

Resources of Geothermal Energy within Intersalt Deposits of the Pripyat Trough, Belarus

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ABSTRACT

The Pripyat Trough has a complex geological structure with two salt bodies within its platform cover. The Intersalt deposits separate the Upper Salt and Lower Salt complexes within the trough. A thickness of the permeable intersalt deposits ranges from 100 meters in the western part of the area up to 1000 meter observed in a few wells. The complex geometry of the intersalt deposits reflects in the temperature distribution over the roof of the complex. Low temperature values around 35 °C were observed within the western part of the area. The temperature is on average two times higher in the northern part of the trough, where it reaches 65-70 °C. The southern part exhibits again lower temperature around 40-45 °C.

The map of the density of geothermal resources, within the intersalt complex of the Pripyat Trough, shows that low values 0.2-0.4 tons of oil equivalent (t.o.e.) per square meter are typical for the western part of the area. Though there is a small area, corresponding so-called Turv Depression, where this value increases to 0.5 t.o.e./m². The isoline 0.5 t.o.e./m² has the general meridional orientation and separates the whole considered area into the western and eastern parts. Maximal density of geothermal resources up to 1-1.25 t.o.e./m² and higher corresponds to the northern and north-eastern parts of the Pripyat Trough. It is stretched sub-parallel to the North-Pripyat Marginal Fault. It is the most promising area for the geothermal energy utilization within the trough.

The depth of the intersalt complex surface here is on average 2,000-3,000 meters. High salinity brines were observed within this complex. The content of dissolved chemicals reaches on average here up to 200-300 g.p.l.

The results show that the intersalt complex of the Pripyat Trough represents the interest for recovery of its geothermal resources especially in the northern and partially central zones. Dozens of abandoned deep wells, drilled originally for oil prospecting and plugged later, represent the interest for geothermal energy extraction. Their use will increase the economic feasibility of such projects.

1. INTRODUCTION

The Pripyat Trough located in the southeastern part of Belarus represents a deep sedimentary basin. Its crystalline basement represents a system of blocks, limited by deep faults with varying thickness of the overlying platform cover. Tectonic movements along faults produced developed salt tectonics, Geology (2001). The trough is limited by the North-Pripyat, South-Pripyat super-regional faults, the Bragin-Loev and Mikashevichi-Zhitkovichi salients. Thin sediments overlie the latter one. Its thickness usually ranges here from 200 to 400 m. The thickest cover

up to 5-5.5 km corresponds to the northern and southern zones of the trough.

The main tectonic activity, which formed the Pripyat Trough, took place during the Devonian time. It was accompanied by the Devonian volcanism within its northeastern part and explosion pipes, discovered recently, were formed within the Zhlobin Saddle, separated from the trough by the North-Pripyat Arm, Fig.1. The Pripyat Trough has its continuation through the Bragin-Loev Saddle into the Dnieper-Donets Depression located within the territory of the Ukraine. The Ukrainian Shield Polesskaya Saddle, Bobvnya, and Bobruisk buried salients adjoin it in southern, western and northwestern directions, respectively, Tectonics (1979).

The platform cover of the Pripyat Trough includes two thick salt complexes separated by so-called intersalt deposits. These complexes form the Upper Salt and Lower Salt bodies non-permeable for fluids. The salt tectonics widely developed within the whole Pripyat Trough, resulted in a complex geometry of salt bodies and the intersalt complex of rocks. The total thickness of salt bodies reaches sometimes 2-3 km. This corresponds to approximately 60-70% of the thickness of the whole platform cover, Garetsky et al. (1982).

Devonian rocks of terrigenous sediments permeable for fluids overlay the surface of the Upper Salt complex and under-salt carbonate and terrigenous permeable rocks underlay the Lower Salt.

The most of oil fields within the Pripyat Trough belong namely to the intersalt complex. It resulted in a good coverage of the whole trough area by drilling. Hundreds of oil boreholes were drilled in the process of oil prospecting here. Temperature logs were recorded in many of them. We used these diagrams as well as our own measurements to estimate the density of geothermal resources within this complex. Closed circles in Fig. 1 show the distribution of studied boreholes.

It is necessary to note that until now there was no estimates of geothermal resources fulfilled for the intersalt complex. Only very preliminary estimates of geothermal resources were fulfilled earlier for the whole territory of Belarus, Zui, Levashkevich (2000), Zui, Gribik (2000). The territory of the Pripyat Trough was identified as promising one for the geothermal energy utilization.

2. TEMPERATURE DISTRIBUTION AT THE SURFACE OF INTERSALT DEPOSITS

The intersalt complex exists within the whole Pripyat Trough excluding narrow local areas. Its depth is dependent on the crystalline basement tectonics within its individual blocks, the geometry of the Lower Salt and underlying carbonate and terrigenous formations.

The thickness of the intersalt deposits range mainly from 300 to 500 m. Up to 900-1,000 meters is observed in the western part of the considered area. The depth to the surface of this complex has sufficient lateral variations from a few hundred meters in the western part till a few kilometers in several local areas, Fig. 2.. In turn, it leads to sufficient temperature fluctuations, depending on these depths in addition to its dependence from heat flow density, characteristic for individual boreholes.

At the same time, the temperature of the intersalt sediments is one of the most important parameters for calculating the geothermal resources. We used temperature diagrams for 121 deep boreholes to compile this map, which was necessary to fulfill estimates of the density of geothermal resources available within this complex. This temperature distribution map is shown in Fig.3. The most detailed data are available for the northern and partly the central zones of the trough. Its western and northwestern parts are poor studied until now because of rare net coverage of those areas by drilling. The pattern of temperature isotherms here is very preliminary and has to be corrected when new boreholes will be drilled and respective temperature diagrams will be recorded.

The temperature at the roof of intersalt complex varies in a wide range from less than 30 °C till more than 75 °C. The lowest temperature values correspond to the western and northwestern parts of the Pripyat Trough. We extrapolated some of not numerous temperature diagrams recorded in shallow boreholes here to calculate temperature values at the considered surface. In result, the reliability of the map here is much lower than for the rest area.

A strip with temperature values above 50 °C was confidently traced within the northern zone of the trough. It is oriented sub-parallel to the North-Pripyat Marginal Fault and is tightly bounded to the burial depth of the intersalt complex roof, which reaches here up 3 and sometimes up to 4 km.

The temperature varies from 35-40 till 50 °C within the southern zone of the trough. Geothermal data are not available to the west of the Turov Depression. In result, it was not possible to trace reliable isotherms there. The isolines shown in this part of the map were drawn purely by an extrapolation. Their configuration could be considered as a preliminary one.

We don't consider the temperature distribution pattern for the base of the intersalt complex. It is similar to the considered map for the roof of the complex. The maximum difference in temperature between the base and the roof was recorded in the northern part of the studied area. We observe here 75-80 °C at the complex base instead of 70-75 °C for its roof. For the main part of the studied territory it differs only in 4-6 °C and occasionally in a few boreholes located in the northern and northeastern zones it reaches 10-15 °C. Therefore, we ignored this difference and the temperature at the roof of the intersalt complex was used below to calculate the density of geothermal resources.

The prevailing meridian orientation of isotherms was observed in the map, Fig. 3. The isotherm of 40 °C separates the central and eastern parts of the Pripyat Trough good studied by temperature logging from its less investigated western one.

It is necessary to mention that similarly to the western part of the Pripyat Trough, the geothermal information for the Bragin-Love Salient is scarce and isotherms drawn here are preliminary ones.

3. METHOD USED TO ESTIMATE THE DENSITY OF GEOTHERMAL RESOURCES

A number of approaches exist to estimate the density of geothermal resources, for instance Dyadkin, et al. (1991), Franko, Kral (1994), Sliupa et al. (2000), Hurter, Haenel (2002).

As this is the first attempt to determine the density of geothermal resources for the intersalt complex of the Pripyat Trough and we didn't consider any individual consumer of geothermal heat, it was enough to use one of comparatively simple methods. The calculations were aimed mainly to reveal quantitatively areas with higher and lower density geothermal resources. It will be also enough to outline the most promising territory of the Pripyat Trough for the first-priority utilization of geothermal energy. More detailed investigations will be necessary at the following steps when developing projects of geothermal energy utilization for particular heat consumers.

Geothermal resources represent that part of geothermal energy, which could be extracted in the nearest future taking into account the economic feasibility of its recovery.

The geothermal resources in Joules were estimated using the following formula, Hurter, Haenel (2002):

$$H_I = H_0 \cdot R_0, \quad (1)$$

where H_0 is the heat, accumulated in rocks in situ. It assumes the volumetric method of its recovery and includes both the heat, accumulated in the rock matrix (m) and in the water (w) saturated it.

$$H_0 = [(1-P) \cdot \rho_m \cdot c_m + P \cdot \rho_w \cdot c_w] \cdot [T_i - T_0] \cdot A \cdot \Delta z, \quad (2)$$

Where ρ_m, ρ_w is the density of the rock matrix and water, respectively, kg/m³, c_m, c_w is the specific heat capacity of the rock matrix and water, respectively, J/(kg·K), P is the effective porosity, dimensionless, T_i is the temperature at the roof of a water-bearing layer, °C, T_0 is the ground surface temperature, °C, A is the considered ground surface area, m², Δz is the effective thickness of the water-bearing horizon, m. R_0 is the recovery coefficient. It represents the part of heat, which could be extracted. This coefficient is dependent on the used technology. The doublet of wells is preferred for geologic conditions of the Pripyat Trough where one well is used to extract the warm water/brine and the another one is used to return the cooled water/brine to the aquifer. Then:

$$R_0 = 0.33 (T_i - T_r) / (T_i - T_0), \quad (3)$$

Where T_r is the reinjection temperature, °C. The rest parameters were explained above.

Experts of the European Union suggest the T_r to be accepted 25 °C, Hurter, Haenel (2002), though sometimes other values are used. For instance, at the Klaipeda Geothermal Plant, Lithuania, this value use 11 °C, Radeckas and Lukosevicius (2000). When only one production well is used to exploit a warm fresh water horizon, then, Hurter, Haenel (2002)

$$R_0 \approx 0.1. \quad (4)$$

The described approach doesn't require special tests preliminary of wells to be done. All the necessary data are available from the lithologic-mineralogical description of the drill core, log diagrams and the information on the

porosity of rock samples. We don't consider here the information on salinity of warm mineral water and brines of the Pripyat Trough. It represents a special problem, as the salinity of brines in deep parts of the trough reaches sometimes up to 400-420 g.p.l.

4. GEOTHERMAL RESOURCES

The density of geothermal resources of the intersalt complex was estimated using the equations (1)-(4). The specific capacity of the rock matrix and warm water/brines was accepted to be $2.76 \cdot 10^6$ and $4.18 \cdot 10^6$ J/(m³·°C), respectively. The averaged porosity was accepted to be 5%. Our estimates showed that lateral variations of the porosity from 0 to 10% result in an error in the density of geothermal energy determination around 10%, and seldom 20%. The temperature 11 °C of reinjected water/brines is accepted like it is used at the Klaipeda Geothermal Plant, as geologic conditions of the Pripyat Trough are similar to those existing in the central part of the Baltic Syncline. The resulting data in Joules were recalculated into tons of oil equivalent (t.o.e.) using the coefficient $k = 0.034 \cdot 10^{-9}$ t.o.e./J, Dyadkin et al. (1991, p.170). In other words, to produce 1 J of heat it is necessary to use $0.034 \cdot 10^{-9}$ t.o.e. Temperature diagrams were analysed for around 135 deep boreholes for this analysis. Their distribution was shown in Fig. 1.

The map of the density of geothermal resources within the intersalt complex of the Pripyat Trough is shown in Figure 4. The isolines are given in t.o.e./m². The location of some towns and settlements at the map indicates possible consumers of geothermal energy and their relation to areas with different density of geothermal resources.

The studied boreholes correspond to the northern and partly the central part of the trough. As it was indicated above, sparse boreholes were studied in the western part of the Pripyat Trough within the Turov and Starobin depressions, as well as within its southeastern part, stretched along the Bragin-Love Salient. In result, the pattern of the drawn isolines could be considered here as a preliminary one. We extrapolated them in poor studied parts of the trough area, e.g. within the Bragin-love Salient, or within the western part of the trough.

The density of geothermal resources varies within the whole area in a wide range from 0.112 till 1.75 t.o.e./m². They exceed 1.0 t.o.e./m² only within the northern and northeastern parts of the trough. The latter one adjoins the Bragin-Love Salient. The isolines are oriented mainly sub-parallel to the North Pripyat Marginal Fault. It is possible to indicate three anomalies of high density of geothermal resources. Two of them are related to the Sudovitsa and Berezina local geologic structures with the density of 1.44 and 1.41 t.o.e./m², respectively. The third anomaly has a wider area and includes a number of local structures: Pervomaiskaya (1.27 t.o.e./m²), Rechitsa (1.35 t.o.e./m²), East-Pervomayskaya (1.08-1.2 t.o.e./m²), and others.

There are a number of local structures with the density of geothermal resources ranging from 0.2 to 0.75 t.o.e./m². The Visha (0.26-0.49 t.o.e./m²), Davydovka (0.28-0.75 t.o.e./m²), Ozeiminskaya (0.65-0.71 t.o.e./m²), Ostashkovichi (0.56-0.60 t.o.e./m²) and others.

Values lower relatively to the northern area are typical for the southern part of the trough. Their background range is 0.25-0.65 t.o.e./m². Only a single value reaches here 1.8 t.o.e./m². The isoline 0.50 t.o.e./m² contour the Elsk, East-

Elsk, East-Vystupovichi local structures. The maximal value 1.80 t.o.e./m² was estimated for the Elsk-28 borehole due to anomalously thick intersalt deposits existing here (1623 m). A similar situation was observed for the East-Vystupovichi-2 (1.16 t.o.e./m²) and Grebeni-1 (1.20 t.o.e./m²) boreholes, where the thickness of intersalt rocks reaches 950 and 858 metres, respectively. A chain of such local anomalies with increased density of geothermal energy was traced sub-parallel to the South Pripyat Marginal Fault.

The isoline of 0.50 t.o.e./m² crosses the whole Pripyat Trough in the sub-meridional direction and subdivides it into the western colder and the eastern and northeastern warmer parts. The prevailing values of the density of geothermal resources within the trough range from 0.20 to 0.60 t.o.e./m², for instance the Mozyr (0.29-0.41 t.o.e./m²), Savichskaya (0.33-0.37 t.o.e./m²), Kopatkevichi (0.16-0.21 t.o.e./m²), Kamenka (0.26-0.37 t.o.e./m²) local structures. A high value of 1.14 t.o.e./m² received for the single borehole Turov-1 is explained by anomalous thickness of the intersalt rocks (907 m). There are no temperature logs recorded to the west of the Turov Depression.

As it was mentioned, the intersalt deposits absent in some narrow zones of the trough, but these areas are small and were ignored when calculating the density of geothermal resources as well as the geothermal potential, representing the total amount of recoverable heat within the considered complex, which could be economically extracted by means of technique available at present time.

To calculate the geothermal potential for the whole area, the intersalt complex was subdivided into squares 10x10 km. In this way the area of the intersalt complex was estimated to be 23125 km² or 23125000000 m². The averaged density of geothermal resources within each of squares multiplied by its area in metres square allowed to receive the geothermal potential for each of them. Summation of off all squares gave the geothermal potential of the intersalt complex which is $3,6948E \cdot 10^{20}$ J or 12 562 321 967 t.o.e.

5. CONCLUSIONS

The intersalt deposits of the Pripyat Trough represent an interest for practical utilization of geothermal energy. The geothermal conditions of the trough are similar to those in the western Lithuania, where the Klaipeda Geothermal Plant is used during several years. This renewable geothermal energy was not used within the Pripyat Trough until the last time.

The northern and northeastern parts of the trough represent the paramount interest to construct here a pilot geothermal plant, though the rest area has the density of geothermal resources, acceptable for practical utilization, e.g. for heating of greenhouses and buildings. It varies from 0.2 to 1-1.5 t.o.e./m² depending on the local area.

Many boreholes were drilled within the Pripyat Trough outside oil fields in the process of oil prospecting,. Dozens of them could be repaired and used to exploit the geothermal resources.

It is necessary to construct one or two demonstration projects as the first step in practical utilization of geothermal energy within the Pripyat Trough and Belarus as a whole.

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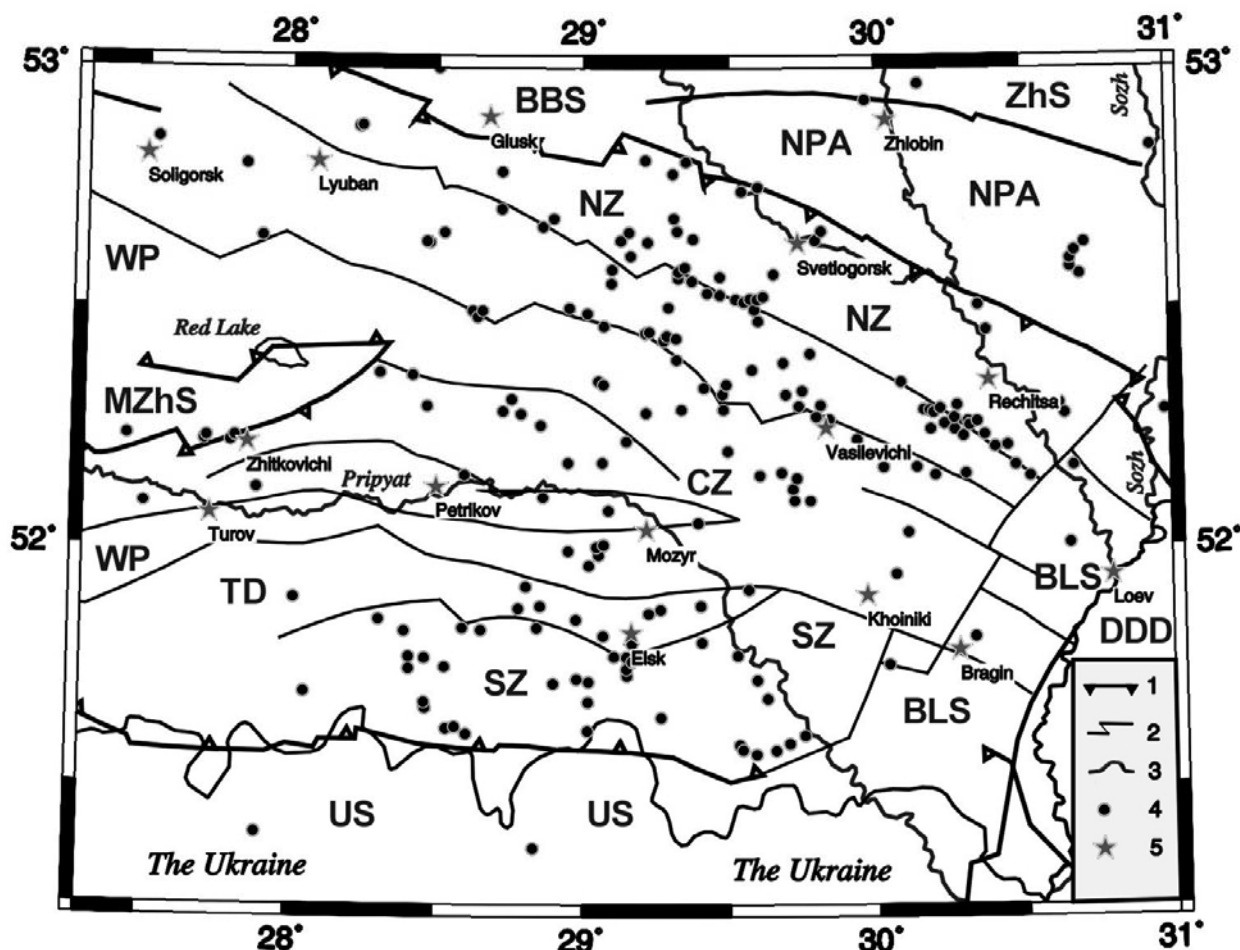


Figure 1: A Position of the Pripyat Trough.

Legend: 1 – Super-regional faults, 2 – Regional faults, 3 – Belarus border, 4 – Position of boreholes with available thermograms, 5 – Main towns and settlements. Abbreviations: BBS – Bobruisk Buried Salient, BLS – Bragin-Love Saddle, MZHS – Mikashevichi-Zhitkovichi Salient, NPA – North-Pripyat Arm, CZ, NZ, SZ – Central, North, and South zones of the Pripyat Trough, respectively, TD – Turov Depression, US – Ukrainian Shield. WP – Western Part of the Pripyat Trough, ZhS – Zhlobin Saddle.

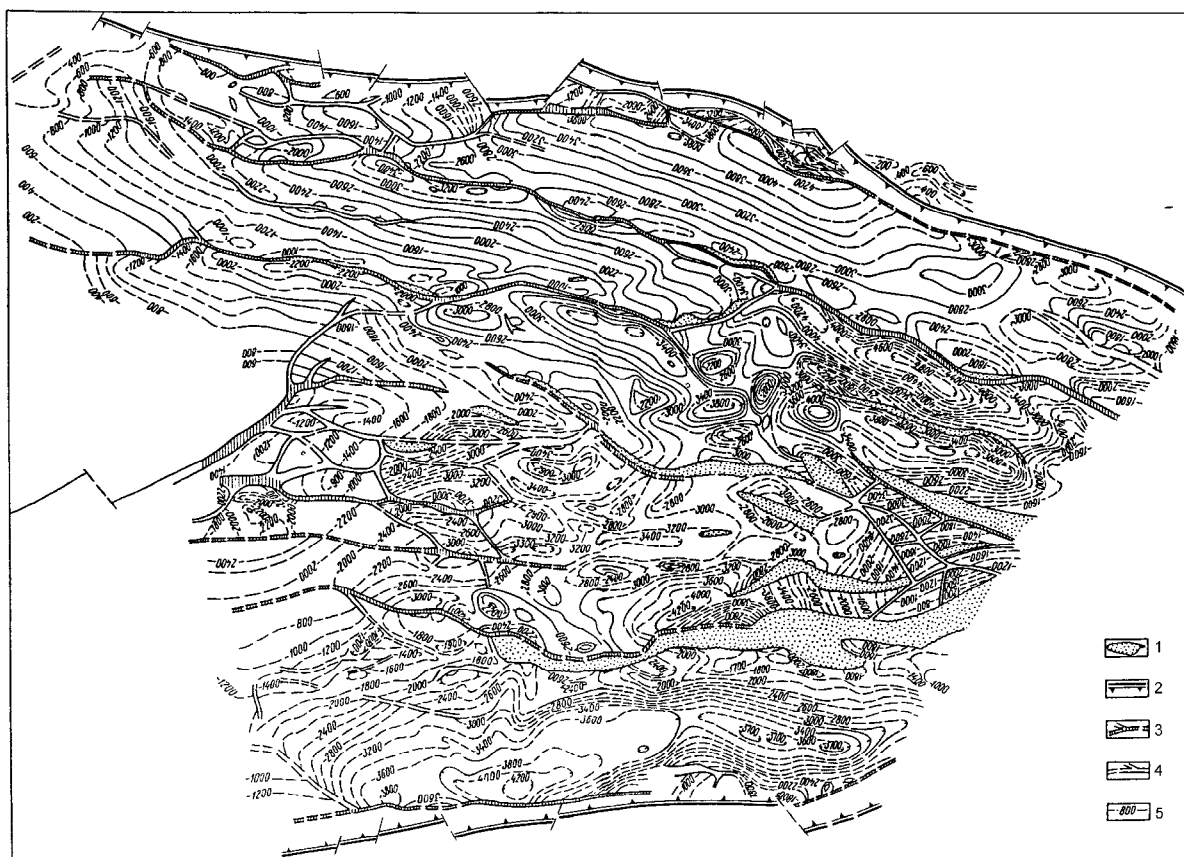


Figure 2: A map of the depth to the roof of the intersalt complex within the Pripyat Trough (Geology..., 2001).
Legend: 1 – Zones, where intersalt deposits are absent, 2 – Pripyat Graben, 3 – Steps, salients, 4 – Local faults, 5 – Isohypes of the surface of intersalt deposits, m.

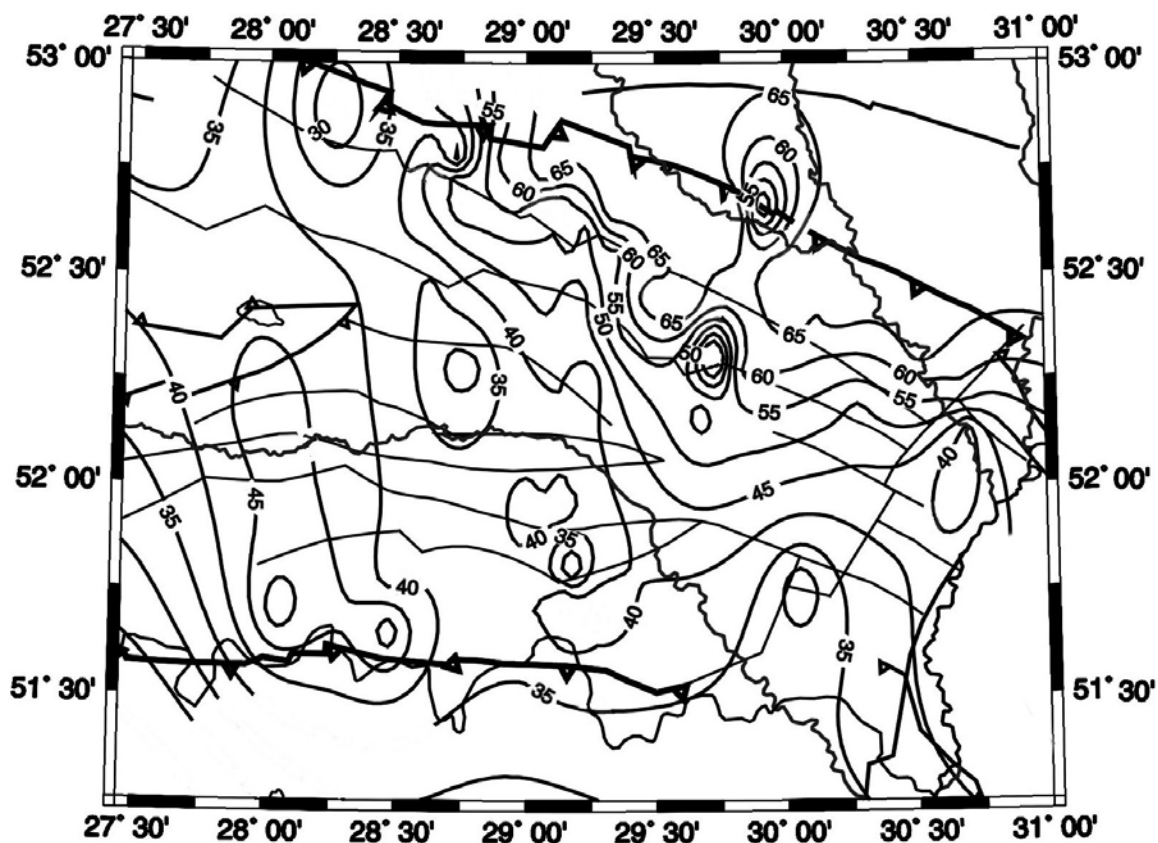


Figure 3: Temperature distribution at the roof of the intersalt complex within the Pripyat Trough.
Legend: See Figure 1. Isolines are in °C.

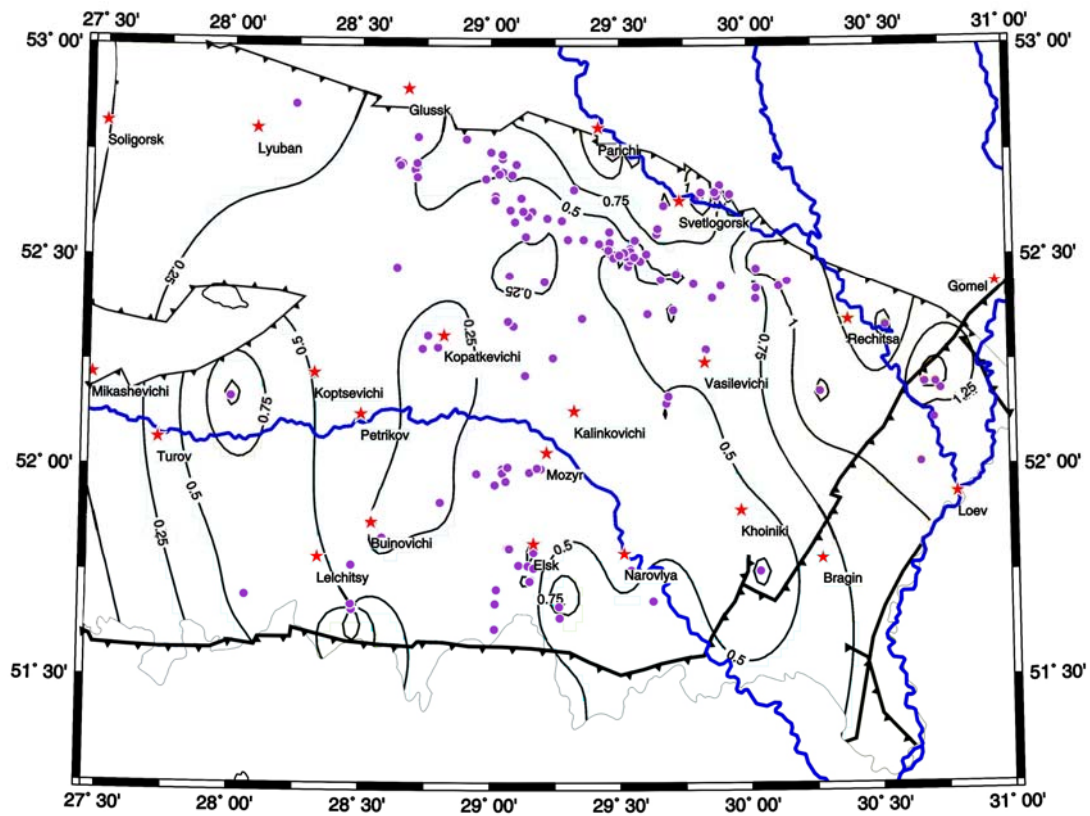


Figure 4: Density of geothermal resources of the intersalt complex within the Prip'yat Trough.

Legend: See Figure 1. Isolines are in t.o.e./m².