Perchuk L.L., Gerya T.V. Geothermobarometry and geodynamics of the Precambrian crust

[1]Department of Petrology, Geological Faculty, Moscow State University (MSU),Vorobievy Gory, Moscow, 119899 Russia; e-mail: llp@geol.msu.ru
[2]Institute of Experimental Mineralogy, Russian Academy of Sciences (IEM RAS) Chernogolovka,Moscow District, 142432 Russia; e-mail: taras@iem.ac.ru

keywords: [granulites, cratons, geothermobarometry, geodynamics, Precambrian, continental crust, P-T paths]

During the last two decades, Phanerozoic and even Precambrian crustal evolution was successfully modeled by plate tectonics (e.g., Perchuk et al., 1985; Barbey and Raith, 1990, Roering et al.,1992, Treloar et al., 1992, de Wit et al., 1992). The thermal regimes in which Precambrian crust evolve differ, however, substantially from that of younger crust. The Achaean and Early Proterozoic crust were, for instance, relatively soft and thin as a result of high-temperature geothermic regimes limiting the movement of possible microcontinents. The aim of this paper is to demonstrate that the formation and evolution of the Precambrian continental crust have been driven by gravitational redistribution of rocks in a Precambrian supercontinent such as Gondwana due to mantle derived fluid-heat flow (plume). Geological, geochemical and petrological data on the relationships between greenstone belts and adjacent granulites are used. Among the diversity of hypotheses (see a review by Thompson, 1990) on the formation and evolution of Precambrian granulite facies terrains, collisional models are the most popular. Such models suggest that the formation of granulite facies terrains should lead to the formation of double thickened (60-80 km) crust, that should eventually thin through surface erosion or tectonic denudation. There is, however, no evidence for exhumation of Precambrian granulite complexes marked by typical eclogites. Moreover there is no evidence for the existence of Precambrian granulites that have been exhumed from the depths more than 45 km. Only a few collisional models discuss the evolution of closely associated granite-greenstone belts against which the granulite complex have been juxtaposed. Many granulite facies terrains are also younger than adjacent cratons. Granulite facies terrains are commonly separated from cratons by large bounding shear zones (e.g. Limpopo, Lapland, Aldan Shield, Yenisey Range in eastern Siberia). Isotopic ages of such shear zones are similar to the granulites and commonly show metamorphic zoning. Detailed kinematic studies show that movement of cratonic material was directed downwards adjacent granulite facies terrains, while granulites simultaneously moved upward. According to seismic data granulites form large bodies with shapes resembling that of a harpolith (harp – in Greek means sickle) similar in shape to some igneous bodies (Fig.4). Local mineral equilibria allow correct calculation of P-T paths for granulites and rocks from bounding shear zones. Harley (1989) suggested that the shape of a P-T path recorded in rocks of granulite facies terrains defines isobaric cooling (IC) or decompression cooling (DC) of a particular complex during its exhumation. This "tectonic rule" is, however, not correct. This conclusion is based on a comparable study of several granulite complexes that are very similar in their geology and petrology. The most exiting data obtained were for the Limpopo granulite facies terrains from South Africa (e.g., van Reenen and Smit, 1996; Perchuk et al., 1996, 2000) and the Lapland complex from the Kola Peninsula and Fennoscandia (e.g., Perchuk et al., 1999). Some authors (e.g., Treloar et al., 1992) also compare tectonic settings of the granulite complexes and adjacent cratons with a Himalayan type of continent-continent collision, while others (e.g., Barbey and Raith, 1990; Roering et al., 1992) proposed a full Wilson cycle (protolith deposited during plate divergence, granulite facies metamorphism and related nappe tectonic development through subduction and collision).

Both high-grade terrains are located among green stone belts. Crustal scale shear zones separate high-grade terrains from the green stone belts. Major mineral reaction (coronitic and symplectitic) textures occurring in metapelites of both the Limpopo and the Lapland granulite facies terrains are Grt+Qtz => Opx+Crd (Fig.1) and Grt+Qtz+Sil => Crd. Two typical retrograde P-T paths (Harley, 1989; Perchuk, 1989; Perchuk et al., 1989) that reflect isobaric cooling (IC) and common decompression cooling (DC) of the metapelites are recorded by these textures developed in rocks from both granulite facies terrains. The only difference is the location of these samples. The IC paths based on the Crd => Grt+Qtz+Sil (Fig.1) reaction texture are recorded in rocks collected near the contact of the granulite with the cratonic wall rocks, while the DC path is a common P-T trajectory for samples collected far from the contact.

This is characteristic for many studied granulite facies terrains: the majority of the Precambrian granulite facies terrains preserve evidence for both decompression-cooling and isobaric cooling regimes and strongly contradicts any collisional model. Some years ago we explained this feature from a kinematical viewpoint (Perchuk et al., 1996) while granulites move up to the surface, relatively cool metabasalts and metakomatiites move down and cool the granulite material along the contact shear zone. This causes change in direction of movement of some uprising granulite blocks towards the contact with craton and, as a result, record the IC path at a given level of the Earth's crust while other granulitic blocks ascent to the Earth's surface. Mineral growth (Fig.2) and equilibrium Grt+Bt+Ms+Qtz+Ky±Chl from the mica schists immediately adjacent to the granulite complexes have recorded P-T loops (Fig.3) that suggest circulation, i.e. convection within the relatively narrow portion of the sheared rocks immediately adjacent to the granulites. This circulation, caused by ascending granulite material, creates a narrow return flow into the shear zone. As a result the mica schists from the immediate contact with the granulites preserve textural and P-T paths are the only evidence for such a circulation (Figs.2 and 3). The method of numerical modeling (Newtonian flow) was used in order to test the gravitational redistribution mechanisms of exhumation and emplacement of the Precambrian high-grade terrenes within cratons (Gerya et al., 2000; Perchuk et al., 1992). The results clearly demonstrate systematic dipping of the greenstone wall rocks along the immediate contact with granulitic body up to about 15 km depth recording the metamorphic conditions (maximal P-T parameters) and coinciding with the rising IC granulites. The joint upward movement of both groups of rock to surface follows this stage (Gerya et al., 2000). Finally, granulites form crustal scale harpolithic bodies (Fig.4). The results of the numerical modeling further suggest that granulite facies terrains can be formed and exhumed within relatively thin, about 30-35 km thick continental crust due to the activity of mantle derived fluid-heat flow. Such a plume would trigger gravitational redistribution of material to exhume granulites to the upper portion of the crust in a period of about 10 Myr (calculated value, see Fig.4).

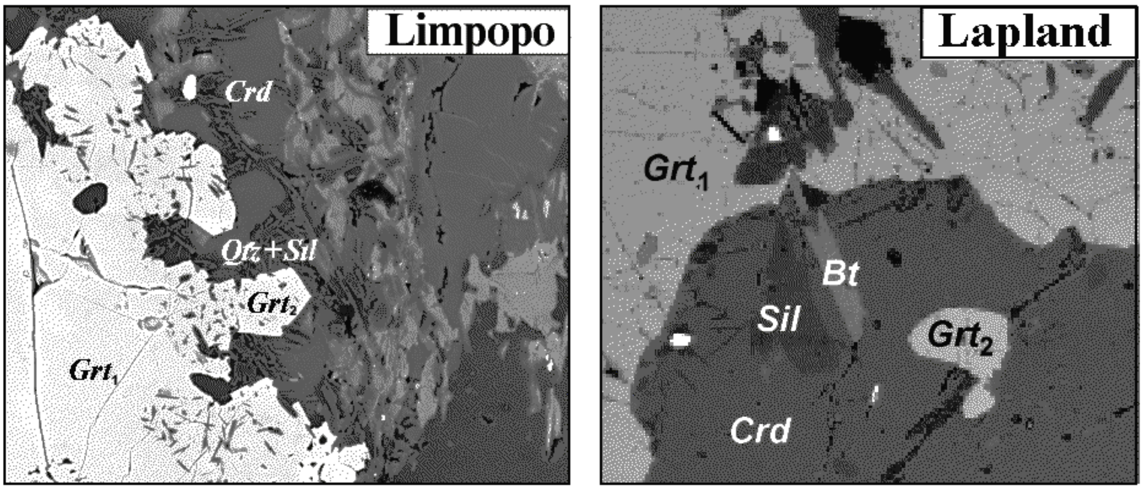

Fig.1. Typical reaction textures that occur in granulites from the Limpopo and Lapland complexes (Perchuk et al., 2000).

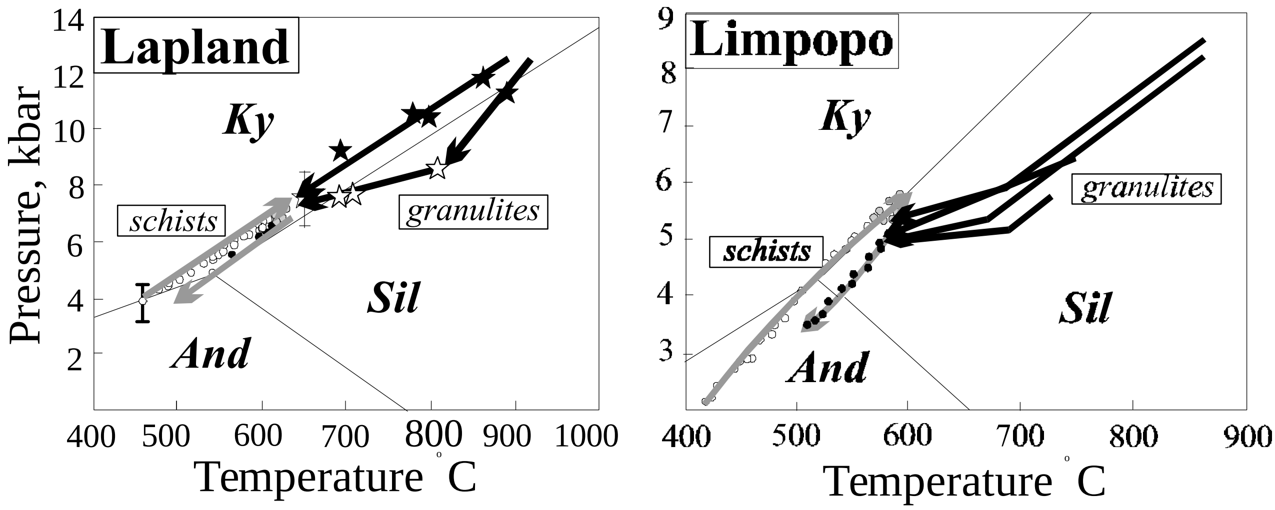

Fig.3. Junction of P-T paths for schists from shear zones in greenstone belts with immediately adjacent granulites from the Lapland (Kola Peninsula) and Limpopo (South Africa) complexes (Perchuk et al., 1996,2000; Perchuk and Krotov, 1998).

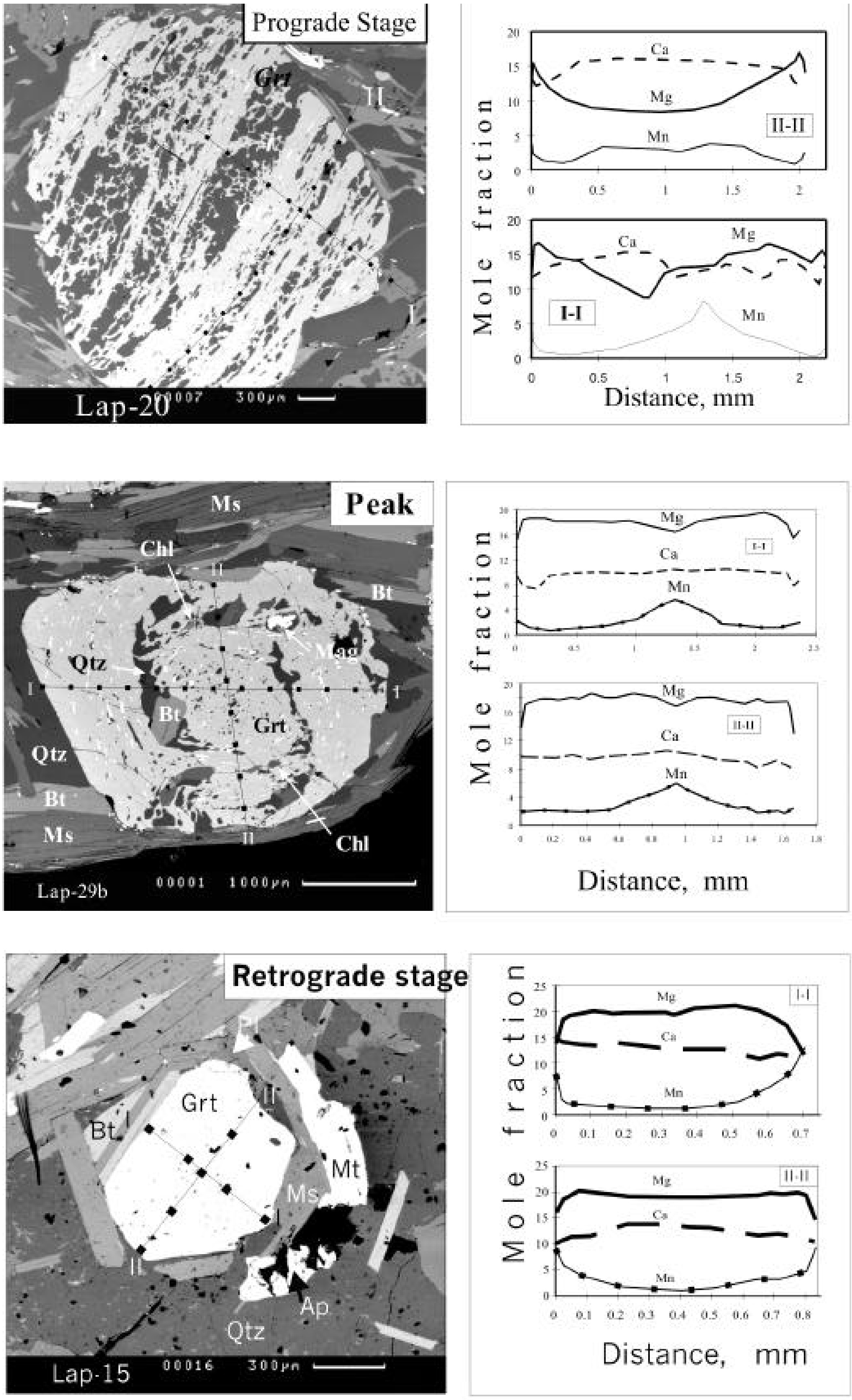

Fig.2. Main metamorphic stages recorded into textures and chemical compositions of garnet from mica schists that separate granulites from the Lapland complexes from the Karelian green-stone belt (Perchuk and Krotov, 1998)

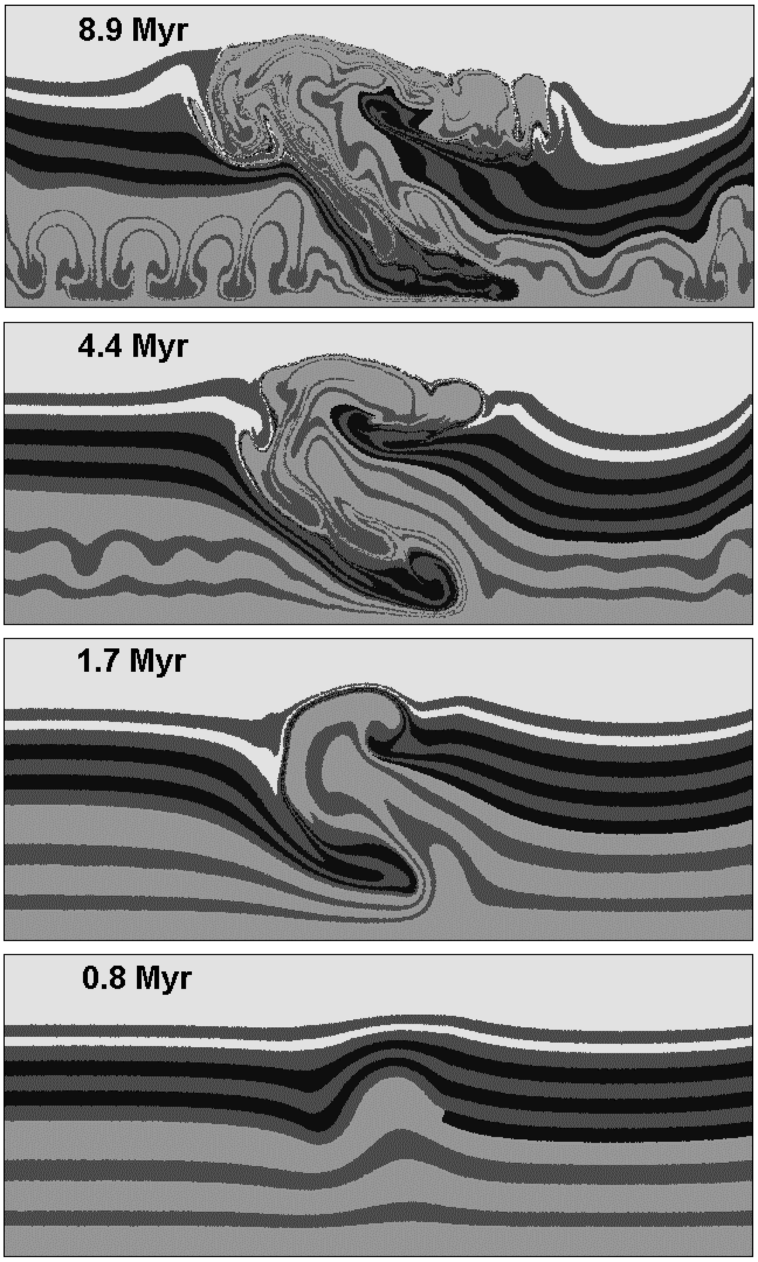

Fig.4. Results of numerical modeling of the upward movement of a granulite body (gray body) generated under lower crustal conditions and the downward movement of an upper crustal greenstone sequence composed of metakomatiites (black), metabasalts (dark gray), and sediments (white). The crust thickness is 35 km (Gerya et al., 2000).

References:

1. Barbey P, Raith M. (1990) The granulite belt of Lapland: In: Granulites and crustal evolution. In: Eds. Vielzeuf D., Vidal Ph. NATO ASI Series. Series C). Kluwer. Dordrecht, V.311, P.111-132
2. De Wit M.J., Roering C., Hart R.J., Armstrong R.A., de Ronde C.J., Green R.W.E., Tredoux M, Pederdy E., Hart R.A. (1992) Formation of an Archean continent. Nature, V.357, P.553-562.
3. Gerya T.V., Perchuk L.L., van Reenen D. D., Smit C. A. (2000) Two-dimentional numerical modeling of pressure-temperature-time paths for the exhumation of some granulite facies terrains in the Precambrian. Journal of Geodynamics, V.30, P.17-35.
4. Harley S.L. (1989) The origin of granulites: a metamorphic perspective. Gological Magazine, V.126, P.215-231.
5. Perchuk L.L. P-T-fluid regimes of metamorphism and related magmatism with specific reference to the Baikal Lake granulites. Evolution of Metamorphic belts. In: Ed. Daly S., Yardley D.W.D. and Cliff B. Geological. Society of London: Special Publication. 1989, V. 2(20), P. 275-291.
6. Perchuk L.L. (1991) Studies in magmatism, metamorphism, and geodynamics. International Geology Review. V. 33(4), P.311-374.
7. Perchuk L.L., Krotov A.V. (1998) Petrology of the mica schists of the Tanaelv belt in the southern tectonic framing of the Limpopo granulite complex. Petrology, V.6, P.149-179
8. Perchuk L.L. Krotov A.V. Gerya, T.V. (1999) Petrology of amphibolites of the Tanaelv Belt and granulites of the Lapland complex. Petrology. V.7(4), P.539-563.
9. Perchuk L.L., Gerya T.V., Van Reenen D.D., Smit C.A, Krotov A.V., Safonov O.G., Shur M.Yu. (2000) Comparable petrology and metamorphic evolution of the Limpopo (South Africa) and Lapland (Fennoscandia) high-grade terrains. Mineralogy and Petrology, V.69, P.69-107.
10. Roering C., van Reenen D. D. Smit, C.A. Barton J.M., de Beer J.H., de Wit M.J., Stettler E.H., van Schalkwyk J.F., Stevens G, and Pretorius S. (1992) Tectonic model for the evolution of the Limpopo Belt. Precambrian Research, V.55, P. 539-552.
11. Smit C.A., Van Reenen D.D., Gerya T.V., Varlamov D.A, Fed'kin A.V. (2000) Structural-metamorphic evolution of the Southern Yenisey Range of Eastern Siberia: implications for the emplacement of the Kanskiy granulite complex. Mineralogy and Petrology, V.69, P.35-67.
12. Thompson A.B. (1990) Heat, fluids, and melting in the granulite facies. In: Granulites and Crustal Evolution. In: Eds. Vielzeuf D., Vidal Ph. NATO ASI Series, Series C. Kluwer. Dordrecht. V.311, P. 37-58.
13. Treloar P.J., Coward M.J., Harris B.W. (1992) Hymalayan-Tibetian analogies for the evolution of the Zimbabwe craton and Limpopo belt: Precambrian Research, V. 55, P.571-587.
14. van Reenen D.D. and Smit C.A. (1996) The Limpopo metamorphic complex, South Africa: 1. Geological setting and relationships between the granulite complex and the Kaapvaal and Zimbabwe cratons. Petrology, V.4(6), P. 562-570.

This work has been carried out due to the Russian Fund for Basic Researches (grants N 99-05-65602 and N 00-15-98519 to LLP, N 00-05-64939 to TVG).