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# Geothermal Resources and their Utilization in Belarus

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## ABSTRACT

Belarus is located within western part of the East European Platform. In geologic respect it is a junction of crustal blocks of different age. The thickness of deposits varies from 80 – 100 m to 1.5 – 5.5 km within deep sedimentary basins: Pripyat Trough, Orsha and eastern part of the Podlaska-Brest depressions. A contrast terrestrial temperature field was revealed within sediments ranging from 7 – 8 ºC within fresh water horizons to 80 – 115 ºC in deep complexes of the Pripyat Trough.

Resources of geothermal energy were estimated for both shallow horizons within the western part of the country and deep ones exceeding 1 km in the Pripyat Trough and the Podlaska-Brest Depression. They vary in a wide range from 10 – 20 to 200 – 300 kilograms of oil equivalent per square meter (kg.o.e./$m^2$) within crustal blocks with thin sedimentary cover. The highest density of resources was observed in deep complexes of the Pripyat Trough up to 1 – 4 t.o.e./$m^2$. These horizons have high content of dissolved chemicals up to 350 – 420 g/l.

Around 15 geothermal installations are in operation in the country supplying space heating for industrial buildings with the total installed heat pump capacity approaching to 2 MWth. Around 40 small heat pump systems were installed in private cottages in and around the main towns and cities with total heat capacity around 1 – 1.5 MWth. All installations use cold water taken from shallow boreholes with typical temperature 8 – 10 ºC as a primary energy source. One installation is based on utilization of river water. Another 12 - 15 heat pump installations are under construction.

It is planned to create experimental heat pump installations in several new apartment houses in 3 – 5 forthcoming years for space heating and warm water supply. Project documentation is finishing for a pilot geothermal station for the greenhouse complex “Berestye” in the western part of the country. It was scheduled to put it into experimental operation during the end of 2009 – beginning of 2010.

## 1. INTRODUCTION

The whole area of Belarus is located within western part of the Precambrian East European Platform. Its crust represents a system of crustal blocks of different age and origin comprised by three main lirtosphere blocks: Fennoscandia, Sarmatia and Volgo-Uralia. Their junction is in the territory of the country.

Three deep sedimentary basins exist in the northeastern, southeastern and southwestern parts of the considered area. They are the Orsha Depression, Pripyat Trough and the eastern part of the Podlyaska-Brest Depression, respectively. The main part of the latter one is stretched into the territory of Poland and only its easternmost margin is traced in southwestern Belarus. Less than 10 boreholes were drilled through the whole sedimentary cover within the vast area of the Orsha Depression. It results in rather preliminary knowledge in geologic features of its deep horizons, including the terrestrial temperature field. The highest thickness of the platform cover within the Mogilev and Vitebsk muldes of the Orsha Depression reach 1.7 – 1.9 km, Aizberg et al. (2004).

The crystalline basement within the whole territory of the country is covered by sediments. The platform cover has a variable thickness which ranges from 80 – 100 m within the Central Belarusian Massif to 1.5 – 1.7 km within negative structures: Podlaska-Brest and Orsha depressions, Fig.1. Margins of the Belarusian Anteclise were traced along the depth –0.5 km below sea level and –0.7 km for the Orsha Depression. The Polesian Saddle and Mikashevichi-Zhitkovichi salient separate the Podlaska-Brest Depression from the Pripyat Trough. The southern marginal fault limits the latter one from the Ukrainian Shield, and the northern superregional fault, separates it from the Bobruisk Buried Inlier, North-Pripyat Arch and the Zhlobin Saddle. The Bragin-Loev Saddle joins the Pripyat Trough with the Dnieper-Donets Depression, the main part of which is stretched into the territory of Ukraine.

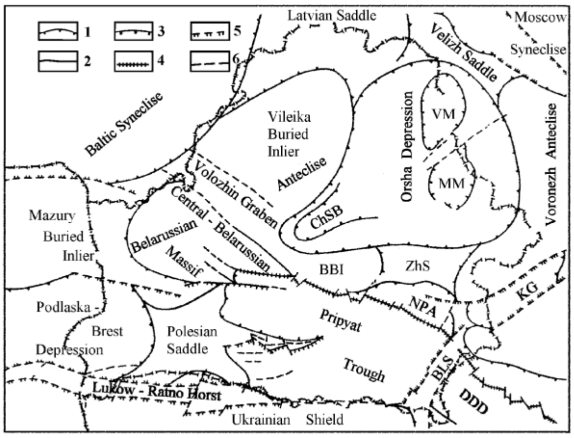


**Figure 1: Main geologic units within the territory of Belarus.**

Legend: 1 – the largest, 2 – large, 3 – medium-size platform faults: 4 – super regional, 5 – regional, 6 – sub regional and local faults. Abbreviations: DDD – Dnieper-Donets Depression; KG – Klintsy Graben; BLS – Bragin-Loev Saddle; NPA – North Pripyat Arch; BBI – Bobruik Buried Inlier; ZhS – Zhlobin Saddle; ChSB – Cherven Structural Bay; VM, MM – Vitebsk and Mogilev muldes, respectively.

High salinity brines were observed in deep strata in the Pripyat Trough. The content of dissolved chemicals reaches on average here up to 200-300 g/l. It reaches 400 – 420 g/l in its deepest parts.

Hundreds of deep boreholes were drilled during oil prospecting works within the whole territory of the Pripyat Trough. In result its geologic features were best studied comparable to other structures in the country. A crystalline basement represents here a system of blocks, limited by deep faults with varying thickness of the overlying platform cover. Many faults penetrate the whole crust and reach the upper mantle.

Tectonic movements along faults within the Pripyat Trough produced developed salt tectonics, Geology (2001). The tectonic activity, which formed the Pripyat Trough, took place during the Devonian and its main stage of downwarping belongs also to the Devonian time. Its development was accompanied by the Devonian volcanism within its north-eastern part as well as explosion pipes, formed to the north of it within the Zhlobin Saddle, separated from the trough by the North-Pripyat Arm, see Fig.1. The Lower Salt base reaches the depth 4.5 – 5.5 km depending on the considered basement block.

The platform cover of the trough has a complex geological structure with two salt bodies. Terrigenous sediments separate the Upper Salt and Lower Salt deposits. They comprise so-called Intersalt Complex. The depth to its surface is on average 2.0 – 3.0 km. A thickness of permeable intersalt deposits ranges from 100 m in the western part of the area to 1000 m observed in a few wells. The complex geometry of these rocks influences the terrestrial temperature field pattern.

The sedimentary cover within the easternmost part of the Podlaska-Brest Depression varies on average from c.a. 0.5 km along its margin with the Mazury Buried Inlier of the Byelorussian Anteclise, Lukow-Ratno Horst and the Polesian Saddle till 1.7 km along the polish border. A few dozens of deep boreholes were drilled here, but their areal distribution within the depression is irregular. A specific feature of this structure is a deep position of the fresh water base. It reaches in some localities up to 1.0 – 1.3 km.

Very thin sedimentary cover overlies the crystalline basement of the Central Byelorussian Massif. Its thickness ranges approximately from 80 to 150 meters. Within the rest part of the Belarussian Anteclise, Polesian and Latvian saddles, Bobruisk and Surazh buried inliers and the Zhlobin Saddle it usually ranges from 200 to 500 meters. Dozens of boreholes within their limits were studied in geothermal respect. In most cases there are no laterally extended water-confining beds and the fresh water frequently was observed in cracked rocks of the crystalline basement.

The western slope of the Voronezh Anteclise is stretched into the easternmost part of Belarus. Its main part is in the territories of the Russian Federation and the northeastern Ukraine. The geology within the considered area was studied mostly by shallow boreholes.

## 2. TERRESTRIAL TEMPERATURE FIELD

Geothermal investigations were started since fifties of the last century, though very first temperature measurements undertaken in a hole drilled in Minsk in 1929, Bogomolov, et al., (1972). At that time it was the deepest borehole drilled in the territory of Belarus. The observed temperature at the depth of 353.5 m was 16.5 ºC. Separate geothermal measurements in deep boreholes were started in fifties when first oil prospecting boreholes were drilled within the Pripyat Trough. Regular geothermal investigations were undertaken since the beginning of sixties and continued to our time.

Hundreds of thermograms were accumulated during a few decades of investigations. They were used to compile temperature distribution maps for selected depths. In the early stage of geothermal observations it was believed that the thermal state of rocks is rather uniform within Precambrian platforms. As the data were accumulated it became evident that a contrast pattern of the terrestrial temperature field was revealed within the territory of the country.

A temperature at the base of the sedimentary cover of the Belarusian Anteclise ranges from 8 –9 till 13 –17 ˚C. The maximal recorded values at the surface of the crystalline basemebnt within the Podlaska-Brest Depression increases to 37 –40 ˚C and to around 25 – 35 ºC for the Orsha Depression. The highest temperature within the platform cover was observed within the Pripyat Trough. In some boreholes it reaches 100 – 115 ºC at the depths 4 – 5 km.

### 2.1 Temperature map for the depth of 100 m

Temperature distribution map at the depth 100 m for the whole territory of Belarus is shown in Fig. 2.

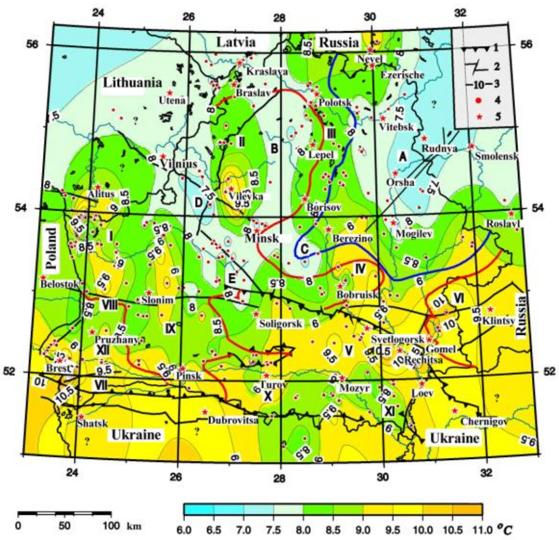


**Figure 2: Temperature distribution map at the depth of 100 m within Belarus.**

Legend: 1, 2 – superregional and regional faults within the crystalline basement, 3 – isotherms, ˚C, 4 – studied boreholes, 5 – towns and settlements. Anomalies of increased temperature: I – Grodno, II – Molodechno-Naroch, III – West Orsha, IV – Chechevichi-Rechitsa, V – Pripyat, VI – western slope of the Voronezh Anteclise, VII – Podlaska-Brest, VIII – Mosty, IX – Lyakhovichi-Elnya, X – Turov, XI – Vystupovichi-Elsk, XII – Kobrin-Pruzhany. Low temperature anomalies: A – East-Orsha, B – eastern part of the Belarusian Anteclise, C – Cherven Structural Bay, D – central part of the Belarusian Anteclise, E – Central Belarusian Massif. Red heavy lines indicate margins of positive structures: Belarussian Anteclise, Polesian Saddle and the Voronezh Anteclise (their limits were outlined by –500 m isoline). The blue line traces margins of the Orsha Depression (outlined by –700 m isoline).

Only a few thermograms recorded in boreholes were used within adjoining territories beyond borders of the country. Therefore a pattern of isotherms outside the territory of the country is very preliminary.

The depth of 100 m wholly belongs to the fresh water zone (a zone of active water exchange). An influence of the water filtration effect reflects in shapes of thermograms. In other words, a convective component of heat transfer is pronounced here. Thermograms from around 350 sites were used to compile the map. Only around 10 diagrams of the standard logging, recorded by drilling companies, were added after the careful selection of them for those boreholes, where enough time elapsed after the drilling was finished and temperature measurements were undertaken. In other words, the temperature equilibrium between the wellbore fluid and the surrounding massifs of rocks at the moment of measurements was reached.

Isotherms were drawn by means of an interpolation within the territory of Belarus. Outside its borders they were extrapolated and their configuration is very preliminary one, as no reliable temperature-depth diagrams were available for the territory of Poland and the Ukraine. We had only a few diagrams for territories of Lithuania, Latvia and Russia adjoining the borders of Belarus. The interval 0.5 °C was used to draw isolines, which is acceptable, keeping in mind that the calibrated thermistor thermometer, was used for borehole temperature measurements, had the error of absolute temperature readings around ±0.05 °C.

The temperature at the depth of 100 m varies in the range of 7 – 11.5 °C. The difference between them is 4.5 ºC. Temperature values above 8 ºC are typical for the northern zone of the Pripyat Trough and the Podlaska-Brest Depression. The isotherm of 9 ºC has the continuation beyond the North Pripyat marginal fault and is traces into the North Pripyat Arch, Zhlobin Saddle and the western slope of the Voronezh Anteclise. We had a lack of reliable thermograms in the northern part of the Pripyat Trough at the considered depth of 100 m. It was relted in smooth course of isotherms. Available thermograms, recorded in the course of standard logging, when the ambient temperature of rock massif disturbed by drilling process was not reached, have very low quality to be used to compile this map. The temperature field within the whole territory of the country has a contrast pattern at the studied depth. Regional and local anomalies are clearly distinguished. A part of them was revealed recently.

In the eastern part of the Orsha Depression within a triangle of Orsha – Smolensk – Cherikov towns exists the *East Orsha anomaly* of low temperature values 6.5 – 7.5 ºC. It includes almost the whole area of the Mogilev Mulde. Its shape within adjoining area of Russia is very preliminary because of a lack of reliable thermograms.

A strip of increased temperature of meridian orientation crosses the whole territory of the Orsha Depression. This *West Orsha anomaly* was traced in the western part of it and partly within the eastern slope of the Belarussian Anteclise along the line joining towns: Rechitsa – Svetlogorsk – Klichev – Belynichi – Berezino – Borisov – Lepel Chashniki – Ezerishche – Nevel. Its north continuation in the vicinity of Ezerishche and Nevel towns again has very preliminary shape as only one thermogram was available in the adjoining area of Russia. Temperature values within the *West Orsha anomaly* range from 10 to 11.5 ºC.. The local Belynichi-Chechevichi-Rechitsa anomaly temperature above 8.5 ºC was observed in its southern part. The isoline of 8 ºC separates the Belarussian Anteclise from the Cherven Structural Bay of the Orsha Depression.

The *Chashniki-Polotsk anomaly* of low temperature values exists in the north-eastern part of the country. Its western part at the latitude of Polotsk town is joined with the anomaly of the eastern slope of the Belarussian Anteclise and the Cherven Structural Bay of the Orsha Depression.

The isotherm of 9.5 ºC in the eastern part of the Podlaska-Brest Depression is traced along the Belarus-Ukraine border through the Polesian Saddle. It reaches the longitude of Stolin town and continues into the territory of Ukraine. The isotherm of 9.0 ºC of this anomaly as well through the Polesian Saddle has its continuation into the Pripyat Trough. Then it is continued into the Belynichi-Rechitsa anomaly and is traced to the western slope of the Voronezh Anteclise and continues into Russia, Zui (2004, 2005).

*The Grodno anomaly* of increased temperature above 9 °C is stretched in the meridian direction and has its continuation into the territory of Lithuania. A lack of reliable data there doesn't allow tracing its northern part.

*The Molodechno-Naroch anomaly* of elevated temperature above 8 ºC has the meridian orientation and in its northern part reaches the junction of Belarus, Lithuania and Latvia borders. It subdivides the anomaly of low temperature of the Belarussian Anteclise into two parts. They are the *anomaly of the eastern slope of the anteclise* and the *anomaly of its central part (the Central-Belarusian Anomaly)*. The local *Kobrin-Pruzhany*, as well as the *Mosty* and *Lyakhovichi-Elnya* anomalies of elevated temperature, exceeding 9 ºC, has also the meridian orientation.

### 2.2 Temperature map for the depth of 400 m

Temperature distribution at the depth of 400 m is shown in Fig.3.

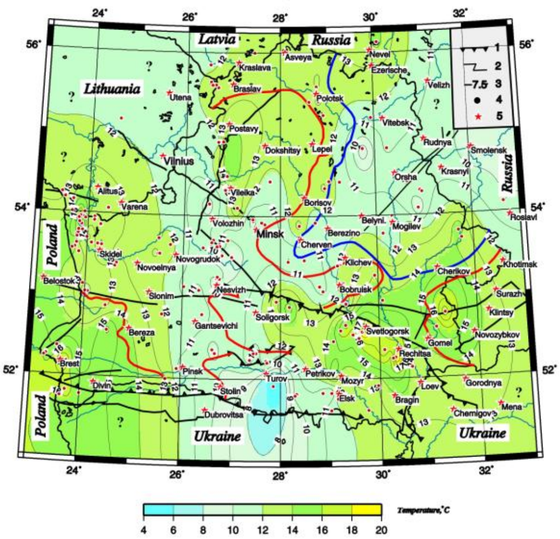


**Figure 3: Temperature distribution map at the depth of 400 m within Belarus.**

Legend: See Figure 2.

A number of extrapolated temperature-depth profiles were used to compile this temperature map. The linear downward extrapolation of thermograms was applied. Only 214 temperature-depth diagrams were used to prepare this map.

Almost 50% of them were extrapolated ones. Around 20 reliable curves of standard logging were used as well. They were recorded mostly in boreholes of adjoining areas of Russia, Lithuania and the north-eastern Belarus.

The temperature field contrast increases with depth at the map, shown in Fig. 2. But the main features are remaining similar. The temperature ranges here from 8.5 to 19 ºC. Its values in the southern part of the country exceeding 12 ºC are typical for the Pripyat Trough, Zhlobin Saddle, as well as the western slope of the Voronezh Anteclise. The West-Orsha anomaly with the temperature of 11 – 19 ºC is traced from Rechitsa in the south to Nevel towns in the north. Higher values are typical for the northern zone of the Pripyat Trough. It is possible to reveal besides this anomaly another one within the trough. It has the SSW – NNE direction along the deep Perga Fault within the crystalline basement, which crosses the Pripyat Trough. Its main axis is traced along the following towns and settlements: Mozyr – Rechitsa – Svetilovichi – Mstislavl, see Fig. 3.

The *East - Orsha Anomaly* of low temperature below 11 ºC is clearly distinguished to the east of the line, crossing the towns: Roslavl – Belynichi – Vitebsk – Velizh. It occupies a smaller area, which is also the result of reduced number of reliable thermograms used to compile this map.

The *Belynichi – Rechitsa Anomaly* has the same position, but its shape is very preliminary one as within the triangle of Klichev – Belynichi – Borisov towns studied boreholes were absent. It has the continuation into the Zhlobin Saddle and joins with the positive anomaly in the western slope of the Voronezh Anteclise. The low temperature anomaly limited by the isotherm of 11 ºC is distinguished in the Cherven Structural Bay and the Osipovichi Uplift. A small low temperature anomaly near a junction of the Belarus – Lithuania – Latvia borders was traced very preliminary because of the lack of reliable thermograms within this area.

A positive temperature anomaly exists in the eastern part of the Podlaska-Brest Depression. It has a continuation into Poland. The *Grodno Anomaly* is observed at the depth of 400 m as well, but its limits are shown without details because of a lack of thermograms. In general, it is necessary to note when the depth increases more and more small details disappear within the whole studied territory mainly because a lack of reliable data.

The *Molodechno – Naroch* anomaly of increased temperature (12 – 14 ºC) has the similar shape. At the same time the *Lyakhovichi – Elnya* anomaly, distinguished in the temperature map for the depth of 100 m, "disappears" at the depth of 400 m as the available thermograms recorded in shallow boreholes within its limits couldn't be extrapolated to the depth of 400 m. Isolines of 12 and 13 ºC join the Grodno anomaly with the anomaly of increased temperature, existing within the Podlaska-Brest Depression.

### 2.3 Temperature distribution at the depth of 2 km

It was possible to compile terrestrial temperature maps for depths deeper than 700 – 1,000 m in Belarus only for the Pripyat Trough which was the best studied area in geothermal respect among other sedimentary basins of the country. As mentioned above, when the depth increases small details disappear, because the number of available thermograms also decreases. It also concerns the Pripyat Trough. For instance, for the depth of 4 km the number of reliable thermograms doesn't exceed 20 which is not enough to compile detailed maps.

The temperature field pattern for the depth of 2 km is shown in Fig. 4. It has a distinct contrast. In the northern zone of the trough the temperature in average is two times higher than in its southern and western parts. A wide zone of low temperature exists to the left of the isotherm of 35 °C. Only a few thermograms were available here and they didn't allow distinguishing small details within this area. The highest temperature exceeds 60 – 70 °C within the northern and north-eastern zones of the trough. The main oil fields were encountered namely within this warm area, Fig. 4.

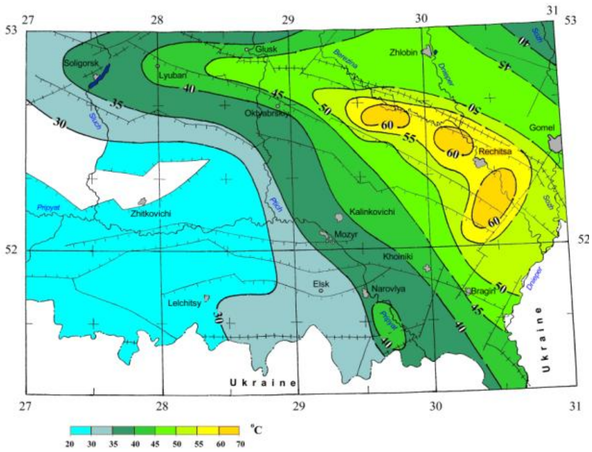


**Figure 4: Temperature distribution at the depth of 2 km within the Pripyat Trough, Belarus.**

The central part of the anomaly existing in the northern part of the trough is limited by the isotherm of 50 °C. This zone is traced in the western direction till Luban town and continues to the south-east into the Gremyachy Buried Salient, Russia and the Dnieper-Donets Depression, the main part of the latter one is in Ukraine. In the north direction it was traced into the North Pripyat Arch. Local anomalies within the Elsk Graben and the Vystupovichi Step were contoured by the isotherm of 40 °C. They are based only on three thermograms of deep boreholes drilled within the Karpovichi and Zhelon local uplifts in the southern part of the trough. The background temperature values here from 35 to 40 °C.

The platform cover within the trough and the Podlaska – Brest Depression is the most warmed up among adjoining tectonic units. Temperature at the sedimentary cover base reaches 40 – 42 °C within the Podlaska – Brest Depression and increases up to 100-115 °C within the Pripyat Trough (Pervomaisk, Barsuki and other local structures). Maximal temperature, for instance, recorded in the hole Basuki 63, was 115 °C at the depth of 4 km.

### 3. HEAT FLOW DENSITY

To compile Heat flow density distribution within Belarus a catalogue of heat flow was used. It contains the base of 481 values, determined for individual boreholes drilled within all tectonic units of the country.

All published heat flow density data were used to compile this map (Zui et al., (1993); Zhuk et al., (2004); Zui, (2005); Zui, Zhuk, (2006)), as well as published data for adjoining areas of Poland, Lithuania, Latvia, Russia and Ukraine. Heat flow density distribution is differentiated, Fig. 5. At the background of low values (30 – 40 mW/m$^2$) positive anomalies are distinguished within the Podlaska-Brest Depression (50 – 55 mW/m$^2$) and the Pripyat Trough where it exceeds 60 mW/m$^2$ in its northern zone.

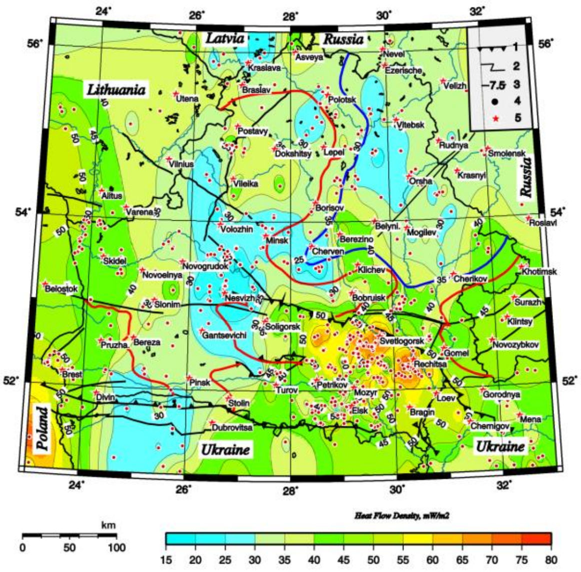


**Figure 5: Heat flow density map for Belarus.** Legend see in Fig. 2.

Heat flow density of 40 – 50 mW/m$^2$ was observed also within local anomalies of the Belarusian Anteclise, Orsha Depression, North Pripyat Arch, Zhlobin Saddle, and the western slope of the Voronezh Anteclise. As before the Pripyat Trough represents the best studied in heat flow geologic unit within the whole territory of Belarus. Detailed pattern of heat flow distribution within its limits is shown in Fig. 6.

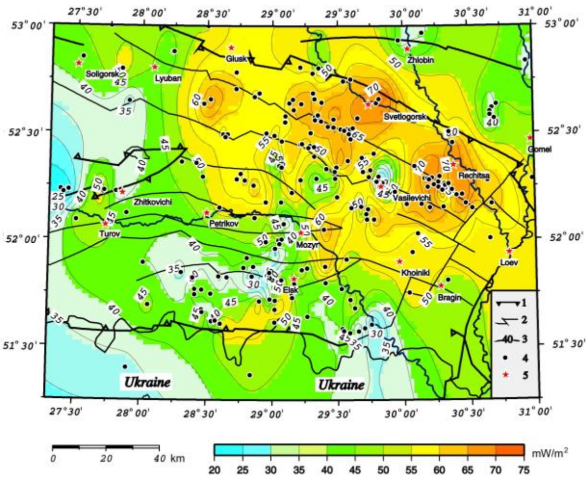


**Figure 6: Heat flow density map for the Pripyat Trough, Belarus.**

Legend: Dots show the location of studied boreholes, see also Fig. 2.

Besides the main orientation of heat flow density isolines along the North Pripyat Fault, it is clearly distinguished their another direction with heat low of 50 – 60 mW/m$^2$, traced along the line joining Mozyr – Rechitsa towns. It is orthogonal to the main stretching of the anomaly in the north zone and follows the Perga crustal fault, penetrating into the upper mantle.

Heat flow density within the Pripyat Trough varies in a wide range from less than 40 mW/m$^2$ in its western part to more than 100 mW/m$^2$ within nuclei of salt domes., Tsybulya, Levashkevich, (1990); Zui et al., (1991); Zhuk et al., (2004). It was observed that nterval heat flow values are dependent on the depth. This fact is the result of many factors: thermal conductivity variations for rocks comprising the platform cover, groundwater filtration, varying tectonic conditions, etc., Zhuk et al., (2004). A considerable influence on the observed heat flow has the salt tectonics, especially within near-the-fault zone of the Rechitsa – Visha Swell. Salt domes are good studied within the Pripyat Trough both by drilling as well as by geophysical methods. Within most of them geothermal measurements were fulfilled and heat flow determinations done. In the vicinity of the Vasilevichi settlement a heat flow was calculated for shallow depth intervals (above-the-salt deposits) and the influence of near-the-surface factors is noticeable there. It resulted in lower heat flow comparably to adjoining areas of the Pripyat Trough.

Heat flow density values below 30 mW/m$^2$ form a chain of small anomalies, partly located along the Volyn – Orsha – Krestsy Paleodepression, Paleotectonics…, (1983), having as a rule, the longitudinal orientation. One of them, covering the largest area, is traced from the northern part of the Polesian Saddle and the Mikashevichi – Zhitkovichi Salient to the northern part of the Belarussian Anteclise in the direction of Gantsevichi – Nesvizh towns. At the latitude of Minsk the strip has a tongue into the Cherven Structural Bay and the Osipovichi Uplift. Low heat flow is typical for the Central Belarussian Massif, see Fig.5.

The Grodno and the Podlaska Brest anomalies are joined by the isoline of 40 mW/m$^2$ with heat flow values in their central, parts exceeding 50 mW/m$^2$. It is continued in its northern part into the territory of Lithuania and probably joins with the high heat flow anomaly in western Lithuania. A lack of thermograms doesn't allow tracing it more reliably. A heat flow density pattern within the adjoining area of Poland was also studied only in a few near the Belarus-Poland border locations.

## 4. GEOTHERMAL RESOURCES

Ggeothermal resources were studied for several horizons of the Pripyat Trough, eastern part of the Podlaska-Brest Depression within the territory of Belarus as well as for shallow sedimentary horizons in the western part of the country. The approach described in (Atlas..., 2002) was used to calculate them. Recoverable resources, accumulated within the Intersalt Complex, deposits of the Upper Salt, Devonian sediments, overlying the Upper Salt Complex and the Jurassic rocks of the Pripyat trough were determined.

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

$$H_1 = H_0 \bullet R_{0,} \qquad (1)$$

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.

$$H_0 = [(1\text{-}P)\cdot\rho_m\cdot c_m + P\cdot \rho_w\cdot c_w]\cdot[T_t - T_0]\cdot A\cdot \Delta z, \qquad (2)$$

where $\rho_m$, $\rho_w$ = density of the rock matrix and water, respectively, kg/m$^3$; $c_m$, $c_w$ = specific heat capacity of the rock matrix and water, respectively, J/(kg·K); $P$ = effective porosity, dimensionless;, $T_t$ = temperature at the roof of a water-bearing layer, ºC; $T_0$ = ground surface temperature, ºC; $A$ = ground surface area, m$^2$; $\Delta z$ = effective thickness of the water-bearing horizon, m; $R_0$ = 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 another one is used to return the cooled water/brine to the aquifer. Then:

$$R_0 = 0.33\ (T_t - T_r) / (T_t - T_0), \qquad (3)$$

where $T_r$ is the reinjection temperature, ºC.

It was suggested the $T_r$ to be accepted 25 ºC, Hurter and, Haenel (2002), though other values can be used. For instance, at the Klaipeda Geothermal Plant, Lithuania, this value is 11 ºC, Radeckas and Lukosevicius (2000).

When only one production well is used to exploit a warm fresh water horizon, then, Hurter and Haenel (2002):

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

The described approach doesn't require special tests 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.

### 4.1 Geothermal Resourcdes of the Pripyat Trough

Geothermal resources was calculated for several geothermal horizons within the Pripyat Trough using the standard approach, Hurter and Haenel (2002). They are: (a) the Intersalt sediments, (b) Upper Salt complex, (c) Jurassic deposits.

The results show that the Intersalt Complex represents the primary interest for recovery of its geothermal resources especially in the northern and partially in central zones, Fig.7. Dozens of abandoned deep wells, drilled originally for oil prospecting and plugged later, are useful for geothermal energy extraction. They could be opened, repaired and put into operation to extract warm and hot geothermal liquids. The feature of the Pripyat trough is rather high salinity of brines. It reaches in some localities up to 300 – 420 g/l of dissolved chemicals which requires to reinjection the used geothermal brines into the same horizon. They also can be used as well as borehole heat exchangers. It allows reducing expenses to construct geothermal systems and will increase the economic feasibility of such projects.

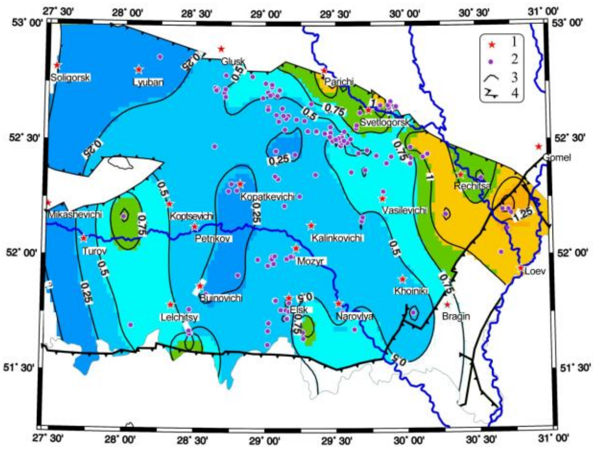


**Figure 7: Density of Geothermal resources within the Intersalt Complex of the Pripyat Trough, Belarus.**

Legend: Dots show positions of studied boreholes. 1 – main towns and settlements, 2 – studied boreholes, 3 - isolines in t.o.e./m$^2$, 4 – deep faults.

The map for the Intersalt Complex 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, see Fig. 7. Though there is a small area, corresponding so-called Turov Depression, where this value increases to 0.5 t.o.e./m$^2$. The main isoline of 0.5 t.o.e./m$^2$ has the longitudinal orientation and separates the considered area into western and eastern parts. Maximal density of geothermal resources up to 1-1.25 t.o.e./m$^2$ and higher corresponds to the northern and northeastern parts of the Pripyat Trough. It is stretched sub-parallel to the North Pripyat Marginal Fault and is the most promising area for the geothermal energy utilization.

The Upper Salt Complex is spread practically within the whole area of the trough. The depth to its roof sufficiently varies even at small lateral distances from first hundreds of meters (mainly within the western part of the paleorift) to more than 2 km in some of local parts. A salt tectonics produced differentiated roof relief within the central part of the paleorift. A wide range of depth variations to the salt roof resulted in the temperature pattern and, finally in the density of geothermal resources. We used 108 thermograms to calculate these resources. As before, the most of them were concentrated within the northern area and partly in its central zone.

The temperature at the roof of the Upper Famennian salt ranges from 18 – 20 to 40 – 45 °C. Its lower values correspond to the western part of the trough. Resources distribution within the Upper Salt Complex of the trough are rather contrast, Fig. 8. The main feature of the map is much higher density of geothermal resources within this complex relatively to the underlying intersalt deposits, as well as in the overlying Devonian terrigenous rocks. It results, first of all, both from a higher volumetric heat capacity of the rock salt and the higher thickness of this complex.

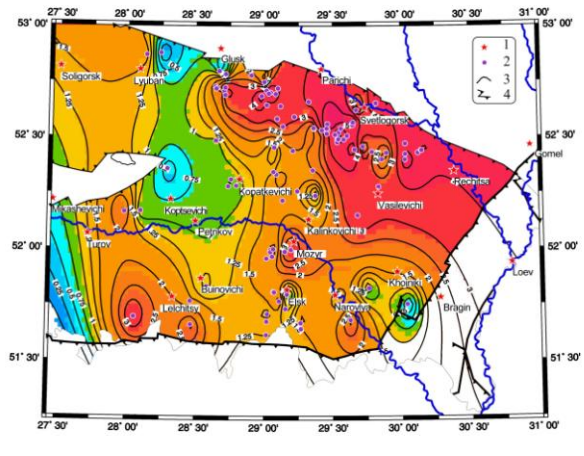


**Figure 8: Density of Geothermal resources within the Upper Salt Complex of the Pripyat Trough, Belarus.** Isolines are in t.o.e./m$^2$. Dots show positions of studied boreholes. See also Fig.7.

Ggeothermal resources vary in a wide range from less than 0.5 to more than 4 t.o.e./m$^2$ depending on the thickness of the complex and its temperature. The northern zone of the Pripyt Trough has again higher density of resources relatively to other parts. The isoline of 3 t.o.e./m$^2$ is limiting here a wide area stretched along the North Pripyat Fault. Prevailing values 1.25 – 2 t.o.e/m$^2$ correspond to the central and southern zones of the trough. Within the Turov Depression the density of geothermal resources doesn't exceed 1 – 1.5 t.o.e/m$^2$. The same concerns the western part of the trough.

Within the Jurassic and the Devonian deposits, overlying the Upper Salt, the density of geothermal resources usually corresponds to a few dozens of kg.o.e./m$^2$. We don't consider them here as well as in the so-called "under-the-salt" carbonate and terrigenous complex of rocksand the Lower Salt deposits.

### 4.2 Geothermal Resources of the Podlaska-Brest Depression

The Podlaska-Brest Depression is stretching from the longitude of Drogichin town to the edge of the East European Platform limited by the Teisseyre – Tornqvist Zone, which crossing the territory of Poland in the SSE-NNW direction. We consider only its part within Belarus. Geothermal resources were studied for the Cambrian and Proterozoic geothermal complexes. The former one contains practically fresh water. Porous Proterozoic rocks contain saline water to 20 – 30 g/l. Its porosity is low though the temperature is higher – 40 – 42 ºC. Therefore only the most promising Cambrian Complex was considered below, Zui, (2007), Fig. 9.

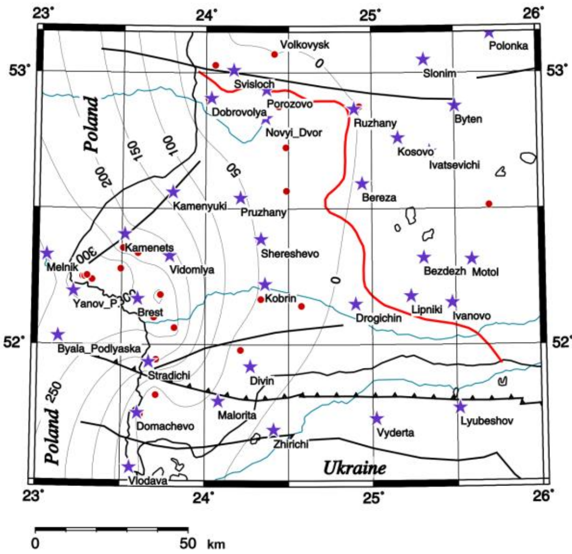


**Figure 9: Density of geothermal resources within Cambrian rocks in the eastern part of the Podlaska – Brest Depression, Belarus.**

Legend: The red line show limits of the Podlaska-Brest Depression; black lines show positions of tectonic faults. Isolines are shown in kg.o.e./m$^2$. The zero isoline represents the margin, where Cambrian deposits absent. Isolines are in t.o.e./m$^2$.

The resources vary in a wide range from 0 to more than 350 kg.o.e./m$^2$. Maximal values of them were observed to the north-west of Brest town within the area adjoining the Belarus – Poland border. In the direction to outer borders of the depression the geothermal resources density decrease. It results from both the shallower position of the roof of Cambrian deposits and a reduction of their thickness. Within the area around Brest town the density varies from 250 to 300 kg.o.e./m$^2$.

In southern part of the considered region near the Lukow – Ratno Fault we observe a rapid reduction of the resources values below 50 kg.o.e./m$^2$. Within the triangle of Kamenets – Dobrovolya – Shereshevo settlements studied boreholes are absent. In result, the position of isolines was extrapolated, the same concerns adjoining areas of Poland and Ukraine.

### 4.3 Geothermal Resources in western part of Belarus

Shallow boreholes or horizontal circulation loops are used for small geothermal installations. From this point of view there was a sense to assess the geothermal resources density in shallow horizons.

Figure 10 shows a distribution of geothermal resources for the western part of Belarus accumulated in the depth interval 100 – 200 m.

The resource base ranges from 12 to around 25 – 26 kg.o.e/m$^2$. Values above 17 kg.o.e/m$^2$ are typical for southwestern part of the country. In geologic respect it corresponds to the Podlaska-Brest Depression and the Polesian Saddle. A narrow band of increased values is stretched in between Kobrin and Pruzhany towns, it was traced also in the vicinity of Grodno.

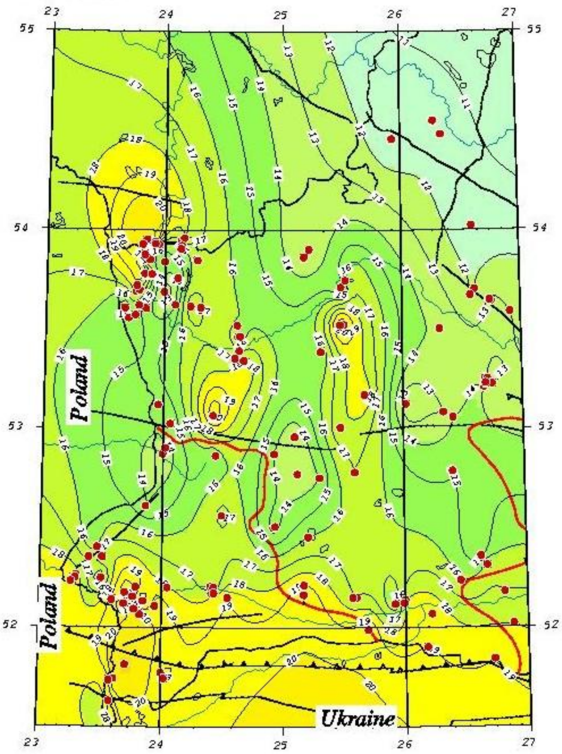


**Figure 10: Density of geothermal resources within western part of Belarus in the depth interval 100 – 200 m.**

### 5. GEOTHERMAL INSTALLATIONS

Since 1997 first small heat pump systems were installed in Belarus for heating of waterworks and sewage header buildings mostly in the Minsk District. At present around 15 geothermal installations are in operation in the country supplying space heating for industrial buildings with the total installed heat pump capacity approaching to 2 MWth. Additionally around 40 small heat pump systems were installed in private cottages within and around the main towns and cities (Brest, Gomel, Grodno, Mogilev, Vitebsk and Minsk) with total heat capacity around 1 – 1.5 MWth. All installations use cold water taken from shallow boreholes with typical temperature 8 – 10 ºC as a primary energy source. One installation is based on utilization of river water. Another 12 - 15 heat pump installations are under construction. The location for some of them is shown in Fig. 11.

It is planned to create experimental heat pump installations in several new apartment houses in 3 – 5 forthcoming years for space heating and warm water supply. Project documentation is finishing for a pilot geothermal station for the greenhouse complex “Berestye” located at the eastern suburb of Brest town in the western part of the country. It was scheduled to put it into experimental operation during the end of 2009 – beginning of 2010. It will use warm water with the temperature 24 – 25 C, pumped out from the depth about 1 km. Its installed heat capacity according to preliminary estimations is around 1 – 1.5 MWth.

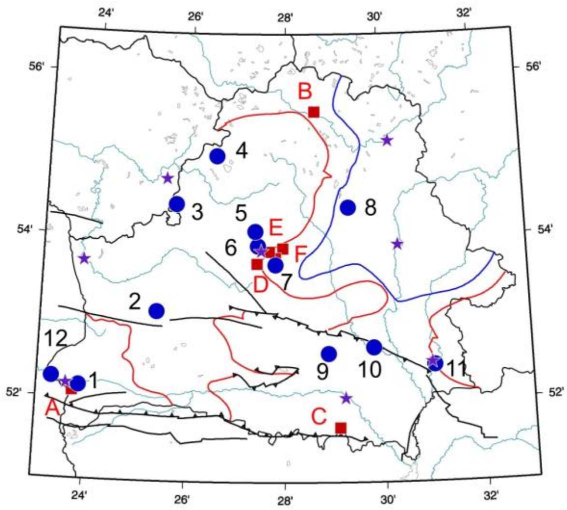


**Figure 11: Position of main operating and constructed heat pump installations in Belarus.**

Legend: Red squares show positions of operating heat pump installations and blue circles indicate installations under construction and projected ones to be created in nearest years. A – groundwater intake Mukhavetsky, B – river water intake in Nivopolotsk, C – frontier point Novaya Rudnya, D – groundwater intake Vitskovshchina, E – sewage installation Novyi Dvor, F – groundwater intake Felitsianovo, 1 – geothermal station “Berestye”, 2 – industrial enterprise in Slonim town, 3 – frontier point Kamennyi Log, 4 – recreation department, 5 – dwelling house in Karnyutki settlement, 6 – sport complex in Minsk, 7 – bath house, 8 – small cafe, 9 and 10 – experimental heat exchangers in Borisovskaya 504 and Berezinskaya 1 boreholes, respectively, 11 – rowing watercourse in Gomel, 12 – camp for geologists in Orlya village.

## CONCLUSIONS

Both the temperature and heat flow parameters have a contrast pattern within the territory of Belarus. Variations of them are especially pronounced within areas of salt tectonics, like salt swells and domes of the Pripyat Trough.

The terrestrial heat is a perspective renewable and ecologically clean resource of energy in the country. Its utilization represents an important national goal for the economics of Belarus. Low-enthalpy geothermal energy could be used practically within the whole territory of the country.

The density of geothermal resources varies in a wide range from 0.01 to about 4 t.o.e./m$^2$. Low values are typical for the main part of the Belarussian Anteclise and adjoining Latvian, Polesian and Zhlobin Saddles. These values are slightly higher for the Orsha Depression (0.05 – 0.1 t.o.e./m$^2$). The density of geothermal resources within the Intersalt Complex of the Pripyat Trough ranges on average from 0.1 to 1.75 t.o.e./m$^2$. Within the impermeable Upper Salt Complex they reach in some blocks up to 2 – 4 t.o.e./m$^2$. The Pripyat Trough and the Podlaska-Brest Depression are the most promising areas in Belarus for its direct utilization. A construction of a pilot geothermal station would be useful to stimulate the practical utilisation of geothermal resources in the whole country.

Dozens of abandoned deep wells, drilled within the Pripyat Trough for oil prospecting were plugged as nonproducing ones. Their reanimation will increase the economic feasibility of such projects.

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**РЕЗЮМЕ**

Территория Беларуси расположена в западной части Восточно-Европейской платформы. В геологическом плане она представляет собой сочленение блоков литосферы разного возраста. Мощность платформенного чехла изменяется в регионе от 80 – 100 м до 1,5 – 5,5 км в границах глубоких осадочных бассейнов – Припятского прогиба, Оршанской и восточной части Подлясско-Брестской впадин. Контрастное тепловое поле выявлено в толще осадочных отложений с широким интервалом изменения температуры от 7 – 8 ºC в зоне пресных вод до 80 – 115 ºC в глубоко погруженных комплексах Припятского прогиба.

Плотность ресурсов геотермальной энергии оценена как для мелко залегающих горизонтов в западной части страны, так и для комплексов отложений залегающих глубже 1 км в Припятском прогибе и в Подлясско-Брестской впадине. Она изменяются в широком диапазоне от 10 – 20 кг.у.т./м$^2$ в блоках земной коры с тонким осадочным чехлом до 200 – 300 кг.у.т./м$^2$ в кембрийских отложениях Подлясско-Брестской впадины. Наибольшая плотность ресурсов природного тепла выявлена в глубоких комплексах отложений Припятского прогиба вплоть до 1 – 4 т.у.т/м$^2$. Эти горизонты содержат крепкие рассолы с минерализацией до 350 – 420 г/л.

Около 15 геотермальных установок находятся в эксплуатации на территории страны. Они используются для отопления зданий и сооружений, в основном – промышленного назначения. Их суммарная тепловая мощность достигает 2 МВт. Около 40 небольших теплонасосных установок смонтированы в коттеджах, расположенных в основных городах страны и их окрестностях, их суммарная тепловая мощность оценивается в 1 – 1.5 МВт. Все инсталлированные теплонасосные системы отопления используют в качестве первичного источника тепла холодную воду с температурой 8 – 10 ºC, отбираемую из мелких скважин. Одна геотермальная установка использует в первичном контуре теплового насоса речную воду, забираемую из реки Западная Двина. Около 12 – 15 теплонасосных установок находятся в настоящее время в стадии проектирования, либо строительства.

В настоящее время планируется в течение 3 – 5 ближайших лет создание экспериментальных теплонасосных установок в нескольких жилых домах. Завершено составление рабочего проекта и ведется строительство первой в стране пилотной геотермальной станции для Тепличного комбината «Берестье», расположенного на восточной окраине г. Брест. Планируется ее пуск в опытную эксплуатацию в конце 2009 – начале 2010 гг.

**РЭЗЮМЕ**

Тэрыторыя Беларусі належыць да заходняй часткі Усходне-Еўрапейскай платформы. У геалагічным сэнсе яна з'яўляецца сучляненнем блокаў літасферы рознага ўзросту. Магутнасць платформеннага чахла вагаецца ў рэгіёне ад 80 – 100 м да 1,5 – 5,5 км у межах глыбокіх осадкавых бассейнаў – Прыпяцкага прагіну, Аршанскай і ўсходняй часткі Падляска-Брэсцкай упадзін. Кантрастнае цеплавое поле вызначана ў тоўшчы осадачных адкладаў з шырокім інтервалам вагання тэмпературы ад 7 – 8 ºC у зоне прэсных вод да 80 – 115 ºC у глыбокіх комплексах Прыпяцкага прагіну.

Шчыльнасць рэсурсаў геатермальнаой энергіі ацэнена як для мелка залягаючых гарызонтаў у заходняй частцы краіны, так і для комплексаў адкладаў, якія залягаюць глыбей за 1 км у Прыпяцкім прагіне і ў Падляска-Брэсцкай упадзіне. Яна змяняецца ў шырокім дыяпазоне ад 10 – 20 кг.у.п./м$^2$ (кілаграм умоўнага паліва) у блоках зямной кары з тонкім осадачным чахлом да 200 – 300 кг.у.п./м$^2$ у кембрыйскіх адкладах Падляска-Брэсцкай упадзіны. Найбольшая шчыльнасць рэсурсаў прыроднага цяпла вызначана ў глыбокіх комплексах адкладаў Прыпяцкага прагіну да 1 – 4 т.у.п/м$^2$. Гэтыя гарызонты ўтрымліваюць моцныя расолы з мінералізацыяй да 350 – 420 г/л.

Каля 15 геатэрмальных установак зараз знаходзяцца ў эксплуатацыі на тэрыторыі краніы. Яны выкврыстоўваюцца для ацяплення будынкаў і збудаванняў, галоўным чынам – прамысловага прызначэння. Іх сумарная цеплавая магутнасць дасягае 2 МВт. Каля 40 невялікіх цеплапомпавых установак пабудаваны ў катэджах, якія знаходзяцца, галоўным чынам, у осноўных гарадах краіны і іх наваколлі, іх сумарная цеплавая магутнасцть ацэньваецца ў 1 – 1.5 МВт. Усе інсталіраваныя цеплапомпавыя сістэмы ацяплення выкарыстоўваюць у якасці пярвічнай крыніцы цяпла халодную ваду з тэмпературай 8 – 10 ºC, якая адпампоўваецца з мелкіх свідравін. Адна геатэрмальная ўстаноўка выкарыстоўвае ў пярвічным контуры цеплавой помпы рачную ваду, якая забіраецца з ракі Заходняя Дзвіна. Каля 12 – 15 цеплапомпавых установак знаходзяцца ў сучасны момант у стадыі проекціравання, альбо будаўніцтва.

У сучасны момант плануецца ў наступеыя 3 – 5 год будаўніцтва эксперыментальных цеплапомпавых установак у некалькіх жылых дамах. Закончана стварэнне рабочага праекта і вядзецца будаўніцтва першай у краіне пілотнай геатэрмальнай станцыі для Цяплічнага комбіната «Бярэсце», які знаходзіцца на ўсходняй акраіне г. Брэст. Планіруецца яе пуск у вопытную эксплуатацыю ў канцы 2009 – пачатку 2010 гг.