# GEOTHERMAL FIELDS IN THE NORTHERN EUROPEAN CONTINENT

**Lev A. Tsibulya**

Geologic Institute of Kola Science Center of the Russian Academy of Sciences. 184200 Apatity, Russia

## ABSTRACT

This research aimed at revealing positive temperature anomalies and geothermally promising regions. **A** heat flow density map **of** the region has been compiled to show the energy states **of** certain geologic blocks and tectonic zones. The temperature anomalies have been found to be related to deep structure, current geodynamic processes and direction of fluid movement. Regions characterized by increased geothermal activity, which is mostly associated with ascending movement of **fluids,** have been outlined.

Key words: heat flow, temperature, geologic structures, convective heat and mass transfer.

## Introduction

Identifying sources of geothermal energy in the Northern European continent is a crucial task not only from an economic but also an environmental point of view. Economic development of the Arctic and the growth of oil and gas industry on the Arctic shelf have brought up a necessity to search for geothermal energy sources not only on the continent but also on the islands and shelf of the Arctic seas. Therefore, geothermal investigations have been camed out on the islands and continental shelf. *Assuming* that geologic structures and temperature anomalies on the continent and islands continue under the sea, we consider it reasonable to discuss the anomalies and their subaqueous extension together

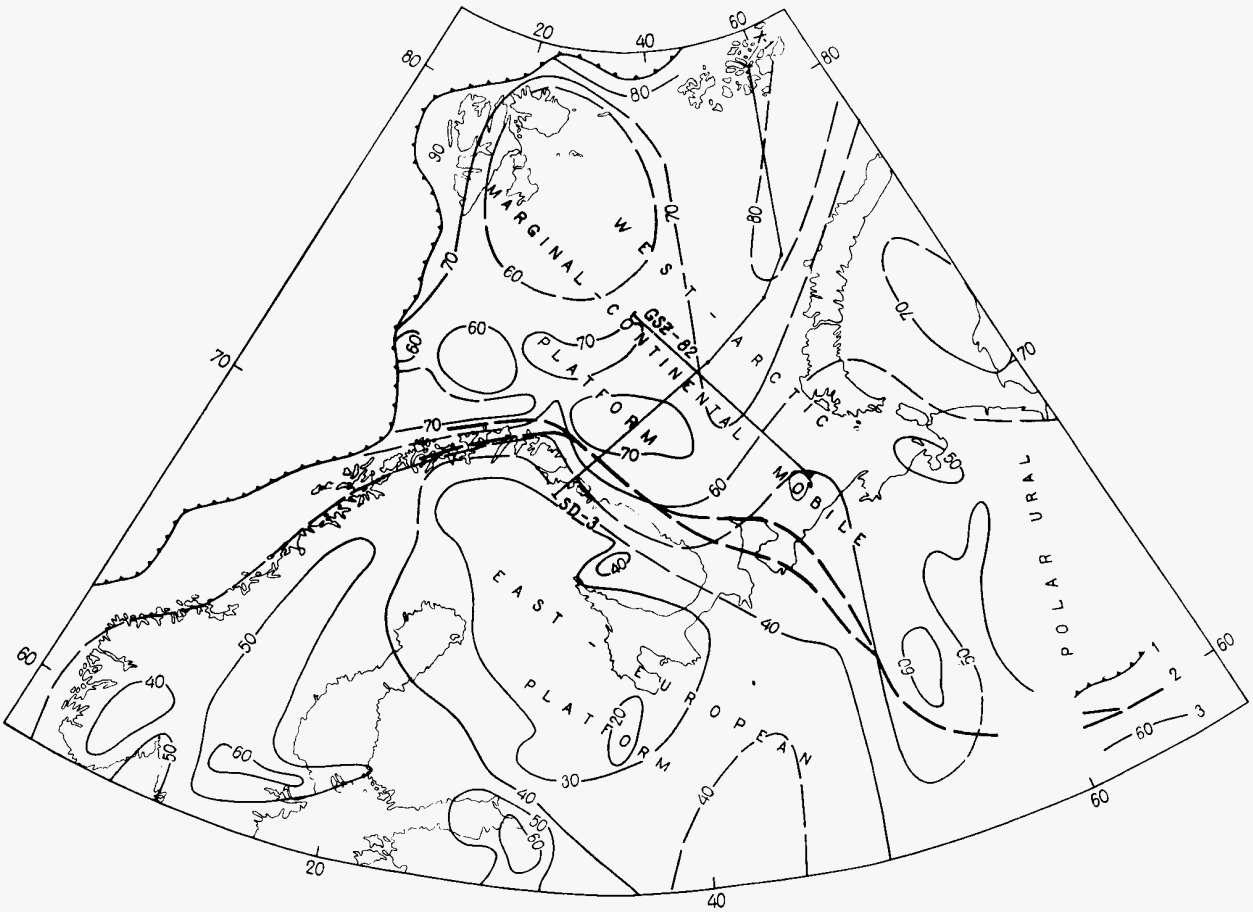



Fig.1. Heat flow map of the North of the European continent. 1- boundary of continental slope; 2- platform boundary; 3- HFD isolines, in mW/m$^2$. SD-3 — **X-** 1 and GSZ-82 - profiles shown in Fig.3 & **4.**

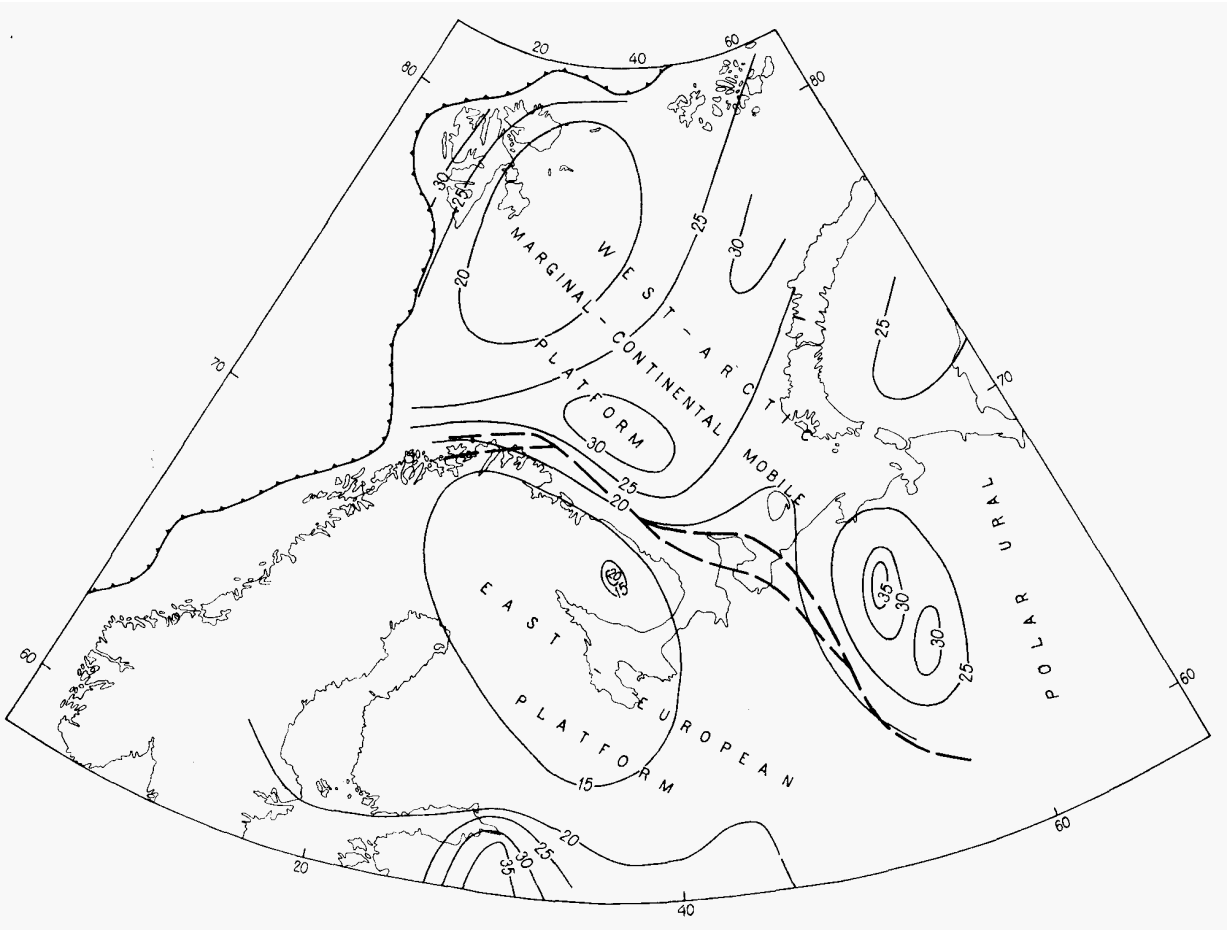



Fig.2. Schematic map of temperature (in °C) at a depth of 1 km. For other symbols see Fig. 1.

in order to produce a more complete geothermal zonation and prediction of geothennal field.

## Techniques and data employed

Geothermal data obtained by the Geologic Institute of Kola Science Center in the European sector of the Arctic (Tsibulya and Levashkevich, 1992) were used. They include heat flow density (HFD) values and temperatures measured in deep and engineering drill holes on land and off-shore, and HFD values obtained in bottom sediments on the Barents Sea shelf by a specially developed method. The method is based on measuring a vertical temperature profile by thermal probing and correcting for non-steady state of temperature regime of the bottom (Tsibulya and Levashkevich, 1992). Thermal probing is combined with geochemical studies to enable a less ambiguous interpretation of temperature anomalies related with vertical heat and mass movement.

Geothermal data obtained by other researchers (Chermak and Rybach (Eds), 1979; Gordienko *et al.,* 1987; Geothermal Atlas of Europe, 1991-1992; Crane *et al.*, 1991) and irifonniation on geologic structures of the region (Senin *et al.,* 1988; Belousov *et al.,* 1991) were also employed.

## Results

Heat flow density is the **most** informative parameter characterizing energy state at depth. HFD in the region under consideration varies from 20 to 80 mW/m$^2$ (Fig.1). Elevated HFD values (50-80 mW/m$^2$) are typical of northern and northeastern regions of the West-Arctic continent-margin mobile platform. In some localities of the Platform HFD reaches 90 and in places over 100 mW/m$^2$.

Lower HFD values (20-50 mW/m$^2$) are generally found in the East-European Platform, although some areas have increased HFD exceeding 60 mW/m$^2$. The most extensive and best determined fields of increased surficial heat flow are reported from the zone outside the southern margins of the Baltic Shield. On the Shield, positive anomalies are of local nature and have not been properly studied.

Zones of increased HFD are considered to be promising areas as thermal sources. Temperatures in these zones at different depth levels are also higher. For example, at a depth of 1 km the temperature in these zones is 10-20°C higher than in the regions with moderate and low HFD. In the region as a whole, the temperature at a depth of 1 km ranges froni 15 to 35°C (Fig.2). Maximum temperatures at depths of 2 and 3 km in zones of increased HFD are 68 and 106°C, respectively.

The geothermal gradient on average varies from 10 to 40 mK/m. It depends mostly on HFD and, to a lesser extent, on heat conductivity in different of rocks. The average heat conductivity in different parts of the section does not show a considerable variation, nor significantly influence the temperature field refraction. In several cases, the geothermal gradient is markedly affected by fluid movement, and this is reflected in the contours of thermograms.

## Discussion

Positive temperature anomalies of HFD over 60 mW/m$^2$ are found predominantly within the West-Arctic continent-margin mobile platform. This is a result of the platform

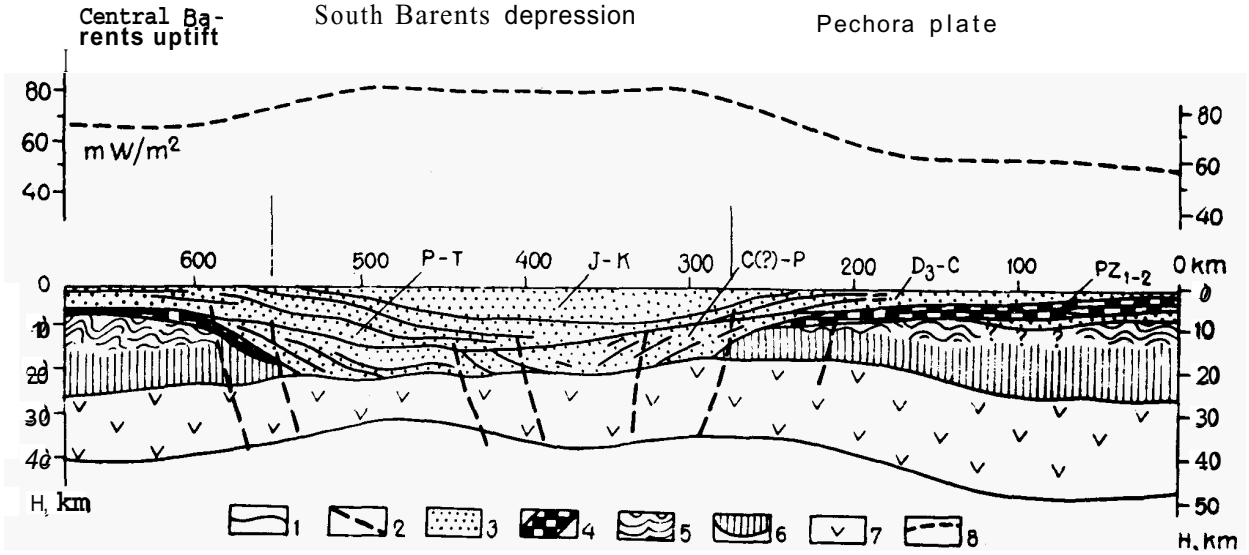



Fig.3. Geological section of the crust (Belousov *et al.,* 1991) and heat-flow density in the South-Barents depression along GSZ-82 Profile **DSS** (See Fig.1). 1- contours of geologic complexes; 2- faults. Platform cover complexes: 3- terrigenous, **4-** carbonate; 5- folded basement; 6- granite-metamorphic layer; **7-** lower high-velocity ("basalt") layer; 8- heat-flow density level.

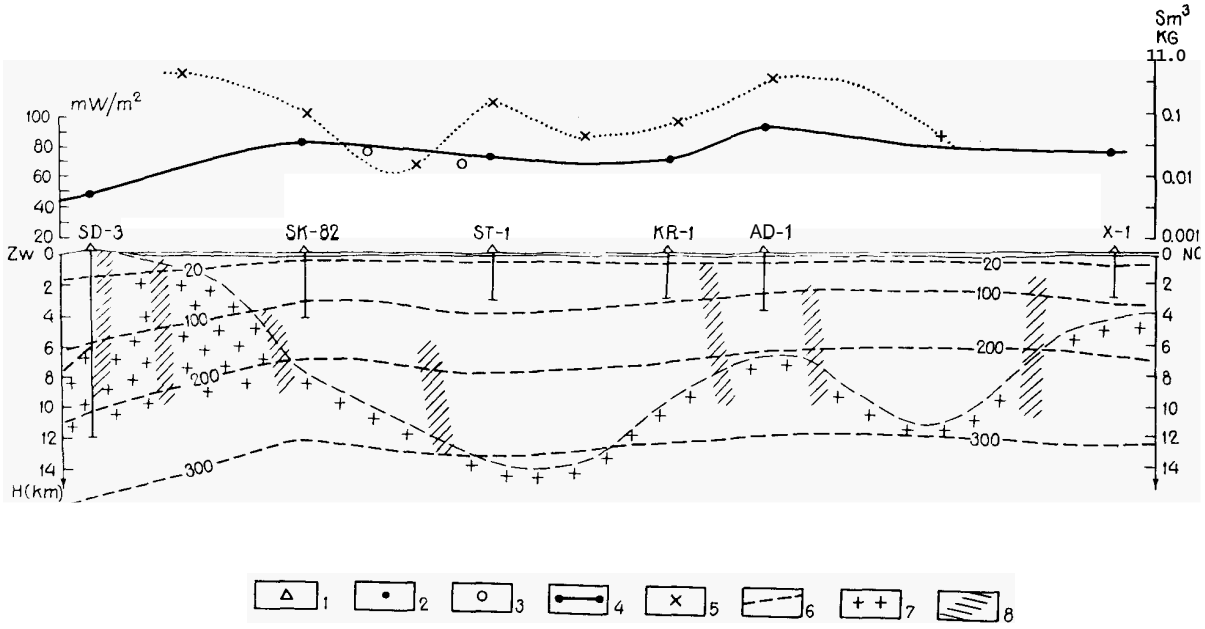



Fig.4. Schematic geologic-geothermal profile Kola Peninsula- Franz Josef Land (See Fig.1). 1- deep drill holes. Factual data on heat flow: 2- in drill holes, 3- in bottom sediment, **4-** heat-flow density level; 5- methane content in bottom sediments; 6- isotherms in °C; **7-** basement; 8- faults.

structure, the presence of highly permeable unconsolidated zones, and processes of Meso-Cenozoic tectonic-magmatic and fluid-dynamic activation caused by the formation and development of the Arctic Ocean's geodynamic system (Senin *et al.,* 1988). The most contrasting positive anomalies are revealed in the Nordkap-Hammerfest trough system and in the East-Barents and Pechora megadepressions. In the zones of positive anomalies confined to these structures, there are areas with uplifted Moho interface, where the thickness **of** platform cover is increased and that of the granite-metamorphic layer is decreased (Fig.3). High values **of** surficial heat flow in areas with anomalous crust testify to an increased activity of lower-crustal and upper-mantle layers. At the modem state of development, these structures can be considered as degrading mantle heat windows.

The basement depth does not significantly influence the HFD field pattern. But the basement relief determines the direction of groundwater movement in artesian basins, which finds its manifestation in the surficial heat flow and temperature distribution in the cover (Fig.4). *An* increase in

HFD and temperature in the area of the Admiralteisky High (hole AD-1) is related to ascending movement of water. This is supported by the results from hydrogeologic studies.

Fluid-dynamic processes in highly permeable zones also result in the formation of positive temperature anomalies in the East-European platform. For example, in the area of ring-type Khibiny alkaline massif on the Kola Peninsula, there have been observed 20°C water kicks in drill holes. HFD in the massif exceeds background values, which is explained by radiogenic heat generation in the crust, rather than by residual effects of tectonic-magmatic activation.

Intense positive temperature anomalies are observed outside the southern margins of the Baltic Shield, in the area of the Baltic geosyncline. The development of these anomalies is related **to** faulting and fluid-dynamic processes, however, the influence of tectonic-magmatic activation cannot be ruled out. Possibly, the entire area outside the margins of the Baltic Shield, except **for** its eastern segment where positive temperature anomalies are absent, is characterized by analogous temperature anomalies.

summary

In the North ***of*** the European continent, geothermally promising regions are associated with zones of positive temperature anomalies, where HFD exceeds 60 $mW/m^2$ and contrasting variations of heat flow related to increased fluid-dynamic activity are recorded. They are confined mostly to geologic structures of the West-Arctic Platform. On the continent and islands, such zones are found in the Pechora basin, Franz **Josef** Land Megablock and western Svalbard. In the East-European Platform, the geothermally promising zones are concentrated around the Baltic Shield.

## REFERENCES

Belousov, V.V., Pavlenkova, N.I., and Kvyatkovskaya, G.N. (Eds.). (1991). ***Deep Structure of the USSR territory.*** Moscow, Nauka. 224pp.

Chermak, V. and Rybach, **L.** (Eds.) (1979). ***Terrestrial Heat Flow in Europe.*** Springer-Verlag, Berlin-Heidelberg-New York. 376pp.

Crane, **K.,** Sundvor, E., Buck, R. and Martinez, F. (1991). Rifting in the Northern Norwegian-Greenland Sea. Thermal test of asymmetric spreading. ***Geophysical Res. J.,*** Vol.96(89), pp. 14529-14550.

Geothermal Atlas of Europe. (1991-1992). Hurtig, E. (Editor-in-Chief). *Hermann Haack Verlagskgesellschaft mbH. Geographisch-Kartographische Anstalt Cotha.*

Gordienko, V.V., Zavgorodnaya, O.V., Moiseenko, U.I. and Smyslov, AA. (1987). ***Heat Flow Map of the European Part of the USSR (1:5000000). Explanatory Note.*** Leningrad, VSEGEI. 35pp.

**Senin,** B.V., Shipilov, E.V. and Yunov, A.Yu. (1988). ***Tectonics of the Arctic Continent-Ocean Transition Zone.*** Murmansk. 176pp.

Tsibulya, **L.A.** and Levashkevich, V.G. (1992). ***Terrestrial Heat Flow in the Barents Sea Region.*** Apatity, KSC Rus.Ac.Sci. 115pp.