

## Geochronology and geochemistry of Precambrian basement from the Fort McMurray area, Alberta: A geothermal perspective

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To reduce energy consumption and CO<sub>2</sub> emissions in oil sands processing, a study was recently initiated under the auspices of the Helmholtz-Alberta Initiative to examine the possibility of a cheaper source of hot water in northeastern Alberta by geothermal methods. The particular geothermal method being considered is Engineered Geothermal Systems (EGS), which aims to extract economic quantities of heat from low permeability and porosity rocks. The present study is the geochemical/petrological component of a larger investigation into the feasibility of using EGS as a hot water source for oil sands processing in the Fort McMurray area. Specifically, our aim is to document the rock types, mineralogy, crystallization ages and heat-producing element concentrations of 37 basement drill core samples recovered in 23 petroleum exploration wells drilled into Precambrian basement within a 125 km radius of Fort McMurray.

Most of the drill core samples are part of the Taltson Magmatic Zone (TMZ), a 500 km long, Paleoproterozoic orogenic belt, more than half of which is buried beneath Phanerozoic cover rocks. The investigated samples are mostly deformed granitoids but also include two amphibolites and one sample likely of metasedimentary origin. Preliminary U-Pb isotopic age determinations conducted on thin sections of these samples by laser-ablation MC-ICP-MS yielded zircon crystallization ages ranging from 1.84 to 2.4 Ga. On the basis of these data, the samples can be divided into five age suites. The oldest suite yields relatively poorly constrained ages between 2.2 and 2.4 Ga (n=5). A second group of samples indicate ages of ~2.0 Ga (n=2). The samples from suites 3 (n=6) and 4 (n=6) record two separate periods of granitoid intrusion at 1.95-1.97 Ga and 1.925-1.935 Ga, respectively. The ages noted above correspond well with ages that have been previously reported from the exposed part of the TMZ. The 5<sup>th</sup> suite (n=1), which is from the Rimbey domain immediately to the south of the TMZ, yielded an age of ~1.84 Ga.

Heat-producing element concentrations (K, U, Th) are wide ranging but on average the younger granitoid suites have higher concentrations of these elements. The youngest suite (Suite 5) has by far the highest U content (13.6 ppm) of any of the rocks analyzed in the present study. The temperature recorded at the base of the 2.36 km deep Hunt Well, which is located near the Fort McMurray town site, is ~47°C [1]. Given that the Hunt Well is drilled in the older (ca. 2.2-2.4 Ga) and less radiogenic rock suite, it seems reasonable to conclude that geothermal gradients at other locations within the study area may be at least as high as those documented at the Hunt Well.

[1] Majorowicz et al., 2011

## Origin of saline aqueous fluids in the lower crust

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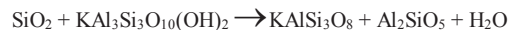
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Low viscosity H<sub>2</sub>O plus NaCl fluids are an important component of metamorphism in the lower crust. They contain up to 50 wt% NaCl (X<sub>NaCl</sub> = 0.24) that varies widely over short distances judging from fluid inclusion observations. The origin of these fluids is still being debated. Downward circulation of salt-rich surface fluids by thermal convection has been proposed [1]. These fluids are ruled out because they are too buoyant to penetrate downward into the middle or lower crust where fluid pressure = rock pressure and buoyancy controls fluid movement. Low-density H<sub>2</sub>O-rich fluids at these depths like magmas tend to rise but not sink.

H<sub>2</sub>O with NaCl is given off by upper mantle and lower crustal magma during the final stages of their crystallization. By interacting with deeply buried evaporites these fluids could become even more saline [2]. The fluids could then flux upward. However, considering the dynamics of fluid flow it is likely that these fluids will coalesce into major channelways as they are transported upward. This is similar to flow in the dendritic pattern of stream flow on the earth's surface. These mantle and lower crustal fluids are then likely to be contained in widely spaced fractures and not produce the extensive metamorphism or variable salt concentration observed.

This leaves fluids produced locally during metamorphism by the destruction of hydroxyl containing minerals as they are buried. These fluids are produced at every volatile mineral that is undergoing destruction with increased pressure and temperature and therefore can be pervasive. In pelites ~2 moles of fluid per 1 kg of rock is produced to medium grades of metamorphism [3]. This process is responsible for the low salinity fluids that are a component of mid-crustal metamorphism. How can some of these fluids become more saline at lower crustal levels while others are less so?

The H<sub>2</sub>O-bearing minerals, hornblende in mafic rocks and mica in pelites that survive to lower crustal levels have lower thermodynamic activities. This occurs because Cl<sup>-</sup> and F<sup>-</sup> are present in the OH<sup>-</sup> sites in these minerals. For the activity of muscovite in mica:



$$K = \frac{a_{\text{Ksp}} a_{\text{Kyn}} a_{\text{H}_2\text{O}} / a_{\text{qtz}} a_{\text{mus}}}{a_{\text{mus}} = (X_{\text{K}})(X_{\text{Al-M1}})(X_{\text{Al-M2}})^2 (X_{\text{S}})^3 \text{O}_{10} (X_{\text{OH}})^2}$$

When this low activity mica finally becomes unstable, high Cl<sup>-</sup> fluids are produced with F<sup>-</sup> partitioning into the remaining minerals. For the same activity of the hydrous phase if the F<sup>-</sup> changes locally the fluid produced will change its Cl<sup>-</sup> fluid concentration. Mica and hornblende compositions whose destruction produces X<sub>Cl</sub> > 0.24 can be present [4],[5]. Destruction of compositionally different hydrous phases, stable in the lower crustal because of their high salt content, can account for the range of salinities observed in fluid inclusions.

[1] McLelland, *et al* (2002) *J. Meta. Geol.* **20**, 175-190. [2] Yardley & Graham (2002) *Geofluids* **2**, 249-256. [3] Walther and Orville (1982) *Contrib. Min. Petrol.* **79**, 252-257. Walther (2009) *Essentials of Geo-chemistry* 2<sup>nd</sup> ed, 342-352. [4] Tracy (1991) *Amer. Mineral.* **76**, 1683-1693. [5] Oen & Lustenhouwer (1992) *Econ. Geol.* **87**, 1638-1648.