The Athabasca Basin Ore-systems Project: A New Generation of Geoscience in the Athabasca Basin

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Abstract

The Athabasca Basin ore-systems project represents the next step in expanding publicly available geoscience directly related to the uranium deposits hosted by the Athabasca Basin and environs. The project's goal is to present data in the 3-D environment in order to gain a better understanding of the Athabasca Basin's uranium deposits. The project entails: data collection necessary to construct a best-fit geologic model for the Athabasca Basin; a regional compilation of geoscience information; and generation of new data that can be modelled in the 3-D environment that will provide a better understanding of ore-forming processes.

A small field program was carried out at Pasfield Lake to log deep drillholes through the Athabasca Group. The two drillholes were collared southeast of a circular, 9 to 10 km wide basement uplift with a vertical displacement of ~600 m when compared to the regional unconformity depth, near the southeast edge of Pasfield Lake. The drillcores, PF-09-007 and -008, contain an anomalously thick intersection, up to 190 m, of Lazenby Lake Formation, typically not present in this part of the eastern Athabasca Basin. Previous to these two drillholes, the eastern extent of the Lazenby Lake Formation was a ~10 m interval in drillhole WC-79-1 located northwest of the basement uplift. Drillholes PF-09-007 and -008 are interpreted to transect a down-dropped rim of the Athabasca Group immediately adjacent to the basement uplift. Additionally, two drillcores were extracted from the Davy Lake region of the Athabasca Basin in 2011. Cores DV10-001 and -002 were drilled in a poorly known region of the north-central Athabasca Basin about 40 km from the nearest previous drill collar. The holes are the closest to the geographic and depositional centre of the basin and contain much of the Athabasca Group stratigraphy. The core will be stored in Regina and will be available for public viewing after January 20, 2012. A small basement mapping component was also undertaken in 2011, which included compilation of bedrock geology surrounding the basin and logging of nine basement cores stored in Regina.

The focus of this project is to create a geologically meaningful 3-D model of the Athabasca Basin. This framework will act as a display area for various datasets, both old and new, that can be interpreted in the 3-D environment. This new perspective will provide insights into the ore-forming processes in the Athabasca Basin. For example, two regional whole-rock geochemical sets viewed in the 3-D environment provide insight into the geochemical character of the Athabasca Group.

Keywords: *Athabasca Basin, uranium ore systems, Athabasca Group, lithostratigraphy, Davy Lake, Pasfield Lake, basement uplift, Manitou Falls Formation, Read Formation, Lazenby Lake Formation, Wolverine Point Formation, digital core logging, 3-D modelling, aeromagnetic data.*

1. Introduction

The EXploration science and TECHnology initiative (EXTECH IV) Athabasca Uranium Multi-disciplinary Study was carried out between 2000 and 2004 with the results published in 2007 (Jefferson and Delaney, 2007). This work represented the first major public geoscience initiative regarding uranium exploration and deposit geology in the Athabasca Basin since the Athabasca Basin Test Area research near the McClean Lake and Midwest uranium deposits (Cameron, 1983). The Saskatchewan Geological Survey has continued work in the Athabasca region following EXTECH IV (*e.g.*, Bosman and Schwab, 2009; Card, 2009). This work has overlapped with a Memorandum of Understanding between the Province of Saskatchewan and the State of South Australia, the objective of which is advancing and promoting best practices in geoscience activities and maximising the development of their respective mining industries. In Saskatchewan, the primary focus of this cooperative geoscience has been modelling the 3-D architecture of the Athabasca Basin and its basement rocks (Card *et al.*, 2010).

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In order to further advance our understanding of the uranium deposits of the Athabasca Basin and surrounding region, the Saskatchewan Geological Survey has launched the Athabasca Basin ore-systems project, which represents the next generation of a publicly funded geoscience initiative and builds on the successes and shortcomings of EXTECH IV. Ore-systems projects are designed to study both the regional and local processes involved in the genesis of economic ore deposits in a particular environment rather than using the traditional ore-deposit model approach, in which the host rocks are the most important factor. The postulated result is a better understanding of processes that have made the Athabasca region a prolific source of uranium since the 1950s.

a) Project Components

The Athabasca Basin ore-systems project is a multi-faceted initiative that involves regional compilation work and new geoscience. The goal of the project is to present data in the 3-D environment [2] using Mira Geoscience's Paradigm™ GOCAD® Mining Suite (GOCAD). Layers are either built in GOCAD or are constructed in other software, such as ESRI® ArcMap™, and imported into GOCAD. It is hoped that viewing datasets in a new environment will make it easier to model geologic units that host uranium deposits in the region and the processes responsible for forming them (*e.g.*, Bosman *et al*., 2011). The project is broken down into several components, the most significant ones being: 1) field- and office-based data collection aimed at furthering our understanding of both the Athabasca Group and its basement; 2) regional compilation of available geoscience information; and 3) generation of new data and adding it to existing data in order to better understand the ore-forming processes.

1) The data collection necessary for constructing a best-fit geologic model of the Athabasca Basin is effectively complete. New data, however, is continuously being collected and, where relevant, it will be integrated as time allows. The details of geoscience work based out of both Regina and northern Saskatchewan in 2010 and 2011 are presented below.

2) Traditionally, geoscience information from the Athabasca region has been presented in a series of geologic maps (*e.g.*, Slimmon and Pana, 2010) and cross sections (*e.g.*, Ramaekers *et al*., 2007). The same data presented in the 3-D environment provides a new perspective that is sometimes more easily interpreted because visualisation of the intricacies in 2-D is not always intuitive. The geometry of geologic units, their intersections with structural features such as faults and the distribution of clay species in the rock column, for example, are all more easily interpreted in 3-D space.

   In order to bring pre-existing geological products into GOCAD, the original data must be organised and its integrity checked. The Athabasca Basin is particularly challenging to model because, in spite of copious data, it is all concentrated in specific areas. This leaves enormous, data-poor tracts that make regionally extensive surfaces such as the unconformity and formation boundaries difficult for the software to model. To mitigate this difficulty, regional cross sections imported into, and digitised in, GOCAD are necessary. The authors are currently compiling the necessary data to build a best-fit model for the major geologic features of the Athabasca Basin, including the unconformity and the various lithostratigraphic units of the Athabasca Group.

3) Once a model of the geologic elements of the Athabasca Basin is completed, various datasets can be displayed and interpreted in the 3-D environment. This makes it easier to determine relationships among lithostratigraphic units and cross-cutting features, such as faults or the Mackenzie diabase intrusions. For example, two geochemical datasets have been imported into GOCAD and have been examined sufficiently to offer preliminary observations. The first was generated from samples collected by industry from Athabasca Group core stored in the Saskatchewan Geological Survey's Subsurface Laboratory located in Regina (Saskatchewan Ministry of Energy and Resources, 2010). The second was generated from samples of Athabasca Group outcrops stored at the Subsurface Laboratory (Card *et al*., 2011). Broadly speaking, the independently generated datasets show similar chemical associations, a brief discussion of which is presented in Card *et al*. (2011). For example, the rare elements, such as Y and the REE elements, are particularly anomalous in the Lazenby Lake Formation, which sits above a major sequence boundary and proximal to major structures such as the Snowbird tectonic zone and Grease River shear zone. These observations demonstrate that there are both stratigraphic and structural controls on the distribution of elements in the Athabasca Group. In the future, we envision modelling a variety of datasets in GOCAD, such as clay-species distribution.

2. Field Work

Drillcore logging and outcrop mapping produce the most important datasets for developing the lithostratigraphic and basement geology used in the Athabasca Basin 3-D model. Field projects have been structured over the last several years so that an adequate dataset could be acquired. To date, over 150 drillcores of the Athabasca Group

[2] The phrase "the 3-D environment" encompasses all aspects of 3-D modelling including 2.5-D, 3-D, and 4-D space; 2.5-D space is where 2-D objects are displayed in the third dimension; true 3-D space contains objects that are volumes; and 4-D space attempts to bring a temporal component to the modelling.

have been logged using multi-parameter logging, modelled on the EXTECH IV method (Bosman and Korness, 2007). Extensive basement mapping around the edge of the basin was used in conjunction with geophysical data to extend various basement geological units under the Athabasca sandstone (*e.g.*, Card, 2006). Both drillcore analysis and basement mapping projects have led to significant improvements in our understanding of the relevant rock units.

a) Drillcore Logging

During the summers of 2007, 2008, and 2009, multi-parameter logging of the Athabasca Group was completed on over 130 drillcores from many areas of the basin allowing a comprehensive regional dataset to be captured. As more data became available and early versions of a 3-D model evolved, it was decided that most of the remaining priority drillcores were stored in the Regina Subsurface Core Laboratory. The Regina facility has over 100 drillcores from the Athabasca Basin, many of which represent the deepest holes ever drilled. A complete list of all available core stored at the Regina facility is included in the Geological Atlas of Saskatchewan (Slimmon, 2011). In 2010 and 2011, drillcore logging became more targeted. Five drillcores from the Regina facility were logged and analyzed with an Analytical Spectral Device on loan from the Geological Survey of Canada in 2010. In addition to logging drillcore in Regina in 2011, a small, two-part field program was carried out, the details of which are discussed below. This program included drillcore logging at Pasfield Lake and transportation of two drillcore from the Davy Lake area (Figure 1) to Regina.

Preliminary Observations of Pasfield Lake Lithostratigraphy

Part one of the 2011 summer field program involved logging drillcores from the Pasfield Lake Property (Canterra Minerals Corporation, 100%; previously owned by Triex Minerals Corporation (Triex)). Two other drillcores from Triex's/Energy Fuels Inc.'s Stony Road property, stored at Pasfield Lake, were also logged but are not discussed (Figure 1). Historically, the Pasfield Lake area has been of interest due to the presence of radioactive springs northwest of the lake. It is also known to be an anomalously deep lake compared with many of the others in the basin. Aeromagnetic and gravity data also show anomalous features under the lake (Witherly *et al*., 2010). Most recently, Triex drilled eight holes in the area of which four collared on lake ice intersected basement rocks at a substantially shallower depth than in drillholes from the surrounding area. This, along with geophysical data (Witherly *et al*., 2010), implies that there is a circular, 9 to 10 km wide basement uplift beneath the lake of some 600 m relative to WC-79-1, the assumed regional unconformity depth (Figure 1). Unfortunately, a bush fire in 2010 destroyed six of the eight drillcores and therefore logging the remaining two drillcores from the area was a priority for 2011.

Both drillholes are east of the basement uplift and contain thick sections of the Athabasca Group, including lithostratigraphic units above the Manitou Falls Formation, which are generally not present in the region. Figure 2 is a cross section that displays the multi-parameter stratigraphic logs of Triex's remaining Pasfield Lake drillholes PF-09-007 and -008, located in the southeast part of the Pasfield Lake area, as well as a log from historic drillhole WC-79-1, located on the northwest side of the lake (Figure 1). In the cross section, the Read Formation, the basal unit in much of the eastern part of the basin, is only present in WC-79-1. Due to the Read Formation's lithological similarities with the overlying unit, in this case the Manitou Falls Raibl member, and because it is quite thin in WC-79-1, the main criterion for making this pick is the increased gamma-ray signature typical of Raibl member's base (Bosman and Korness, 2007; Mwenifumbo and Bernius, 2007). The gamma-ray data was obtained from Saskatchewan Ministry of Energy and Resources assessment file 74I-0012). Above the Read Formation is the Manitou Falls Bird member (conglomerate rich) or its more distal lateral equivalent, the Raibl member (pebbly). Both Raibl and Bird members have been subdivided into upper (up or u, respectively) and lower (lp or l, respectively) units. Successive units, the Manitou Falls Collins and Dunlop members overlie the conglomeratic rocks of the Bird and Raibl members. The presence of a relatively thick succession of the Lazenby Lake Formation above the Manitou Falls Formation, however, is anomalous for the area. Drillhole PF-09-008 contains ~190 m and drillhole PF-09-007 ~30 m of Lazenby Lake Formation. Drillhole WC-79-1, the most westerly of the drillholes (Figure 2), located well outside the structural features surrounding the uplift, contains a comparatively thin intersection, ~10 m of Lazenby Lake Formation. Apart from one drillhole about 40 km south of Pasfield Lake, Lazenby Lake Formation was not previously known to be preserved this far east. Both PF-09-007 and -008 are located just outside of the basement uplift and inside the topographic high that surrounds the lake. This area is interpreted to have been down-dropped during formation of the basement uplift, thereby preserving Lazenby Lake Formation. Drillhole PF-09-008 contains more Lazenby Lake Formation relative to PF-09-007 likely representing a larger negative displacement. Also noteworthy is the repeated unconformity in drillhole PF-09-007, which was likely caused by a reverse fault.

Based on its magnitude and petrographic textures observed in thin section, the uplift has been interpreted by Harper *et al*. (2010) to represent a meteorite impact site. It is important to note, however, that many researchers suggest circular geologic features have a volcanic origin and are the result of the explosive release of CO_2-rich gas (*e.g.*, Phipps Morgan *et al.*, 2004).

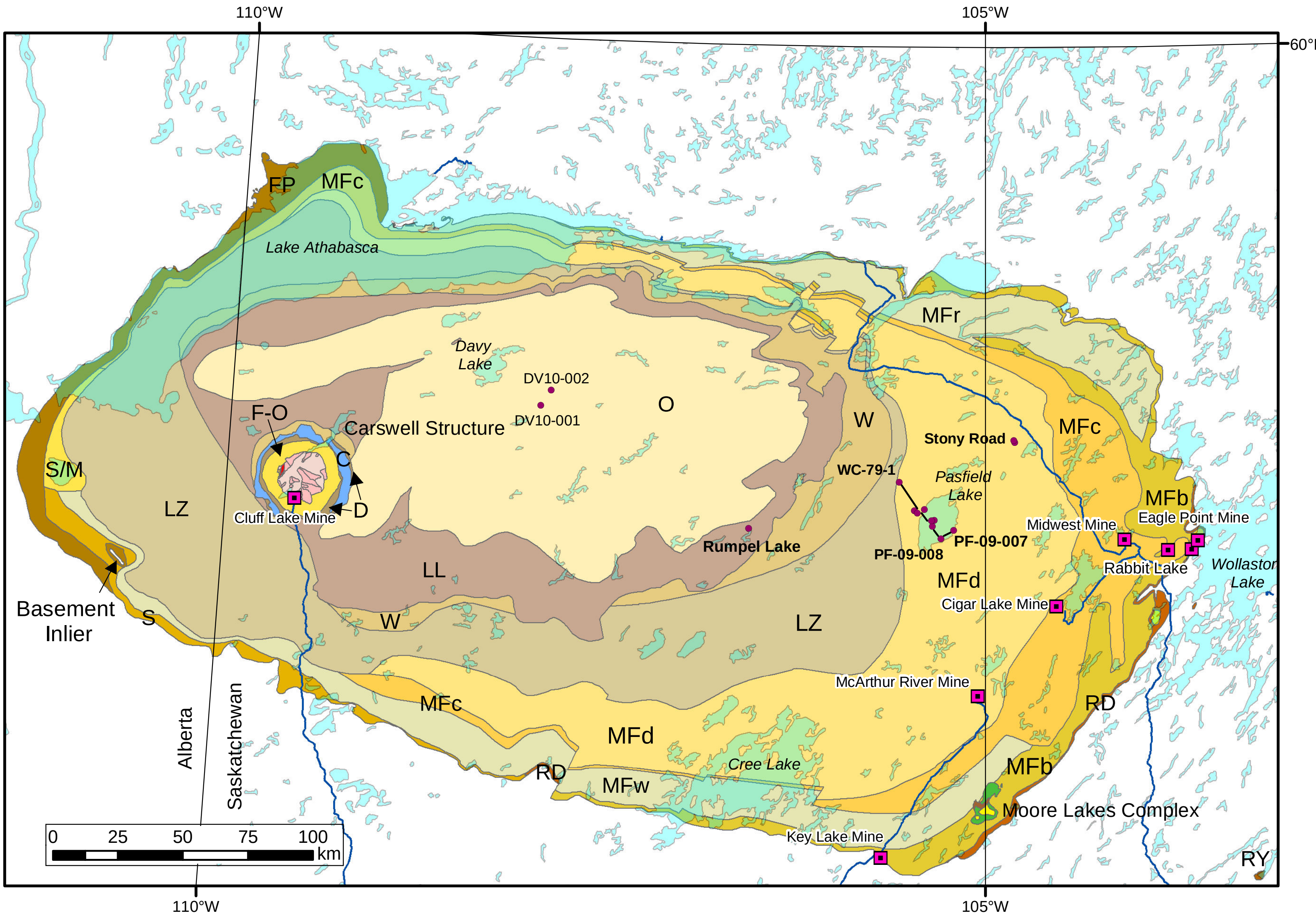

***Figure 1** - Location of the major lithostratigraphic units of the Athabasca Group. Location of drillholes (red circles) discussed in this report are included. Formation codes are, in order of ascending stratigraphic position: FP = Fair Point; RY = Reilly; RD = Read; S = Smart; MF = Manitou Falls (members: MFb = Bird, MFr = Raibl, MFw = Warnes, MFc = Collins, and MFd = Dunlop); LZ = Lazenby Lake; W = Wolverine Point; LL = Locker Lake; O = Otherside; D = Douglas; C = Carswell; S/M = undifferentiated Smart and/or Manitou Falls formations; and F-O = undivided Fair Point to Otherside formations in the Carswell Structure. Blue lines represent selected roads. Red squares show locations of selected uranium mines.*

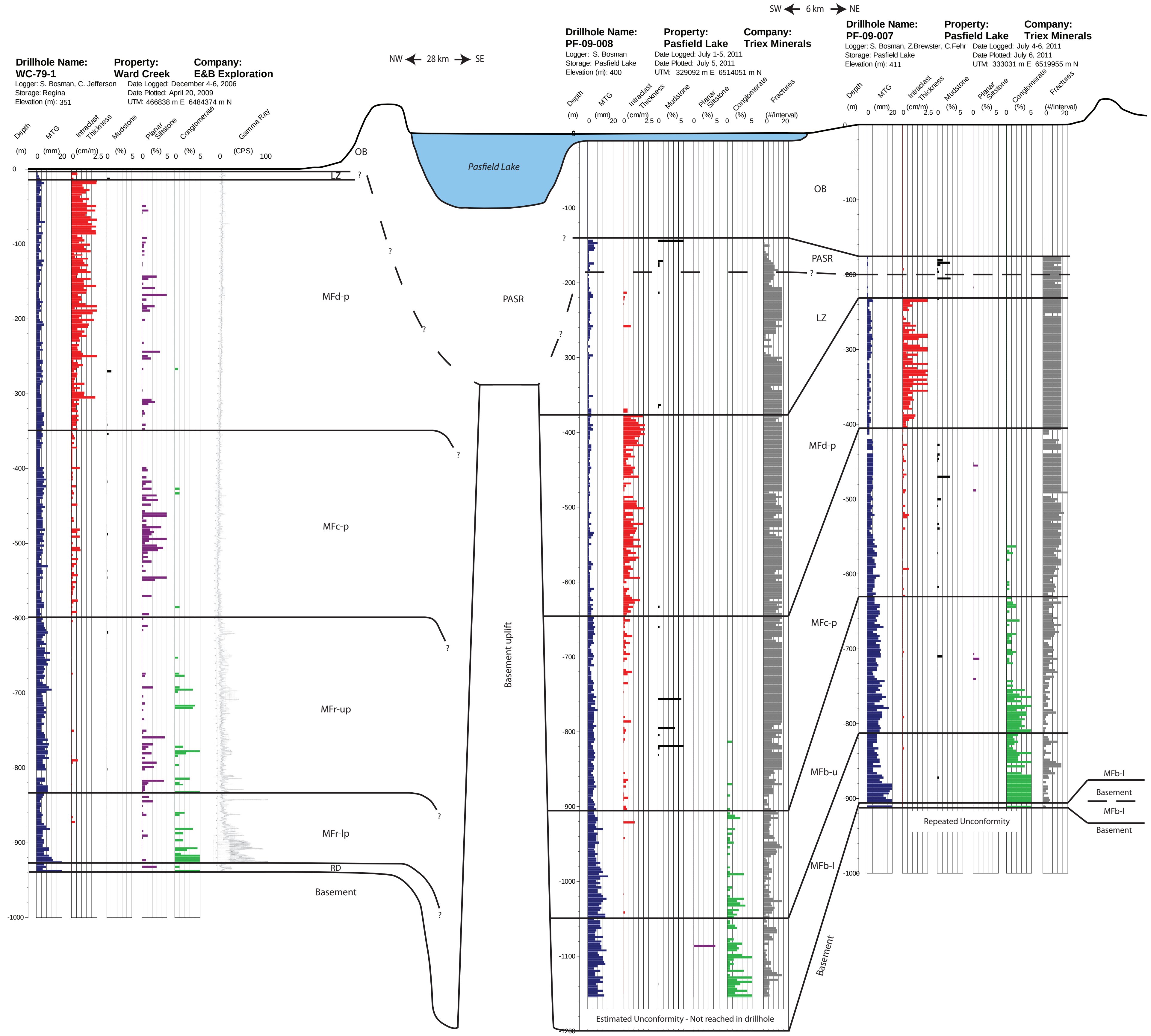

Figure 2 - Cross section of multi-parameter logs of three drill holes in the Pasfield Lake area. Formations in ascending order: RD = Read; MF = Manitou Falls (members: MFr = Raibl (lp = lower pebbly, up = upper pebbly), MFb = Bird (l = lower, u = upper), MFc = Collins (p = pebbly), MFd = Dunlop (p = pebbly)); and LZ = Lazenby Lake. Other abbreviations: PASR = Post-Athabasca sedimentary rock; MTG = maximum transported grain; and OB = overburden.

Fission Energy Corp.'s Davy Lake Property Drillcore Extraction

During the 2010 summer drill season, Fission Energy Corp. completed two exploration drillholes on its Davy Lake property (Figure 1). Due to their location in a relatively unexplored region, these two drillholes represent the most important stratigraphic holes in the Athabasca Basin since the 1969 Rumpel Lake drillhole (Figure 1). These two new holes are approximately 40 km away from any previous drillhole in the basin, are the closest holes to the geographical and depositional centres of the basin, and also transect the stratigraphy of the entire typical Athabasca Group.

Because of their geological significance and location, these cores have been removed from the property and stored at the Subsurface Laboratory in Regina where they are no longer at risk from forest fires or from degradation by the elements. The cores, DV10-001 and -002, consisting of 250 and 267 wooden boxes, respectively, were extracted over a two-day period in July 2011. They were transported from the storage location at White Bear Camp on a small lake about 30 km east of Davy Lake to Stony Rapids via float plane (see Fission Energy's website for more detailed information about the property and drillhole location at: URL<http://www.fission-energy.com/s/davylake.asp>). From Stony Rapids, the core travelled by semi-tractor trailer to Regina. The core was subsequently logged and then transferred into the Subsurface Laboratory's standard boxes. Results of the logging will be available at a later date. These two drillcores will be available for public viewing after January 20, 2012.

b) Basement Mapping

A preliminary map of the basement for the western Athabasca Basin was published in 2006 (Card, 2006). A second-generation map will encompass the entire Athabasca region, including compilation of the geology in the region flanking the Athabasca Basin. Arriving at a best-fit basement map beneath the Athabasca Basin is a multi-step process. Wide gaps in data across the basin render aeromagnetic data a critical component of the interpretation process. The first step in the regional basement-mapping process is identification of regions of comparable aeromagnetic "pattern". This process does not necessarily rely on relating magnetic anomalies to specific rock units, unless the relationship is unequivocal, but rather on domains with like patterns and/or structural character. Interpretation of gravity anomalies may add further confidence to the interpretation. An interpretation of the magnetic domains beneath the Athabasca Basin was nearly complete at the end of 2010; however, the release of new aeromagnetic data for the northwest part of the Athabasca Basin (Fortin *et al*., 2011a, 2011b, 2011c, 2011d, 2011e) made re-evaluation of this region appropriate.

Further detail will be added to the map through "ground truthing" of the defined magnetic regions. Available bedrock maps in regions flanking the basin will be compiled and distinct rock units correlated with magnetic anomalies. The units can then be extrapolated only a certain distance beneath the basin depending on their orientation and continuity, after which drillholes become the primary data source. To that end, the basement was logged in nine drillcores stored at the Subsurface Laboratory in Regina during the 2011 summer. Drillhole data is useful for interpretations of the deeper parts of the basin, but is only available sporadically. This information will be incorporated into the final version of a basement map for the Athabasca region.

3. Data Compilation and 3-D Model

The primary goal of this project is construction of a geologically meaningful 3-D model of the Athabasca Basin and the use of this framework geology to display additional datasets such as geophysical, geochemical, and mineralogical parameters. With the help of geoscientists from the Geological Survey of South Australia, an initial model of the basin was created in February 2010. The first surface built was the unconformity at the base of the Athabasca Group, which included several interpreted vertical offsets of the unconformity representing displacement along major faults in the basin. Two circular uplift features were also modelled, one at Pasfield Lake and the other at the Carswell Structure (Figure 1). A preliminary interpretation of the large-scale basement units, largely defined using aeromagnetic data (*e.g.*, Fortin *et al*., 2011a, 2011b, 2011c, 2011d, 2011e), has been draped on the unconformity surface. Other surfaces built include the contact between the overburden and the Athabasca Group and the bases of Athabasca Group formations. Large-scale fault surfaces, interpreted from basement and surface lineaments, were also added and basement and surface lineaments were connected where appropriate. Additional objects such as uranium deposits, drillhole traces, mine locations and the digital elevation model have also been incorporated into the model. These objects represent the framework of the model and subsequently the process of adding geochemical datasets was undertaken. Two notable datasets that have been added include the Geochemical Analyses of Athabasca Group Outcrops (Card *et al*., 2011) and the Industry Drillcore Data geochemical dataset (Saskatchewan Ministry of Energy and Resources, 2010). These regional datasets provide a geochemical picture for the Athabasca Group.

4. Summary

The Athabasca Basin ore-systems project is in its formative stage. Its primary goal is to present regional geoscience data, traditionally reserved for 2-D viewing in the 3-D environment. Once a 3-D model for the geology of the Athabasca Basin is generated, data, both new and historic, can be displayed allowing for geoscientists to better interpret the significance of this data. Through a combination of office- and field-based data collection, compilation of pre-existing information and new interpretation techniques, the geology and history of the Athabasca Basin can be presented in a manner never before seen. The ultimate goal of the project is a better understanding of the processes that led to the formation of economic uranium deposits in the Athabasca Basin and its underlying basement.

In the first year of the project, the Saskatchewan Geological Survey has undertaken several new tasks aimed at accomplishing these goals. The first is an ambitious data-compilation exercise that will allow for the best presentation of the various elements of the Athabasca Basin. We have also undertaken field activities to collect and preserve data in critical parts of the Athabasca Basin, particularly the drillcores extracted from Fission Energy Corp.'s Davy Lake property. In addition, we have generated new data, specifically geochemical datasets that will allow us to better interpret the diagenetic and hydrothermal fluid history of the Athabasca Basin.

5. Acknowledgements

The authors are grateful to Fission Energy Corp.'s (Fission) support in permitting the Davy Lake core to be stored at the Regina Subsurface Laboratory. Canterra Minerals Corporation (Canterra) is also acknowledged for allowing us to study the Pasfield Lake and Stony Road drillcore. The authors would especially like to thank company employees including: Ross McElroy, Ray Ashley, and Caroline West (Fission); and Francis Moul (Canterra). Site visits to Uravan Minerals Inc.'s Outer Ring property (Chris Pettman) and to Hathor Exploration Limited's Roughrider deposit (Alistair McCready) were also appreciated as were the accompanying discussions. The authors are also grateful to Jeanne Percival of the Geological Survey of Canada for allowing us to use her Analytical Spectral Device.

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