Is Illite Still a Pathfinder Mineral for the Geological Environment of Athabasca Unconformity-type Uranium Deposits??

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Summary

Pathfinder minerals provide a wider indication of the presence of a mineralizing system. Several are used in exploration for the unconformity-type uranium deposits of the Athabasca Basin (northern Saskatchewan and Alberta) as mineralogical host-rock alteration haloes occur at sites of mineralized basement-sandstone interaction. These haloes typically include clay mineral alteration features, including ubiquitous illitization. Because of this, illite has been the most utilized pathfinder mineral in unconformity-type uranium exploration.

In the early 1980s, based on basic optical petrography, lithogeochemistry, and XRD methods, it was postulated that the presence of illite was a direct consequence of the geological environment present during diagenesis and during the mineralization and host-rock alteration formation event(s). Subsequent work using additional methods, like SWIR reflectance spectrometry, EMP, SEM, and illite polytype analyses, carried out to examine the characteristics of Athabasca illite on the macro- and micro-scale, has confirmed that the presence of illite was a direct consequence of the geological environment present at these times. Thus, illite has been reaffirmed/refined as a pathfinder mineral for Athabasca unconformity-type uranium deposits.

Introduction

Pathfinder minerals are those minerals that are diagnostic indicators of the mineralizing system under investigation. The unconformity-type uranium deposits of the Athabasca Basin display a suite of host-rock alteration minerals genetically related to the uranium mineralization system. Acid-base reactions resulted in the formation of mineralogical host-rock alteration haloes at sites of basement-sandstone interaction. The haloes typically include clay mineral alteration features, primarily illitization. Because illite is a ubiquitous alteration feature present around both sandstone- and basement-hosted deposits, it has been, and is, the most utilized pathfinder mineral in unconformity-type uranium exploration.

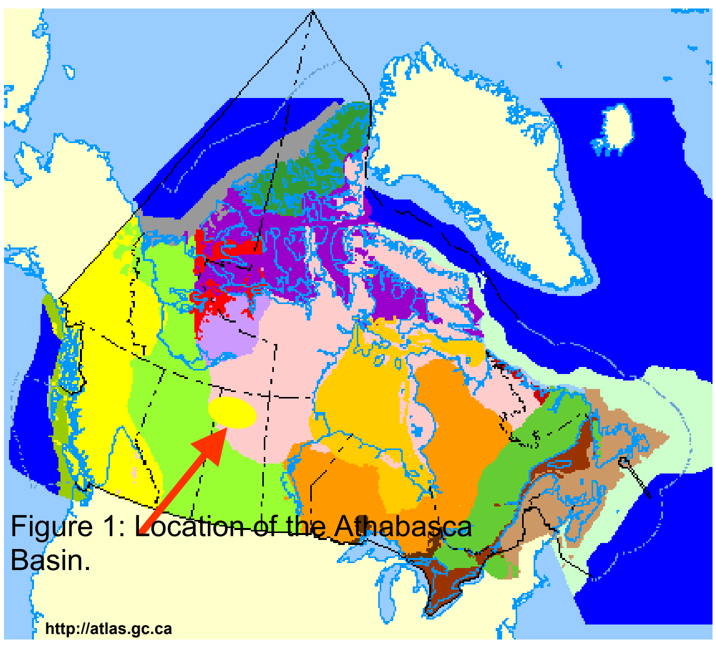

Figure 1: Location of the Athabasca Basin.

Geological Setting

The Early Proterozoic Athabasca Basin is an intracratonic (sensu lato) sandstone basin located in northern Saskatchewan and Alberta (Figure 1). It covers an area of ~100,000 km^2 and is undeformed except by faulting and by the Carswell meteorite impact structure. It unconformably overlies a crystalline basement complex comprising highly-deformed, medium- to high-grade metamorphic Archean granitoid gneisses, Paleoproterozoic metasediments, and Hudsonian intrusives, belonging to the west-central part of the Canadian Shield. The present Athabasca Group sandstone cover ranges from 0 to ~1500 m in thickness and is dominantly composed of mature coarse-grained quartz arenite with a kaolin-illite clay ± hematite matrix.

The Athabasca unconformity-type deposits are located around the unconformity between the Athabasca Group and underlying Archean to early Proterozoic metamorphic basement. They are localized at fault intersections, associated with breccia zones, and are within clay mineral and silicification/desilicification host-rock alteration haloes. Unconformity mineralization can be found up to 40 m above and/or below the unconformity, while basement-hosted mineralization can occur up to several hundred metres below the unconformity. High-grade mineralization consists of massive to botyroidal pitchblende/uraninite replacements, veins, and impregnations, with widely varying amounts of Ni-Co-Fe arsenides, sulpharsenides, and sulphides.

The host-rock alteration haloes contain illite, sudoitic chlorite, dravite, kaolinite, silicification (euhedral quartz) or desilicification, and locally, Ni-Co-As-Cu sulfide minerals (Figure 2). They are up to 400 m wide at the basal unconformity, can be over a thousand metres in strike length, and extend several hundred metres above major deposits (e.g. McArthur River, Shea Creek, Cigar Lake). This alteration typically envelops the main ore-controlling structures, forming plume-shaped or flattened elongate bell-shaped halos that taper gradually upward from the base of the sandstone and narrow sharply downward into the basement.

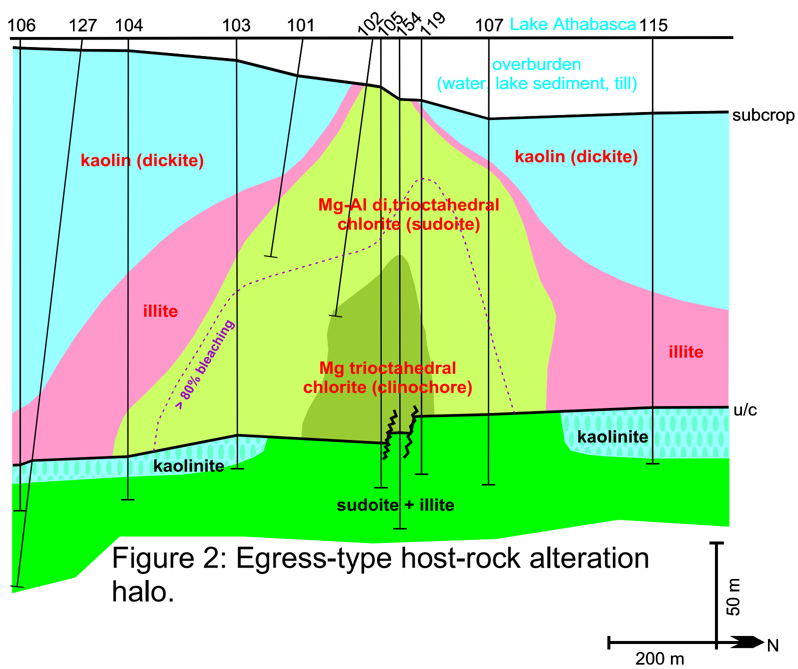

Figure 2: Egress-type host-rock alteration halo.

Illite as a pathfinder mineral

In the early 1980s, it was postulated that the presence of illite was a direct consequence of the geological environment present during diagenesis and during the mineralization and host-rock alteration formation event(s). There are diagenetic lithostratigraphic variations in the illite proportion in the Athabasca sandstone (Figure 3), as well as distinctive illitic clay mineral alteration haloes around the uranium deposits, due respectively to lithologically- and hydrothermally-available potassium in the surrounding brine. The quantities and/or characteristics of pathfinder alteration minerals vary with proximity to mineralization. For illite, the absolute and relative quantities increase toward mineralization, with concurrent illite mineralogical and chemical compositional changes being related to deposit genesis. It was beginning to be understood that diagenetic-hydrothermal alteration illite contrasts with diagenetic illite in a variety of features, such as grain size, polytype, morphology, crystallinity, and mineral chemical composition. At that time, optical petrography, lithogeochemistry, and XRD methods were used in mineral exploration to determine the absolute amounts of the clay minerals, the absolute quantities and relative proportions of illite, and some basic recognition features of illite (broad-scale composition and crystallinity variations (Figure 4); rarely polytypes) of the alteration illite relative to the diagenetic background.

During the 1990s, SWIR reflectance spectrometry was added to the analytical tool box to provide field-sourced clay mineral proportion data and EMP analyses were also providing some advances in the understanding of the mineral chemistry of the diagenetic and alteration clay mineral suite. But, illite polytype analyses were still only rarely performed. In the later 1990s and in the 2000s, research work has focussed on the illite polytypes. SEM (and optical petrographic) work have provided corroborating evidence for the differences between the coarse-grained, platy, and lath-like 1Mc diagenetic illite polytype and the fine-grained, “hairy”, wispy 1Mt hydrothermal illite polytype (Figure 5). Similarly, detailed EMP mineral chemical work has provided thermodynamic constraints on the formation of 1Mt illite and has demonstrated the small, but consistent, increase in Al content of 1Mt hydrothermal illite relative to 1Mc diagenetic illite.

Conclusions

The determination of the basic thermodynamic constraints of 1Mt illite relative to 1Mc illite, of 1Mt:1Mc proportions by XRD, and detailed SEM imaging of the transitions from background sandstone with diagenetic 1Mc illite to host-rock altered material with hydrothermal 1Mt illite, have provided micro-scale views of the illitic alteration phenomena. These developments have confirmed that the presence of illite was a direct

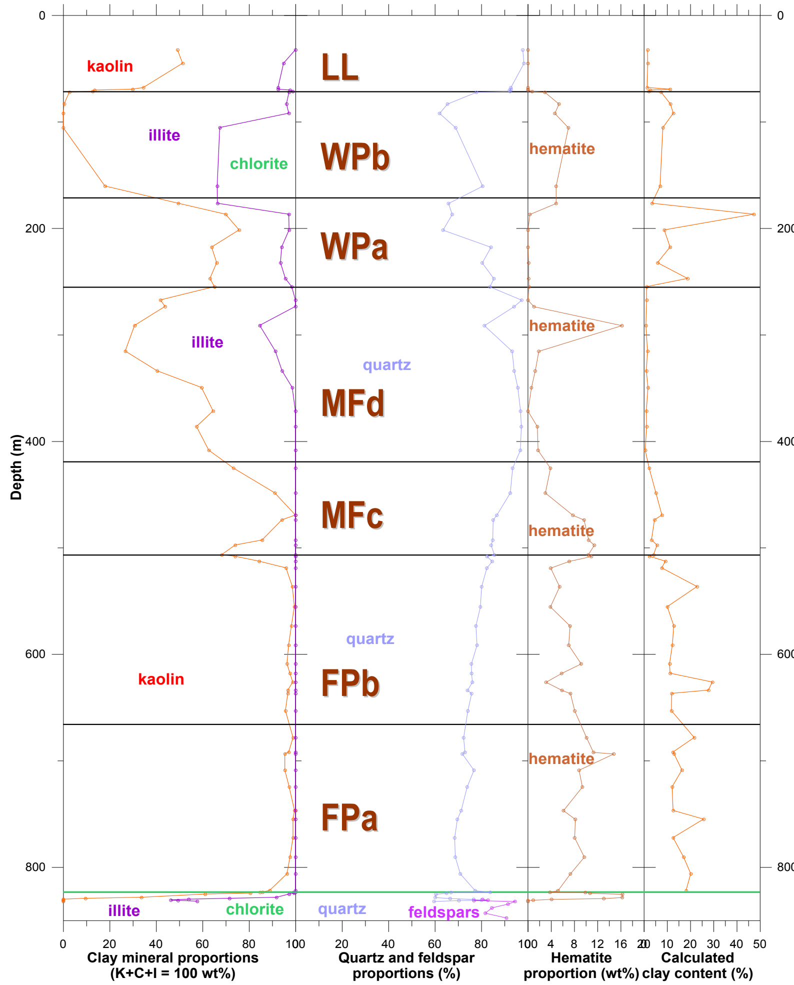

Figure 3: Lithostratigraphic variations in clay mineralogy.

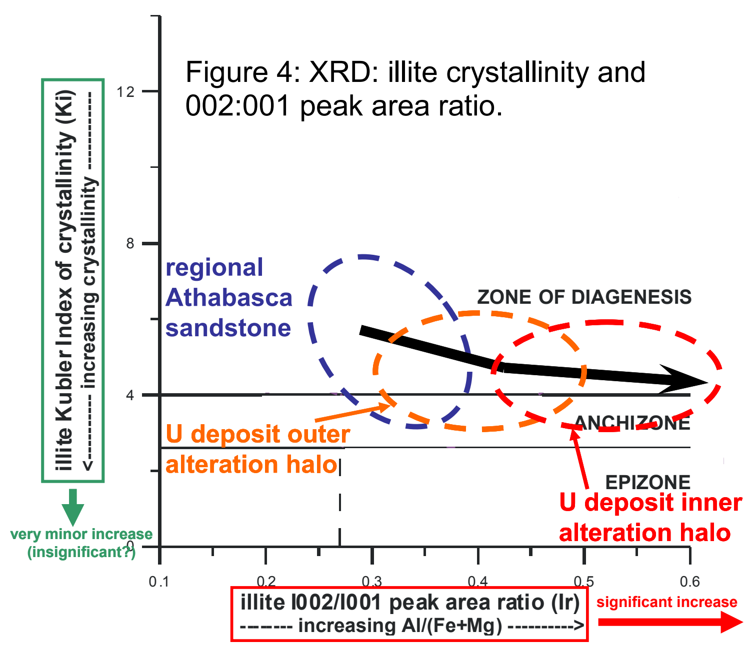

Figure 4: XRD: illite crystallinity and 002:001 peak area ratio.

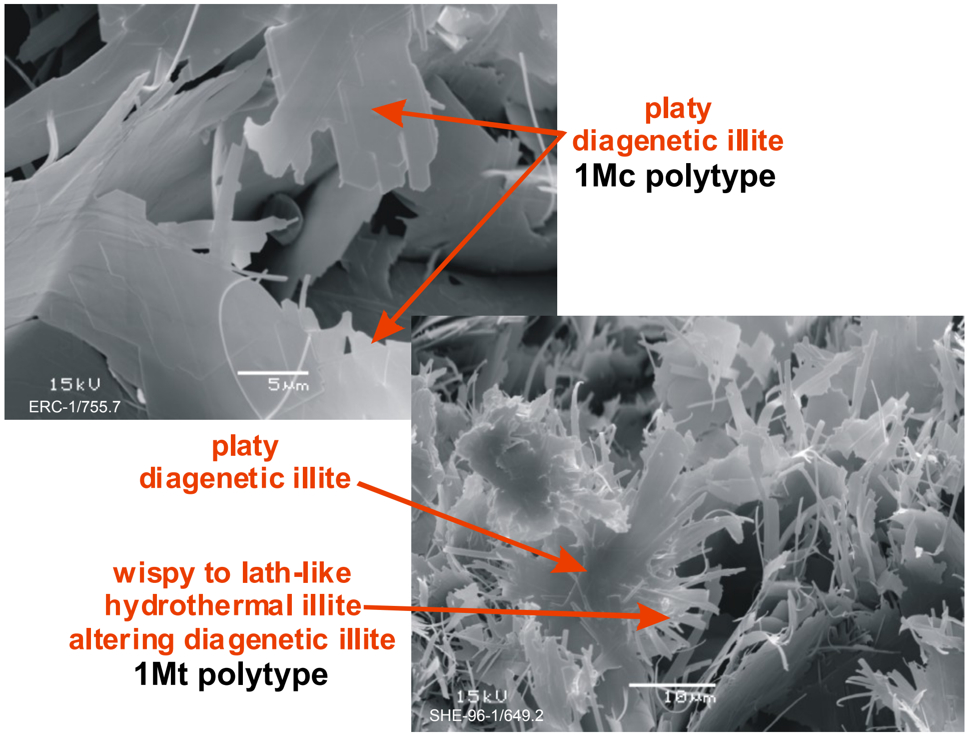

Figure 5: SEM: images of 1Mc and 1Mt illite polytypes.

consequence of the geological environment present during diagenesis and the host-rock alteration formation event(s). Thus, the recent advances in mineralogical analysis have reaffirmed illite as a pathfinder mineral for Athabasca unconformity-type uranium deposits.

Acknowledgements

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Further reading

Hoeve, J., and Quirt D. (1984): Mineralization and host rock alteration in relation to clay mineral diagenesis and evolution of the Middle-Proterozoic, Athabasca Basin, northern Saskatchewan, Canada. Saskatchewan Research Council, Technical Report 187, 187 p.

Jefferson, C.W., Thomas, D., Quirt, D.H., Mwenifumbo, C.J., and Brisbin, D. (2007): Empirical models for Canadian unconformity-Associated uranium deposits. *In*: Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration (Milkereit, B, ed.), p. 741-769.

Kister, P., Viellard, P., Cuney, M., Quirt, D.H., and Laverret, E. (2005): Thermodynamic constraints on the mineralogical and fluid composition evolution in a clastic sedimentary basin: the Athabasca Basin (Saskatchewan, Canada). European Journal of Mineralogy, v. 17, no. 2, p. 325-342.

Kister, P., Laverret, E., Quirt, D.H., Cuney, M., Patrier Mas, P., Beaufort, D., and Bruneton, P. (2006): Mineralogy and geochemistry of the host-rock alterations associated with the Shea Creek unconformity-type uranium deposits (Saskatchewan, Canada), Part 2: Regional-scale spatial distribution of the Athabasca Group sandstone matrix minerals. Clays and Clay Minerals, v. 54, no. 3, p. 295-313.

Laverret, E., Patrier Mas, P., Beaufort, D., Kister, P., Quirt, D.H., Bruneton, P., and Clauer, N. (2006): Mineralogy and geochemistry of the host-rock alterations associated with the Shea Creek unconformity-type uranium deposit (Athabasca Basin, Saskatchewan, Canada), Part 1: Spatial variation of illite properties. Clays and Clay Minerals, v. 54, no. 3, p. 275-294.

Quirt, D.H. (2003): Athabasca unconformity-type uranium deposits: One deposit type with many variations. *In*: Uranium Geochemistry (Cuney, M., ed.), International Conference Proceedings, Nancy 2003, p. 309-312.