EXTECH IV Athabasca Uranium Multidisciplinary Study: Mid-year 2002-03 Overview and Impact Analysis

C.W. Jefferson [1], G. Delaney, and R.A. Olson [2]

Jefferson, C.W., Delaney, G., and Olson, R.A. (2002): EXTECH IV Athabasca uranium multidisciplinary study: Mid-year 2002-03 overview and impact analysis; *in* Summary of Investigations 2002, Volume 2, Saskatchewan Geological Survey, Sask. Industry Resources, Misc. Rep. 2002-4.2, CD-ROM, Paper D-1, 12p.

Abstract

In the third and final year, EXTECH IV has progressed on 15 sub-projects, evolving from data acquisition to interpretation with a strong focus on integration. Two main goals are being addressed.

1) *The Athabasca Basin geoscience framework is being improved by: a) mapping of Rae-Hearne-Taltson basement domains and their boundaries to simplify and resolve uncertainties, b) mapping open pits to put into regional context and document the predictive relationships of uranium ore to brittle reactivation of previous ductile basement structures; c) quantitative litho-sequence stratigraphy across the six regional deposystems in the Athabasca Basin to resolve east-west inconsistencies and update the regional framework; d) documenting fluvial style, detailed facies relationships, and paleo-valleys associated with ore in open pits and drill camps; e)mineralogical refinement of alteration vectors to ore; f) geochronology studies that have generated detrital zircon U-Pb ages to constrain sequences and provenance and resulted in the development of new SHRIMP standards to date uraninite; g) Quaternary geology and geochemistry is calibrating unusual K-U trends in airborne gamma ray maps; h) high-quality 2D and pseudo-3D seismic images that are extending borehole stratigraphy and structure, tracking the unconformity and its offset by the ore-related P2 reverse fault zone, and identifying a possible mafic intrusion at depth as a possible heat source for hydrothermal ore generation; and i) public domain and new data are being captured and managed in GIS databases.*
2) *New and enhanced EXploration TECHnology (seismic reflection, gravity, magnetotellurics, gamma ray and multiparameter borehole geophysics) are correlating in new ways and calibrating typical ore, host rock, and alteration parameters of the world class McArthur River mining camp as tools to aid exploration within Athabasca Basin and beyond.*

Sustainable economic and social development in northern Saskatchewan and Alberta have been enhanced by improved exploration decision making, new ideas, new land acquisitions, and training of 10 young scientists. New partnerships and new ideas are being developed for potential future projects.

***Keywords**: Mesoproterozoic, northern Saskatchewan-Alberta, Athabasca Basin, organic matter, Taltson-Rae-Hearn gneiss, K-U anomalies, seismic reflection, magnetotelluric, gravity, multi-parameter borehole geophysics, unconformity uranium deposits, EXTECH.*

1. Introduction

Unconformity-type deposits are the highest grade, lowest cost uranium resource in the world. The 1.7 billion year-old Athabasca Basin of northern Saskatchewan and Alberta (Figure 1) is the premier host for unconformity-type deposits and has an estimated resource in excess of 375 000 t U (969.6 million lbs U_3O_8). Because it takes 10 to 15 years from discovery to mining, exploration companies must plan far in advance and have been consistent supporters of geoscience research. Although exploration for new unconformity-type deposits continues in the Athabasca Basin, other Proterozoic basins are also being explored around the world, including the Thelon Basin in the Northwest Territories and Nunavut of Canada, the McArthur Basin of northern Australia, and those on the Aldan and Anabar shields of Russia and on the Indian Shield (Thomas *et al*., 2000).

Public domain geoscience framework data on the Athabasca Basin and its mineral deposits were previously acquired up to about 1983. Those projects included comparative studies of exploration methods in the Nuclear Energy Agency/International Atomic Energy Agency Athabasca Test Area and adjacent regions (Cameron, 1983), a study of basement beneath the Athabasca Basin in Alberta (Gilboy, 1983) and a comprehensive study of the

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, ON K1A 0E8; PAS/TGI Project PS1018.
[2] Alberta Geological Survey, 4th Floor, Twin Atria, 4999 - 98 Avenue, Edmonton, AB T6B 2X3.

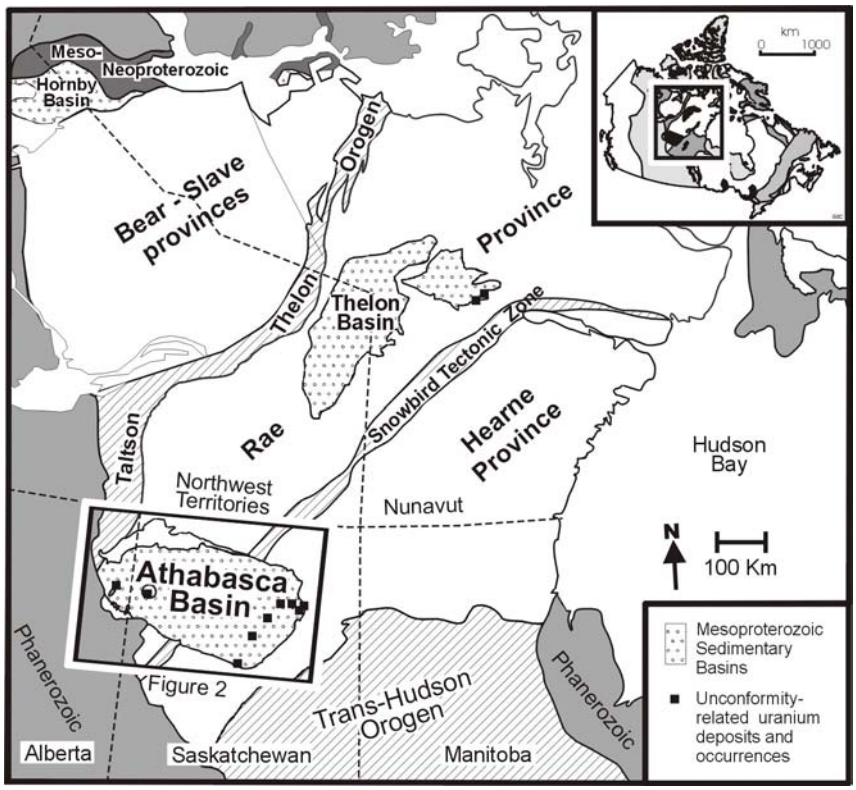

Figure 1 - Location of the study area for EXTECH IV, Athabasca Uranium Multidisciplinary Study (http://www.nrcan.gc.ca/gsc/mrd/extech4/index.html). Northwestern Canadian Shield elements after Ruzicka (1996), Thomas** et al**. (2000), and Card (2001).

Athabasca Group in northern Saskatchewan (Ramaekers, 1990). A spectrum of research projects have also been conducted by industry consultants and university professors supported by the uranium exploration industry (e.g., Kotzer and Kyser, 1995) and by individual government and industry geologists who have published a number of generalized accounts, (e.g., Thomas *et al.*, 2000;Andrade *et al.*, 2002 and references therein), however, many of the results have been kept confidential and stakeholders requested renewed public domain studies.

The EXTECH IV Athabasca Uranium Multidisciplinary Study was developed through needs and planning meetings that were organized by stakeholders over a two-year period. It was initiated in April 2000 with funding from the Geological Survey of Canada's (GSC) Project Approval System and Targeted Geoscience Initiative, matched by cash and in-kind resources from NSERC, the governments of Saskatchewan and Alberta, and two major exploration companies: Cameco Corp. and COGEMA Resources Inc., with the participation of the universities of Saskatchewan, Laurentian, Alberta, and Regina. It comprises 15 sub-projects: five geophysical, eight geological, one GIS database, and one co-ordination. The locations of these sub-projects and their geological context are shown in Figure 2. Total resources of $7.5 million have been allocated over three years to acquire and deliver data with preliminary interpretations. A fourth year is proposed to complete publication of a peer reviewed comprehensive volume.

EXTECH IV (EXploration science and TECHnology initiative) aims to enhance the four-dimensional geoscience knowledge base of the 1.7 billion year old Athabasca Basin and to develop new exploration methods for deep uranium deposits that are located at or near its basal unconformity with basement gneisses, thereby sustaining and enhancing the environmentally sound development of this mature mining camp. Each partner has specific goals, and is contributing their special expertise which together makes EXTECH IV comprehensive. The focus in Saskatchewan is on documenting and archiving existing world-class mine areas, and developing and calibrating new exploration tools. In both northeastern Alberta and northern Saskatchewan, new detailed and regional studies are updating and expanding geological information about relatively unexplored parts of the Athabasca Basin in order to stimulate further mineral exploration.

Individual sub-project teams showing partner affiliations and results of EXTECH IV since September 2001 are summarized below for each sub-project as of October 2002. Goals, objectives, and details of the results are presented in this volume by the authors cited. Distribution on CD-ROM in this format provides mid-year information conveniently to all partners and stakeholders. A longer version of this overview including Goals and Objectives, and Impact analysis, is provided by Jefferson *et al.* (in press).

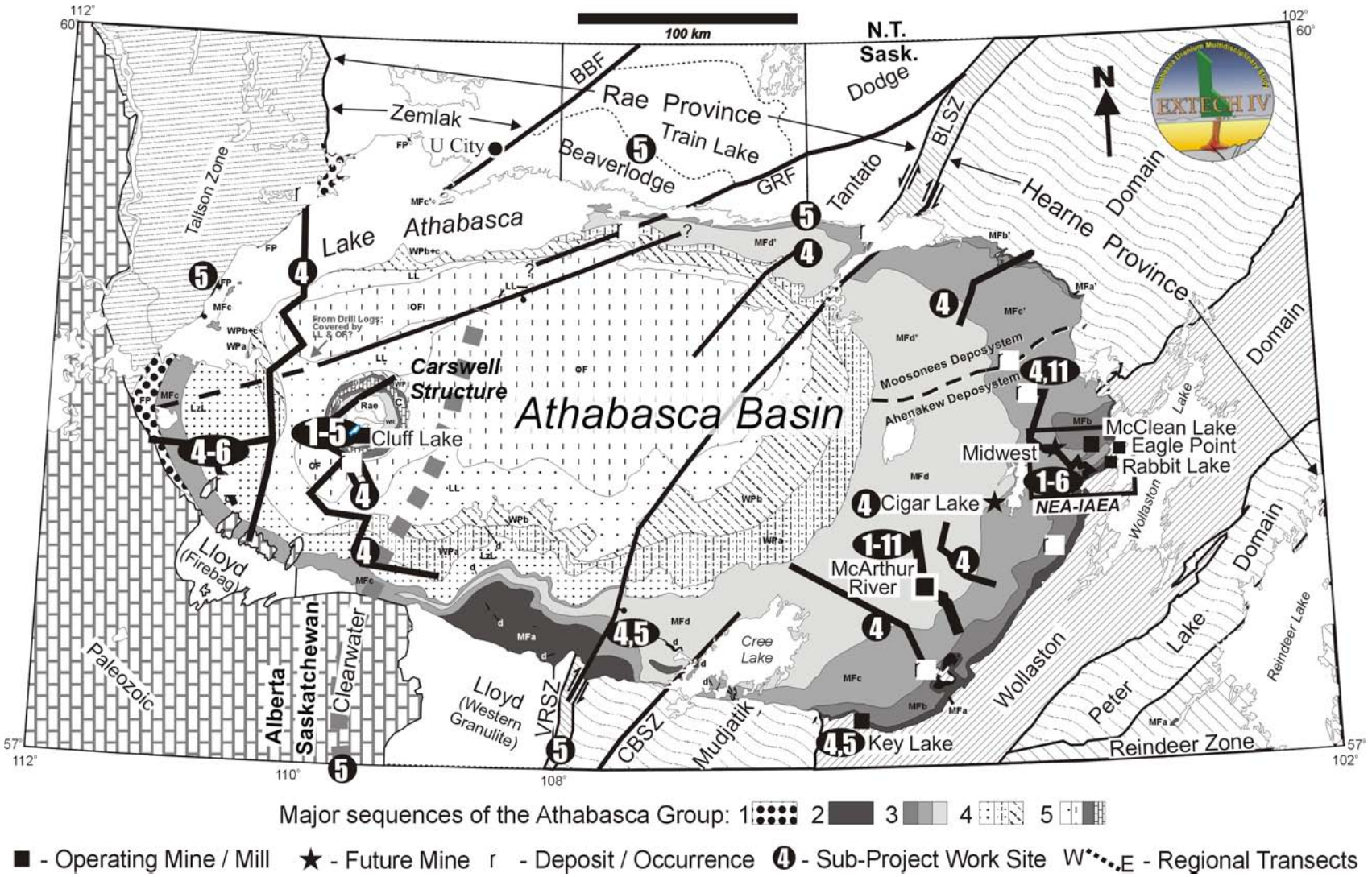

Figure 2 - Locations of EXTECH IV sub-projects with respect to geology of the Athabasca Basin region, after Ramaekers (1990), Thomas** et al. **(2000), Card (2001), and Ramaekers** et al. **(2001). BBF=Black Bay Fault; GRF=Grease River Fault; BLSZ=Black Lake Shear Zone; CBSZ=Cable Bay Shear Zone; and VRSZ=Virgin River Shear Zone.

Sub-project 1: Regional and High-resolution Seismic Reflection Survey

Co-leaders (team): Z. Hajnal[1], D. White[2], E. Takacs[1], S. Gyorfi[1], B. Reilkoff[1], S. Woelz[2], R. Koch[3], B. Powell[4], I.R. Annesley[5], D. Schmitt[6], D. Jamieson[2], B. Roberts[2], E. Adam[2], G. Bellefleur[2], B. Pandit[1], and P. Portella[3]

Results for 2002-03 (details in Hajnal *et al*. (this volume), Gyorfi *et al*. (this volume), and White *et al.* (this volume; in press)

- New data along 39 km of regional 2D seismic profiles (lines A and B) and 8 km of high-resolution profiles (lines 12 and 14) in the McArthur River Mine area have been migrated and initially interpreted through pattern recognition and partial integration. A limited 3D high-resolution survey of the P2 North deposit at McArthur River, including three-component recording, high-frequency three-component vertical seismic profiles (VSP) and a 3D three-component VSP, has been initially processed and a series of cross-sections constructed to form a pseudo-3D array. The zero-offset and near-offset high-frequency VSP data have been processed and are being used to calibrate high-resolution and pseudo-3D models.
- These provide some excellent data compared to recent LITHOPROBE results, with superimposed thrusts and escape structures clearly visible in basement rocks, and the unconformity clearly imaged at 400 to 600 m depth.
- Offset of the unconformity by the 2.5 km thick P2 fault system, a key control on P2 uranium deposit, is traceable upward through the overlying Athabasca Group sandstones and downward more than 4 km as a listric structure that curves past the southeastern limit of the survey.
- Lateral variations in sandstone porosity, silicification, or facies changes are inferred from variable reflection response and velocity variations. Angular discordances in stratigraphy suggest onlaps or unconformities due to tectonic controls on sedimentation.
- A reflection response from the vicinity of the orebody is apparent.
- This survey, and a LITHOPROBE survey to the northeast, imaged a bright reflector interpreted as an extensive thick sill approximately 6 km deep that may be associated with the Mackenzie Igneous Event (1.265 Ga). This could have provided a heat source for hydrothermal convection focused on the P2 structure.
- A post-doctoral fellow (Takacs) is carrying the regional data interpretation forward; a Ph.D. student (Gyorfi) has completed his training and has processed high resolution lines 12 and 14 with initial interpretation of basement uplifts as escape structures.
- Technology was transferred at GAC/MAC in May 2002 and two subsequent workshops.

Sub-project 2: Multiparameter Borehole Geophysics

Leader (team): C.J. Mwenifumbo[2], M. Salisbury[2], B.E. Elliott[2], W. Hyatt[2], R. Koch[3], J. Robbins[3], B. Powell[4], and G. Wood[4]

Results for 2002-03 (details in Mwenifumbo *et al.*, in press, this volume):

- Multi-sensor geophysical combinations of spectrometric natural γ-ray, spectral γ-γ density, full waveform sonic, magnetic susceptibility, inductive conductivity, resistivity, IP, and temperature were fully processed from 11 boreholes at Shea Creek and McArthur River sites. Results were presented at the KEGS symposium August 21 to 23, 2002 and submitted to the Journal of Applied Geophysics.
- Two new surface drill holes and one underground drill hole at the McArthur River mine site, through a high-grade uraninite pod, have filled critical data gaps. The former have provided our first modern sonic data on relatively fresh basement rocks, the latter on uraninite. In both cases special cooperation and initiative from Cameco staff from working to senior management levels, and enhanced funding allocated by the Steering Committee, facilitated the data acquisition.
- Lithology, alteration (mainly silicification), and uranium ore with associated alteration are now characterized by several of the geophysical parameters, which correlate directly with (e.g., gamma ray for conglomerates) or help to correct data gaps in (e.g., density for silicification) geological logs. These parameters offer new tools for stratigraphic correlation in the Athabasca Basin, facilitated by software such as GSC's Logview or commercial products.
- *In-situ* physical rock properties data such as compressional wave velocities, densities, and electrical properties, from more than 13 drill holes, helped to design the high-resolution seismic survey and now help interpret resulting seismic, magnetotelluric, and gravity data.

Sub-project 3: Bitumens, Hydrocarbons, Fluids, and Diagenesis

Leader (team): L.D. Stasiuk[7], N.S.F. Wilson[7], M.G. Fowler[7], D. Jirika[4], K. Wheatley[3], M. Li[7], V. Sopuck[4], G. Zaluski[4], and D. Morrison[3]

Results for 2002-03:

- All pyrobitumens found by detailed petrography of a diverse sample suite invariably post-date uraninite, either enveloping pitchblende inclusions or occupying veinlets that cross-cut massive pitchblende. The presence of bitumen does not indicate proximity to ore.
- Work continues on archived samples from the Muskwa Group of northeastern British Columbia for fingerprinting and comparison with those from the Douglas Formation.
- Spectral analysis and vitrinite reflectances of Douglas Formation hydrocarbons are consistent with burial temperatures of 160º to <200°C and likely the generation of Proterozoic petroleum. Such temperatures accord with fluid inclusion data and suggest ~190º to 230ºC at the unconformity during peak diagenesis.
- Crude oil inclusions and solid to semi-solid bitumens within Fair Point, Wolverine Point, and Manitou Falls formation sandstones distal to uranium deposits in the vicinity of Maybelle River, Rumple Lake, Virgin River, Cluff Lake, Hook Lake, Dawn Lake, and possibly McArthur River and Rabbit Lake deposits have been fingerprinted as Devonian to Cretaceous in origin.
- RockEval analyses of carbon-enriched sandstone samples from CLU9-79 suggest that the solid carbons could be pyrobitumen derived from a Proterozoic oil reservoir. Similar carbon-enriched zones are in samples from various joint venture projects managed by Cameco including, Dawn Lake, Hook Lake, Virgin River, and southwest Athabasca.
- Training of a young scientist (Wilson) is being supported by GSC-industry cost-sharing at GSC Calgary. In return, Wilson is sharing petrographic expertise with other sub-projects, providing assistance to deposit-scale structural studies (Tourigny) and to geochronology through identification of favourable mineralogy (Rainbird).
- The above results are detailed by Wilson *et al.* (2002).

Sub-project 4: Athabasca Stratigraphy and Sedimentology

Co-Leaders (team): G.M. Yeo[8], C.W. Jefferson[2], S. Bernier[9], B. Collier[9], B. Kupsch[10], D.G.F. Long[9], R. Post[11], P. Ramaekers[12], J.B. Percival[2], O. Catuneanu[10], C. Belyk[4], C. Cutts[3], G. Delaney[8], G.L. Drever[4], D. Jiricka[4], I. Koning[3], S. McHardy[4], D. Morrison[3], D. Quirt[13], K. Wheatley[3], and R. Rainbird[2]

Results for 2002-03:

- From January to September 2002 the following three new metre-by-metre quantitative drill logs were acquired: three in the western Saskatchewan part of the basin; two more in each of the Ahenakew, Karras, and Moosonees deposystems (Yeo *et al.,* this volume), and by Post in Alberta; eight along the Net Lake Trend; 11 along the Maybelle River Trend; and seven to calibrate reconnaissance cross section D-D' of Ramaekers. These regional studies were complemented with bed-by-bed logs and other detailed sedimentologic work reported under sub-project 4a.
- Fifty-five previously published and new regional reconnaissance drill logs by Ramaekers (Ramaekers *et al.*, 2001; 2002) have been analyzed on a series of sections flattened at different stratigraphic breaks interpreted as sequence boundaries. This has provided a tectonic-sedimentary framework for the entire basin, amplifying interpretations of syn-sedimentary tectonic flexures and minor brittle faults at McArthur River (Bernier) and Wheeler River (Jefferson) and detailed study of stratigraphy and alteration at the Maybelle River uranium occurrence (Kupsch, sub-project 4a).
- Regional comparison of the Manitou Falls Formation, that preserves four of seven Athabasca deposystems, has reinforced the fundamental strength of its member subdivisions, highlighted unconformity breaks that define major sequence boundaries, and provided additional tools to see through lithologic variations and carry sequence stratigraphy at the member level. Details are reported by Yeo *et al*. (this volume)

Sub-project 4a: Detailed Stratigraphic Studies in Athabasca Basin

Co-leaders (team): D.G.F. Long[9], O. Catuneanu[10], S. Bernier[9] B. Collier[9], B. Kupsch[10], G.M. Yeo[8], C.W. Jefferson[2], P. Ramaekers[12], G.L. Drever[4], J. Robbins[3], K. Wheatley[3], I. Koning[3], D. Jiricka[4], D. Morrison[3], P. Portella[3], R. Post[11], and B.Sc. students

Results for 2002-03:

- In the Shea Creek M.Sc. project area (Collier, this volume), a preliminary stratigraphic framework was re-evaluated with a closer look at the relationship between grain-size characteristics and sedimentary structure. These data were combined with the previous variables to delineate facies associations. Conclusions include: a) Changes in primary sedimentary structure correlate with and help to refine stratigraphy based on grain size, intraclast abundance, and conglomerate thickness; b) five 3rd-order sequences (Shea Creek, "Lower Manitou Falls", "Upper Manitou Falls", Lazenby Lake–Wolverine Point, and Locker Lake) are defined; c) the only clearly recognizable unconformity in core is the Lazenby Lake–Manitou Falls contact; d) the lowermost "Shea Creek Sequence" is distinguished from the rest of Manitou Falls by indicators of a humid fluvial setting, such as thick debris flow deposits, and larger bedforms which distinguish them from overlying rippled, horizontally bedded deposits of ephemeral braided streams deposited in semi-arid settings; and e) Lazenby Lake–Wolverine Point through Locker Lake have abundant overturned and convolute bedding, thought to result more from frictional drag from high-energy stream flows rather than slumping of channel walls.
- In the McArthur River transect area, an M.Sc. sub-project by Bernier (this volume) is analyzing metre-by-metre stratigraphic logs of 18 drill logs, augmented by three new metre-by-metre logs of strategic holes and several sets of 1.5 m interval logs contributed by Cameco. Sequence analysis by flattening cross-sections on a series of sub-unit boundaries, shows that if the boundaries are temporal planes, then the P2 fault was active periodically through out deposition of the preserved Manitou Falls Formation. Sedimentological interpretations and sequence boundaries were tested by detailed bed-by-bed logs that described key stratigraphic sections and documented an unconformity between members MFa and MFb, precisely at the top of the remarkably persistent pebble-free MFa4 sub-unit. Clay mineral analyses by PIMA and ASD (Percival *et al*., this volume) and paleocurrent measurements in several holes complement the research.
- In the Maybelle River area of Alberta, the M.Sc. project by Kupsch (this volume), is combining stratigraphic and alteration studies and has contributed organic geochemical samples to Stasiuk *et al*. for the Bitumens sub-project. Fifteen holes were logged using the standard stratigraphic parameters as well as those required to document basement lithology and alteration. Initial results are: a) the Maybelle River basement conductor is related to graphitic mylonite that transects granitoid gneiss along the east side of the Maybelle River mineralized trend, and also includes brittle structures; b) two sub-units of the Fair Point Formation – FPb2, a coarse pebbly conglomeratic sandstone and FPc, a pebbly sandstone – have abundant interstitial clay and increase in aggregate thickness from 30 to 50 m toward the west; c) the Manitou Falls Formation is represented by the MFc member characterized by ripple cross-bedded, fine- to medium-grained sandstone with minor small pebbles at the base and upward-increasing intraclasts that rarely exceed 1%; d) the Lazenby Lake Formation sharply overlies MFc; this contact is defined by the loss of intraclasts and gain of pebbles; and e) six types of alteration are distinguished: i) clay replacement and dissolution of both *in situ* and faulted sandstones, mainly in Fair Point Formation and rarely in Manitou Falls Formation, ii) drusy quartz veins above dissolution zones, iii) pyrite in fractures higher in the Manitou Falls and Lazenby Lake formations, iv) red upper hematitic and clay-rich 2 to 30 m thick paleo-weathering zone, v) green lower chlorite- and illite-bearing paleoweathered zone, 1 to 8 m thick grading to fresh basement, and vi) bleaching of basement including paleo-weathered zone in and around the mineralized drill hole.
- Linking the above to regional context, R. Post has logged bed-by-bed and paleocurrent data for select Athabasca holes and is petrographically analyzing four drill holes each along the Net Lake and Maybelle River trend, and two along Ramaekers' D-D' trend.
- A B.Sc. thesis has been initiated (Ickert) to: 1) evaluate the informal subdivision of the Fair Point Formation (Ramaekers 2002), and apply it to strata in Alberta with a emphasis on the "FPb1" east-west-trending unit. 2) petrographically document the Fair Point lithology; 3) define the sedimentary facies and facies associations in drill core; and 4) develop a preliminary depositional model and a tectonostratigraphic framework for Fair Point in the Alberta.

Sub-project 5: Basement to Western Athabasca Basin

Co-leaders (team): C. Card[8], D. Pana[11], K. Ashton[8], H. Lyatsky[14], P. Ramaekers[12], K. Wheatley[3], D. Thomas[4], E. Koning[3], W. Slimmon[8], C. Gilboy[8], K. Bethune[15], and M. Leppin[4]

Results for 2002-03 (see Card, this volume):

- Significant similarity between the supracrustal packages in the western and eastern Lloyd Domain in part justifies their amalgamation into a single domain.
- The Clearwater Magnetic High is underlain by various co-magmatic granite phases which carry large xenoliths of older granitic gneiss. The interaction between the different magma phases and the xenoliths apparently led to the precipitation of significant magnetite causing the anomalously high magnetic signature apparent in regional airborne magnetic data.
- The Virgin River Shear Zone formed during multiple events originating with west-side-up reverse offset. The Virgin Schist Group was intercalated with gneisses of the Lloyd Domain during this event and later deformed and partially melted(?) during dextral shearing. It has similarities to other supracrustal units in the Rae Province, however, its provenance is not yet known.
- Although there appears to be continuity in magnetic trends beneath the Athabasca Basin between rocks in the Tantato and Lloyd domains, the rock proportions, metamorphic grade, and rocks which underlie various magnetic lineaments do not match. There is, however, some similarity between the supracrustal packages preserved in the two domains.
- Graphitic mylonites transecting granitoid gneisses are associated with conductors and resulting uranium concentrations in the Maybelle River area.

Sub-project 5a: Detailed Structural Studies of Athabasca Uranium Deposits

Leader (team): G. Tourigny[8], G. Breton[3], S. Wilson[3], P. Portella[3], E. Koning[3], R. Stern[2], D. Thomas[4], I.R. Annesley[13], C. Madore[13], and D. Quirt[13]

Results for 2002-03:

- A paper on the basement-sandstone structural geology and its predictive relationship to ore has been submitted to Economic Geology and is under revision.
- The spatial association of paleo-valley development related to different competences of various basement gneiss units and fault zones is being incorporated into stratigraphic and exploration technology aspects of EXTECH IV.

Sub-project 6: Gamma Ray Geophysics

Leader (team): R.B.K Shives[2], P. Holman[2], J. Carson[2], J. Grant[2], J.B. Percival[2], R.A. Klassen[2], G. Wood[3], K. Wasyliuk[2], D. Thomas[4], C. Cutts[3], K. Wheatley[3], R. Koch[3], D. Quirt[13], J. Campbell[8], E. Grunsky[11], and M. Fenton[11]

Results for 2002-03 (details in Campbell *et al*., this volume):

- Re-processed and levelled high-resolution gamma ray ternary data, reported in 2001-02 for the NEA-IAEA test area in and around Dawn Lake–Midwest Lake, were used to design a follow-up Quaternary geological-geochemical transect for calibration and interpretation, the results being reported under sub-project 6a.

Sub-project 6a: Surficial Geology

Co-leaders (team): J. Campbell[8], R. Klassen[2], R. Shives[2], M. Fenton[11], B. Schreiner[13], J. Pawlowicz[11], G. Prior[11], E. Grunsky[2], S. McHardy[4], K. Wheatley[3], D. Jiricka[4], V. Sopuck[4], K. Wasyliuk[3], and C. Cutts[3]

Results for 2002-03:

- The 2002 field work involved geochemical and spectrometric field analyses along transects designed to calibrate spectral domains, in particular a distinctive U-K-Th curvilinear ribbon anomaly expressed by detailed airborne gamma ray data in the NEA–IAEA test area. The field and follow-up analyses were a cooperative effort involving Saskatchewan and GSC geologists, geochemists, and geophysicists.

- Ground spectrometry results suggest that the ribbon anomaly reflects large crystalline boulders and, to a lesser degree, till. Rare outcrops along the transect do not reflect the ribbon spectral domain. Preliminary geochemical results also show little anomalous results in the clay fraction. The anomaly is therefore interpreted as a Quaternary feature. Glacial processes to create such a narrow, evenly defined, curvilinear feature are not yet understood.
- Results of the NEA–IAEA transect are being used to refine geochemical tools for mineral exploration that will help explain the origin of a geochemical anomaly in terms of mineralogy and provenance.
- RadarSAT and digital surficial geology for the Bitumont map area of Alberta (74E) have been combined into an updated surficial map. Fort Chipewyan map area (74L) is in progress.

Sub-project 7: Clay Mineral Studies

Leader (team): J.B. Percival[2], K. Wasyliuk[4], D. Quirt[13], G.L. Drever[4], K. Wheatley[3], C. Cutts[3], C.W. Jefferson[2], S. Bernier[9], T. Reif[16], G. Yeo[8], V. Sopuck[4], P. Portella[3] and K. Kyser[17].

Results for 2002-03 (details in Percival *et al.*, this volume):

- Trends in mineralogy with depth are consistent in closely spaced drill cores surrounding the McArthur River deposit. Controls are structural and lithologic (porosity and permeability of the Manitou Falls Formation). Regional dickite with lesser illite has been altered to illite and kaolinite/dravite/chlorite and zoned similar to Key Lake. Zonation has been inverted, however, due to preservation of dickite in silicified sandstone immediately above the ore.
- Applicability of analytical tools is being clarified. For example, PIMA clearly distinguishes kaolinite from dickite in core samples, whereas XRD better identifies mixed-layer clay minerals such as illite-sudoite. A portable infrared spectrometer, the FieldSpec Pro FR (Analytical Spectral Devices, Inc.), newly acquired at the GSC, was field-tested in concert with Cameco's PIMA-II infrared spectrometer (Integrated Spectronics Ltd.) and is being calibrated against PIMA results using semi-quantitative clay estimates by the MINSPEC algorithm for PIMA. Subtle differences in the spectra between the PIMA-II and FieldSpec Pro instruments resulted in illite being overestimated by MINSPEC at the expense of other minerals, particularly chlorite and dravite. It was known that chlorite and dravite are in some cases overestimated with respect to illite by MINSPEC for PIMA spectra. Separate best-fit algorithms must be calibrated with the aid of artificial mineral mixtures for standards.
- A related Synchrotron study of uranium associated with illitic clays from the alteration halo around the Cigar Lake Uranium Deposit, is contributing to understanding of the genesis of clays in Athabasca Basin and to design of follow-up EXTECH studies on clay mineralogy. The new data are being used to assess whether U occurs as UO_2, is adsorbed onto the clay surface, or occurs within the illite interlayer in the alteration halo.
- A visiting scientist from South Australia (Reif) is collaborating on analyses and reports on mineralogical applications of visible-infrared spectrometers.

Sub-project 8: Coordination (Steering Committee)

Co-chairs: P. Portella[3] and D. Thomas[4] or J. Marlatt[4]
Co-coordinators: C.W. Jefferson[2], G. Delaney[8], and R.A. Olson[11]

Results for 2002-03:

- Coordinators ensured full cooperation of staff in all supporting organizations, smoothed logistics for the many activities involved (staff accommodation, transportation, core logging, sampling, mapping, processing of samples, etc.) to enhance efficiency and effectiveness.
- Communications include newspaper, newsletter and government publications, posters, Website, workshop, and Open House plans. Coordinators managed and accounted for resource contributions of their respective sponsoring agencies.
- More than a dozen presentations from EXTECH IV contributed to the Calgary Mining Forum April 24-25 and a follow-up workshop that linked eastern and western Athabasca experiences.
- Each sub-project leader updated their synopsis including revised work plans and budgets. Initial field work was guided by these and a logistical framework developed to facilitate collaboration and optimize logistics, and guided initial work.
- Twenty six presentations from EXTECH IV at Special Session 18 (Athabasca Basin and Its Uranium Deposits) of the GAC/MAC Annual Meeting, in May were supplemented by 16 additional presentations from peer academic and exploration researchers, making it the largest at Saskatoon 2002. Wrap up comments by D. Quirt and P. Ramaekers summarized the main contributions and enhanced its value to stakeholders.

- Geophysical workshops in Saskatoon were held on June 4 focusing on Seismic Reflection and on September 25 focusing on multiparameter geophysical integration. At each workshop, progress was reported, issues and actions determined, and subsequently followed up.
- A field trip from August 22 to 25, featured the recently published GAC/MAC guidebook (Andrade *et al*., 2002) and supplementary notes. More than 20 participants represented Cameco, COGEMA, Cigar Lake Mining Corp., GSC, Saskatchewan Industry and Resources, Saskatchewan Research Council, and South Australian Office of Minerals and Energy Resources. Participants saw new material at each site, reviewed common approaches to fieldwork, were brought up to date with basement and stratigraphic work of EXTECH IV and SIR mapping projects, and held a brainstorming session to review and suggest future priorities for EXTECH IV and possible follow-up projects.
- All EXTECH sub-projects will contribute to a workshop planned for December 5 to 6, 2002 in Saskatoon. Individual sub-project working groups have met or are meeting on separate occasions to allow more in-depth discussion, for example a general workshop on April 26 after the Calgary Mining Forum, the above-mentioned geophysics workshops and field trip, and a Stratigraphy-Sedimentology workshop on October 29, 2002. Partners are ensuring that key team members attend these workshops for full, informal, around-the-table discussion of results, data gaps, issues, and future directions. Minutes and action items are distributed and implemented.
- Ongoing results of all sub-projects from the Calgary Mining Forum workshop and GAC/MAC are captured in EXTECH IV CD-ROMs, as will be public talks and posters at Saskatchewan Industry and Resources' annual Open House, December 2-4, 2002. Final reports due March 31, 2003 will be distribution to partners and undergo peer review for publication in a final volume in 2004.

Sub-project 8a: GIS Database

Co-leaders (team): W. Slimmon[8], J. Waters[11]; I. Aldrich[11], Z. Amer[11], R. Bennett[8], G. Delaney[8], R. Droter[4], C.W. Jefferson[2], B. Kupsch[10], R. Moroz[3], J.C. Mwenifumbo[2], R.B.K. Shives[2], K. Tong[8], G.M. Yeo[8], and G. Zaluski[4]

Results for 2002-03:

- An extensive GIS database has been built by Saskatchewan Industry and Resources in ArcView and is providing data conveniently to participating scientists and coordinators as needed.
- Data entry and analysis are ongoing. Generalized contents to date include: a) 10 base maps at scales of 1:1 000 000 to 1:50 000; b) 15 geology maps at scales of 1:1 000 000 to 1:20 000; c) nine images of regional magnetic, gamma ray, gravity, and quaternary data; and d) 19 working data sets such as drill core collections and locations, geochemistry, geochronology, mines and mineral deposits, paleocurrent data, and references; and e) preliminary data from 14 sub-projects, including locations of data collected, drill logs, some geophysical data sets, and a variety of images.
- Data compiled and generated by the Alberta Geological Survey (AGS) for EXTECH are hosted by an Access database, in conjunction and compatible with other database needs at the AGS and Saskatchewan, for core logs, samples, petrology, stratigraphy, geophysics, and other data for the EXTECH IV project.
- A regional basin map updated by Ramaekers under contract to the AGS and GSC forms a new base for information exchange and resolves previous inconsistencies at the Alberta-Saskatchewan border.
- An updated compendium of drill hole locations within Alberta identifies the Athabasca Basin and underlying Precambrian basement core in storage at the AGS Mineralized Core Repository Facility, and tabulates the various publications, including prior industry assessment reports, that contain information pertinent to the Athabasca Basin EXTECH IV project. This builds on AGS ESR report 2000-18, includes 86 new drill logs (41 new this year), and will be reissued as an interactive GIS product (AGS ESR 2002-01) by March 31, 2003.

Sub-project 9: Electromagnetics and Deep Graphite Exploration (EDGE)

Co-leaders (team): J.A. Craven[2], R. Koch[3], G. Wood[4], G. McNeice[18], J.C. Mwenifumbo[2], I.R. Annesley[13], M. Unsworth[10]

Results for 2002-03 (details in Craven *et al.*, this volume):

- A three-dimensional audio-magnetotelluric (AMT) survey was conducted in the McArthur River mining camp. One hundred and thirty-five AMT sites at an average site spacing of 300 m were acquired along eleven profiles over the P2 and P2 North mineralized zones. Processing aims to generate a 3D view into the subsurface conductivity structure of the basement gneiss units structure, McArthur deposit, the overlying Athabasca Group, and the alteration assemblages associated with the uranium deposit.

- During initial processing, digital comb filters tuned to the harmonics were utilized to remove their effects. Calculated MT responses show that the data are of high quality and generally representative of the overall data-set, however, data collected near the mine site are lower in quality because of electrical activity associated with the mine workings.
- Initially processed induction arrows are aligned orthogonal to the prevailing electrical strike directions in the southwestern part of the survey, in accord with previous observations from the single 2D profile. In the northern part of the survey area, electrical strike directions are sub-parallel to the profiles, suggesting more complex electrical and geological structure.
- The existing data grid is ideal for planned full 2D and 3D modelling of the data.

Sub-project 10: High-resolution Gravity Surveys

Co-leaders: M. Thomas[2], B. Hearty[19], R. Koch[3], T. Mitchell[20] and G. Wood[4]

Results for 2002-03 (details in Wood and Thomas, this volume):

- Gravity data, collected at 50 m or 100 m station spacing along 27.2 km of the seismic reflection line transecting the McArthur River uranium deposit, has been initially modeled.
- The range of terrain-corrected Bouguer anomalies (reduction density=2.00 g/cm^3) in a derived gravity profile is approximately 2.9 mGal. A relatively long wavelength gravity high (>2500 m wide, +1.75 mGal amplitude) and low (6000 m, -1.15 mGal) dominate the southern part of the profile. The northern part is characterized by less extreme variations in gravity, and anomalies have smaller wavelengths and amplitudes, generally about 500 m and <0.5 mGal, respectively.
- Modelling of anomalies is constrained by magnetic data, drill-hole logs and density information, and reflection seismic data. Long wavelength anomalies are attributed to variations in basement density and offset of the basement unconformity, the principal gravity high being modeled as a quartzite ridge.
- The shortest wavelength anomalies are explained by variations in overburden thickness, consistent with drill-hole data. Thickened overburden may be indicate faults which locally weaken the Athabasca sandstone, making it more susceptible to glacial scouring.
- Intermediate wavelength anomalies are explained by alteration in the Athabasca Basin, manifested as relatively high-density sandstone silicification, particularly above quartzite ridges. Desilicification is present, but limited. Such alteration zones record the passage of mineralizing fluids, are vectors to ore and help to model paleo-fluid flow.

Sub-project 11: Geochronology

Co-leaders: R. Stern[2], R. Rainbird[2], I.R. Annesley[13], D. Quirt[13], D. Jiricka[4], C. Cutts[3], P. Portella[3].
Team members: C. Madore[13], G. Yeo[8], C. Card[8], G. Tourigny[8], G. Ross[7], N. Rayner[2], N. Morrisett[2], J. Percival[2], and C.W. Jefferson[2]

Results for 2002-03 (details in Rainbird *et al.*, this volume):

- Approximately 300 detrital zircon grains have yielded preliminary U-Pb ages on the SHRIMP. The Fair Point Formation (Fidler Deposystem) sample is dominated by Neoarchean zircons with a peak at 2.6 Ga and a significant secondary peak at 1.9 Ga. Provenance from the Taltson magmatic zone and western Rae Province is suggested.
- The Manitou Falls Formation member MFb (Ahenakew Deposystem) sample also shows a pronounced bimodal age distribution with modes at 2.58 Ga and 1.85 Ga. These data support provenance from the Hearne Province and Trans-Hudson Orogen respectively, consistent with northerly to easterly paleocurrents that characterize the Ahenakew Deposystem.
- The Manitou Falls Formation member MFd (Moosonees Deposystem) sample yielded detrital zircons with a mode at 1.83 Ga, characteristic of the Trans-Hudson Orogen.
- The Wolverine Point Formation (Bourassa Deposystem) sample has a similar age distribution to the Fair Point Formation with a broader and less pronounced mode spanning 2.7 to 2.5 Ga and a pronounced mode spanning 1.88 to 1.78 Ga. The similarities, in part, reflect a more southerly provenance from the western Churchill Province. Four much younger, still rounded detrital zircons dated ca. 1.66 Ga constrain the maximum age of the upper Athabasca Group.
- The stratigraphically highest sample comes from the Douglas Formation (McLeod Deposystem) that is preserved in the Carswell Structure in the western part of the basin. The detrital zircon age spectrum emulates that of the

Wolverine Point Formation, supporting common provenance and the idea that both formations are part of the same deposystem.

2. Acknowledgments

The authors are grateful for the combined energy and enthusiasm of the more than 80 scientists from all partners in this project who have achieved such remarkable results in only 2.5 years. Funding approved by managers of our partner organizations and NSERC has been strong and sustained, and allowed us to involve and train young scientists who in turn have done some of the best work. In kind expertise and guidance combined with logistical and cash support from Cameco and COGEMA from inception to the present have been outstanding. Critical reviews by Don White, Jeanne Percival, and Jonathan Mwenifumbo, and comments from each sub-project team improved the manuscript.

3. References

Andrade, N., Breton, G., Jefferson, C.W., Thomas, D.J., Tourigny, G., Wilson, W., and Yeo, G.M. (eds.) (2002): The Eastern Athabasca Basin and its uranium deposits; Geol. Assoc. Can./Mineral. Assoc. Can., Jt. Annu. Meeting, May 24-26, Field Trip A-1 Guidebook, 102p.

Cameron, E.M. (ed.) (1983): Uranium exploration in Athabasca Basin: Comparative studies of exploration methods in the NEA–IAEA Athabasca test area and adjacent regions; Geol. Surv. Can., Pap. 82-11, 310p.

Card, C.D. (2001): Basement rocks to the western Athabasca Basin in Saskatchewan; *in* Summary of Investigations 2001, Volume 2, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 2001-4.2, CD B, p321-333.

Gilboy, C.F. (1983): Sub-Athabasca basement geology project; *in* Summary of Investigations 1983, Saskatchewan Geological Survey, Sask. Energy Mines, Misc. Rep. 83-4, p28-31.

Jefferson, C.W., Delaney, G., and Olson, R.A. (in press): EXTECH IV Athabasca Uranium Multi-disciplinary Study of northern Saskatchewan and Alberta: Overview and Impact; *in* Current Research, Geol. Surv. Can.

Kotzer, T. and Kyser, T.K. (1995): Fluid history of the Athabasca Basin and its relation to diagenesis, uranium mineralization and paleohydrology; Chem. Geol., v120, p45-89.

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

_____ (2002): Stratigraphy of the Athabasca Group, Proterozoic of Alberta, Canada - Improvements for EXTECH IV; Geol. Assoc. Can./Mineral. Assoc. Can., Jt. Annu. Meet., Saskatoon, Abstr. Vol. 27, p95-96.

Ramaekers, P., Yeo, G.M., and Jefferson, C.W. (2001): Preliminary overview of 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.

Ruzicka, V.R. (1996): Unconformity-associated uranium; *in* Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I. (eds.), Geology of Canadian Mineral Deposit Types, Geol. Surv. Can., Geology of Canada, No. 8, vP-1, p197-210.

Thomas, D.J., Matthews, R.B., and Sopuck, V. (2000): Athabasca Basin (Canada) unconformity-type uranium deposits: Exploration model, current mine developments and exploration directions; *in* Cluer, J.K., Price, J.G., Struhsacker, E.M., Hardyman, R.F., and Morris, C.L. (eds.), Geology and Ore Deposits 2000: The Great Basin and Beyond, Geol. Soc. Nevada, May 15-18, Symp. Proceed., Volume 1, p103-126.

White, D.J., Hajnal, Z., Gyorfi, I., Takacs, E., Roberts, B., Mueller, C., Reilkoff, B., Koch, R., Powell, B., Annesley, I., Bernier, S., and Jefferson, C.W. (in press): Interim results of the EXTECH IV seismic reflection program in the Athabasca Basin, northern Saskatchewan; *in* Current Research, Geol. Surv. Can.

Affiliations

[1] Department of Geological Sciences, University of Saskatchewan, Saskatoon, SK S7N 5E2.

[2] Geological Survey of Canada, 601 Booth Street, Ottawa, ON K1A 0E8.

[3] COGEMA Resources Inc., P.O. Box 9204, 825 - 45th Street West, Suite 817, Saskatoon, SK S7K 3X5.

[4] Cameco Corporation, 2121 - 11th Street West, Saskatoon, SK S7M 1J3.

[5] Saskatchewan Research Council, 125 - 15 Innovation Boulevard, Saskatoon, SK S7N 2X8.

[6] Avadh Bhatia Physics Laboratory, University of Alberta, Edmonton, AB T6G 2J1.

[7] Geological Survey of Canada, 3303 - 33rd Street NW, Calgary, AB T2L 2A7.

[8] Saskatchewan Industry and Resources, 2101 Scarth Street, Regina, SK S4P 3V7.

[9] Department of Earth Sciences, Laurentian University, 935 Ramsay Lake Road, Sudbury, ON P3E 2C6.

[10] Department of Earth and Atmospheric Science, 1 - 26 Earth Science Building, University of Alberta, Edmonton, AB T6G 2E3.

[11] Alberta Geological Survey, 4th floor, Twin Atria, 4999 - 98 Avenue, Edmonton, AB T6B 2X3.

[12] Contract to Alberta Geological Survey and Geological Survey of Canada; MF Resources Inc., 832 Parkwood Drive SE, Calgary, AB T2J 3W7.

[13] Saskatchewan Research Council, 15 Innovation Boulevard, Saskatoon, SK S7N 2X8.

[14] Contract to Alberta Geological Survey; Lyatsky Consultants Ltd., c/o 4th floor, Twin Atria, 4999-98 Avenue, Edmonton, AB T6B 2X3.

[15] Department of Geology, CW234.8, University of Regina, Regina, SK S4S 0A2.

[16] Visiting Scientist at GSC c/o Jefferson (above); Office of Minerals and Energy Resources SA, Level 5 - 101 Grenfell Street, GPO Box 1671, Adelaide, SA 5001 Australia.

[17] Department of Geological Sciences, Queens University, Kingston, ON K7L 3N6.

[18] Geosystem Canada, 560 Raftsman Lane, Ottawa, ON K1C 2V3.

[19] Geomatics Canada, 615 Booth Street, Ottawa ON K1A 0E9.

[20] Patterson Mining Geophysics Ltd., 1012 Finlayson Street, P.O. Box 100, La Ronge, SK S0J 1LO.