Mineralogical Aspects of Three Drill Cores Along the McArthur River Transect Using a Portable Infrared Spectrometer

J.B. Percival [1], K. Wasyliuk [2], T. Reif [3], S. Bernier [4], G. Drever [2], and C.T. Perkins [2]

Abstract

Detailed logging and infrared analyses of samples from three drill cores were completed during field activities in 2002 at the McArthur River mine site in northern Saskatchewan. Both FieldSpec Pro and PIMA-II portable spectrometers were used to determine mineralogy of the matrix in representative samples selected every 1.5 m. Spectral data from the FieldSpec Pro were converted to PIMA format and processed using the MINSPEC algorithm for semi-quantitative mineral analysis. Results for the three cores are highly comparable, although a separate algorithm is needed for processing FieldSpec Pro spectra.

Mineralogy distribution in each core is similar. The upper MFa and MFb members of the Manitou Falls Formation contain abundant kaolinite with subordinate dravite and chlorite. Illite is present in variable amounts. There is a sharp increase in illite content at the base of MFb. From there, illite gradually decreases to the unconformity as dickite concomitantly increases. The preservation of dickite, the regional diagenetic clay mineral, is due to intense silicification in MFc and MFd. Alteration minerals in basement rocks include chlorite and illite with minor kaolinite and dravite. Illite and chlorite reflect circulating hydrothermal fluids and dravite has been ascribed to mineralizing fluids. The clay mineral distributions are controlled by parameters such as porosity, permeability, and fluid pressures as well as fluid chemistry and follow lithological variations in the Manitou Falls Formation.

Keywords: *infrared spectroscopy, FieldSpec Pro, PIMA-II, clay mineralogy, dickite, kaolinite, illite, chlorite, dravite, McArthur River, uranium deposits.*

1. Introduction

Clay minerals are a major component of the sandstones and alteration haloes surrounding the world-class unconformity-type uranium deposits in the Athabasca Basin. Their genesis can be related to several processes including paleo-weathering, sedimentation, diagenesis and hydrothermal alteration. As sensitive indicators of a low temperature environment (Keller, 1970; Hoeve and Quirt, 1984), the composition, structure, and crystallinity of the clay minerals are controlled by temperature, fluid chemistry, and fluid flux. The nature and extent of alteration can provide valuable information about diagenetic/hydrothermal conditions and depth of burial in a sedimentary environment (Kisch, 1983; Percival *et al*., 1993).

This study forms part of a larger project, the EXTECH IV–Athabasca Uranium Multidisciplinary Study, which is an integrated partnership between the geological surveys of Saskatchewan, Alberta, and Canada, Cameco Corp., COGEMA Resources Inc., and the universities of Alberta, Laurentian, Regina, and Saskatchewan (Jefferson and Delaney, 2001). The main objective of this sub-project (Clay Mineralogy) is to use clay mineralogy to enhance the interpretation of stratigraphy, diagenesis, basement geology, geophysical surveys (i.e., gamma ray) and surficial geology, thereby assisting in the development of exploration tools and an improved geological framework for these deposits.

This report summarizes the results from fieldwork undertaken in June 2002 in the McArthur River area of northern Saskatchewan. During this time several drill cores were logged using Palm PDA's as described in Yeo *et al.* (2001). In addition, a portable infrared spectrometer (FieldSpec Pro FR, Analytical Spectral Devices, Inc.), newly acquired at the Geological Survey of Canada, was field tested in concert with Cameco's PIMA-II infrared spectrometer (Integrated Spectronics Ltd.).

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, ON   K1A 0E8; E-mail: jperciva@nrcan.gc.ca.
[2] Cameco Corporation, 2121 11th Street West, Saskatoon, SK   S7M 1J3.
[3] Office of Minerals and Energy Resources South Australia, 101 Grenfell Street, Adelaide, SA   5001.
[4] Department of Earth Sciences, Laurentian University, Ramsey Lake Road, Sudbury, ON   P3E 2C6.

2. Materials and Methods

Three drill holes, MAC-198, MAC-218, and RL-064, located along the high-resolution seismic transect of the P2 fault zone and the McArthur River mine area (Gyorfi *et al.*, this volume), were logged and systematically sampled (Figure 1). For stratigraphic purposes, observations were made for every 1 m interval and recorded on a hand-held Palm III PDA. Key parameters of interest include maximum transported grain size in millimetres (MTG), percent grains greater than sand (%>2 mm), aggregate thickness and type of intraclasts, percent matrix clay, silicification, and friability. More detailed discussion on the choice of parameters is given in Jefferson *et al.* (2001) and Bernier *et al.* (2001). In addition, the cores were also logged on a row-by-row basis and a representative sample was selected from each row for further analyses. The samples were split in the field, sun-dried and then analyzed *in situ* using both PIMA-II and FieldSpec Pro infrared spectrometers.

Both the PIMA-II and FieldSpec Pro instruments are field-portable infrared spectrometers that can provide rapid *in situ* qualitative to semi-quantitative clay mineral
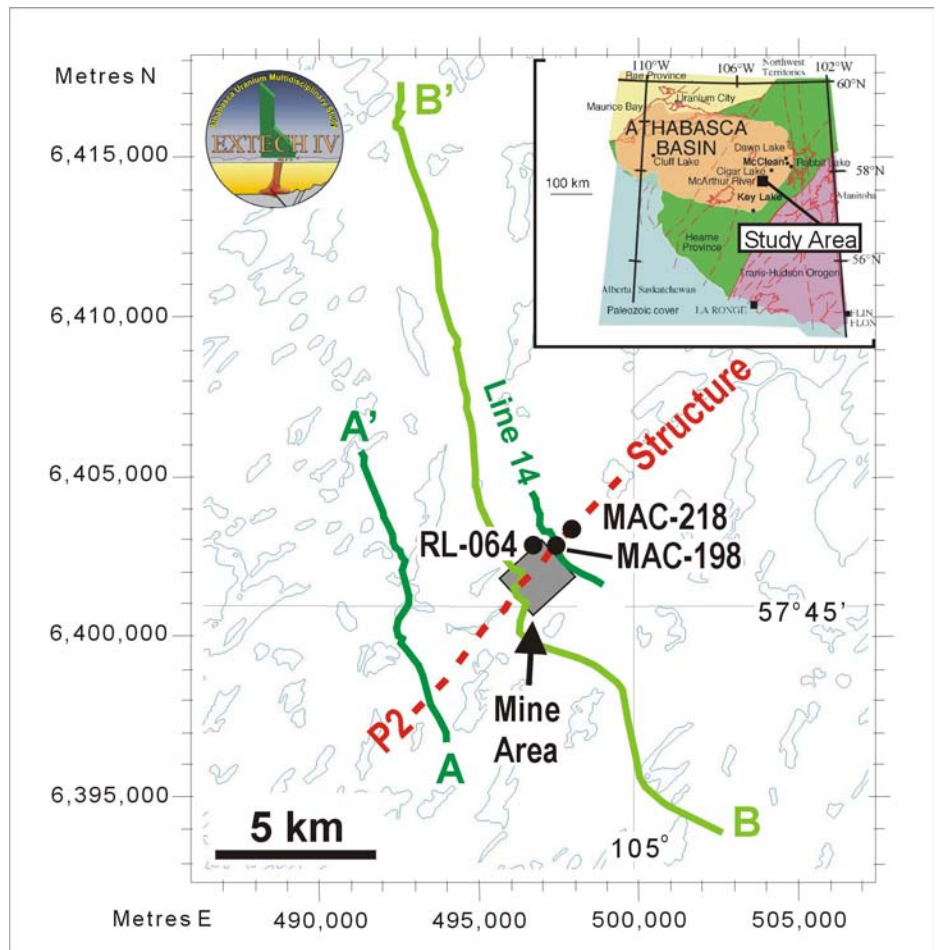

Figure 1 - Location of drill holes at the McArthur River uranium deposit. The regional seismic reflection lines, A-A' and B-B', are shown for context. The P2 North uranium deposit is located on the P2 Structure at about its intersection with line A-A'.

analyses. Infrared analysis is particularly useful in differentiating between the kaolin-group polymorphs, kaolinite and dickite, both of which occur in the Athabasca sandstones. The PIMA-II instrument measures reflectance wavelengths from 1300 to 2500 nm (short-wavelength infrared region or SWIR) and mineral identification is based on the wavelength position and shape of absorption peaks. Spectral data collected from Athabasca Group samples with known mineral proportions were used to develop an algorithm for semi-quantitative analyses (Earle, 1994, 1995, 1996). The mineral proportions were originally determined using XRD (Hoeve *et al.*, 1981). Estimates calculated from PIMA-II spectra are thus rapidly obtained for the common minerals present in the Athabasca Group, including illite, chlorite, dickite, kaolinite, and dravite (field term for microcrystalline blue tourmaline).

The FieldSpec Pro measures reflectance wavelengths from 350 to 2500 nm and includes the visible (350 to 780 nm), near infrared (780 to 1300 nm), and SWIR region (1300 to 2500 nm). Instrument specifications are listed in Table 1 for both spectrometers. Although the instruments operate with different detectors, other parameters are comparable. Spectral resolution for the PIMA-II is 7 nm for the SWIR region and for the FieldSpec Pro resolution ranges from 3 nm in the visible and near infrared range, and up to 10 in the SWIR region. PIMA-II uses more spectral channels for the SWIR than the FieldSpec Pro.

As the FieldSpec Pro is a relatively new acquisition, the software to process the spectra in a similar manner to the PIMA-II spectra is not yet available. In order to provide some preliminary estimates of mineral content, the spectra were processed in a somewhat convoluted manner. The spectra files were converted from the FieldSpec Pro format (350 to 2500 nm) to the PIMA format (1300 to 2500 nm) and then processed using Cameco's program MINSPEC (Earle, 1996). Preliminary results were compiled in a Microsoft Excel spreadsheet and then brought into Logview (Elliott *et al.,* 1996; Markarian *et al.*, 1996) for plotting purposes.

Table 1 - Instrument specifications for PIMA-II and FieldSpec Pro FR portable infrared spectrometers.

	PIMA-II	**FieldSpec Pro FR**
Detector	PbS	Si photo-diode 350 to 1000 nm InGaAs @1000 to 2500 nm
Wavelength Interval	1300 to 2500 nm	350 to 2500 nm
Spectral Resolution	~7 nm	3 nm @ 700 nm 10 nm @ 1400 and 2100 nm
Sampling Interval	2 or 4 nm (selectable)	1.4 nm @ 350 to 1050 nm 2 nm @ 1000 to 2500 nm
Spectral Channels	601	2148 512 @ 350 to 1000 nm 528 @ 1000 to 1800 nm 528 @ 1800 to 2500 nm
Sampling Time	20 to 60 s (mode dependent)	100 ms
Calibration	Automatic	Uses Spectralon disc

3. Results

Some of the key logging parameters are plotted for each drill core in Figures 2 to 4. Overall, grain size decreases upwards (see MTG and %>2 mm columns), beginning with interbedded conglomerate and sandstone with red mudstones, typical of the lowermost MFa member. The contact between MFa and MFb is interpreted as a disconformity (Bernier, this volume). At this boundary, the fluvial facies change upward from flat-laminated and cross-bedded sandstone to a coarser sandstone (even conglomerate) rich in cross-beds (trough?) but lacking flat-laminations (Bernier, this volume). Other differences between MFa and MFb are in the mudstones which are commonly red, desiccation-cracked, scoured and reworked as intraformational conglomerates in MFa, but grey or green, uncracked, non-scoured and rarely ripped-up in MFb. In all three cores, the MFd (upper member) is characterised by abundant intraclasts. Intraclasts are minor in MFb, although conglomerate beds are also abundant in MFb3.

Two of the three cores were observed to be intensely silicified (based on tombstone appearance). MAC-198 is highly silicified between 347 and 400 m and MAC-218 below 330 m. RL-064 is moderately silicified, but has no zone that is considered highly silicified.

Mineralogy of the matrix as determined using FieldSpec Pro and PIMA-II infrared spectrometers is plotted for each drill core in Figures 5 to 7. Overall, results for both instruments are comparable, although illite content appears to be slightly greater in the FieldSpec Pro data set, and dravite content more in the PIMA-II data set. In some samples, a kaolinite-dickite mixed layer clay mineral was determined, but to simplify the plots it was included as dickite.

In MAC-198, the upper part (<200 m) is dominated by kaolinite with variable amounts of chlorite (variety sudoite) and dravite. Minor to trace amounts of illite occur in some zones. Between 200 and 400 m, illite dominates and then decreases with depth as dickite content increases from 300 to 480 m. Below the unconformity, basement rocks contain abundant chlorite. MAC-218 shows a similar mineral distribution with depth. The upper section to the bottom of the MFd (<200 m), is dominated by kaolinite, chlorite, minor dravite and variable amounts of illite. Below this (in MFc), illite dominates but decreases with depth as dickite content increases. The basement rocks are chlorite-rich. Note that in both sections, there is a sharp change in mineralogy at or near the base of MFd.

Core RL-064 contains abundant kaolinite in the MFd unit (<200 m) but contains more variable amounts of chlorite. Dravite content increases in the lower part of MFd and in MFc; and the greatest proportions occur in an intraclast-rich zone. The change from kaolinite-dominant to illite occurs at the base of the MFc. From this point until the unconformity dickite is abundant in distinct zones. Basement rocks contain abundant illite and only traces of chlorite.

For each of these cores, large intraclasts were analysed separately. An example of their composition, in relation to the matrix composition is given in Table 2. There appears to be only a few samples that show any significant differences.

4. Discussion

In this study, the validity of the FieldSpec Pro data relative to the PIMA-II was tested, because the algorithm used to process the spectra was developed for the PIMA-II instrument. A series of standards were initially processed for this

Diamond Drill Hole Identification: **MAC-198**

UTM East	497350
UTM North	6402590
End of Hole	650
Overburden	13.1 m
Unconformity depth	484.5 m
Orientation	000 / -90
Drilling Year	1988
Property	CAMECO Corporation
Compilation date	2002-07-23
Data compilation	*Sebastien Bernier, M.Sc. Student (Laurentian University)*
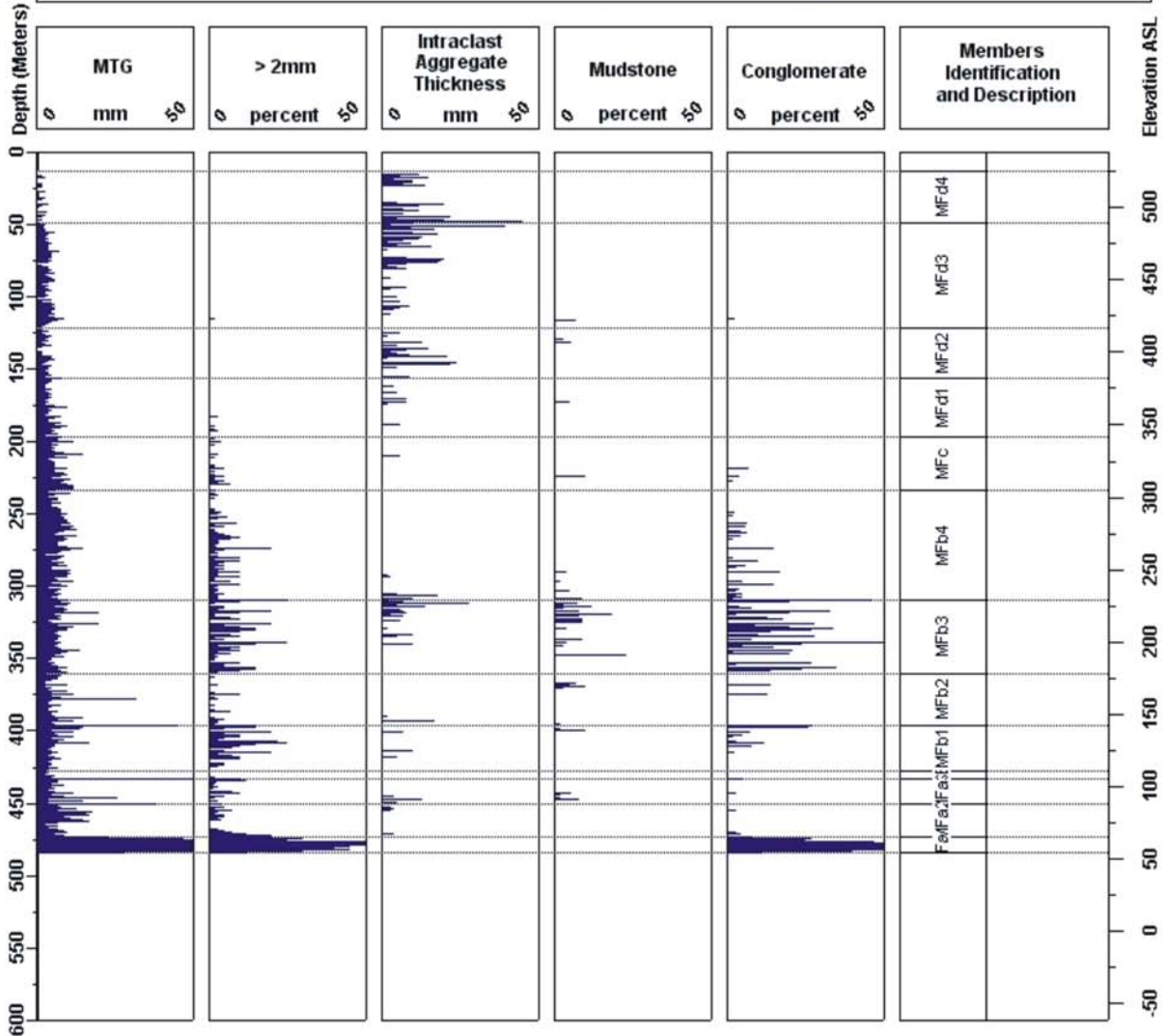
EXTECH IV

Based on a 1 m interval unit description and characterisation

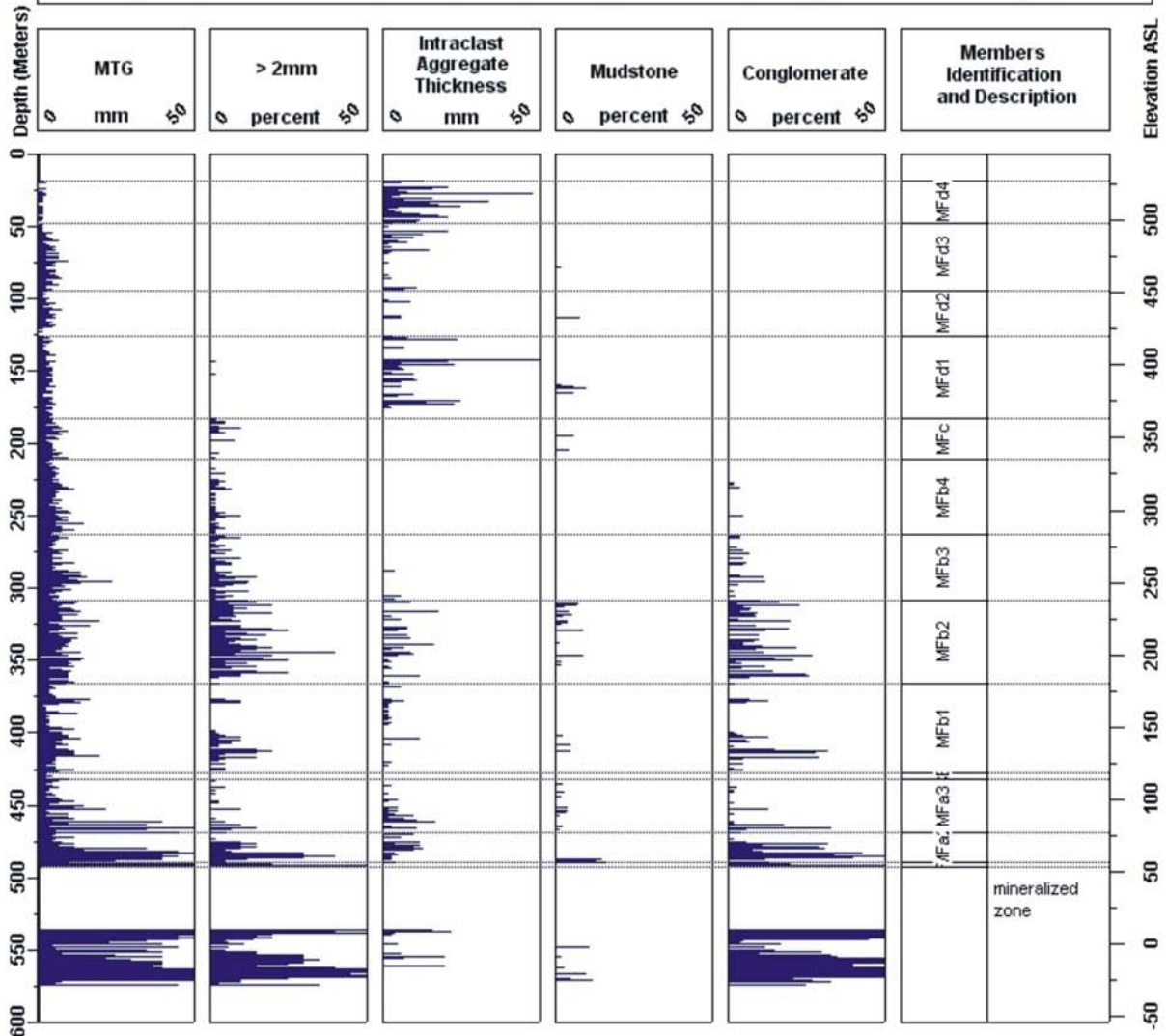EXTECH IV   MAC-198

Figure 2 - Plot of selected key logging parameters for drill hole MAC-198. Stratigraphic subdivisions after Ramaekers (1990) and Ramaekers et al. (2001).

Diamond Drill Hole Identification: **MAC-218**

UTM East	497567
UTM North	6402797
End of Hole	658 m
Overburden	19 m
Unconformity depth	493 m
Orientation	000 / -90
Drilling Year	1990
Property	CAMECO Corporation
Compilation date	2002-07-23
Data compilation	*Sebastien Bernier, M.Sc. Student (Laurentian University)*

EXTECH IV

Based on a 1 m interval unit description and characterisation

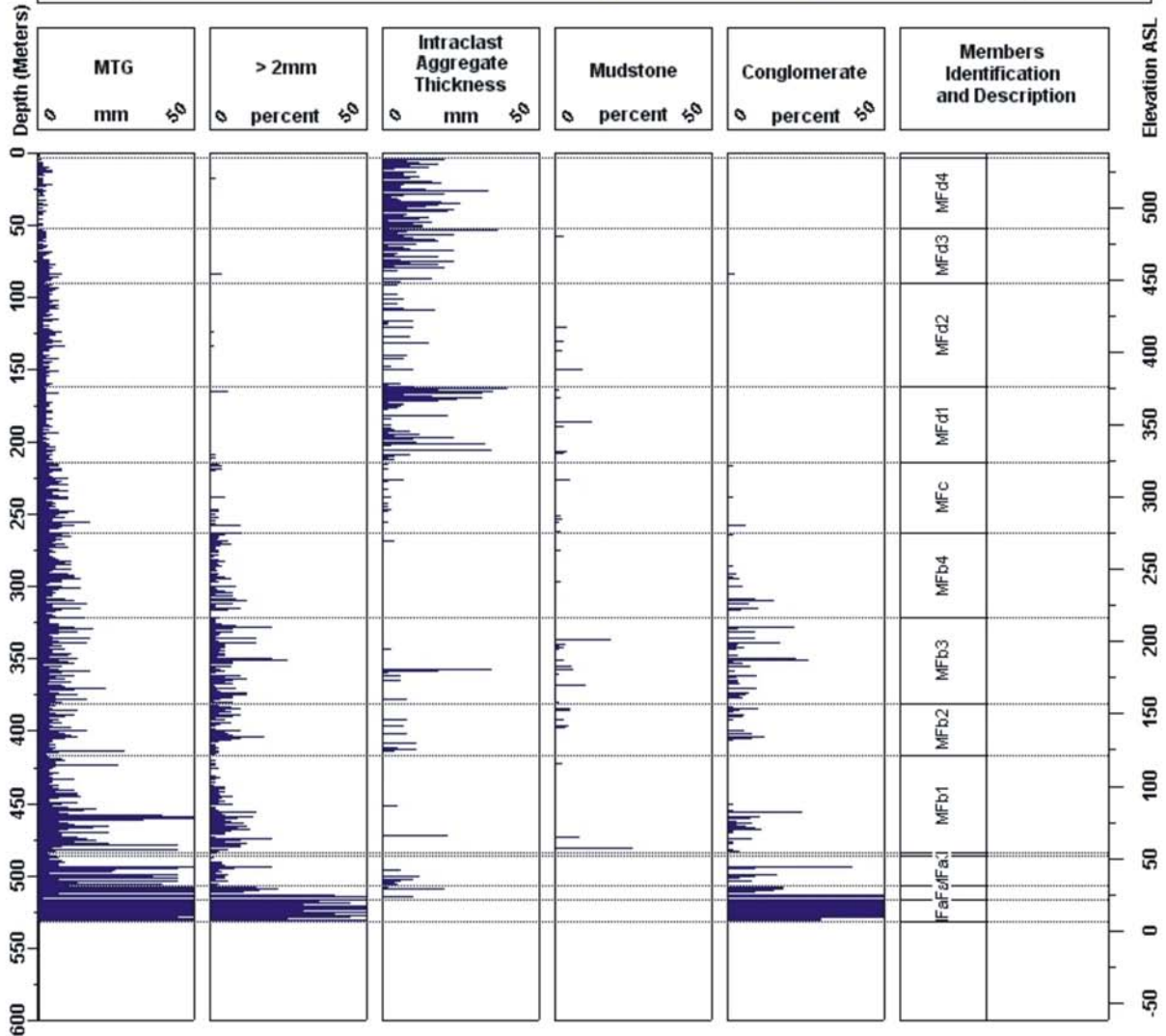EXTECH IV   MAC-218

Figure 3 - Plot of selected key logging parameters for drill hole MAC-218. Stratigraphic subdivisions after Ramaekers (1990) and Ramaekers et al. (2001).

Diamond Drill Hole Identification: **RL-064**

UTM East	496700
UTM North	6402350
End of Hole	554 m
Overburden	21.6 m
Unconformity depth	531.30 m
Orientation	000 / -90
Drilling Year	1989
Property	CAMECO Corporation
Compilation date	2002-07-02
Data compilation	*Sebastien Bernier, M.Sc. Student (Laurentian University)*

Based on a 1 m interval unit description and characterisation

EXTECH IV

RL-064

Figure 4 - Plot of selected key logging parameters for drill hole RL-064. Stratigraphic subdivisions after Ramaekers (1990) and Ramaekers et al. (2001).
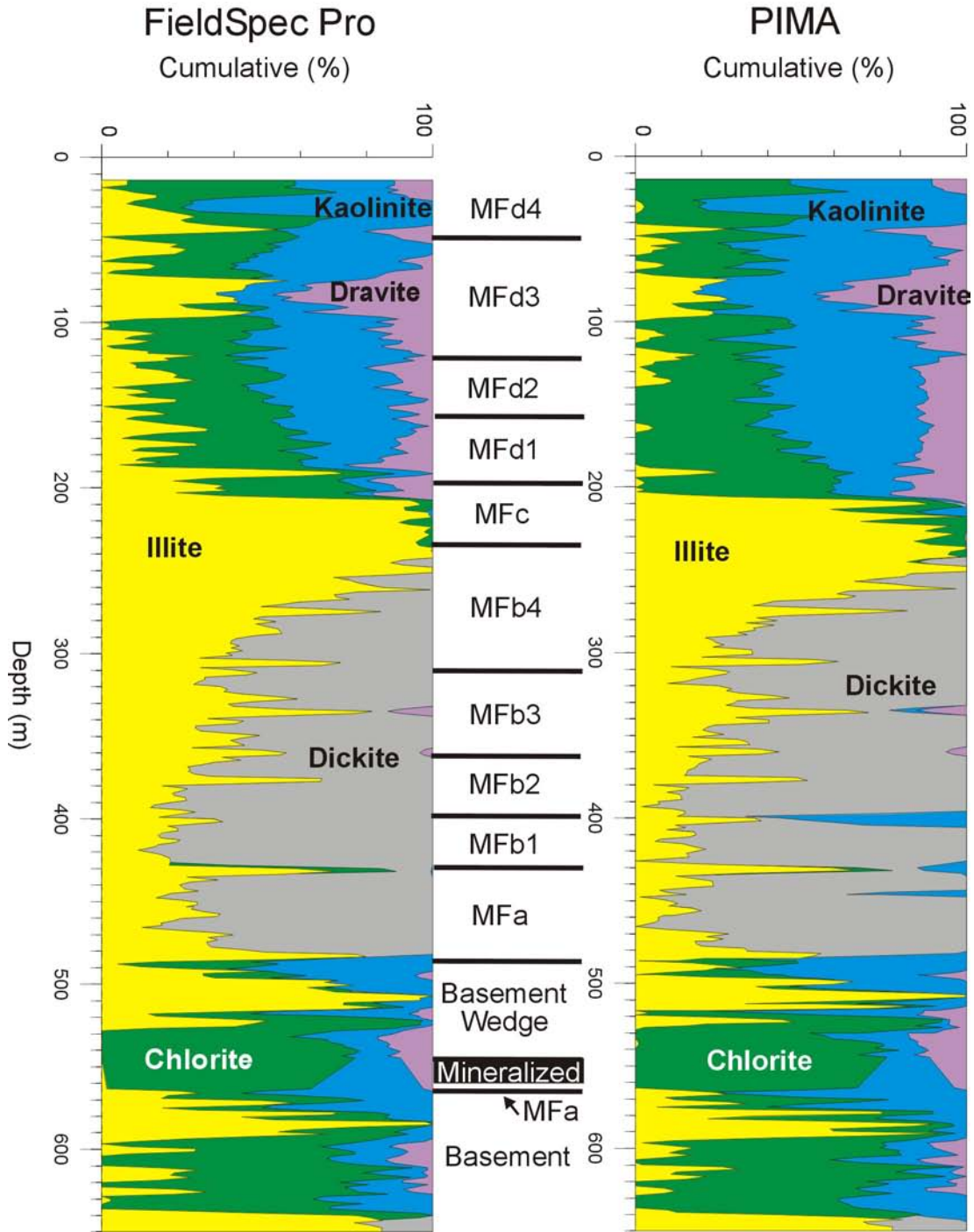
MAC-198

Figure 5 - *Mineralogy of the matrix of selected samples (every 1.5 m) plotted against depth for FieldSpec Pro and PIMA spectral data for MAC-198. Each column shows mineralogical data plotted as cumulative percent in order of illite, chlorite, dickite, kaolinite, and dravite. Each inflection point represents a sample.*
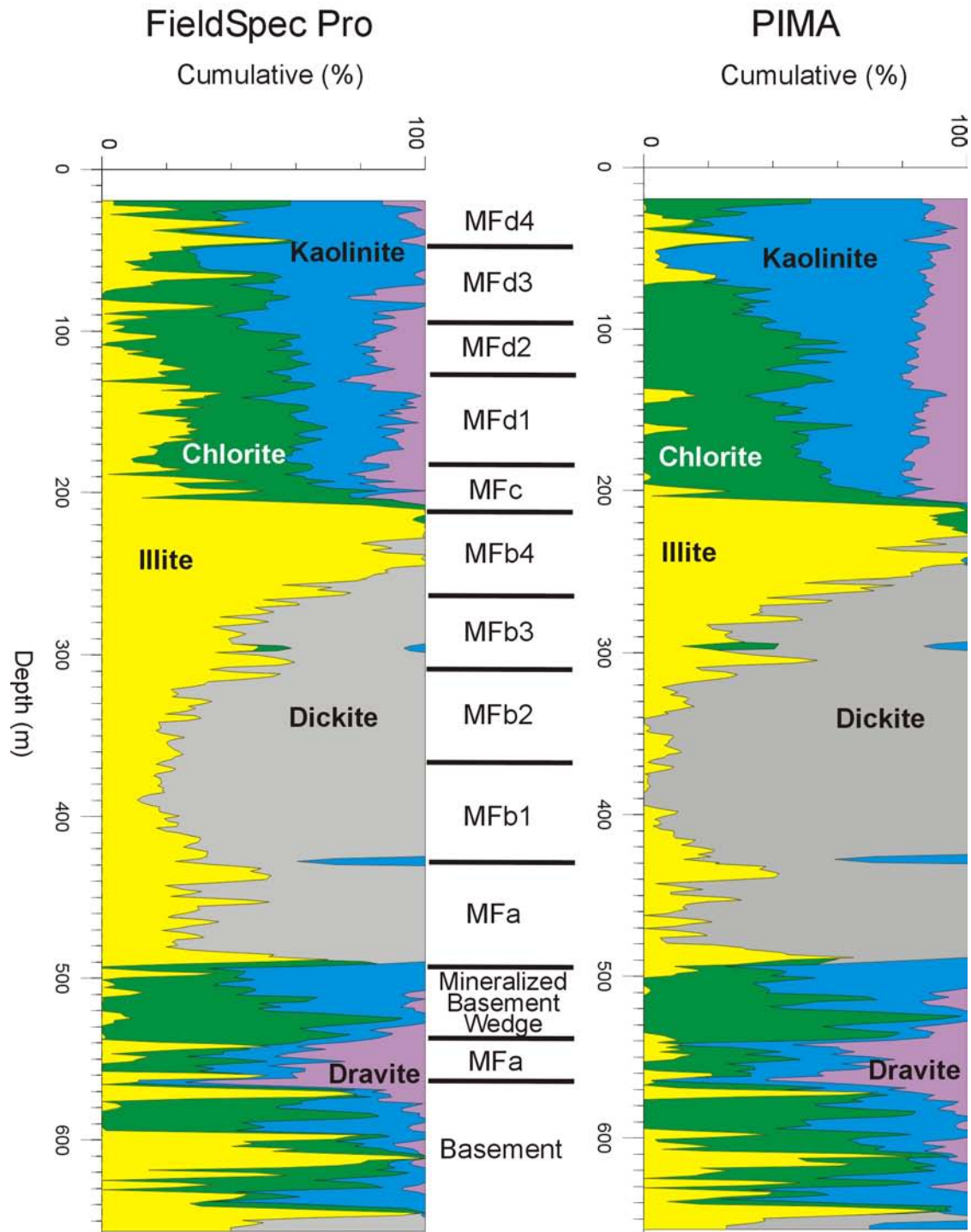
MAC-218

Figure 6 - Mineralogy of the matrix of selected samples (every 1.5 m) plotted against depth for FieldSpec Pro and PIMA spectral data for MAC-218. Each column shows mineralogical data plotted as cumulative percent in order of illite, chlorite, dickite, kaolinite, and dravite. Each inflection point represents a sample.
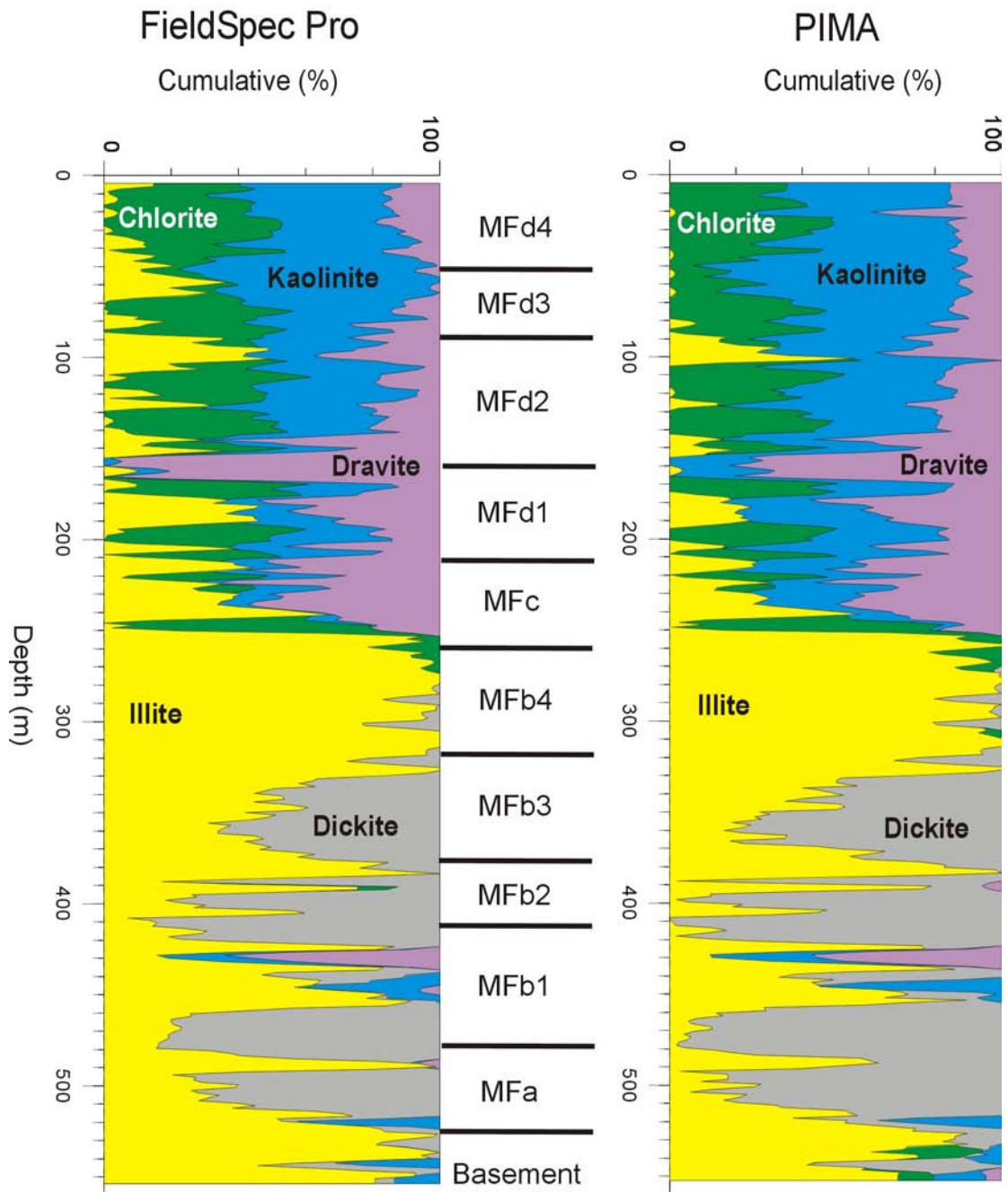
RL-064

Figure 7 - Mineralogy of the matrix of selected samples (every 1.5 m) plotted against depth for FieldSpec Pro and PIMA spectral data for RL-064. Each column shows mineralogical data plotted as cumulative percent in order of illite, chlorite, dickite, kaolinite, and dravite. Each inflection point represents a sample.

Table 2 - Comparison of mineralogy from selected samples showing variations between the matrix and large intraclasts for RL-064.

Depth (m)	Sample Type	Illite	Chlorite	Dickite	Kaolinite	Dravite
20.73	Intraclast	9	27	0	53	11
	Matrix	14	0	0	35	51
45.45	Intraclast	12	21	0	60	7
	Matrix	0	40	0	33	27
57.28	Intraclast	28	0	0	72	0
	Matrix	22	9	0	69	0
58.73	Intraclast	3	21	0	61	15
	Matrix	42	0	0	58	0
109.38	Intraclast	0	50	0	22	28
	Matrix	0	60	0	26	14
116.67	Intraclast	0	39	0	50	11
	Matrix	2	20	0	67	11
128.23	Intraclast	0	41	0	48	11
	Matrix	7	18	0	63	12
163.91	Intraclast	0	0	0	3	97
	Matrix	0	0	0	6	94
165.32	Intraclast	0	0	0	0	100
	Matrix	0	0	0	4	96
190.03	Intraclast	36	0	0	37	27
	Matrix	21	0	0	64	15
205.04	Intraclast	42	0	0	18	40
	Matrix	48	0	0	22	30
362.83	Intraclast	44	0	56	0	0
	Matrix	48	0	52	0	0

test. The FieldSpec Pro results showed that illite was overestimated by MINSPEC at the expense of other minerals, particularly chlorite and dravite. In turn, it has been previously noted that chlorite and dravite are in some cases overestimated with respect to illite by MINSPEC for PIMA spectra. True confirmation would come from X-ray diffraction analysis, however, a minimum amount (e.g., 2 to 3 wt %) is needed for detection and in some of these samples, there is less than 5% matrix.

As further validation, the normative clay mineralogy was plotted for each core in Figure 8. Normative mineralogy is based on major element chemistry (Al_2O_3, K_2O, MgO) of composite samples every 10 to 20 m (combined chips over the sampled interval). For MAC-198, there is a low but consistent amounts of illite in the upper 200 m, similar to the FieldSpec Pro results. Illite content peaks at about 250 m and steadily decreases with depth to the basement. Chlorite is in the upper unit as well as in the basement wedge. Kaolinite (here as undifferentiated kaolinite and dickite) dominates throughout the section. Dravite was not calculated, but its presence can be correlated to the B content (see Figure 9).

In contrast to MAC-198, the normative mineralogy calculations revealed MAC-218 does not have as much illite in the upper 200 m (Figure 8); this is more consistent with the PIMA results. Increase in illite in MFb and occurrence of chlorite are reflected in both of the infrared data sets. Kaolinite group minerals also dominate throughout the section.
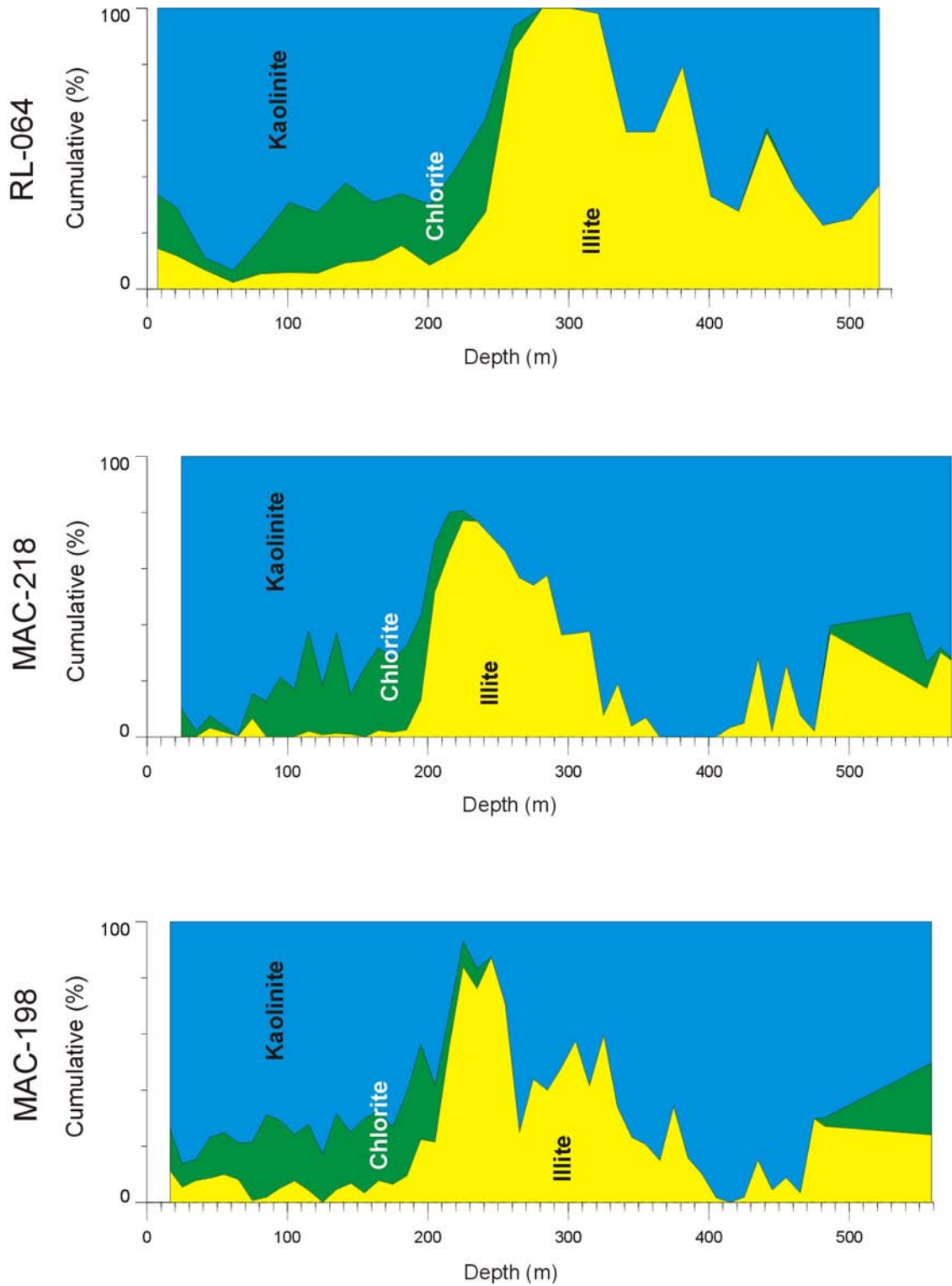
Figure 8 - Normative clay mineralogy calculations plotted against depth for MAC-198, MAC-218, and RL-064.
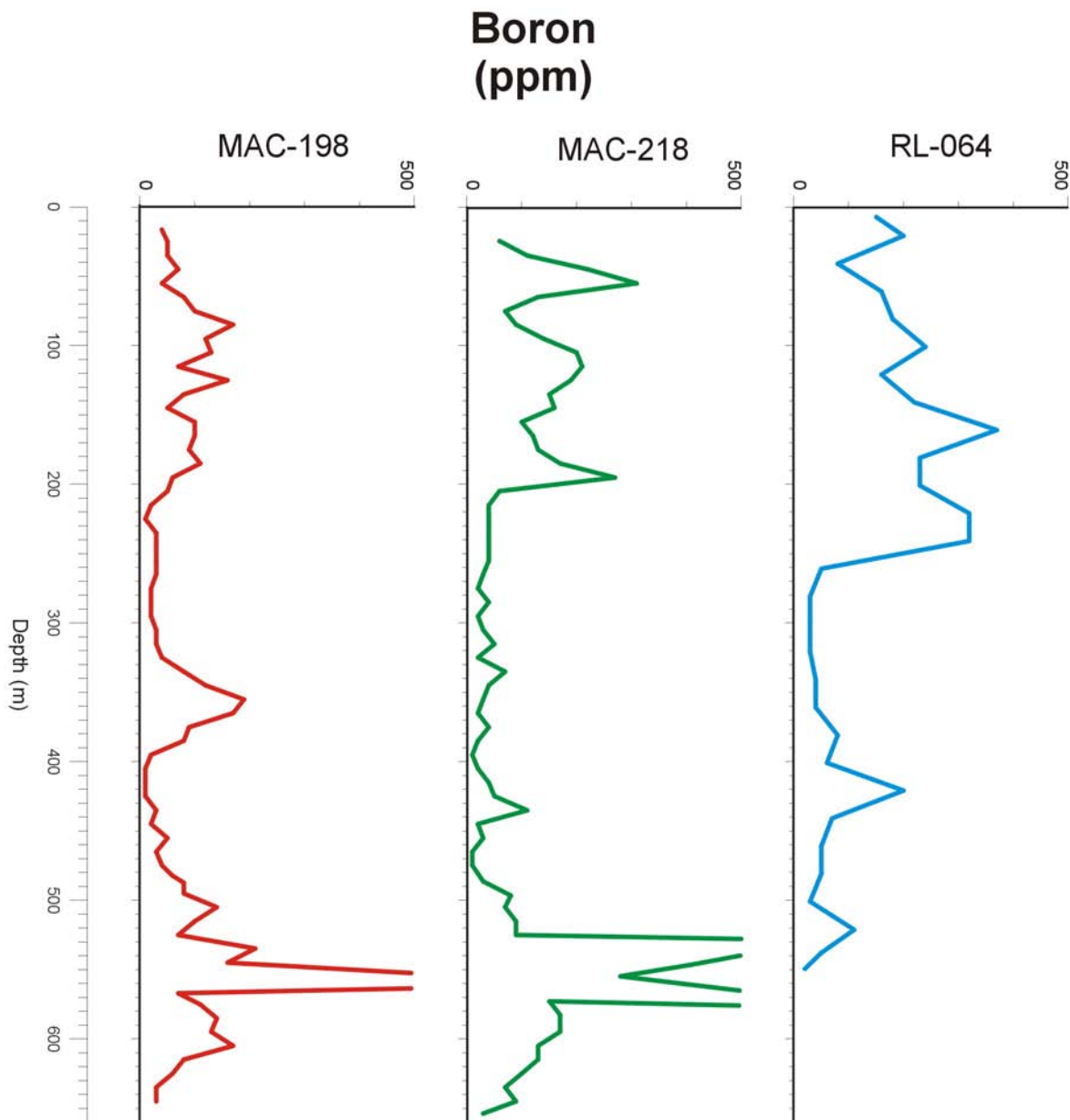
Boron
(ppm)

Figure 9 - Boron concentrations plotted against depth for MAC-198, MAC-218, and RL-064. Note that concentrations up to 500 ppm have been plotted for comparison purposes.

In core RL-064, the normative mineralogy trends are well represented in the infrared data plots. Illite, as in MAC-198, is in the upper 200 m in minor amounts and is most abundant in the middle part of the section. Chlorite content is variable and diminishes to zero at the bottom of MFc. Kaolinite minerals group dominate in the upper and lower parts of the core, as also shown in the FieldSpec Pro and PIMA data.

Regionally, the dominant clay mineral is dickite. Dickite is a result of the transformation from detrital kaolinite, typical of low temperature environments, to this higher temperature polymorph due to regional, high-grade diagenesis. Independent confirmation regarding the intensity of diagenesis in the Athabasca Basin is based on illite crystallinity studies (Hoeve *et al*., 1981; Hoeve and Quirt, 1984; Percival *et al.*, 1993; Quirt, 2000). According to Ruiz Cruz and Andreo (1996), in sedimentary basins dickite predominates in sandstones whereas kaolinite is in siltstones or mudstones. They suggested that the transformation is controlled not only by temperature, but also by permeability.

For all three cores, dickite is abundant in the MFb and MFa members. These units consist of medium- to coarse-grained sandstone interbedded with conglomerate; grain size increases with depth to the unconformity. These units also tend to be the most intensely silicified (as in MAC-198 and MAC-218). Kaolinite is in the MFd member, a

fine-grained sandstone, as well as in the basement below the unconformity (possibly related to the basement regolith, zone of intense paleo-weathering).

Dravite tends to be localized along fractures and faults. Dravite in other units has been ascribed to mineralizing fluids. Figure 9 plots Boron content with depth for the three cores. For comparison purposes, concentrations up to 500 ppm are plotted but in MAC-198 and MAC-218 concentrations range up to 1950 and 1300 ppm, respectively. Slightly elevated Boron concentrations (background <20 ppm) correspond to dravite as shown in Figures 5 to 7 (see also Zhang *et al.*, 2001). In the basement, there is an intense Boron anomaly associated with mineralization, but this is not reflected in the infrared data. For MAC-198 and MAC-218, the high concentration of chlorite may interfere in the calculation of dravite due to their peak positions. Chlorite in the basement is clinochlore, not sudoite. In addition, the signal/noise ratio for the basement samples is noticeably low (<10) due to their darker colour.

Illite and chlorite in the core reflect circulating hydrothermal fluids. Earle and Sopuck (1989) attributed a regional illite anomaly to hydrothermal alteration along major structural features extending from McArthur River to Key Lake. Clay mineral distributions are controlled by parameters such as porosity, permeability, and fluid pressures as well as fluid chemistry. Subtle variations are related to stratigraphically or structurally controlled small-scale porosity/permeability contrasts (Wasyliuk, 2002).

5. Summary

The trends in clay mineralogy with depth, in all three cores are similar, reflecting their geographic proximity. In general, the clay mineral distributions surrounding the McArthur River deposit are controlled structurally and lithologically by the porosity and permeability characteristics of the Manitou Falls Formation and its individual members. Regional dickite with lesser illite has been altered to illite and kaolinite/dravite/chlorite and zoned similar to Key Lake (Earle *et al.*, 1996). However, zonation has been inverted due to the affects of an early silicification event in the lower sandstone immediately above the mineralization.

Subtle differences in the spectra between the PIMA-II and FieldSpec Pro instruments resulted in some discrepancies in the semi-quantitative clay estimates using the MINSPEC algorithm. This suggests that separate algorithms need to be derived for both instruments. This does not imply that infrared (SWIR) spectroscopy cannot be used to quantify clay or alteration minerals. The use of SWIR to quantitatively estimate clay or mineral proportions is relatively new. However, recent studies (Zhang *et al.*, 2001) have shown that high-quality, quantitative results can be obtained provided that peak resolution is established using the appropriate mineral standards, and that artificial mixtures can be created and used to develop the best-fit algorithms.

6. Acknowledgments

7. References

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