

# Chapter 28

## Deep Fluid Systems of Fennoscandia Greenstone Belts



A. A. Petrova, Yu. A. Kopytenko and M. S. Petrishchev

**Abstract** A study of the basement of Fennoscandia on magnetic and gravity anomalies has been carried out. There are detected magnetic and density features of the structure of the greenstone belts of the Early Precambrian crust of the Baltic Shield as a result of interpretation of CHAMP and GRACE satellite data and near surface magnetic anomalies. Magnetic and density sections have been constructed through the mega blocks of Fennoscandia with the age of the Earth's crust ranging from 3.2 to 1.6 billion years that underwent different stages of metasomatism. There are detected magnetoactive layer in the basement of the Early Precambrian crust ("magnetite zone") and fluid systems at depths of 12–15 and 25–35 km that are the source of the formation of rich deposits of Fennoscandia greenstone belts. Based on the concept of the distribution of fluid supply flows, there are selected several areas promising for electromagnetic monitoring that can help to detail the features of the basement conductivity of the Baltic Shield.

**Keywords** Magnetite zone · Fluid systems · Gold

### Introduction

The goal of this paper is to study the deep structure of the Fennoscandia region from geophysical data for solving a fundamental problem related to the nature of significant concentrations of ore substances and placers in a given area.

One of the important factors in the formation of gold deposits is the carrying out of high-quality concentrates of relics of the Precambrian basement by fluid flows of mineralized aqueous solutions supplied from deep-focus fluid systems. Migration of

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deep fluid plays a huge role in the location of mineral deposits and determines the location of gold ore objects.

In this regard, special attention is paid to the following tasks:

- the allocation of blocks of the pre-Riphean basement as possible sources of formation of rich gold deposits;
- mapping of channels of thermofluid flows, carrying out the carrying out of high-quality concentrates, supplied from deep-focus fluid systems;
- detection of the location of deep fluid systems;
- searching of buried troughs, which are the ore-generating structures that have their own geochemical specialization and metallogeny.

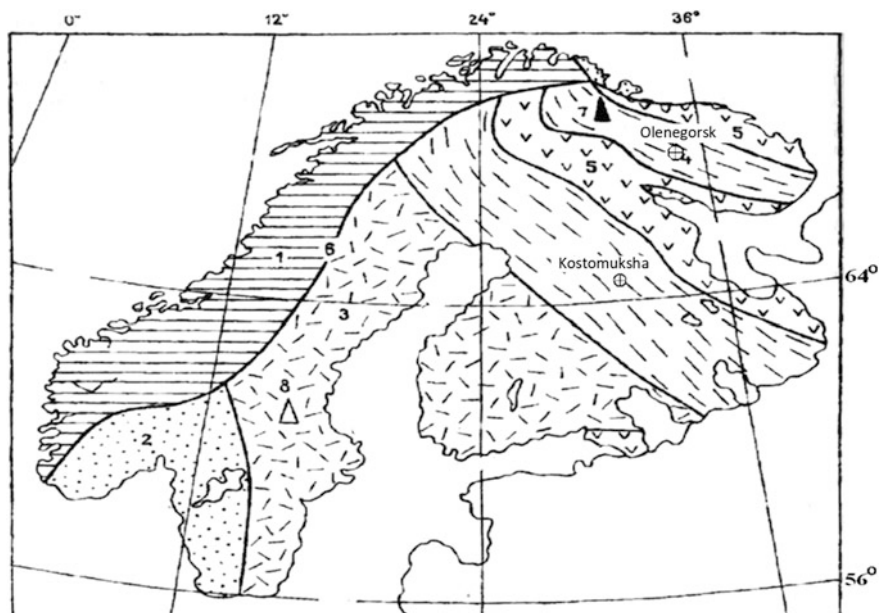
There are creating favorable conditions for the formation of the primary deposits and the accumulation of large gold-bearing placers near such zones of increased fracturing in the places of approaches to the surface of fluid flows. The rich gold deposits of the study area are the result of the carrying out of high-quality Archean concentrates by fluid flows under the pulsating influence of deep-focus fluid mantle systems.

## **Investigation of the Basement by Magnetic and Gravity Anomalies**

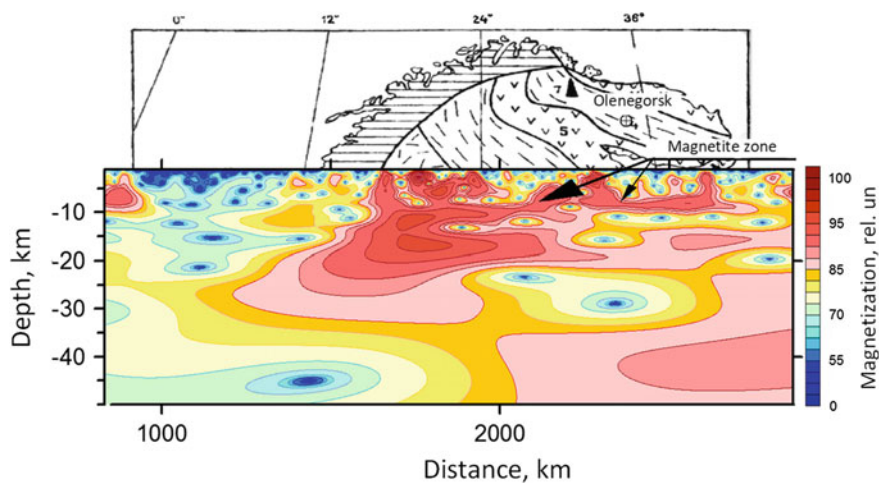
Investigations of the deep structure of the Early Precambrian Earth's crust of Fennoscandia have been made on the basis of near-surface air and hydromagnetic measurements, magnetic anomalies from CHAMP satellite and gravity anomalies in the Fay reduction obtained using the GRACE altimetry (International Centre; Kaban and Reigber 2005; Korhonen et al. 2007; Kopytenko and Petrova 2014, 2016; Mayer-Gürr et al. 2014).

The visualization of heterogeneities in the Early Precambrian crust of the Baltic Shield in the form of geophysical sections made it possible to clarify the concept of the deep crustal structure with an age of 3.2–1.6 billion years, which underwent different stages of metasomatism (Fig. 28.1). Magnetic and density sections are performed by the method of spectral-spatial representation of fields that are convertible into the deep sections (Petrova 1976, 2015; Kopytenko and Petrova 2016; Hahn et al. 1976; Petrishchev et al. 2014; Litvinova et al. 2014).

Ore-generating processes determine the regularity of the location of the magnetite layer in the Early Precambrian Earth's crust. Studies have shown that it is allocated along the lower boundary of the zone of regional granitization along the boundary of the granite and granulite-basite layers. Deposits presented by the iron ore formation of the Archean magnetite quartzites form as a result of the granitization process of magnetite formation. Magnetic sections crossing the megablocks of the Baltic shield made it possible to visualize a magnetoactive horizon underlying the bottom of the granite layer in the foundation of the Early Precambrian Earth's crust (Fig. 28.2).



**Fig. 28.1** Age characteristics of the Earth's crust of the Baltic Shield: 1—caledonites (PZ); 2—dalclandides (R); beetrofenides ( $PR_1^1-PR_1^2$ ); 4—Karelides ( $AR_1^1-PR_1^2$ ); 5—Lapländides and White Seabelomorides ( $AR_1^1-PR_1^2$ )

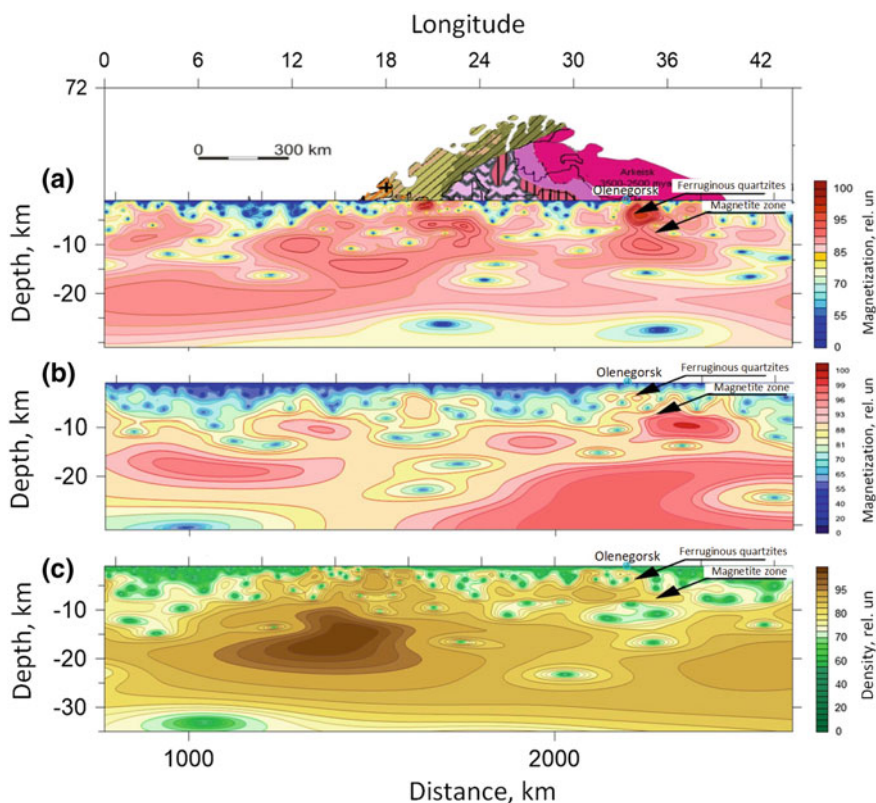


**Fig. 28.2** Magnetite zone in the magnetic section of the basement

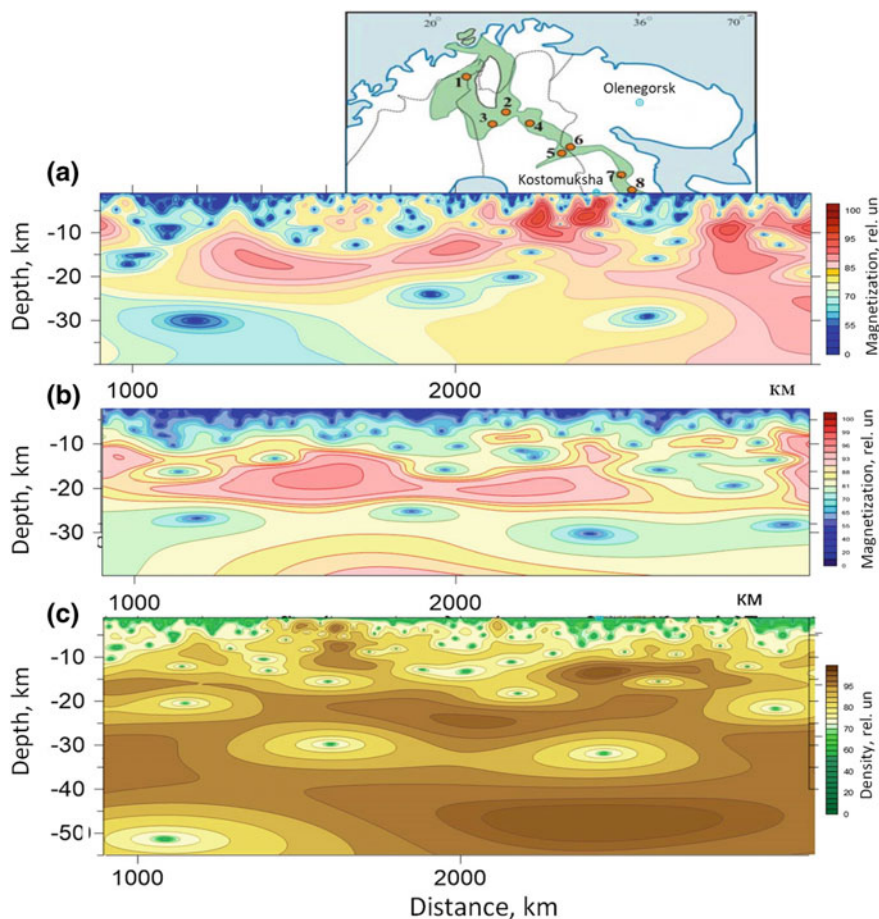
Mineral deposits in the Early Precambrian Earth's crust are formed in greenstone belts where they are manifested in the form of deposits of ferruginous quartzites of sedimentary-volcanogenic genesis. Large-scale deposits of Kostomuksha and Olenegorsk are known on the Baltic Shield (Fig. 28.1). The iron content in the ore bodies of these deposits of ferruginous quartzites is 20–45%, in the weathering crusts of ore bodies—up to 55–70%.

Anomalies of the magnetic field is played the main role in the investigation of iron ores of the Kostomuksha deposit. This is due to the high magnetization of magnetite-bearing ferruginous quartzites, as well as the contrast of the magnetic susceptibility of the investigated ferruginous-siliceous rocks and their host complexes. In addition, magnetite quartzites and magnetite schists have a high density reaching 3.5–3.7 g/cm<sup>3</sup>, so the interpretation of the anomalies of gravity supplements magnetometric studies, allowing a more accurate trace of iron ore horizons.

We have also interpreted magnetic anomalies and gravity anomalies for tracking of iron ore horizons at depth. We have completed deep magnetic and density sections through Olenegorskoe (Figs. 28.1 and 28.3) and Kostomuksha (Fig. 28.1 and 28.4) iron ore deposits.



**Fig. 28.3** Magnetic (a, b) and density (c) section through the Olenegorsk iron ore deposit



**Fig. 28.4** Magnetic (a, b) and density (c) sections through the Kostomuksha iron ore deposit

Visualization of the correlation of density and magnetic inhomogeneities on the deep sections provides the basis for the formation of a new concept of the geodynamic regularities of the development of greenstone belts. Analysis of density sections has been showed that the greenstone belt of Fennoscandia tends toward blocks with a decompressed mantle. Interpretation of deep magnetic and density sections of the Earth's crust has been allowed to test the hypothesis of the genesis of deposits of archean ferruginous quartzites emerging on the surface from the magnetite zones of the granite layerbasement. It was confirmed by the deep sections that the "magnetite zone" can be a source of formation of rich deposits of ferruginous quartzites in the tectonic structures of greenstone belts (Figs. 28.3 and 28.4).

Magnetite zones are the source of the formation of rich iron deposits and noble metal ores. Sharing the anomalies of the vertical and horizontal components of

the Earth's magnetic field has been allowed to delineate the location of the magnetite zones, which is of great importance for the search for promising deposits.

## **Identification of Fluid Systems and Zones of Fluid-Magmatic Metasomatism in the Earth's Crust of the Greenstone Belt of Fennoscandia**

There are known the occurrence of gold-platinum-metal mineralization in ferruginous quartzites in the greenstone belts of Fennoscandia (Kostomuksha ore region 2015). Geological and structural features of gold ore occurrence of the Kostomuksha region treat the genesis of ores formed as a result of regeneration and redeposition of ore matter as hydrothermal. We have obtained the ideas on the deep features of the gold ore zone based on the interpretation of the anomalies of the vertical and horizontal components of the Earth's magnetic field. Analysis of density and magnetic sections has been allowed to identify the main features of the deep structure of these zones and to reveal specific features of gold ore mineralization for detection of new promising areas.

One of the most important factors in the formation of gold deposits are deep fluid flows of mineralized aqueous solutions supplied from depths of more than 15 km by deep focus tectonic zones from high-quality Archean concentrates. On the density and magnetic sections, the migration paths of the deep fluid streams are reflected in the form of weakly magnetic supply channels of reduced density (Fig. 28.4). Fluid-supply channels are arising under the influence of an ascending heat flow and fluids rising along faults from great depths and diverging in the upper part of the crust into separate streams. There is a directed transformation of rocks inside the channels, changing their physical properties, including magnetic and density.

The migration routes of fluidized hot streams are traced on geomagnetic and density sections in the form of through weakly magnetic tracks of reduced density. Fluid-saturated stream are rising from the depths of 15–30 km, dividing into separate streams near the day surface. Analyzing the ways of fluid ascent to the surface, it can be assumed that the bulk of the fluidized flow of the Kostomuksha deposit rises, mainly from the south-west direction, from a depth of more than 20–25 km (Fig. 28.4). Since the magnetization of geological formations is more dependent on temperature than other parameters of the medium, such as porosity, fracture and fluid saturation, the migration paths of fluids are most clearly traced on magnetic sections (Fig. 28.4a). Figure 28.2 shows that in the Kostomuksha region the fluid system appears in the vertical (Fig. 28.4a) and horizontal (Fig. 28.4b) components and is located in the depth range from 15 to 28 km. It underlies the magnetite layer, which is the source of the iron ore deposit.

At the magnetic and density sections to the East of Kostomuksha, the migration paths of mineralized streams from the fluid system are reflected in the form of



weakly magnetic supply channels of reduced density (Fig. 28.4). They are confined to the gold ore troughs (1–8) of greenstone structures (Fig. 28.4a) and capture the northern part of another powerful fluid system south of Belomorsk. There it manifests itself in a magnetic section in the form of three lenses located in the depth interval from 15 to 35 km.

The conducting channel can be clearly seen in the magnetic and density sections. It reflects the trajectory of streams of mineralized fluids, which gradually form deposits with gold ore and copper mineralization in the greenstone structures of the Shombozero, Lekhtinsky and Chirko-Kemsky troughs (Kostomuksha ore region 2015).

Fluid streams, interacting with metamorphosed strata, lead to the formation of gold ore mineralization in the structures of the greenstone belts. Visualization of deep sections is allowed to estimate the depth of occurrence and reveal the location in the Earth's crust of fluid systems and the zone of fluid-magmatic processing of Archean rocks by streams of mineralized fluids forming ore deposits of the structures of the greenstone belt of Fennoscandia.

The ore fields and deposits of Precambrian gold in all known cases are spatially associated with extended systems of deep faults, and the faults themselves usually play the role of fluid and ore-supplying channels. We have revealed the fluid-conducting pathways of the outlet of mantle streams based on the results of an analysis of the distribution of magnetic and density inhomogeneities in deep sections in the basement of the greenstone belt Fennoscandia (Figs. 28.3 and 28.4).

The decomposition of sulphide minerals is happen at one of the last stages of the hypergene-metasomatic process and the release of previously-contained noble metals occur in them. An additional increase in gold in the ore deposition zone is introduced by hydrothermal solutions during the activation of riftogenic structures. At the same time, platinum-metal ore mineralization tends to high-temperature processes, and the formation of gold—to lower-temperature processes.

The development of a geological-genetic model for the formation of noble metal mineralization in ferruginous quartzites will make it possible to determine the role of endogenous processes in its formation. It is possible that in the tectonic structures of greenstone belts the “magnetite zone” is the source of the formation of deposits of ferruginous quartzites and the accompanying noble metal mineralization.

The “magnetite zones” of the continents are of exceptional interest for studying the deep structure of the Earth's lithosphere. Manifested in the anomalies of the magnetic field at temperatures below 560 °C, they indicate the thermal regime of the formations of the ancient crust of the continents and trace the position of the deep boundary of the Curie surface. The study of the Early Precambrian crust forming the basement of ancient continents allows us to approach the evaluation of its deep structure at a real level and show that regional magnetic anomalies reflect the influence of “magnetite zones” occurring at depths of more than 10–15 km along the boundary of granite and granulite-basite layers.

## Discussion and Conclusions

We have studied the features of the structure of the ancient blocks of the Doriphean basement, deep fluid systems and fluid supply channels. Hydrothermal study of ancient Precambrian complexes in areas of fluid-magmatic activations manifests itself in the form of deep minima of magnetic anomalies. For example, the traces of fluid-magmatic activations are clearly manifested in the minima of the magnetic anomalies of the horizontal component of the Earth's magnetic field, emphasizing the hydrothermal genesis of gold ore objects. The zones of fluid magmatic activations and intense fluid flow are manifested in the minima of the magnetic field. Magnetic anomalies of the Earth's magnetic field module made it possible to identify zones of deep thermofluid processing that affect younger rocks.

Ways of migration of heat fluxes, fluids and the location of fluid systems can be clearly seen on deep sections in the form of channels and lenses of reduced density and magnetization. The location of fluid channels and terrestrial systems can be estimated from magnetic and density sections. In the lower crust and in the mantle, where the rocks are in a demagnetized state due to high temperatures (more than 560 °C), the location of deep-focus fluid systems is estimated from density depth sections.

Faults are reflected in the form of block boundaries that differ in physical characteristics. Inside the weakened layers that are located in the fluid channels are appeared the weakly-magnetic low density lenses. The trajectory of a deep fault that passes through the Earth's crust to the mantle is traced through a chain of low density lenses. The migration routes of mineralized streams are manifested as weakly magnetic feed channels and lenses of reduced density.

Our studies have been shown that injective dislocations associated with the penetration of deep matter into the Earth's crust led to the decomposition of its matter in vertical fault zones. As a result, powerful subvertical ore-bearing magma-metasomatic columns with a length of 3–8 km arose. Favorable conditions for the continuous circulation of ore-bearing solutions and subsequent ore deposition are created due to the presence of resistive horizons overlapping large ore-bearing highly permeable near-fault zones at depths of 2.5–3 km.

Vertical thermofluid flow, rising along the fault zones of the basement, creates favorable conditions for the formation of large ore-bearing columns and above them—promising gold ore sites. Prospective areas are located above the gold columns in the ore sites. Magmatic processes were accompanied by metasomatic phenomena with the formation of ore-metasomatic columns with a length of up to 8 km in magmatic-fluid systems of the near-fault zones.

Deep density sections showed that the endogenous processes and the mining of the examined gold ore deposits are most likely due to the prolonged impact of multiple stages of tectonic magmatic activation of deep sources—thermal and fluid—on rocks enclosed in zones of subvertical faults of the upper crust.

Thus, we have presented the new ideas of the stratification and vertical crumbling of the Earth's crust, taking into account the features of the influence of factors



of depths. It is based on the usage of original technology of interpreting the complex of geophysical data—module anomalous magnetic field, the horizontal component of the magnetic field and gravity field anomalies. The application of the original technology reveals new possibilities for studying the deep structure of the lithosphere and the search for criteria for the localization of mineralization. This has made it possible to clarify the prospects of gold mining in the area and recommend exploratory work on potentially ore-bearing areas above the outlets of vertical channels.

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