Post-mineralization Origin of Organic Matter in Athabasca Unconformity Uranium Deposits, Saskatchewan

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Abstract

The EXTECH IV sub-project 3 in the Athabasca Basin, Saskatchewan, aimed to evaluate: 1) the origins of pyrobitumens, bitumens, and hydrocarbons associated with uranium mineralization; 2) the role and/or influence of bitumens and hydrocarbons on uranium mineralization; and 3) the possibility of a Proterozoic petroleum (including source rock, petroleum migration, and petroleum reservoirs). In this paper we present petrographic, paragenetic, and thermal maturity data for pyrobitumens associated with mineralization and for bitumens distal to mineralization. The main conclusions thus far indicate.

1) *That all pyrobitumen was introduced (i.e., as petroleum) after mineralization, cross-cuts uranium mineralization, and consequently had no role in mineralization. Additionally, the presence of pyrobitumen does not indicate proximity to mineralization.*
2) *Similar paragenetic relationships between pyrobitumen associated with uranium mineralization from different deposits suggests that the pyrobitumen was probably was derived from similar source materials and had a similar emplacement history.*
3) *Reflectance data supports the paragenetic data and differentiates between older pyrobitumen (anisotropic with variable reflectance between ~1 to 2.6%) and younger regional bitumens identified within Athabasca Group sandstone (<0.8%Ro).*
4) *That low-maturity regional bitumens in sandstones are not Proterozoic in age and were most likely derived from Phanerozoic crude oils which likely migrated during late Cretaceous to Early Tertiary times, and subsequently degraded to a higher molecular weight product.*

Keywords: *Proterozoic, Athabasca Basin, unconformity uranium deposits, organic matter, pyrobitumen, bitumen.*

1. Introduction

Organic matter is associated with many Athabasca unconformity-type uranium deposits (Hoeve and Sibbald, 1978). It's significance and relationship, if any, to deposit genesis has been widely disputed. Previous researchers have suggested that the organic matter was either related to mineralization and formed by polymerization of short chain hydrocarbons in response to alteration of basement graphite (Landais *et al.*, 1993), post-dated mineralization (Leventhal *et al.*, 1987), or was simply not related to mineralization (Kyser *et al.*, 1989).

In this paper we summarize some of the results and include petrographic, paragenetic, and thermal maturity data that indicates the organic matter was introduced after mineralization and consequently played no active role in mineralization.

2. Sampling

Samples of organic matter were collected from across the Athabasca Basin (Figure 1) and additional samples were supplied by industry partners Cameco Corporation and COGEMA Resources Inc. The sample suite is diverse, ranging from uranium-enriched blocks of pyrobitumen (Figure 2A) and high-grade uranium ores intergrown with pyrobitumen (Figure 2B and C), to soluble tarry bitumens present in primary and secondary porosity distal to mineralization (Figure 2D).

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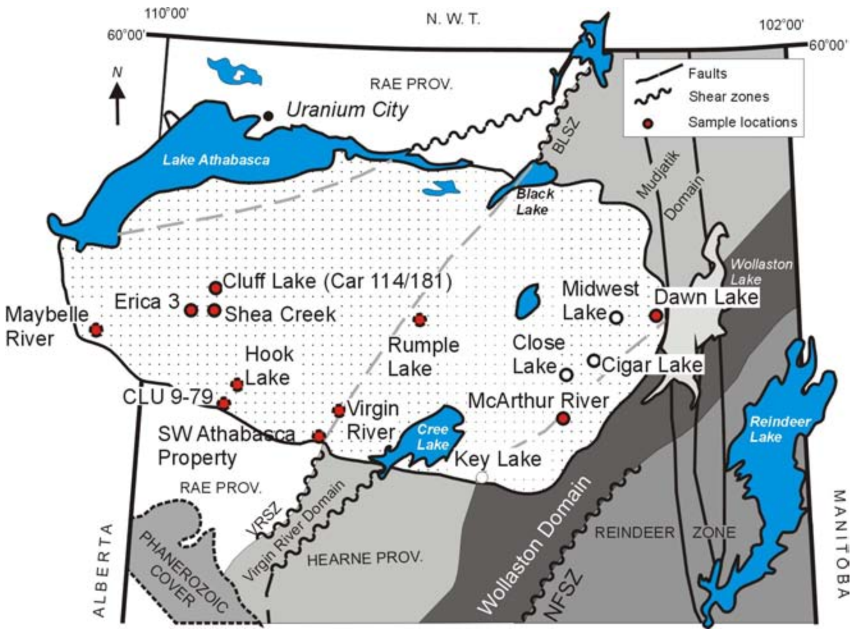

Figure 1 - General geological subdivisions of the Precambrian Shield in northern Saskatchewan and sampling localities used in this study (adapted from Thomas** et al.**, 2000).Filled circles indicate samples collected for this study. BLSZ=Black Lake Shear Zone; NFSZ=Needle Falls Shear Zone; and VRSZ=Virgin River Shear Zone.

3. Petrography and Paragenesis

Consistent cross-cutting relationships between organic matter and uranium ores and the inclusion of earlier formed uranium ores into pyrobitumen were observed at Cluff Lake (Claude and Dominique-Janine deposits) in Saskatchewan and at Maybelle River in Alberta, indicating that organic matter was introduced post-mineralization (Figures 2 and 3).

Rare samples of pyrobitumen intergrown with clays from clay-hematite altered basement at Shea Creek (Figures 2E and 3D) are difficult to relate to mineralization as no samples with both organic matter and mineralization were observed. The paragenesis and significance of organic matter at Shea Creek is not clear and is still under investigation.

Later, tarry bitumens distal to mineralization and commonly observed at Erica and Maybelle River (and present at the SW Athabasca property, Hook Lake, and Dawn Lake) were probably not derived from the same source as the pyrobitumen associated with mineralization. This is supported by the high reflectance of pyrobitumen associated with uranium mineralization in Maybelle River drill cores (MR 34 and MR 39, ~2.6%Ro, also see section below) which contrasts with the low maturity tarry bitumens (< 0.4%Ro) that surround the mineralized zone.

4. Reflectance

Percent reflectance in oil (%Ro) data were collected from pyrobitumen associated with uranium mineralization from the Claude and Dominique-Janine orebodies, the Maybelle River prospect (Table 1), and from bitumen within the Athabasca group sandstones not directly associated with uranium mineralization (Hook Lake, Dawn Lake, southwest Athabasca Cameco property, and at CLU 9 to 79, Table 2).

Reflectance of pyrobitumen from Claude, Dominique-Janine, and Maybelle River (Table 1) is significantly higher than that of 'regional' bitumens collected from Athabasca Group sandstones not associated with deposits (Table 2). The incorporation of uranium minerals into the pyrobitumen has resulted in strong anisotropy within samples. Pyrobitumen adjacent to mineral inclusions typically forms an anomalous lower reflecting halo (~ 0.5%Ro), surrounded by an intermediate reflecting transitional zone (~0.7 to 0.9%), within a background of higher reflectance (~1 to 2%, Figure 3A). The data in Table 1 indicate these trends are consistent in most samples but the reflectance of the individual zones between samples is variable. Significantly, the reflectance of adjacent bitumen and pyrobitumen samples (i.e., MR 34 at 198.5 m and 198.7 m) vary by almost 2%. Anomalous high thermal maturation and development of anisotropy within the pyrobitumen associated with the ore is most likely due to burial (including deformation?) and radiogenic decay of the uranium ores.

The bulk of bitumens from Dawn Lake Q14-38-H-02, Dawn Lake Q14A-66A, Hook Lake HK-13, Hook Lake HK-11, and CLU 9-79, not associated with mineralization, are of low thermal maturity with %Ro values ranging from < 0.10 to 0.38. The average bitumen reflectance values for these samples are consistent with post-bitumen emplacement, maximum thermal maturity levels equivalent to vitrinite reflectance values on the order of 0.30 to 0.50 percent equating to a maximum temperatures of ~50 to <90°C and maximum burial depths of <2 to 3 km under normal geothermal conditions (see Jacob, 1985; Barker and Pawlewicz, 1994; Stasiuk *et al.,* 2001).

Anomalous bitumen reflectance values ranging from 0.43 to 0.82%Ro, were recorded at Hook Lake HK-6 and Virgin River DF08 suggesting equivalent thermal maturity levels as high as 0.90%Ro vitrinite reflectance, or

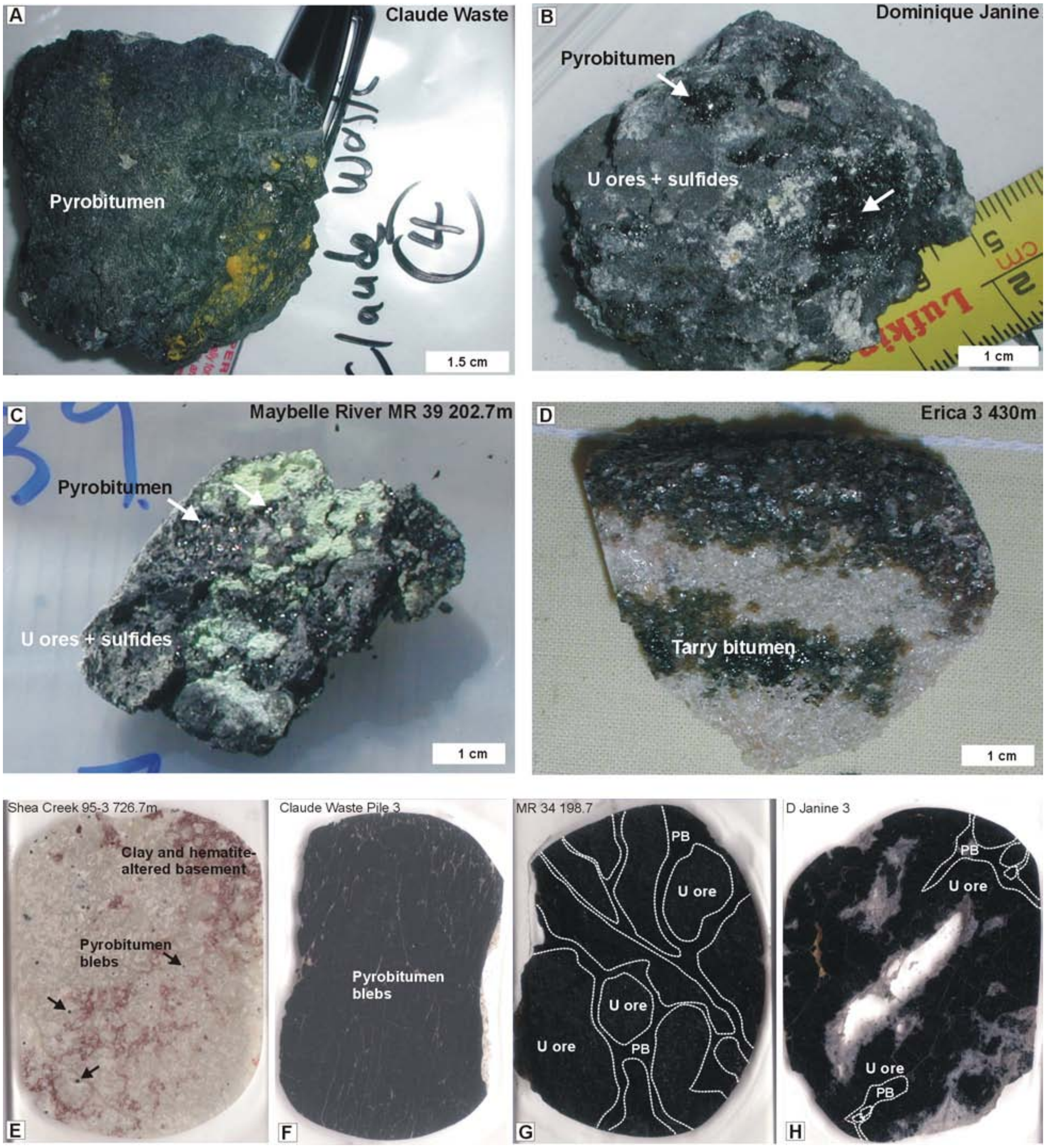

Figure 2 - Photographs of hand specimens and thin sections (4.5 cm by 2.5 cm) of pyrobitumen associated with uranium mineralization and regional bitumens distal to mineralization. (A) Pyrobitumen containing angular pitchblende-pyrite inclusions from the Claude waste pile. (B) High-grade pitchblende overgrown by pyrite and later pyrobitumen (arrows). (C) Uranium mineralization crosscut by pyrobitumen (arrows) from Maybelle River. (D) Coarse-grained tarry bitumen-stained Athabasca sandstone. (E) Thin section image of clay-hematite altered basement with fine pyrobitumen blebs. (F) Thin section image of a pyrobitumen block from the Claude deposit. (G) Thin section image of brecciated mineralization from Maybelle River cross-cut by pyrobitumen veinlets. (H) Thin section image of high-grade ore from Dominique-Janine cross-cut by pyrobitumen veinlets.

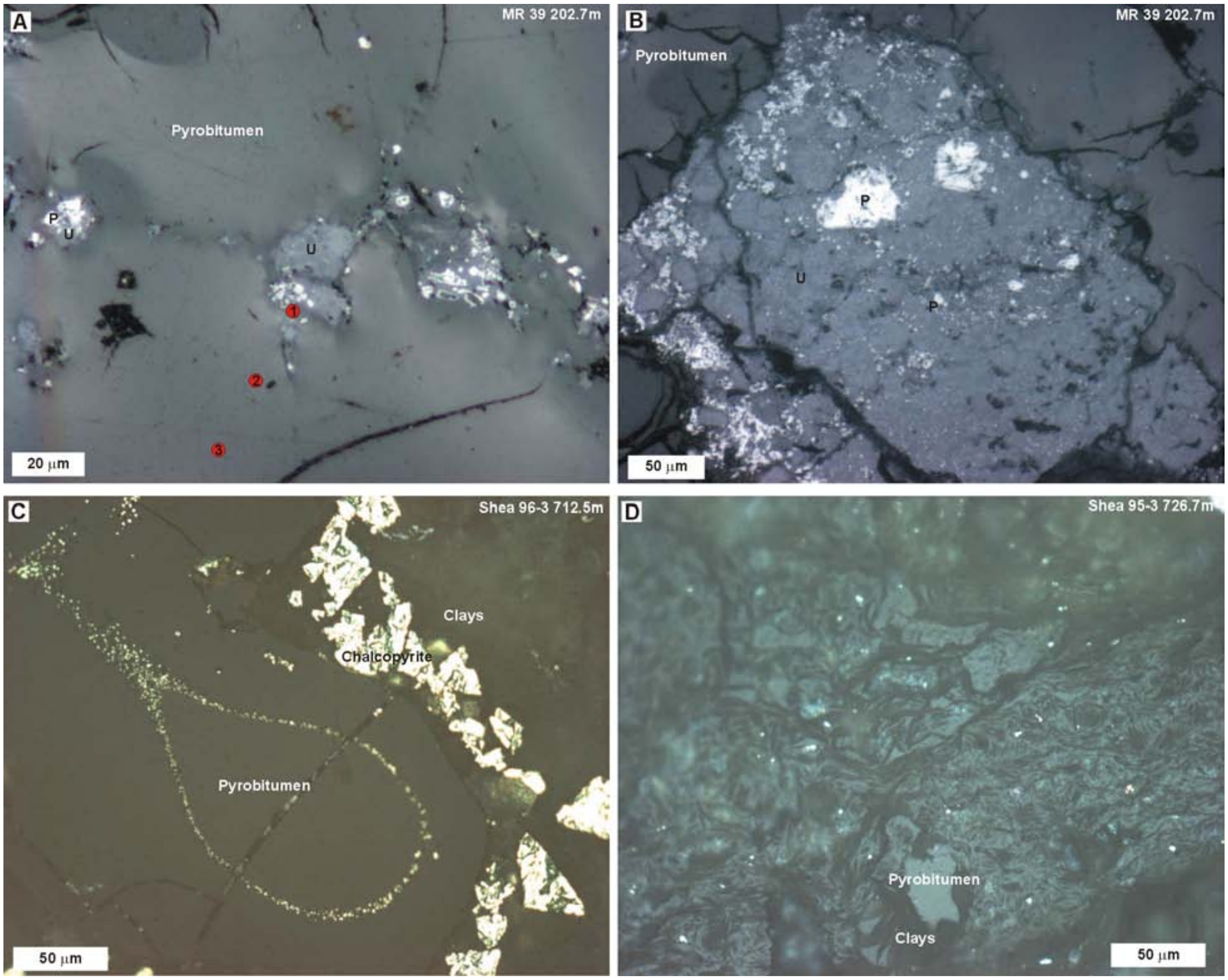

Figure 3 - Reflected light photomicrographs of pyrobitumen associated with uranium mineralization. A) Anisotropic pyrobitumen containing inclusions of pitchblende (U) and pyrite (P). ① Altered low reflecting halo around inclusions, ② transition zone, and ③ background reflectance of the pyrobitumen (see Table 1). B) Pitchblende (U) and pyrite (P) inclusions in pyrobitumen from Maybelle river. C) Late pyrobitumen containing aligned chalcopyrite inclusions overgrown by later chalcopyrite and clays. D) Intergrown pyrobitumen(?) and clays from altered (hematite-clay) basement.

maximum temperatures of 130°C (see Jacob, 1985; Barker and Pawlewicz, 1994; Stasiuk *et al.,* 2001). The implications of these anomalies are not understood at this time but could represent post-bitumen emplacement thermal maturation above 'background' levels (i.e., Dawn Lake, Hook Lake HK-11, Hook Lake HK-13 and CLU 9-79), and thus could point to regions of recent geothermal activity, or remobilization of bitumens altered by uranium deposits at depth.

Table 1 - Random percent reflectance in oil (%Ro_R) for pyrobitumens associated with uranium mineralization in the Athabasca Basin; D=Dominique.

							Ro background			Ro transition zone			Ro halo		
GSC C #	NAD	Zone	UTM	Sample	Depth (m)	Pellet #	%Ro_R	SD	N	%Ro_R	SD	N	%Ro_R	SD	N
n/a	83	12V	E585742 N6472258	Claude Waste 3	Surface	225/02	1.30	0.15	100	n/a	n/a	n/a	n/a	n/a	-
n/a	83	12V	E585742 N6472258	Claude Waste 4	Surface	226/02	2.20	0.39	100	n/a	n/a	n/a	1.00	0.10	50
n/a	83	12V	E585455 N6471178	D Janine 2	Near surface	230/02	0.79	0.07	100	n/a	n/a	n/a	0.51	0.14	9
n/a	83	12V	E585455 N6471178	D Janine 5	Near surface	231/02	0.89	0.08	50	n/a	n/a	n/a	0.49	0.11	16
C-418273	83	13V	E167706 N6465421	MR 34	198.5	232/02	0.65	0.07	50	n/a	n/a	n/a	0.54	0.08	50
C-418274	83	13V	E167706 N6465421	MR 34	198.7	233/02	2.60	0.40	50	0.73	0.13	50	0.43	0.13	50
C-418285	83	13V	E167707 N6465424	MR 39	202.7	234/02	1.90	0.50	18	0.96	0.13	50	0.50	0.13	12

Table 2 - Random percent reflectance in oil (%Ro_R) for bitumens not directly associated with uranium mineralization in the Athabasca Basin.

GSC C #	GSC lab #	NAD	Zone	UTM	Locality-Property	Drill hole	Depth (m)	Unit/member	%Ro_R	SD	N
C-418253	**124/01**	83	13V	E548323 N6438584	Dawn Lake	Q14-38-H-02	162.20	Manitou Falls B	0.06	0.00	13
C-418253	**124/01**	83	13V	E548323 N6438584	Dawn Lake	Q14-38-H-02	162.20	Manitou Falls B	0.59	0.02	3
C-418254	**125/01**	83	13V	E533257 N6430946	Dawn Lake	Q14A-66A	36.65	Manitou Falls B	0.28	0.03	15
C-418254	**125/01**	83	13V	E533257 N6430946	Dawn Lake	Q14A-66A	36.65	Manitou Falls B	0.15	0.03	5
C-418471	**329/01**	83	12V	E628705 N6393904	Hook Lake	DDH HK-13	72.00	Manitou Falls D	0.24	0.03	20
C-418472	**330/01**	83	12V	E628705 N6393904	Hook Lake	DDH HK-13	98.40	Manitou Falls D	0.21	0.03	10
C-418473	**331/01**	83	12V	E613659 N6406107	Hook Lake	DDH HK-11	176.40	Wolverine Point	0.19	0.05	10
C-418474	**332/01**	83	12V	E634725 N6404322	Hook Lake	DDH HK-6	197.50	Manitou Falls D	0.43	0.03	50
C-418474	**332/01**	83	12V	E634725 N6404322	Hook Lake	DDH HK-6	197.50	Manitou Falls D	0.72	0.07	8
C-418255	**170/01**	27	13V	E338340 N6371805	SW Athabasca	#DF08	139.00	Manitou Falls D ?	0.45	0.03	30
C-418255	**170/01**	27	13V	E338340 N6371805	SW Athabasca	#DF08	139.00	Manitou Falls D ?	0.55	0.06	8
C-418255	**170/01**	27	13V	E338340 N6371805	SW Athabasca	#DF08	139.00	Manitou Falls D ?	0.82	0.05	10
C-418475	**396-01**	27	13V	E339135 N6371844	SW Athabasca	SW-07	308.3	Manitou Falls C	0.17	0.02	15
C-418206	**132/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	60.11	Manitou Falls D	0.32	0.05	25
C-418206	**132/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	60.11	Manitou Falls D	0.15	0.04	6
C-418207	**133/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	60.35	Manitou Falls D	0.32	0.05	15
C-418207	**133/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	60.35	Manitou Falls D	0.13	0.03	8
C-418208	**134/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	62.51	Manitou Falls D	0.34	0.07	21
C-418208	**134/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	62.51	Manitou Falls D	0.12	0.02	8
C-418209	**135/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	62.85	Manitou Falls D	0.33	0.07	8
C-418209	**135/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	62.85	Manitou Falls D	0.16	0.03	6
C-418210	**136/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	63.34	Manitou Falls D	0.32	0.05	15
C-418210	**136/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	63.34	Manitou Falls D	0.18	0.04	8
C-418211	**137/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	67.97	Manitou Falls D	0.37	0.11	3
C-418211	**137/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	67.97	Manitou Falls D	0.13	0.04	6
C-418212	**138/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	73.64	Manitou Falls D	0.31	0.08	15
C-418212	**138/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	73.64	Manitou Falls D	0.17	0.03	13
C-418213	**139/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	74.25	Manitou Falls D	0.28	0.04	3
C-418213	**139/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	74.25	Manitou Falls D	0.14	0.04	9
C-418214	**140/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	75.77	Manitou Falls D	0.33	0.07	11
C-418214	**140/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	75.77	Manitou Falls D	0.13	0.06	8
C-418215	**141/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	82.24	Manitou Falls D	0.27	0.03	2
C-418215	**141/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	82.24	Manitou Falls D	0.12	0.05	14
C-418216	**142/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	84.43	Manitou Falls D	0.09	0.03	20
C-418216	**143/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	85.13	Manitou Falls D	0.38	0.07	20
C-418216	**143/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	85.13	Manitou Falls D	0.12	0.05	18
C-418218	**144/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	86.11	Manitou Falls D	0.13	0.03	15
C-418219	**145/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	87.48	Manitou Falls D	0.12	0.05	15
C-418220	**146/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	103.17	Manitou Falls D	0.13	0.05	6
C-418221	**147/01**	83	13V	E237678 N6405889	n/a	CLU 9-79	104.88	Manitou Falls D	0.18	0.03	7

Based on reflectance data, preliminary fluorescence microspectrometry, and biomarker data (Stasiuk *et al.*, 2001), the bitumens from Dawn Lake Q14-38-H-02, Dawn Lake Q14A-66A, Hook Lake HK-13, Hook Lake HK-11, and CLU 9-79 are clearly not Proterozoic and were most likely derived from Phanerozoic crude oils which migrated into the sandstones during late Cretaceous to Early Tertiary, and subsequently degraded to a higher molecular weight product.

5. Discussion and Conclusions

Paragenetic data indicate that organic matter was introduced into the Athabasca uranium deposits after mineralization and consequently had no role in their genesis. It is unlikely that arguments can be made that organic matter had a role in deposit preservation since it is apparent that many of the deposits do not contain significant amounts of organic matter, and in some cases only traces of organic matter are associated with mineralization (e.g., McArthur River).

The consistent presence and relative age relationships between uranium mineralization and organic matter suggest that organic matter within the individual deposits probably had a similar source origin and emplacement history.

Reflectance data supports the paragenetic data and allows differentiation between older pyrobitumen and younger bitumens that likely migrated into the basin during late the Cretaceous to Early Tertiary, and as such are probably related to tar sand bitumens.

Future work aims to: 1) determine the age and/or stratigraphic source rock origin of the pyrobitumen and bitumens, 2) place precise constraints on the paragenetic stages (mineralization, introduction of pyrobitumen and bitumens), and 3) integrate all data to produce a robust model of petroleum generation and/or migration within the Athabasca Basin and its relationship, or lack thereof, to uranium mineralization.

6. Acknowledgments

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