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EXTECH IV Athabasca uranium multidisciplinary study of northern Saskatchewan and Alberta, Part 2: current results of subprojects 1 to 5

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EXTECH IV Athabasca uranium multi-disciplinary study of northern Saskatchewan and Alberta, Part 2: current results of subprojects 1 to 5[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 for the world-class McArthur River camp as an aid to uranium exploration in the Athabasca Basin and elsewhere. Subprojects 1 to 5, reported on here, mainly serve as a framework to help focus technology: 1) seismic imaging of the stratigraphy, the unconformity, the P2 reverse-fault zone, possible alteration zones, the orebody itself, and a deep reflector possibly representing a mafic sill and heat source for hydrothermal convection; 2) quantitative linking of geophysical and geological parameters by multiparameter borehole geophysics; 3) determination of the paragenesis of organic matter, both Proterozoic and Phanerozoic (but all postdating the ore and therefore not a guide); 4) establishment of a quantitative lithological and sequence-stratigraphic framework across drill camps and six regional deposystems; 5) mapping, simplifying, and correlating basement domains and their boundaries; and 4a / 5a) relating uranium to reactivation structures and sedimentary style in paleovalleys.

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, afin d'accroître l'efficacité de l'exploration ciblant les minéralisations d'uranium dans le bassin d'Athabasca et ailleurs. Les sous-projets n^{os} 1 à 5, dont on traite dans le présent rapport, visent principalement à définir un cadre qui permettra de mieux mettre au point la technologie. Le sous-projet n^{o} 1 consiste à produire une imagerie sismique de la stratigraphie, de la discordance entre le socle et le Groupe d'Athabasca, de la zone de failles inverses P2, des zones d'altération potentielles, du corps minéralisé lui-même et d'un réflecteur profond pouvant représenter un filon-couche mafique qui aurait fait office de source de chaleur entraînant la convection hydrothermale. Le sous-projet n^{o} 2 a pour but d'établir des liens quantitatifs entre les paramètres géophysiques et géologiques en se basant sur des levés géophysiques multiparamétriques en sondage. Le sous-projet n^{o} 3 est axé sur la détermination de la paragenèse de la matière organique aussi bien protérozoïque que phanérozoïque (bien que toute la matière organique soit postérieure à la minéralisation et ne constitue donc pas un guide pour celle-ci). Le sous-projet n^{o} 4 porte sur l'établissement d'un cadre stratigraphique quantitatif selon les approches lithologique et séquentielle, s'étendant aux camps de forage et à six systèmes de dépôt régionaux. Le sous-projet n^{o} 5 a pour objet la cartographie, la simplification et la corrélation des domaines du socle et de leurs limites. Les sous-projets n^{os} 4a et 5a visent à relier la minéralisation uranifère à des structures de réactivation et au style de sédimentation dans les paléovallées.

[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 of subprojects 1, 2, 3, 4, 4a, 5, and 5a since September 2001 are summarized below at mid-year 2002–03. The remaining subproject results are reported 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 1: Regional and high-resolution seismic-reflection surveys

Co-leaders: Z. Hajnal, D. White, E. Takacs, and S. Gyorfi

Team: B. Reilkoff, S. Woelz, R. Koch, B. Powell, I.R. Annesley, D. Schmitt, D. Jamieson, B. Roberts, E. Adam, G. Bellefleur, B. Pandit, and P. Portella

Goals: To develop a viable seismic-reflection survey technique for deep mineral exploration, and to contribute to a four-dimensional geoscience framework for mineral exploration in the Athabasca basin.

Strategies: Using PAS-TGI and Division funds, in partnership with Industry and NSERC under the ESS-NSERC Industry Research Partnership Program, to acquire and interpret high-resolution and regional seismic reflection data in the McArthur River area of the Athabasca Basin. To map acoustic discontinuities of sandstone units, sandstone-basement contacts, structure within the sandstone and underlying basement and orebodies, and associated alteration.

Results for 2002–2003 (details in Hajnal et al. (2002), Gyorfi et al. (2002), and White et al. (2002, 2003)):

1. New data along 39 km of regional two-dimensional seismic profiles (lines A and B) and 8 km of high-resolution profiles (lines 12 and 14) have been migrated and initially interpreted through pattern recognition and partial integration. A limited three-dimensional high-resolution survey has been initially processed to form a three-dimensional image of the subsurface. The zero-offset and near-offset high-frequency Vertical Seismic Profile data have been processed and are being used to calibrate high-resolution and pseudo–three-dimensional models.
2. These provide some excellent data, with superimposed thrusts and escape structures clearly visible in basement rocks, and the unconformity clear at 400 to 600 m depth.
3. Offset of the unconformity by the 2.5 km thick P2 fault system is traceable upward through the overlying Athabasca Group sandstone units and downward more than 4 km as a listric structure that curves past the southeastern limit of the survey.
4. Lateral variations in sandstone porosity, silicification, or facies are inferred from variations in reflection response and velocity. Angular discordances in stratigraphy suggest onlaps or unconformities that may have resulted from tectonic control on sedimentation.
5. A reflection response from the vicinity of the orebody is apparent.
6. The entire survey area and a Lithoprobe survey area to the east are underlain by a bright reflector at ~6 km depth, interpreted as an extensive thick sill 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.
7. A postdoctoral fellow (Takacs) is carrying the regional data interpretation forward; a Ph.D. candidate (Gyorfi) has completed his training, and has processed high-resolution lines 12 and 14 with initial interpretation of basement uplifts as escape structures.

Subproject 2: Multiparameter borehole geophysics

Leader: C.J. Mwenifumbo

Team: M. Salisbury, B.E. Elliott, W. Hyatt, R. Koch, J. Robbins, B. Powell, and G. Wood

Goals: To develop uranium exploration science, technology, and strategies for multiparameter borehole, seismic, magnetotelluric, and gravity geophysics in the Athabasca Basin.

Strategies: To improve knowledge of a spectrum of bulk geophysical characteristics of Athabasca uranium deposits, host rocks and associated alteration, using state-of-the-art and new multiparameter borehole logging technologies, such as: 1) full-waveform sonic logging for seismic surveys; 2) electrical logging for magnetotelluric, electromagnetic, and resistivity surveys; 3) gamma-ray spectrometry for radioelement distribution and stratigraphy; 4) thermal logging for basin heat-flow modelling; 5) rock mass characteristics for exploration, geotechnical, and other mine-development needs; and 6) calibration of spectral (K, U, Th) gamma-ray probes for ore delineation and grade estimation.

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

1. Multisensor geophysical combinations of spectrometric natural γ-ray, spectral γ-γ density, full-waveform–sonic, magnetic-susceptibility, inductive-conductivity, resistivity, Induced-Polarization and temperature logs were fully processed from 11 boreholes at Shea Creek and McArthur

River sites. Results were presented at the KEGS (Canadian Exploration Geophysicists Society) symposium August 21 to 23, 2002, and a manuscript was submitted to the Journal of Applied Geophysics.

2. Two new surface drillholes, and one underground drillhole 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 co-operation and initiative from all levels of Cameco staff, and enhanced funding allocated by the Steering Committee, facilitated the data acquisition.
3. Lithology, alteration (mainly silicification), and uranium ore with associated alteration are now characterized by several of the geophysical parameters, which correlate directly with geological logs (e.g. gamma-ray for conglomerate) or help to correct data gaps in them (e.g. density for silicification). These parameters offer new tools for stratigraphic correlation within the Athabasca Basin, facilitated by software such as GSC's Logview or commercial products.
4. In situ physical rock property data from more than 13 drillholes, such as compressional-wave velocities, densities and electrical properties, have helped to design the high-resolution seismic survey and now help to interpret resulting seismic, magnetotelluric and gravity data.

Subproject 3: Bitumens, hydrocarbons, fluids, and diagenesis

Co-leaders: L.D. Stasiuk and N.S.F. Wilson

Team: M.G. Fowler, D. Jirika, K. Wheatley, M. Li, V. Sopuck, G. Zaluski, and D. Morrison

Goals: To evaluate the origin of bitumens/hydrocarbons associated with uranium ore (i.e. organic versus inorganic) and determine the role/influence of bitumens/hydrocarbons on the uranium mineralization process, possibly as a 'petroleum system' in the Basin (source, migration, and 'reservoirs').

Strategies: Regional samples were collected from key areas: McArthur River, Midwest–Dawn lake–Rabbit Lake–La Rocque Lake, Virgin River, Cluff Lake–Shea Creek, and the Carswell Structure, with help from partners (e.g. Kupsch for Maybelle River). Bitumen-rich zones associated with uraninite, and bitumens removed from uraninite samples from both sandstone and basement, are being characterized using organic petrology and organic geochemistry. Organic-rich sequences within the Carswell and Douglas Formations at Cluff Lake as well as the Muskwa Assemblage of northeastern British Columbia were evaluated for total organic carbon and hydrocarbon biomarkers. Sandstone samples near and distal to ore were evaluated for paragenetic sequences, and for aqueous and hydrocarbon fluid inclusions.

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

1. All pyrobitumens found by detailed petrography of a diverse sample suite postdate uraninite, either enveloping pitchblende inclusions or occupying veinlets that crosscut massive pitchblende. The presence of bitumen does not indicate proximity to ore.
2. Work continues on archived samples from the Muskwa Assemblage of northeastern British Columbia for fingerprinting and comparison with those from the Douglas Formation. Petrographic and geochemical work on samples of graphite and semi-graphite from altered and unaltered basement and sandstone is in progress.
3. Spectral analysis and vitrinite-reflectance–equivalent values derived from the Douglas Formation kerogen are consistent with burial temperatures of 160°C to < 200°C and generation of Proterozoic petroleum. Such temperatures agree with fluid-inclusion data suggesting temperatures ranging from 190° to 230ºC at the unconformity during peak diagenesis. High-thermal-maturity crude-oil inclusions (45° to > 50°API) are still preserved in the Douglas Formation.
4. Crude-oil inclusions and solid to semisolid bitumens have been fingerprinted as Devonian to Cretaceous in origin within Fair Point, Wolverine Point and Manitou Falls formations sandstone units distal to uranium deposits in the vicinity of the Maybelle River, Rumple lake, Cluff Lake, Hook Lake, Dawn lake, and possibly McArthur River deposits.
5. Petrographic (%Ro) and Rock-Eval analyses of carbon-enriched sandstone samples from CLU9-79 suggest that the solid carbons are not pyrobitumen, as previously noted, but rather are derived from low-maturity Paleozoic hydrocarbons. Similar zones exist in Cameco's Dawn lake, Hook Lake, and southwest Athabasca projects.
6. 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 subprojects, and providing assistance to deposit-scale structural–ore-deposit studies (Tourigny) and to geochronology through identification of favourable mineralogy (Rainbird).

Subproject 4: Athabasca stratigraphy and sedimentology

Co-leaders: G.M Yeo and C.W. Jefferson

Team: S. Bernier, B. Collier, B. Kupsch, D.G.F. Long, R. Post, P. Ramaekers, J.B. Percival, O. Catuneanu, C. Belyk, C. Cutts, G. Delaney, G.L. Drever, D. Jiricka, I. Koning, S. McHardy, D. Morrison, D. Quirt, K. Wheatley, and R. Rainbird

Goals: To refine Athabasca Group stratigraphy and sedimentology, and determine their relationships to geophysical parameters and uranium ore, thereby assisting in the development of deep exploration tools and enhancing the geoscience framework for uranium exploration.

Strategies: To determine facies architecture, lithostratigraphy, provenance and diagenesis for the Basin. Key foci include McArthur River, Close Lake, Midwest–Dawn lake–Rabbit Lake, Virgin River, Cluff Lake–Shea Creek, McClean Lake, and Maybelle River, which have good diamond drill core for logging. The McArthur River transect is linked with geophysical subprojects. Ramaekers' 1990 framework is being enhanced by developing quantitative lithological parameters, new logging methods, and linkages with geophysics. Emphasis is on basal units hosting uranium deposits and, for all units, on elements relevant to basin fluid flow and metal provenance, including primary, diagenetic, and hydrothermal alteration effects, all linked to clay mineral studies (Subproject 7).

Results for 2002-2003 (details in Yeo et al., 2002a):

1. From January to September 2002, one new metre-by-metre quantitative drill log was acquired in the western Saskatchewan part of the Basin, three more in the Ahenakew, and two more in each of the Karras and Moosonees deposystems (Yeo et al., 2002a). In Alberta, R. Post logged eight along the Net Lake Trend, eleven along the Maybelle River Trend, and seven to calibrate Ramaekers' (2002) reconnaissance cross-section D-D'. These regional studies were complemented with bed-by-bed logs and other detailed sedimentological work reported under Subproject 4a below.
2. Fifty-five previously published and new regional reconnaissance drill logs by Ramaekers (2002) have been analyzed from 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 synsedimentary tectonic flexures and minor brittle faults at McArthur River (Bernier et al., 2001, Subproject 4a) and Wheeler River (Jefferson et al., 2001). Ramaekers' work provides context for a detailed study of stratigraphy and alteration at the Maybelle River occurrence (Kupsch, Subproject 4a).
3. Regional comparison of the Manitou Falls Formation that preserves three of the 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 lithological variations and implement sequence stratigraphy at the member level. Details were reported by Yeo et al. (2002a), and geochronological calibration and provenance aspects were reported by Rainbird et al. (2002).
4. Paleocurrent measurements in inclined drill holes at McClean Lake, Dawn lake, Cigar Lake and La Rocque Lake were made to augment similar work at McArthur River in 2001. Results were generally consistent with sediment transport data from outcrop measurements (i.e. northerly to westerly), except for La Rocque Lake, where southerly sediment transport was documented as well.
5. With the assistance of Andrew Gracie (Saskatchewan Industry and Resources) and co-operation from COGEMA and Cameco, two more cores were collected and archived at the core storage facility in Regina: diamond drillholes DGS-7 from north of Shea Creek, and VIR-1 from northwest of Cree Lake.
6. A workshop involving all participants in subprojects 4 and 4a was held at Laurentian University on October 28 to 30, 2002. Progress was made on coherent regional and detailed lithostratigraphic and sequence-stratigraphic frameworks, as well as on understanding facies associations, fluvial styles and depositional environments as context for property-scale work.

Subproject 4a: Detailed stratigraphic and sedimentological studies in the Athabasca Basin

Co-leaders: D.G.F. Long, O. Catuneanu, S. Bernier, B. Collier, and B. Kupsch

Team: G.M. Yeo, C.W. Jefferson, R. Post, R. Ickert, P. Ramaekers, G.L. Drever, J. Robbins, K. Wheatley, I. Koning, D. Jiricka, D. Morrison, P. Portella, and B.Sc. students

Goals: To improve understanding of Athabasca stratigraphy and sedimentology and of their role in the localization of uranium ore within some of the major uranium deposits. In particular, this subproject will provide a link between core and geophysical studies and outcrop expressions of Athabasca strata.

Strategies: To learn as much as possible about detailed facies relationships, stratigraphy, and sedimentology of the deposits that have been mined as open pits (e.g., Rabbit, McClean, Key, and Cluff lakes) or have dense drill-core arrays (the above and McArthur River). Areas of relatively good exposure (e.g. southeast of Black Lake, Carswell Structure) were also examined. Three B.Sc. theses were supported at the universities of Regina and Alberta in Year 1. In years 2 and 3, three M.Sc. theses and one undergraduate thesis are being supported through partnerships involving the University of Alberta (O. Catuneanu), Laurentian University (D.G.F. Long), Cameco-COGEMA, NSERC, GSC (C.W. Jefferson, Earth Sciences Sector of Natural Resources Canada), and the provinces of Alberta (R.A. Olson) and Saskatchewan (G.M. Yeo).

Results for 2002–2003 (details in papers cited):

1. In the Shea Creek M.Sc. project area (Collier, 2002), a preliminary stratigraphic framework was re-evaluated, paying closer attention to the relationship between grain-size characteristics and sedimentary structure. These data were combined with the above-mentioned variables to delineate facies associations, producing the following conclusions: a) changes in primary sedimentary structure

correlate with, and help to refine, stratigraphy based on grain size, intraclast abundance, and conglomerate thickness; b) five third-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 the Manitou Falls sequence by indicators of both arid and humid fluvial settings, such as thick distal sheet-flow deposits, and predominance of larger bedforms which distinguish them from overlying, mainly rippled deposits of ephemeral braided streams in semi-arid settings; and e) The Lazenby Lake–Wolverine Point through Locker Lake sequences have abundant overturned and convolute bedding, thought to be the result of frictional drag from high-energy stream flows rather than slumping of channel walls.

2. In the McArthur River transect area, an M.Sc. project by Bernier (2002) is analyzing metre-by-metre stratigraphic logs of 18 drillholes, 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 accomplished 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 throughout deposition of the preserved Manitou Falls Formation. Sedimentological interpretations and sequence boundaries were tested through detailed bed-by bed logs that describe key stratigraphic sections and document an unconformity between members MFa and MFb, precisely at the top of the remarkably persistent pebble-free MFa4 subunit. In situ clay mineral analyses by infrared spectrometry (Percival et al., 2002) and paleocurrent measurements in several holes complement the thesis.

3. In the Maybelle River area of Alberta, the M.Sc. project by Kupsch and Catuneanu (2002) is combining stratigraphic and alteration studies and has contributed organic geochemical samples to Stasiuk for Subproject 3 ('Bitumens, hydrocarbons, fluids, and diagenesis'). Fifteen holes were logged using the standard stratigraphic parameters as well as those required to document basement lithology and alteration. Initial results typical of other uranium deposits in the Basin are: a) the Maybelle River basement conductor is related to graphitic mylonite and parallel brittle structures that transect granitoid gneiss along the east side of the Maybelle River mineralized trend; b) two sub-units of the Fair Point Formation (FPb2 coarse pebbly conglomeratic sandstone and FPc 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 ripple–cross-bedded, fine- to medium-grained sandstone with minor small pebbles at the base and upward-increasing intraclasts that rarely exceed 1%, and is classified lithologically as MFc member; d) the Lazenby Lake Formation, which overlies the MFc member, contains pebbles but no intraclasts; and e) six types of alteration are present, namely i) clay replacement and dissolution of both in situ and faulted sandstone, mainly in Fair Point and rarely in Manitou Falls Formation, ii) drusy quartz veins above dissolution zones, iii) pyrite in fractures higher in Manitou Falls and Lazenby Lake formations, iv) bleaching of basement in and around the mineralized drillhole, which overprints v) a red, hematitic and clay-rich upper paleoweathering zone 2 to 30 m thick, and vi) a green, chlorite- and illite-bearing lower zone 1 to 8 m thick, grading to fresh basement.

4. Linking the above to regional context, R. Post has logged bed-by-bed and paleocurrent data in 26 drillholes. He is petrographically analyzing four drillholes along each of the subparallel Net Lake and Maybelle River trends in Alberta, and two drillholes along a fence that transects the two trends.

5. A B.Sc. thesis has been initiated by R. Ickert under the supervision of O. Catuneanu to 1) evaluate the informal subdivision of the Fair Point Formation proposed by Ramaekers (2002), and apply it to the Formation in Alberta with an emphasis on the 'FPb1' east-west trending unit; 2) petrographically document the Fair Point Formation lithology; 3) define the sedimentary facies and facies associations in drill core; and 4) develop a preliminary depositional model and a tectonostratigraphic framework for the Fair Point Formation in Alberta.

6. The presence of hematitic clay oncoids at Hook Lake and of silicified hematitic cryptomicrobial laminites at Read Lake, at the base of the Manitou Falls MFa member, in Saskatchewan (Yeo et al., 2002b), and the presence of similar oncoids at the same stratigraphic position in Alberta (R. Ickert and others), establish the regional extent of these deposits and record a relatively wet climate during earliest MFa sedimentation.

Subproject 5: Basement to western Athabasca Basin

Co-leaders: C. Card and D. Pana

Team: K. Ashton, H. Lyatsky, P. Ramaekers, K. Wheatley, D. Thomas, E. Koning, W. Slimmon, C. Gilboy, K. Bethune, and M. Leppin

Goals: To better understand the basement geology of the western Athabasca Basin and its influence on the location of uranium ore; to create a reasonably detailed subcrop map of the western Athabasca Basin in Saskatchewan and Alberta.

Strategies: To work on the exposed shield north of the western part of the Basin, begun in 1998, has been restarted under a Saskatchewan Industry and Resources–GSC partnership to train a young structural geologist (Card), and to provide a geological framework from which to extrapolate southward. A previous Saskatchewan Industry and Resources study of sub-Athabasca basement geology and geochemistry is being updated and incorporated. Existing basement geology knowledge in Alberta (Pana) is being compiled, and data gaps are being investigated to create a regional structural-tectonic synthesis. The only basement exposure within the Basin, at Cluff Lake, is being re-evaluated. Existing GSC geophysical maps and more detailed company geophysical maps are being compiled, reprocessed (Alberta), and updated with new mapping and laboratory studies on Saskatchewan Industry and Resources and Alberta Geological Survey mineralized core collections and on exploration core contributed by industry. Representative basement rocks of appropriate composition are being processed for geochronology and geochemistry. Rocks that can be correlated with distinctive aeromagnetic anomalies (e.g. Clearwater Magnetic High, Virgin River Domain, and shear zones such as Grease River, Marguerite River, and Maybelle River) are being linked across provincial borders and tracked under thick Athabasca strata, clarifying exploration targets and providing clues to the region's tectonic history. Of equal importance are rocks that could contribute to the uranium mineralizing process (e.g. graphitic metasediments, graphitic shear zones transecting other rock types).

Results for 2002–2003 (details in Card, 2001, 2002, and Card and Pana, 2002):

1. Significant similarities in supracrustal and granitoid lithology and aeromagnetic signatures between the western (formerly 'Firebag') and eastern (formerly 'Western granulite') parts of the Lloyd Domain justify their amalgamation into a single domain.

   The Clearwater Magnetic High is underlain by the weakly foliated, multiphase Clearwater granite, which carries large xenoliths of older, strongly foliated granitic gneiss. The interaction between the different magma phases and between these and the xenoliths apparently led to the crystallization of significant magnetite, causing the anomalously high magnetic signature.

2. The Virgin River Shear Zone formed during multiple events beginning with west-side-up reverse displacement. The middle-amphibolite-facies Virgin Schist Group was juxtaposed between granulite-facies gneiss of the Lloyd Domain and upper-amphibolite-facies felsic gneiss of the Virgin River Domain during this event, and was later deformed and possibly partially melted during dextral shearing. The Virgin Schist Group is lithologically similar to other supracrustal packages in the Rae Province; however, its provenance is not known.

3. Although magnetic trends appear to continue between rocks of the Tantato and Lloyd domains beneath the Athabasca Basin, the pressures and proportions of rock types that are associated with the main magnetic highs in the two domains do not match. The supracrustal packages preserved in the two domains are very similar, although of smaller proportions in the Lloyd Domain.

4. Graphitic mylonite transecting granitoid gneiss is associated with conductors and uranium concentrations along the north-northwest–striking Maybelle River trend. Geochemical and isotopic characteristics of these granitoid rocks are similar to those at Cigar Lake and other granitic pegmatites of the Wollaston Domain that underlie the world's largest uranium deposits.

5. A re-evaluation of regional aeromagnetic and gravity data by H. Lyatsky, coupled with studies by D. Pana of basement core on file with the Alberta Geological Survey and of geochronology, are improving our understanding of the basement rock types and structures in the western part of the Athabasca Basin, and have resolved their continuity with basement domains in western Saskatchewan.

Subproject 5a: Detailed structural studies of Athabasca uranium deposits

Leader: G. Tourigny

Team: G. Breton, S. Wilson, S. Harvey, P. Portella, E. Koning, R. Stern, D. Thomas, I.R. Annesley, C. Madore, and D. Quirt

Goals: To understand the structural history of the basement/cover rocks at some of the major uranium deposits, and the role of structure in the localization of uranium ore.

Strategies: Detailed mapping of active open-pit uranium mines is the only means to document accurate 3-D relationships between the various structural elements and the uranium deposits that are localized at or near the unconformity between the Athabasca Group and underlying supracrustal rocks and granitoid gneiss. Repeated working visits to the open pits have documented fresh exposures and new perspectives, as well as fostering information exchange between government and industry geologists. Completed targets include Dielmann Pit at Key Lake (mapped by S. Harvey; Harvey and Bethune, 2000), Sue Pit at McClean Lake (Tourigny et al., 2002), and a variety of basement exposures and pits at Cluff Lake (reconnaissance by G. Tourigny and later by Card, 2002). Structural elements from detailed studies are being integrated with the regional context.

Results for 2002–2003:

1. A paper by Tourigny, on the basement-sandstone structural geology and its predictive relationship to ore in Sue Pit at COGEMA's McClean Lake operation, is undergoing revision after peer review.

2. Aspects of the above paper were incorporated into the Geological Association of Canada guidebook (Tourigny et al., 2002), which was used to support the field trip component at McClean Lake in August 2002.

3. The spatial relation of paleovalley development to basement gneiss units and fault zones of varied competences is being incorporated into stratigraphic and exploration-technology aspects of EXTECH IV.

SUMMARY

This paper is a summary of summaries for seven of the fifteen subprojects of the EXTECH IV Athabasca uranium multidisciplinary study (1, 2, 3, 4, 4a, 5, 5a). 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 not only improve the geoscience framework and enhance exploration technology, but also raise new questions regarding fundamental geoscience of the Taltson–Rae–Hearne structural provinces and the Paleoproterozoic Athabasca Basin.

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