Integrating Geodynamic Modeling with Geophysical and Geological Data: A LITHOPROBE Perspective

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The Canadian LITHOPROBE program (1984 to 2005) is an internationally acclaimed research project that was established to study the development of the North American continent from the Paleoarchean to the present and to investigate the varied and complex processes involved in that development. Collaborative, multidisciplinary research was the key to LITHOPROBE's scientific and related successes (Clowes 2010). Within the project, geodynamic modeling using numerical procedures was an important component of the multidisciplinary scientific program to better understand active tectonic processes and their effects on crustal structure and geology. Much of this research was carried out by Chris Beaumont of Dalhousie University in Halifax, Nova Scotia with his staff, postdoctoral fellows, graduate students and colleagues (e.g., Beaumont et al. 2010). This presentation follows their work.

The numerical modeling procedures are based on Lagrangian-Eulerian methodology in which flows with free upper surfaces are calculated on an Eulerian finite-element grid that stretches in the vertical dimension to conform to the material domain. A Lagrangian particle tracking cloud and grid, which is tied to the velocity model field, is used to update the mechanical and thermal material-property distribution on the Eurlerian grid as their position changes. The modeling predicts the development of large, hot orogens using 2-D calculations that assume plane-strain conditions in a vertical cross-section through the orogen. The thermal and mechanical evolution is solved subject to velocity boundary conditions applied at the sides and the base of the model domain. Thermal-mechanical coupling occurs through the thermal activation of viscous power-law creep in the model materials and through the redistribution of radioactive crust by material flow. Both crustal-scale and upper-mantle-scale models have been investigated (Beaumont et al. 2010).

In this presentation, crustal-scale, 2-D, coupled thermomechanical models in which the behavior of the mantle is kinematically described are considered. One of the key features of the models is the inclusion of a "melt-weakening" effective viscosity to represent partial melting of felsic rocks for temperatures greater than 700 °C in the middle to lower crust. One particular model is derived to represent the development of the Mesoproterozoic western Grenville Orogen (about 1090 Ma to 980 Ma). Crustal structure in this region has been interpreted from LITHOPROBE seismic reflection data and geological studies. In addition, metamorphic data from one area (Georgian Bay in Ontario) provide pressure-temperature (P-T) plots and pressure-temperature-time (P-T-t) plots. Crustal structure derived from the end result of numerical modeling compares favorably with the crustal interpretation from the seismic data (Fig. 1). Plots of pressure at maximum temperature versus maximum temperature derived from the model results cluster within the mid-range of the observed metamorphic data on a P-T diagram. By following tracking points during development of the numerical model, P-T-t paths from the tracked points are shown to correspond well with observed P-T-t paths determined from metamorphic data. The details and figures that will be presented are taken from the work of Jamieson et al. (2010), published in a special LITHOPROBE issue of the Canadian Journal of Earth Sciences.

References

Beaumont, C., Jamieson, R., and Nguyen,M., 2010, Models of large, hot orogens containing a collage of reworked and accreted terranes, Canadian Journal of Earth Sciences, 47, 485-515.

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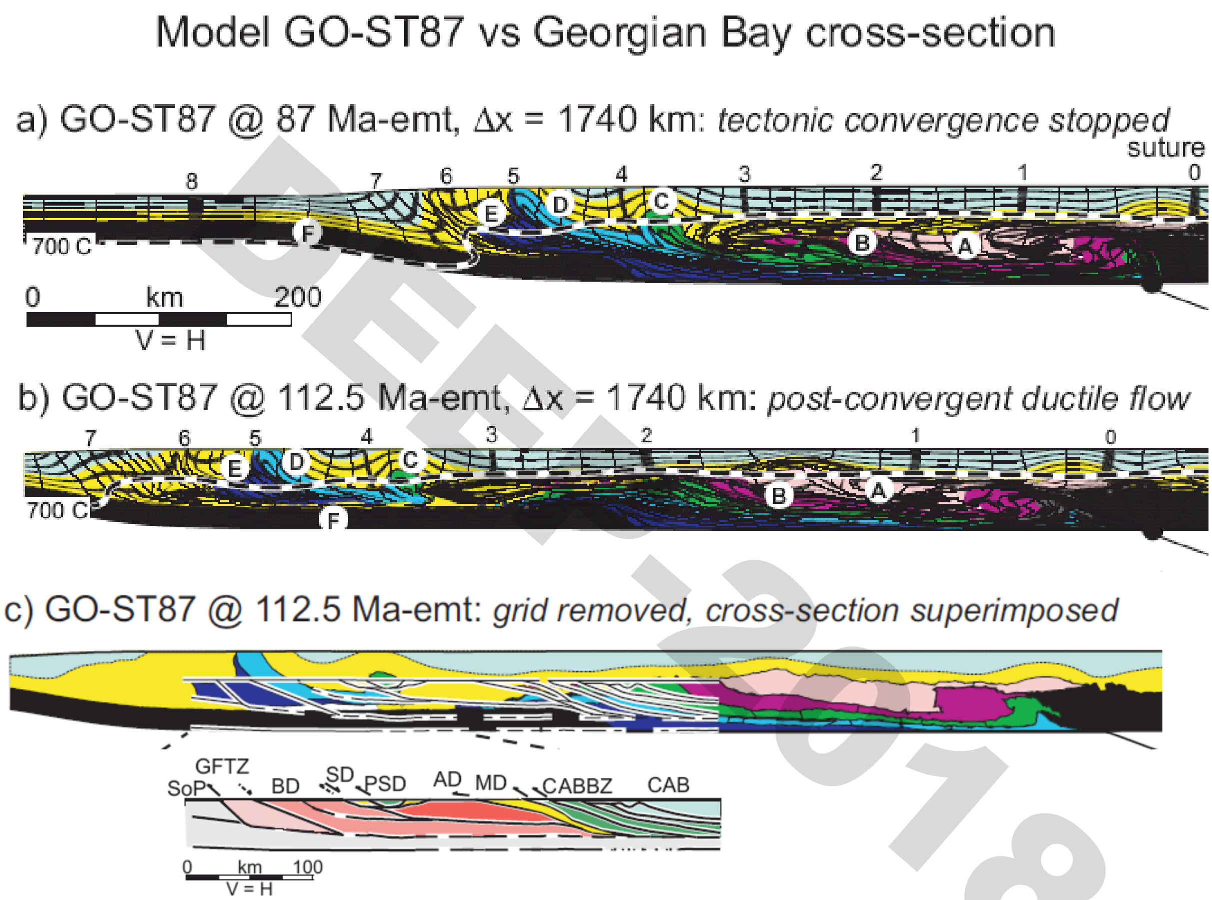

Figure 1. Selected results from model Grenville Orogen GO-ST87 after convergence of 1740 km stopped at 87 Ma elapsed model time (emt). a) Deformed marker grid, crustal blocks and 700°C isotherm at the time convergence is stopped. Strong lower crustal block F has started to underthrust blocks E and D, and is about to underthrust the leading edge of block C, which has already been exhumed to mid-crustal levels. b) Model GO-ST87 at 112.5 Ma-emt, 25.5 Ma after the end of convergence, and the result of post-convergent ductile flow. Note transport of blocks E, D and C 200 km toward the foreland, accompanied by ductile thinning in the orogenic core. c) Same as b) with grid removed and outline of the interpreted Georgian Bay cross-section superimposed. Below: the Georgian Bay cross-section interpreted from seismic reflection data and geological studies. SoP, Southern Province; GFTZ, Grenfille Front Tectonic Zone; BD, Britt domain; SD, Shawanaga domain; PSD, Parry Sound domain; AD, Algonquin domain; MD, Muskoka domain; CABDZ, Composite Arc Belt boundary zone; CAB, Composite Arc belt. Figure adapted from Jamieson et al. (2010).