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Geothermal Atlas of Lithuania

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ABSTRACT

Geothermal resources for Republic of Lithuania are assembled in the recently completed Geothermal Atlas of Lithuania. The atlas consists of a set of 33 maps. Tectonic Map of the Baltic States (Suveizdis et al., 1991) has been used to compile the Geothermal Map of Lithuania. Isogeotherms of the crystalline basement are shown on the map. The connection of pre-platform tectonic zones with intensity of present thermal field shows up; especially it is pertain to Taurage-Ogre and Nemunas zones, West Lthuania. The thermal field extremely varies within Telsiai fault zone, West Lithuania. Zoning of geothermal field was carried out, and three zones were distinguished and characterized.

The geothermal map set includes 4 maps of tops and bottoms of two Devonian (D_2up-D_3šv and D_1tl-D_2pr) hydrothermal complexes; map of Cambrian hydrothermal complex. Maps show variation of temperature within top and bottom of the complex. Isogeotherms are drawn by every +10 °C.

The structural map set consists of 4 maps of tops and bottoms of two Devonian (D_2up-D_3šv and D_1tl-D_2pr) hydrothermal complexes; map of Cambrian hydrothermal complex.

Nine maps intended to show thickness of complexes, thickness of porous intervals and average porosity of them. Thickness maps of Devonian (D_2up-D_3šv and D_1tl-D_2pr); and Cambrian; Productive thickness maps of Devonian (D_2up-D_3šv and D_1tl-D_2pr) and Cambrian; Porosity maps of Devonian (D_2up-D_3šv and D_1tl-D_2pr) and Cambrian.

Seven maps show hydrochemical properties of the thermal water. Two parameters to characterize thermal water were chosen: total mineralization (g/l) and bromine content (mg/l).

Two maps featuring a temperature at 100 m depth and geothermal gradient throughout sedimentary cover: geothermal gradient map of Lithuania and map of temperature at 100 m depth in Lithuania.

Four maps intended to the geothermal potential of Lithuania: Maps of geothermal resources of Devonian (D_2up-D_3šv and D_1tl-D_2pr) and Cambrian as well map of petrogeothermal resources down to 7 km depth in Lithuania.

1. INTRODUCTION

Lithuanian, as entire Earth's subsurface, has unfailing geothermal energy resources. It is to be accepted that geothermal characteristics of Lithuanian geological section is underestimated and is reasonless quite pessimistic appreciable by energy specialists. The compiled Geothermal Atlas of Lithuania partly fills the existing gap.

2. STATE OF EXPLORATION

Geothermal research activities have begun in Lithuania in 1988 and during the last decade they were particularly broadened (Povilas Suveizdis was initiator of these activities). West Lithuanian geothermal anomaly was distinguished and its general features, its predictive prolongation to the Baltic Sea described. Regional hydrothermal complexes within the sedimentary cover distinguished, their main features estimated as well geothermal resources. Scientific research was crowned with practical works – two geothermal wells have been drilled out in Vydmantai. Well Vydmantai-1 is the deepest one in Lithuania – 2564 m and providing a lot of new information to science. In 1992, the Baltic geothermal project was began to carry out founding by Danish Environment Protection Agency (Supervisor of work Lars Tallbacka). As result of this study, Klaipeda Geothermal Demonstration Project was launched. Four geothermal wells were drilled out in Klaipeda and a geothermal demonstration district heating plant was built. It can supply heat for third of town's users. German company Geothermie Neubrandenburg in 1995-1997 carried out Vilkaviskis balneological geothermal project and geothermal studies for Vydmantai and Silute.

In 1996, Lithuanian energy system had order from the European Union – to prepare a geothermal map set of Lithuania for the Atlas of geothermal resources of European Union states. The order has been made by Lithuanian company "Geoterma".

Geothermal resources of Lithuania down to 5 and down to 10 km depth were estimated by techniques of St. Petersburg Institute of Mining (Dadkin, Vaynblat, Boguslavskiy (1989)). The geothermal resources were estimated for Cambrian, Lower-Middle Devonian and Middle-Upper Devonian hydrothermal complexes using above-mentioned techniques in 1996.

Research and generalization of Cambrian rocks and fluids of the Baltic States was carried out in 1997-2000. Work had support from German Government. It shows the importance and necessity of geothermal research.

Actual data for the compiled atlas were collected from geological reports presented by the Geological Archive of Lithuanian Geological Survey and geophysical thermal measurements data was taken from thermal logs.

2.1 Tectonic-structural Location of Lithuania

From the tectonic-structural point of view, Lithuanian territory is fairly complicated part of the Earth‘s crust in the western margin of the East-European platform. The Baltic Craton covers the largest area – a syneclise and its slope. In the eastern margin of Lithuania and in the southeast, the positive structure - Belarus-Mazurian crystalline massive - anteclise is distinguished. Latvian Saddle occupies north eastern part of territory.

2.2 Stratigraphical-lithological Features of the Geological Succession

Rocks of the crystalline basement (hot dry rocks) occur under sedimentary cover and can be reached only by boreholes. They are plunged to 1000-2200 m depth in the Baltic syneklise, 600-1000 m depth in Baltic syneklise slope, -700 – -900 m depth Latvian saddle, and 50-600 m – in Belarus-Mazurian anteklise.

The crystalline basement consists of intensively dislocated complexes of sedimentary-metamorphic and igneous rocks (Lietuvos geologija (1994)).

Rocks of the sedimentary cover are relatively little dislocated and characterized by variety of lithological composition. Lithological composition is very important to heat distribution and thermal field formation within sedimentary cover. Thermal properties of the rocks conditioned by their lithology, mineralogical-petrological and grain size composition. Variations of layers of the rocks with different lithology and thermal properties as well with different thickness, and anisotropy of rocks manifest by variations of geological geothermal parameters and anomalous heat distribution within local structures.

Palaeozoic group. Palaeozoic group consists of rocks of Cambrian, Ordovician, Silurian, Devonian, Carbon and Permian systems in Lithuania. These are terrigenous, terrigenous-carbonate, carbonate and chemogenic rocks. The common thickness of them is more than 2200 m. The main part of section (1000 m) and outspread consists of Silurian rocks. Devonian rocks also compound more than 900 m of section.

Mesozoic group. In Lithuania, this group consists of rocks of Triassic, Jurassic and Cretaceous systems, distributed in western and south-western part of Lithuania. Common thickness of rocks is more than 1000 m. Continental, lagoon and marine terrigenous and carbonates rocks compound the section.

Cainozoic group. Palaeogene and Neogene rocks do not occur throughout Lithuania, and Quaternary rocks thick sedimentary cover (more than 300 m) spreads over the whole territory. Quaternary deposits consist of moraine sandy and clayey loam, clay, sand, peat.

3. METHODOLOGY OF THE ASSESSMENT OF GEOTHERMAL RESOURCES

Although the Earth’s heat is immense, but only little share of it could be used practically. However, how one can estimate this heat amount? Researchers searching a answer, use presumptions and call this estimation of geothermal resources. It was estimated amount of geothermal energy that can be reached in the near future, meaning technological progress and economy.

In estimation of geothermal energy, the united methodology and terminology is used, in order to compare with other kinds of energy sources. The conception and terminology most often used in estimation of resources is graphically expressed by McKelvey diagram. States of the European Union use this methodology for estimation of geothermal resources too.

In the estimation of geothermal resources, vertical axis shows degree of economic exploitation validity, while horizontal axis – geological verification (i.e. is energy already proved or is not discovered yet. Vertical axis is divided into four categories more favourable towards the top. Diagram is used to determine terms of estimation of geothermal energy resources.

The base of resources is the entire heat of the Earth’s crust in the territory, considering a local mean annual temperature. The reachable base of resources is the thermal energy, which reachable by boreholes at present or in the predictive future.

Reserves – a part of the base of resources legitimate and economically determined as well explored at present.

Basing on this conception, the geothermal resources of Lithuania down to 7 km depth (Fig. 2) as well the geothermal reserves of Cambrian (Fig. 3), Lower-Middle Devonian (Fig. 4) and Middle-Upper Devonian (Fig. 5) hydrothermal complexes were assessed. The assessment is conditional. Actually the geothermal resources are renewable.

4. ASSESSMENT OF GEOTHERMAL RESOURCES

Geothermal energy potential of Lithuania estimated according to actual data, geological structure and calculated with equations. The database of actual data was compiled.

Density of the geothermal energy resources (J/m^2) down to 7 km depth assessed using equation (1) (Haenel and Staroste (1988)):

$$Q_7 = \frac{(H - h_0) \cdot q \cdot C \cdot (T_7 - T_0)}{2} \qquad (1)$$

where H – depth, 7 km; h_0 - depth to “neutral” layer or to steady-state temperature zone, 30 m in average; q – mean density in rock column, kg/m^3; C – mean comparative heat susceptibility, J/(kg·°K); T – temperature at 7 km depth; T_0 – surface temperature, +25 °C.

Temperature at 7 km depth is determinable with equation (2):

$$T_7 = G \cdot (H - h_0) + t_0 \qquad (2)$$

where G – geothermal gradient, °C/km; t_0 – mean annual surface temperature, +7.5 °C.

Geothermal resources of Cambrian and Devonian hydrothermal complexes were estimated according to techniques developed in St. Petersburg Institute of Mining (Dadkin, Vaynblat, Boguslavskiy (1989), using equation (3):

$$Q = K \cdot \xi_k \cdot \xi_t \cdot Cv \cdot S \cdot m \cdot (T - t_0) \qquad (3)$$

K – transformation coefficient of thermal energy to conventional fuel (K=0.043·10-9); ξ_k – coefficient of conductive heat transfer from rocks to productive hydrothermal complex (ξ_k = 1.2); Cv – volumetric heat susceptibility of rocks, J/m^3·°C; S – distribution area of geothermal resources; m – thickness of hydrothermal complex, m; T – mean temperature of rocks of the hydrothermal complex; t_0 – mean annual temperature.

According to equation (4), temperature coefficient ξ_t is:

$$\xi_t = \frac{T - 0.5(t_g + t_0)}{T - t_0} \quad (4)$$

The final temperature (t_g) of heat carrier (groundwater) supplying to heat exchangers calculated with equation (5):

$$t_g = \Theta \cdot (T - t_0) + t_0 - 1 \cdot 10^{-3} \cdot H \quad (5)$$

This equation includes a non-dimensional value Θ, which is calculated using equation (6):

$$\Theta = \frac{t_g - t_0}{T - t_0} \quad (6)$$

Θ means ratio between temperature supplied to heat exchangers and returning one with difference between temperatures of layer and returning temperature. Usually this value equal to 0.9.

5. CONTENTS OF THE MAP SET

Maps of two types were compiled. 11 maps in a scale 1:500,000 were compiled manual and later digitized using MapInfo™ software. Other 22 maps in a scale 1:1,000,000 were compiled by means of SURFER® software according to earlier compiled database.

The map set of first type describes three regional hydrothermal complexes, their structure, extent, volumetric properties, thermal water, temperature and geothermal energy potential.

- Structural maps of top and bottom of Devonian (D_2up-D_3šv) hydrothermal complex of Lithuania (two maps).
- Structural maps of top and bottom of Devonian (D_1tl-D_2pr) hydrothermal complex of Lithuania (two maps).
- Structural map of Cambrian hydrothermal complex of Lithuania.

Maps show top and bottom of structural surfaces of the complex. Contours are drawn by every 100 m.

- Geothermal maps of top and bottom of Devonian (D_2up-D_3šv) hydrothermal complex of Lithuania (two maps).
- Geothermal maps of top and bottom of Devonian (D_1tl-D_2pr) hydrothermal complex of Lithuania (two maps).
- Geothermal map of Cambrian hydrothermal complex of Lithuania.

Maps show variation of temperature within top and bottom of the complex. Isogeotherms are drawn by every +10 °C.

- Geothermal map of Lithuania (1).
- Map of wells used in the geothermal atlas of Lithuania.

The Tectonic Map of the Baltic States (Suveizdis et al. (1991)) has been used to compile this map. Isogeotherms of the crystalline basement are shown in the map. The connection of pre-platform tectonic zones with intensity of present thermal field comes out; especially it is pertain to Taurage-Ogre and Nemunas zones, Southwest Lithuania. The thermal field extremely varies within Telsiai fault zone, West Lithuania.

Zoning of geothermal field was carried out, and three zones were distinguished and characterized.

The map set in a scale 1:1,000,000 could be grouped to four main groups:

1st group of maps (nine map set) intended to show thicknesses of complexes, thicknesses of pore intervals and average porosity of them.

- Thickness map of Devonian (D_2up-D_3šv) of Lithuania.
- Effective thickness map of Devonian (D_2up-D_3šv) of Lithuania.
- Porosity map of Devonian (D_2up-D_3šv) of Lithuania.
- Thickness map of Devonian (D_1tl-D_2pr) of Lithuania.
- Effective map of Devonian (D_1tl-D_2pr) of Lithuania.
- Porosity map of Devonian (D_1tl-D_2pr) of Lithuania.
- Thickness map of Cambrian of Lithuania.
- Effective thickness map of Cambrian of Lithuania.
- Porosity map of Cambrian of Lithuania.

2nd group of maps (seven map set) show features of the thermal water. Two parameters to characterize thermal water were chosen: total mineralization g/l and bromine content mg/l.

- Map of mineralization of thermal water of Devonian (D_2up-D_3šv) of Lithuania.
- Map of mineralization of thermal water of Devonian (D_1km-D_2pr) of Lithuania.
- Map of bromine content in thermal water of Devonian (D_1km-D_2pr) of Lithuania.
- Map of mineralization of thermal water of Devonian (D_1gr) of Lithuania.
- Map of bromine content in thermal water of Devonian (D_1gr) of Lithuania.
- Map of mineralization of thermal water of Cambrian of Lithuania.
- Map of bromine content in thermal water of Cambrian of Lithuania.

3rd group consists of two maps featuring a temperature at 100 m depth and geothermal gradient throughout sedimentary cover.

- Geothermal gradient map of Lithuania.
- Map of temperature at 100 m depth in Lithuania.

4th group consists of maps (four map set) intended to the geothermal potential of Lithuania.

- Map of geothermal resources of Devonian (D_2up-D_3šv) of Lithuania.
- Map of geothermal resources of Devonian (D_1tl-D_2pr) of Lithuania.
- Map of geothermal resources of Cambrian of Lithuania.
- Map of geothermal resources down to 7 km depth in Lithuania.

6. CONCLUSIONS

Geothermal atlas of Lithuania does not replace the need for detailed local studies of the geothermal resources, the maps presented permit a first order evaluation in terms of technical and economic viability.

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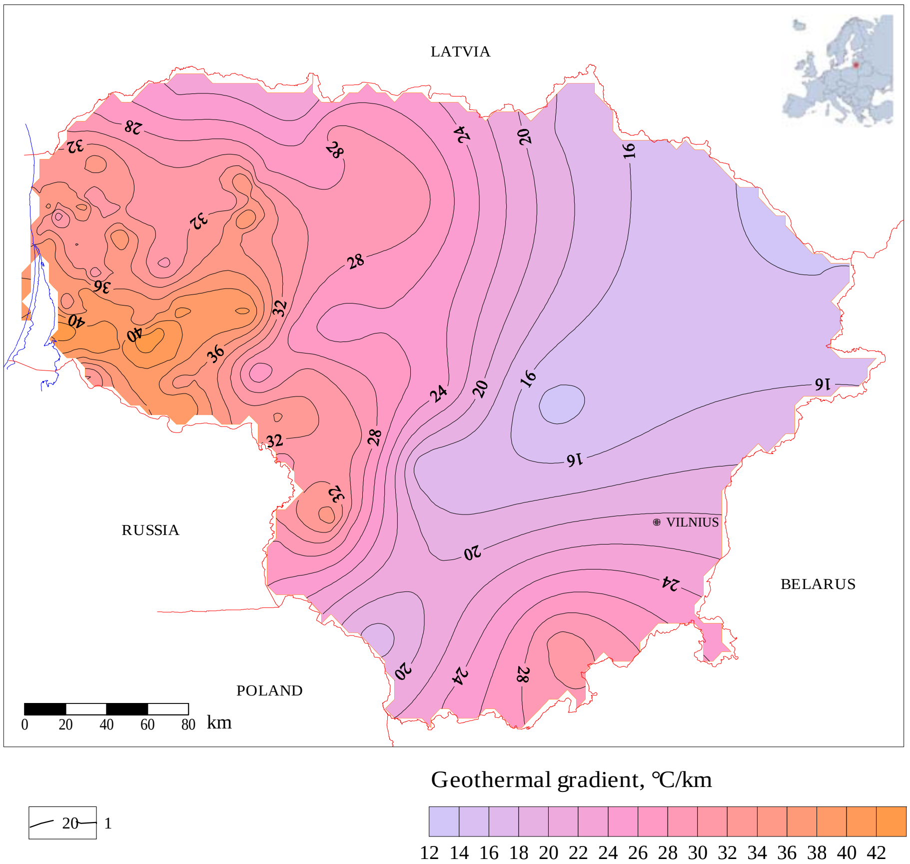

Fig. 1. Map of geothermal gradient of Lithuania. 1 – isogeotherms

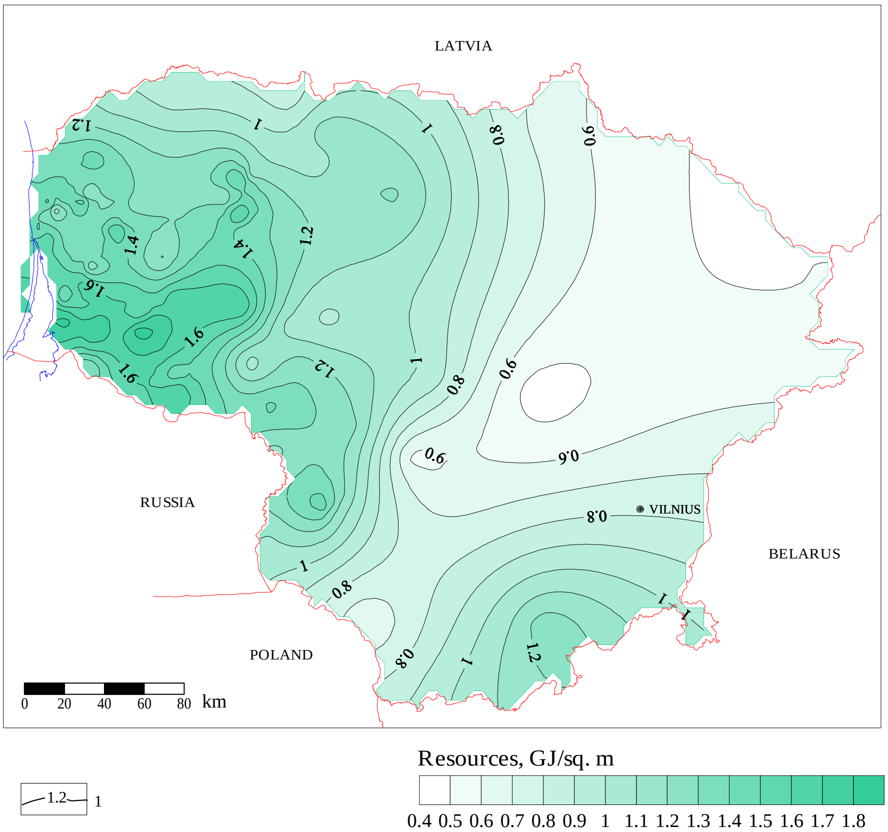

Fig. 2. Map of density of geothermal resources in 7 km depth. 1 – isolines of density of geothermal resources

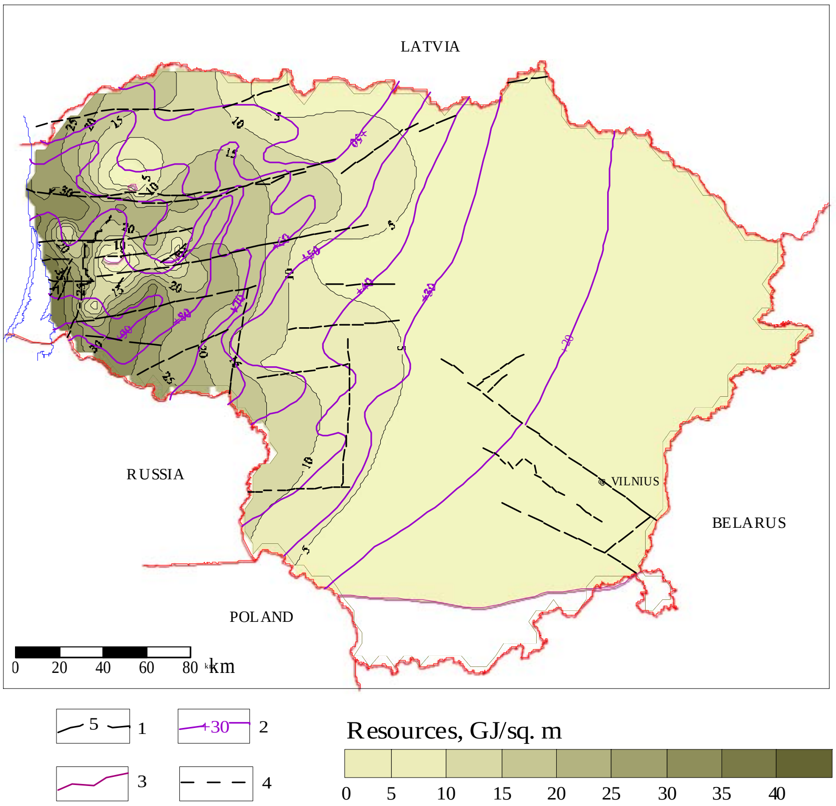

Fig. 3. Map of density of geothermal resources and temperature of Cambrian hydrogeothermal complex. 1 – isolines of density of geothermal resources; 2 – isohydrotherms of the bottom of Cambrian complex; 3 – present distribution limit of Cambrian rocks; 4 – tectonic faults

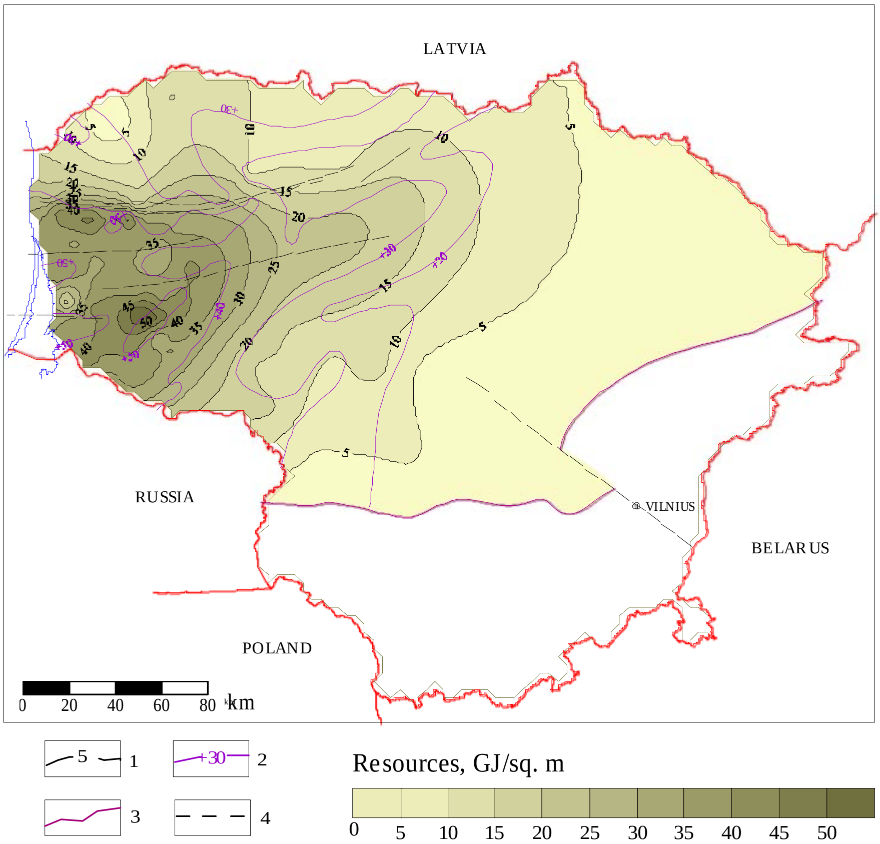

Fig. 4. Map of density of geothermal resources and temperature of Middle-Lower Devonian hudrogeothermal complex. 1 – isolines of density of geothermal resources; 2 – isohydrotherms of the bottom of D_2pr-D_1tl complex; 3 – present distribution limit of D_2pr-D_1tl rocks; 4 – tectonic faults

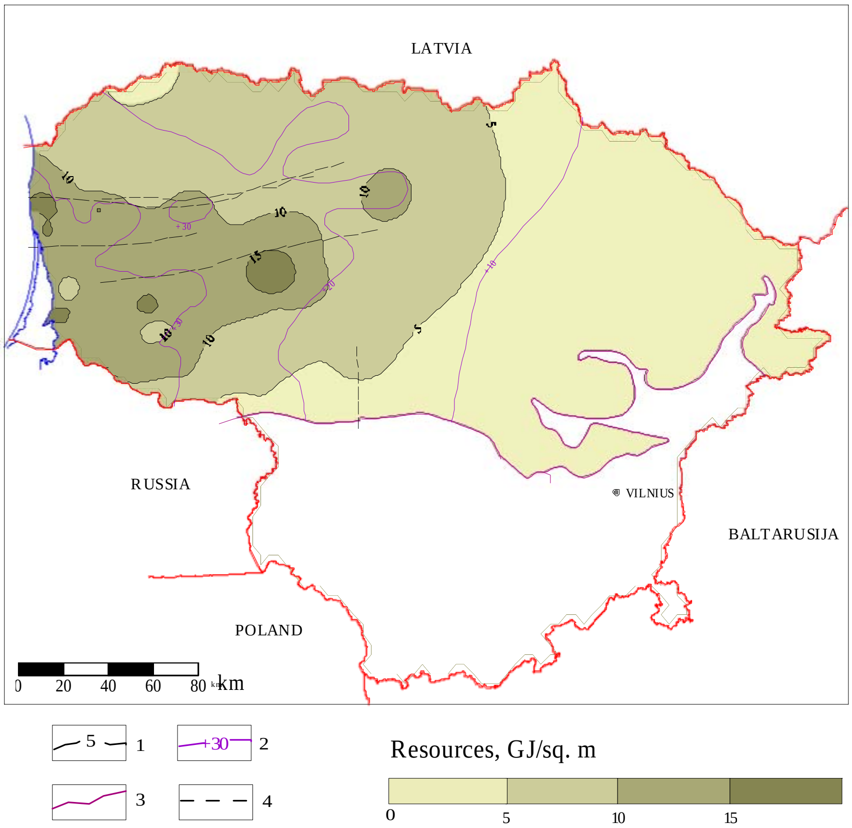

Fig. 5. Map of density of geothermal resources and temperature of Upper-Middle Devonian hudrogeothermal complex. 1 – isolines of density of geothermal resources; 2 – isohydrotherms of the bottom of D_3šv-D_2up complex; 3 – present distribution limit of D_3šv-D_2up rocks; 4 – tectonic faults