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Convective modelling based on geophysical imaging of deep crustal intrusions – A new foundation for mineral exploration?

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With 2 figures in the text

The 200 x 500 km Yenisei Ridge metallogenic province, which runs along the southern reach of the north-flowing Yenesei River, is one of the great metallogenic provinces of the world. Pb, Zn, Au, Pt, Pd, Mn, and V ore occurrences are believed to have been produced, mainly by hydrothermal activity during a protracted period of rifting in Riphean time (1600–650 million years before present). Over 60 stratiform Pb-Zn deposits in carbonate and carbonate-ferruginous flysch occur in the western part of the Ridge, and over 20 major gold deposits in its eastern part.

A unique aspect of the Yenisei Ridge metallogenic province is that deep crustal intrusions have been imaged there by the Soviet Union's Deep Seismic Sounding (DSS) program. Earthquake, and nuclear explosion data were integrated with conventional reflection profiling sources, and both shear and compressional wave data were collected. This data set has been analyzed statistically for the frequency of crustal reflections and phase conversions (Cherkasov, Vishnevskaya, 1999), for variations in compressional (Vp) and shear wave (Vs) velocity and their ratio (Vp/Vs), and for covariation with gravity measurements. It has been found that zones of seismic transparency (ZST's) with low numbers of seismic reflections can be easily identified with a moving filter, and that these transparent zones coincide with zones of density variation and possible alteration. At 35 to 50 km depth (lower crust) transparent intervals 15–25 km long form a funnel-shaped "feeder" connecting the Moho to a mid-crustal, 10 km thick, sill-shaped zone of seismic transparency with lateral dimensions of over 100 km. The upper part of this seismically transparent sill shows a density deficit and an anomalously low Vp/Vs ratio, suggesting widespread granitization. Variations in crustal reflections are more difficult to map in the upper crust (0–15 km), but transparent columns with density deficits can be detected at the margins of the seismic sill. When traced to the surface, these seismically transparent columns coincide with granitoid outcrops and the gold districts are restricted to the margins of the seismic sill (Bulin, Egorkin, 1995).

Features of the seismically-suggested intrusions in the Yenisei Ridge province have significance for the pattern of hydrothermal convection that heat from the intrusions might produce. When magmas invade the middle and upper crust, adjacent pore waters are heated and caused to convectively circulate. The convection is strongest at the margins of the sill where the horizontal thermal gradients that drive convection are greatest (Cathles et al., 1997). This will be further promoted if magmas invade the shallower parts of the crust at the sill margins in tabular form as suggested by the seismic data.

Our intention is to calculate the alteration caused by this circulation and to relate it quantitatively to both the geophysical data (magnetics, gravity, and seismic) and the intensity of rock alteration and mineralization. As a first step toward this goal we have reconstructed and thermally

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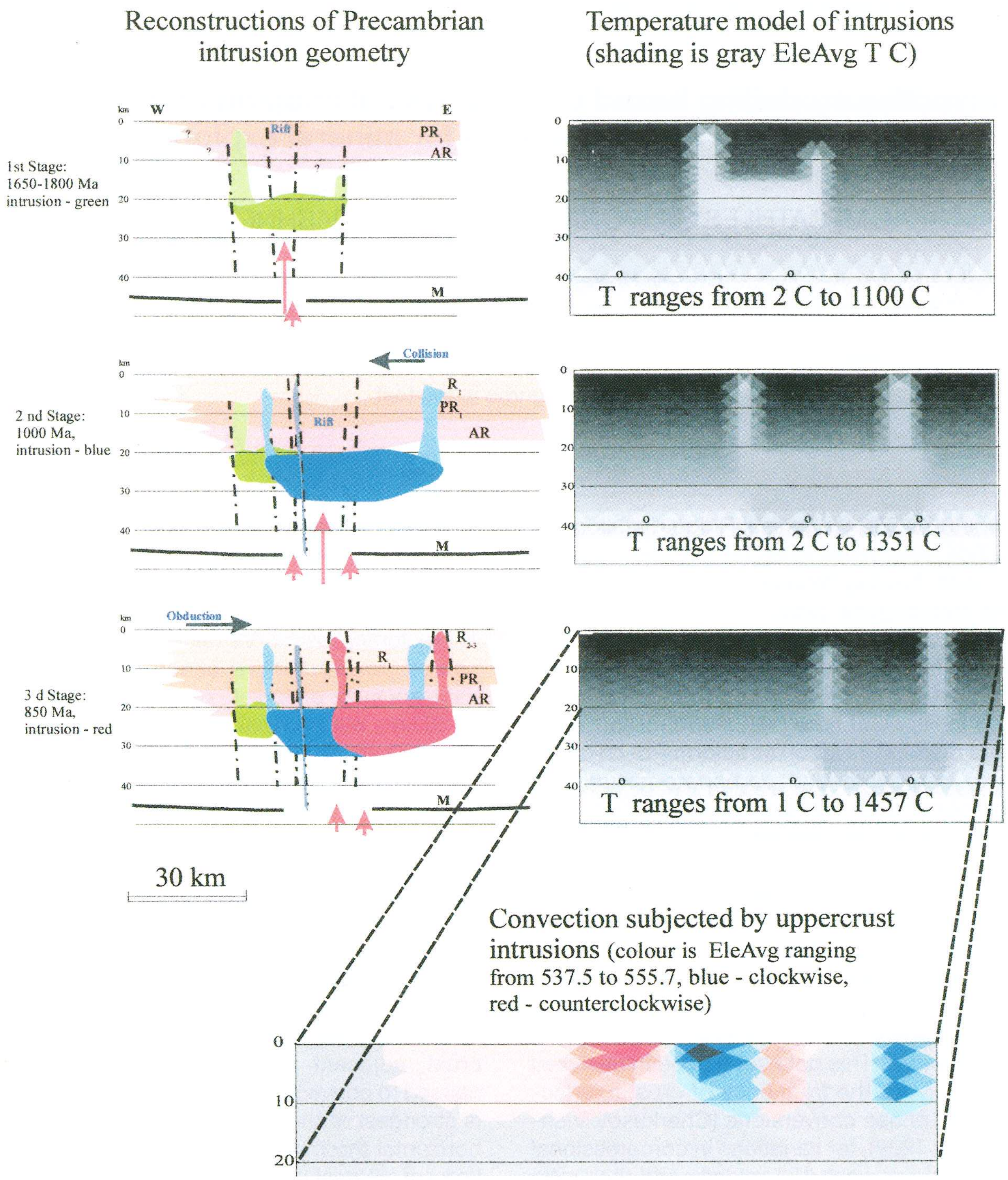

Fig. 1. Example of thermal reconstruction and convection modeling on the basis of intrusions' geometry revealed by DSS, gravimetric, and geological data interpretation

modeled sedimentation and intrusion over 800 Ma of Riphean time. Fig. 1 shows the 3 major stages of intrusion at 1650, 1000, and 850 Ma. Over this period about 10 km of sediments have accumulated (the section is 10 km thicker at 850 Ma). The sills and their edge-plutons intrude at 800 °C. Temperature is indicated by shading. Since triangular finite elements are

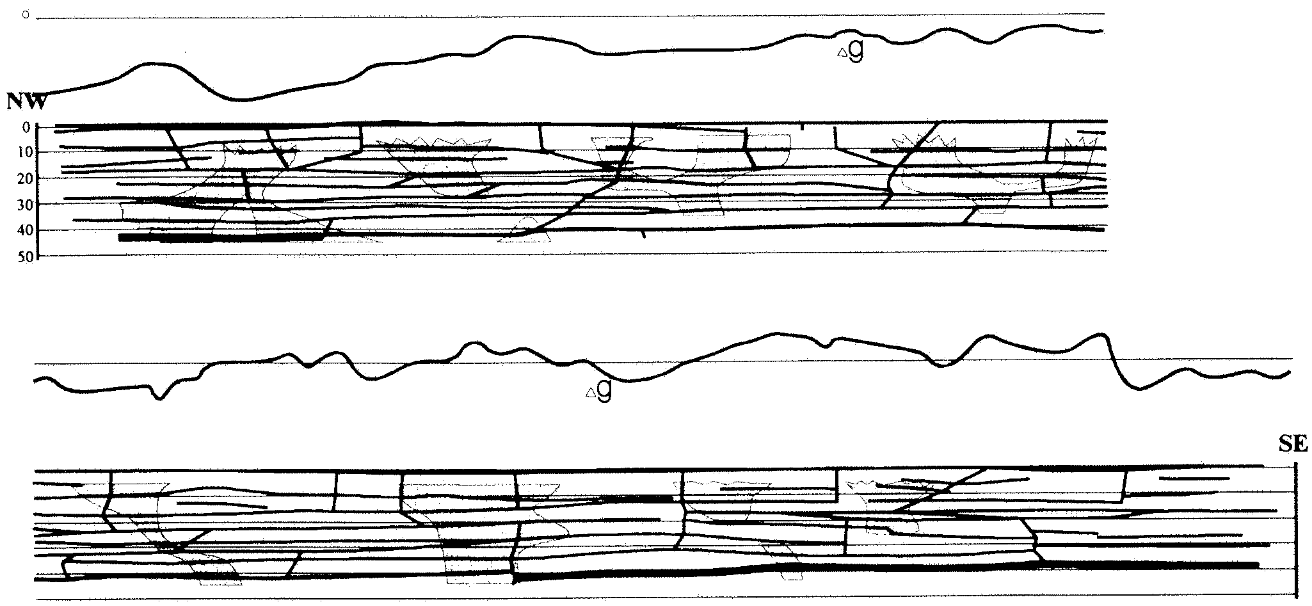

Fig. 2. An example of revelation of crustal intrusions (gray) using DSS and gravity data

given a common shade, the temperature field appears scalloped although it is in fact smoothly varying. The combination of the three episodes of intrusion gives the geophysically-indicated intrusion complex. Below, the strong convection that is calculated at the margins of the last sill (850 Ma) is shown. The coloring here is the streamfunction. Circulation is counter-clockwise in red zones, clockwise in blue zones. The convection is driven by the subplutonic intrusions at the intrusion margins.

We have just completed the geologic compilation and the first models. The models are not yet realistic. The Moho is twice as hot as it should be, and we did not allow time enough for the intrusions to cool before adding additional strata (with much larger modeling timesteps). The figures show, however, that it is feasible to calculate crustal evolution and intrusion over protracted periods of time and on a spatial scale that is suitable for comparison to geophysical data, alteration, and mineralization. If large scale convection/alteration models can be combined successfully with geophysical data we believe that useful constraints on crustal dynamics and metallogenesis may result. Our project works toward this goal.

At the same time, the work on DSS geotransects is in progress. Fig. 2 demonstrates a preliminary interpretation result of DSS data in terms of seismic transparency along the "Basalt-4" geotransect, which is about 500 km long (Russian Far East). Our belief is that application of thermodynamic modelling at this scale will allow us to reconstruct a thermal history of the Earth crust. A more detailed study of the upper layers, with alteration modeling will produce a prognosis for ore fields and districts along the DSS profiles.

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