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EXTECH IV Athabasca uranium multi-disciplinary study of northern Saskatchewan and Alberta, Part 3: current results of subprojects 6, 6a, 7, 9, 10, and 11[1]

C.W. Jefferson, G. Delaney, and R.A. Olson

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Abstract: Fifteen subprojects aim to enhance the geoscience framework and EXploration TECHnology to calibrate typical ore, host-rock and alteration parameters of the world-class McArthur River camp as an aid to uranium exploration in the Athabasca Basin and elsewhere. Subprojects 6, 6a, 7, 9, 10, and 11, reported on here, are a blend of exploration technology with some framework elements, as follows: 6, 6a) calibration and interpretation of enigmatic U-K-Th domains and of a ribbon-shaped K-U anomaly in high-resolution airborne NATGAM (National Gamma-Ray Spectrometry Program) data; 7) mineralogical refinement of alteration vectors to ore and calibration of a new field infrared spectrometric device; 9) magnetotelluric imaging of conductive and altered zones; 10) gravimetric detection of basement highs and alteration zones; and 11) detrital-zircon and basement geochronology by SHRIMP (Sensitive High Resolution Ion Microprobe), documenting provenance of deposystems and timing of Paleoproterozoic basin development.

Résumé : Quinze sous-projets ont été mis en oeuvre pour améliorer le cadre géoscientifique du camp minier de classe mondiale de McArthur River, ainsi que la TECHnologie d'EXploration (EXTECH) qui s'y rapporte. En procédant à l'étalonnage des paramètres de la minéralisation typique, des roches encaissantes et de l'altération, on vise ainsi une meilleure efficacité de l'exploration ciblant les minéralisations d'uranium dans le bassin d'Athabasca et ailleurs. Les sous-projets n^{os} 6 et 7 et 9 à 11, dont on traite dans le présent rapport, portent sur des sujets allant de la technologie d'exploration jusqu'à certains éléments du cadre géoscientifique. Le sous-projet n^{o} 6-6a est axé sur l'étalonnage et l'interprétation de domaines de U-K-Th énigmatiques et d'une anomalie de K-U en forme de ruban qui ont été détectés dans les données de levés aériens à haute résolution du programme NATGAM (programme national de spectrométrie gamma). Le sous-projet n^{o} 7 a pour but de parfaire les connaissances minéralogiques sur les vecteurs d'altération qui pointent vers la minéralisation et d'étalonner un nouvel appareil de spectrométrie infrarouge utilisable sur le terrain. Le sous-projet n^{o} 9 s'intéresse à l'imagerie magnétotellurique des zones conductrices et des zones d'altération. Le sous-projet n^{o} 10 porte sur la détection à l'aide de la gravimétrie de hauteurs du socle et de zones d'altération. Le sous-projet n^{o} 11 vise à établir la géochronologie du socle, par l'analyse à la microsonde SHRIMP (microsonde ionique à haute résolution et à haut niveau de sensibilité) de zircons détritiques, afin de documenter les sources de sédiments dans les systèmes de dépôt et la chronologie de l'évolution du bassin au Paléoprotérozoïque.

[1] Contribution to the Targeted Geoscience Initiative (TGI) 2000–2003.

INTRODUCTION

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 (Jefferson and Delaney, 2001). The background information, location maps, co-ordination details (subprojects 8 and 8a), affiliations of team members, and a discussion of the impact of the overall project are provided by Jefferson et al. (2003a). Individual subproject teams, goals, strategies, and results since September 2001 are summarized below for subprojects 6, 6a, 7, 9, 10, and 11 at mid-year 2002-2003. The other subproject results are summarized in Jefferson et al. (2003b). Most results are detailed in Saskatchewan Industry and Resources Summary of Investigation papers cited here. These were delivered on CD-ROM at their early December 2002 Open House, conveniently providing mid-year information to all clients. A short overview accompanies that volume (Jefferson et al., 2002).

SUBPROJECT SUMMARIES

Subproject 6: Gamma-ray geophysics

Leader: R.B.K. Shives

Team: P. Holman, J. Carson, J. Grant, J.B. Percival, R.A. Klassen, G. Wood, Ken Wasyliuk, D. Thomas, C. Cutts, K. Wheatley, R. Koch, D. Quirt, J. Campbell, E. Grunsky, and M. Fenton.

Goals: To improve our understanding of existing regional radiometric data over the Athabasca Basin, and to evaluate their relevance to mineral alteration and other components of the Athabasca EXTECH.

Strategies: Published regional and detailed NATGAM gamma-ray spectrometric surveys covering the entire Athabasca Basin and adjacent areas have been recompiled, levelled, and standardized. Known near-surface chemical variations related to regional diagenetic and to local hydrothermal alteration processes, including weak uranium-enrichment 'chimneys', were re-surveyed in the field using ground spectrometry at McArthur River, and are being assessed through Quaternary mapping and geochemical sampling in the NEA-IAEA (Nuclear Energy Agency–International Atomic Energy Agency) test area.

Results for 2002–2003 (details in Campbell et al., 2002):

1. Reprocessed and levelled high-resolution gamma-ray ternary data reported in 2001–2002 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 are reported under Subproject 6a below.

Subproject 6a: Surficial geology

Co-leaders: J. Campbell, R. Klassen, R. Shives, and M. Fenton

Team: B. Schreiner, J. Pawlowicz, G. Prior, E. Grunsky, S. McHardy, K. Wheatley, D. Jiricka, V. Sopuck, K. Wasyliuk, and C. Cutts

Goals: To support the mining industry of northern Saskatchewan and Alberta by establishing a surface geology framework for the Athabasca Basin. Mineral exploration and sustainable development require knowledge of baseline conditions and of geological models that describe the properties, provenance, and origins of surficial sediments. Specifically, to provide a component critical to the interpretation of airborne and ground radiometric surveys.

Strategies: Existing Quaternary geological data have been or are being compiled in both digital-database and map formats for study areas in Saskatchewan and Alberta. Resulting databases and maps include i) ice-flow indicators and summary of ice-flow history; ii) dispersal trains and indicator erratics; iii) geochemical data (both existing and new analyses); iv) surficial geology; v) till composition data (database only); vi) drift-thickness and bedrock-surface topography maps based on existing digital drillhole data; vii) satellite imagery including LandSAT and RadarSAT; viii) lake sediment data for the Alberta portion of a 1992–1995 National Geochemical Reconnaissance survey enhanced by industry data from assessment reports.

Results for 2002–2003 (details in Campbell et al., 2002):

1. The 2002 fieldwork involved integrated geochemical and lithological sampling 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.
2. Ground-spectrometry results demonstrate that the differences in ground spectral signatures are coincident with defined airborne spectral domains. The spectrometry results along the Black Lake road transect suggest that the southwestern portion of the ribbon anomaly is particularly reflected by large crystalline boulders, and to a lesser degree in the till. Rare outcrops along the transect do not reflect the ribbon spectral anomaly. Preliminary results of field investigations in the central and northeastern portions of the ribbon neither confirmed nor disproved this correlation. A few preliminary trace-element geochemical results are anomalous in the clay-size fraction of the tills. The anomaly is therefore interpreted as a Quaternary feature. Glacial processes that would create such a narrow, evenly defined, curvilinear feature remain to be determined.
3. 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.

4. RadarSAT and digital surficial geology for the Bitumont map area of Alberta (NTS 74 E) have been combined into an updated surficial map. Work on the Fort Chipewyan map area (NTS 74 L) is in progress.

Subproject 7: Clay-mineral studies

Leader: J. B. Percival

Team: K. Wasyliuk, D. Quirt, G.L. Drever, K. Wheatley, C. Cutts, C.W. Jefferson, S. Bernier, T. Reif, G. Yeo, V. Sopuck, and P. Portella

Goals: To enhance the interpretation of stratigraphy, diagenesis, basement geology, gamma-ray geophysics, and surficial geology, thereby assisting in the development of deep-exploration tools and enhancing the geoscience framework for these deposits.

Strategies: Clay minerals are a major component of the Paleoproterozoic ('Hudsonian') regolith, Athabasca Group sandstone, and alteration halos surrounding the ore bodies, the clay mineralogy of these sites being related in various degrees to weathering, diagenesis, and hydrothermal processes. Systematic clay mineral analysis by portable infrared spectrometers and compilation of existing data along key lithostratigraphic transects are helping to build a three-dimensional map of diagenetic mineral zones with reference to the physical stratigraphic framework provided by subprojects 4 and 4a. Focus is on the McArthur River transect; next will be a regional east-west transect of the Basin. Detailed mineralogical analyses using X-ray diffraction and scanning electron microscopy are conducted in conjunction with stratigraphy, petrography, whole-rock mineralogy, geochemistry, textural studies, and rock property analyses.

Results for 2002–2003 (details in Percival et al., 2002):

1. Trends in mineralogy vs. depth are consistent in closely spaced drill cores surrounding the McArthur River deposit. Controls are structural and lithological (porosity and permeability of the Manitou Falls Formation). K. Wasyliuk has shown that regionally distributed dickite was originally associated with lesser illite, but alteration has changed the dominant clay mineralogy to illite and created a kaolinite/dravite/chlorite zonation similar to that at Key Lake, except that it is partly inverted by the preservation of dickite in silicified sandstone immediately above the ore.
2. The applicability of analytical tools is being clarified. For example, portable infrared spectrometers clearly distinguish kaolinite from dickite in core samples, whereas X-ray diffraction better identifies mixed-layer clay minerals (e.g. illite-sudoite). A portable infrared spectrometer (FieldSpec Pro, Analytical Spectral Devices, Inc.), newly acquired by the Geological Survey of Canada, was field-tested in concert with Cameco's PIMA-II infrared spectrometer (Integrated Spectronics Ltd.) and is being calibrated against PIMA-II results using semiquantitative clay estimates by the MINSPEC algorithm for PIMA-II. Subtle differences in the spectra between the PIMA-II and FieldSpec Pro instruments resulted in illite being overestimated by MINSPEC for FieldSpec Pro spectra at the expense of other minerals, particularly chlorite and dravite. K. Wasyliuk had previously established that chlorite and dravite are in some cases overestimated with respect to illite by MINSPEC for PIMA-II spectra. Separate best-fit algorithms must be therefore be calibrated with the aid of artificial mineral mixtures for standards.
3. A related Synchrotron study of uranium associated with illitic clays from the alteration halo around the Cigar Lake Uranium Deposit is contributing to understanding the genesis of clay minerals in the Athabasca Basin and to planning follow-up EXTECH studies on clay mineralogy. The new data are being used to assess whether uranium occurs as UO_2, is adsorbed onto the clay mineral surface, or occurs within the illite interlayer in the alteration halo.
4. A visiting scientist from the South Australia Office of Minerals and Energy Resources (Reif) is collaborating on analytical work and on reports regarding mineralogical applications of visible-infrared spectrometers.

Subprojects 8 and 8a are reported on in Jefferson et al. (2003a).

Subproject 9: Electromagnetics and deep graphite exploration

Co-leaders: J.A.Craven, R. Koch, G. Wood, and G. McNeice

Team: J.C. Mwenifumbo, I.R. Annesley, and M. Unsworth

Goals: To evaluate a natural-source electromagnetic technique, magnetotellurics (MT), as an exploration tool for detecting graphitic material associated with deep (400–650 m) uranium ore in the Athabasca Basin, through testing of the deep McArthur River ore zone. To map regional resistivity contrasts within the Basin and underlying crust associated with one or more of the following: changes in Basin sandstone porosity, brine content of an interconnected fluid phase, undulation of the basement-sediment interface, tectonically disturbed graphitic conductors in the sub-Athabasca basement, and alteration zones that are associated with subvertical faults or with the unconformity in basement and sandstone.

Strategies: Magnetotelluric methods use oscillations in the natural electromagnetic field of the Earth as the multi-frequency transmitter component of a traditional electromagnetic (EM) exploration technique. A new survey across the deep McArthur River ore zone was designed in co-ordination with high-resolution seismic surveys to test the utility of modern audio-magnetotelluric (AMT) acquisition hardware and processing methodologies in comparison with previous surveys. The success of this led to a follow-up three-dimensional survey in 2002 using lines cut for industry-led potential surveys, allowing close comparison of results. Broadband MT data are inverted in conjunction with the borehole-logging and rock-property information to create a true resistivity map of the substructure. From the map, one can infer rock properties such as porosity and brine content. These activities will test MT as a regional exploration tool to

characterize stratigraphic properties for regional-, district-, and mine-scale mechanical–fluid flow–heat flow–geochemical modelling of the Basin and of its underlying Archean/Paleoproterozoic basement (e.g. SRC/CSIRO/CREGU [Saskatchewan Research Council/Commonwealth Scientific and Industrial Research Organization/Centre de recherches sur la géologie des matières premières minérales et énergétiques] Eastern Athabasca Basin Modelling Project).

Results for 2002–2003 (details in Craven et al., 2002):

1. A three-dimensional audio-magnetotelluric (AMT) survey was conducted in the McArthur River camp, 135 AMT sites being acquired along eleven profiles over the P2 and P2-North mineralized zones, with an average site spacing of 300 m. Processing aims to generate a three-dimensional view into the subsurface conductivity structure of the McArthur deposit, the overlying Athabasca Group, the basement gneiss units and structure, and the alteration assemblages associated with the uranium deposit.
2. During initial processing, digital comb filters were tuned to the harmonics 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 operations.
3. Initially processed induction arrows are aligned orthogonal to the prevailing electrical strike directions in the southwestern part of the survey area, in accord with previous observations from the single two-dimensional profile. In the northern portion of the survey area, electrical strike directions are subparallel to the profiles, suggesting more complex electrical (and geological) structure.
4. The existing data grid is ideal for planned full two- and three-dimensional modelling of the data.

Subproject 10: High-resolution gravity surveys

Co-leaders: M. Thomas, B. Hearty, R. Koch, T. Mitchell, and G. Wood

Goals: To evaluate the potential of detailed gravity measurements as an exploration tool by examining their effectiveness at a) differentiating basement lithology, b) identifying offsets of the basement-sandstone contact, and c) identifying subtle density changes in sandstones, related to alteration. This evaluation will be controlled to some extent by, and in turn contribute to, interpretation of detailed and pseudo–three-dimensional seismic reflection data. To contribute high-resolution gravity data to the regional gravity database (and to the Canadian Gravity Database). To assist in mapping basement lithology and in understanding the regional structural setting of the Athabasca Basin, particularly in the third dimension. To provide additional constraints for interpretation of regional high-resolution seismic data. To contribute to the Canadian Gravity Standardization Net (CGSN).

Strategies: To conduct gravity surveys of practical value to detailed uranium prospecting, which must measure gravity anomalies with high accuracy, preferably to within 0.02 mGal. To interpret longer wavelength and larger amplitude anomalies in terms of major structure and lithological changes in the basement, in co-ordination with other geophysical and geological tools being tested by EXTECH IV, especially seismic reflection analysis. To help characterize rock properties for regional-, district-, and mine-scale mechanical–fluid flow–heat flow–geochemical modelling of the basin and of its underlying Archean/Paleoproterozoic basement (e.g. SRC/CSIRO/CREGU Eastern Athabasca Basin Modelling Project). To establish a local base station that is tied to the absolute gravity site (Geodetic Survey Division - GSD station no. 9812-1990) in La Ronge, and possibly to other Canadian Gravity Standardization Net (CGSN) stations in the surrounding region. This will fill a significant gap in the CGSN and facilitate other gravity surveys in the Athabasca Basin region. To measure densities of rock samples collected from the basement and the Basin, to provide a constraint for gravity modelling.

Results for 2002–2003 (details in Wood and Thomas, 2002):

1. Initial modelling has been performed for 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.
2. 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) dominates 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 of about 500 m (but ranging from about 250 m to about 1800 m) and <0.5 mGal, respectively.
3. Modelling of anomalies is constrained by magnetic data, drillhole 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 modelled in terms of a quartzite ridge.
4. The shortest wavelength anomalies are explained by variations in overburden thickness, consistent with drillhole data. Thickened overburden may indicate faults, which locally weakened Athabasca Group sandstone units and made them more susceptible to glacial scouring.
5. Intermediate-wavelength anomalies are explained by alteration within the Athabasca Sandstone, 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.

Subproject 11: Geochronology

Co-leaders: R. Stern, R. Rainbird, C. Card, I.R. Annesley, D. Quirt, D. Jiricka, C. Cutts, and P. Portella

Team: C. Madore, G. Yeo, G. Tourigny, N. Rayner, N. Morisset, J.B. Percival, and C.W. Jefferson

Goals: To compile all public-domain geochronological data relevant to Athabasca uranium, and co-ordinate all new geochronological research under EXTECH IV. To obtain up-to-date constraints on the age of uranium ore and of related diagenetic or alteration events by precise SHRIMP (Sensitive High Resolution Ion Microprobe) and conventional dating of specific minerals within the Athabasca Basin and its basement. This will constrain the regional stratigraphic geochronology of Paleoproterozoic sequences with which the Athabasca Basin has been or may be correlated by empirical stratigraphy.

Strategies: To conduct a SHRIMP Study of the Dawn lake uranium deposit, using detailed petrography to provide mineralogical orientation for SHRIMP analyses, and using co-ordinated stratigraphic and structural logs of relevant drill core to link the geochronology to the regional EXTECH IV structural-stratigraphic-alteration context and regional geochronological studies listed below. Study to be co-led by Irvine Annesley, Dan Jiricka and Richard Stern. A conventional- and SHRIMP-geochronology study of authigenic xenotime and detrital zircon and monazite of the Paleoproterozoic Athabasca Group of northern Saskatchewan and Alberta will be co-led by Rob Rainbird and Richard Stern (GSC) and Dave Quirt (Saskatchewan Research Council), with input from Charlie Jefferson and Gerry Ross (GSC) and Gary Yeo (Saskatchewan Industry and Resources). This will be augmented with detailed petrographic and full stratigraphic contextual studies. To conduct conventional (ID-TIMS) analysis of hydrothermal xenotime associated with uranium ore (co-led by Dave Quirt (Saskatchewan Research Council), Rob Rainbird and Richard Stern (GSC)). To determine age of structural and tectonic events in the basement (co-led by Colin Card (Saskatchewan Industry and Resources), Dinu Pana (Alberta Geological Survey) and Richard Stern (GSC)).

Results for 2002–2003 (details in Rainbird et al., 2002):

1. Approximately 300 detrital zircon grains have yielded preliminary U-Pb SHRIMP ages. The Fair Point Formation (Fidler Deposystem of Ramaekers et al., 2001) sample is dominated by Neoarchean zircon grains 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.
2. The Manitou Falls Formation MFb member (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.
3. The Manitou Falls Formation MFd member (Moosonees Deposystem) sample yielded detrital zircon grains with a mode at 1.83 Ga, an age characteristic of the Trans-Hudson orogen.
4. 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, but still rounded detrital zircon grains dated at ca. 1.66 Ga constrain the maximum age of the upper Athabasca Group.
5. 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.
6. Zircon grains observed both petrographically (in situ) and after separation for analysis show normal ranges of morphology and preservation. There is no textural evidence in the detrital zircon grains for systematic regional dissolution, unusual levels of alteration, or abnormally high uranium contents.

SUMMARY

This paper is a summary of summaries for the second half (6, 6a, 7, 9, 10, and 11) of the 15 subprojects of the EXTECH IV Athabasca uranium multidisciplinary study (the co-ordination and database subprojects are reported on in Part 1, and subprojects 1 to 5 are reported on in Part 2). Each subproject has captured the essential data required for completion, and is now interpreting and comparing with sister subprojects to produce final results. Preliminary interpretations for each subproject listed above demonstrate substantive and, in some cases, surprising results that enhance exploration technology in novel ways, demonstrating high potential for integrating geophysical and geological tools to image unconformity-type uranium deposits and their associated host rocks, including alteration patterns. These results also fill data gaps in the geoscience framework of the Taltson-Rae-Hearne structural provinces and highlight the dramatic influence of ongoing minor brittle faulting during the development, diagenesis, hydrothermal alteration, and uranium mineralization of the overlying late Paleoproterozoic Athabasca Basin and of its immediate basement.

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