The Role of S-Type Granite Emplacement and Structural Control in the Genesis of the Athabasca Uranium Deposits

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Summary

Uranium unconformity deposits of the eastern Athabasca Basin are typically located along major long-lived structures orientated in the NE quadrant that exhibit both ductile and brittle deformation. The structures are locally characterized by accumulations of peraluminous S-type granites and pegmatoids derived from partial melting of Wollaston Domain metasediments during the Trans-Hudson Orogeny (THO). The S-type granites also accumulated in other zones of structural complexity, such as fold noses, sheared limbs and areas of dilation. Uranium, in uraninite and monazite, was enriched in the S-type granites during the partial melting process (ca. 1850–1800 Ma). The major structures and uraninite-monazite-bearing S-type granites contributed to the creation of localized high-heat production zones that helped to drive fluid movement along the structures at the later stages of the THO ca.1790-1720 Ma. This primary concentration of uranium within the S-type granites would later become a major source of uranium for the unconformity deposits formed at about 1550 Ma.

Introduction

Uranium unconformity deposits of the eastern Athabasca Basin are typically located along major long-lived structures orientated in the NE quadrant (N000° to N090°) that exhibit both ductile and brittle deformation. Reactivation of these structures that were developed during the THO played a major part in the creation of the unconformity deposits. This reactivation localized fluid flow, (ie. fluids provided by the basinal brines from the overlying sandstone and fluids from the basement) both along strike and vertically along the structure. Several phases of fluids, as identified by fluid inclusion work (Derome et al. 2005, Mercadier et al., 2008), are evident and include carbonic fluids during retrograde metamorphism during the late stages of the THO, and basinal brines during the maximum burial diagenesis of the Athabasca sandstone basin. Field observations and stable isotope work (Alexandre et al, 2005) have identified at least three different stages of alteration which occurred pre-, syn- and post-ore deposition. One post-ore alteration stage was a destructive process which introduced nickel, arsenic and copper that remobilized, contaminated and diluted the high grade ore.

Identifying major structures and accumulation of peraluminous S-type granites within the lower Wollaston Domain can be used as a tool for predicting where uranium deposits may be located in the eastern Athabasca Basin. Areas that a) are structurally complex, preferably at an intersection of structures with a long active history b) are characterized by sets of structures that are orientated anywhere from north-south to east-west c) have a higher than normal amount of S-type granite development d) lie within the basal Wollaston Domain meta-sediments, typically associated with a graphitic unit and e) lie close to an Archean granite antiform or quartzite ridge, which provides a competency contrast, are areas picked as the most likely to host an unconformity deposit. One view of how the basement lithologies could have made a major contribution to providing uranium for the unconformity deposits is presented.

Theory

Uranium enriched peraluminous S-type granites formed by partial melting of the Wollaston Domain metasediments during the THO were developed mostly in zones of structural complexity such as fold noses, sheared limbs, dilation zones (Figure 1) and most important, fault intersections that strike in the NE quadrant. The S-type granites helped create zones of high-heat production within the structures due to their high radiogenic values. Many of these structures were reactivated during deposition of the Athabasca sandstone as a consequence of far field stresses. Basinal fluids were pulled into the basement structures, interacted with the basement lithologies and became variably reduced, allowing zones of alteration to be developed in the structurally complex areas within both basement and sandstone lithologies. Then, at ca 1550 Ma, the uranium in the S-type granites was scavenged and mobilized by oxidizing basinal brines that migrated down and through the basement lithologies, and was re-deposited at or near the unconformity as high-grade deposits. Later reactivation of the same structures brought in metal-bearing fluids (Ni, As, Cu) which remobilized some of the deposits, contaminating and diluting the ore. Several deposits avoided this diluting event, and almost all these are located in the basement and not at the unconformity (Millennium, P-Patch, Eagle Point, the basement pod at McArthur, Sue C and D, Rabbit Lake and most of Roughrider). It is the author's opinion that most of the uranium that formed the high-grade deposits of the Athabasca Basin was derived from the basement lithologies, and not from the overlying sandstones.

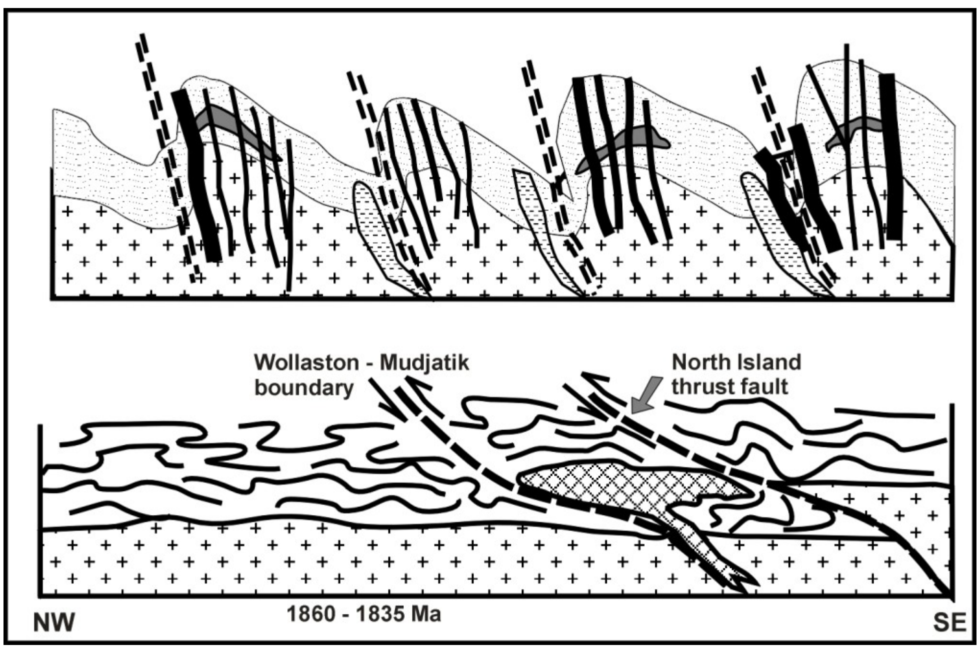

Figure 1: Model of S-type Granite Locations within Areas of Structural Complexity.

Archean granitoids and orthogneisses overlain by Wollaston Group metasedimentary rocks underlie the eastern part of the Athabasca Basin. The basal metasedimentary sequence of graphitic pelitic to psammopelitic gneisses exhibit a high volume of peraluminous S-type granites that have been interpreted to be a partial melting phase of the metasediments near the thermal peak of the THO (1820 Ma to 1800 Ma, Annesley et. al., 2005). When the existing metasediments were enriched in uranium, the anatectic crustal melts derived from partial melting were also enriched in uranium (Cuney and Friedrich, 1987). It has been noted by the authors through years of field work, both in drill core and in outcrop outside the sandstone cover, that the S-type granites were concentrated in areas of structural complexity, such as dilation zones, fold noses, sheared limbs and major, and long-lasting structures that are perpendicular to, or oblique to, the main direction of compression during the THO.

Examples

Most, if not all, of the known deposits in the eastern Athabasca are associated with N000°, N030°, and/or N060° to N070° structures (Figure 2). Several basement-hosted showings/ deposits (Roughrider, Sue C, P-Patch) are presented as examples of mineralization located in areas of structural complexity with associated alteration zones and abundant peraluminous S-type granites. The Roughrider Zone and the Sue C deposit (McClean Lake) are located in the northeast part of the Athabasca Basin. The P-Patch is located about 3km east of the Key Lake deposits in the southeast part of the Athabasca Basin.

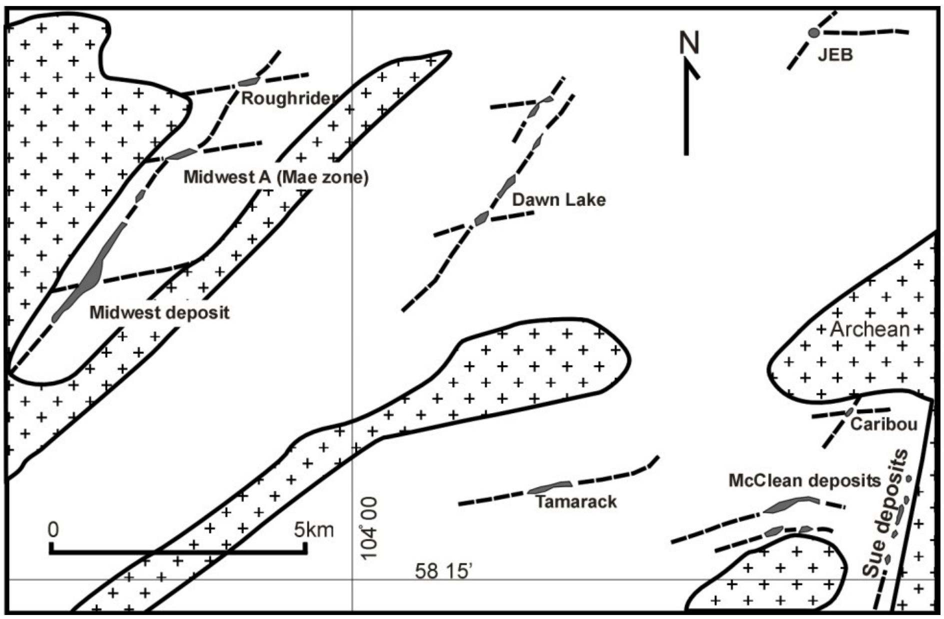

Figure 2: Location of U Deposits in the NE Athabasca Basin with N030° and N070° Controls

The Roughrider Zone is located within a package of altered pelitic to graphitic pelitic gneisses overlain by S-type granites and underlain by Archean granites, beneath 200m of sandstone. The mineralized zone trends N070° and dips steeply to the NW. The mineralization is on strike with a major N030° that hosts the Midwest and Midwest A (Mae zone) deposits. A large bleached alteration zone extends for 100's of metres within the basement beyond the mineralization, with illite and, to a lesser extent, chlorite as the clay minerals. Most basement deposits have a much smaller alteration zone with the exception of Shea Creek, located south of Cluff Lake on the west side of the basin. The Roughrider Zone has all the components mentioned above, including a structural intersection, a large quantity of S-type granites, and simple mineralization hosted in the basal Wollaston Group lithologies.

The Sue C deposit lies on a N012° trend within graphitic pelitic gneisses under approximately 60m of sandstone. The deposit is subvertical, parallels a contact with Archean gneisses 100m to the east, is relatively simple (little to no Ni, As, Cu) and is bounded by a competent quartzite unit immediately to the west. The mineralization is situated within a reverse fault that dips steeply to the east. An illite halo is present both above the deposit in the overlying sandstone and within the surrounding basement lithologies. A number of S-type granites are present within the open pit of the deposit, typically altered and somewhat contorted. While the main control on the mineralization is N012°, the secondary control is by cross-cutting N030° faults.

The P-Patch zone is situated within pelitic to psammopelitic gneisses and S-type granites that dip at 30° to the east, along a north-south trend approximately 3km east of the Key Lake deposits. Graphitic pelitic gneiss overlies the mineralization, and this in turn is overlain by an Archean granite wedge that was thrust and/or folded over the younger lithologies. The basement lithologies are overlain by approximately 80m of sandstone. The main control on mineralization is the intersection of a N070° structure, parallel to the Key Lake structure that lies to the north, with the north-south trending graphitic pelitic lithologies. Alteration extends several 10's of metres beyond the mineralization for most of the zone, but extends to an unknown depth along a north-south trending fault on the west side of the zone. This alteration consists of bleaching and the development of illite and dravite clays, both within the basement and the overlying sandstone.

Based on these observations, one can predict the location of new unconformity deposits on the east side of the Athabasca Basin. The probability of finding a uranium occurrence is tremendously increased by utilizing the latest in geology, airborne magnetic and airborne gravity maps with a compilation of all the EM conductors (typically graphitic lithologies), areas with structural intersections within the NE quadrant, and basement lithologies that involve graphitic units with an abundance of peraluminous S-type granites. A map showing the locations of these areas is beyond the scope of this abstract, but will be in the full paper.

Conclusions

All of the known uranium occurrences in the eastern part of the Athabasca Basin show structural control by a long-lived structure that strikes within the NE quadrant (N000° to N090°). Most, if not all, show evidence of peraluminous S-type granites and pegmatoids of Hudsonian age within the basement lithologies, either under an unconformity hosted deposit, or within or immediately adjacent to a basement hosted deposit. The combination of the long-lived structures with an abundance of uranium-rich, high-heat production S-type granites allowed basinal brines from the overlying Athabasca sandstones to strongly infiltrate the basement and leach uranium, especially from the granites, to form the unconformity deposits. The location of these deposits was fixed at the intersections of cross-cutting structures where pore space was created by dissolution, allowing uranium to precipitate. This helped create multiple mineralized pods along the same structure over distances of up to 7km (e.g. Midwest to Roughrider).

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