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# Deep Seated and Near-Surface Geothermal Resources of Russia

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## ABSTRACT

The electric-power industry of Russia is represented by a high-power system of centralized power and heat supply that uses traditional sources of energy. This strategy generated in due course the notion of donor-regions and recipient-regions according to energy supply. Growing independence of some regions of Russia in political, economic and industrial development, as well as significant transportation losses and expenditures during transportation and channeling fossil fuel stipulate their own energy policy.

Satisfaction of needs of the population and industry for electric and heat energy, especially in the regions distant from centralized power circuits results in necessity of nonconventional energy development, which is also stipulated by the requirement of global problems solving to make provision of energy for the mankind in future that is connected with limitation of reserves of mineral kinds of fuel and ecological security requirements.

The highest priority of energy strategy of Russia for the period until 2020 is aimed at a maximum effective use of natural fuel-energy resources and available scientific-technical and economic potential to increase the life quality of the country. In doing so a wide use of nonconventional power sources corresponds to energy strategy goals of Russia.

## 1. CLASSIFICATION AND CONCEPTUAL APPARATUS OF GEOTHERMAL RESOURCES ASSESSMENT

In compliance with prediction, the global geothermal resources are in 10 times excess over summary resources of fossil fuel. On the territory of Russia they are at accessible depths (as deep as 5-6 km). They are 4-6 times in excess over hydrocarbon resources and according to the St. Petersburg Mining University assessment Boguslavsky (1980, 1981, 1984, 1996, 2003), Litvinenko (2003), Pevzner (1996), geothermal resources amount to 57 trillion tons of reference fuel for heat supply needs.

Considering thermal energy of the interior of the Earth as a mineral wealth it is necessary to define a quantitative, qualitative, economic and social significance of it. Geothermal resources in connection with their specificity and foremost their alternative for an observable period assignment demand compulsory economic assessment. At the University, former LMI, the principal concepts were developed and the first methodology of geothermal resources geological-economic assessment was created, Boguslavsky (1980, 1984, 1994). A certain progress in this direction was reached as a result of joint investigations with FSUE “Nedra”.

The concept “geothermal resources” itself has been disputable for many years. Their designation proposed in the works Boguslavsky (1980, 1981, 1984): «*the quantity of heat, containing in the lithosphere and its sections as far as the depth achievable by drilling means for an observable period*», for the past 37 years did not provoke radical argumented objections, widely used by other authors and apparently can be considered to be commonly recognized as *potential geothermal resources.*

The geothermal resources are to be divided into two groups (Fig. 1)

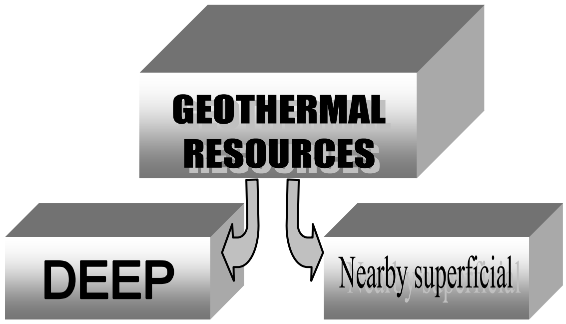


**Figure 1: Classification of Geothermal Resources**

### 1.1 Classification of Deep Seated Geothermal Resources

According to the elaborated classification (Fig. 2) deep seated potential (**P**) geothermal resources with allowance for mining and geological conditions, extent of commercial development, technology of heat energy extraction and its use, they can be divided into two groups:

a) Petrogeothermal ($\mathbf{P}^{И}$) rocks are geothermal resources of low-permeable formation. Their total potential is determined as heat content of the lithosphere thickness at a maximum drilling depth (10 km). Meanwhile rocks temperature falls as low as the environment ambient temperature of a consumer. The technology of geothermal resources extraction is at an experimental level; only pilot circulation systems with artificial reservoirs have been created (Fenton Hill – USA, Cornwall – England, Hidgiory – Japan, Tyrniauz – Russia, Baden-Vürtemberg – Germany, Soultz – les – Bains (Alsace), France).

b) Geothermal resources of natural reservoirs are hydrogeothermal ($P^e$). Their potential is defined as summary capacity heat content of pervious beds (with conductive addition from enclosing rocks) to a sedimentary section depth within the limits of drilling technique capabilities, their temperature cooling to the ambient temperature. They are run commercially by circulation systems (France, USA, Germany, Denmark, Ukraine, Poland, Switzerland, Turkey, Russia and others).

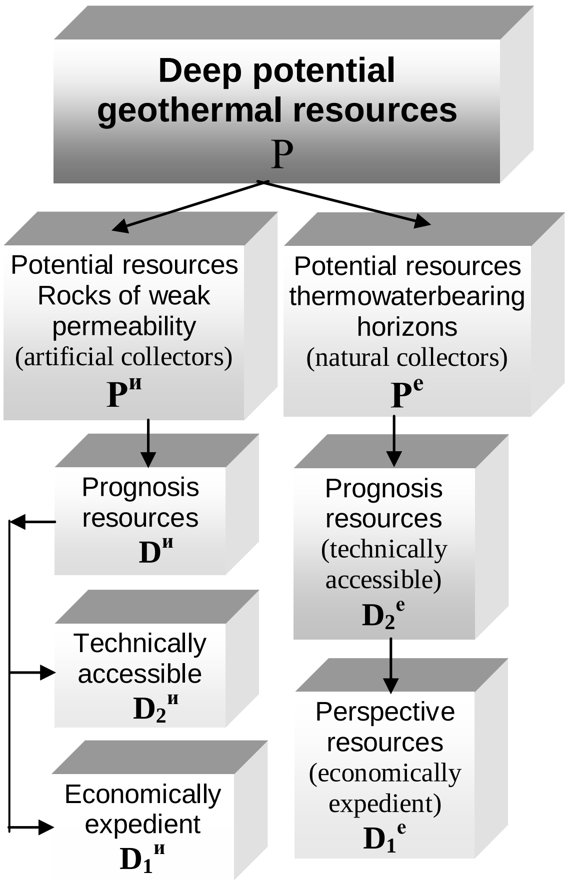


**Figure 2: Classification of deep seated geothermal resources based on the extent of their process design development**

*Expected* geothermal resources are a part *potential petrogeothermal* or *hydrothermal* resources. *Possible petrogeothermal* resources of weak permeable rocks (**$D^{и}$**) are divided into two groups:

*1) Technically accessible petrogeothermal resources* (**$D_2^{и}$**) are evaluated as heat content of rock thickness to the depth of commercial drilling (6 km), on the basis of extraction ratio. They are limited by designed temperature of consumable and discharged heat carrier (for heat supply needs, viz. for hot water supply this factor is 70/20 and for heating it is 90/40), i.e. they are characterized not only quantitatively, but also qualitatively.

*2) Economically efficient petrogeothermal resources* (**$D_1^{и}$**) are evaluated on the basis of competition with heat production of a boiler-room where fossil fuel is burnt, i.e. the upper bound of the resource interval is calculated relying on additional heating in the peak boiler-room or thermotransition, and the lower bound is calculated according to economic comparison with an alternative boiler-room.

*Expected (technically accessible) hydrothermal resources* of natural reservoirs (**$D_2^{е}$**) are estimated as heat content of thermoaquifer beds, that is limited by the environmental temperature and extraction temperature ratio. Additionally, conductive heat penetration from bedding and overlying rocks is taken into account.

*Perspective (economically efficient) hydrothermal resources* of natural collectors (**$D_1^{е}$**) are estimated as part of the possible ones, which can be efficiently extracted and used at the current state of development technology of heat energy of the interior of the earth.

### 1.2 Classification of Near-Surface Geothermal Resources

The near-surface geothermal resources according by the genesis, temperature and hydrogeological characteristics differ from geothermal resources of deeper horizons (>500 m). The uppermost layer that is to the neutral layer depth is located within the limits of the area of intensive influence of solar radiation and that is why its heat content almost completely depends on climatic conditions of a region, and therefore changes dynamically. This part of near-surface resources (Fig.3) is formed from heat resources of rocks (in a less degree) and heat resources of insolation (owing to solar heating of soil).

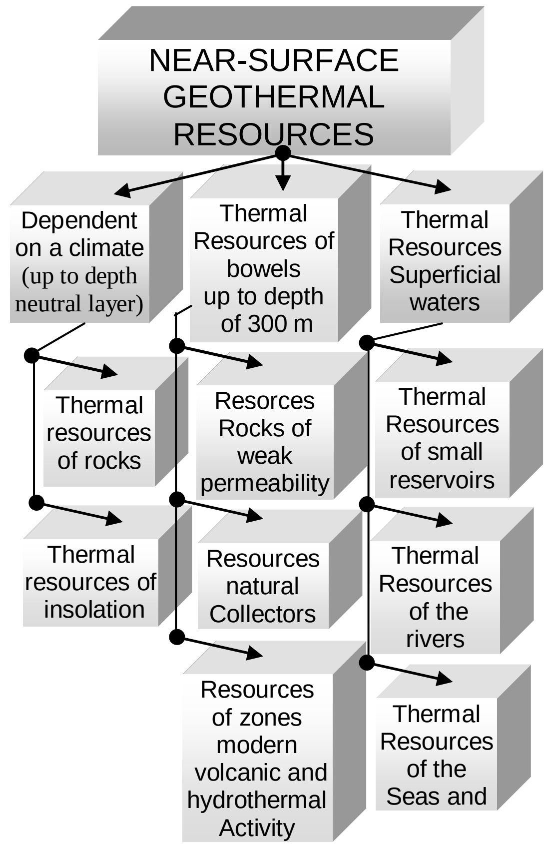


**Figure 3: Classification of near-surface geothermal resources**

Rocks from the neutral layer to the depths of 200-300 m according to temperature parameters are connected with forms of heat transfer from internal sources and almost to the full extent are determined by geological, geothermal and hydrogeological properties of the interior of the earth. Under the conditions of low permeability of rocks or small velocities of filtration of a basic component of extraction of geothermal resources is conductive heat transfer. Convective heat transfer takes place when the water content of rocks is high and filtration velocities are sufficiently high. The energy of hydrothermal activity and influence of an increased heat flow as a volcanic activity function give a certain addition to the heat content of the near-surface layer of rocks.

Solar energy without doubt is the main component of heat content of the low temperature potential of surface water bodies and water flows. However, the heat flow from the deep interior maintains heat of water body beds and retain the energy accumulated by water. Therefore, the proposed classification of near-surface geothermal resources includes a group of heat resources of surface water. In this regard there is hardly a necessity of creating an assessment methodology of thermal resources of this group.

## 2. ASSESSMENT AND REGIONALIZATION OF DEEP SEATED PETROGEOTHERMAL RESOURCES

The density of deep seated petrogeothermal resources of all categories was determined at St. Petersburg Mining University according to the developed first in the worldwide practice methodology of geologic-economic evaluation of geothermal resources, Boguslavsky (1980, 1981, 1984), viz.

- potential resources of low pervious rocks (**$P^{u}$** );

- expected resources of geothermal heat supply of two categories, i.e. technically accessible (**$D_2^{u}$**) and economically efficient (**$D_1^{u}$**), each of them including two temperature conditions of heat supply: heating and hot water supply.

The specified method was formalized into an economic-mathematic model of calculating the magnitude of expected, technically accessible and economically efficient resources. Computer modeling of it made it possible to assess geothermal resources of listed categories in more than 3000 points of the territory of Russia.

The obtained values for every point were mapped [8, 10] with the scale authentic material, i.e. 1:10,000,000 and by using them with the method of simple interpolation the system of isolines was constructed, the latter reflecting density changes of resources of geothermal heat supply to the depth of 6,000 m.

Maps of possible technically accessible (Fig. 4) and economically efficient (Fig. 5) resources of geothermal heat supply have been published (E.I. Boguslavskiy, A.A. Smyslov, A.B. Wineblat, L.A. Pevzner, B.N. Khakhayev). They reflect geologic-geothermal conditions of economic regions of the territory of Russia, characterizing different grade of heating of its entails and allow the assessment of the real raw material resources base of heat consumers. Besides they reflect specified technical and economic indices of geothermal circulating systems in comparison with alternative boiler-rooms that burn fossil fuel and render possible to estimate the perspectives of development of real resources of geothermal energy aimed at heating in different regions. Potential resources of geothermal energy of category *P* characterize the raw material resources base of geothermal power industry. Their total thermal potential is equivalent to 1,702 trillion t.c.f. (Table 1). Calculated expected technically accessible resources of geothermal energy of category ($D_2^{u}$) amount to 70/20°C, i.e. 56.9 trillion t.c.f. to satisfy the requirements for heat supply needs, including heating systems that makes 16.4 trillion t.c.f. (Table 1). Resources of geothermal heat supply of category ($D_2^{u}$) for newly established 7 Federal political districts of Russia wereassessed in 2000 (Table 2).

## 3. ASSESSMENT AND REGIONALIZATION OF DEEP SEATED HYDRO GEOTHERMAL RESOURCES

A significant part of the territory of Russia is characterized by low and medium-temperature natural reservoirs. To develop them an industrial circulating technology was created. However on an unconventional power industry basis its expansion is limited.

**Table 1. Petrogeothermal resources of the territory of Russia**

| Regions | Potential $P$ $1*10^{12}$ t.c.f. | Expected resources of heat supply $D^{u}$, $1*10^{12}$ t.c.f. | | | |
|---|---|---|---|---|---|
| | | Technically accessible $D_2^{u}$ | | Economically efficient $D_1^{u}$ | |
| | | 70/20 °C | 90/40 °C | 70/20 °C | 90/40 °C |
| Northern | 132 | 3.7 | 1.1 | 3.4 | 0.95 |
| North-Western | 18 | 0.9 | 0.2 | 0.6 | 0.1 |
| Central | 35 | 1.5 | - | 0.99 | - |
| Central-Black Belt | 19 | 5.7 | 1.3 | 4.8 | 0.07 |
| Volgo-Viatsky | 12 | 0.54 | - | 0.37 | - |
| Volga region | 59 | 2.7 | 1.49 | 2.1 | 1.37 |
| Northern-Caucasian | 45 | 1.86 | 1.35 | 1.6 | 0.97 |
| Urals region | 64 | 1.2 | 0.36 | 0.6 | 0.18 |
| Western-Siberian | 258 | 9.8 | 7.4 | 8.2 | 3.8 |
| Eastern-Siberian | 364 | 7.9 | 5.4 | 5.1 | 1.86 |
| Far-Eastern | 696 | 21.1 | 11.9 | 16.8 | 6.15 |
| Kalinin-grad Region | -- | -- | -- | 0.1 | 0.09 |
| Total in Russia | 1,702 | 56.9 | 30.5 | 44.64 | 16.44 |

The assessment of *possible resources* makes it possible to identify maximum reserves of geothermal resources on the territory under consideration when developing specific horizon with the use of circulating technology excluding the statement of costs to extract geothermal heat-transfer medium and power generation.

*Potential geothermal* resources are the resources of heat content bed that can be effectively extracted and harnessed applying state-of-the-art technology of extraction and energy usage under market competitive ability conditions.

*The main value of quantity assessment* of geothermal resources is the density of their distribution or sufficient availability of resources of a square unit in t.c.f./m$^2$, that can characterize geothermal resources basis of several territories of regions and entirely Russia.

**Table 2: Possible petrogeothermal resources of heating category D**

| Federal districts | The area occupied with geothermal resources, thous. km | Geothermal resources 1*10 ton of coal equivalent | |
|---|---|---|---|
| | | For hot water supply 70/20 C | For central heating 90/40 C |
| Central | 652,8 | 0,8 | 0,1 |
| North-west | 1496,9 | 3,4 | 1,2 |
| North Caucasus | 600,4 | 2,7 | 1,5 |
| Volga' district | 836,4 | 2,4 | 1,8 |
| Urals | 1698,4 | 11,4 | 6,4 |
| Siberian | 5006,7 | 11,5 | 5,4 |
| Far Eastern | 6030,4 | 24,7 | 14,1 |
| Total | 16322,0 | 56,6 | 30,5 |

Preliminary integration of assessment of potential geothermal resources of natural reservoirs ($D^E$) within the territory of Russia (Table 3) testifies to the opportunity of significant contribution to the energy economy of the country, Boguslavsky (1995), Litvinenko (2002), Pevzner (1996).

There are several geothermal anomalies connected with a deep-seated heat gain (Saint Petersburg and Yaroslavl), as well as shielding action of joined heat energy of deposits that are slightly lithificated bysedimentary formation (Baltic anomaly) in the north-west of the East-European platform. Within these anomalies geothermal gradient is 2-3.5 more rarely 3.5-4.5$^0$ C/100m in the sedimentary formation of the platform case. On prosperous conditions that (capacity of sedimentary formation 1.5 km, effective collectors 20-100 m., their penetration factor 0.3-1.0 darcy, these anomalies can be practically interesting while extracting and using energy to supply heat.

## 4. ASSESSMENT AND REGIONALIZATION OF NEAR-SURFACE POTENTIAL GEOTHERMAL RECOURSES OF RUSSIA

The assessment of potential near-surface geothermal resources, their zoning and mapping has been carried out for the territory of Russia. Relative to a territory variety and uncertainty information of the depth, capacity, temperature, location of penetrable, water-saturated beds and seams, the upper part of lithosphere (up to 200 m) considered to be as low permeable strata. This assumption led to a certain understatement of resource basis of this category, but it can be justified with applying the principle of "reservation", to be in pledge in the concept of geothermal resources assessment.

Potential near-surface geothermal resources of rocks are characterized by heat potential of strata from the neutral bed to desired depth (40,100 and 200 m), considering that mass can be cooled up to the temperature that is adequate for a heat pumping station (HPS) feasibility. To assess the potential geothermal resources two temperature conditions have been accepted:

**Table 3: Potential resources of natural reservoirs of Russia.**

| Regions | Square thous. km | Square of hydrothermal basin, thous.km | Potential resources, bln |
|---|---|---|---|
| North | 1466.3 | 439.8 | 110 |
| North-west | 196.5 | 49.2 | 172 |
| Central part | 485.1 | 221.0 | 44 |
| Central Black Belt | 167.7 | 167.7 | 15 |
| Volga-Vyatsk region | 263.6 | 263.6 | 20 |
| Volga region | 568.1 | 340.8 | 853 |
| North Caucasian region | 355.1 | 355.5 | 1243 |
| Ural region | 824.0 | 82.4 | 166 |
| West Siberian region | 2427.0 | 1942.0 | 9710 |
| East Siberian region | 412.8 | 2474.0 | 3711 |
| Far East region | 6215.9 | 933.0 | 4665 |
| Kalininskaya region | 15.1 | 15.1 | 38 |
| Total around Russia | 17075.4 | 7284.1 | 20747 |

- the temperature supplied by HPS to a borehole of the heat transfer medium is +1$^0$C, that is as a rule meets the customer's requirements not to block the mass of rocks;

- the temperature delivered by HPS to borehole of heat transfer medium -3$^0$C, that meets the word customer's requirements.

According to an administrative division seven regions of the Russian Federation, in which 26 geology-geothermal blocks are united have been considered. There are10 blocks of an approximate magnitude of the neutral depth and the temperature of rocks at 40,100, 200 deep on the territory of 4 federal districts in the European part of Russia. In the Asiatic part there are 16 blocks on the territory of 4 regions.

According to calculations, the maps of potential near-surface geothermal resources up to 40,100,200 have been carried out. Total assessment characteristics of potential near-surface geothermal resources at the temperature delivered by HPS is +1$^0$C and -3$^0$ C and they are represented in Table 4, Table 5 respectively.

Two main characteristics of potential near-surface geothermal resources have been determined:

- density of resources on the m$^2$ of the surface, i.e. a potential quantity of heat energy in core of the section 1 m to a desired depth (40,100,200 m) mega joule/ m$^2$,

- quantity characteristics of resources in every single territory of regions and districts within the geology-geothermal blocks up to 40, 100, 200 in t.c.f.

Analyzing the resource base of potential geothermal energy of the upper layer of lithosphere up to 200 deep we can note:

**In the European parts of Russia for temperature of the heat transfer medium delivered by HPS is +1$^0$C:**

- average value of density of near-surface potential geothermal resources up to 40, 100, 200 m is 0.180; 0.885 and 2.538 mega joule/ m$^2$, respectively;

- North Caucasian (South) region is characterized with maximum of density for depth 40,100 and 200 will be 0.294; 1.303 and 3.693 mega joule/ m$^2$ respectively;

- North-west region due to colder subsoil assets is characterized by the minimum values, i.e. for a depth of 40,100 and 200 will be 0.112, 0.656 and 1.928 mega joule/ m$^2$ m correspondingly at that Yamalo-Nenetsk region having 119 thous km doesn't have these resources;

- near-surface potential geothermal resources of the whole territory of European part of Russia having 3.55 mln. is for a depth of 40,100 and 200 will be 22.6; 118.2 and 346.2 mln ton of t.c.f. or 147.3; 769.4 and 2254.3 heat TVt./Hour.

**Across the European Part of Russia for the Temperature of Heat Transfer Medium Delivered by HPS is -3$^0$C**

- average value of density of sub area potential geothermal resources up to 40, 100, 200 m is 0.254; 1.182 and 3.176 mega joule/ m$^2$, respectively;

- North Caucasian (South) region is characterized with maximum of density for a depth of 40,100 and 200 and it will be 0.410, 1,731 and 4.641 mega joule/ m$^2$, respectively;

- North-west region due to colder subsoil assets is characterized with the minimum values for a depth of 40,100 and 200 and it will be 0.160; 0.832 and 2.274 mega joule/ m$^2$, respectively;

- near-surface potential geo thermal resources of the whole territory of European part of Russia having 3.55 mln is for a depth of 40,100 and 200 it will be 37.2; 181.5 and 491.8 mln tons of coal equivalent or 242.1; 1181.7 and 3202.6 heat TVt./Hour.

**In the Asian Part of Russia for the Temperature of Heat transfer Medium Delivered by HPS is +1$^0$C**

- average value of density of near-surface potential geothermal resources up to 40, 100, 200 m is 0.086; 0.493 and 1.554 mega joule/ m$^2$, respectively;

- Ural region is characterized by maximum of density for a depth of 40,100 and 200 and it will be 0.107; 0. 537 and 1.614 mega joule/ m$^2$, respectively;

- Siberian region is characterized by the minimum figures for a depth of 40,100 and 200 and it will be 0.073; 0.537 and 1.599 mega joule/ m$^2$, respectively at that Polar Ural, Polar West Siberia, north west Siberia, north of Krasnoyarsk region and Taymyr peninsula, Magadansk region, Yakutsk and Chukotka having totally 6.64 mln km out of 12.58 don't have these resources at all or part of the depths;

- Near-earth potential geothermal resources of the territory 5.94mln km of the Asian part of Russia is for a depth of 40,100 and 200 it will be 19.5, 105.4 and 337.5 mln of coal equivalent or 127.1, 686.2 and 2197.9 heat TVt./Hour.

**In the Asian part of Russia for the Temperature of Heat Transfer Medium Delivered by HPS is -3$^0$** C

- average density value of near-surface potential geothermal resources of the territory for a depth of 40,100 and 200 and it will be 0.166; 0.740 and 2.023 respectively;

- Far East region is characterized with maximum density for a depth of 40,100 and 200 and it will be 0.169; 0.747 and 2.093 mega joule/ m$^2$

- Siberian region is characterized with the minimum figures for a depth of 40,100 and 200 and it will be 0.159; 0.737 and 1.677 Meg Watt-second/ m, and at that Polar West Siberia, north west Siberia region, Yakutsk and Taimyr peninsula of the North East part having totally 3.93 mln km out of 12.58 don't have these resources on all or part of the depth;

- near-surface potential geothermal resources of the territory 8,62 mln km of Asian part of Russia is for a depth of 40,100 and 200 and it will be 53.8; 239.8 and 664.2 tons of coal equivalent or 350.2; 1516 and 4325 heat TVt./ Hour.

**Totally in Russia for the Temperature of Heat Transfer Medium Delivered by HPS is +1$^0$**C

- density value of near-surface potential geothermal resources of the territory for a depth of 40,100 and 200 and it will be from 0. 073 up to 0.294; from 0.450 up to 1. 303 and 1.5 up to 3. 693 mega joule/ m$^2$

- North Caucasian region is characterized by a maxim value of density for a depth of 40,100 and 200 and it will be 0.294; 1.303 and 3.693 mega joule/ m$^2$

- Far East region is characterized with a minimum density for a depth of 40,100 and 200 and it will be 0.080' 0.450 and 1.500 mega joule/ m$^2$, respectively

- near-surface potential geothermal resources of the territory 16.25 mln km part of Russia for a depth of 40,100 and 200 and it will be 42.2; 223.5 and 683.7 tons of coal equivalent or 274.5; 1455.6 and 4452.2 of heat TVt./Hour

**Totally in Russia for the temperature of heat transfer medium delivered by HPS is -3$^0$** C

- density value of Subaerial potential geothermal resources of the territory for depth 40,100 and 200 and it will be from 0. 160 up to 0.410; from 0.740 up to 1. 731 and from 1.677 up to 4. 641 mega joule/ m$^2$

- North Caucasian region is characterized by a maxim value of density for a depth of 40,100 and 200 and it will be North Caucasian region is characterized by a maxim value of density for a depth of 40,100 and 200 and it will be 0.410; 1.731 and the North Caucasian region is characterized by a maxim value of density for a depth of 40,100 and 200 and it will be 4.641 mega joule/ $m^2$

- Siberian region is characterized by minimum values, i.e. for a depth of 40,100 and 200 and it will be 0.159; 0.731 and 1.677 mega joule/ $m^2$.

- near-surface potential geothermal resources of the territory 16.25 mln km part of Russia for a depth of 40,100 and 200 and it will be 90.9; 223.5 and 421.3 and 1156.1 tons of coal equivalent or 552.2; 2742.9 and 7527.7 heat TVt/ Hour

## REFERENCES

Boguslavsky, E.I.: Geology Economical Assessment of Thermal Resources of the Interior of the Earth. Problems of Biosphere. AN USSR , vol.4 M. Published by VINITI, (1981), 100-104.

Boguslavsky, E.I.: Geological Resources of the USSR. Physical Processing of Mining Production. All-Union inter University Collected Works. L. Published by LGI, (1980), vol.12

Boguslavsky, E.I.: Geological Resources of Russia. Renewable Energy. 2003: Situation, Problems, Perspectives. SPb GPU, SPb, (2003), 20-23.

Boguslavsky, E.I.: Classification of Thermal Resources of the Interior of the Earth. The Problems of Mine Thermal Physics. L. Published by LGI, (1981), 98-100.

Boguslavsky, E.I.: Methodical Principles of Assessment of Thermal Resources of the Interior of the Earth. Economical Mechanism of Rational Usage and Protection of the Interior of the Earth. ANX USSR, M., Published by MSU, (1980), 91-94.

Boguslavsky, E.I.: Technical Economical Assessment of Thermal Resources of the Interior of the Earth. Higher School, L. Published by LGU, (1984).

Boguslavsky, E.I., Vainblat, A.B., Smyslov, A.A., Pevzner,L.A., Khakhaev,B.N.: Resources of Geothermal Heat Supply, 7, M. Nedra (1996), 17-20.

Boguslavsky, E.I., Vainblat, A.B., Dyadkin, Y.D., and others: Map of Geothermal Resources for Heat Supply oh the Territory of Russia. 1 : 10 000 000, Ministry of Geology of the USSR, (1991).

Litvinenko, V.S. . Boguslavsky, E.I.: Geological Resources of Russia.Technology and Economy of their Development, Geofund-2003, *Proceedings* of the International Seminar, M., ENIN, (2003), 75-89.

Boguslavsky, E. I., Vainblat, A.B., Smyslov, A.A., Pevzner, L.A., Khakhaev, B.N.: Geological and economic evaluation and mapping of resources geothermal energy on the territory of Russia and contiguous states, “Geothermische Energie. Nutzung, Erfahrung, Perspektive.” Schwerin, (1994), 73-79.

Boguslavsky, E. I., Vainblat, A.B., Smyslov, A.A., Pevzner, L.A., Khakhaev, B.N.: Development of geothermal resources of Moskow artesian basin. *Proceedings* of the World Geothermal Congress, . Florence, Italy, Volume 1, (1995), 601-605.

Litvinenko, V.S., Boguslavsky, E. I., Pevzner,L.A., Khakhaev,B.N.: Geothermal resources of natural collectors and forecasting of their development, “The earths thermal field and related research methods”, M., (2002), 166-169.

Pevzner, L. A., Boguslavsky, E. I., Vainblat, A.B., Smyslov, A.A., Khakhaev, B.N.: Low potential geothermal resources of central regions of Russia, International Geological Congress. Beijing, China, (1996), 139-142.

**Table 4: Assessment of Potential Near-Surface Geothermal Resources of Russia at the Temperature Delivered by HPS +1$^0$C.**

| Regions, Federal district | Square of block thous. km | Depth 40m | | Depth 100 m | | Depth 200 m | |
|---|---|---|---|---|---|---|---|
| | | Density mega joule/ $m^2$ | Resources Mln tons of coal equivalent | Density mega joule/ $m^2$ | Resources Mln tons of coal equivalent | Density mega joule/ $m^2$ | Resources Mln tons of coal equivalent |
| North Caucasian region | 574 | 0.29 | 7.5 | 1.30 | 34.8 | 3.69 | 100.7 |
| Central region | 629 | 0.19 | 4.6 | 0.88 | 22.8 | 2.46 | 64.4 |
| North-west region | 1489 | 0.11 | 5.3 | 0.66 | 31.5 | 1.93 | 94.5 |
| Volga region | 979 | 0.13 | 5.3 | 0.71 | 29.1 | 2.12 | 86.6 |
| Ural region | 1884 | 0.11 | 6.3 | 0.54 | 31.6 | 1.61 | 95.4 |
| Siberian | 4654 | 0.07 | 9.8 | 0.54 | 53.8 | 1.60 | 167.2 |
| Far East region | 6038 | 0.88 | 3.4 | 0.45 | 19.9 | 1.50 | 74.9 |
| Total | **16247** | | **42.2** | | **223.5** | | **683.7** |

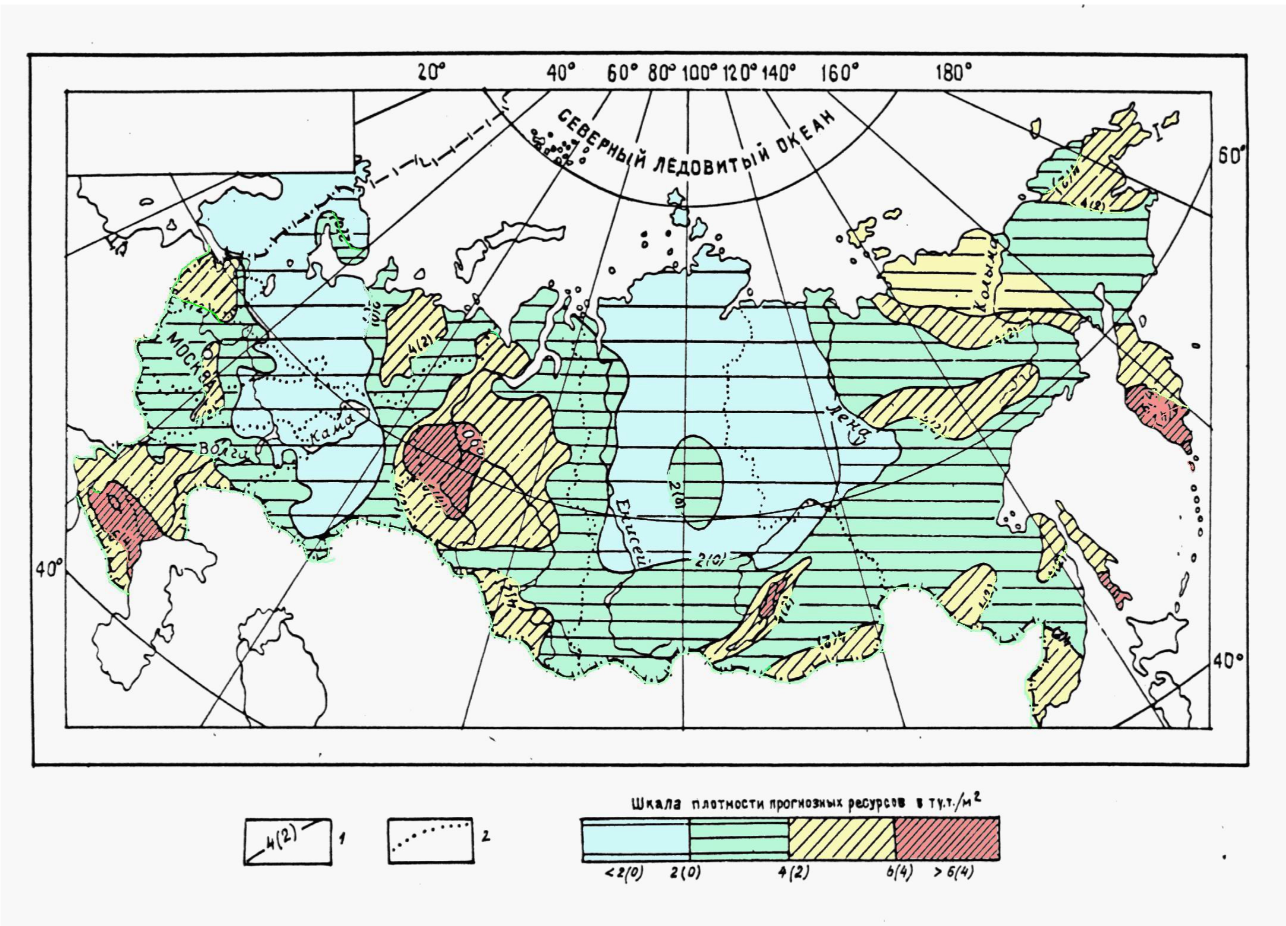


**Figure 4: Contour map of expected, technically accessible resources of geothermal heat supply. 1 stands for isolines of geothermal heat supply density, tons of conventional fuel/m$^2$. Designation 4(2) is deciphered as 4 t. c.f. /m$^2$ are for heat supply (conditions being 70/20$^o$ C), 2 t c.f. /m$^2$ are for heating systems (conditions being 90/40$^o$ C); 2 stands for regions boundaries**

**Table 5: Assessment of potential near-surface geothermal resources of Russia at the temperature delivered by -3$^0$C**

| Regions, Federal district | Square of Block Thous. km | Depth 40m | | Depth 100 m | | Depth 200 m | |
|---|---|---|---|---|---|---|---|
| | | Density mega joule/ m$^2$ | Resources Mln tons of coal equivalent | Density mega joule/ m$^2$ | Resources Mln tons of coal equivalent | Density mega joule/ m$^2$ | Resources Mln tons of coal equivalent |
| North Caucasian region | 574 | 0.41 | 10.1 | 1.73 | 45.1 | 4.64 | 123.9 |
| Central region | 629 | 0.29 | 7.2 | 1.29 | 33.8 | 3.39 | 89.5 |
| North-west region | 1489 | 0.16 | 10.8 | 0.83 | 56.5 | 2.24 | 153.0 |
| Volga region | 979 | 0.22 | 9.2 | 1.12 | 46.1 | 3.05 | 125.6 |
| Ural region | 1884 | 0.17 | 14.1 | 0.74 | 62.1 | 1.98 | 167.5 |
| Siberian region | 4654 | 0.16 | 25.8 | 0.73 | 116.4 | 1.68 | 312.1 |
| Far East region | 6038 | 0.17 | 13.9 | 0.75 | 61.3 | 2.09 | 184.7 |
| **Total** | **16247** | | **91.1** | | **421.3** | | **1156.3** |

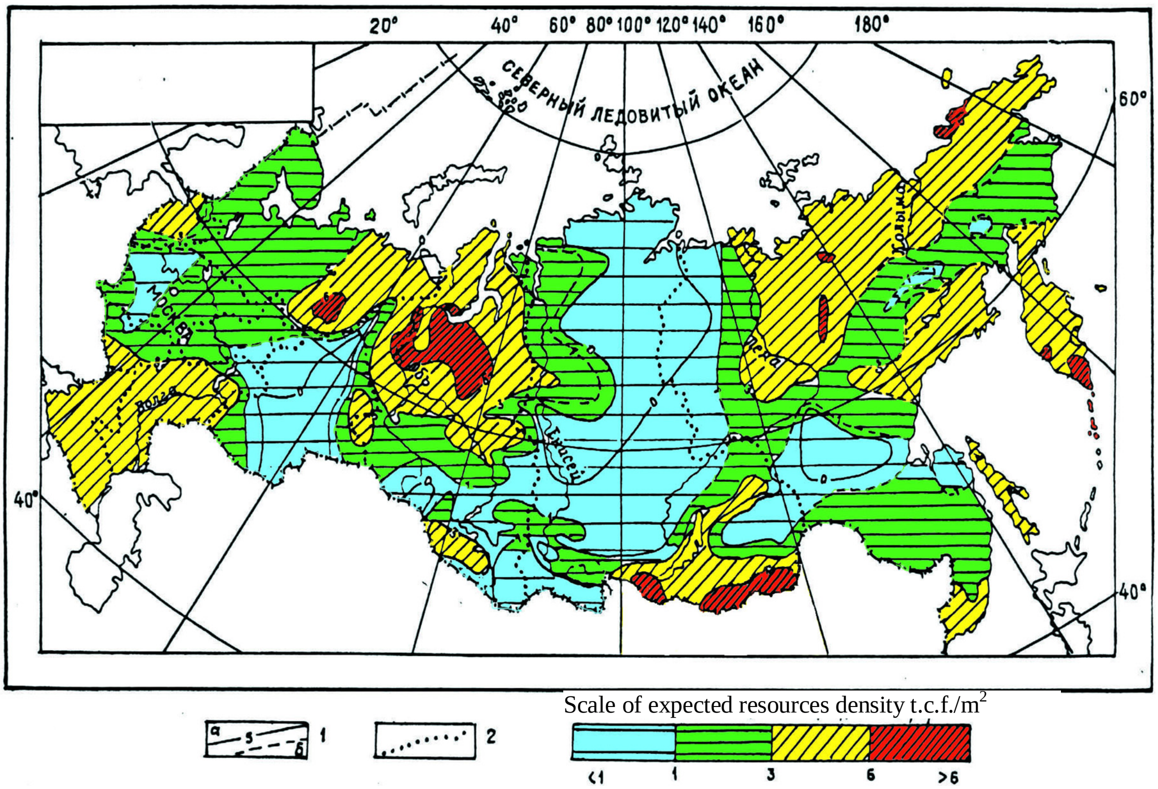


**Figure 5: Contour map of expected economically efficient resources of geothermal heat supply. 1 stands for isolines of geothermal heat supply density, t.c.f./m$^2$(conditions being 70/20$^o$C): a) proven, b) assumed; 2 stands for boundaries of economic regions of Russia**