XRF Elemental Analysis for Prediction of Clay-related Process Variables in Oil Sands

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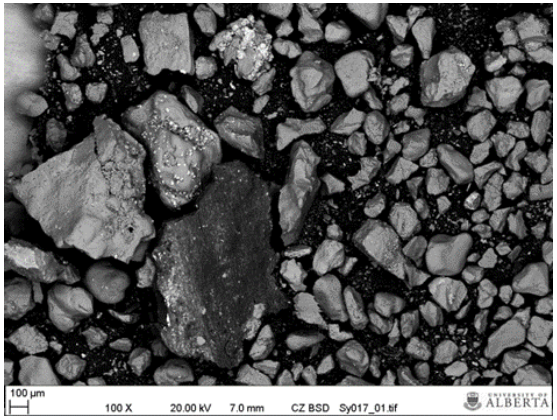
Clays, Fines, and Clay Minerals

- Clays – Mineral solids with particle sizes ≤ 2 µm
- Fines – Mineral solids with particle sizes ≤ 44 µm
- Clay Minerals – Hydrous aluminosilicates with layered structures

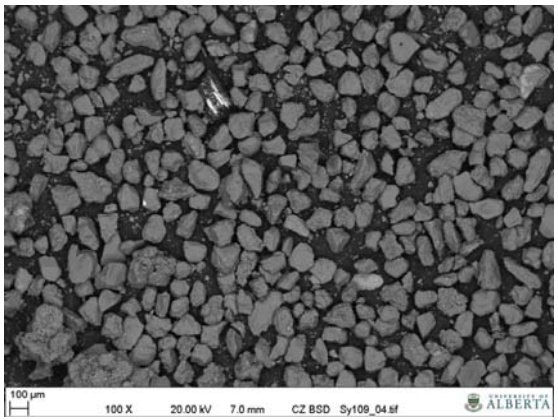
Major Clay Minerals in Oil Sands

- **Kaolinite**, kaolinite-smectite mixed layer clays
- **Illite**, degraded illite, illite-smectite mixed layer clays
- Smectite (montmorillonite)
- Chlorite

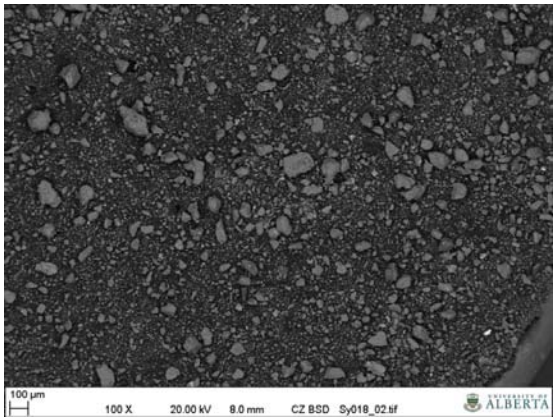
Grain Size Distribution of Oil Sands Solids (SEM)



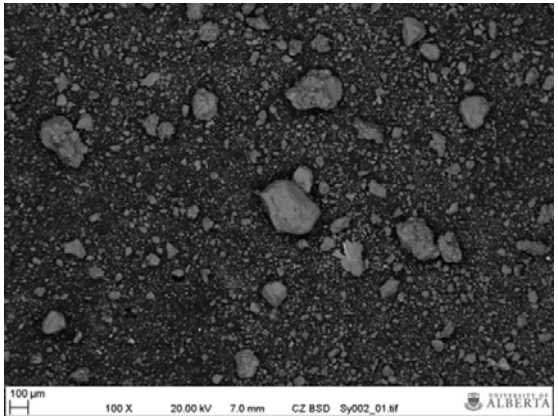
high grade estuarine ore



high grade marine ore



estuarine waste



marine channel interburden

Oil Sands Samples Used in this Study

Sample ID	Ore Type / Description	Bitumen (wt%)	Water (wt%)	Solid (wt%)	Fines (wt%)	Clay (wt%)	MBI (meq/100g)
Sy001	Medium Grade Estuarine (with Minor Marine)	10.98	2.60	86.17	19.83	5.25	0.6
Sy002	Marine Channel Interburden	5.00	10.12	84.80	50.72	10.73	1.4
Sy003	Marine Channel	5.55	10.69	83.68	42.27	10.55	1.7
Sy004	Multi Bench Estuarine & Marine Ore	9.34	5.03	85.46	23.39	7.07	0.9
Sy005	High Grade Estuarine Ore	11.06	3.26	85.24	27.62	6.92	0.4
Sy006	Marine Ore; Burrowed	10.05	4.54	84.98	17.24	5.85	0.5
Sy013	Estuarine Ore	7.81	8.86	83.43	48.19	12.11	1.7
Sy015	Estuarine Ore	12.82	4.25	82.57	15.96	3.90	0.3
Sy016	Estuarine Ore	5.91	10.50	83.71	48.04	10.28	1.7
Sy017	Estuarine Ore	13.84	4.16	82.22	10.21	2.50	0.2
Sy018	Estuarine Waste	4.49	8.48	87.20	60.30	12.63	2.2
Sy019	Marine Ore	12.46	5.28	82.37	14.82	4.80	0.5

Mineralogical Composition (XRD)

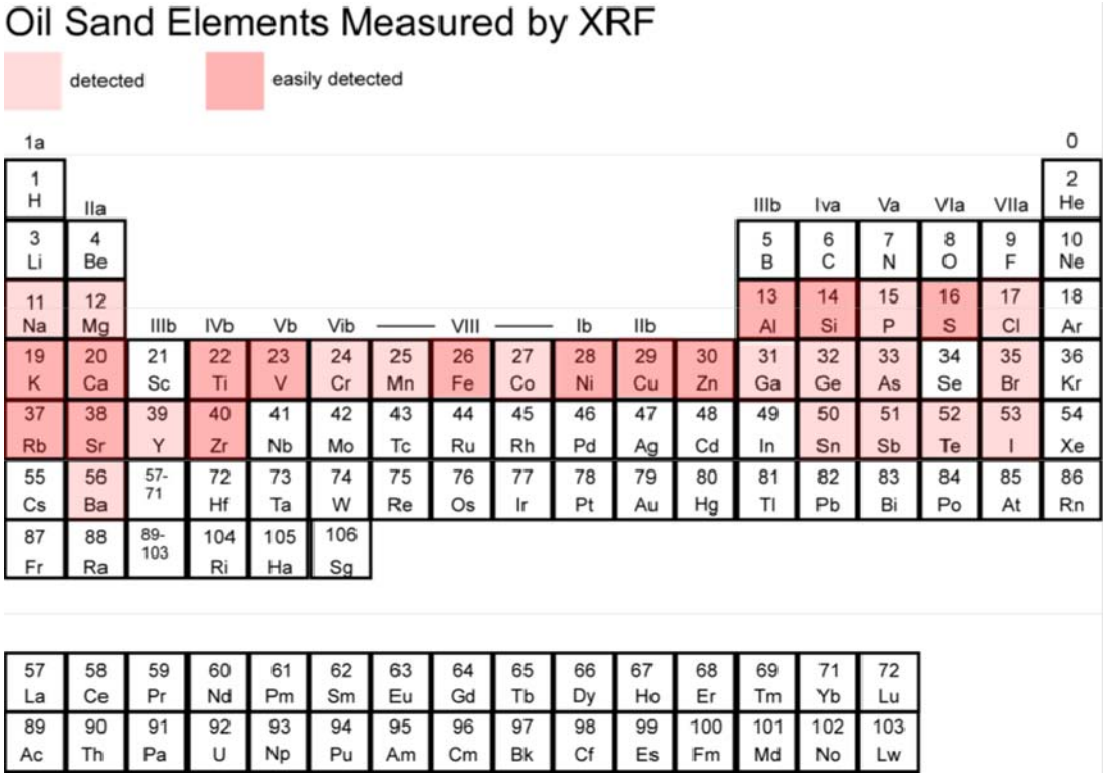
Sample ID	Qtz	Ksp	Pla	Cal	Dol	Sid	Anh	Pyr	Kao	Ill	Chl	Sme	M-L	Total Clay
Sy001	85	5	1	0	1	0	0	0	5	3	0	0	0	8
Sy002	66	3	1	2	3	1	0	1	15	8	0	0	0	23
Sy003	67	1	1	2	2	0	0	1	17	9	0	0	0	26
Sy004	89	3	0	0	0	0	0	0	5	3	0	0	0	8
Sy005	87	6	0	0	0	0	0	0	6	1	0	0	0	7
Sy006	88	2	0	0	0	0	0	0	7	3	0	0	0	10
Sy013	74	3	1	0	0	1	0	0	10	11	0	0	0	21
Sy015	90	1	0	0	0	0	0	0	7	2	0	0	0	9
Sy016	71	4	1	0	0	0	0	0	11	13	0	0	0	24
Sy017	93	1	0	0	0	0	2	0	4	0	0	0	0	4
Sy018	72	1	0	0	0	1	0	0	13	13	0	0	0	26
Sy019	92	2	0	0	0	0	0	0	3	2	1	0	0	6

Chemical Formulae of Minerals

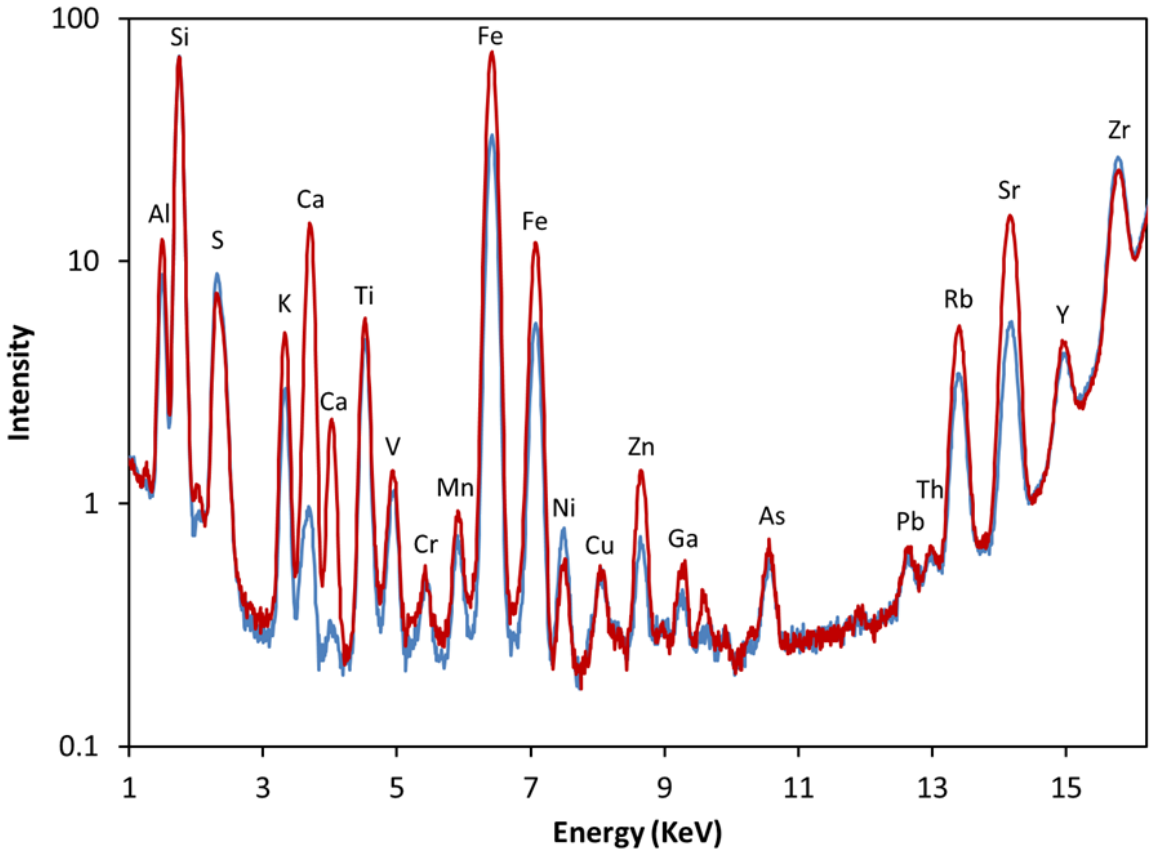
Class	Mineral Name	Chemical Formula
Detrital Silicate	Quartz	SiO_2
	K-feldspar	$KAlSi_3O_8$
	Plagioclase	$(Na, Ca)AlSi_3O_8$
Carbonate	Calcite	$CaCO_3$
	Dolomite	$CaMg(CO_3)_2$
	Siderite	$FeCO_3$
Sulfate	Anhydrite	$CaSO_4$
Sulfide	Pyrite	FeS_2
Clay Mineral	Kaolinite	$Al_2Si_2O_5(OH)_4$
	Illite	$K_{0.6}(Al,Mg)_2(Si,Al)_4O_{10}(OH)_2 \cdot H_2O$
	Chlorite	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2 \cdot (Mg,Fe)_3(OH)_6$
	Montmorillonite (smectite)	$(Na,Ca)_{0.33}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$

X-ray Fluorescence Spectrometry (XRF)

- Rapid measurement of elemental composition
- Up to 31 elements detected in oil sands by ED-XRF spectrometer
- Potentially useful for both oil sands ore and tailings



ED-XRF Spectra of Oil Sands Samples



Sy002: Interburden

Sy005: High grad Ore

Process Variables Examined

Process Variables	Description	Comments
Bitumen Content	weight percent of bitumen	high grade, good processability
Fines Content	weight percent of fines (< 44 µm)	high fines content, poor processability correlated to clay content
Clay Content	weight percent of clay-size fraction (< 2 µm)	composed mainly of clay minerals
Kaolinite/illite	mass ratio of kaolinite to illite	kaolinite/illite > 2 ?
Total Clay	sum of clay minerals in weight percent	sometimes used interchangeably with clay content
Methylene Blue Index (MBI)	amount of methylene blue adsorbed (meq/100 g)	surface reactivity of clay minerals used commonly in oil sand industry

Principal Component Analysis: Peak Area of Elements Measured by XRF

Factor 1: Al, S, K, Ti, Zn, Ga, Pb, Th, Rb, and Y

Clay indicator?

Factor 2: Mg, Ca, Sr, and Ba

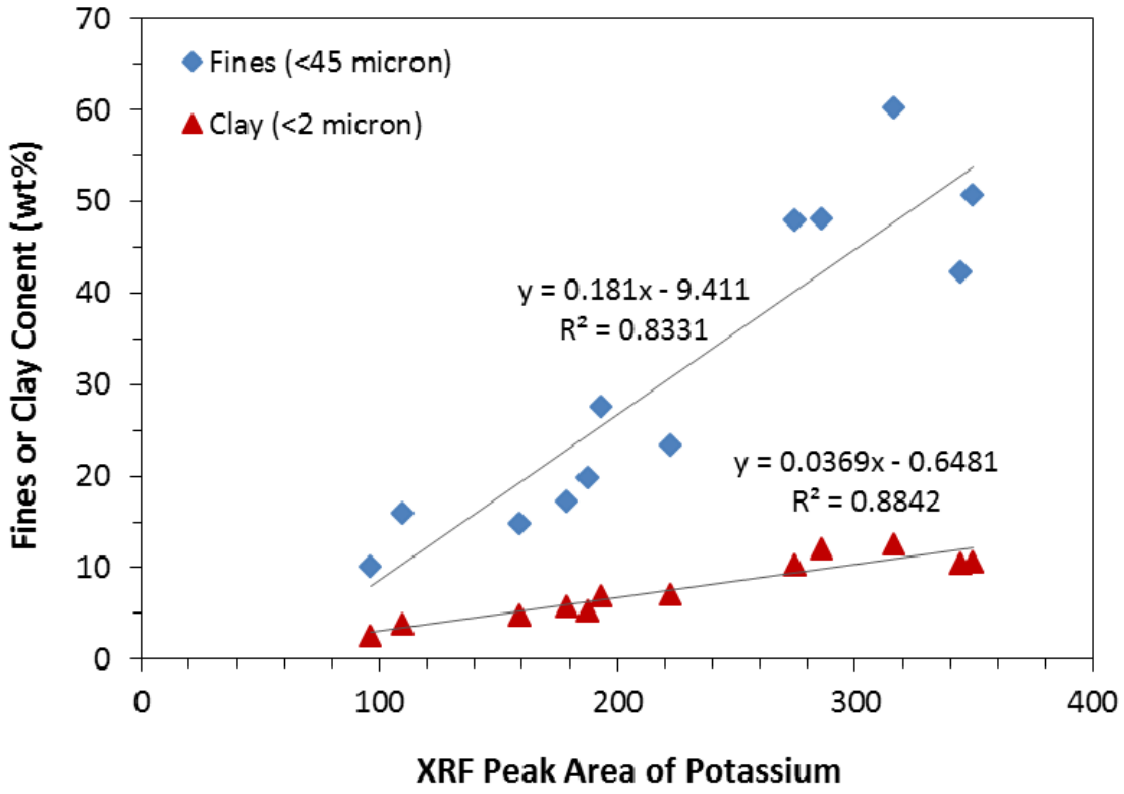
Carbonates?

Correlations between Process Variables and Individual Elements

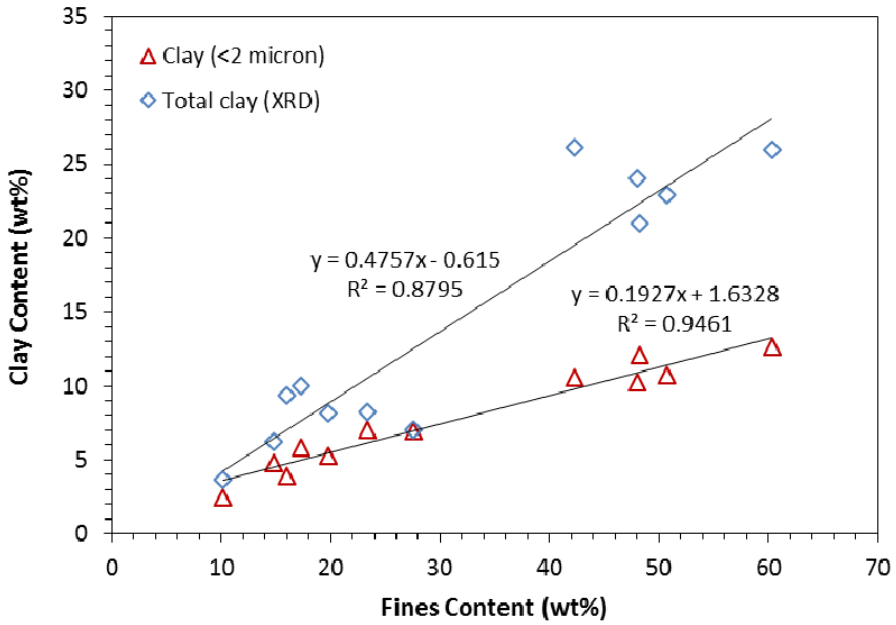
- Bitumen Content
- Fines Content
- Clay Content
- MBI
- Kaolinite
- Illite
- Total Clay

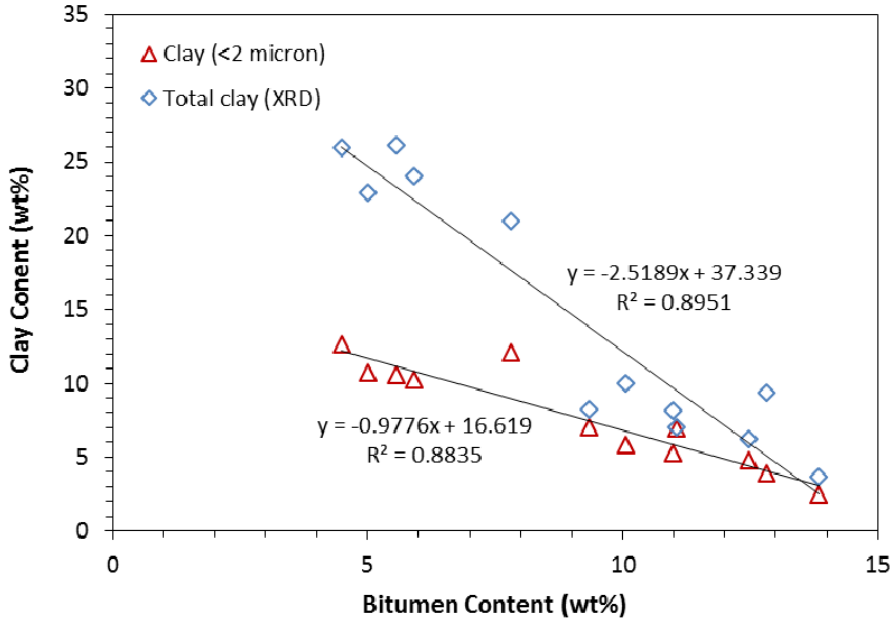
Al, S, K, Ti, Zn, Ga, Pb, Th, Rb, and Y

Correlations of Fines and Clay Content with K

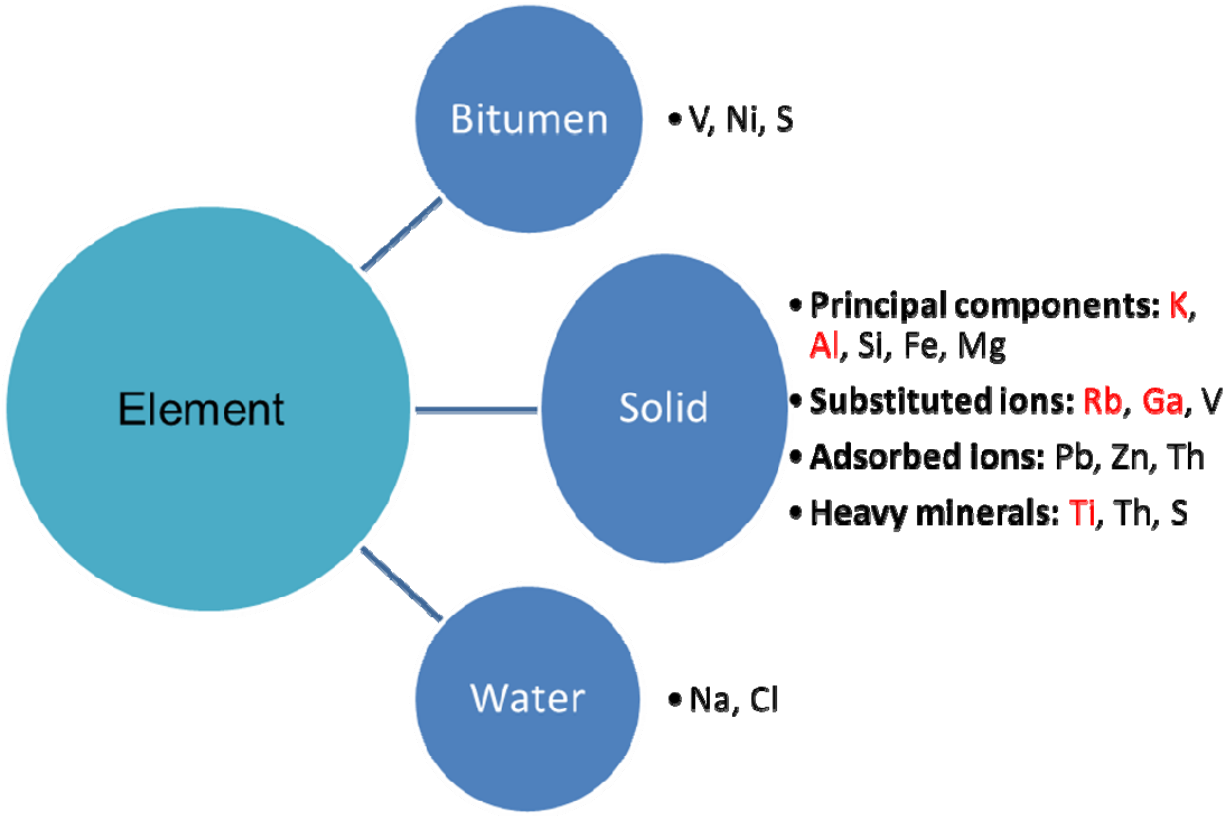


Inter-relationships between Process Variables



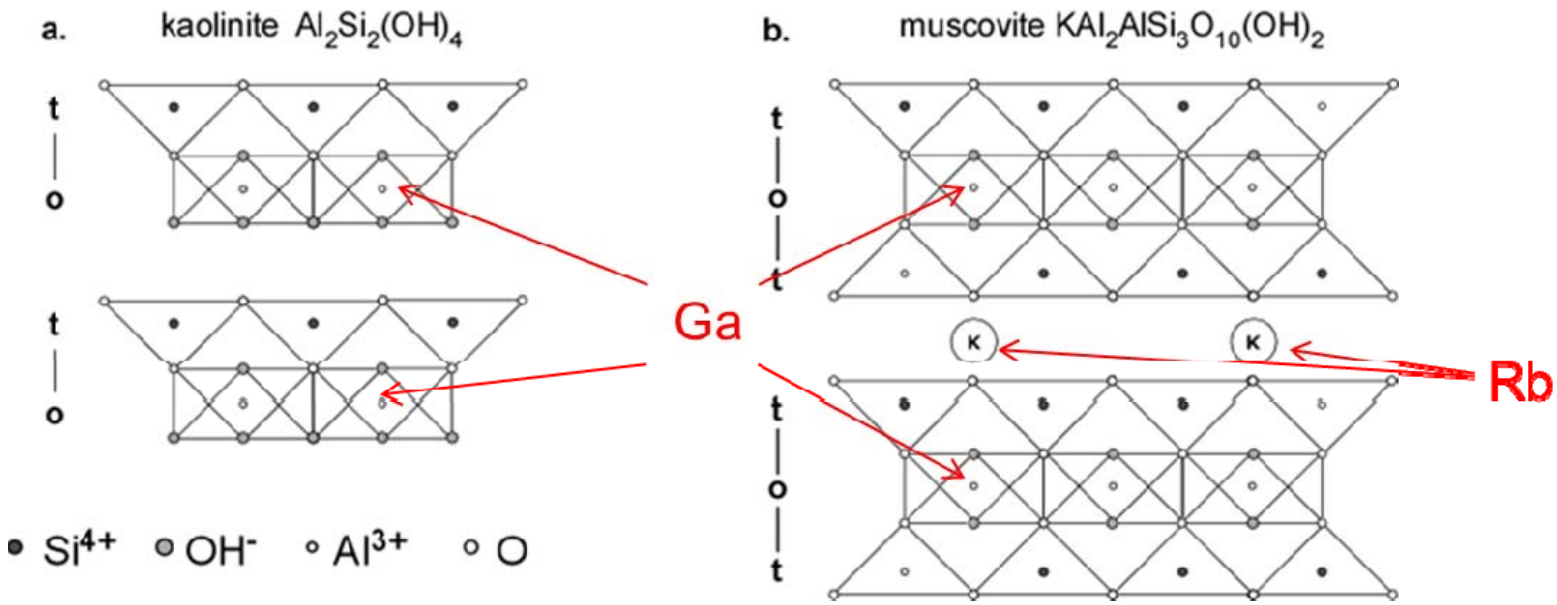


Elemental Distribution in Oil Sands

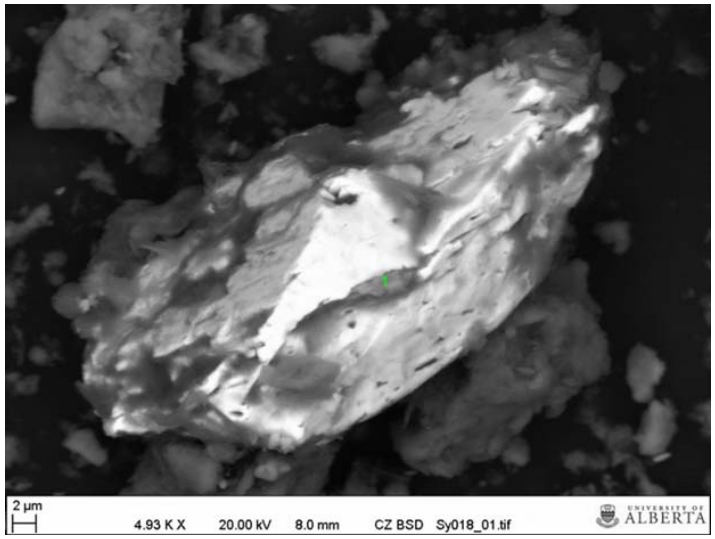


Isomorphic Substitution in Clay Structures

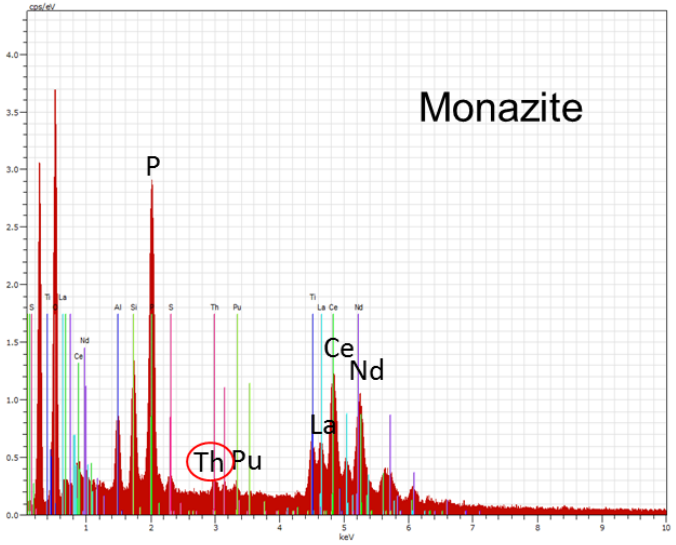
- **Ga** – substitute for Al in silicate minerals.
- **Rb** – substitutes for K in silicate minerals.



Thorium-bearing Mineral in Oil Sands

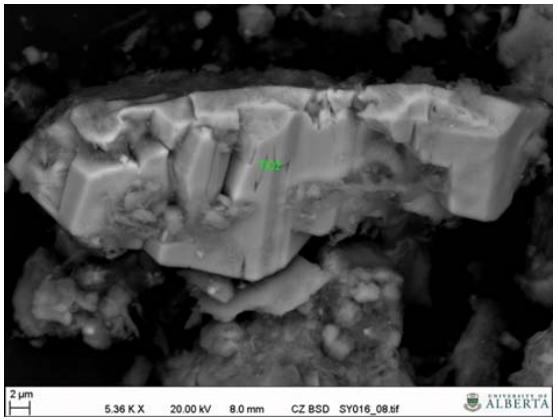


Monazite found in oil sands
(Ce, Nd, La, **Th**, Pu)PO_4

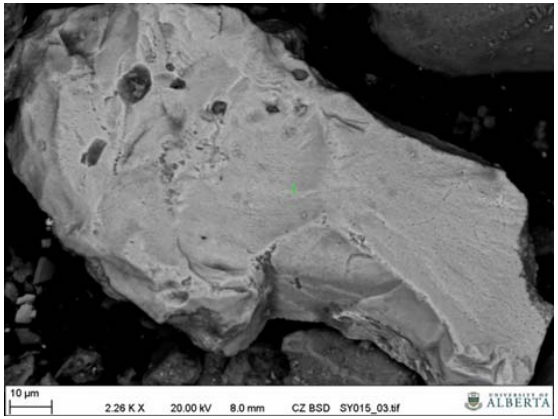


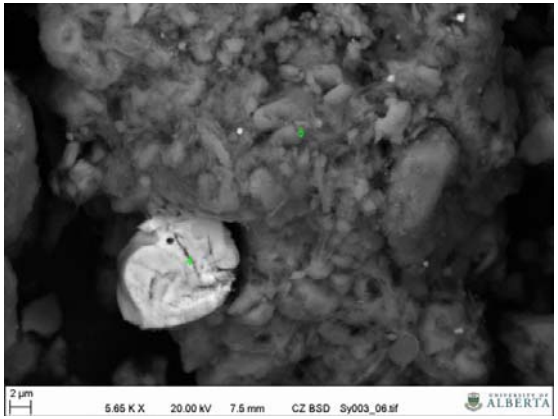
EDX spectrum of monazite

Ti-bearing Minerals in Oil Sands



Titanium oxide (TiO_2)





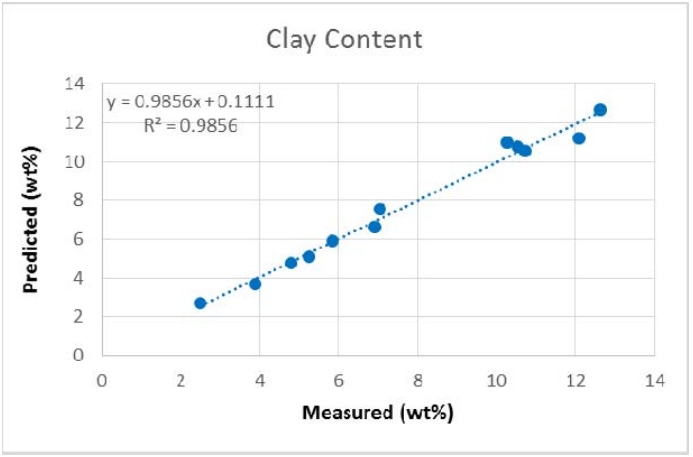
Titanium iron oxide

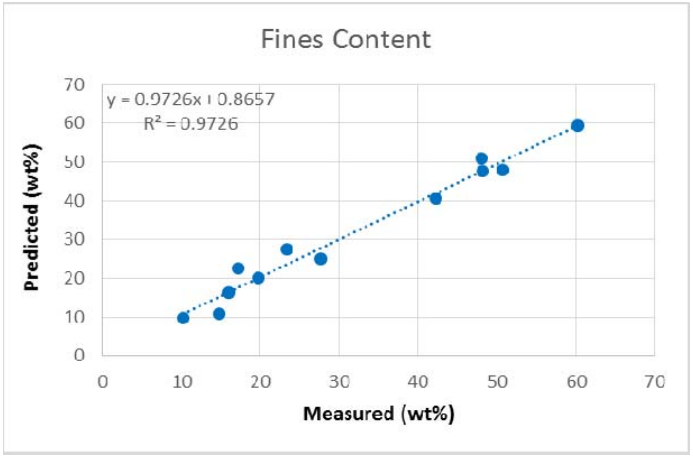
Multiple Regression Models for Process Variables

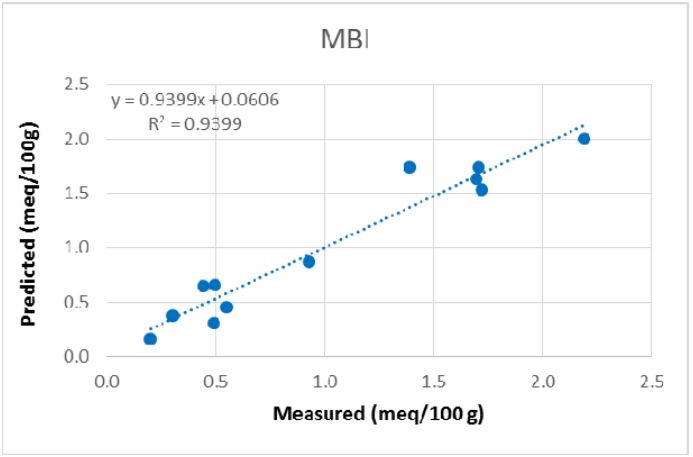
- Bitumen Content
- Fines Content
- Clay Content
- MBI
- Kaolinite
- Illite
- Total Clay

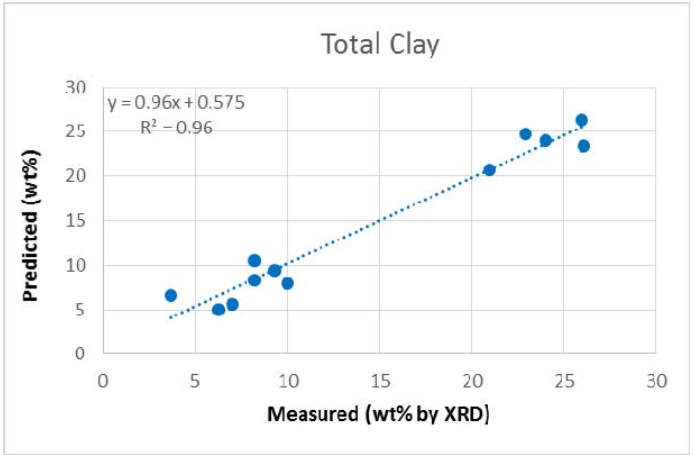
Multiple Regression Models including three or more elements

Process Variables: Predicted vs. Measured



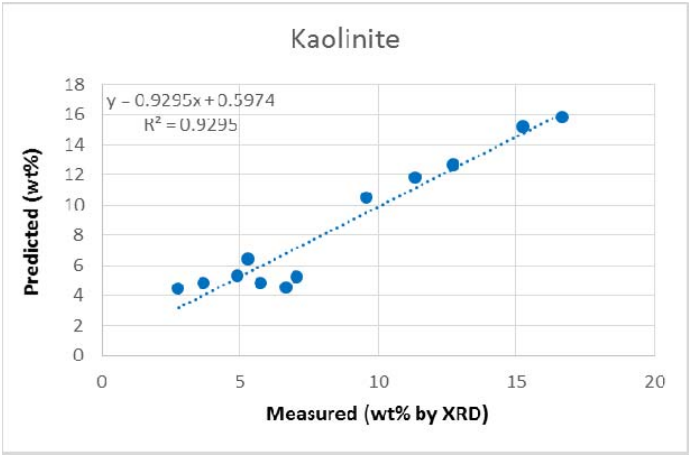


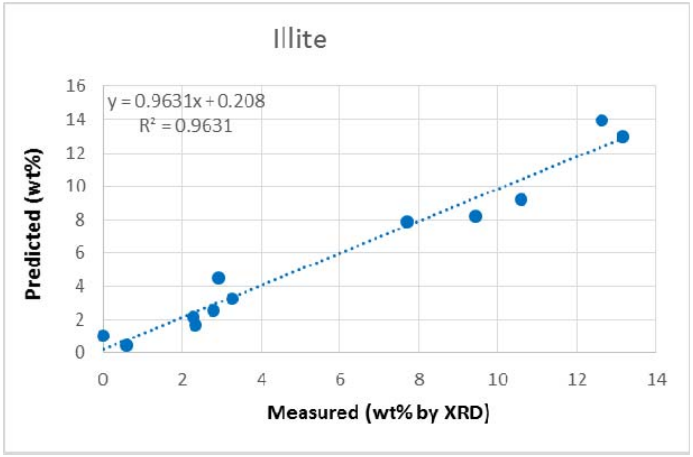


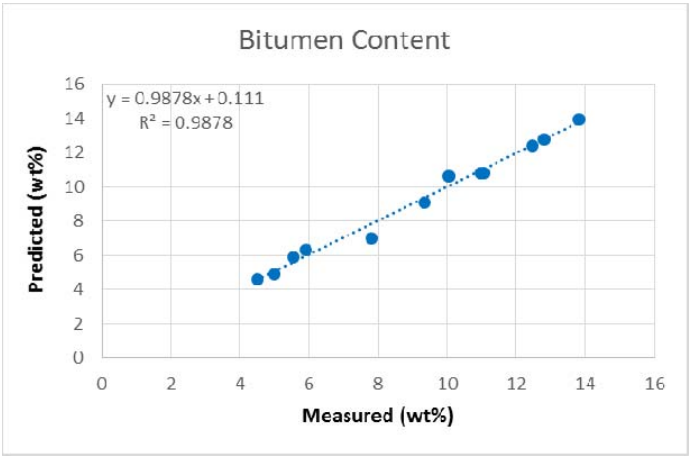


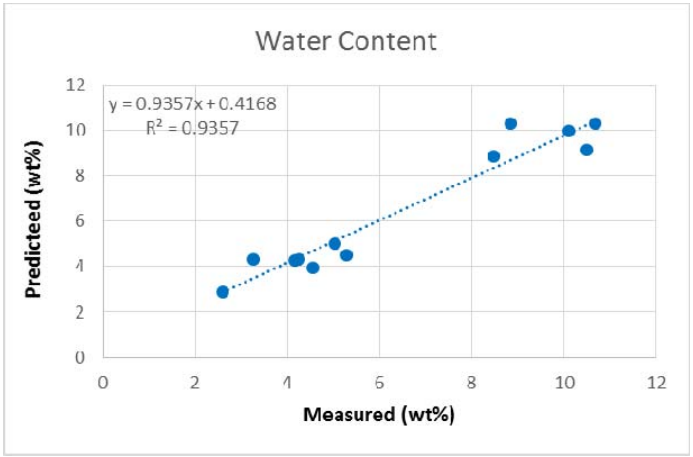
ALBERTA INNOVATES

Process Variables: Predicted vs. Measured

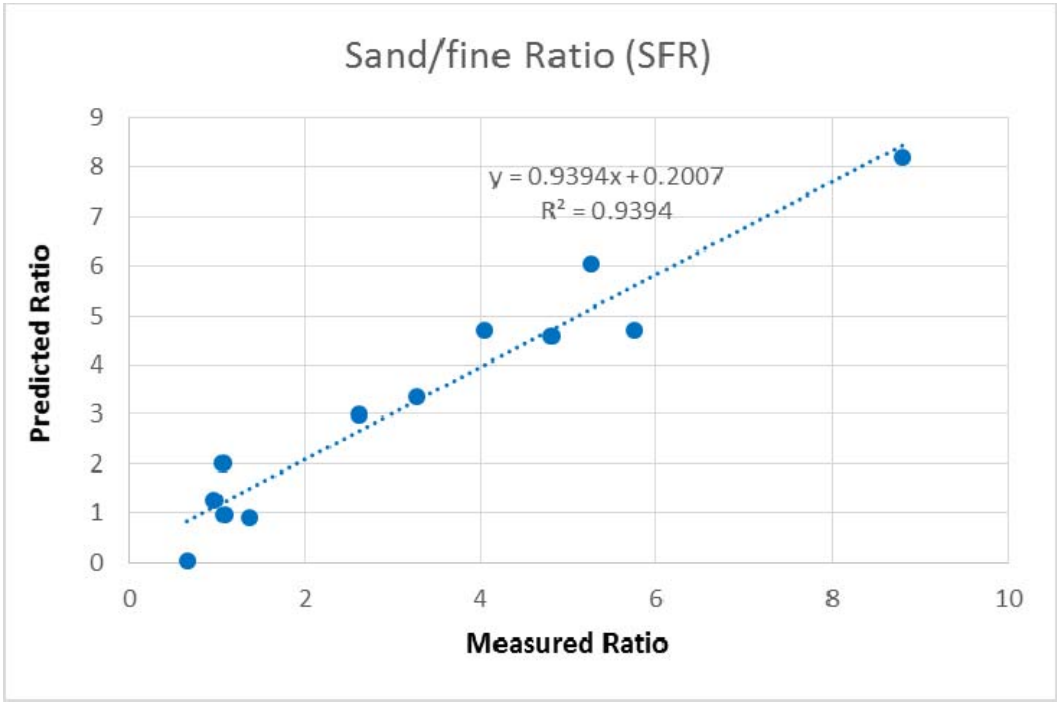








Prediction of Sand/fine Ratio (SFR)



Summary

- XRF can provide rapid measurement of elemental compositions.
- Some elements can be used as clay indicators in oil sands.
- Clay-related process variables can be predicted using multiple regression models based on XRF analysis.
  - Geochemical investigation is necessary to develop clay models.
  - Models are site specific.
- The method have a potential application in oil sands tailings.
- This work has been filed for a US provisional patent.