Fluid Evolution and Structural Control on Uranium Deposits in the Beaverlodge Successor Basin, Canada

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Paleoproterozoic basins in Canada and Australia host world-class unconformity-related uranium deposits that currently supply 30 % of the global uranium market (Ghandi, 2005). Formation of these deposits is related to a reduction front near the unconformity between Paleoproterozoic sandstones, such as the Athabasca Group in Saskatchewan, Canada, and the Kombolgie Group in the Northern Territory, Australia, and underlying metamorphosed basement lithologies (Hoeve and Sibbald, 1978; Sibbald, 1985; Fayek and Kyser, 1997). Because of their economic importance, these deposits have been the focus of much research activity. In contrast, there has been a paucity of research on the spatially-related, basement-hosted uranium mineralization in the Beaverlodge area, Saskatchewan, Canada, and in the South Alligator Uranium Field, Northern Territory, Australia. This style of mineralization occurs in crystalline basement rocks beneath Paleoproterozoic basins that are stratigraphically older than, but are spatially related to, the younger uranium-rich Athabasca and Kombolgie basins. Clastic sedimentary rocks belonging to the Martin Lake Basin in the Beaverlodge area of Canada (Fig. 1) and the El Sherana Group in the South Alligator Uranium Field of Australia overlie the basement host-rocks, but whether the deposits are unconformity-related like those in the Athabasca and Kombolgie basins is inconclusive. These older sedimentary and volcanic successions filled successor basins, a term that conveys the fact that they immediately succeed orogenic events that may or may not be related to the major overlying basin filling successions. The Martin Lake Basin and the El Sherana Group are successor basins and are distinguished from the Athabasca and Kombolgie basins by their smaller size and temporal relationship to older Paleoproterozoic orogens, hence making them successor basins to an orogen.

This paper reflects results of a study on the fluid evolution and structural control on uranium deposits in the Beaverlodge successor basin in Northern Canada, based on structural and geological data obtained from Ace-Fay-Verna, Gunnar and Cinch Lake deposits (Fig. 1). Mineralized and background samples were examined using standard petrographic techniques and the observations combined with field data and U/Pb dating on paragenetically constrained uraninite samples. U/Pb dating was done on polished thin sections and analyzed by laser ablation-high resolution (LA-HR)-ICP-MS.

The rocks of the Beaverlodge area were involved in a long and complex history of deformation and metamorphism, alteration and mineralization. Repeated reactivation along major faults over a protracted period is revealed through a range of fault rocks, spanning from mylonites to breccias and veins (Bergeron, 2001). Each tectonic event is associated with a period of uranium mineralization, with the major mineralization hosted by breccias. U/Pb dating shows that these mineralizing events span from the early Kenoran Orogen at about 2.4 Ga, through the Thelon and the Trans-Hudson Orogens, to the last Athabasca mineralizing event at 1.6 Ga, with multiple post-mineralization alteration events (Fig. 2).

An early low-grade uranium-mineralizing event is associated with a period of intense mylonitization at significant depth, in a ductile environment. Field relationships and crosscutting relationships in thin section indicate that the mylonite event pre-dates cataclasite deformation, with fragments of mylonitized rocks embedded in the matrix of cataclasite rocks (Tortosa, 1983; Turek, 1962). Based on cell edge of pitchblende, Turek (1962) estimate a maximum age of 2528 Ma for this early mineralizing event in the Cinch Lake deposit which, likely corresponds to the early stage of the Kenoran Orogen (Stockwell, 1964). Mylonitized rocks were then exhumed to a higher structural level at the brittle-ductile transition, where these rocks became overprinted by cataclastic deformation. This deformation is associated with the second minor uranium-mineralizing event, which has 2271 Ma as its oldest Pb/Pb date, coincident with the late stage of the Kenoran Orogen (Fig. 2). At a later stage, high fluid pressure followed by exhumation caused hydraulic fracturing of the cataclasite rock. Pore fluids leached part of the pre-existing uranium and were driven into these hydraulically generated fractures by seismic pumping where the uranium precipitated. This third uranium-mineralizing event has 2221 Ma as its oldest uraninite Pb/Pb date and marks the final stage of the Kenoran Orogen (Kraus, et al 2000).

Following emplacement of the North Shore Granitic Complex near 2191 Ma (Schmus, 1986), massive metasomatic alteration caused pervasive albitisation of the Gunnar granite, followed by a fourth moderate mineralizing event during the final stage of the albitization process. Field relationships and crosscutting relationships in thin section indicate that the metasomatic-related uranium mineralization in the Gunnar deposit pre-dates the breccia mineralization event (Evoy, 1963) and would likely take place during the Thelon-Taltson Orogen at about 1.9 – 2.0 Ma (Chacko et al., 2000).

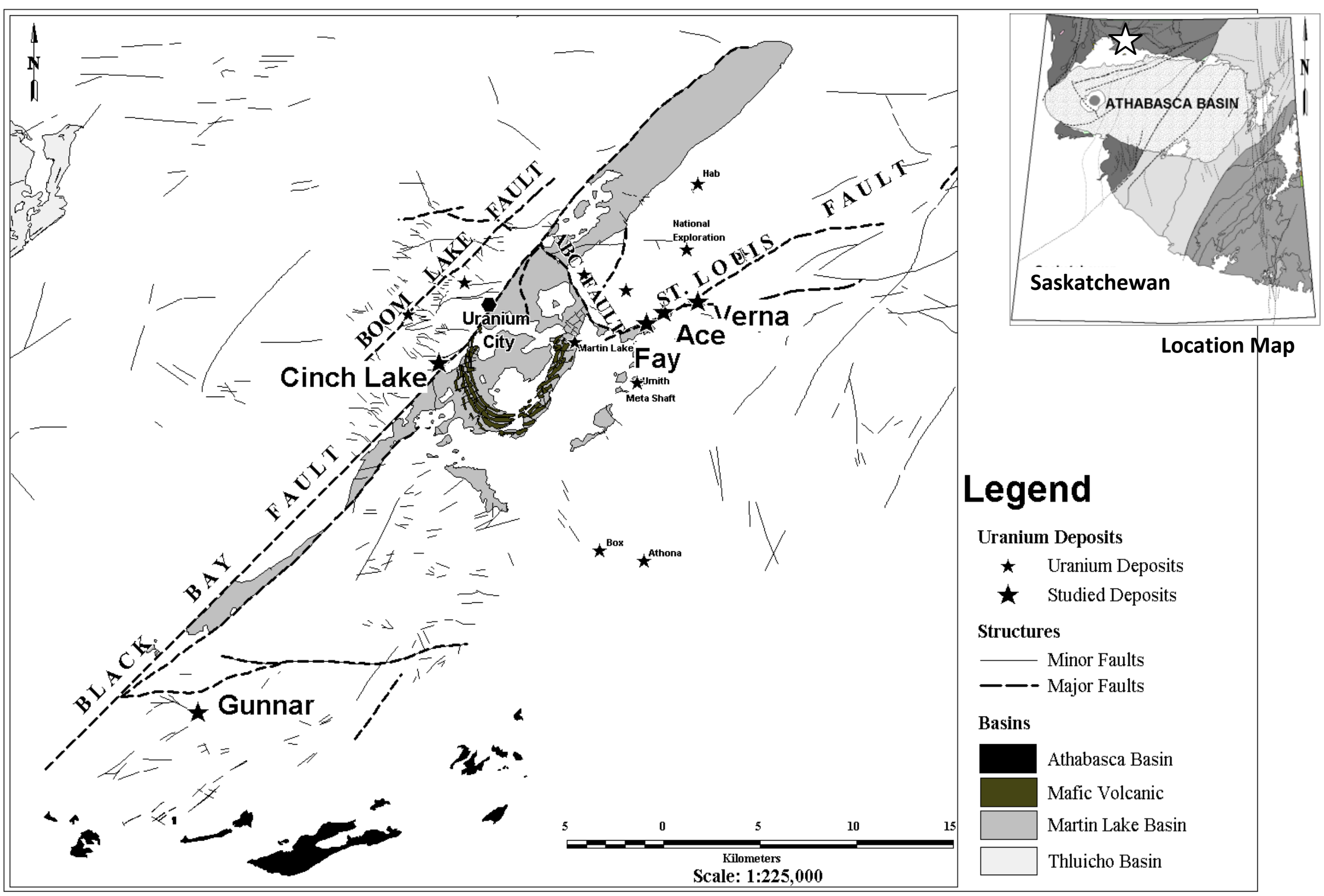

Figure 1: Beaverlodge area: Location of uranium deposits.

During the later Paleoproterozoic, cooling during exhumation caused the deformation style to change from dominantly brittle-ductile to brittle at a higher structural level. The nature of the breccia mineralization suggests that the area was near the surface at this time. Massive brecciation of pre-existing rocks is associated with the major and fifth uranium-mineralizing event at 1860 Ma (Fig. 2), coincident with the early Trans-Hudsonian Orogen (Hoffman, 1990).

Subsequently, deposition of sediments in the Martin Lake Basin occurred during extension and rifting of the Murmac Bay Group at about 1818 Ma (Morelli et al., 2009). Early Martin Lake Basin deposition is associated with emplacement of alkaline to sub-alkaline mafic sills through deep basin-related faults. Fluids related to mafic volcanism were associated with the sixth minor uranium-mineralizing event that takes place along pre-existing structures at about 1808 Ma (Fig. 2). Following folding and erosion of the Martin Lake Basin, the Athabasca Basin was deposited at about 1750 Ma (Kyser et al., 2000). Late stage mineralized veins which crosscut the breccia rocks during the late Paleoproterozoic are associated with the seventh minor uranium-mineralizing event at 1599 Ma, coincident with the major unconformity-related uranium-mineralizing event in the Athabasca Basin (Alexandre et al., 2009).

Post-mineralization alteration events that affected the uranium mineralization in the Beaverlodge area include the Berthoud Orogen at about 1400-1300 Ma, the Mackenzie Dyke Event around 1300 Ma (Fig. 2) and late remobilization during the Carboniferous (350 Ma) and the Upper Cretaceous (130 Ma) based on lower U/Pb intercept age from U/Pb Concordia diagrams.

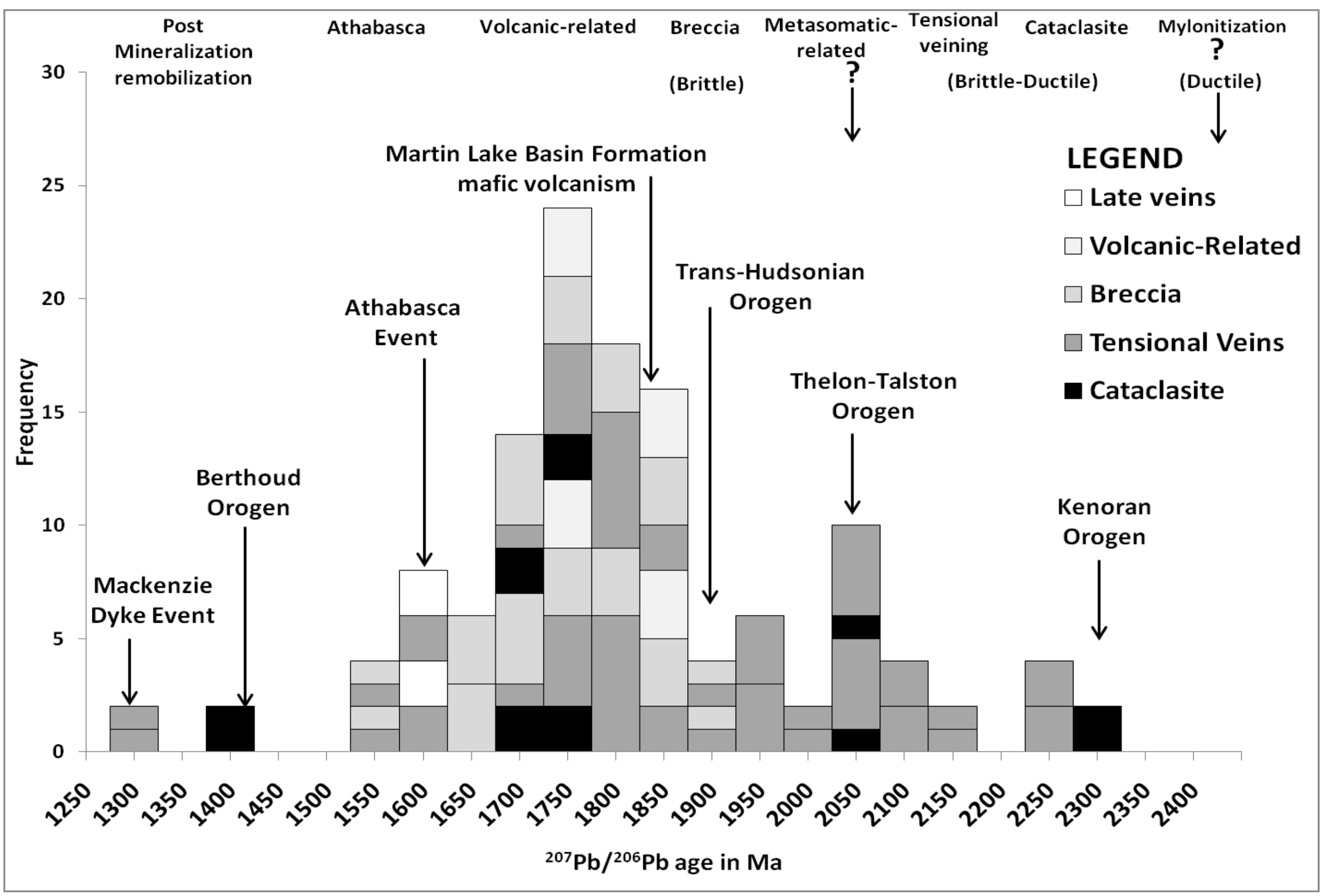

Figure 2: Timing of Uranium mineralization and resetting in the Beaverlodge area. This histogram reflects

the $^{207}Pb/^{206}Pb$ dates on uraninite associated with distinct styles of mineralization shown at the top of the diagram. The oldest $^{207}Pb/^{206}Pb$ dates are most likely the initial formation age because $^{207}Pb/^{206}Pb$ ratios in uraninite are less susceptible to resetting by younger events than are the U/Pb ratios. Also indicated are the ages of various tectonic events. The breccia stage mineralization is considered here as the major uranium mineralizing event as it hosts higher tonnage and grade of the uranium mineralization in the Beaverlodge area (Sassano, 1972; Tremblay, 1972; Beck, 1969).

Conclusion

Multistage deformation, magmatic and hydrothermal processes accompanied by events of uranium mineralization of various ages and types have affected rocks of the Beaverlodge area (Fig. 2). Seven distinct uranium-mineralizing events are identified. Each event is marked by a deformational phase, which promoted fluid mobilization and deposition. This suggests that mobilization of fluids that formed uranium mineralization in the Beaverlodge area is mainly tectonically-controlled. U/Pb and Pb/Pb geochronology shows that these mineralization events span over 800 million years from the early Kenoran Orogen at about 2.4 Ga, to the Athabasca mineralizing event at 1.6 Ga, with additional multiple late post mineralization alteration events. The most important mineralization event occurs during the brecciation phase and is associated with the Trans-Hudsonian Orogen at about 1.9 Ga. These breccias host much of the minable uranium mineralization in the Beaverlodge area and are localized along shear zones that they overprint. Any exploration strategy for finding economic uranium mineralization should explain the foci of these breccias along major shear zones. Further research will particularly focus on this main mineralizing phase and will assess the input of the volcanic-related and metasomatic-associated uranium mineralization that are not negligible, and will determine the origin and characteristics of the fluids associated with each mineralization event.

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