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Numerical modelling of hot tectonic belts, implications for the Trans-Hudson Orogen (Hearne Craton, Canada) and the establishment of associated fluid channels

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Field observations from Archean and Paleoproterozoic cratons show strain zones often marked by widespread sub-vertical stretching lineations throughout the crust and partial melting conditions. These regions contain deformation bands that show large strains despite a lack of metamorphic jumps and often contain economical ore deposits. But, these provinces are often interpreted under the lens of modern plate tectonics (i.e. vertical motions with a stronger localisation of strain seen in modern orogenic systems). This contrasts with ancient orogens with a consensus for gravity-driven tectonics due to an inverse density contrast that describe the structural profiles of granite-greenstone belts. However, gravity-driven tectonics could not be applied to provinces that contain a normal crustal density profile. This led to a proposal of an Archean-Proterozoic transitional tectonic style. Recent analogue modelling experiments and field observations confirm vertical tectonics is the dominant driving force for syntectonic meta-sediment concentration, strains, and generate associated fluid channels for mineral concentration.

The Canadian Hearne craton contains a region that conforms to the structural profiles generated by vertical tectonics. The Trans-Hudson Orogeny (THO; 1.82 - 1.78 Ga) was responsible for creating a NE-SW sub-vertical structural corridor sandwiched between, and imbricating, two Archean tectonic domains containing Paleoproterozic meta-sedimentary material. During the THO, peak metamorphic conditions recorded in meta-sedimentary rocks achieved high metamorphic facies P-T conditions (i.e. P > 8 kbar, T > 700 ˚C) before undergoing a period of rapid isobaric decompression and cooling. The large ductile shear zones that extend into the Archean orthognessic basement were then subjected to brittle reactivation 200-300 Myr after their genesis. The subsequent reactivations of the shear zones coincide with key uranium mineralisation periods. However, the tectonic process to generate such an ancient but long lasting fault system remains still poorly understood.

In this study, we performed a series of 2D visco-elasto-plastic thermo-mechanical numerical modeling experiments using standard rheological and thermal parameters from previous laboratory experiments. The initial geometry, thermal structure, and boundary conditions of the models are further constrained by applying existing geophysical and geological data. The model setup consists of the emplacement of a thin meta-sedimentary layer over a 25 to 35 km continental crust while under hot to ultra-hot Moho conditions. Our results show that, during compression, (1) the meta-sedimentary units demonstrated vertical burial during a constant compressive regime, (2) the meta-sedimentary units also reached the high P-T constraints indicated by peak metamorphism values, and (3) the structural and metamorphic profiles observed in numerical experiments conform to field observations from the Hearne craton.

The model we propose is therefore capable of engaging vertical burial of meta-sedimentary units under a long-protracted period of tectonic convergence. The meta-sedimentary units also achieve their respective P-T targets given sufficient horizontal shortening. The structural profile generated subsequent to their burial is indicative to potential permeability-enhanced high fluid flux profiles capable of future ore deposit genesis. Finite strain patterns after material exhumation seen in the post-Athabasca Basin can be used as a tectonic template for future coupled fluid and thermo-mechanical simulations.