resins.

With respect to vertical compositional variations, the majority (five out of nine) of sets of samples show increased amounts of asphaltenes with depth in the set, and for several sets there is a corresponding increase in the content of total resins and a decrease in the amount of saturates. However, there are no consistent trends with respect to the amount of ONS.

TRACE ELEMENTS IN BITUMEN

The data on trace elements in bitumen (Appendix C) are insufficient for a thorough evaluation, hence only the ranges of selected elements are reported in general terms in Table 7. Elements of particular environmental interest include As, Hg, Se, Sb and Zn. Of these the most startling value, which needs confirmation based on other samples, is the 5740 ppb (5.74 ppm!) reported for Hg in sample BH-429D from the Peace River oil sand deposit. Contamination is suspected.

Table 5. Mean contents (%) of S, O and N in bitumen from oil sand deposits

	Oil sand deposit			
	Athabasca	Cold Lake	Loon River/ Peace River	Wabasca
No. of samples	10	11	4	8
Mean S content	4.66	4.25	6.16	4.73
Mean O content	1.07	1.19	1.13	1.30
Mean N content	0.43	0.40	0.39	0.39

Table 6. Range and mean contents (%) of saturates, aromatics, resins and asphaltenes in bitumen from oil sand deposits

		Oil sand deposit			
		Athabasca	Cold Lake	Loon River/ Peace River	Wabasca
No. of samples		10	11	4	8
Saturates	range	12.1-22.0	21.6-25.4	12.2-19.6	13.4-27.5
	mean	18.9	23.7	15.2	20.2
Aromatics	range	19.4-29.0	17.1-24.4	15.9-22.8	13.6-24.0
	mean	22.0	19.7	19.2	18.8
Σ Resins	range	39.5-45.2	36.2-39.6	43.7-49.3	38.8-47.9
	mean	42.2	38.8	46.0	43.9
Asphaltenes	range	14.6-19.4	14.9-24.0	18.7-21.8	11.5-20.6
	mean	17.0	19.0	19.6	17.1

Table 7. Generalized ranges of some trace elements in bitumen from oil sand deposits

Element	General range	Outliers
Na (ppm)	15-30	45 (Peace River), 70 (Wabasca)
K (ppm)	<5-25	* (Cold Lake), 70 (Peace River), 75 (Wabasca)
Fe (ppm)	20-75	100-110 (Wabasca), 120 (Peace River)
Ni (ppm)	60-90	50 (Wabasca), 115 (Wabasca)
As (ppb)	100-200	80 (Athabasca), 90 (Cold Lake), 325 (Wabasca)
Hg (ppb)	200-400	*(Wabasca), 680 (Athabasca), 730-845 (Wabasca), 5740 (Peace River)
Se (ppb)	350-500	300 and 620 (Wabasca)
Sb (ppb)	20-50	15 (Cold Lake)
Zn (ppb)	1.5-3.5	*(Wabasca), 5.8 (Wabasca)

* Value below detection

MICROFOSSILS IN ASSOCIATED SHALES

Appendix D is a report prepared by Dr. J.H. Wall on the microfossils found in shales sampled from the same core as the oil sands reported in this Open File report. It is presented without further comment.

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**APPENDIX A
PHYSICAL AND CHEMICAL PROPERTIES
OF BITUMEN-FREE OIL SANDS**

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-426A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Union McIvor 6-6-103-12-W4 Location: 6-6-103-12-W4 Mer Depth (m): 48.16-54.56 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	91.75	Montmorillonite	0.0
Silt	7.43	Kaolinite	80.3
Clay	0.82	Illite	19.7
OIL SATURATION (% by wt.)		12.5	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	92.32	Fe	7.8
TiO ₂	0.25	Ti	19.7
Al ₂ O ₃	2.78	Zr	5.3
ΣFe as Fe ₂ O ₃	0.65	Mn	0.32
CaO	0.20	Cr	0.20
MgO	0.32	- = not determined	
Na ₂ O	0.17	. = below detection	
K ₂ O	0.80	Heavy fraction (%,	0.31
H ₂ O	0.19	+325)	
L.O.I.	1.58		
	Σ 99.26		
<u>COMMENTS</u>			
Test Hole No. 2 on Permit No. 130; rig released 1968-02-07. Composite sample taken from the following cores: Core No. 5 158-165 ft; rec 4 ft good oil sand Core No. 6 165-172 ft; good oil sand with some grey shale Core No. 7 172-179 ft; rec. 5 ft good oil sand			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-426B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Union Mclvor 6-6-103-12-W4 Location: 6-6-103-12-W4 Mer Depth (m): 71.63-75.90 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	94.67	Montmorillonite	0.0
Silt	4.79	Kaolinite	67.8
Clay	0.54	Illite	32.2
<u>OIL SATURATION (% by wt.)</u>		14.5	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	95.58	Fe	10.4
TiO ₂	0.26	Ti	13.5
Al ₂ O ₃	1.48	Zr	5.0
ΣFe as Fe ₂ O ₃	0.44	Mn	1.10
CaO	0.14	Cr	0.21
MgO	0.17	- = not determined	
Na ₂ O	0.04	. = below detection	
K ₂ O	0.59	Heavy fraction (%,	0.56
H ₂ O	0.08	+325)	
L.O.I.	0.79		
	Σ 99.57		
<u>COMMENTS</u>			
Test Hole No. 2 on Permit No. 130; rig released 1968-02-07. Composite sample taken from the following cores: Core No. 16 235-244 ft; rec 5 ft good oil sand. Top 18 inches have quite a few oil-free shaley and silty laminae Core No. 17 244-249 ft; good oil sand with rare shale laminae			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-435A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 270.66-283.46 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	93.26	Montmorillonite	0.0
Silt	5.56	Kaolinite	76.9
Clay	1.18	Illite	23.1
<u>OIL SATURATION (% by wt.)</u>		10.3	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	91.27	Fe	8.9
TiO ₂	0.30	Ti	15.5
Al ₂ O ₃	2.12	Zr	8.6
ΣFe as Fe ₂ O ₃	1.17	Mn	0.18
CaO	0.90	Cr	0.11
MgO	0.25	- = not determined	
Na ₂ O	0.48	. = below detection	
K ₂ O	1.45	Heavy fraction (%,	0.47
H ₂ O	0.22	+325)	
L.O.I.	1.79		
	Σ 99.95		
<u>COMMENTS</u>			
Rig released 1973-02-18. Composite of 6 samples from 888-930 ft in the following cores: Core No. 1 888-917 ft, good oil sand Core No. 2 919-938 ft, good oil sand Zones with > 50% shale: 900'6"-902'10"; 926'4"-926'10"			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-435B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 283.46-295.66 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	87.73	Montmorillonite	0.0
Silt	10.50	Kaolinite	83.3
Clay	1.77	Illite	16.7
<u>OIL SATURATION (% by wt.)</u>		11.0	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	90.73	Fe	15.3
TiO ₂	0.26	Ti	12.2
Al ₂ O ₃	2.99	Zr	8.1
ΣFe as Fe ₂ O ₃	0.98	Mn	0.18
CaO	0.60	Cr	0.12
MgO	0.28	- = not determined	
Na ₂ O	0.58	. = below detection	
K ₂ O	1.92	Heavy fraction (%,	0.41
H ₂ O	0.21	+325)	
L.O.I.	2.10		
	Σ 100.65		
<u>COMMENTS</u>			
Composite of 6 samples from 930-970 ft in the following cores: Core No. 2 919-938 ft, good oil sand Core No. 3 938-968 ft, good oil sand Core No. 4 968-990 ft, good oil sand			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-435C Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 295.66-307.85 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	90.65	Montmorillonite	0.8
Silt	6.49	Kaolinite	80.4
Clay	2.86	Illite	18.8
<u>OIL SATURATION (% by wt.)</u>		10.5	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	93.59	Fe	9.7
TiO ₂	0.26	Ti	16.3
Al ₂ O ₃	1.98	Zr	4.0
ΣFe as Fe ₂ O ₃	0.44	Mn	0.27
CaO	0.45	Cr	0.16
MgO	0.12	- = not determined	
Na ₂ O	0.08	. = below detection	
K ₂ O	0.62	Heavy fraction (%,	0.38
H ₂ O	0.15	+325)	
L.O.I.	1.55		
	Σ 99.24		
<u>COMMENTS</u>			
Composite of 6 samples from 970-1010 ft in the following cores: Core No. 4 968-990 ft, good oil sand Core No. 5 1001-1028 ft, good oil sand Zone with >50% shale: 984'0"-989'0"; a greyish black fissile shale was sampled for microfossils at 988-989 ft (see sample BH-435F, Appendix D). This same shale was analyzed for major and trace elements, and the kerogen extracted and studied (see Data Sheet 13 in Hitchon, 1993)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-435D Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 307.85-320.04 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	94.38	Montmorillonite	0.0
Silt	4.99	Kaolinite	82.2
Clay	0.63	Illite	17.8
<u>OIL SATURATION (% by wt.)</u>		15.1	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	95.95	Fe	6.8
TiO ₂	0.27	Ti	21.6
Al ₂ O ₃	1.17	Zr	6.5
ΣFe as Fe ₂ O ₃	0.33	Mn	0.22
CaO	0.12	Cr	0.18
MgO	0.03	- = not determined	
Na ₂ O	0.28	. = below detection	
K ₂ O	1.01	Heavy fraction (%,	0.60
H ₂ O	0.05	+325)	
L.O.I.	0.67		
	Σ 99.88		
<u>COMMENTS</u>			
Composite of 6 samples from 1010-1050 ft in the following cores: Core No. 5 1001-1028 ft, good oil sand Core No. 6 1028-1058 ft, good oil sand Zones with >50% shale: 1037'0"-1037'9"			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-435E Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 320.04-326.14 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	93.62	Montmorillonite	0.8
Silt	5.05	Kaolinite	78.0
Clay	1.33	Illite	21.2
<u>OIL SATURATION (% by wt.)</u>		14.0	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	95.64	Fe	5.7
TiO ₂	0.30	Ti	24.6
Al ₂ O ₃	1.55	Zr	5.5
ΣFe as Fe ₂ O ₃	0.17	Mn	0.21
CaO	1.22	Cr	0.20
MgO	0.03	- = not determined	
Na ₂ O	0.04	. = below detection	
K ₂ O	0.58	Heavy fraction (%,	0.30
H ₂ O	0.10	+325)	
L.O.I.	0.73		
	Σ 100.36		
<u>COMMENTS</u>			
Composite of 3 samples from 1050-1070 ft in the following cores: Core No. 6 1028-1058 ft, good oil sand Core No. 7 1058-1082 ft, good oil sand Zones with >50% shale: 1052'0"-1052'10" Core missing: 1065'0"-1066'0" Oil-free from ~1068 ft to base; Paleozoic top 1076'6" (328.12 m)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-425A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Atlantic Richfield R.O.C. Buffalo Lake 11-22-90-18W4 Location: 11-22-90-18-W4 Mer Depth (m): 195.07-200.86 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	85.80	Montmorillonite	2.1
Silt	12.22	Kaolinite	84.6
Clay	1.98	Illite	13.3
OIL SATURATION (% by wt.)		11.5	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	87.89	Fe	18.8
TiO ₂	0.20	Ti	2.7
Al ₂ O ₃	3.81	Zr	1.7
ΣFe as Fe ₂ O ₃	1.68	Mn	0.12
CaO	0.51	Cr	0.19
MgO	0.63	- = not determined	
Na ₂ O	0.16	* = below detection	
K ₂ O	1.10	Heavy fraction (%,	0.49
H ₂ O	0.35	+325)	
L.O.I.	2.81		
	Σ 99.14		
<u>COMMENTS</u>			
Test Hole No. 1 on Permit No. 104; rig released 1959-02-18. Composite sample from Core No. 1 (640-659 ft, comprising broken pieces of good oil sand with minor pieces of oil-free light grey shale). A medium dark grey shale lies immediately below the oil sand at 659-678 ft, which was sampled for microfossils (see Appendix D, sample BH-425B).			

****PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS**

Sample number: BH-438A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell House Creek EV 10-23-80-13 Location: 10-23-80-13-W4 Mer Depth (m): 468.78-471.22 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	93.02	Montmorillonite	0.0
Silt	6.33	Kaolinite	70.8
Clay	0.65	Illite	29.2
<u>OIL SATURATION (% by wt.)</u>		13.8	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	94.68	Fe	8.4
TiO ₂	0.37	Ti	21.8
Al ₂ O ₃	1.86	Zr	7.1
ΣFe as Fe ₂ O ₃	0.29	Mn	0.37
CaO	0.23	Cr	0.18
MgO	0.06	- = not determined	
Na ₂ O	0.09	. = below detection	
K ₂ O	0.76	Heavy fraction (%,	0.66
H ₂ O	0.11	+325)	
L.O.I.	0.78		
	Σ 99.23		
<u>COMMENTS</u>			
Composite of 10 samples taken over cored interval 1538-1546 ft. Good oil sand with an increasing amount of small oil-free shale pellets toward the base of the good oil sand. Contemporaneous minor faulted structures at 1541'6". Rig released 1973-03-04.			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-438B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell House Creek EV 10-23-80-13 Location: 10-23-80-13-W4 Mer Depth (m): 480.21-485.62 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	80.79	Montmorillonite	1.0
Silt	17.92	Kaolinite	84.1
Clay	1.29	Illite	14.9
<u>OIL SATURATION (% by wt.)</u>		13.9	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	93.78	Fe	10.1
TiO ₂	0.40	Ti	20.0
Al ₂ O ₃	2.05	Zr	3.9
ΣFe as Fe ₂ O ₃	0.40	Mn	0.64
CaO	0.35	Cr	0.19
MgO	0.05		
Na ₂ O	0.08	- = not determined	
K ₂ O	0.64	. = below detection	
H ₂ O	0.11	Heavy fraction (%,	0.62
L.O.I.	1.30	+325)	
	Σ 99.16		
<u>COMMENTS</u>			
Composite of 7 samples taken as follows: Within the silty section 1569'2"-1593'3" are a series of good oil sand bands, which were samples as follows: 1575'6"-1575'11" 1 sample 1579'6"-1580'0" 1 sample 1581'6"-1582'1" 1 sample 1590'3"-1593'3" 4 samples (clayey oil sand)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-433B Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 458.27-469.39 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	93.68	Montmorillonite	26.8
Silt	5.09	Kaolinite	47.0
Clay	1.23	Illite	26.2
<u>OIL SATURATION (% by wt.)</u>		12.9	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	75.17	Fe	16.1
TiO ₂	0.38	Ti	4.3
Al ₂ O ₃	10.88	Zr	*
ΣFe as Fe ₂ O ₃	2.28	Mn	0.33
CaO	1.51	Cr	0.17
MgO	0.83		
Na ₂ O	2.96	- = not determined	
K ₂ O	2.01	. = below detection	
H ₂ O	0.49	Heavy fraction (% +325)	0.20
L.O.I.	1.77		
	Σ 98.28		
<u>COMMENTS</u>			
Rig released 1973-03-21. Composite of 6 samples from 1503'6"-1540'0" in the following cores: Core No. 1 1491-1521 ft, rec 30 ft good oil sand, mostly very friable, with essentially no shale bands Core No. 2 1521-1551 ft, rec 26 ft, similar to Core No. 1, with hard bands at 1521-1525 ft and 1548'-1553'6" Upper Grand Rapids Formation 354.18 m (1162 ft) Lower Grand Rapids Formation 421.84 m (1384 ft) Clearwater Formation 457.50 m (1501 ft) McMurray Formation 502.31 m (1648 ft) Microfossils are reported from a dark grey shale at 1491-1503.5 ft (see Appendix D, sample BH-433A). This same shale was analyzed for major and trace elements and the kerogen extracted and studied (see Data Sheet 12 in Hitchon, 1993)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-433D Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 469.39-481.58 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	90.00	Montmorillonite	7.7
Silt	7.04	Kaolinite	88.6
Clay	2.96	Illite	3.7
<u>OIL SATURATION (% by wt.)</u>		11.0	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	73.82	Fe	16.7
TiO ₂	0.44	Ti	5.1
Al ₂ O ₃	11.04	Zr	*
ΣFe as Fe ₂ O ₃	3.05	Mn	0.40
CaO	1.50	Cr	0.19
MgO	0.95	- = not determined	
Na ₂ O	2.97	. = below detection	
K ₂ O	2.01	Heavy fraction (%,	0.25
H ₂ O	0.53	+325)	
L.O.I.	2.18		
	Σ 98.49		
<u>COMMENTS</u>			
Composite of 6 samples from 1540-1580 ft in the following cores: Core No. 2 1521-1551 ft, rec 26 ft good oil sand, mostly very friable, with essentially no shale bands Core No. 3 1551-1581 ft, rec 24'9", similar to Core No. 2, with hard bands at 1548-1553'6", and 1567'6"-1568'6"			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-433F Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 481.58-493.78 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	94.63	Montmorillonite	42.0
Silt	4.11	Kaolinite	29.0
Clay	1.26	Illite	29.0
<u>OIL SATURATION (% by wt.)</u>		13.2	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	73.96	Fe	20.7
TiO ₂	0.39	Ti	5.4
Al ₂ O ₃	11.54	Zr	1.3
ΣFe as Fe ₂ O ₃	2.15	Mn	0.46
CaO	1.67	Cr	0.20
MgO	0.80	- = not determined	
Na ₂ O	3.16	. = below detection	
K ₂ O	2.05	Heavy fraction (%,	0.50
H ₂ O	0.44	+325)	
L.O.I.	2.01		
	Σ 98.17		
<u>COMMENTS</u>			
Composite of 6 samples from 1580-1620 ft in the following cores; Core No. 3 1551-1581 ft, rec 24'9", good oil sand, mostly very friable, with essentially no shale bands Core No. 4 1581-1612 ft, rec 27 ft, similar to Core No. 3 Core No. 5 1612-1642 ft, rec 30 ft, similar to Core No. 3			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-433G Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 493.78-503.38 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	92.44	Montmorillonite	44.2
Silt	6.23	Kaolinite	34.3
Clay	1.33	Illite	21.5
<u>OIL SATURATION (% by wt.)</u>		13.1	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	74.78	Fe	17.7
TiO ₂	0.40	Ti	5.4
Al ₂ O ₃	11.59	Zr	*
ΣFe as Fe ₂ O ₃	2.02	Mn	0.45
CaO	1.56	Cr	0.30
MgO	0.77		
Na ₂ O	3.12	- = not determined	
K ₂ O	2.06	. = below detection	
H ₂ O	0.39	Heavy fraction (%,	0.29
L.O.I.	1.73	+325)	
	Σ 98.42		
<u>COMMENTS</u>			
Composite of 6 samples from 1620-1651'6" in the following cores: Core No. 5 1612-1642 ft, rec 30 ft good oil sand, mostly friable, with essentially no shale bands Core No. 6 1642-1672 ft, rec 29 ft; from 1642-1651'6" banded good oil sand with increasing contents of light grey shale; some shale bands up to 12" thick, also some silty shales; from 1651'6"-1672' friable (sometimes with poorly cemented thin bands) glauconitic sandstone, medium- to fine-grained, with very faint traces of bedding. At 1662'6" is a hard (calcareous?) cemented zone. No trace of hydrocarbons.			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-434B Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 482.19-484.63 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	90.45	Montmorillonite	9.8
Silt	7.75	Kaolinite	58.6
Clay	1.80	Illite	31.6
<u>OIL SATURATION (% by wt.)</u>		12.6	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	92.30	Fe	10.9
TiO ₂	0.24	Ti	18.9
Al ₂ O ₃	3.08	Zr	2.7
ΣFe as Fe ₂ O ₃	0.54	Mn	0.37
CaO	0.26	Cr	0.15
MgO	0.15	- = not determined	
Na ₂ O	0.44	. = below detection	
K ₂ O	0.65	Heavy fraction (%,	0.21
H ₂ O	0.24	+325)	
L.O.I.	1.68		
	Σ 99.58		
<u>COMMENTS</u>			
Rig released 1964-03-30 Composite of samples from 1582-1590 ft in the following core: Core No. 4 1580-1601 ft: 1580-1582 med grey shale with minor plant remains; 1582-1590 good, friable oil sand; 1590-1601 fine-grained sandstone and silty sandstone with poor to fair oil staining (no good or medium oil sands)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-434C Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Lloydminster Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 512.52-516.33 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	88.94	Montmorillonite	0.0
Silt	9.49	Kaolinite	96.1
Clay	1.57	Illite	3.9
<u>OIL SATURATION (% by wt.)</u>		12.9	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	92.33	Fe	12.7
TiO ₂	0.28	Ti	21.0
Al ₂ O ₃	2.99	Zr	4.5
ΣFe as Fe ₂ O ₃	0.59	Mn	0.34
CaO	0.30	Cr	0.27
MgO	0.20	- = not determined	
Na ₂ O	0.47	. = below detection	
K ₂ O	0.78	Heavy fraction (%,	0.26
H ₂ O	0.11	+325)	
L.O.I.	1.33		
	Σ 99.38		
<u>COMMENTS</u>			
Composite of samples from 1681'6"-1694' in the following core: Core No. 5 1680-1694 ft: 1680-1681'6" silty sandstone with slight oil staining; 1681'6"-1694' good, mostly friable oil sand without structure			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-434D Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Lloydminster Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 521.21-527.30 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	96.31	Montmorillonite	1.7
Silt	2.74	Kaolinite	91.7
Clay	0.95	Illite	6.6
<u>OIL SATURATION (% by wt.)</u>		13.3	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	95.25	Fe	-
TiO ₂	0.13	Ti	-
Al ₂ O ₃	1.57	Zr	-
ΣFe as Fe ₂ O ₃	0.54	Mn	-
CaO	0.32	Cr	-
MgO	0.10	(not sufficient sample)	
Na ₂ O	0.20	- = not determined	
K ₂ O	0.48	. = below detection	
H ₂ O	0.06	Heavy fraction (%,	0.13
L.O.I.	0.92	+325)	
	Σ 99.57		
<u>COMMENTS</u>			
Composite of samples from 1710-1730 ft in Core No. 6 (1710-1730 ft, rec 20 ft good, friable oil sand)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-434E Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Lloydminster Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 530.35-533.40 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	95.60	Montmorillonite	0.4
Silt	3.52	Kaolinite	95.6
Clay	0.88	Illite	4.0
<u>OIL SATURATION (% by wt.)</u>		12.2	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	95.41	Fe	-
TiO ₂	0.14	Ti	-
Al ₂ O ₃	1.52	Zr	-
ΣFe as Fe ₂ O ₃	0.41	Mn	-
CaO	0.21	Cr	-
MgO	0.13	(not sufficient sample)	
Na ₂ O	0.66	- = not determined	
K ₂ O	0.83	* = below detection	
H ₂ O	0.07	Heavy fraction (%,	0.11
L.O.I.	0.85	+325)	
	Σ 100.23		
<u>COMMENTS</u>			
Composite of samples from 1740-1750 ft in Core No. 7 (1740-1750 ft, rec. 10 ft good oil sand, coarse-grained nearer the base)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-439C Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Michel Lake No. 10-25 Location: 10-25-58-5-W4 Mer Depth (m): 489.66-492.71 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	92.51	Montmorillonite	4.7
Silt	6.18	Kaolinite	70.6
Clay	1.31	Illite	24.7
<u>OIL SATURATION (% by wt.)</u>		13.4	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	93.08	Fe	13.2
TiO ₂	0.23	Ti	15.3
Al ₂ O ₃	2.42	Zr	2.8
ΣFe as Fe ₂ O ₃	0.52	Mn	0.35
CaO	0.30	Cr	0.24
MgO	0.15	- = not determined	
Na ₂ O	0.42	. = below detection	
K ₂ O	0.65	Heavy fraction (%,	0.21
H ₂ O	0.18	+325)	
L.O.I.	1.57		
	Σ 99.52		
<u>COMMENTS</u>			
Rig released 1964-03-20 Composite of samples from 1606'6"-1616'6" in Core No. 3, as follows: 1599-1601'6" medium grey, laminated siltstone, some fine cross-bedding; some oil staining 1601'6"-1606'6" mixed oil-stained siltstones with very minor oil sand bands (core very broken) 1606'6"-1616'6" good, friable oil sand 1616'6"-1621'6" light grey rather structureless mudstone 1621'6"-1629' good, friable oil sand, with occasional quite hard oil sand bands Indeterminate microfossils are reported from a medium dark grey shale at 1569-1584 ft (see sample BH-439B, Appendix D). Sample BH-439A is a light to medium grey fissile shale studied extensively (see Data Sheet 11, Hitchon, 1993).			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-439D Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Michel Lake 10-25 Location: 10-25-58-5-W4 Mer Depth (m): 494.23-499.87 Description: Medium oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	81.37	Montmorillonite	8.7
Silt	16.45	Kaolinite	73.9
Clay	2.18	Illite	17.4
<u>OIL SATURATION (% by wt.)</u>		9.9	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	71.04	Fe	17.4
TiO ₂	0.54	Ti	6.6
Al ₂ O ₃	11.77	Zr	*
ΣFe as Fe ₂ O ₃	2.89	Mn	0.38
CaO	1.54	Cr	0.34
MgO	0.91		
Na ₂ O	2.79	- = not determined	
K ₂ O	2.15	. = below detection	
H ₂ O	0.43	Heavy fraction (%,	1.03
L.O.I.	3.62	+325)	
	Σ 97.68		
<u>COMMENTS</u>			
Composite of samples from 1621'6"-1640' in the following cores: Core No. 3 (base) 1621'6"-1629' good, friable oil sand, with occasional hard oil sand bands Core No. 4 1629'-1640' good, friable oil sand, with a few non-oil stained shaly bands without obvious structure; 1640'-1646'6" poor to medium banded oil sand; 1646'6"-1649'6" medium grey shale with minor pieces of coaly material; some slickensiding; 1649'6"-1650'6" good oil sand			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-439E Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation; Lloydminster Sandstone Well name: Pan Am A1 Michel Lake No. 10-25 Location: 10-25-58-5-W4 Mer Depth (m): 502.77-524.86 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	95.42	Montmorillonite	1.2
Silt	3.48	Kaolinite	91.1
Clay	1.10	Illite	7.7
<u>OIL SATURATION (% by wt.)</u>		13.6	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	90.50	Fe	9.1
TiO ₂	0.31	Ti	21.1
Al ₂ O ₃	2.78	Zr	2.7
ΣFe as Fe ₂ O ₃	0.55	Mn	0.38
CaO	1.22	Cr	0.21
MgO	0.16	- = not determined	
Na ₂ O	0.54	. = below detection	
K ₂ O	0.78	Heavy fraction (%,	0.48
H ₂ O	0.09	+325)	
L.O.I.	2.01		
	Σ 98.94		
<u>COMMENTS</u>			
Composite of samples from 1649'6"-1722' in the following cores: Core No. 4 (base) 1649'6"-1650'6" good oil sand Core No. 5 1662'-1692' rec 8 ft good oil sand, not always friable; without obvious structure Core No. 6 1692'-1722' rec 30 ft good oil sand, some friable, grading to medium/poor oil sand near the base of the core			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-427D Oil sand deposit: Loon River Stratigraphic unit: Wabiskaw Member Well name: Union Red Earth 10-14-88-9 Location: 10-14-88-9-W5 Mer Depth (m): 379.48-383.44 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	82.47	Montmorillonite	0.3
Silt	15.28	Kaolinite	88.8
Clay	2.25	Illite	10.9
<u>OIL SATURATION (% by wt.)</u>		10.8	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	87.20	Fe	7.3
TiO ₂	0.32	Ti	4.7
Al ₂ O ₃	4.57	Zr	*
ΣFe as Fe ₂ O ₃	0.90	Mn	0.26
CaO	1.05	Cr	0.26
MgO	0.61	- = not determined	
Na ₂ O	0.26	. = below detection	
K ₂ O	0.82	Heavy fraction (%,	1.08
H ₂ O	0.24	+325)	
L.O.I.	3.42		
	Σ 99.39		
<u>COMMENTS</u>			
Rig released 1966-10-10 Composite of 12 samples from core at 1245-1258 ft, comprising good oil sand with minor thin (max. 5 mm) oil-free bands and one oil-free band about 2 cm thick. Sample BH-427A is a medium grey shale with pyrite nodules, sampled at 1198-1245 ft, immediately above BH-427D; it was subject to analysis for major and trace elements, and the extracted kerogen studied by a variety of techniques (see Data Sheet 10 in Hitchon, 1993).			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-429B Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte OV 1-27 Location: 1-27-86-19-W5 Mer Depth (m): 512.98-516.33 Description: Medium oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	88.02	Montmorillonite	0.7
Silt	9.75	Kaolinite	84.7
Clay	2.23	Illite	14.6
<u>OIL SATURATION (% by wt.)</u>		9.8	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	87.82	Fe	20.1
TiO ₂	0.33	Ti	3.5
Al ₂ O ₃	3.66	Zr	*
ΣFe as Fe ₂ O ₃	0.71	Mn	0.52
CaO	1.36	Cr	0.35
MgO	0.50		
Na ₂ O	0.01	- = not determined	
K ₂ O	0.67	. = below detection	
H ₂ O	0.16	Heavy fraction (%,	0.16
L.O.I.	3.93	+325)	
	Σ 99.15		
<u>COMMENTS</u>			
Rig released 1972-12-21 Composite of 9 samples taken about 1 ft apart from the inside of Core No. 1 (1681-1694 ft) at 1683-1694 ft. Well saturated oil sand with a few thin unsaturated irregular bands; pebbly in places. Microfossils are reported from a mudstone (medium greenish grey in colour) almost immediately above the oil sand (1681-1683 ft); see Appendix D, sample BH-429A, for details.			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-429D Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte OV 1-27 Location: 1-27-86-19-W5 Mer Depth (m): 516.33-518.62 Description: Medium oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	83.10	Montmorillonite	0.0
Silt	14.19	Kaolinite	93.2
Clay	2.71	Illite	6.8
<u>OIL SATURATION (% by wt.)</u>		7.3	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	84.69	Fe	15.2
TiO ₂	0.40	Ti	1.1
Al ₂ O ₃	4.31	Zr	*
ΣFe as Fe ₂ O ₃	1.19	Mn	0.21
CaO	1.84	Cr	0.18
MgO	0.93	- = not determined	
Na ₂ O	0.12	. = below detection	
K ₂ O	0.94	Heavy fraction (%,	0.69
H ₂ O	0.19	+325)	
L.O.I.	5.32		
	Σ99.93		
<u>COMMENTS</u>			
Composite of 9 samples taken from the centre of the core at 1694'-1701'6" in Core No. 2 (1694-1709 ft), comprising massive oil sand with some thin calcareous stringers (almost a calcareous carbonaceous shale). At 1701'6"-1702' is a thin coal seam with highly carbonaceous, coaly shale			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-428A Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte 1-9-83-17 Location: 1-9-83-17-W5 Mer Depth (m): 680.31-686.41 Description: Medium oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	82.38	Montmorillonite	0.0
Silt	15.53	Kaolinite	84.9
Clay	2.09	Illite	15.1
<u>OIL SATURATION (% by wt.)</u>		7.4	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	75.58	Fe	12.4
TiO ₂	0.21	Ti	1.2
Al ₂ O ₃	4.43	Zr	*
ΣFe as Fe ₂ O ₃	1.39	Mn	0.16
CaO	5.16	Cr	0.25
MgO	2.22	- = not determined	
Na ₂ O	0.28	. = below detection	
K ₂ O	0.99	Heavy fraction (%,	0.89
H ₂ O	0.25	+325)	
L.O.I.	8.55		
	Σ 99.06		
<u>COMMENTS</u>			
Rig released 1973-02-24 Cored from 2232-2311 ft Composite of sample from 2232-2252 ft, comprising good, uniform oil sand with only minor oil-free laminae which increase in number toward the base of the section sampled; minor carbonized plant remains			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-437A Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: Atlantic Sandy Lake 16-5 Location: 16-5-86-21-W4 Mer Depth (m): 339.85-342.90 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	83.64	Montmorillonite	0.0
Silt	14.51	Kaolinite	94.1
Clay	1.85	Illite	5.9
<u>OIL SATURATION (% by wt.)</u>		10.2	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	89.23	Fe	7.4
TiO ₂	0.44	Ti	19.3
Al ₂ O ₃	3.43	Zr	5.8
ΣFe as Fe ₂ O ₃	0.91	Mn	0.21
CaO	0.75	Cr	0.25
MgO	0.38	- = not determined	
Na ₂ O	0.05	. = below detection	
K ₂ O	0.88	Heavy fraction (%,	0.74
H ₂ O	0.22	+325)	
L.O.I.	2.73		
	Σ 99.02		
<u>COMMENTS</u>			
Composite sample taken over 1115-1125 ft, as follows: 1110-1125 ft medium-good oil sand, with some shale at top; composite sample taken at 1115-1125 ft (BH-437A) 1125-1152 ft black, medium-grey and brownish-grey, sometimes calcareous shales, generally rather massive and blocky, fossiliferous, with plant remains near base; 1140-1145 (black shale: BH-437B; sampled for microfossils; see Appendix D) 1152-1182 ft bluish-grey, variably oil-stained, highly slickensided and fractured calcareous shale; fault zone material at ~1182 ft; BH-437C (1152 ft, junction of medium-grey calcareous shale and bluish-grey oil-stained shale); BH-437D (clean, oil-free bluish-grey shale at ~1169 ft; no microfossils reported, see Appendix D)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-431B Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: BA Wabasca 10-25-81-22 Location: 10-25-81-22-W4 Mer Depth (m): 228.30-239.27 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	94.03	Montmorillonite	16.7
Silt	5.05	Kaolinite	46.3
Clay	0.92	Illite	37.0
<u>OIL SATURATION (% by wt.)</u>		12.7	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	81.59	Fe	19.6
TiO ₂	0.33	Ti	6.6
Al ₂ O ₃	7.93	Zr	1.4
ΣFe as Fe ₂ O ₃	1.75	Mn	0.71
CaO	1.01	Cr	0.35
MgO	0.56	- = not determined	
Na ₂ O	1.79	. = below detection	
K ₂ O	1.55	Heavy fraction (%,	0.89
H ₂ O	0.29	+325)	
L.O.I.	2.06		
	Σ 98.86		
<u>COMMENTS</u>			
Rig released 1968-03-02 Composite of 12 samples from 749-785 ft in Core No. 1 (730-987 ft) as follows: Core No. 1 730-744 ft base of Joli Fou shale, medium-dark grey shale, slightly silty toward the base (13 samples, BH-431A); 746 ft top of Grand Rapids Formation; 749-785 ft good oil sand, conglomeratic at base of section sampled			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-431C Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: BA Wabasca 10-25-81-22 Location: 10-25-81-22-W4 Mer Depth (m): 259.08-262.13 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	92.69	Montmorillonite	23.0
Silt	5.93	Kaolinite	32.7
Clay	1.38	Illite	44.3
<u>OIL SATURATION (% by wt.)</u>		12.7	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	74.12	Fe	39.2
TiO ₂	0.37	Ti	3.2
Al ₂ O ₃	11.65	Zr	-
ΣFe as Fe ₂ O ₃	1.68	Mn	-
CaO	1.49	Cr	-
MgO	0.67	(not sufficient sample for	
Na ₂ O	3.19	- = not determined rest of analysis)	
K ₂ O	2.28	. = below detection	
H ₂ O	0.31	Heavy fraction (%,	0.12
L.O.I.	1.90	+325)	
	Σ 97.66		
<u>COMMENTS</u>			
Composite of 7 samples from 850-860 ft in Core No. 1 (730-987 ft) as follows: Core No. 1 850-860 ft good oil sand, sampled from centre of the core; ~878 ft highly carbonaceous sandstone (BH-431D); ~951 ft highly carbonaceous shale (BH-431E)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-431F Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: BA Wabasca 10-25-81-22 Location: 10-25-81-22-W4 Mer Depth (m): 409.96-413.00 Description: Medium oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	93.73	Montmorillonite	3.1
Silt	4.46	Kaolinite	84.5
Clay	1.81	Illite	12.4
<u>OIL SATURATION (% by wt.)</u>		6.9	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	92.87	Fe	16.2
TiO ₂	0.17	Ti	7.3
Al ₂ O ₃	2.51	Zr	*
ΣFe as Fe ₂ O ₃	0.75	Mn	0.30
CaO	0.31	Cr	0.40
MgO	0.21	- = not determined	
Na ₂ O	0.09	. = below detection	
K ₂ O	0.66	Heavy fraction (%,	0.20
H ₂ O	0.28	+325)	
L.O.I.	1.65		
	Σ 99.50		
<u>COMMENTS</u>			
Composite of several samples from 1345-1355 ft in Core No. 2 (1304-1422 ft) as follows: Core No. 2 1345-1355 ft very loose, crumbly oil sand; oil stained for ~10 ft below 1355 ft (the lowest point sampled); 1396-1404 ft carbonaceous shale overlying coal at 1410 ft (composite of 10 samples: BH-431G); 1410 ft coal (sampled: BH-431H). Sample BH-431G, a carbonaceous shale, was subject to detailed major and trace element analysis, and the kerogen extracted and analysed (see Data Sheet 9 in Hitchon, 1993)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-436A Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Texaco Wabasca 6-8-81-25 Location: 6-8-81-25-W4 Mer Depth (m): 224.33 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	96.03	Montmorillonite	13.1
Silt	3.47	Kaolinite	62.6
Clay	0.50	Illite	24.3
<u>OIL SATURATION (% by wt.)</u>		12.9	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	75.77	Fe	-
TiO ₂	0.22	Ti	-
Al ₂ O ₃	11.14	Zr	-
ΣFe as Fe ₂ O ₃	1.64	Mn	-
CaO	1.85	Cr	-
MgO	0.57	(not sufficient sample)	
Na ₂ O	3.00	- = not determined	
K ₂ O	1.99	. = below detection	
H ₂ O	0.39	Heavy fraction (%,	0.03
L.O.I.	1.72	+325)	
	Σ 98.29		
<u>COMMENTS</u>			
Rig released 1967-03-15 Sampled over 6-inch interval at ~736 ft in Core No. 1 (715-744 ft) as follows: Core No. 1 715-738 ft medium-grained friable sandstone, poor to moderate oil sand, occasional thin unsaturated bands; slight bedding and banding in places but no other obvious structures. Papery carbonaceous shale, 2" thick, at ~736'6"; few pebbles at 738 ft. BH-436A 736 ft medium to good oil sand; BH-436B 736'3" glauconitic sandstone; 738-744 ft medium oil sand with abundant pebbles (part of core missing)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-430A Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: 7-8-75-1-W5 Mer Depth (m): 501.09-502.92 Description: Medium oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	82.65	Montmorillonite	0.2
Silt	15.05	Kaolinite	99.1
Clay	2.30	Illite	0.7
<u>OIL SATURATION (% by wt.)</u>		7.6	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	76.62	Fe	16.4
TiO ₂	0.26	Ti	4.8
Al ₂ O ₃	10.50	Zr	*
ΣFe as Fe ₂ O ₃	1.94	Mn	0.42
CaO	0.88	Cr	0.41
MgO	0.64	- = not determined	
Na ₂ O	1.90	. = below detection	
K ₂ O	1.80	Heavy fraction (%,	0.78
H ₂ O	0.24	+325)	
L.O.I.	3.73		
	Σ 98.51		
<u>COMMENTS</u>			
Rig released 1964-02-23 Composite of 9 samples from 1644-1650 ft in Core No. 1 (1630-1691 ft), as follows: 1644-1650 good oil sand without obvious structure; a few 2-3 mm thick pale grey shaly bands; occasional 2 mm pebbles in good oil sand 1652 calcite-cemented nodule (BH-430B)			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-430C Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: 7-8-75-1-W5 Mer Depth (m): 512.98-515.11 Description: Good oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	97.26	Montmorillonite	0.5
Silt	2.37	Kaolinite	96.1
Clay	0.37	Illite	3.4
<u>OIL SATURATION (% by wt.)</u>		11.2	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	95.83	Fe	6.5
TiO ₂	0.49	Ti	19.6
Al ₂ O ₃	1.72	Zr	5.7
ΣFe as Fe ₂ O ₃	0.29	Mn	0.28
CaO	0.28	Cr	0.19
MgO	0.12	- = not determined	
Na ₂ O	0.21	. = below detection	
K ₂ O	0.54	Heavy fraction (%,	0.33
H ₂ O	0.06	+325)	
L.O.I.	0.71		
	Σ 100.25		
<u>COMMENTS</u>			
Composite of 6 samples from 1683-1690 ft in Core No. 1 (1630-1691 ft), as follows: 1683-1690 ft good oil sand (3 samples), plus medium oil sand (3 samples); includes ~10% of pale grey shaly material. Microfossils are reported from a medium grey to medium dark grey shale (BH-430D) at 2170-2190 ft (see details in Appendix D). Microfossils were also reported in a shale from 2193-2195 ft (see Appendix D, sample BH-430E).			

PHYSICAL AND CHEMICAL PROPERTIES OF BITUMEN-FREE OIL SANDS

Sample number: BH-430F Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: 7-8-75-1-W5 Mer Depth (m): 671.47-679.70 Description: Medium/poor oil sand			
<u>TEXTURE (%)</u>		<u>CLAY MINERAL COMPOSITION (%)</u>	
Sand	91.07	Montmorillonite	0.0
Silt	7.55	Kaolinite	96.6
Clay	1.38	Illite	3.4
<u>OIL SATURATION (% by wt.)</u>		5.6	
<u>COMPOSITION OF CLEAN SAND (%)</u>		<u>COMPOSITION OF HEAVY MINERAL FRACTION (%)</u>	
SiO ₂	92.40	Fe	11.3
TiO ₂	0.19	Ti	3.4
Al ₂ O ₃	2.72	Zr	1.0
ΣFe as Fe ₂ O ₃	0.91	Mn	0.08
CaO	0.28	Cr	0.17
MgO	0.18		
Na ₂ O	0.01	- = not determined	
K ₂ O	0.54	. = below detection	
H ₂ O	0.14	Heavy fraction (%,	0.19
L.O.I.	1.93	+325)	
	Σ 99.30		
<u>COMMENTS</u>			
Composite of several samples from 2203-2204 ft and 2225-2230 ft in Core No. 3 (2193-2231 ft) and Core No. 4 (2238-2262 ft), as follows: Core No. 3 2193-2195 dark grey shale (BH-430E); 2203-2204 good oil sand, some less well saturated bands, with a few thin silty zones; Core No. 4 2225-2230 good oil sand, with a few thin silty zones			

APPENDIX B
PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-426A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Union McIvor 6-6-103-12-W4 Location: 6-6-103-12-W4 Mer Depth (m): 48.16-54.56 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	18.2	27.2	30.1	9.9	14.6
C	84.18	86.16	85.62	82.07	78.15	80.25
H	10.44	13.10	10.97	9.57	9.68	8.54
O	1.01	0.01	0.07	2.37	6.82	2.68
N	0.40	0.53	0.04	0.64	0.52	1.12
S	3.97	0.20	3.29	5.34	4.83	7.40
Atomic H/C	1.478	1.812	1.527	1.390	1.476	1.269
Atomic O/C	0.0090	0.0001	0.0006	0.0217	0.0656	0.0251
Atomic N/C	0.0040	0.0053	0.0004	0.0067	0.0057	0.0120
Atomic S/C	0.0177	0.0009	0.0144	0.0244	0.0232	0.0345
Normalized heteroatom composition (Sum ONS = 100)						
O	29.33	1.40	3.96	41.11	69.41	34.98
N	13.14	84.65	2.59	12.73	6.08	16.78
S	57.53	13.95	93.45	46.16	24.51	48.24
Specific gravity (15.56°C, 60°F)	1.003±0.001					
API gravity (15.56°C, 60°F)	9.5±0.2					
Viscosity (cps) (43°C, 110°F)	6313					
(66°C, 150°F)	871					
(86°C, 186°F)	252					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-426B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Union McIvor 6-6-103-12-W4 Location: 6-6-103-12-W4 Mer Depth (m): 71.63-75.90 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	12.1	29.0	29.4	10.1	19.4
C	83.15	85.80	85.54	81.57	78.76	79.91
H	10.51	13.39	10.68	9.63	9.79	8.30
O	1.14	0.00	0.08	2.31	5.95	2.40
N	0.42	0.63	0.04	0.61	0.62	1.15
S	4.78	0.18	3.66	5.87	4.87	8.24
Atomic H/C	1.506	1.860	1.487	1.406	1.481	1.238
Atomic O/C	0.0103	0.0000	0.0007	0.0213	0.0567	0.0226
Atomic N/C	0.0043	0.0063	0.0004	0.0065	0.0068	0.0123
Atomic S/C	0.0215	0.0008	0.0160	0.0270	0.0232	0.0386
Normalized heteroatom composition (Sum ONS = 100)						
O	28.47	0.00	4.15	38.91	65.44	30.70
N	11.98	88.90	2.37	11.79	7.84	16.73
S	59.56	11.10	93.48	49.30	26.73	52.57
Specific gravity (15.56°C, 60°F)	1.021±0.005					
API gravity (15.56°C, 60°F)	7.1±0.8					
Viscosity (cps) (43°C, 110°F)	-					
(66°C, 150°F)	3081					
(86°C, 186°F)	716					

- = not determined

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-435A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 270.66-283.46 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	19.5	20.0	32.5	12.7	15.3
C	83.05	86.78	85.67	81.07	79.31	80.52
H	10.30	12.86	10.19	9.74	10.51	8.10
O	1.22	0.06	0.11	2.96	5.31	2.27
N	0.39	0.00	0.07	0.46	0.52	0.95
S	5.04	0.30	3.96	5.78	4.36	8.17
Atomic H/C	1.477	1.764	1.416	1.430	1.578	1.197
Atomic O/C	0.0110	0.0005	0.0010	0.0273	0.0502	0.0211
Atomic N/C	0.0040	0.0000	0.0007	0.0048	0.0056	0.0102
Atomic S/C	0.0227	0.0013	0.0173	0.0267	0.0206	0.0380
Normalized heteroatom composition (Sum ONS = 100)						
O	29.22	28.61	5.13	46.46	65.73	30.51
N	10.67	0.00	3.73	8.19	7.32	14.66
S	60.11	71.39	91.15	45.35	26.95	54.83
Specific gravity (15.56°C, 60°F)	1.005±0.006					
API gravity (15.56°C, 60°F)	9.3±0.8					
Viscosity (cps) (43°C, 110°F)	19542					
(66°C, 150°F)	2322					
(86°C, 186°F)	774					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-435B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 283.46-295.66 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	18.4	22.4	30.1	12.0	17.1
C	83.11	86.68	84.93	81.01	79.37	80.52
H	10.55	12.99	10.71	9.89	10.36	8.43
O	0.86	0.09	0.08	2.56	5.40	2.18
N	0.39	0.00	0.00	0.46	0.54	1.04
S	5.09	0.24	4.28	6.08	4.33	7.82
Atomic H/C	1.511	1.784	1.501	1.454	1.554	1.246
Atomic O/C	0.0077	0.0008	0.0007	0.0237	0.0511	0.0203
Atomic N/C	0.0040	0.0000	0.0000	0.0049	0.0058	0.0111
Atomic S/C	0.0229	0.0010	0.0180	0.0281	0.0204	0.0364
Normalized heteroatom composition (Sum ONS = 100)						
O	22.25	42.91	3.61	41.82	66.08	30.01
N	11.66	0.00	0.00	8.65	7.53	16.34
S	66.09	57.09	96.39	49.53	26.39	53.65
Specific gravity (15.56°C, 60°F)	1.023±0.003					
API gravity (15.56°C, 60°F)	6.8±0.4					
Viscosity (cps) (43°C, 110°F)	32409					
(66°C, 150°F)	3173					
(86°C, 186°F)	760					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-435C Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 295.66-307.85 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	17.6	21.1	32.5	12.3	16.50
C	82.92	86.49	85.38	81.66	78.96	80.58
H	10.55	13.13	10.07	9.09	10.66	8.09
O	1.22	0.09	0.13	2.88	5.86	2.33
N	0.37	0.00	0.00	0.42	0.47	0.86
S	4.94	0.29	4.42	5.95	4.05	8.15
Atomic H/C	1.514	1.807	1.404	1.326	1.608	1.195
Atomic O/C	0.0110	0.0008	0.0012	0.0264	0.0556	0.0217
Atomic N/C	0.0038	0.0000	0.0000	0.0044	0.0051	0.0091
Atomic S/C	0.0223	0.0013	0.0194	0.0273	0.0192	0.0378
Normalized heteroatom composition (Sum ONS = 100)						
O	29.73	38.35	5.60	45.44	69.61	31.62
N	10.22	0.00	0.00	7.62	6.37	13.25
S	60.06	61.65	94.40	46.93	24.02	55.12
Specific gravity (15.56°C, 60°F)	1.020±0.002					
API gravity (15.56°C, 60°F)	7.2±0.2					
Viscosity (cps) (43°C, 110°F)	16967					
(66°C, 150°F)	2474					
(86°C, 186°F)	629					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-435D Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 307.85-320.04 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	21.9	19.8	31.5	10.3	16.5
C	83.31	86.30	85.38	80.96	78.95	80.11
H	10.56	13.28	10.21	9.57	10.40	8.26
O	1.19	0.16	0.19	2.80	5.60	2.37
N	0.58	0.03	0.10	0.63	0.62	1.13
S	4.37	0.23	4.12	6.05	4.42	8.13
Atomic H/C	1.509	1.833	1.425	1.407	1.569	1.228
Atomic O/C	0.0107	0.0014	0.0017	0.0259	0.0532	0.0222
Atomic N/C	0.0060	0.0003	0.0010	0.0067	0.0067	0.0120
Atomic S/C	0.0196	0.0010	0.0181	0.0280	0.0210	0.0380
Normalized heteroatom composition (Sum ONS = 100)						
O	29.51	51.78	8.05	42.82	65.78	30.75
N	16.43	11.09	4.84	11.01	8.32	16.66
S	54.07	37.14	87.11	46.17	25.90	52.59
Specific gravity (15.56°C, 60°F)				1.018±0.004		
API gravity (15.56°C, 60°F)				7.5±0.5		
Viscosity (cps) (43°C, 110°F)				16229		
(66°C, 150°F)				1809		
(86°C, 186°F)				489		

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-435E Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Eils OV 6-25-95-16-W4 Location: 6-25-95-16-W4 Mer Depth (m): 320.04-326.14 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	22.0	19.4	30.4	11.7	16.5
C	83.36	86.20	85.44	80.96	79.22	80.35
H	10.48	13.50	10.23	9.78	10.25	8.23
O	0.96	0.05	0.11	2.37	5.43	2.14
N	0.49	0.07	0.11	0.66	0.65	1.00
S	4.71	0.18	4.11	6.23	4.44	8.28
Atomic H/C	1.497	1.865	1.426	1.439	1.541	1.219
Atomic O/C	0.0086	0.0004	0.0010	0.0220	0.0514	0.0200
Atomic N/C	0.0051	0.0007	0.0011	0.0070	0.0070	0.0107
Atomic S/C	0.0211	0.0008	0.0180	0.0288	0.0210	0.0386
Normalized heteroatom composition (Sum ONS = 100)						
O	24.74	22.75	4.81	38.04	64.74	28.87
N	14.58	36.38	5.50	12.07	8.85	15.41
S	60.68	40.87	89.69	49.89	26.41	55.73
Specific gravity (15.56°C, 60°F)	1.018±0.001					
API gravity (15.56°C, 60°F)	7.5±0.1					
Viscosity (cps) (43°C, 110°F)	16930					
(66°C, 150°F)	1809					
(86°C, 186°F)	496					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-425A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Atlantic Richfield R.O.C. Buffalo Lake 11-22-90-18W4 Location: 11-22-90-18-W4 Mer Depth (m): 195.07-200.86 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	19.6	19.5	29.7	12.7	18.5
C	83.58	85.84	85.75	79.78	79.43	79.67
H	10.37	13.19	10.37	9.76	9.97	8.25
O	1.27	0.03	0.13	4.61	5.65	2.88
N	0.41	0.57	0.04	0.59	0.57	1.06
S	4.37	0.38	3.72	5.26	4.38	8.14
Atomic H/C	1.478	1.831	1.441	1.457	1.495	1.234
Atomic O/C	0.0114	0.0003	0.0011	0.0433	0.0534	0.0271
Atomic N/C	0.0042	0.0057	0.0004	0.0064	0.0062	0.0114
Atomic S/C	0.0196	0.0016	0.0162	0.0247	0.0207	0.0383
Normalized heteroatom composition (Sum ONS = 100)						
O	32.41	3.40	6.38	58.24	66.53	35.29
N	11.95	75.10	2.24	8.58	7.72	14.85
S	55.64	21.50	91.37	33.18	25.75	49.86
Specific gravity (15.56°C, 60°F)	1.018±0.001					
API gravity (15.56°C, 60°F)	7.5±0.1					
Viscosity (cps) (43°C, 110°F)	59594					
(66°C, 150°F)	5563					
(86°C, 186°F)	1197					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-438A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell House Creek EV 10-23-80-13 Location: 10-23-80-13-W4 Mer Depth (m): 468.78-471.22 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	19.6	22.2	34.1	6.8	17.3
C	83.56	86.15	85.49	81.36	79.92	80.05
H	10.41	13.47	10.17	9.68	10.25	8.75
O	0.98	0.03	0.09	2.58	4.77	1.85
N	0.40	0.05	0.03	0.64	0.57	1.01
S	4.66	0.30	4.21	5.75	4.50	8.34
Atomic H/C	1.483	1.862	1.417	1.416	1.526	1.0302
Atomic O/C	0.0088	0.0003	0.0008	0.0237	0.0447	0.0173
Atomic N/C	0.0041	0.0005	0.0003	0.0067	0.0062	0.0108
Atomic S/C	0.0209	0.0013	0.0185	0.0264	0.0211	0.0390
Normalized heteroatom composition (Sum ONS = 100)						
O	25.96	12.67	4.04	41.74	62.19	25.79
N	12.23	24.12	1.54	11.78	8.55	16.12
S	61.82	63.21	94.43	46.48	29.26	58.09
Specific gravity (15.56°C, 60°F)				1.010±0.004		
API gravity (15.56°C, 60°F)				8.6±0.6		
Viscosity (cps) (43°C, 110°F)				17462		
(66°C, 150°F)				1954		
(86°C, 186°F)				593		

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-438B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell House Creek EV 10-23-80-13 Location: 10-23-80-13-W4 Mer Depth (m): 480.21-485.62 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	19.7	19.4	35.6	7.4	17.9
C	83.51	86.35	85.81	80.41	79.90	80.27
H	10.45	13.48	10.15	9.76	9.93	8.16
O	0.89	0.02	0.09	2.73	4.97	2.11
N	0.49	0.00	0.01	0.58	0.72	1.12
S	4.66	0.15	3.94	6.53	4.48	8.33
Atomic H/C	1.490	1.858	1.408	1.445	1.479	1.211
Atomic O/C	0.0080	0.0002	0.0008	0.0255	0.0467	0.0198
Atomic N/C	0.0050	0.0000	0.0001	0.0061	0.0077	0.0120
Atomic S/C	0.0209	0.0007	0.0172	0.0304	0.0210	0.0388
Normalized heteroatom composition (Sum ONS = 100)						
O	23.60	21.09	4.36	41.10	61.93	28.00
N	14.71	0.00	0.55	9.90	10.23	16.99
S	61.69	78.91	95.08	49.00	27.84	55.01
Specific gravity (15.56°C, 60°F)						
API gravity (15.56°C, 60°F)	1.013±0.001					
Viscosity (cps) (43°C, 110°F)	8.2±0.1					
(66°C, 150°F)	14754					
(86°C, 186°F)	1785					
	465					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-433B Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 458.27-469.39 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	24.9	23.7	28.1	8.4	14.9
C	83.93	85.73	85.36	81.25	80.58	81.26
H	10.72	13.71	10.26	10.10	10.04	8.28
O	0.88	0.12	0.11	2.67	4.90	2.01
N	0.31	0.04	0.02	0.46	0.61	0.92
S	4.16	0.39	4.24	5.52	3.86	7.53
Atomic H/C	1.522	1.906	1.433	1.482	1.485	1.214
Atomic O/C	0.0079	0.0011	0.0010	0.0247	0.0456	0.0186
Atomic N/C	0.0032	0.0004	0.0002	0.0049	0.0065	0.0097
Atomic S/C	0.0186	0.0017	0.0186	0.0255	0.0180	0.0347
Normalized heteroatom composition (Sum ONS = 100)						
O	26.59	33.31	4.92	44.88	65.09	29.46
N	10.70	12.68	1.02	8.83	9.29	15.42
S	62.71	54.01	94.05	46.29	25.62	55.12
Specific gravity (15.56°C, 60°F)	1.002±0.007					
API gravity (15.56°C, 60°F)	9.7±1.0					
Viscosity (cps) (43°C, 110°F)	7703					
(66°C, 150°F)	1038					
(86°C, 186°F)	302					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-433D Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 469.39-481.58 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	23.6	24.4	26.2	9.0	16.8
C	84.17	86.08	85.44	81.63	80.70	80.81
H	10.48	13.46	10.42	9.71	10.07	8.65
O	0.97	0.11	0.16	2.53	4.17	2.11
N	0.40	0.03	0.01	0.50	0.52	1.04
S	3.99	0.32	3.97	5.61	4.53	7.39
Atomic H/C	1.484	1.863	1.453	1.418	1.488	1.275
Atomic O/C	0.0086	0.0010	0.0014	0.0233	0.0388	0.0196
Atomic N/C	0.0041	0.0003	0.0001	0.0053	0.0056	0.0111
Atomic S/C	0.0178	0.0014	0.0174	0.0258	0.0210	0.0343
Normalized heteroatom composition (Sum ONS = 100)						
O	28.34	36.19	7.52	42.87	59.30	30.17
N	13.35	11.27	0.54	9.75	8.53	17.07
S	58.31	52.53	91.94	47.38	32.17	52.76
Specific gravity (15.56°C, 60°F)	1.001±0.001					
API gravity (15.56°C, 60°F)	9.8±0.1					
Viscosity (cps) (43°C, 110°F)	6821					
(66°C, 150°F)	996					
(86°C, 186°F)	290					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-433F Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 481.58-493.78 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	21.8	20.6	30.1	9.1	18.4
C	83.79	86.35	85.77	82.45	79.22	80.94
H	10.52	13.37	10.45	9.73	10.19	8.49
O	0.86	0.03	0.05	2.35	6.24	1.99
N	0.28	0.00	0.06	0.42	0.48	1.11
S	4.54	0.24	3.66	5.05	3.86	7.47
Atomic H/C	1.496	1.846	1.452	1.406	1.533	1.251
Atomic O/C	0.0077	0.0003	0.0004	0.0214	0.0592	0.0185
Atomic N/C	0.0029	0.0000	0.0006	0.0043	0.0052	0.0117
Atomic S/C	0.0203	0.0010	0.0160	0.0230	0.0183	0.0346
Normalized heteroatom composition (Sum ONS = 100)						
O	25.03	20.03	2.59	43.99	71.61	28.55
N	9.31	0.00	3.55	8.89	6.30	18.10
S	65.65	79.97	93.86	47.11	22.08	53.35
Specific gravity (15.56°C, 60°F)	1.006±0.002					
API gravity (15.56°C, 60°F)	9.2±0.3					
Viscosity (cps) (43°C, 110°F)	17450					
(66°C, 150°F)	1945					
(86°C, 186°F)	501					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-433G Oil sand deposit: Cold Lake Stratigraphic unit: Clearwater Formation Well name: Imp 73-5 Leming OV 13-33-64-3 Location: 13-33-64-3-W4 Mer Depth (m): 493.78-503.38 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	22.2	19.9	30.0	9.6	18.3
C	83.48	86.37	85.43	81.13	78.66	80.42
H	10.67	13.22	10.51	9.98	10.13	8.49
O	1.02	0.06	0.11	2.85	6.70	2.24
N	0.45	0.00	0.00	0.51	0.66	0.90
S	4.38	0.35	3.95	5.53	3.85	7.95
Atomic H/C	1.521	1.823	1.465	1.465	1.534	1.258
Atomic O/C	0.0092	0.0005	0.0010	0.0263	0.0639	0.0209
Atomic N/C	0.0046	0.0000	0.0000	0.0053	0.0072	0.0095
Atomic S/C	0.0196	0.0015	0.0173	0.0255	0.0183	0.0370
Normalized heteroatom composition (Sum ONS = 100)						
O	27.54	25.57	5.29	46.02	71.43	30.98
N	13.75	0.00	0.00	9.34	8.10	14.15
S	58.71	74.43	94.71	44.64	20.47	54.87
Specific gravity (15.56°C, 60°F)				1.006		
API gravity (15.56°C, 60°F)				9.2		
Viscosity (cps) (43°C, 110°F)				14923		
(66°C, 150°F)				1821		
(86°C, 186°F)				496		

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-434B Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 482.19-484.63 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	25.4	20.6	25.6	10.6	17.8
C	83.50	86.24	85.92	81.24	78.76	80.63
H	10.76	13.48	10.60	10.10	10.34	8.37
O	1.42	0.09	0.13	3.29	5.79	2.84
N	0.34	0.00	0.00	0.45	0.44	1.06
S	3.98	0.19	3.36	4.91	4.67	7.10
Atomic H/C	1.535	1.861	1.469	1.481	1.563	1.236
Atomic O/C	0.0128	0.0008	0.0011	0.0304	0.0552	0.0264
Atomic N/C	0.0035	0.0000	0.0000	0.0047	0.0048	0.0113
Atomic S/C	0.0179	0.0008	0.0146	0.0226	0.0222	0.0330
Normalized heteroatom composition (Sum ONS = 100)						
O	37.44	48.70	7.20	52.64	67.15	37.36
N	10.17	0.00	0.00	8.20	5.86	15.97
S	52.39	51.30	92.80	39.16	26.99	46.67
Specific gravity (15.56°C, 60°F)	1.013±0.001					
API gravity (15.56°C, 60°F)	8.2±0.1					
Viscosity (cps) (43°C, 110°F)	9820					
(66°C, 150°F)	1226					
(86°C, 186°F)	814					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-434C Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Lloydminster Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 512.52-516.33 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	24.5	17.6	30.6	7.6	19.7
C	83.28	85.92	85.72	81.20	78.99	80.48
H	10.68	13.67	10.27	9.88	10.25	8.65
O	1.20	0.11	0.12	3.40	5.52	2.57
N	0.48	0.00	0.00	0.48	0.53	0.66
S	4.37	0.30	3.89	5.03	4.70	7.64
Atomic H/C	1.527	1.895	1.427	1.449	1.545	1.280
Atomic O/C	0.0108	0.0010	0.0010	0.0314	0.0524	0.0240
Atomic N/C	0.0049	0.0000	0.0000	0.0051	0.0058	0.0070
Atomic S/C	0.0196	0.0013	0.0170	0.0232	0.0223	0.0355
Normalized heteroatom composition (Sum ONS = 100)						
O	30.51	42.36	5.82	52.62	65.14	36.04
N	13.94	0.00	0.00	8.54	7.18	10.58
S	55.56	57.64	94.18	38.84	27.68	53.38
Specific gravity (15.56°C, 60°F)	1.017±0.001					
API gravity (15.56°C, 60°F)	7.6±0.1					
Viscosity (cps) (43°C, 110°F)	41793					
(66°C, 150°F)	3948					
(86°C, 186°F)	931					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-434D Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Lloydminster Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 521.21-527.30 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	24.2	19.7	29.5	7.0	19.6
C	83.15	86.10	85.69	81.31	79.29	80.61
H	10.74	13.56	10.63	10.37	10.54	8.46
O	1.26	0.01	0.03	2.44	5.37	2.23
N	0.51	0.00	0.01	0.33	0.42	0.93
S	4.35	0.33	3.64	5.55	4.38	7.78
Atomic H/C	1.538	1.875	1.476	1.519	1.582	1.249
Atomic O/C	0.0113	0.0001	0.0003	0.0225	0.0508	0.0207
Atomic N/C	0.0052	0.0000	0.0001	0.0035	0.0045	0.0099
Atomic S/C	0.0196	0.0014	0.0159	0.0255	0.0207	0.0361
Normalized heteroatom composition (Sum ONS = 100)						
O	31.36	5.73	1.61	43.66	66.87	31.07
N	14.50	0.00	0.61	6.72	5.94	14.77
S	54.14	94.27	97.78	49.62	27.19	54.15
Specific gravity (15.56°C, 60°F)	1.009±0.001					
API gravity (15.56°C, 60°F)	8.7±0.1					
Viscosity (cps) (43°C, 110°F)	41140					
(66°C, 150°F)	3434					
(86°C, 186°F)	803					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-434E Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Lloydminster Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: 10-10-59-2-W4 Mer Depth (m): 530.35-533.40 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	21.6	17.1	30.7	8.7	21.9
C	82.91	86.55	86.09	81.25	79.05	80.87
H	10.61	13.22	10.07	10.32	10.19	8.09
O	1.53	0.07	0.07	2.91	5.74	2.43
N	0.36	0.00	0.03	0.44	0.55	0.84
S	4.60	0.16	3.74	5.07	4.48	7.76
Atomic H/C	1.523	1.818	1.393	1.512	1.535	1.191
Atomic O/C	0.0139	0.0006	0.0006	0.0269	0.0545	0.0225
Atomic N/C	0.0037	0.0000	0.0003	0.0047	0.0059	0.0089
Atomic S/C	0.0208	0.0007	0.0163	0.0234	0.0212	0.0359
Normalized heteroatom composition (Sum ONS = 100)						
O	36.18	46.72	3.57	48.97	66.75	33.43
N	9.66	0.00	1.75	8.49	7.24	13.21
S	54.16	53.28	94.68	42.55	26.00	53.35
Specific gravity (15.56°C, 60°F)	1.019±0.001					
API gravity (15.56°C, 60°F)	7.4±0.1					
Viscosity (cps) (43°C, 110°F)	45712					
(66°C, 150°F)	4178					
(86°C, 186°F)	977					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-439C Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Michel Lake No. 10-25 Location: 10-25-58-5-W4 Mer Depth (m): 489.66-492.71 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	25.2	18.0	31.7	6.2	19.9
C	84.08	86.29	86.02	81.38	79.61	80.54
H	10.25	13.07	10.13	10.48	9.55	7.92
O	1.19	0.02	0.16	2.39	4.82	2.57
N	0.42	0.01	0.04	0.51	0.66	1.16
S	4.05	0.61	3.65	5.24	5.36	7.82
Atomic H/C	1.451	1.803	1.402	1.533	1.429	1.170
Atomic O/C	0.0107	0.0002	0.0014	0.0221	0.0454	0.0239
Atomic N/C	0.0043	0.0001	0.0004	0.0054	0.0071	0.0123
Atomic S/C	0.0181	0.0027	0.0159	0.0241	0.0252	0.0364
Normalized heteroatom composition (Sum ONS = 100)						
O	32.29	5.96	7.89	42.80	58.48	32.95
N	13.02	3.40	2.25	10.39	9.10	16.94
S	54.69	90.64	89.85	46.81	32.42	50.11
Specific gravity (15.56°C, 60°F)	1.002±0.001					
API gravity (15.56°C, 60°F)	9.7±0.1					
Viscosity (cps) (43°C, 110°F)	13339					
(66°C, 150°F)	1601					
(86°C, 186°F)	411					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-439D Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Michel Lake 10-25 Location: 10-25-58-5-W4 Mer Depth (m): 494.23-499.87 Description: Medium oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	25.1	18.1	32.9	5.6	18.3
C	83.64	86.28	86.08	82.48	79.03	80.26
H	10.57	13.27	10.28	9.15	10.18	8.75
O	1.47	0.06	0.15	2.80	5.44	2.66
N	0.41	0.02	0.02	0.53	0.53	1.14
S	3.92	0.37	3.48	5.04	4.82	7.19
Atomic H/C	1.504	1.832	1.422	1.321	1.534	1.298
Atomic O/C	0.0132	0.0005	0.0013	0.0255	0.0516	0.0248
Atomic N/C	0.0042	0.0002	0.0002	0.0055	0.0058	0.0122
Atomic S/C	0.0175	0.0016	0.0151	0.0229	0.0228	0.0335
Normalized heteroatom composition (Sum ONS = 100)						
O	37.76	22.43	7.90	47.30	64.36	35.21
N	11.95	8.54	1.20	10.23	7.19	17.26
S	50.29	69.02	90.90	42.48	28.45	47.53
Specific gravity (15.56°C, 60°F)	1.008±0.001					
API gravity (15.56°C, 60°F)	8.9±0.2					
Viscosity (cps) (43°C, 110°F)	14367					
(66°C, 150°F)	1577					
(86°C, 186°F)	423					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-439E Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation; Lloydminster Sandstone Well name: Pan Am A1 Michel Lake No. 10-25 Location: 10-25-58-5-W4 Mer Depth (m): 502.77-524.86 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	22.1	17.2	30.5	6.2	24.0
C	83.41	86.22	86.10	81.63	79.34	80.83
H	10.41	13.24	10.43	10.18	10.09	7.91
O	1.30	0.13	0.15	2.52	4.98	2.46
N	0.47	0.00	0.04	0.59	0.65	1.18
S	4.41	0.41	3.28	5.08	4.94	7.61
Atomic H/C	1.486	1.829	1.442	1.486	1.514	1.165
Atomic O/C	0.0117	0.0011	0.0013	0.0232	0.0471	0.0228
Atomic N/C	0.0048	0.0000	0.0004	0.0062	0.0070	0.0125
Atomic S/C	0.0198	0.0018	0.0143	0.0233	0.0233	0.0352
Normalized heteroatom composition (Sum ONS = 100)						
O	32.12	38.86	8.19	44.07	60.85	32.35
N	13.27	0.00	2.49	11.69	9.04	17.72
S	54.61	61.14	89.32	44.24	30.12	49.93
Specific gravity (15.56°C, 60°F)	1.018±0.003					
API gravity (15.56°C, 60°F)	7.5±0.4					
Viscosity (cps) (43°C, 110°F)	70816					
(66°C, 150°F)	5817					
(86°C, 186°F)	1212					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-427D Oil sand deposit: Loon River Stratigraphic unit: Wabiskaw Member Well name: Union Red Earth 10-14-88-9 Location: 10-14-88-9-W5 Mer Depth (m): 379.48-383.44 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	16.4	21.2	32.2	11.5	18.7
C	83.13	85.87	85.21	80.83	79.44	80.23
H	10.18	13.45	10.89	10.08	10.19	8.18
O	1.12	0.00	0.12	2.50	4.76	2.38
N	0.38	0.53	0.04	0.49	0.53	1.04
S	5.19	0.15	3.74	6.10	5.07	8.16
Atomic H/C	1.459	1.866	1.522	1.486	1.529	1.215
Atomic O/C	0.0101	0.0000	0.0011	0.0232	0.0450	0.0223
Atomic N/C	0.0039	0.0053	0.0004	0.0052	0.0058	0.0111
Atomic S/C	0.0234	0.0007	0.0165	0.0283	0.0239	0.0381
Normalized heteroatom composition (Sum ONS = 100)						
O	26.92	0.00	5.88	40.93	60.29	31.19
N	10.53	89.00	2.24	9.24	7.72	15.53
S	62.56	11.00	91.89	49.83	31.99	53.28
Specific gravity (15.56°C, 60°F)	1.041±0.003					
API gravity (15.56°C, 60°F)	4.4±0.4					
Viscosity (cps) (43°C, 110°F)	86392					
(66°C, 150°F)	8441					
(86°C, 186°F)	1688					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-429B Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte OV 1-27 Location: 1-27-86-19-W5 Mer Depth (m): 512.98-516.33 Description: Medium oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	12.2	16.7	37.8	11.5	21.8
C	81.94	86.18	84.39	80.75	78.98	79.93
H	10.26	13.39	10.70	9.17	10.06	8.25
O	1.04	0.10	0.07	2.41	5.08	2.36
N	0.41	0.00	0.04	0.41	0.39	0.98
S	6.35	0.33	4.79	7.26	5.49	8.48
Atomic H/C	1.492	1.851	1.512	1.354	1.518	1.230
Atomic O/C	0.0095	0.0009	0.0006	0.0224	0.0483	0.0222
Atomic N/C	0.0043	0.0000	0.0004	0.0044	0.0043	0.0105
Atomic S/C	0.0290	0.0014	0.0213	0.0337	0.0260	0.0397
Normalized heteroatom composition (Sum ONS = 100)						
O	22.28	37.78	2.81	37.06	61.42	30.63
N	9.94	0.00	1.83	7.23	5.44	14.49
S	67.78	62.22	95.36	55.71	33.14	54.87
Specific gravity (15.56°C, 60°F)	1.038±0.006					
API gravity (15.56°C, 60°F)	4.8±0.8					
Viscosity (cps) (43°C, 110°F)	23944					
(66°C, 150°F)	2895					
(86°C, 186°F)	876					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-429D Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte OV 1-27 Location: 1-27-86-19-W5 Mer Depth (m): 516.33-518.62 Description: Medium oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	12.7	22.8	33.5	12.1	18.9
C	81.43	86.38	83.97	81.54	79.27	79.86
H	10.52	13.27	10.19	9.34	10.01	8.33
O	1.12	0.04	0.07	2.65	5.05	2.22
N	0.41	0.00	0.05	0.43	0.44	1.03
S	6.51	0.30	5.72	6.04	5.24	8.56
Atomic H/C	1.540	1.831	1.447	1.365	1.505	1.242
Atomic O/C	0.0104	0.0003	0.0006	0.0244	0.0478	0.0209
Atomic N/C	0.0043	0.0000	0.0005	0.0045	0.0047	0.0110
Atomic S/C	0.0300	0.0013	0.0255	0.0277	0.0248	0.0402
Normalized heteroatom composition (Sum ONS = 100)						
O	23.22	21.09	2.37	43.09	61.87	28.96
N	9.62	0.00	1.93	7.95	6.11	15.31
S	67.16	78.91	95.70	48.96	32.02	55.73
Specific gravity (15.56°C, 60°F)	1.040±0.004					
API gravity (15.56°C, 60°F)	4.6±0.5					
Viscosity (cps) (43°C, 110°F)	29386					
(66°C, 150°F)	4849					
(86°C, 186°F)	1028					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-428A Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte 1-9-83-17 Location: 1-9-83-17-W5 Mer Depth (m): 680.31-686.41 Description: Medium oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	19.6	15.9	34.4	11.0	19.1
C	81.76	86.08	83.01	79.37	77.86	79.52
H	10.06	13.28	10.56	9.79	10.10	8.39
O	1.22	0.04	0.09	2.55	4.50	2.23
N	0.37	0.00	0.05	0.33	0.39	1.03
S	6.58	0.60	6.29	7.96	7.15	8.83
Atomic H/C	1.467	1.838	1.516	1.470	1.546	1.257
Atomic O/C	0.0112	0.0003	0.0008	0.0241	0.0434	0.0210
Atomic N/C	0.0039	0.0000	0.0005	0.0036	0.0043	0.0111
Atomic S/C	0.0301	0.0026	0.0284	0.0376	0.0344	0.0416
Normalized heteroatom composition (Sum ONS = 100)						
O	24.79	11.79	2.72	37.00	52.88	28.54
N	8.59	0.00	1.73	5.45	5.21	15.02
S	66.62	88.21	95.56	57.55	41.91	56.44
Specific gravity (15.56°C, 60°F)				1.014±0.006		
API gravity (15.56°C, 60°F)				8.0±0.8		
Viscosity (cps) (43°C, 110°F)				7848		
(66°C, 150°F)				929		
(86°C, 186°F)				295		

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-437A Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: Atlantic Sandy Lake 16-5 Location: 16-5-86-21-W4 Mer Depth (m): 339.85-342.90 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	25.9	15.7	34.5	6.3	17.6
C	83.24	85.98	85.24	80.77	80.19	79.64
H	10.75	13.62	10.34	9.93	10.41	8.77
O	1.34	0.02	0.07	3.11	4.85	2.57
N	0.48	0.07	0.04	0.57	0.40	1.00
S	4.19	0.31	4.30	5.62	4.14	8.02
Atomic H/C	1.537	1.886	1.445	1.463	1.546	1.311
Atomic O/C	0.0121	0.0002	0.0006	0.0289	0.0454	0.0242
Atomic N/C	0.0049	0.0007	0.0004	0.0061	0.0043	0.0107
Atomic S/C	0.0188	0.0013	0.0189	0.0260	0.0193	0.0377
Normalized heteroatom composition (Sum ONS = 100)						
O	33.69	7.85	3.08	47.41	65.74	33.35
N	13.70	31.40	2.01	9.92	6.26	14.76
S	52.60	60.74	94.91	42.67	28.00	51.89
Specific gravity (15.56°C, 60°F)	1.022±0.003					
API gravity (15.56°C, 60°F)	7.0±0.5					
Viscosity (cps) (43°C, 110°F)	51467					
(66°C, 150°F)	4366					
(86°C, 186°F)	936					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-431B Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: BA Wabasca 10-25-81-22 Location: 10-25-81-22-W4 Mer Depth (m): 228.30-239.27 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	18.4	19.3	32.6	12.4	17.3
C	83.68	86.35	85.61	81.75	79.72	80.00
H	10.13	13.43	10.39	9.81	10.26	8.70
O	1.16	0.07	0.06	2.49	5.28	2.29
N	0.35	0.00	0.05	0.50	0.60	1.13
S	4.68	0.16	3.89	5.45	4.14	7.88
Atomic H/C	1.442	1.853	1.446	1.429	1.534	1.296
Atomic O/C	0.0104	0.0006	0.0005	0.0229	0.0497	0.0215
Atomic N/C	0.0036	0.0000	0.0005	0.0053	0.0064	0.0121
Atomic S/C	0.0209	0.0007	0.0170	0.0250	0.0195	0.0369
Normalized heteroatom composition (Sum ONS = 100)						
O	29.79	46.72	2.94	43.09	65.75	30.46
N	10.38	0.00	2.80	9.92	8.52	17.17
S	59.83	53.28	94.27	46.99	25.74	52.37
Specific gravity (15.56°C, 60°F)				1.023±0.002		
API gravity (15.56°C, 60°F)				6.8±0.3		
Viscosity (cps) (43°C, 110°F)				37488		
(66°C, 150°F)				4650		
(86°C, 186°F)				1081		

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-431C Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: BA Wabasca 10-25-81-22 Location: 10-25-81-22-W4 Mer Depth (m): 259.08-262.13 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	14.3	19.3	33.2	14.7	18.5
C	82.89	86.21	85.24	80.10	78.91	80.01
H	9.97	13.40	10.47	10.19	9.94	8.63
O	1.37	0.11	0.09	2.80	5.34	2.04
N	0.39	0.00	0.06	0.47	0.62	1.10
S	5.39	0.28	4.14	6.44	5.18	8.23
Atomic H/C	1.433	1.853	1.464	1.516	1.502	1.285
Atomic O/C	0.0124	0.0010	0.0008	0.0263	0.0508	0.0191
Atomic N/C	0.0040	0.0000	0.0006	0.0050	0.0068	0.0118
Atomic S/C	0.0244	0.0012	0.0182	0.0301	0.0246	0.0385
Normalized heteroatom composition (Sum ONS = 100)						
O	30.38	44.05	4.08	42.82	61.85	27.54
N	9.88	0.00	3.11	8.12	8.22	16.96
S	59.75	55.95	92.81	49.06	29.93	55.50
Specific gravity (15.56°C, 60°F)	1.029±0.002					
API gravity (15.56°C, 60°F)	6.0±0.3					
Viscosity (cps) (43°C, 110°F)	131450					
(66°C, 150°F)	10763					
(86°C, 186°F)	2467					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-431F Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: BA Wabasca 10-25-81-22 Location: 10-25-81-22-W4 Mer Depth (m): 409.96-413.00 Description: Medium oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	27.5	22.2	30.8	8.0	11.5
C	83.04	86.00	84.76	80.34	79.05	79.51
H	10.92	13.30	10.11	10.04	10.10	8.88
O	1.05	0.02	0.14	2.85	5.08	2.75
N	0.32	0.00	0.06	0.55	0.55	0.98
S	4.68	0.67	4.92	6.22	5.21	7.89
Atomic H/C	1.566	1.843	1.422	1.489	1.523	1.330
Atomic O/C	0.0095	0.0002	0.0013	0.0267	0.0483	0.0259
Atomic N/C	0.0033	0.0000	0.0006	0.0059	0.0060	0.0106
Atomic S/C	0.0211	0.0029	0.0218	0.0290	0.0247	0.0372
Normalized heteroatom composition (Sum ONS = 100)						
O	27.96	5.64	5.32	43.33	61.11	35.21
N	9.73	0.00	2.60	9.56	7.62	14.33
S	62.31	94.36	92.08	47.12	31.28	50.46
Specific gravity (15.56°C, 60°F)	0.983±0.002					
API gravity (15.56°C, 60°F)	12.4±0.3					
Viscosity (cps) (43°C, 110°F)	-					
(66°C, 150°F)	-					
(86°C, 186°F)	-					

- = not determined

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

<p>Sample number: BH-436A Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Texaco Wabasca 6-8-81-25 Location: 6-8-81-25-W4 Mer Depth (m): 224.33 Description: Good oil sand</p>						
<p>Normalized elemental composition (Sum CHONS = 100)</p>						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	13.4	19.7	33.2	13.1	20.6
C	82.82	86.50	85.18	80.67	79.12	79.61
H	10.21	13.03	10.21	9.51	10.34	8.76
O	1.34	0.04	0.13	2.72	5.29	2.40
N	0.48	0.06	0.04	0.63	0.49	0.90
S	5.15	0.37	4.43	6.46	4.76	8.32
Atomic H/C	1.469	1.794	1.428	1.404	1.556	1.311
Atomic O/C	0.0121	0.0003	0.0014	0.0253	0.0501	0.0226
Atomic N/C	0.0050	0.0006	0.0004	0.0067	0.0053	0.0097
Atomic S/C	0.0233	0.0016	0.0195	0.0300	0.0225	0.0391
<p>Normalized heteroatom composition (Sum ONS = 100)</p>						
O	29.97	13.64	5.41	40.83	64.34	31.64
N	12.35	23.38	1.90	10.84	6.74	13.63
S	57.68	62.98	92.68	48.33	28.92	54.73
Specific gravity (15.56°C, 60°F)	1.036±0.006					
API gravity (15.56°C, 60°F)	5.1±0.8					
Viscosity (cps) (43°C, 110°F)	429539					
(66°C, 150°F)	25274					
(86°C, 186°F)	4438					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-430A Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: 7-8-75-1-W5 Mer Depth (m): 501.09-502.92 Description: Medium oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	19.8	16.9	34.5	11.6	17.2
C	83.60	86.45	85.67	81.19	78.93	80.09
H	10.22	13.27	10.71	9.61	9.74	8.12
O	1.39	0.09	0.13	3.04	5.92	2.63
N	0.46	0.00	0.06	0.33	0.41	0.98
S	4.33	0.18	3.44	5.82	5.00	8.18
Atomic H/C	1.457	1.830	1.490	1.411	1.471	1.208
Atomic O/C	0.0125	0.0008	0.0011	0.0282	0.0563	0.0247
Atomic N/C	0.0047	0.0000	0.0006	0.0034	0.0044	0.0105
Atomic S/C	0.0194	0.0008	0.0150	0.0269	0.0238	0.0383
Normalized heteroatom composition (Sum ONS = 100)						
O	34.07	50.05	6.84	48.15	66.64	33.62
N	12.97	0.00	3.61	5.89	5.24	14.29
S	52.96	49.95	89.55	45.96	28.12	52.09
Specific gravity (15.56°C, 60°F)	1.030±0.005					
API gravity (15.56°C, 60°F)	5.9±0.6					
Viscosity (cps) (43°C, 110°F)	31152					
(66°C, 150°F)	3405					
(86°C, 186°F)	706					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-430C Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: 7-8-75-1-W5 Mer Depth (m): 512.98-515.11 Description: Good oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	21.4	13.6	32.3	12.2	20.5
C	83.47	86.12	85.21	81.84	79.37	81.24
H	10.03	13.23	10.50	9.89	10.11	8.43
O	1.63	0.14	0.16	3.19	5.56	2.11
N	0.38	0.00	0.05	0.32	0.49	1.03
S	4.49	0.51	4.08	4.75	4.47	7.20
Atomic H/C	1.432	1.831	1.468	1.440	1.518	1.236
Atomic O/C	0.0147	0.0012	0.0014	0.0293	0.0526	0.0195
Atomic N/C	0.0039	0.0000	0.0005	0.0034	0.0053	0.0108
Atomic S/C	0.0202	0.0022	0.0179	0.0218	0.0211	0.0332
Normalized heteroatom composition (Sum ONS = 100)						
O	37.87	35.49	7.17	53.81	66.54	30.72
N	10.08	0.00	2.56	6.21	6.76	17.04
S	52.05	64.51	90.28	39.98	26.70	52.24
Specific gravity (15.56°C, 60°F)	1.022±0.002					
API gravity (15.56°C, 60°F)	7.0±0.3					
Viscosity (cps) (43°C, 110°F)	134352					
(66°C, 150°F)	9783					
(86°C, 186°F)	1983					

PROPERTIES OF BITUMEN AND BITUMEN FRACTIONS

Sample number: BH-430F Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: 7-8-75-1-W5 Mer Depth (m): 671.47-679.70 Description: Medium/poor oil sand						
Normalized elemental composition (Sum CHONS = 100)						
	Bitumen	Saturates	Aromatics	Resins I	Resins II	Asphaltenes
% in bitumen	100.0	21.1	24.0	33.4	8.3	13.2
C	83.28	86.19	84.74	80.92	78.93	79.94
H	10.38	13.35	10.59	9.93	10.38	8.43
O	1.15	0.06	0.13	2.34	5.06	2.52
N	0.29	0.00	0.07	0.47	0.41	1.05
S	4.90	0.39	4.47	6.34	5.23	8.06
Atomic H/C	1.485	1.846	1.489	1.463	1.566	1.256
Atomic O/C	0.0103	0.0005	0.0012	0.0217	0.0481	0.0236
Atomic N/C	0.0030	0.0000	0.0007	0.0050	0.0045	0.0113
Atomic S/C	0.0221	0.0017	0.0198	0.0293	0.0248	0.0378
Normalized heteroatom composition (Sum ONS = 100)						
O	29.22	23.57	5.33	38.74	62.18	32.50
N	8.49	0.00	3.28	8.89	5.75	15.55
S	62.29	76.43	91.40	52.37	32.07	51.95
Specific gravity (15.56°C, 60°F)				1.006±0.002		
API gravity (15.56°C, 60°F)				9.2±0.2		
Viscosity (cps) (43°C, 110°F)				-		
(66°C, 150°F)				-		
(86°C, 186°F)				-		

- = not determined

APPENDIX C
TRACE ELEMENTS IN BITUMEN

TRACE ELEMENTS IN BITUMEN

Sample number: BH-426A Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Union McIvor 6-6-103-12-W4 Location: Lsd 6 Sec 6 Twp 103 Rge 12 W4 Mer Depth (m): 48.16-54.56						
Na (ppm)	17.39	(0.137)				
K (ppm)	10.88	(0.545)				
Fe (ppm)	44.8	(1.25)				
Ni (ppm)	63.37	(0.542)				
Zn (ppb)	1.661	(0.064)	Au (ppb)		Ce (ppb)	
Co (ppb)	266.6	(4.67)	Sb (ppb)	20.0	(3.31)	Lu (ppb)
Se (ppb)	391.2	(16.2)	Cr (ppb)	474.2	(12.1)	Th (ppb)
Hg (ppb)	679.8	(31.9)	Rb (ppb)			Hf (ppb)
Cs (ppb)			Sc (ppb)	18.4	(0.209)	Ba (ppm)
Br (ppb)	466	(10.7)	Eu (ppb)	2.442	(0.674)	Tb (ppb)
As (ppb)	82	(3.8)	Ga (ppb)	77	(2.0)	Ta (ppb)
						97
						(11.5)
						0.544
						(0.114)
						16.18
						(0.968)
						5.671
						(1.026)
						1.584
						(0.414)
						2.377
						(0.595)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

<p>Sample number: BH-435B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: Lsd 6 Sec 25 Twp 95 Rge 16 W4 Mer Depth (m): 283.46-295.66</p>					
Na (ppm)	29.53	(0.284)			
K (ppm)	24.15	(2.38)			
Fe (ppm)	52.06	(0.996)			
Ni (ppm)	68.97	(0.453)			
Zn (ppb)	2.089	(0.044)	Au (ppb)		Ce (ppb)
Co (ppb)	280.4	(3.31)	Sb (ppb)	25.62	173 (9.6)
Se (ppb)	368.7	(10.5)	Cr (ppb)	668.9	Lu (ppb)
Hg (ppb)	369.9	(17.5)	Rb (ppb)	0.146	0.626 (0.124)
Cs (ppb)	7.237	(0.868)	Sc (ppb)	20.54	Th (ppb)
Br (ppb)	495	(20.9)	Eu (ppb)	5.218	24.07 (0.733)
As (ppb)	114	(8.7)	Ga (ppb)	88	Hf (ppb)
					4.628 (0.520)
					Ba (ppm)
					2.354 (0.211)
					Tb (ppb)
					2.994 (0.444)
					Ta (ppb)
					1.517 (0.373)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

Sample number: BH-435C Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell Ells OV 6-25-95-16-W4 Location: Lsd 6 Sec 25 Twp 95 Rge 16 W4 Mer Depth (m): 295.66-307.85					
Na (ppm)	30.35	(0.24)			
K (ppm)	22.60	(1.07)			
Fe (ppm)	66.30	(1.26)			
Ni (ppm)	82.44	(0.541)			
Zn (ppb)	2.644	(0.056)	Au (ppb)		Ce (ppb)
Co (ppb)	684.2	(6.04)	Sb (ppb)	29.35	93 (10.0)
Se (ppb)	445.4	(13.1)	Cr (ppb)	942.7	Lu (ppb)
Hg (ppb)	303.2	(15.2)	Rb (ppb)	0.106	0.514 (0.105)
Cs (ppb)	52.42	(1.48)	Sc (ppb)	34.40	Th (ppb)
Br (ppb)	496	(19.1)	Eu (ppb)	3.302	22.84 (0.944)
As (ppb)	104	(7.1)	Ga (ppb)	155	Hf (ppb)
					9.770 (0.777)
					Ba (ppm)
					2.413 (0.266)
					Tb (ppb)
					3.101 (0.558)
					Ta (ppb)
					3.287 (0.847)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

Sample number: BH-438B Oil sand deposit: Athabasca Stratigraphic unit: McMurray Formation Well name: Shell House Creek EV 10-23-80-13 Location: Lsd 10 Sec 23 Twp 80 Rge 13 W4 Mer Depth (m): 480.21-485.62					
Na (ppm)	15.81	(0.152)			
K (ppm)	12.10	(1.40)			
Fe (ppm)	29.53	(1.18)			
Ni (ppm)	83.61	(0.62)			
Zn (ppb)	1.685	(0.066)	Au (ppb)		Ce (ppb)
Co (ppb)	1159	(10.09)	Sb (ppb)	40.14	85 (11.5)
Se (ppb)	482.0	(15.2)	Cr (ppb)	504.4	Lu (ppb)
Hg (ppb)	208.5	(11.8)	Rb (ppb)		0.594 (0.156)
Cs (ppb)			Sc (ppb)	19.31	Th (ppb)
Br (ppb)	352	(11.7)	Eu (ppb)	3.058	20.83 (0.947)
As (ppb)	167	(5.9)	Ga (ppb)	150	Hf (ppb)
					6.265 (0.752)
					Ba (ppm)
					1.745 (0.445)
					Tb (ppb)
					Ta (ppb)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

<p>Sample number: BH-434B Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Little Rock No. 10-10 Location: Lsd 10 Sec 10 Twp 59 Rge 2 W4 Mer Depth (m): 482.19-484.63</p>					
Na (ppm)	30.20	(0.266)			
K (ppm)	4.555	(1.31)			
Fe (ppm)	32.94	(0.74)			
Ni (ppm)	61.78	(0.40)			
Zn (ppb)	2.353	(0.043)	Au (ppb)	1.0	(0.2)
Co (ppb)	278.1	(3.07)	Sb (ppb)	15.76	(1.41)
Se (ppb)	366.3	(9.61)	Cr (ppb)	344.8	(7.63)
Hg (ppb)	359.7	(16.9)	Rb (ppb)		
Cs (ppb)			Sc (ppb)	35.19	(0.211)
Br (ppb)	5968	(63.3)	Eu (ppb)	3.146	(0.376)
As (ppb)	135	(9.5)	Ga (ppb)	50	(5.3)
			Ce (ppb)	98	(8.5)
			Lu (ppb)	0.839	(0.118)
			Th (ppb)	19.20	(0.694)
			Hf (ppb)	5.899	(0.620)
			Ba (ppm)	1.893	(0.202)
			Tb (ppb)	3.181	(0.455)
			Ta (ppb)	14.72	(1.31)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

<p>Sample number: BH-439D Oil sand deposit: Cold Lake Stratigraphic unit: Mannville Formation, Sparky Sandstone Well name: Pan Am A1 Michel Lake 10-25 Location: Lsd 10 Sec 25 Twp 58 Rge 5 W4 Mer Depth (m): 494.23-499.87</p>								
Na (ppm)	26.06	(0.207)						
K (ppm)	5.223	(0.716)						
Fe (ppm)	33.53	(0.798)						
Ni (ppm)	68.44	(0.45)						
Zn (ppb)	3.266	(0.053)	Au (ppb)		Ce (ppb)			
Co (ppb)	187.6	(2.57)	Sb (ppb)	13.93	(1.45)	Lu (ppb)	1.538	(0.133)
Se (ppb)	403.8	(11.6)	Cr (ppb)	363.0	(9.01)	Th (ppb)	16.75	(0.724)
Hg (ppb)	379.8	(18.3)	Rb (ppb)			Hf (ppb)	3.822	(0.763)
Cs (ppb)			Sc (ppb)	52.44	(0.288)	Ba (ppm)	1.992	(0.232)
Br (ppb)	9207	(85.5)	Eu (ppb)	3.169	(0.529)	Tb (ppb)	3.608	(0.488)
As (ppb)	91	(7.6)	Ga (ppb)	51	(3.1)	Ta (ppb)		

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

<p>Sample number: BH-429D Oil sand deposit: Peace River Stratigraphic unit: Bullhead Formation Well name: Shell Cadotte OV 1-27 Location: Lsd 1 Sec 27 Twp 86 Rge 19 W5 Mer Depth (m): 516.33-518.62</p>						
Na (ppm)	46.96	(0.360)				
K (ppm)	70.56	(1.76)				
Fe (ppm)	118.1	(2.24)				
Ni (ppm)	72.62	(0.62)				
Zn (ppb)	2.433	(0.078)	Au (ppb)		Ce (ppb) 599 (17.5)	
Co (ppb)	507.2	(6.57)	Sb (ppb)	48.45 (3.58)	Lu (ppb)	
Se (ppb)	345.5	(19.3)	Cr (ppb)	919.4 (16.8)	Th (ppb)	49.15 (1.36)
Hg (ppb)	5740	(258)	Rb (ppb)	0.298 (0.029)	Hf (ppb)	10.66 (1.09)
Cs (ppb)	149.9	(3.25)	Sc (ppb)	94.37 (0.564)	Ba (ppm)	13.05 (0.527)
Br (ppb)	503	(18.9)	Eu (ppb)	16.32 (1.39)	Tb (ppb)	6.86 (1.01)
As (ppb)	206	(8.7)	Ga (ppb)	131 (4.9)	Ta (ppb)	7.411 (1.99)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

<p>Sample number: BH-431B Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: BA Wabasca 10-25-81-22 Location: Lsd 10 Sec 25 Twp 81 Rge 22 W4 Mer Depth (m): 228.30-239.27</p>							
Na (ppm)	16.46	(0.149)					
K (ppm)	3.506	(0.622)					
Fe (ppm)	108.9	(1.83)					
Ni (ppm)	112.2	(0.708)					
Zn (ppb)			Au (ppb)	1.0	(0.2)		
Co (ppb)	736.7	(6.58)	Sb (ppb)	38.15	(2.70)		
Se (ppb)	618.8	(17.6)	Cr (ppb)	828.9	(12.6)		
Hg (ppb)			Rb (ppb)				
Cs (ppb)			Sc (ppb)	214.7	(0.931)		
Br (ppb)	163	(9.0)	Eu (ppb)	12.54	(0.853)		
As (ppb)	191	(5.7)	Ga (ppb)	115	(4.0)		
					Ce (ppb)	118	(10.2)
					Lu (ppb)	7.551	(0.190)
					Th (ppb)	14.49	(0.902)
					Hf (ppb)	3.677	(0.913)
					Ba (ppm)	8.140	(0.353)
					Tb (ppb)	15.40	(1.060)
					Ta (ppb)		

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

Sample number: BH-436A Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Texaco Wabasca 6-8-81-25 Location: Lsd 6 Sec 8 Twp 81 Rge 25 W4 Mer Depth (m): 224.33					
Na (ppm)	14.46	(0.128)			
K (ppm)	1.354	(0.386)			
Fe (ppm)	75.31	(1.57)			
Ni (ppm)	88.84	(0.675)			
Zn (ppb)			Au (ppb)		Ce (ppb)
Co (ppb)	246.4	(4.39)	Sb (ppb)	44.75	927
Se (ppb)	476.1	(24.4)	Cr (ppb)	834.1	(19.0)
Hg (ppb)			Rb (ppb)		Lu (ppb)
Cs (ppb)			Sc (ppb)	332.7	19.76
Br (ppb)	105	(12.6)	Eu (ppb)	83.41	(0.310)
As (ppb)	160	(7.4)	Ga (ppb)	89	(1.43)
					Hf (ppb)
					Ba (ppm)
					19.79
					(0.526)
					Tb (ppb)
					35.46
					(1.75)
					Ta (ppb)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

Sample number: BH-430A Oil sand deposit: Wabasca (Grand Rapids A) Stratigraphic unit: Grand Rapids Formation Well name: Pan Am G-2 Marten Hills 7-8-75-1 Location: Lsd 7 Sec 8 Twp 75 Rge 1 W5 Mer Depth (m): 501.09-502.92					
Na (ppm)	20.73	(0.161)			
K (ppm)	9.723	(0.562)			
Fe (ppm)	26.68	(1.07)			
Ni (ppm)	61.33	(0.525)			
Zn (ppb)	1.853	(0.066)	Au (ppb)		Ce (ppb)
Co (ppb)	624.8	(6.81)	Sb (ppb)	42.37	86
Se (ppb)	314.2	(14.4)	Cr (ppb)	274.8	(10.1)
Hg (ppb)	768.0	(35.4)	Rb (ppb)		Lu (ppb)
Cs (ppb)	14.01	(1.67)	Sc (ppb)	13.20	16.72
Br (ppb)	4689	(44.5)	Eu (ppb)	5.178	(1.11)
As (ppb)	111	(4.9)	Ga (ppb)	50	(0.887)
					Ba (ppm)
					4.032
					(0.327)
					Tb (ppb)
					Ta (ppb)

Note: Relative standard deviation (counting statistics) in parenthesis

TRACE ELEMENTS IN BITUMEN

<p>Sample number: BH-430F Oil sand deposit: Wabasca (Wabiskaw) Stratigraphic unit: Wabiskaw Member Well name: Pam Am G-2 Marten Hills 7-8-75-1 Location: Lsd 7 Sec 8 Twp 75 Rge 1 W5 Mer Depth (m): 671.47-679.70</p>					
Na (ppm)	24.89	(0.217)			
K (ppm)	74.69	(2.29)			
Fe (ppm)	96.49	(2.61)			
Ni (ppm)	52.49	(0.70)			
Zn (ppb)	5.809	(0.158)	Au (ppb)		Ce (ppb)
Co (ppb)	205.2	(6.12)	Sb (ppb)	20.47	584
Se (ppb)	395.7	(30.8)	Cr (ppb)	526.1	(20.8)
Hg (ppb)	728.2	(36.0)	Rb (ppb)	0.448	(0.061)
Cs (ppb)	563.0	(7.28)	Sc (ppb)	72.76	(0.609)
Br (ppb)	1301	(29.9)	Eu (ppb)	21.97	(2.23)
As (ppb)	211	(9.5)	Ga (ppb)	57	(4.3)
					Lu (ppb)
					3.395
					(0.283)
					Th (ppb)
					51.18
					(1.90)
					Hf (ppb)
					19.79
					(1.77)
					Ba (ppm)
					3.948
					(0.563)
					Tb (ppb)
					8.361
					(1.30)
					Ta (ppb)

Note: Relative standard deviation (counting statistics) in parenthesis

APPENDIX D
MICROFOSSILS IN ASSOCIATED SHALES

MEMORANDUM

RESEARCH COUNCIL OF ALBERTA, 11315 - 87TH AVENUE, EDMONTON 7, ALBERTA.

TO Dr. B. Hitchon

FROM J. H. Wall

DATE August 20, 1973

Re: Mannville equivalent shale samples

As per your request of July 6, 1973, our laboratory has processed 20 samples for conventional microfossils using 100 grams from each sample. Most of the samples yielded microfossils which are identified below with remarks on their stratigraphic and paleoecologic significance.

Sample Number BH-425B

R.O.C. Buffalo Lake 11-22-90-18W4. Depth 659-678 ft.

Your description: Medium dark grey shale below oilsand

Foraminifera:

Haplophragmoides gigas minor Nauss

H. sp. cf. H. sluzari Mellon and Wall

Ammobaculites humei Nauss

"Tritaxia" athabascensis Mellon and Wall

Trochammina sp. - one specimen

Verneuilinoides sp.

Remarks: This assemblage is characteristic of the Grand Rapids Formation and of the shoreward facies of the Clearwater Formation. It is indicative of a shallow, marine environment.

Sample Number BH-426C

Union McIvor 6-6-103-12W4. Depth 397-402 ft.

Your description: Medium light grey shale below oilsand.

Microfauna: This sample contains ostracods belonging to the genera Aechminella, Halliella and Semihealdioides (?) together with several unidentified forms. Tentaculitids are also present.

Remarks: The age of this fauna is interpreted as Upper Devonian.

Sample Number BH-427A

Union Red Earth 10-14-88-9W5. Depth 1198-1245 ft.

Your description: Medium dark grey shale above oilsand.

Foraminifera:

Bathysiphon sp. B of Stelck and Wall (1956, R.C.A. Rept. 75, pl. 2, figs. 33, 34)

Saccamina sp.

Ammodiscus sp. of Stelck and Wall (ibid., pl. 2, figs. 31, 32)

Glomospira sp.

Haplophragmoides gigas minor Nauss

H. spp.

Verneuilina porta Stelck and Wall

Dorothia sp.

Uvigerinamina (?) sp.

Remarks: This assemblage is characteristic of the Clearwater Formation and suggests a shallow, near-shore marine environment.

Sample Number BH-428C

Shell Cadotte EV 1-9-83-17W5. Depth 2260-2265 ft.

Your description: Greyish black shale below oilsand.

Remarks: No microfauna was recovered.

Sample Number BH-428L

Shell Cadotte EV 1-9-83-17W5. Depth 2306'8"

Your description: Medium dark grey shale below oilsand.

Microfauna: Only fragments of Cretaceous ostracods were recovered from this sample.

Although it is risky to make comparisons on the basis of such fragmentary material, there does appear to be some similarity with a brackish marine fauna obtained from the Loon River (or Gething according to Conservation Board Schedule of Wells) from the Pacific Keg River No. 1 well in 13-1-105-22W5 between 880-890 ft.

Sample Number BH-429A

Shell Cadotte EV 1-27-86-19W5. Depth 1681-1683 ft.

Your description: Medium greenish grey mudstone above oilsand.

Foraminifera:

Saccamina sp. - one specimen

Ammodiscus sp. of Stelck and Wall (1956, R.C.A. Rept. 75, pl. 2, figs. 33, 34) - one specimen

Glomospira sp.

Haplophragmoides multiplum Stelck and Wall

H. sp. cf. H. sluzari Mellon and Wall

Ammobaculites sp.

Verneuilinoides (?) sp. - one specimen

Remarks: This rather meager fauna could be expected in the Loon River Formation or in the overlying Harmon Member of the Peace River Formation. A shallow marine environment is indicated.

Sample Number BH-430D

Pan Am G2 Marten Hills 7-8-75-1W5. Depth 2170-2190 ft.

Your description: Medium grey to medium dark grey shale below Grand Rapids "B" oilsand

Foraminifera:

Ammodiscus sp. - one specimen

Haplophragmoides gigas minor Nauss - one specimen

H. sp.

Ammobaculites (?) sp.

Remarks: This depauperate fauna could be expected within the Clearwater - Grand Rapids sequence. It probably indicates a shallow, restricted marine environment.

Sample Number BH-430E

Pan Am G2 Marten Hills 7-8-75-1W5. Depth 2193-2195 ft.

Your description: Medium dark grey to dark grey shale above Wabasca oilsand.

Foraminifera:

Haplophragmoides sp.

Ammobaculites sp.

Verneuilinoides (?) sp.

Remarks: By itself, this assemblage is inadequate for determination of stratigraphic level. The same interpretation can be applied to it as for the previous sample from this well.

Sample Number BH-431A

B.A. Wabasca 10-25-81-22W4. Depth 730-744 ft.

Your description: Medium dark grey shale above Grand Rapids "A" oilsand

Foraminifera:

Glomospira sp. - one specimen

Haplophragmoides gigas Cushman

H. sp. cf. H. linki Nauss

Ammobaculites fragmentarius Cushman

A. tyrrelli Nauss

Ammobaculoides athabascensis Stelck and Wall

Gaudryina hectori Nauss

Spiroplectinata (?) sp.

Ostracoda:

Cythereis sp.

Diatomaceae

Morphotype A of Given and Wall (1971)

Morphotype A-5 of Wall (in press)

Morphotype B of Given and Wall (1971)

Remarks: This faunal assemblage is characteristic of the lower part of the Joli Fou Formation and is commonly referred to as the Haplophragmoides gigas fauna, which has an extensive distribution in the Western Canada Plains region. The indicated environment is shallow, cool, marine perhaps somewhat brackish.

Sample Number BH-431G

B.A. Wabasca 10-25-81-22W4. Depth 1396-1404 ft.

Your description: Greyish black shale and interbedded medium grey siltstone, below Wabasca oilsand and above (6 ft) coal.

Remarks: No microfauna was recovered.

Sample Number BH-432

Seaboard Sander Lake 11-34-80-3W5. Depth 1221-1256 ft.

Your description: Oil-stained olive black siltstone (Clearwater Formation ?)

Remarks: No microfauna was recovered.

Sample Number BH-433A

Imperial 73-5 Leming OV 13-33-64-3W4. Depth 1491' - 1503' 6"

Your description: Dark grey shale above oilsand.

Foraminifera:

Hippocrepina sp.

Miliammina sproulei Nauss

Psamminopelta sp.

Haplophragmoides gigas minor Nauss - abundant

"Tritaxia" athabascensis Mellon and Wall

Verneuilinoides sp.

Remarks: This assemblage is like many found in the Grand Rapids Formation and shoreward facies of the Clearwater Formation or their equivalents within the Mannville Group of east-central Alberta.

Sample BH-433J

Imperial 73-5 Leming OV 13-33-64-3W4. Depth 1795-1830 ft.

Your description: Medium grey shale at 150 ft. below oilsand

Foraminifera:

Miliammina sp. - one specimen

Haplophragmoides gigas minor Nauss - rare

Remarks: This depauperate fauna suggests a limited brackish marine incursion within the Mannville Group.

Sample Number BH-434A

Pan Am AI Little Rock 10-10-59-2W4. Depth 1545-1549 ft.

Your description: Medium dark grey shale above oilsand.

Microfauna: This sample contains an assemblage of tintinnids and some unidentified micro-organisms which are possibly thecamoebians. Similar assemblages have been found in the Grand Rapids Formation in the B.A. Pelican Lake 11-18-79-21W4 well between 766 and 776 ft and in the B.A. Wabasca 10-25-81-22W4 well between 835 and 841 ft from samples submitted by Dr. J.W. Kramers.

Remarks: The presence of this assemblage and the absence of foraminifera suggest a fresh to brackish water environment marginal to the Clearwater Sea.

Sample Number BH-435F

Shell Ells OV 6-25-95-16W4. Depth 988-989 ft.

Your description: Greyish black fissile shale between thick oilsands.

Foraminifera:

Miliammina sproulei Nauss

Haplophragmoides sp.

Verneuilinoides (?) sp. of Mellon and Wall (1956, R.C.A. Rept. 72, Pl. 1, figs. 13, 14)

Remarks: This assemblage suggests a shallow, perhaps brackish, marine environment within the Clearwater or upper part of the McMurray Formation.

Sample Number BH-437B

Atlantic Sandy Lake 16-5-86-21W4. Depth 1140-1145 ft.

Your description: Greyish black shale below oilsand.

Microfauna: A sparse fauna is present consisting of several specimens of the foraminifer Saccammina along with two fish teeth. Although the evidence is not conclusive, it does suggest a brackish marginal marine habitat.

Sample Number BH-437D

Atlantic Sandy Lake 16-5-86-21W4. Depth 1169 ft.

Your description: Pale greenish grey shale below oilsand.

Remarks: No microfauna was recovered.

Sample Number BH-438H

Shell House Creek Ev 10-23-80-13W4. Depth 1695-1696 ft.

Your description: Greenish grey fissile shale beneath coal.

Microfauna: An assemblage consisting of the ostracod Aechminella, pyritized gastropods and unidentified hexagonal plates is present.

Remarks: The age of this fauna is interpreted as Upper Devonian.

Sample Number BH-439A

Pan Am A1 Michel Lake 10-25-58-5W4. Depth 1448-1454 ft.

Your description: Pale greenish grey shale far above oilsand.

Microfauna: This sample contains an assemblage of megaspores, tintinnids and some unidentified microorganisms which are possibly thecamoebians.

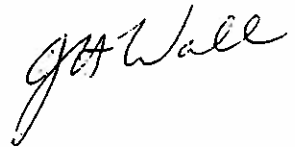
Remarks: The presence of megaspores and tintinnids combined with the absence of foraminifera indicates a nonmarine or perhaps slightly brackish water environment.

Sample Number BH-439B

Pan Am A1 Michel Lake 10-25-58-5W4. Depth 1569-1584 ft.

Your description: Medium dark grey shale above oilsand.

Microfauna: There are a few unidentified objects of probable organic origin in this sample together with a considerable amount of comminuted carbonaceous material. The environment is likely non-marine.



JHW/jc