A Preliminary Comparison of Manitou Falls Formation Stratigraphy in Four Athabasca Basin Deposystems

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Abstract

The stratigraphy of the Manitou Falls Formation is remarkably consistent among the three deposystems in the northern, eastern, and southern parts of the late Paleoproterozoic Athabasca Basin. The Athabasca deposystems were originally defined on the basis of paleocurrent patterns, prior to development of the basin stratigraphy. They are here re-defined as unconformity-bounded sedimentary tongues with a consistent sediment dispersal pattern and lithostratigraphy. The Moosonees, Ahenakew, and Karras deposystems comprise only Manitou Falls strata, and the latter deposystem is now extended westward to include Manitou Falls strata formerly included in the Bourassa deposystem. Four lithostratigraphic members are recognized in each deposystem. The MFa member comprises conglomerate and sandstone with distinctive low-angle cross-lamination. The upper MFa sandstone appears to be traceable across the basin. The MFb member is distinguished by conglomerate beds >2 cm thick. It is widespread, except in western Karras deposystem. The MFc member is a relatively clean sandstone with scattered pebbles. Anomalous local thickening of this member in all three deposystems suggests syndepositional basin subsidence. The MFd member is characterized by relatively abundant (>1%) clay intraclasts, which become less common to the west. An MFc-like, pebbly sandstone sub-unit is common in the lower part of this member throughout much of the basin, but dies out to the west. The lower and upper contacts of the formation are regional unconformities, and hence, sequence boundaries. The MFa-MFb contact is a local unconformity, but more work is needed to demonstrate that it is a regional one.

Keywords: *Proterozoic stratigraphy, Athabasca Basin, Manitou Falls Formation, deposystem.*

1. Introduction

Some of the world's richest unconformity-type uranium deposits are associated with the late Paleoproterozoic Athabasca Basin (Figure 1). The basin contains about 1750 m of little deformed, mainly clastic strata, which comprise the Athabasca Group. The age of these strata is poorly known, but intensive erosion and deep weathering of the crystalline basement rocks prior to deposition indicate it is much younger than their 1.75 to 1.78 Ga youngest retrograde metamorphic age (Annesley *et al.*, 1997). A maximum age constraint for the upper Athabasca Group is provided by the 1.66 Ga detrital zircon suite reported from the Wolverine Point and Douglas formations (Rainbird *et al.*, this volume).

The EXTECH IV Athabasca Uranium study was initiated in 2000 as a multidisciplinary study involving industry, geological survey, and university partnership to improve our understanding of the Athabasca Basin and its uranium deposits, and to develop new technologies and strategies for exploration in the basin.

Field work on regional stratigraphy in the third year of the project included measurement of cross-bed foreset orientations in oriented core (3D paleocurrent studies) from Dawn Lake, McClean Lake, La Rocque Lake, and Cigar Lake in the eastern Athabasca Basin and systematic logging (Yeo *et al*., 2001a) of eight cores (Figure 1): WF-37 and WF-41 at Alligator Lake, the deepest cores yet examined in the northern Ahenakew deposystem; CL-233 at Cigar Lake; CLG-D5 and SLG-D6 on the "Virgin River Trend" in the northern Moosonees deposystem; DF-66 and MC-4, also on the "Virgin River Trend", but in the Karras deposystem; and DGS-4B on the southern rim of the Carswell Structure. Results of the paleocurrent studies are generally consistent with outcrop measurements by Ramaekers (1976), but are not reported here. The new cores allow a relatively detailed comparison of the three deposystems around the northern, eastern, and southern periphery of the Athabasca Basin (Figure 1). This paper is a preliminary comparison of the stratigraphy of the Manitou Falls Formation in the three deposystems, and a step towards development of a deposystem-based stratigraphy.

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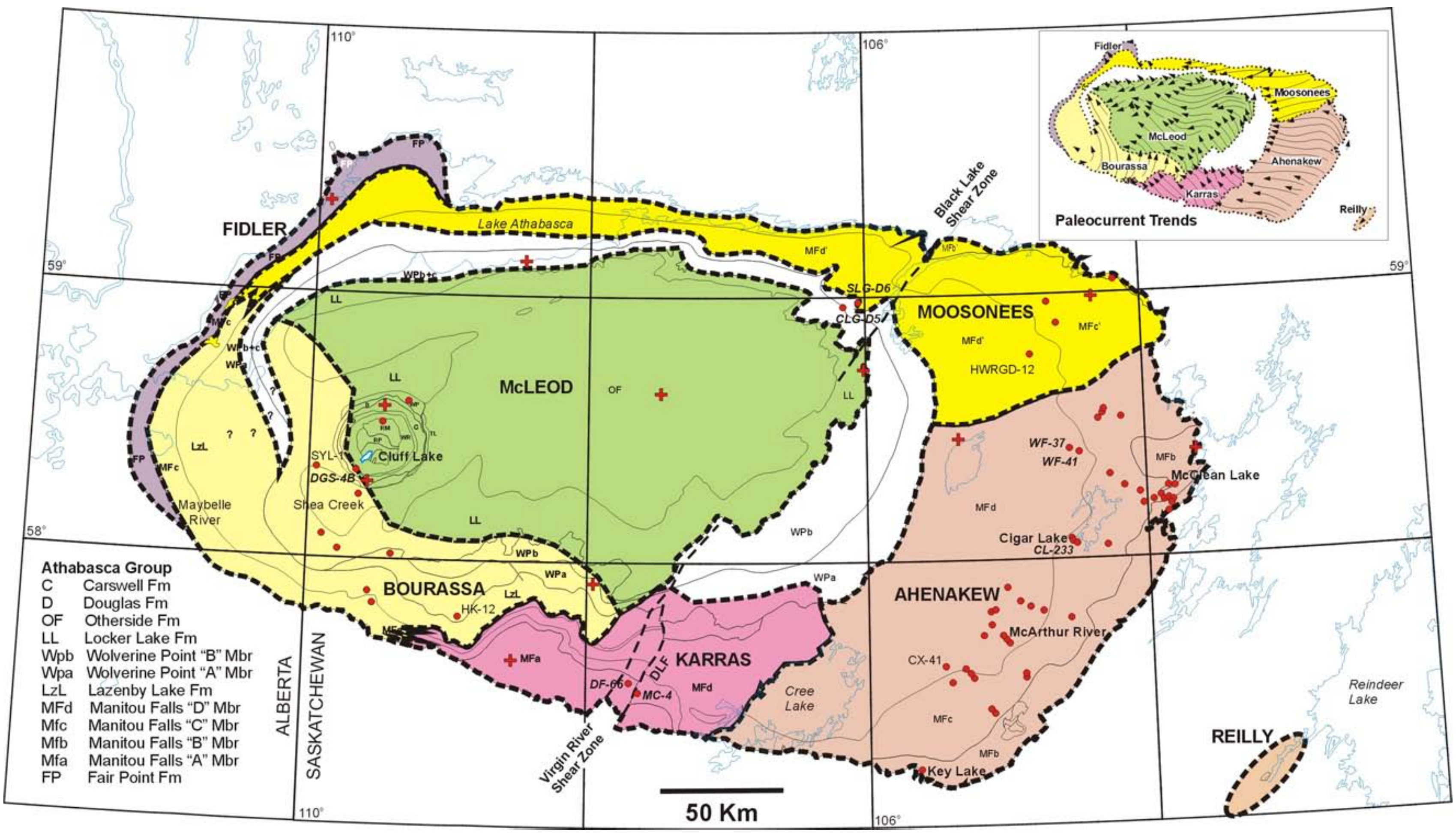

Figure 1 – Geological sketch map of Athabasca Basin (after Ramaekers et al.*, 2001) showing outlines of the seven deposystems (as originally defined; not as re-defined in this report) and locations of cores logged in Saskatchewan as part of the EXTECH IV regional stratigraphy sub-project. Most cores logged as part of detailed studies at McArthur River (Bernier* et al.*, 2001; Bernier, this volume), Shea Creek (Collier* et al.*, 2001, Collier, this volume), McClean Lake, and Key Lake (Long* et al.*, 2000, Long, 2001) have been omitted for clarity. Cores logged in the 2002 field season are labelled in bold type; other cores referred to in this paper are in plain type. Locations of type sections (Ramaekers, 1979, 1990) are indicated by crosses. DLF=Dufferin Lake Fault.*

As used in this paper, "deposystems" (depositional systems) are unconformity-bounded sedimentary tongues within a basin, distinguished on the basis of sediment dispersal pattern, lithostratigraphy, and depositional history. The six main deposystems of Athabasca Basin were originally distinguished on the basis of mapping (Figure 1; Table 1; Ramaekers, 1976, 1977, 1978b) before the Athabasca stratigraphy was subdivided. Unconformities within the succession were not considered. The main practical difference, as here re-defined, is subdivision of the original Bourassa deposystem into two unconformity-bounded parts. The lower one, the western Karras deposystem, comprises only the Manitou Falls Formation, and is probably continuous with the Karras deposystem to the east. The name, Bourassa deposystem, is retained for the upper one, but it is now restricted to the Lazenby Lake–Wolverine Point succession.

2. The Manitou Falls Formation

As part of the EXTECH IV stratigraphy sub-project, current ideas about the regional stratigraphy of the Athabasca Basin (Table 2) have recently been reviewed by Ramaekers *et al.* (2001). The stratigraphy of parts of the Ahenakew deposystem (Yeo *et al*., 2000; Jefferson *et al*., 2001), including Key Lake (Collier and Yeo, 2001), McArthur River (Bernier *et al*., 2001; Bernier, this volume), and McClean Lake (Long *et al*., 2000; Long, 2001) and Karras deposystems (Yeo *et al*., 2001), including Shea Creek (Collier *et al*., 2001; Collier, this volume), has been described, but the Karras and northern Moosonees deposystems have received less attention. This paper attempts to address that knowledge gap.

The Manitou Falls Formation (Table 2) is the most widespread unit in the basin, and hosts or immediately overlies most of the known uranium deposits, except Maybelle River. It is recognized in three of the peripheral deposystems of the Athabasca Basin, but there is much stratigraphic variability among these. The type section is in the Moosonees deposystem along the Fond-du-Lac River (Ramaekers, 1979, 1990), but only the MFc member is exposed there. For this reason, a series of reference sections were designated for the other three members that were informally distinguished within the formation on the basis of lithology (Ramaekers, 1979, 1990; Figure 1). The Manitou Falls Formation rests on crystalline basement over most of the basin, but disconformably on the Fair Point Formation in the western basin (Table 2; Ramaekers, 1990; Ramaekers *et al*., 2001; Yeo *et al*., 2001b). Interstitial clay is common, but much less than in the Fair Point Formation, and overall decreases upward.

Table 1 - Distribution of formations and sediment transport directions in the seven Athabasca deposystems. Note that "deposystem" is used here in the sense of an unconformity-bound sedimentary tongue, rather than an area distinguished primarily on the basis of sediment dispersal pattern as observed in outcrop (e.g., Figure 1). The four unconformity-bounded sequences that comprise the Athabasca Group (Yeo *et al.*, ***2002) are numbered. The MFa member may constitute a fifth sequence.***

	Formation	Abbreviation	DEPOSYSTEMS						
			Fidler	**McLeod**	**Bourassa**	**Karras**	**Ahenakew**	**Moosonees**	**Reilly**
4	Carswell	C		**x**					
	Douglas	D		**x**					
	Otherside	O		**x**					
	Locker L.	LL							
3	Wolverine Pt. B	WPb			**x**				
	Wolverine Pt. A	WPa			**x**				
	Lazenby L.	LzL			**x**				
2	Manitou Falls D	MFd				**x**	**x**	**x**	
	Manitou Falls C	MFc				**x**	**x**	**x**	
	Manitou Falls B	MFb				**x**	**x**	**x**	**?**
	Manitou Falls A	MFa				**x**	**x**	**x**	**?**
1	Fair Pt.	FP	**x**						
	Paleoflow direction		*NW*	*W*	*N*	*NW*	*WNW*	*WSW*	*SW*

Table 2 – Lithostratigraphy of the Athabasca Basin (after Ramaekers et al., 2001).

Sequence	Formation	"Member"	Lithology
Locker Lake–Carswell	Carswell	CF	Dolostones; stromatolites, ooids, and synsedimentary breccia common
	Douglas	DF	Very fine sandstones, siltstones, black, red, and green mudstones; load casts, mud and syneresis cracks common
	Otherside	OFa	Fine sandstones; MTG < 2 mm; clay intraclasts
		OFb	Fine sandstones with granules and pebbles < 8 mm; clay intraclasts
	Locker Lake	LLc	Fine to coarse pebbly sandstones; minor silt and mudstones; MTG 8 to 16 mm
		LLb	Fine to coarse pebbly sandstones; minor silt and mudstones; MTG >16 mm; horizontal and low-angle crossbedding
		LLa	Fine to coarse pebbly sandstones; minor silt and mudstones; MTG 2 to 16 mm
	unconformity		
Lazenby Lake–Wolverine Point	Wolverine Point	WPc	Very well-sorted, clay-rich, fine to medium sandstone, minor siltstone and mudstone
		WPb3	Very fine to medium sandstone, mudstone thicker than 20 cm, tuffaceous relicts; small intraclasts in thin beds
		WPb2	Very well-sorted, clay-rich, fine to medium sandstone, minor siltstone and mudstone
		WPb1	Very fine to medium sandstone, mudstone thicker than 20 cm, tuffaceous relicts; small intraclasts in thin beds
		WPa2	Very fine to coarse sandstones
		WPa1	Very fine to coarse sandstone, minor thin siltstone and mudstone
	Lazenby Lake	LzL	Basal thin conglomerate, pebbly and coarse to fine sandstones
	unconformity		
Manitou Falls	Manitou Falls	MFd	Fine to medium sandstone; clay intraclasts >2% of rock
		MFd'	Fine to coarse sandstone; pebbly sandstone; intraclasts >2% of rock (Moosonees deposystem)
		MFc	Medium to coarse and pebbly sandstone; intraclasts <2% of rock
		MFc'	Medium to coarse and pebbly sandstone; minor silt and mudstone; intraclasts <2% of rock (Moosonees deposystem)
		MFb	Medium to coarse sandstone, pebbly sandstone, conglomerate
		MFa2	Pebbly sandstone and conglomerate; horizontal and low-angle crossbedding common
		MFa1	Fine to coarse sandstone with disseminated pebbles, mudstones; horizontal and low-angle crossbedding common
		MFa0	Basal conglomerate: disseminated or bedded pebbles to boulders in sandstone
	unconformity		
Fair Point	Fair Point	FPc	Pebbly sandstone, sandstone; MTG <50 mm; horizontal and low-angle crossbedding common
		FPb2	Pebbly sandstone, sandstone, thin conglomerates; MTG >50 mm; horizontal and low-angle crossbedding common
		FPb1	Conglomerate and sandstone; horizontal and low-angle crossbedding common
		FPa	Conglomerate, pebbly sandstone, sandstone, siltstone; horizontal and low-angle crossbedding common
	Basal lag		Disseminated or bedded pebbles to boulders in sandstone

The MFa member is the most variable of the formation. It was originally defined as a series of interbedded pebble conglomerates and sandstones, locally with abundant clay intraclasts (Ramaekers, 1990). Pebbly sandstones and siltstones are also common, and low angle cross-bedding is conspicuous (Ramaekers *et al*., 2001). It is reported to be up to 600 m thick (Ramaekers, 1990), but this study describes much thinner sections east of the type area. The conglomerate commonly found at the base of the Manitou Falls Formation is here included in the MFa member because it is interlayered with the overlying sandstone in open pit exposures and in drill core along the McArthur River–Key Lake corridor (e.g., Long, 2000; Yeo *et al*., 2000; Bernier *et al*., 2001; Jefferson *et al*., 2001). Other workers have treated the basal conglomerate separately (e.g., Ramaekers, 1990; Ramaekers *et al*., 2001; Collier *et al*., 2001; Yeo *et al*., 2001b), because in places it may be much older than overlying strata (Ramaekers, 1990; Collier, this volume). Three sub-members have been distinguished (Table 2), the basal conglomerate (MFa0), which locally includes talus deposits with sieve structure, an interbedded and overlying siltstone-bearing unit (MFa1), mainly restricted to southeastern Athabasca Basin, and a widespread, relatively siltstone-free unit (MFa2). The MFa-MFb contact is laterally variable. At least locally in the eastern Ahenakew deposystem, such as in the Key

Lake and Sue pits and some drill holes at McArthur River, it is an unconformity (Long, 2001; Bernier, this volume). In the western Ahenakew deposystem it appears to be conformable (Jefferson *et al*., 2001), but sharp, with a remarkably continuous, thin, pebble-free sandstone (MFa4 member of Bernier, this volume) separating MFa2 conglomerates from MFb conglomerates. The reference section for the MFa member is DDH CSP 6-1 (Ramaekers, 1990). MFa strata are interpreted to be an assemblage of sheet flood and ephemeral lake deposits, overlying local talus aprons derived from paleotopographic highs, deposited in a relatively arid climate (Long *et al*., 2000, Yeo *et al*., 2000; Long 2001; Jefferson *et al*., 2001).

The MFb member is also characterized by interbedded sandstone and conglomerate (Ramaekers, 1990). It is arbitrarily distinguished from sandstones above and below by the presence of at least 2% of clast-supported conglomerate in beds at least 2 cm thick (Ramaekers, 1990; Ramaekers *et al*., 2001). The conglomeratic parts of MFa are very similar to those of MFb, but with a relatively finer overall mode. Ramaekers (1990) recognized the presence of two conglomerate-bearing intervals separated by sandstones over much of the eastern Athabasca Basin. The reference section for the MFb member is at Cunning Bay on Wollaston Lake in the Ahenakew deposystem (Ramaekers, 1979, 1990). MFb strata are interpreted to have been deposited in an alluvial braid-plain characterized by broad channels in a relatively humid climate (Long *et al*., 2000; Jefferson *et al*., 2001).

The MFc member is characterized by relatively clean (i.e., conglomerate-free), medium to very coarse-grained sandstones (Ramaekers, 1990). Although one-grain-thick pebble or granule layers are common, especially in the lower part, conglomerate beds thicker than 2 cm are absent. Intraclast-rich layers constitute less than 1% of the sandstone. Thin mudstone beds are typical, but not common outside the Moosonees deposystem. In the western Karras deposystem, a well-sorted, pebble- and intraclast-free sub-unit is distinguished in the lower part of the MFc member (Ramaekers *et al*., 2001). In the Moosonees deposystem, the entire member is heterogeneous, comprising thinly interbedded coarse granule-rich sandstone, thin, fine to very fine sandstones, siltstones, and mudstones (the MFc' member of Ramaekers *et al*., 2001). The MFb-MFc contact is transitional, and the lateral transition between MFc and MFc' is gradational. As noted above, the reference section for the MFc member (i.e., the MFc' member) is on the Fond-du-Lac River in the Moosonees deposystem (Ramaekers, 1979, 1990). MFc strata are interpreted to have been deposited in a distal alluvial braid-plain lacking well-developed channels, in a humid climate (Yeo *et al*., 2000; Jefferson *et al.*, 2001).

The MFd member is characterized by relatively well-sorted, fine- to coarse-grained sandstones with abundant intraclasts. The key change from MFc is an abrupt increase in intraclast abundance. The member was originally defined as having more than 1% clay intraclast-rich layers (Ramaekers, 1990), however, Ramaekers *et al*. (2001) suggested the cut-off should be 2% intraclasts. This works best in the eastern deposystems whereas 1% or less would be a better cut-off towards the west. Intraclasts increase in abundance upwards. Intraclast-rich beds alternate with intraclast-poor ones on a metre to decametre scale, especially in the lower part (Ramaekers *et al*., 2001). In spite of the abundance of clay intraclasts, interstitial clay content is relatively low in this member. More coarse-grained pebbly sandstones with abundant intraclasts in Moosonees deposystem are distinguished as the MFd' member (Ramaekers *et al*., 2001). The MFc-MFd contact is transitional (Ramaekers, 1990). Pebbles of probable Manitou Falls sandstone in the overlying Lazenby Lake Formation indicates that the MFd–Lazenby Lake contact is a disconformity (Ramaekers, 1980, 1990). The reference section for the MFd member lies northeast of Pasfield Lake, near the transition between the Ahenakew and Moosonees deposystems (Ramaekers, 1979, 1990). The depositional environment is thought to have been similar to that of MFc, but in a somewhat drier climate, as indicated by the clay intraclasts (Jefferson *et al*., 2001).

3. Athabasca Basin Deposystems

As noted in the preceding parts (Figure 1; Table 1), six deposystems are recognized in the Athabasca Basin, and a seventh small one to the east is evidence that the basin was formerly more extensive.

The Fidler deposystem (Ramaekers, 1978b) comprises the Fair Point Formation, the oldest unit preserved in Athabasca Basin. It is restricted to its western-most (Jackfish) sub-basin. Sediment transport as measured in outcrops on the western side of Lake Athabasca was apparently westerly to northwesterly, but pebbles of red sandstone resembling that of the Martin Formation north of Lake Athabasca are common.

The Bourassa deposystem (Ramaekers, 1978a; Ramaekers *et al*., 2001) lies in the southwest part of the basin. It is defined on the basis of northeasterly directed paleocurrents. As noted above, the Manitou Falls Formation formerly included in the Bourassa deposystem is here included in the western Karras deposystem.

The McLeod deposystem (Ramaekers, 1978b) occupies the central part of the basin, and is here restricted to the youngest (post-Wolverine Point) basin fill. Sediment transport was generally westerly, but variability is higher than in the other deposystems.

The Reilly deposystem (Ramaekers *et al*., 2001) is restricted to an outlier of the Athabasca Group at the southwest end of Reilly Lake, an arm of Reindeer Lake. Strata there are lithologically similar to those of the MFa or MFb members (Ramaekers 1981, 1990) and sediment transport was southwesterly, parallel to basement structural grain, in contrast with the Ahenakew deposystem further west (Ramaekers *et al*., 2001). This strata might represent a paleo-valley fill with dispersal at variance with that of overlying strata, as observed at Key Lake (Collier and Yeo, 2001) and at McClean Lake (Long, 2001) in the main part of Athabasca Basin.

The Moosonees, Ahenakew, and Karras deposystems comprise entirely Manitou Falls strata. Stratigraphic relationships within and among these three deposystems are described below.

a) Moosonees Deposystem

The Moosonees deposystem (Ramaekers, 1976; Ramaekers *et al*., 2001) is distinguished on the basis of proximal southwesterly and distal westerly paleocurrent directions, and relative scarcity of conglomerates. Sandstones are generally finer grained than in the Ahenakew deposystem. The description here is based on four cores (Table 3), particularly those logged in the past field season just west of the trace of the Black Lake Shear Zone (Figure 1).

The MFa member is up to 77 m thick, but in most drill holes is much thinner. It thickens basinward and comprises a local basal conglomerate (MFa0 sub-member) up to 17 m thick, overlain by a thicker sub-unit of fine- to coarse-grained sandstone with scattered pebbles (MFa2 sub-member). The sandstone sub-unit is much thicker in DDH SLG-6 than in CLG-5 (Table 3). Matrix clay is abundant. The top of the member is marked by a sharp increase in maximum grain size, as well as typical MFb conglomerate beds. Heavy mineral laminae are locally common. The great variation in thickness of this member suggests an unconformity at its top.

The MFb member is up to 33 m thick. It too thickens basinward and is distinguished by abundant conglomerate beds more than 2 cm thick, interbedded with pebbly sandstones. Fine- to coarse-grained sandstones give way upward to fine- to medium-grained sandstones. Thin mudstones are rare. Heavy mineral laminae are common. The MFb-MFc transition is placed at the top of the uppermost of the abundant conglomerate beds.

The MFc' member in the Moosonees deposystem is distinguished from the MFc member elsewhere on the basis of the relative abundance of mudstones, siltstones, and very fine sandstones (Table 2; Ramaekers *et al*., 2001). It is up to 327 m thick, but in most drill holes is much thinner. It also fines up, from medium and coarse sandstone to fine and medium sandstone, all interbedded with pebbly sandstone. Thin mudstone beds and clay intraclasts become more common upward. Heavy mineral laminae are common in the lower part of MFc, as are thin conglomerate beds and pebble layers. The MFc'-MFd' contact is marked by an upward decline in pebble abundance and an increase in abundance of clay intraclasts.

The MFd' member in the Moosonees deposystem is distinguished from MFd strata elsewhere by the presence of scattered pebbles, one-grain-thick pebble layers, and overall coarser grain (Table 2; Ramaekers *et al*., 2001). It is up to 616 m thick. It comprises well-sorted, fine- to medium-grained sandstone with scattered granules and pebbles as well as the abundant clay intraclasts characteristic of the member. MFd' strata in the eastern part of the deposystem are much more pebbly than to the west (Figure 2). Clay intraclasts increase upward episodically. A pebbly sub-member, about 50 m thick, lies 100 to 125 m above the base (Figure 2). Mudstone and siltstone beds are thinner and less common above the pebbly sub-unit than within and below it, and they die out upward in the upper MFd' sub-member. There is a sharp contact between the pebbly, large intraclast-rich MFd' sandstones and more fine-grained, non-pebbly sandstones lacking large, angular, soft clay intraclasts, but containing the much smaller, rounded indurated intraclasts characteristic of the overlying Wolverine Point Formation. In DDH SLG-6 a pebble lag of very fine-grained white sandstone pebbles at the MFd'-WP contact (Figure 3), represents a ravinement surface. This erosion surface, the great difference in thickness of MFd' over 6 km between SLG-6 and CLG-5 (Table 3), and the absence of the Lazenby Lake Formation above the MFd' member, are suggestive of a major disconformity.

Table 3 - Summary of regional cores logged in the Moosonees deposystem as part of the EXTECH IV project. O/B=overburden thickness; U/C=unconformity; WP=Wolverine Point; and MF=Manitou Falls. Incomplete logs of two additional cores have been omitted. Depths and thicknesses in metres. Thicknesses of the pebbly subunit in MFd and the basal conglomerate in MFa are indicated in brackets.

DDH	NAD83		U/C depth	O/B	WP	MFd (pebbly)	MFc	MFb	MFa? (congl.)
	Easting	Northing							
D-2	518400m	6538200m	373.5	13.3			327	28	5 (0)
D-12	512800	6513850	490.8	6		317 (50)	94	33	42 (0)
CLG-5	432540	6536875	915.21	37.4	62.6	616 (57)	153	25	21 (17)
SLG-6	438400	6538845	827.25	15.3	77	518 (55)	118	22	77 (13)

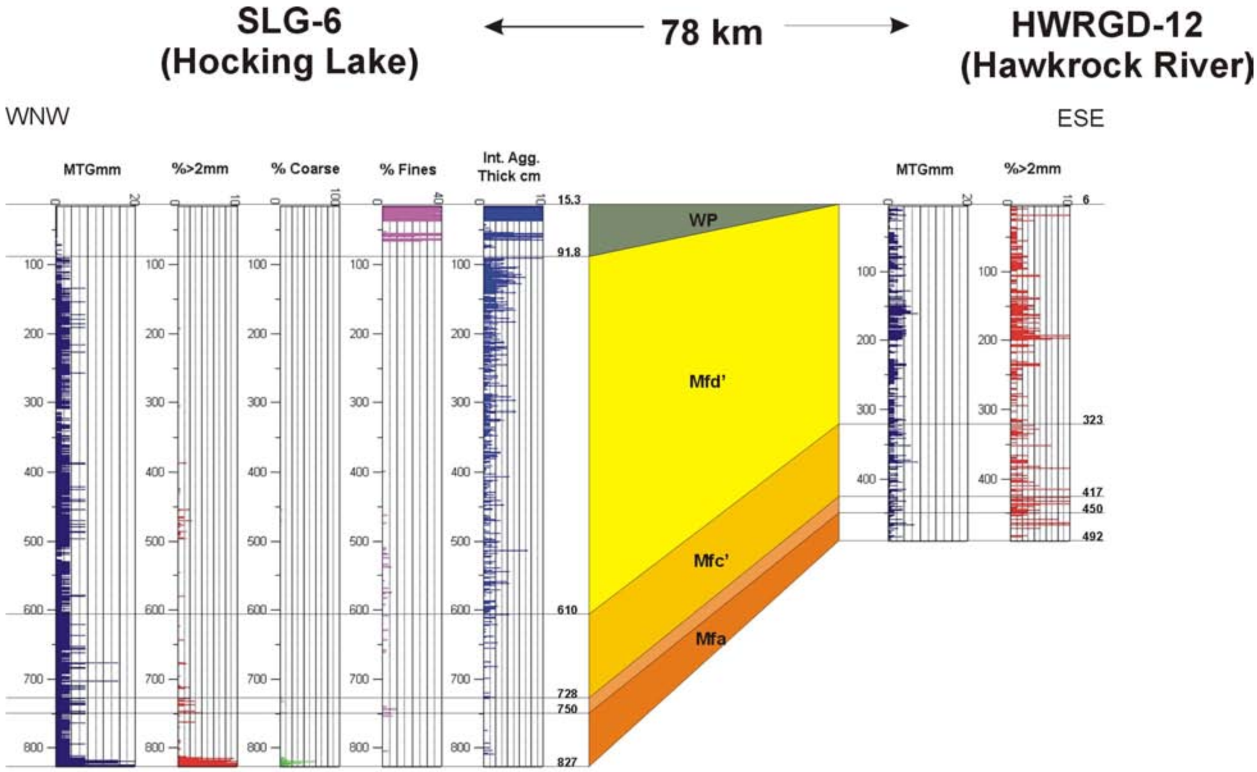

Figure 2 - Graphic logs of DDH SLG-6 and HWRGD-12 from the Moosonees deposystem. Locations of the cores are shown in Figure 1. MTGmm=variation in maximum grain size up to 20 mm; %>2 mm=% of grains over 2 mm up to 10%; % Coarse=% conglomerate beds over 2 cm thick; % Fines=% mudstone to very fine sandstone beds up to 40%; and Int.Agg.Thick=aggregate thickness of intraclast-bearing strata up to 10 cm. Depths are indicated in metres. The last three parameters are not shown for DDH HWRGD-12 because they were not measured quantitatively during the first year of the EXTECH IV project.

Figure 3 - Subangular to rounded, very fine-grained sandstone clasts (arrows) in a pebble lag at the base of the Wolverine Point Formation in DDH SLG-6 indicate that the contact is an erosion surface. The pebbles are associated with smaller quartz pebbles and granules in a medium to coarse sandstone matrix. Another sandstone pebble lies about a metre above the contact. Note the faulted tectonic breccia in the MFd' at left side of the photo.

b) Ahenakew Deposystem

The Ahenakew deposystem (Ramaekers, 1976; Ramaekers *et al*., 2001) was defined on the basis of northerly, northwesterly, and westerly paleocurrent directions and prevalence of conglomerates in the lower Manitou Falls Formation. Most of the known unconformity-type uranium deposits have been found in or beneath the Ahenakew deposystem. Accordingly it is the best studied part of the basin, as reflected in the number of cores logged (Figure1; Jefferson *et al*., 2001, Table 1).

The stratigraphy of the Ahenakew deposystem has been described by Yeo *et al.* (2000) and Jefferson *et al.* (2001). Detailed studies have been undertaken at McArthur River (Bernier *et al*., 2001; Bernier, this volume), McClean Lake (Long *et al*., 2000; Long, 2001), and Key Lake (Collier and Yeo, 2001), with additional stratigraphic fences in the Dawn Lake (Gaze, 2000), Close Lake, and Wheeler River areas (Jefferson *et al*., 2001). Stratigraphic variability of the Manitou Falls Formation in the Ahenakew deposystem is graphically summarized in Figure 4.

In the west-central part of the Ahenakew deposystem, including the McArthur River and Wheeler River transects, the MFa member ranges from 34 to 147 m thick (Jefferson *et al*., 2001; Table 1), but in the

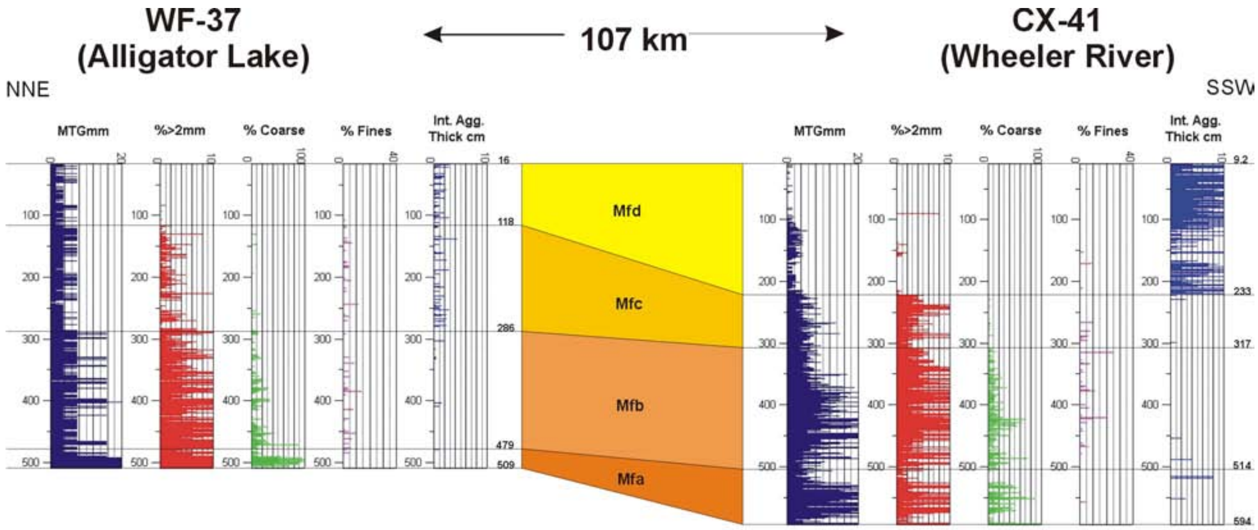

Figure 4 - Graphic logs of DDH WF-37 and CX-41 from the Ahenakew deposystem. Locations of the cores are indicated in Figure 1. Parameters are the same as in Figure 2.

marginal parts of the deposystem, such as at Key Lake, the Sue C Pit, and Dawn Lake it is only preserved locally in paleo-valleys (e.g., Figure 4 of Long, 2001). The MFa2 sub-member, characterized by interbedded conglomerate and sandstone with low-angle lamination, and sparse, oversized pebbles to cobbles, commonly overlies a basal conglomerate (MFa0) or rests directly on basement. The conglomerates have an intact framework and coarse sandstone matrix. Maroon to tan coloured mudstones with sand-filled cracks, micro-scour and fill structures, and ripped-up mud intraclasts, interbedded with sandstones and conglomerates, typical of the MFa1 sub-member, are locally common in the southern Ahenakew deposystem. These mudstones are also intercalated with the basal conglomerate (sub-unit MFa0) as sieve structure in both Sue Pit exposures and in drill core. At McArthur River, metre-scale blocks to angular pebbles of quartzite gneiss are abutted by finely laminated hematitic mudstones that in one sample include crypto-microbial laminites (Yeo *et al*., this volume).

The MFb member ranges from 37 to 223 m thick in the southern part of the Ahenakew deposystem and from 33 to 196 m thick in the northern part. In the centre it is up to 301 m thick (Jefferson *et al*., 2001; Table 1). The MFb member is distinguished by abundant, relatively thick conglomerates (clasts >2 cm) interbedded with seriate fine to coarse sandstones, pebbly sandstones, and minor mudstones. As noted by Ramaekers (1990), at least two conglomerate-dominated sub-units are separated by a conglomerate-poor subunit (Bernier *et al*., 2001; Jefferson *et al*., 2001; Bernier, this volume). In contrast to MFa mudstones, MFb mudstones are dominantly silt grade, horizontal to micro-ripple laminated, lacking in desiccation cracks or scours, and ubiquitously drab grey and green coloured. Mudstone interbeds commonly drape pebbles of underlying conglomerates with sharp micro-relief, and are overlain by conglomerates with no disruption, as if the overlying conglomerates were gently emplaced like unrolling a carpet, likely by water-rich subaerial mass flows. MFb is transitional upward and laterally into MFc, with the contact arbitrarily placed at the top of the last series of 2 cm thick conglomerate beds.

The MFc member ranges from 43 to 243 m thick in the southern part of the deposystem and up to 168 m thick in the north (Figure 4). The upper part of the member has been eroded near the basin margin, and sandstones resembling MFc in marginal sections may simply be conglomerate-poor sections of MFb. This member is distinguished by interbedded pebbly sandstones and sandstones, with minor mudstones. In a number of cores from McArthur River and Wheeler River areas, a thin granule-rich bed or conglomerate provides a subtle, but consistent stratigraphic marker (e.g., DDH CX-41 in Figure 4). In the southern Ahenakew deposystem, its upper contact is marked by an abrupt upward increase in intraclast abundance, the disappearance of pebbles, and a sharp drop in grain-size attributes (see Figure 4). In the north, the contact is more transitional, as scattered intraclasts are common throughout MFc, and pebbly sandstones persist above the level at which clay intraclasts exceed 1% and where the contact is placed. These northern sections of MFc thus have attributes of MFc' at the interface with the Moosonees deposystem.

The MFd member is at least 303 m thick in the Ahenakew deposystem. It is defined by a sharp upward increase in intraclast abundance, as well as small, but abrupt decreases in grain size parameters. Commonly two peaks of intraclast abundance are in the lower part of MFd (e.g., Jefferson *et al*., 2001; Bernier, this volume). The top of the member has not yet been documented for this deposystem, but is preserved in the Rumpel Lake drill hole and others. Pebbles are generally rare, except for a pebbly sandstone sub-member about 50 m thick in the lower part of

MFd, found locally (DDH CX-41 in Figure 4), as in the Moosonees deposystem. Maximum grain size decreases upward. Mudstones are much less common in MFd than in underlying strata.

c) Eastern Karras Deposystem

The eastern Karras deposystem (Figure 1; Ramaekers, 1977; Ramaekers *et al.,* 2001) is distinguished on the basis of northwesterly paleocurrent directions and pebbly sandstones higher in the Manitou Falls Formation than in the Ahenakew deposystem to the east. To the west, the Karras deposystem is overlain by the Bourassa deposystem. To date, only two drill holes have been logged from the eastern part of this deposystem (Figure 5). These lie on either side of the Dufferin Lake Fault, a sub-parallel splay of the Virgin River Shear Zone (Figure 1).

The MFa member ranges from 61 to 68 m thick. It comprises interbedded sandstones, pebbly sandstones, and conglomerates. Thin mudstones and clay intraclasts are rare; hence this assemblage corresponds to the regional MFa2 sub-member. A basal conglomerate (MFa0 sub-member) is present in DDH DF-66. Matrix clay increases in the lower part of the member. The MFa-MFb contact is placed at the first occurrence of pebble conglomerates >2 cm thick, above the MFa2 sandstones. The difference in thickness of the upper MFa sandstone in the cores suggests that the contact is an unconformity.

The MFb member ranges from 27 to 39 m thick. It comprises interbedded conglomerates and pebbly sandstones with rare mudstones and minor clay intraclasts. The amount of conglomerate and maximum clast size decrease upward. The MFb-MFc contact is transitional and is placed at the top of the conglomerate-bearing interval.

The MFc member is from 37 to 89 m thick in the two cores logged. It is characterized by interbedded pebbly sandstones and sandstones with rare mudstones and minor clay intraclasts. Maximum grain size decreases upward in the upper part of the member. The MFc-MFd contact is relatively sharp, marked by an abrupt decrease in maximum grain size as well as the appearance of abundant clay intraclasts.

The MFd member is up to 162 m thick in DDH MC-4, but its upper contact has not yet been observed in an EXTECH IV log from the Karras deposystem. It comprises fine- to medium-grained sandstone with abundant clay intraclasts. The basal 20 m or so is more coarse grained, suggesting a transitional relationship with the underlying MFc member. As in the Moosonees and Ahenakew deposystems, the MFd member includes a relatively pebbly, intraclast-poor sub-member (DDH MC-4 in Figure 5), first recognized by Cameco geologists. This MFc-like sub-unit, about 180 m above the MFc-MFd contact in DDH MC-4, is about 60 m thick.

d) Western Karras Deposystem

The western Karras deposystem only outcrops along the southwestern margin of the basin (Figure 1); hence its sediment dispersal trends are not well known. Strata belonging to the western Karras deposystem have previously been included in the Bourassa deposystem (e.g., Yeo *et al*., 2001), but should be distinguished as the two deposystems are probably separated by an unconformity. The stratigraphy of the western Karras and overlying Bourassa deposystems in Saskatchewan has recently been described by Yeo *et al*. (2001); the stratigraphy of the

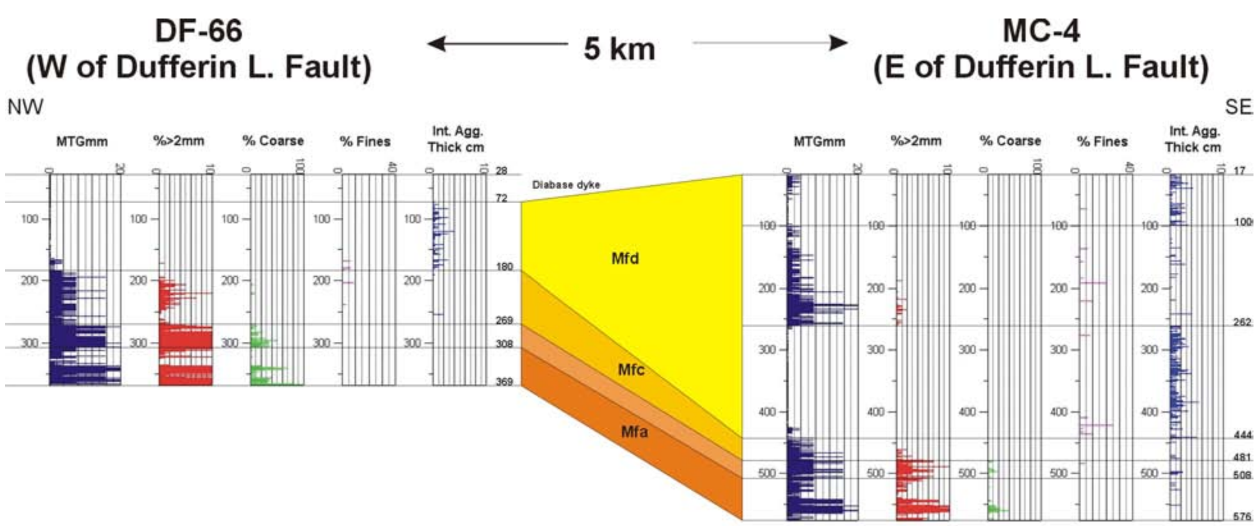

Figure 5 - Graphic logs of DDH DF-66 and MC-4 from the Karras deposystem. Locations of the cores are indicated in Figure 1. Parameters shown are the same as in Figure 2. The pebbly sub-unit within MFd is indicated in DDH MC-4.

Shea Creek area has been described in greater detail by Collier *et al*. (2001) and Collier (this volume). Regional variability is summarized graphically in Figure 6.

The MFa member comprises 3 to 11 m of polymictic conglomerate and pebbly sandstone (Mfa0 and or MFa2 sub-members) overlain by up to 60 m of distinctive, well sorted, fine-grained sandstone. Very low angle cross-bedding and ripple lamination are common. Magnetite-rich heavy mineral laminae are common and mudstones are rare. Locally, the sandstone sub-member rests directly on pre-Athabasca basement rocks or on the more poorly sorted and clay-rich Fair Point sandstones. It may correspond with the MFa4 sandstone sub-member recognized at McArthur River by Bernier (this volume). The top of the member is a sharp break, marked by an abrupt upward increase in maximum grain size to more than 4 mm, where it is overlain by MFb strata, or 2 to 4 mm, where it is overlain by MFc. Variable thickness of the MFa member (Yeo *et al.*, 2001) suggests that the contact may be unconformable.

The MFb member comprises interbedded pebble conglomerates and pebbly sandstones containing magnetite-rich heavy mineral laminae. It is up to 36 m thick, but is only present locally (e.g., DDH ERC-1 on Figure 4 of Yeo *et al*., 2001). More commonly it is represented by a relatively coarse-grained interval at the base of the MFc member. The top of the MFb member is transitional, marked by an upward decrease in maximum grain size to less than 4 mm, and the loss of conglomerate beds.

The MFc member is up to 160 m thick. Two sub-members have been recognized, a lower fine- to medium-grained sandstone, and an upper medium- to coarse-grained sandstone with scattered granules and pebbles. In contrast to underlying members, clay intraclasts are locally common, and increase in abundance upward. Thin mudstones beds are also locally common. As these cannot be correlated even to nearby cores (e.g., Collier, 2001), they most likely represent "slough channel deposits" of very restricted extent. The top of the MFc member is transitional; marked by a decrease in maximum grain size to less than 2 mm, as well as an increase in abundance of clay intraclasts.

Clay-intraclast-bearing, fine-grained MFd sandstones are up to 120 m thick. Intraclasts increase in abundance upward, but decrease basinward. Maximum grain size peaks in the central part of the member. The top of the member is marked by the abrupt upward appearance of pebbly Lazenby Lake Formation sandstones and the loss of intraclasts. Although the increase in maximum grain size in the upper few metres of the MFd member (Figure 6) suggests a gradational contact, with the top of MFd reworked by the streams that deposited Lazenby Lake strata, unmetamorphosed sandstone pebbles in the Lazenby Lake Formation are evidence that the contact is a disconformity (Ramaekers, 1990).

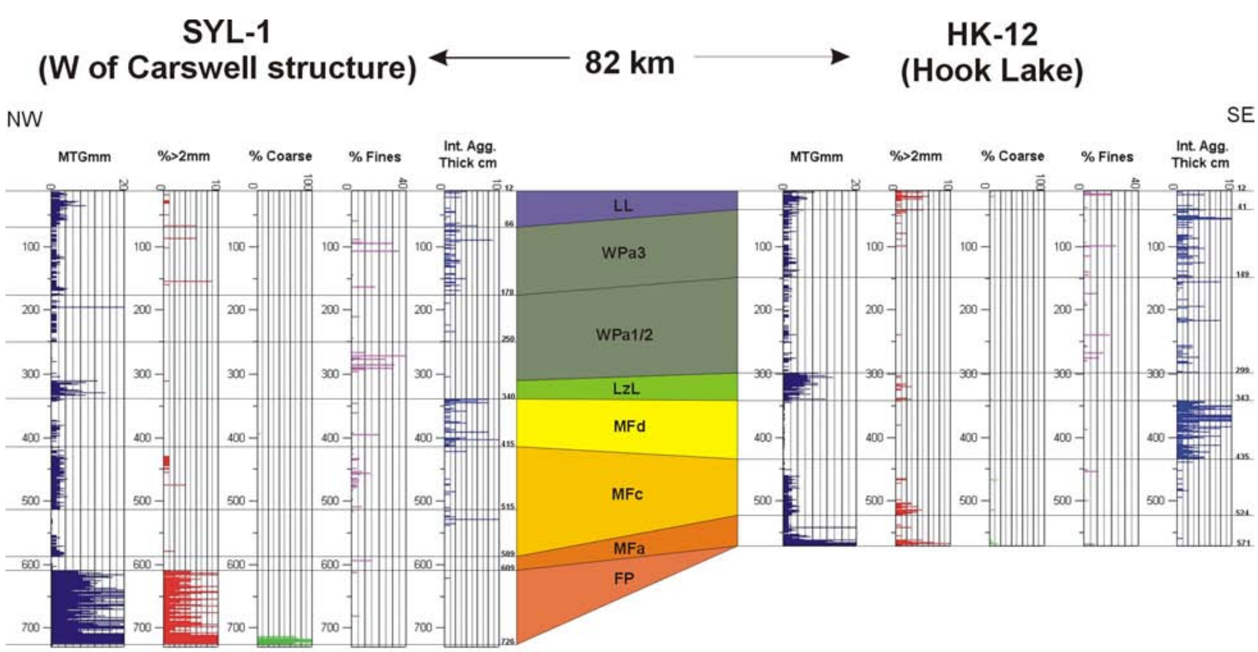

Figure 6 - Graphic logs of DDH SYL-1 and HK-12 from the western Karras and overlying Bourassa deposystems. Locations of the cores are indicated in Figure 1. Parameters are the same as in Figure 2. Variability within the western Karras deposystem is shown in more detail by Collier** et al. **(2001; Figure 2) and Yeo** et al. **(2001; Figure 4).

4. Discussion

Because the bulk of the Athabasca Group is lithologically very similar over broad areas, it was reasonable to propose a "layer-cake" stratigraphy for the basin (Ramaekers, 1978a, 1978b, 1979, 1981, 1990). As more data becomes available, especially from previously poorly known areas, such an approach to the stratigraphy of the basin may no longer be appropriate. Athabasca sedimentation took place in a number of discrete, predominantly fluvial, depositional systems rather than a single one. Basin-scale correlation is problematic as sub-basin- or exploration project-based stratigraphic systems have evolved (e.g., Table 5 of Yeo *et al*., 2000; compare Figure 2 of Mwenifumbo *et al*., 2000 with Figure 2 of Collier *et al*., 2001).

a) The MFa Member

The MFa member was recognized in all three deposystems. It typically comprises interbedded conglomerates, sandstones, and pebbly sandstones, overlain by a sandstone member with prominent low-angle or horizontal bedding. The latter is comparable to facies associations 3 and 5 at Shea Creek (Collier, this volume) and the MFa4 sub-member at McArthur River (Bernier, this volume). A basal conglomerate sub-unit (Mfa0) is common. Red mudstones, with distinctive sand-filled cracks, are common only in the southern Ahenakew deposystem (e.g., the MFa1 sub-member). The great local variability in thickness and discontinuous distribution (e.g., northern Ahenakew deposystem) is indicative of deposition in a basin of variable relief as valley fill, or that it was eroded prior to deposition of the MFb member.

Oncoids and crypto-microbial laminites in MFa0 strata locally in the Ahenakew and western Karras deposystems (Yeo *et al*., this volume) suggest that conditions were humid, at least in early MFa time. Their presence in basal MF strata unconformably overlying the Fair Point Formation at Maybelle River, Alberta (Ryan Ickert, pers. comm., 2002), suggests that they may be a more common feature of the MFa basal conglomerate than previously recognized, possibly reflecting unique environmental conditions in its depositional history. Their absence in basal Fair Point strata suggests that the basal conglomerate is unlikely to be correlative with the basal Fair Point, as some workers have speculated (e.g., Ramaekers, 1990).

An unconformity between the MFa and MFb members is suggested by an abrupt lithologic change in many drill holes, but in others the contact is an arbitrary one based on the first appearance of conglomerate beds >2 cm thick. The common sharp stratigraphic break and possible unconformity at the MFa-MFb contact, suggested by variable thickness of underlying strata, together with distinctly different sedimentary styles and inferred paleoclimates, suggest that MFa and MFb are two separate sequences. If these sequences are of the same order, a fifth second-order sequence within the Athabasca Group must be recognized, and MFa must be separated from the Manitou Falls Formation (see Collier, this volume).

b) The MFb Member

The MFb member is well developed in all deposystems except the western Karras. It comprises interbedded pebbly sandstones and conglomerate beds with minor mudstones and clay intraclasts locally. Most strata previously included in this member in the western Karras deposystem (Yeo *et al*., 2001b) are now included as a pebbly basal sub-unit of the MFc member (Figure 6), because the conglomerate beds >2 cm, which define the member, are absent. The MFb-MFc contact is invariably transitional and defined arbitrarily on the basis of the upward disappearance of conglomerates.

c) The MFc Member

The MFc member has been recognized throughout the basin. Thin mudstones are typical of the MFc member. Although individual mudstone beds cannot be correlated between nearby drill holes, mudstone-rich intervals can. The relatively pebbly basal sub-unit of the MFc in the western Karras deposystem may be a chronostratigraphic equivalent to the MFb member to the east. The MFc member in northern Ahenakew deposystem is transitional to the MFc' member in the Moosonees deposystem. The MFc-MFd contact, here placed at the point where clay intraclast-bearing strata make up about 1% of the rock, is variable. In the Moosonees deposystem it appears to be transitional, but in the Ahenakew and Karras deposystems the upward increase in intraclast abundance is typically abrupt.

A 52 m difference in thickness of this member in the two drill holes logged in the eastern Karras deposystem may reflect syndepositional movement on the Dufferin Lake Fault, which lies between the two cores studied. Note that the Dufferin Lake Fault is a westerly dipping reverse fault with a minimum vertical displacement of 200 m (D. Jiricka, pers. comm., 2002), whereas the difference in thickness of MFc suggests subsidence to the west; hence earlier normal fault movement. The 35 m difference in thickness of MFc between CLG-5 and SLG-6 (Table 3) in the northern Moosonees deposystem may also reflect syndepositional subsidence related to nearby faults.

Anomalous thickening of MFc has been reported on the Wheeler River transect in the southern Ahenakew deposystem as well (Jefferson *et al.*, 2001).

d) The MFd Member

The MFd member is also extensive, but less well developed in the western Karras deposystem, where the characteristic clay intraclasts are smaller and less abundant, suggesting that they are more distal. It generally comprises very fine to fine sandstones with more than 1% intraclast-bearing strata (as originally defined by Ramaekers, 1990). A thick, pebbly, MFc-like sub-member in the lower MFd member is distinguished in every deposystem except the western Karras, and suggests intertonguing of the MFc and MFd members. Like the MFb member, this too may be a chronostratigraphic marker.

The MFd' member in the Moosonees deposystem is more pebbly than the MFd elsewhere, and the eastern part of the deposystem is distinctly more pebbly than either the western part or northern Ahenakew deposystem (Figures 2 and 4). A 98 m difference in thickness in MFd' between CLG-5 and SLG-6 (Table 3) may reflect continued syndepositional subsidence on nearby faults.

The abrupt change in paleocurrent directions at the base of the Lazenby Lake Formation, its conglomeratic base overlying non-pebbly MFd sandstones, and local unmetamorphosed sandstone pebbles in the Lazenby Lake all suggest that the upper contact is an extensive disconformity in the southwestern part of the basin (Ramaekers, 1980, 1990). A pebble lag including rounded, apparently well-indurated pebbles of probable Manitou Falls sandstone at the base of the Wolverine Point Formation in the Moosonees deposystem is evidence for an erosion surface and suggests that the disconformity extends across the basin. Hence the Manitou Falls–Wolverine Point Sequence (Ramaekers *et al*., 2001) is here split into two separate upward-fining sequences (Table 2). The relationship of the Lazenby Lake and Wolverine Point formations requires further assessment to resolve details of this sequence boundary.

Additional reference sections for the various Manitou Falls members in each deposystem, particularly the MFa and MFb members will be described following detailed logging of the deep basin cores stored in Regina.

5. Conclusions

The deposystems within the Athabasca Basin, originally recognized by Ramaekers (1976, 1977, 1978b) on the basis of sediment dispersal patterns, are here re-defined as unconformity-bounded, three-dimensional lithostratigraphic successions with consistent paleocurrent patterns. This re-definition has no effect on the Fidler, Moosonees, Ahenakew, McLeod, and Reilly deposystems. The Bourassa deposystem, however, is now restricted to the Lazenby Lake–Wolverine Point succession in the southwestern part of the basin, and the Karras deposystem, now restricted to the Manitou Falls Formation, is extended westward, to include strata formerly included in the Bourassa deposystem.

In spite of local variability, the members of the Manitou Falls Formation are remarkably similar among the three deposystems described. There is commonly as much variability within the deposystems as among them. The established stratigraphic framework (Ramaekers, 1990; Ramaekers *et al*., 2001) works well on a basin scale; hence a radical overhaul of the stratigraphy is not warranted. A reasonable improvement would be to raise the Manitou Falls Formation to group status (creating an Athabasca Supergroup) and formally define the present members as new formations. Local members within the formations could be defined as appropriate in each deposystem.

A widespread sandstone with low-angle or horizontal bedding is traceable as a distinctive sub-member within MFa across much of basin. It is equivalent to Collier's (this volume) Facies Associations 3 and 5 at Shea Creek and Bernier's (this volume) MFa4 sub-member at McArthur River. Crypto-microbial laminites in basal MFa strata suggest a relatively wet climate at the time of deposition.

The MFb generally forms a distinctive marker unit across the basin except in western Karras deposystem, where it is only locally present.

In the northern Moosonees and eastern Karras deposystem, anomalous thickening of the MFc member records subsidence (basin extension) possibly related to nearby faults. Comparable thickening of MFc is also observed along the Wheeler River transect (Jefferson *et al.*, 2001).

Clay intraclasts are less abundant in the MFd member to the west. Hence 1% intraclasts (Ramaekers, 1990) is a more reasonable limit to define it than 2% (Ramaekers *et al.*, 2001). Westward thickening of the MFd member in the northern Moosonees deposystem may reflect continued basin subsidence. A MFc-like pebbly sub-unit is widespread in the Moosonees, Ahenakew, and eastern Karras deposystems and may be evidence for intertonguing of the MFc and MFd members. If so, then the MFc-MFd contact does not reflect a change to a more arid climate (Jefferson *et al*., 2001), but is simply a boundary between proximal and distal facies.

The upper and lower contacts of the Manitou Falls are probably unconformities and hence, time-lines, but other contacts are equivocal. The MFa-MFb contact is locally an unconformity, and may prove to be an be an extensive one, but more work is needed to demonstrate this. Other contacts within the formation are facies boundaries. Some lithostratigraphic units, such as the MFb member and the correlative, coarse-grained sub-unit at the base of the MFc in the western Karras deposystem, and the pebbly sub-unit in MFd may also be chronostratigraphic units.

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7. References

Annesley, I.R., Madore, C., Shi, R., and , Krogh, T.E. (1997): U-Pb geochronology of thermotectonic events in the Wollaston Lake area, Wollaston Domain: A summary of 1994-1996 results; *in* Summary of Investigations 1997, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 97-4, p162-173.

Bernier, S., Jefferson, C.W., and Drever, G.L. (2001): Stratigraphy of the Manitou Falls formation in the vicinity of the McArthur River uranium deposit, Athabasca Basin, Saskatchewan: Preliminary observations; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p291-296.

Collier, B. and Yeo, G. (2001): Stratigraphy of the Paleoproterozoic Manitou Falls B Member at the Deilmann Pit, Key Lake, Saskatchewan; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p297-305.

Collier, B., Yeo, G., Long, D., Robbins, J., and Koning, E. (2001): Preliminary report on the stratigraphy of the Athabasca Group in the vicinity of the Shea Creek Project, southwestern Athabasca Basin, Saskatchewan; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p266-271.

Gaze, A. (2000): Stratigraphy of the Manitou Falls Formation of the Collins Creek Area, unpubl. B.Sc. thesis, Univ. Saskatchewan, 65p.

Jefferson, C.W., Percival, J.B., Bernier, S., Cutts, C., Drever, G., Jiricka, D., Long, D., McHardy, S., Quirt, D., Ramaekers, P., Wasyliuk, K., and Yeo, G.M. (2001): Lithostratigraphy and mineralogy in the eastern Athabasca Basin, northern Saskatchewan – Progress in year 2 of EXTECH IV; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p272-290.

Long, D.G.F. (2001): Architecture of Late Paleoproterozoic fluvial strata in the Manitou Falls Formation at McClean Lake and Key Lake, eastern Athabasca Basin, northern Saskatchewan; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p306-310.

Long, D., Williamson, C., Portella, P., and Wilson, S. (2000): Architecture and origin of fluvial facies in the Athabasca Group at McClean Lake, northern Saskatchewan; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p140-145.

Mwenifumbo, C.J., Pflug, K.A., Elliott, B.E., Jefferson, C.W., Koch, R., Robbins, J., and Matthews, R. (2000): Multiparameter borehole geophysical logging at the Shea Creek and McArthur River projects: Parameters for exploration, stratigraphy, and high-resolution seismic studies; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p110-122.

Ramaekers, P. (1976): Athabasca Formation, northeast edge (64L, 74I, 74P): Part I, reconnaissance geology; *in* Summary of Investigations 1976 by the Saskatchewan Geological Survey, Sask. Dep. Miner. Resour., p73-77.

__________ (1977): Athabasca Formation, south-central edge (74G): Part I, reconnaissance geology; *in* Summary of Investigations 1977 by the Saskatchewan Geological Survey, Sask. Dep. Miner. Resour., p157-163.

__________(1978a): Athabasca Formation, southwestern edge: Part I, reconnaissance geology (NTS areas 74F, 74K); *in* Summary of Investigations 1978, Saskatchewan Geological Survey, Sask. Miner. Resour., Misc. Rep. 78-10, p124-128.

__________(1978b): Reconnaissance geology of the interior Athabasca Basin; *in* Summary of Investigations 1978, Saskatchewan Geological Survey, Sask. Dep. Miner. Resour., Misc. Rep. 78-10, p133-135.

__________(1979): Stratigraphy of the Athabasca Basin; *in* Summary of Investigations 1979, Saskatchewan Geological Survey, Sask. Dep. Miner. Resour., Misc. Rep. 79-10, p154-160.

__________(1980): Stratigraphy and tectonic history of the Athabasca Group (Helikian) of Northern Saskatchewan; *in* Summary of Investigations 1980, Saskatchewan Geological Survey, Sask. Dep. Miner. Resour., Misc. Rep. 80-4, p99-106.

__________(1981): Hudsonian and Helikian basins of the Athabasca region, northern Saskatchewan; *in* Campbell, F.H.A. (ed.), Proterozoic Basins of Canada, Geol. Surv. Can., Pap. 81-10, p219-233.

__________(1990): Geology of the Athabasca Group (Helikian) in Northern Saskatchewan; Sask. Energy Mines, Rep. 195, 49p.

Ramaekers, P., Yeo, G., and Jefferson, C. (2001): Preliminary overview or regional stratigraphy in the late Paleoproterozoic Athabasca Basin, Saskatchewan and Alberta; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p240-251.

Yeo, G., Jefferson, C.W., Percival, J.B., Jiricka, D., McHardy, S., Munholland, P., Collier, B., Gaze, A., and Williamson, C. (2000): Practical stratigraphy and flashy sedimentology in the Paleoproterozoic Manitou Falls formation, eastern Athabasca Basin, Saskatchewan – an EXTECH IV progress report; *in* Summary of Investigations 2000, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2000-4.2, p123-139.

Yeo, G., Jefferson, C.W., Ramaekers, P., and Tong, K. (2001a): From Palm to plot: Core logging in the EXTECH IV Athabasca Basin stratigraphy sub-project; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p314-320.

Yeo, G., Collier, B., Ramaekers, P., Koning, E., Robbins, J., and Jiricka, D. (2001b): Stratigraphy of the Athabasca Group in the southwestern Athabasca Basin, Saskatchewan (NTS 74F and 74K); *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p252-265.

Yeo, G.M., Collier, B., Ramaekers, P., Koning, E., Robbins, J., and Jiricka, D. (2002): Cyclic stratigraphy in the Late Paleoproterozoic Athabasca Group in the Carswell area, southwestern Athabasca Basin, Saskatchewan; *in* Geol. Assoc. Can. /Mineral. Assoc. Can., Jt. Annu. Meet., Saskatoon, Abstr. Vol. 27, p128.