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Geothermal Energy Use, Country Update for Belarus

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ABSTRACT

Belarus is located within western part of the East European Platform. It is known that within relatively cold Precambrian platforms there are no visible geothermal manifestations such as geysers, fumaroles, mud volcanoes, etc. Nevertheless there are mainly small geothermal installations constructed and used in the country.

Temperature distribution maps compiled for the depths of 100 and 200 m for the whole territory of the country, as well as for the depth of 2 km within the Pripyat Trough show a contrast pattern of the terrestrial temperature field. The same concerns the heat flow map of Belarus.

Geothermal resources were estimated for some of geothermal horizons of the sedimentary cover. Only very preliminary estimates were fulfilled for a depths position at which it could be possible to reach temperatures of 150 – 180 ºC, necessary to construct geothermal power plants. These depths reach 7 – 12 km within different crustal blocks and are within the crystalline basement. They are over the economically acceptable limits. Therefore the geothermal electricity generation is not considered for the nearest future.

The density of recoverable geothermal resources are dependent both on the depth of geothermal reservoir and the individual crustal block. They typically range from 10 to 20 – 25 kilograms of oil equivalent per meter square (kg.o.e/m^2) to as high as a few hundreds of kg.o.e/m^2 within the Podlaska-Brest Depression and even over 1000 kg.o.e/m^2 for the northern part of the Pripyat Trough.

Around 100 geothermal installations were constructed and used all over the country starting from the middle of nineties of the past century and a few more geothermal heating systems are under construction now. All available installations are used for space heating purposes and sometimes simultaneously to heat warm water. The biggest geothermal installation of 1 MW$_{th}$ was put into operation at the Greenhouse Complex "Berestye", located at the eastern suburb of Brest town not far from the Belarus-Poland state border. All heat pump installations excluding the latter one are using shallow depth intervals with low-enthalpy geothermal resources.

1. INTRODUCTION

There are three major crustal segments, existing within Belarus territory, of different age. The Fnnoscandia is traced in the north into the Baltic Shield, Volgo-Uralia exists in the east and Sarmatia in the south. The latter one includes the Ukrainian Shield and the Voronezh Anteclise, separated by the Palaeozoic Pripyat-Dnieper-Donets Palaeorift extending southeast to the Caspian Sea, Gorbatschev and Bogdanova, (1993). A junction of these three Precambrian lithospheric segments takes place within the territory of Belarus.

The Belarusian Anteclise is the main positive structure within the considered region. It occupies the central-west part of the country and is extending beyond its borders into eastern Poland, (Fig.1).

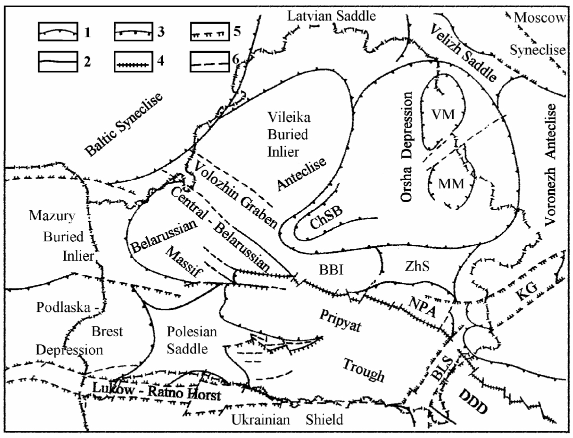

Figure 1: Main geologic units within the territory of Belarus.

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.

Three deep sedimentary basins exist within the area. They are: the Orsha Depression in the east, the eastern edge of the Podlaska-Drest Depression in the southwest, continued into Poland, and the Pripyat Trough in southeast, which is separated of the Dnieper-Donets Depression by the Bragin-Loev Saddle.

The crystalline basement all over the country is hidden by sediments. Thin sedimentary cover overlies the crystalline basement of the Belarusian Anteclise. It ranges from 80 – 100 m within the Central-Belarusian Massif to ~500 m within other parts of this tectonic unit. Its thickness increases to 1.5 – 1.6 km within the Belarusian part of the Podlaska-Brest Depression and to 1.7 – 1.9 km within the Mogilev and Vitebsk muldes of the Orsha Depression, Aizberg et al. (2004). The deepest position of the crystalline basement up to 5 – 5.5 km was observed within the Pripyat Paleorift.

The Polesian Saddle and Mikashevichi-Zhitkovichi Salient separate two Palaeozoic deep sedimentary basins 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, the North-Pripyat Arch and the Zhlobin Saddle. The Bragin-Loev Saddle joins the Pripyat Trough with the Dnieper-Donets Depression.

The Pripyat trough is the best studied tectonic unit comparable to other structures in the country. Hundreds of deep boreholes were drilled during oil prospecting works within its territory. A crystalline basement represents here a system of blocks, limited by deep faults with varying thickness of the overlying platform cover. Many faults penetrate into the upper mantle.

Tectonic movements of crustal blocks 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 platform cover of the trough has a complex geological structure with two salt bodies. The Lower Salt base reaches the depth of 4.5 – 5.5 km depending on the considered basement block. Terrigenous sediments separate the Upper Salt and Lower Salt deposits. They comprise so-called Intersalt Complex. The depth to its surface is on average 1.5 – 3.0 km and its thickness ranges from 100 m in the western part of the area to 1000 m. The complex geometry of these rocks influences the terrestrial temperature field pattern. There is developed salt tectonics with salt domes and swells all over the trough. Carbonate and terrigenous sediments underlie the lower salt complex, contain highly mineralized brines.

A thickness of 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.

The upper part of sedimentary cover within the whole territory of Belarus contain fresh water. Its base was observed at depths of 150 till 400 m, Kudelsky, et al., (2000). Only within the western part of the country this surface deepens to more than 400 m. Fresh water was also encountered in fractured uppermost part of the crystalline basement within some parts of the Belarusian Anteclise with thin sedimentary cover. The deepest position of the fresh water base up to 1000 – 1100 m exists in the area adjoining Brest town. This narrow strip is stretched here along the state boundary and continued into Poland, (Fig.2).

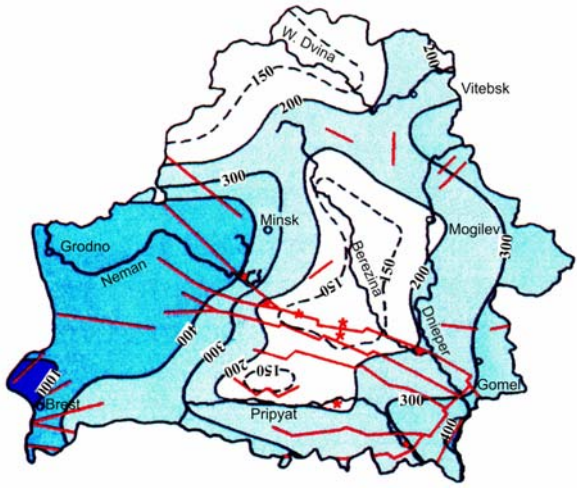

Figure 2: Fresh water base position within Belarus

Legend: black lines represent depth isolines (m); red lines show positions of the main deep penetrating faults; red stars indicate localities with surface water mineralization exceeding 1 g/dm^3.

The content of dissolved chemicals in ground water of deep horizons in the Podlaska-Brest and Orsha depressions reach 25 – 40 g/dm^3. High salinity brines were observed in deep strata within the Pripyat Trough. The mineralization reaches here on average up to 200-300 g/dm^3 within the Intersalt deposits and even 400 – 420 g/dm^3 in the Undersalt Complex.

2. TERRESTRIAL TEMPERATURE FIELD

The first thermogram, recorded in one of deep boreholes of the Pripyat Trough, was published in the middle of fifties, Belyakov (1954), though the very first unpublished measurement was undertaken in 1929 in a hole drilled in Minsk, 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. A gradual accumulation of temperature records occur since the second half of fifties of the last century after oil prospecting works were organized. Regular geothermal investigations were undertaken afterwards since the beginning of sixties in boreholes, reached their temperature equilibrium after the drill works were finished, and are continued till the present time.

Hundreds of thermograms were recorded during more than five decades of geothermal 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 and observed heat flow was revealed within the territory of the country.

A position of boreholes with available thermograms is shown in (Fig. 3).

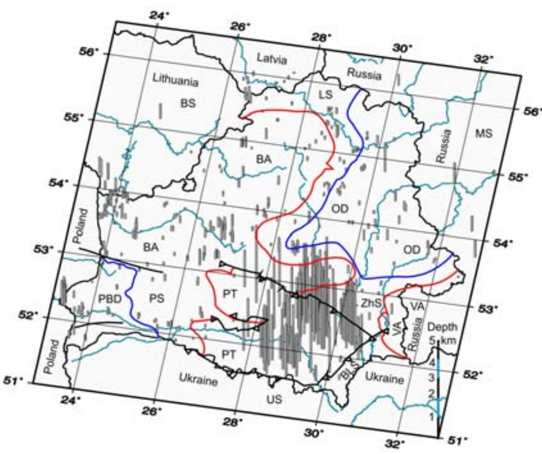

Figure 3: Location of boreholes within Belarus with available thermograms.

Legend: heavy black lines – deep penetrating platform faults; heavy blue lines – margins of negative structures; heavy red lines – margins of positive structures. Abbreviations: BA – Belarusian Anteclise; BLS – Bragin-Loev Saddle; BS – Baltic Syneclise; LS – Latvian Saddle; OD – Orsha Depression; ZhS – Zhlobin Saddle; PBD – Podlaska-Brest Depression; PS – Polesian Saddle; PT – Pripyat Trough; US – Ukrainian Shield; VA – Voronezh Anteclise; vertical lines and their lengths – position of boreholes with available thermograms and depths, reached by thermometers.

The best studied in geothermal respect is the oil-bearing Pripyat Trough with a network of hundreds of deep boreholes, drilled in the course of oil prospecting works. Territories of the Belarusian Anteclise with its saddles, Podlaska-Brest and Orsha depressions are less studied tectonic units, as mostly shallow boreholes were accessible there for geothermal measurements. Most of these holes were drilled for drinking water and were finished within the fresh water zone.

Available thermograms could be subdivided into two groups. The first one represents curves recorded in boreholes reached the equilibrium of their wellbores temperatures and rock massifs after the drilling was finished. Many observational holes, used to monitor a variation of water levels are among them. The second group includes thermograms recorded when the temperature of rocks, adjoining wellbores, was disturbed by the drilling process and not completely recovered before the time when temperature measurements were undertaken. Such logs, recorded by drilling companies, were analyzed and carefully selected. In total up to 1000 temperature-depth diagrams, recorded in boreholes all over the country, were used to compile temperature distribution maps.

It was possible to prepare temperature distribution maps for the whole country based on temperature records in boreholes only to the depths of 100 - 200 m. Extrapolation of thermograms into deeper strata gave a possibility to compile such maps maximum to the depth of 500 m. For deeper horizons such maps were produced only for the good studied Pripyat Trough.

Temperature distribution an the depth of 100 m. The depth of 100 m belongs to the fresh water zone, (Fig.4).

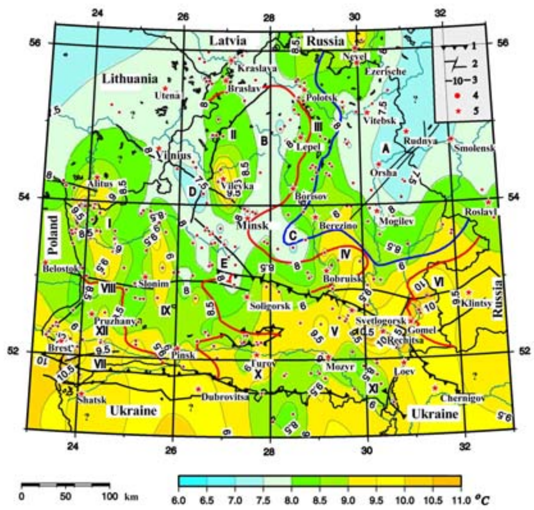

Figure 4: Temperature distribution map at the depth of 100 m within Belarus.

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).

In many boreholes the influence of subvertical water filtration is reflected in shapes of thermograms. The convective component of heat transfer is pronounced here. Thermograms, recorded in around 400 holes, were used to compile the map, Zui, (2010).

Isotherms were drawn within the territory of Belarus by means of an interpolation using individual temperature values, recorded in studied boreholes. Their contours outside the state border should be considered as preliminary ones, as they were received in result of an extrapolation into areas with small amount of thermograms available.

Seasonal temperature variations at the ground surface propagate into different depths within the described region depending on their lithologic composition comprising geologic cross-sections and downward or upward water filtration rates. These depths are typically range from 30 m when a cross-section is formed by a sequence of aquifers and aquitards to 70 – 90 m for mostly sandy layers. Therefore there was a sense to compile maps starting from the depth of 100 m. Temperature values at this depth range from 7 to 11.5 °C. Values above 8 ºC are typical for Palaeozoic geologic units: the northern zone of the Pripyat Trough and the Podlaska-Brest Depression.

The isotherm of 9 ºC has its continuation beyond the North Pripyat marginal fault 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. Available thermograms, recorded in the course of standard logging, have very low quality to be used for temperature readings at the depth of 100 m. Regional and local anomalies are clearly distinguished in the compiled map, (see Fig. 4).

Low temperature values were observed in the eastern part of the Orsha Depression, we named this part as 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 beyond the state border is very preliminary as there are no reliable thermograms, recorded in this adjoining territory.

A strip of increased temperature values of 8.5 – 10 ºC of the meridian orientation crosses the whole territory of the Orsha Depression from the Pripyat Trough and continues into Russia. This is called the *West Orsha anomaly* traced in the western part of the depression and partly within the eastern slope of the Belarussian Anteclise. Its northern continuation has very preliminary shape as only one thermogram was recorded in the adjoining area of Russia. Temperature values within southern part of the *West Orsha anomaly* exceed 10 ºC.

The isotherm of 9.5 ºC in the eastern part of the Podlaska-Brest Depression is traced through the Polesian Saddle along the Belarus-Ukraine border. It reaches the longitude of Stolin town and continues into the territory of Ukraine. The isotherm of 9.0 ºC of this anomaly is oriented in eastern direction and it has the continuation into the Pripyat Trough. Then it is traced into the Belynichi-Rechitsa anomaly and follows to the western slope of the Voronezh Anteclise. Then it continues into Russia, Zui (2004, 2010).

One more *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 beyond the state border doesn't allow its detailed tracing in the northern direction. Nevertheless, it is possible to assume its continuation into the high heat flow anomaly, existing in western Lithuania and the Kaliningrad Enclave of Russia.

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

Temperature distribution at the depth of 200 m. A few hundred of the most reliable thermograms were used to compile a temperature distribution map for the depth of 200 m, (Fig. 5). A similar approach was used when selected used thermograms from the whole available data base.

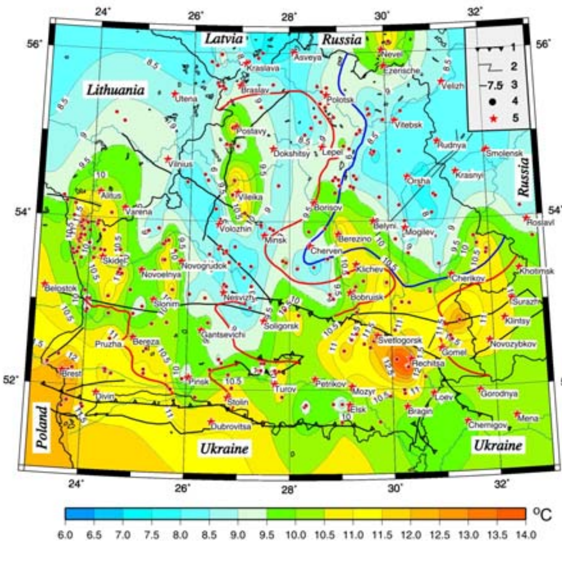

Figure 5: Temperature distribution map at the depth of 200 m within Belarus.

Legend: see Fig. 4.

The temperature field contrast increases with depth at the depth of 200 m, shown in this map. But the main features are remaining similar for both discussed maps. But anomalies of the terrestrial temperature distribution at the depth of 200 m have more contrast pattern within the considered territory, than it was shown in the (Fig. 4). It is closely related to features of the geologic structure of the interiors as well as to individual crustal blocks. Actually all temperature anomalies, shown in the temperature distribution map for the depth of 100 m, exist at the depth of 200 m with slightly changed shape. We will not describe them in details here. It is necessary only to mention that some of them occupy smaller areas. It is resulted from ceased vertical component of the velocity of downward water filtration with depth. First of all, it concerns the Molodechno-Naroch, Kobrin-Pruzhany, Mosty and Lyakhovichi-Elnya anomalies.

Minimal temperature values in the map are 8 – 8.5 ºC, they correspond mainly to the *East Orsha anomaly* of low temperatures. At the same time, maximum values were observed within northern part of the Pripyat Trough, they are above 13 ºC.

Temperature distribution an the depth of 2 km. As mentioned above, it was not possible to compile terrestrial temperature maps depths deeper than 700 – 1,000 m for the whole territory of Belarus. Such thermograms are practically absent for the Nelarusian Anteclise and a few diagrams were recorded in deep boreholes within the Podlaska-Brest and Orsha depressions. Within former one the studied boreholes are located in the narrow strip, stretched along the Belarus-Poland border. Temperature values at the sedimentary cover base reach 40 – 42 °C within the Podlaska – Brest Depression. In both cases it was not possible to prepare temperature distribution maps.

As many thermograms are available for the Pripyat Trough, we consider only its temperature field features, which is the best studied area in geothermal respect among other sedimentary basins of the country. When the depth increases small details in temperature distribution maps disappear, because the number of available thermograms also decreases. Temperature at the base of sedimentary cover in the northern zone here increases to 80 – 100 ºC, but for the depth of 4 – 5 km the number of reliable thermograms doesn't exceed 20, which is not enough to compile detailed temperature maps. The maximal temperature recorded, for instance, in the Basuki 63 oil well, was 115 °C at the depth of 4 km. The temperature field pattern at the depth of 2 km is shown in (Fig. 6).

In the northern zone of the trough the temperature, in average, is two times higher than in its southern and western parts. A wide area of low temperature exists in western and southwestern parts of the structure, it is the area to the left of the isotherm of 35 °C. Only a few thermograms were available in southwestern part, that's why it was not possible distinguishing small details in the map. At this background the highest temperature exceeds 60 – 70 °C within the northern and north-eastern zones of the trough. The main exploited oil fields were encountered namely within this warm area.

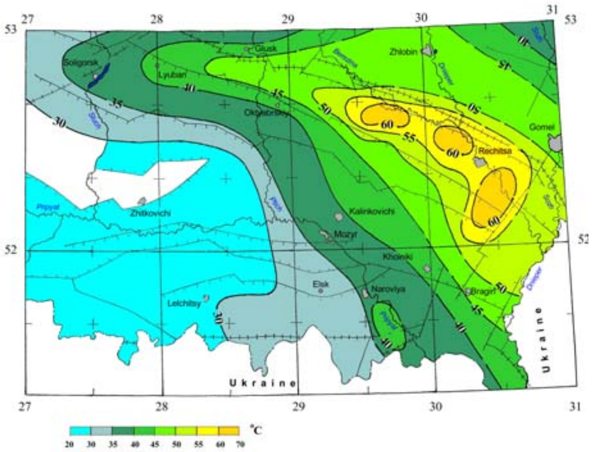

Figure 6: Temperature distribution at the depth of 2 km within the Pripyat Trough, Belarus.

The central part of the anomaly in the northern zone of the Pripyat 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 northern direction the anomaly was traced into the North Pripyat Arch. Small anomalies exceeding 40 °C were observed within southern part of this geologic unit (the Elsk Graben and the Vystupovichi Step). The background temperature values here ranges from 35 to 40 °C.

3. HEAT FLOW

Heat flow density determinations, based on recorded thermograms and thermal conductivities of rock samples, were started since the very end of sixties and the a beginning of seventies of the last century, Bogomolov et al., (1969), Bogomolov et al., (1970). Since those time regular heat flow investigations were organized in the Laboratory of Geothermics (National Academy of Sciences of Belarus).

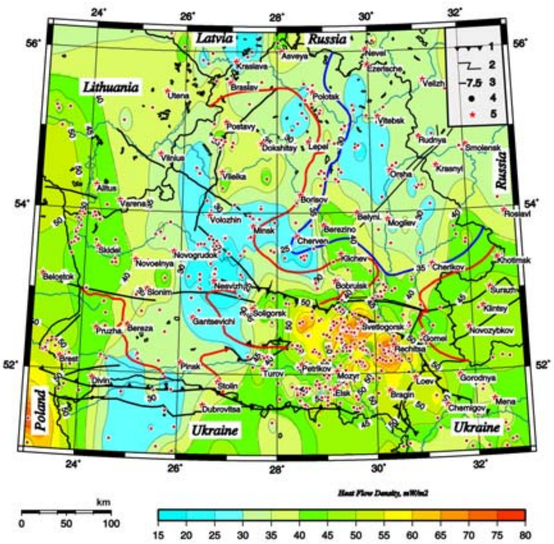

Figure 7: Heat flow density map for Belarus. Legend see in Fig. 4.

The heat flow density map, (Fig. 7), was compiled using all published data, which were collected in the heat flow catalogue, Zui et al., (1993). Data published later, were also used, Zhuk et al., (2004); Zui, (2005); Zui, Zhuk, (2006), Zhuk, Tsalko, (2009) as well as published data for adjoining areas of Poland, Lithuania, Latvia, Russia and Ukraine.

Heat flow density distribution is rather differentiated within the considered area. A chain of low heat flow anomalies below 30 mW/m^2 is stretched from SW (Lvov Palaeozoic Depression) through the Belarusian Anteclise to NE (Orsha Depression). They cross the whole territory of the country. At a background of low values (30 – 40 mW/m^2), positive anomalies are well distinguished within the Podlaska-Brest Depression (50 – 55 mW/m^2) and the Pripyat Trough where heat flow exceeds 60 mW/m^2 in its northern zone.

Heat flow density within the Pripyat Trough ranges from less than 40 mW/m^2 to more than 100 mW/m^2 within nuclei of salt domes., Tsybulya, Levashkevich, (1990); Zui et al., (1991); Zhuk et al., (2004). The geometry of salt tectonics is good studied within the Pripyat Trough both by drilling and by geophysical methods. Geothermal measurements and heat flow determinations were fulfilled in most of boreholes drilled through salt domes and swells. It is evident that the salt tectonics influences on observed interval values of heat flow, e.g. within near-the-fault zone of the Rechitsa – Visha Swell. Heat flow vectors deflect of vertical direction in the vicinity of such salt bodies, as rock salt has 2 – 3 times higher thermal conductivity comparing to surrounding terrigenous sediments and distorts sub horizontal course of isotherms, as shown in (Fig. 8), Zhuk, Tsalko, (2009).

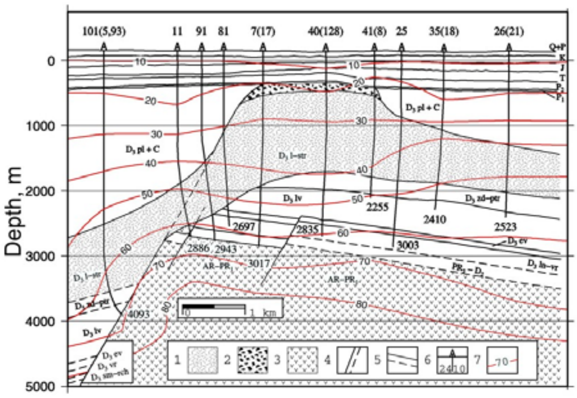

Figure 8: Temperature profile along the Rechitsa Dome in the northern part of the Pripyat Trough.

Legend: 1 – rock salt, 2 – cap rock, 3 – crystalline basement, 4 – deep faults, 5 – boundaries between rocks of different lithology, 6 – studied boreholes with their numbers and their bottom hole depths, 7 – isotherms, ˚C.

In the upper part of geological section within so-called “above-the-salt” sediments interval heat flow values are typically lower in result of the groundwater circulation phenomenon. Therefore, heat flow calculated in shallow boreholes resulted in its lower values comparing to adjoining areas of the trough with deep boreholes. That’s why, it was observed that interval 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).

Besides the main orientation of heat flow density isolines along the North Pripyat Fault, it is clearly distinguished their another direction with heat flow 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 of 40 – 50 mW/m^2 was observed also within local anomalies of the Belarusian Anteclise (areas with granite bodies in the crystalline basement), 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. A correlation of the areal distribution of oil fields, shown by black spots, with heat flow density is shown in (Fig. 9).

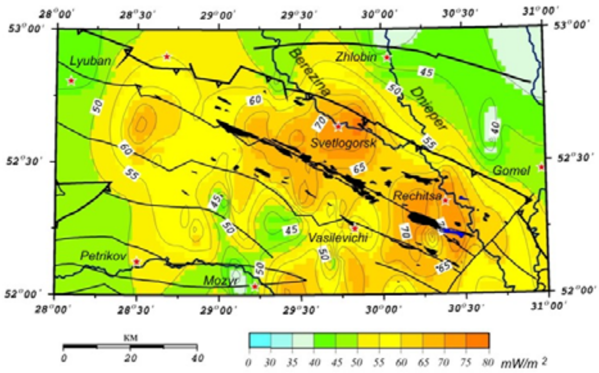

Figure 9: Heat flow density and oil fields in the northern part of the Pripyat Trough.

All exploited oil fields of the Pripyat Trough are located within areas with heat flow above 55 mW/m^2, Gribik, Zui, (2009) and the most of them fall inside the 60 – 75 mW/m^2 isoline. Only less than 10 of them occur inside the area of 55 – 60 mW/m^2. A zone of 65–75 mW/m^2 correspond to two condensate accumulations. They are the Krasnoselskoye and West-Aleksandrovskoye fields.

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.7.

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. This anomaly is continued into the territory of Lithuania in its northern part and probably joins with the high heat flow area in western Lithuania and the Kaliningrad Enclave of Russia. A lack of thermograms in the territory of Lithuania doesn't allow tracing it in more details.

Heat flow density values within the adjoining area of Poland were studied only in a few near the Belarus-Poland border locations. Therefore the pattern of heat flow isolines adjoining the Belarus-Poland boundary should be considered as preliminary ones. Same concerns their configuration along both sides of state borders with Lihuania, Latvia and Russia.

4. GEOTHERMAL RESOURCES

Resources of geothermal energy were estimated for both shallow horizons within 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, exceeding 1 t.o.e./m^2, was observed in deep complexes of the Pripyat Trough, but these horizons have high content of dissolved chemicals up to 350 – 420 g/dm^3.

Recoverable geothermal resources were calculated on the basis of widely used approach, namely according to Hurter and Haenel (2002). Geothermal resources in Joules when using doublets of boreholes are:

$$H_1 = H_0 \bullet R_0, \qquad [1]$$

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.

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

where ρ_m, ρ_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; Δz = 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.

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

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, the project T_r value was 11 ºC, Radeckas and Lukosevicius (2000), which was later increased to ~15–18 ºC to avoid the gypsum precipitation from saline brines.

When only one production well is used to exploit a 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 resources in the depth interval of 100 – 200 meters

Fresh ground waters are encountered till the depth of 200 m almost in the whole territory of Belarus, (see Fig.2). Only within relatively small areas their mineralization slightly exceeds 1 g/dm^3. Therefore using these waters for heat recovery from shallow horizons of the platform cover is a favorable condition from technologic point of view as it is not necessary to drill additional pumping wells.

Moreover, typically there are no scaling problems when exploiting such waters for geothermal energy recovery. To be able to obtain comparable results all over the whole territory of the country for a density of recoverable geothermal resources, it was decided to calculate them for the interval of 100 – 200 m using equations (1) to (4).

This interval is composed of rocks of different age and lithology. Geologic cross-section in this depth interval represents interlaying of aquifers and aquitards, having numerous hydrogeologic "windows", allowing hydraulic connection of different aquifers", (Fig.10).

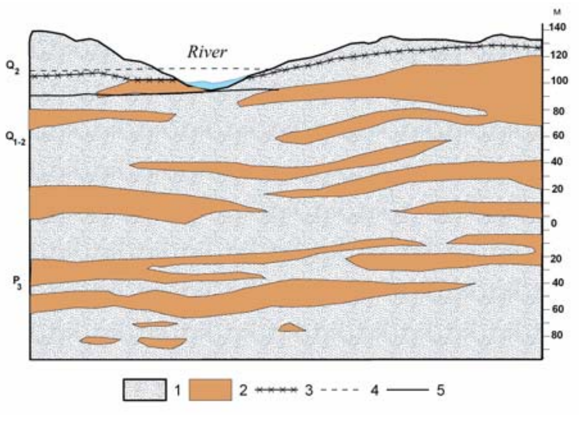

Figure 10: Typical structure of many Paleogene-Quaternary aquifers.

Legend: 1 – aquifers, 2 – aquitards, 3 – water table, 4 – estimated water table during flood time periods, 5 estimated water table below a river during very low water periods.

It was decided, as the first approach, to consider rocks of this interval as a "single aquifer". It gives a possibility to consider and compare recoverable resources within different geologic units of the country. Moreover, shallow boreholes or horizontal circulation loops are typically used for small geothermal installations in the country. From this point of view there was a sense to assess the geothermal resources density in shallow horizons.

Figure 11 shows a distribution of recoverable geothermal resources for Belarus accumulated in the depth interval of 100 – 200 m.

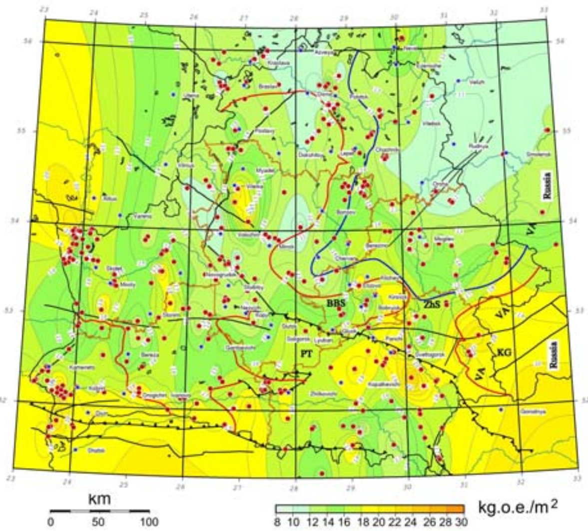

Figure 11: Recoverable density of geothermal resources from the interval of 100 – 200 m within the territory of Belarus.

Legend: BBS – Bobruisk buried Salient, KG – Klintsy Graben, VA – Voronezh Anteclise, PT – Pripyat Trough, ZhS – Zhlobin Saddle. Red heavy lines indicate margins of positive structures: Belarusian Anteclise, Polesian Saddle and the Voronezh Anteclise (their limits were outlined by minus 500 m isoline). The blue line traces margins of the Orsha Depression (outlined by –700 m isoline).

The resource base ranges from 10 to around 25 – 28 kg.o.e/m^2. Values above 18 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 wide area of a positive anomaly exists within the northern part of the Pripyat Trough, joined with the western slope of the Voronezh Anteclise and continued beyond the northern part of the Pripyat Trough as a narrow band of increased values, stretched in northern direction along the line crossing towns and settlements: Stetlogorsk – Parichi – Kirovsk – Elizovo. Small area anomalies exist in between Molodechno – Naroch, Volozhin – Vileyka, Slonim – Pruzhany towns., It was also traced in the vicinity of Grodno, the margin of this anomaly is open into the territory of Lithuania.

Several areas of low values of geothermal resources 10 – 12 kg.o.e/m^2 were observed within northern and northeastern parts of the country. The area of the widest one corresponds to the northern part of the Orsha Depression. It was practically not studied in adjoining territory of Russia, where in deep horizons estimated density of geothermal resources reach up to 50 kg.o.e./m^2. All isolines were drawn by interpolation inside the territory of Belarus. They were extrapolated into adjoining areas beyond the country border and should be considered only as preliminary ones.

The density of geothermal resources were calculated also for different water-bearing complexes, developed within Belarus. They are Albian-Cenomanian water-bearing horizons (Cretaceous sediments), Eifelian (Middle Devonian), Paleogene, etc. This work is in the process now.

4.2 Geothermal resources of deep horizons of the Podlaska-Brest Depression

The Podlaska-Brest Depression is stretching westwards from the longitude of Drogichin town in Belarus to the edge of the East European Platform limited in Poland by the Teisseyre – Tornqvist Zone. We consider only its eastern part, located within Belarus.

Geothermal resources were studied for the Cambrian and Proterozoic water-bearing complexes. The former one contains a fresh water. Porous Proterozoic rocks are saturated by saline waters and their mineralization reaches 20 – 30 g/dm^3. Their porosity is low though the temperature is higher (40 – 42 ºC) than within the Cambrian deposits (ca. 25 ºC). Therefore, the Cambrian Complex is the most favorable one to use its geothermal potential, Zui, (2007), (Fig. 12).

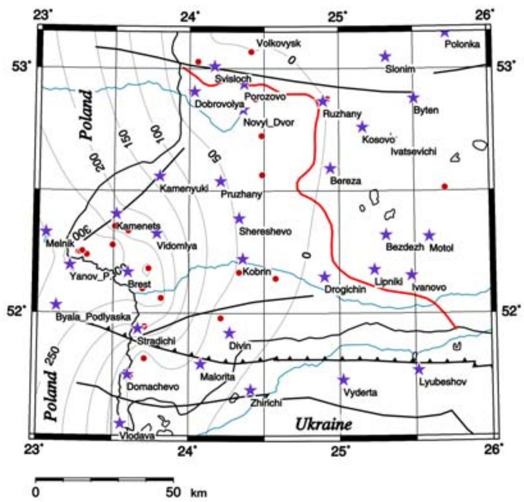

Figure 12: Density of geothermal resources within Cambrian rocks in the eastern part of the Podlaska – Brest Depression, Belarus.

Legend: The red line shows limits of the Podlaska-Brest Depression within Belarus; black lines show positions of tectonic faults. Isolines are given in kg.o.e./m^2. The zero isoline represents the margin, where it was observed wedging-out of Cambrian deposits.

The resources vary in a wide range from 0 kg.o.e./m^2 along the line where takes place a wedging-out of

Cambrian deposits, to more than 350 kg.o.e./m^2 at their deepest position. 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 density geothermal resources decrease. It results from both a shallower position of the roof of Cambrian deposits and the reduction in their thickness. Within the area around Brest the density varies of geothermal resources 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 and the isolines were extrapolated, the same concerns adjoining areas of Poland and Ukraine.

Only a few boreholes with recorded thermograms were drilled through the whole Proterozoic Complex into the crystalline basement. The available data are not enough to compile a corresponding map of geothermal resources. But preliminary estimates show that regardless the temperature is higher within Proterozoic rocks, their thickness is smaller. In result the recoverable resources in Cambrian and Proterozoic deposits actually are comparable. Moreover, to exploit geothermal resources from this complex, it is necessary to drill a doublet of boreholes for each location, as it is necessary to return used mineralized waters into the underground reservoir.

4.3 Geothermal resources within deep horizons of the Pripyat Trough

Geothermal resources were calculated for several geothermal horizons within the Pripyat Trough using the standard approach, Hurter and Haenel (2002). These horizons are: (a) Jurassic deposits, (b) the Intersalt sediments, (c) Upper Salt complex. Terrigenous and carbonate strata underlying the Lower Salt complex were not considered as they have very high mineralization of brines up to 420 – 450 g/dm^3 and even higher in some localities. There are no the world practice to utilize such brines to recover geothermal resources.

The density of geothermal resources for several horizons of the Pripyat Trough was discussed earlier, Zui, (2010). The results show that they range from 0.25 to 1 t.o.e/m^2 in the Intersalt Complex, which represents the primary interest for their recovery especially in the northern and partially in central zones of the Pripyat Trough, (Fig.13).

Dozens of abandoned deep wells, drilled in the course of oil prospecting works in the Pripyat Trough, were plugged later. These abandoned boreholes are useful for geothermal energy extraction. They could be opened, repaired and put into operation to extract warm and hot geothermal liquids and return them to underground after the heat of brines will be used, or to be used as borehole heat exchangers.

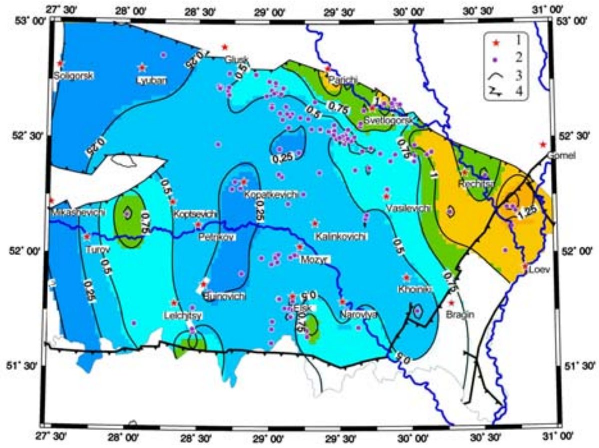

Figure 13: Density of Geothermal resources within the Intersalt Complex of the Pripyat Trough, Belarus (t.o.e/m^2)**.**

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 in fluids which requires a reinjection of used geothermal brines into the same horizon. Because of high mineralization of them it is possible to use drilled wells to create borehole heat exchangers without extracting of brines itself. Using the old abandoned boreholes will allow reducing expenses to construct corresponding geothermal systems.

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 the total number of geothermal installations all over the country is estimated to be around 100, (Table 1), their exact number is not known, as it was not necessary earlier to register such systems in the Ministry of Natural Resources and the Environmental Protection. The biggest installation exists at the Greenhouse Complex “Berestye” in Brest, (Fig.14).

Figure 14: Heat pumps Daikin EWWD 440MBYN at the Greenhouse Complex “Berestye”.

It uses fresh warm water pumped out from one borehole of 1000 m deep. Water temperature reaches of 24 ºC at the well mouth, the well flow rate is around 42 m^3/hour. Two heat pumps Daikin EWWD 440MBYN, with heat output of 505 kW each, are used there, (Fig.15), Zui, Pavlovskaya, (2012).

Table 1: Some existed of geothermal installations.

Location	Primary heat source	Heat capacity, kW_{th}
Greenhouse Complex "Berestye", Brest	Ground water	2 x 505
Waterworks "Vitskovshchina", Minsk District	Ground water	43
Sewage header building No.9, Minsk District	Ground water	45
Waterworks "Vodopoy", Minsk District	Ground water	40+390
Sewage header building No.19, Minsk District	Ground water	122
Sewage header building No.24, Minsk District	Ground water	330
River waterworks, Novopolotsk town	River water	230
Waterworks "Mukhavets", Brest	Ground loop	3x60
Frontier point "Novaya Rudnya", Elsk District	Ground water	273
Hospital, Nesvizh town	BHE	375
Waterworks "Drozdy", Minsk District	Ground water	36
Sewage header building No.46, Minsk district	Ground water	156
Water purification station, Minsk	Ground water	165
Pump plant "Uruchye", Minsk	Ground water	48
Pump plant "Sosny", Minsk	Ground water	40
Waterworks "Felitsianovo", Minsk District	Ground water	29
Waterworks No.11, Minsk District	Ground water	80
Waterworks "Sokol", Minsk	Ground water	150
Rowing channel, Gomel	Ground water	2x46
Waterworks in Rechitsa town	Ground water	≈50
Church near Braslav town	BHE	≈40
Office building, Vitebsk	BHE	≈40
Waterworks in Gorki town, Mogilev region	Ground water	≈140
Cottages	?	≈1500

Existed geothermal installations in the country are mainly used for supplying space heating for some of small industrial buildings, frontier point Novaya Rudnya at the Belarus-Ukraine border, dwellings, etc. with the total installed heat pump capacity approaching to 5.5 – 6 MW_{th}.

Additionally several dozens of 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. Most of installations use cold groundwater taken from shallow boreholes with typical temperature 8 – 10 ºC as a primary energy source. Some of them have horizontal circulations loops. One installation is based on the utilization of river water. The location for some of heat pump installations is shown in (Fig.16).

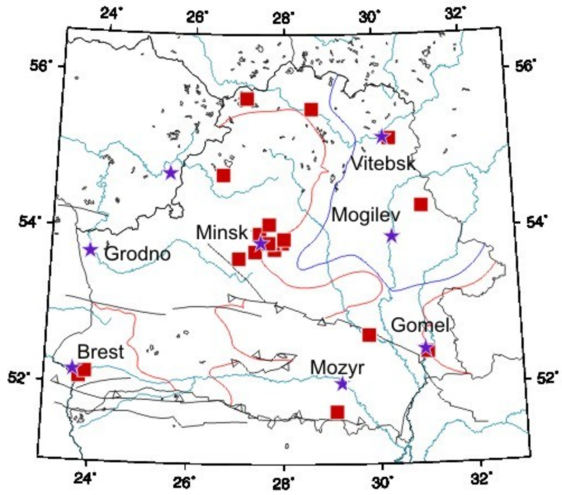

Figure 15: Position of main geothermal installations in Belarus.

6. CONCLUSIONS

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

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

The density of geothermal resources varies in a wide range from 10 to more than 1000 kg.o.e./m^2. Low values are typical for the main part of the Belarusian Anteclise and adjoining Latvian, Polesian and Zhlobin Saddles. These values are slightly higher for deep horizons of the Orsha Depression (up to 50 kg.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. The Pripyat Trough and Podlaska-Brest Depression are the most promising areas in Belarus for the geothermal energy utilization. A construction of a pilot geothermal station using warm brines would be useful to stimulate the practical utilisation of geothermal resources of deep horizons within the Pripyat Trough.

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.

There are no direct utilization of geothermal resources in Belarus. All existing geothermal installations use heat pumps to extract low-enthalpy geothermal resources. Until now there is no utilization of geothermal energy for generation of electricity in the country.

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Tables A-G

Table A: Present and planned geothermal power plants, total numbers*

*Geothermal power plants are not available in the country.

Table B: Existing geothermal power plants, individual sites*

*Geothermal power plants are not available in the country.

Table C: Present and planned geothermal district heating (DH) plants and other direct uses, total numbers

No district heating (DH) is available in Belarus, only "other" direct uses are used.

	(Geothermal DH Plants) No DH, only other uses		Geothermal heat in agriculture and industry		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2012	~5.5	2.38	2.9	12.53	2.3	9.94
Under construction end of 2012	~0.2	0.87	0.1	0.43	0.1	0.43
Total projected by 2015	~0.5	1.8	0.2	0.87	0.3	1.3

Table D: Existing geothermal district heating (DH) plants, individual sites*

***** No District Heating plants (for towns, settlements, villages, etc.) in Belarus. Some individual geothermal installations are listed in the Table 1 in the main text.

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New GSHP in 2012		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2012	~100	5.5	2.38	2	0.2	2
Projected by 2015	~105*	6.0*	2.6			

Comments to the Table E: * - These are estimated values. No detailed information available. Existing geothermal installations are based on fresh water pumping from boreholes, using borehole heat exchangers (BHE), and not many of them use horizontal circulation loops.

Table F: Investment and Employment in geothermal energy

	in 2012		Expected in 2015	
	Investment (million €)	Personnel (number)	Investment (million €)	Personnel (number)
Geothermal electric power	No	No	No	No
Geothermal direct uses	No*	No*	No	N/A
Shallow geothermal (GSHP)	0.2*	No*	0.5 – 1.0	N/A
total	**0.2***	**No***	**0.5 – 1.0**	**N/A**

Comments to the Table F: *) – Estimated data.
All installations available are for the direct use of geothermal energy, at the same time all are "shallow geothermal" (usually they use the fresh water pumping, or the BHE technology). Typically there is no separate personnel to operate these installations, they are served by the users themselves.

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal (GSHP)
Financial Incentives – R&D	No	No	Equivalent to ~25 000 €/ year
Financial Incentives – Investment	No	No	Equivalent to ~250 000 €/year (estimated)
Financial Incentives – Operation/Production	No	N/A	N/A
Information activities – promotion for the public	No	No	Publications in public media (newspapers, magazines).
Information activities – geological information	No	No	Publications in geological journals.
Education/Training – Academic	No	No	We have 1 Prof. and 1 PhD specialists in Geothermics. Now we have 1 PhD student too.
Education/Training – Vocational	Lectures are delivered for students of the Belarusian State Univ. in Geothermics & Geothermal Energy since 2011.		

Key for financial incentives:					
DIS	**Direct investment support**	RC	Risc coverage	FIP	Feed-in premium
LIL	Low-interest loans	FIT	Feed-in tariff	REQ	Renewable Energy Quota

Final comments: If something in the tables A – G are not understandable, or should be extended, or erroneously filled in, please contact Vladimir Zui at zui@geology.org.by (Belarusian Research Geologic Exploration Institute, Minsk, Belarus) to discuss these items.