Geothermal Field and Geothermal Resources, Country Update for Belarus

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ABSTRACT

The geothermal investigations were started in Belarus since 50th of the previous century. The region belongs to the western part of the East European Platform. Its territory formed mostly by Precambrian crustal blocks with Paleozoic Pripyat Trough and the Podlaska-Brest Depression in southern part of the country. There are no warm springs within the considered area.

Since the time elapsed after the World Geothermal Congress 2016 the main efforts were directed to prepare the Geothermal Atlas of Belarus, which was finished in December 2015, but it was published only in the middle of 2018. The density of Geothermal resources were estimated for a number of geothermal horizons. They range from first dozens of kg.o.e./m^2 for shallow depths till a few t.o.e./m^2 in deep sedimentary layers of the Pripyat Trough. Some of these resources are exploited in a number of localities mainly using small heat pump geothermal installations irregularly distributed within the territory of the country.

The Atlas represents results of geothermal investigations fulfilled during few decades of geothermal investigations. A number of geothermal maps were prepared for the studied territory: temperature distribution maps compiled for a number of depths starting from 100 m till 4 km (within the deep sedimentary basin which is the Pripyat Trough), maps of geothermal gradient, heat flow density and geothermal resources.

Geothermal resources were estimated for selected geothermal horizons. No geothermal steam was revealed within the whole platform cover. Preliminary estimates show that a depths position at which it could be possible to reach temperatures of 150–180 ºC, are within the crystalline basement over the economically acceptable limits. Therefore, a possibility for geothermal electricity generation is not considered here. The maximal temperature recorded in the deepest inclined Predrechitsa-1 borehole at the base of the platform cover was around 135-140 ºC at the depth of 6.4 km in the Pripyat Trough.

First heat pump installations were created in the middle of nineties of the past century and for the end of 2018, around 250 geothermal installations were put into operation in the country and a few similar geothermal heating systems are under construction each year. All available installations are used for space heating and simultaneously to produce warm water. The biggest geothermal installation of 1 MW_{th} was put into operation at the Greenhouse Complex "Berestye" at the eastern suburb of Brest town in the west part of the country. All heat pump installations excluding the latter one use shallow depth intervals with low-enthalpy geothermal resources.

1. INTRODUCTION

The territory of Belarus is located in the geographical center of Europe, (fig. 1).

Figure 1: Belarus is located in the geographical Center of Europe.

The crystalline basement of whole territory of the country is hidden under the platform cover of different thickness. The main part of the country belongs to the Precambrian East European Platform and is a junction of three major crustal segments: Fnnoscandia in its northern part, Volgo-Uralia in the east, and Sarmatia in the south, Gorbatschev and Bogdanova, (1993). The latter one includes two Paleozoic sedimentary basins. They are the eastern part of the Podlaska-Brest

Depression and the Pripyat Trough. The trough has a developed salt tectonics.

The Belarusian Anteclise is the main positive structure within the region. It occupies the central- west part of the country and is extending beyond its borders into eastern Poland, (Fig.2).

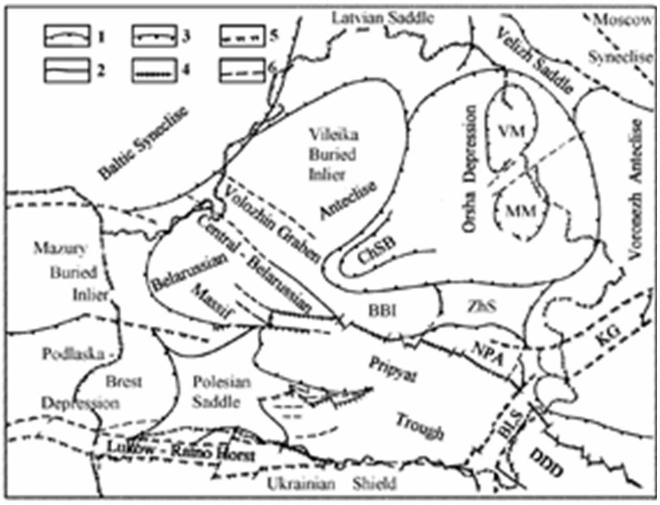

Figure 2: Main geologic units within the territory of Belarus. Legend:
1 – the largest, 2 – large, 3 – medium-size platform faults: 4 – super regional, 5 – regional, 6 – sub regional and local faults. Abbreviations: DDD – Dnieper-Donets Depression; KG – Klintsy Graben; BLS – Bragin-Loev Saddle; NPA –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

Besides the Podlaska-Brest Depression and the Pripyat Trough in western and eastern parts of the country, respectively, the Orsha Depression occupies its eastern part.

A 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 below sea level within other parts of the anteclise. 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 Pripyat Trough is the best-studied tectonic unit in geothermal respect in the country. Hundreds of deep boreholes were drilled there during oil prospecting works within its territory. In many of them thermograms were recorded in the process of their standard logging.

An active development of the Pripyat Trough took place during the Devonian time, Geology…, (2001). The Devonian volcanism took place in its eastern part and an explosion pipes, were observed within the Zhlobin Saddle to the north of North-Pripyat Arm, (see Fig. 2).

Two salt layers (the Upper Salt and Lower Salt) exist within the platform cover of the Pripyat Trough, separated by terrigenous intersalt rocks. A base of the Lower Salt is up to 4.5–5.5 km depending on the individual basement block. Carbonate and terrigenous sediments underlie the Lower Salt complex, which contain highly mineralized brines.

A thickness of sediments within the Belarusian part of the Podlaska-Brest Depression varies from c.a. 0.5 km in its lateral edges until 1.7 km along the Belarus-Poland border. Deep boreholes here have an irregular areal distribution.

The uppermost part of sediments at the whole country belongs to a zone of active water exchange, Kudelsky, et al., (2000). Its deepest parts reach up to 400 m within western part of Belarus and in some localities of the Podlaska-Brest Depression it increases up to 1000 m.

A mineralization in deep horizons in the Podlaska-Brest and Orsha depressions reach 25–40 g/dm^3. High salinity brines up to 400–420 g/dm^3 were observed in deep horizons of the Pripyat Trough.

2. TERRESTRIAL TEMPERATURE FIELD

Besides thermograms of standard logging, regular geothermal investigations were undertaken in a number of boreholes since the end of sixties and beginning of seventies, under temperature equilibrium after their drilling was finished. In result, hundreds of thermograms were accumulated until today within the whole territory of the country. They were used to compile a number of temperature distribution maps for selected depths and surfaces of stratigraphic horizons, as well as geothermal gradient and heat flow density.

These geothermal maps were included into the Geothermal Atlas of Belarus, which was published in 2018, Geothermal…, (2018). The Precambrian territory of the country has a contrast pattern of its terrestrial temperature field. It concerns geothermal gradients and the observed heat flow density as well as the density of geothermal resources distribution. A number of geothermal anomalies were revealed in maps. A complex geometry of salt bodies influences the local terrestrial temperature field pattern within the Pripyat Trough. It is the best studied unit in geothermal respect. Hundreds of deep boreholes were drilled within the trough in the course of oil prospecting works. Other territories outside the Pripyat Trough: the Belarusian Anteclise with its Polesian, Zhlobin and Latvian saddles are less studied tectonic units. A small number of deep prospecting wells are available within the Podlaska-Brest and Orsha depressions.

Mainly shallow boreholes within the Belarusian Anteclise and Orsha Depression were used for geothermal measurements. Most of them were finished within the zone of active water exchange with a pronounced groundwater circulation.

The accumulated database of thermograms was used to prepare temperature distribution maps for the whole country based mostly on reliable temperature records in boreholes only to depths of 100-200 m. Many extrapolated diagram were used to prepare temperature maps to the required depths up to 500 m for the whole country. Only for the better-studied Pripyat Trough, it was possible to compile such maps for deeper horizons.

2.1 Temperature distribution at the depth of 200 m

The temperature distribution map for the depth of 100 m is shown in fig. 3. A pronounced groundwater circulation takes place within the depth interval of 0 100 m there as it belongs to the zone of active water exchange, containing fresh water in pores of rocks.

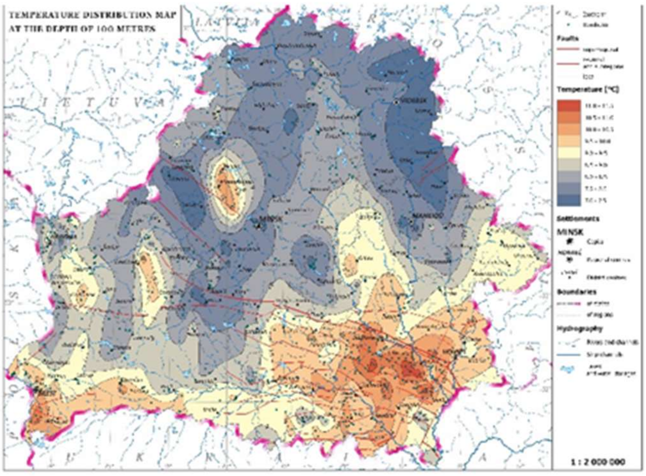

Figure 3: Temperature distribution map at the depth of 100 m within Belarus.

The sub-vertical water filtration influences the shapes of thermograms. The typical form of them in boreholes drilled at elevated form of relief: hills, uplands, watersheds have the concaved forms and, on the contrary, convex ones are typical for wells within valleys. In results a convective component of heat transfer is pronounced here, Zui, (2010).

The isotherms were drawn within the territory of Belarus by means of an interpolation. Their contours outside the state border were received in result of an extrapolation into adjoining areas, Zui (2013).

Seasonal temperature variations at the ground surface propagate into depths within the described region depending on their lithologic composition comprising geologic cross-sections and downward or upward water filtration rates, availability of confining beds, etc. Field measurements show that these depths are typically range from 30 to 70–90 m for areas with thin or absent impermeable layers of clays, mudstones, etc.

Temperature at this depth ranges from 7 to 11.5 °C. Values above 8 ºC are typical for Paleozoic geologic units: the Pripyat Trough and the Podlaska-Brest Depression.

The isotherm of 9 ºC has its continuation beyond the North Pripyat Fault into the North Pripyat Arch, Zhlobin Saddle and the western slope of the Voronezh Anteclise. Available thermograms of the Pripyat Trough, recorded in the course of standard logging, at the depth of 100 m have low quality to be used the temperature map. A number of regional and local anomalies are shown there. Low temperature anomalies of 6.5–7.5 ºC exist in the eastern part of the Orsha Depression. This area includes almost the whole Mogilev Mulde. No data available to trace reliably this anomaly into adjoining area of Russia as there is a very rare network of geothermally studied boreholes.

A strip of slightly increased temperature of 8.5–10 ºC with the meridian orientation of isotherms crosses the whole territory of the Orsha Depression from the Pripyat Trough and continues into Russia. Their northern continuation is unknown due to a lack of data beyond the state border in the adjoining area of Russia.

As before, isotherms of 9.0-9.5 ºC in the eastern part of the Podlaska-Brest Depression are traced through the Polesian Saddle along the Belarus-Ukraine border and continued into the territory of Ukraine. The isotherm of 9.0 ºC of this anomaly has its continuation into the Pripyat Trough and then to the western slope of the Voronezh Anteclise, Zui (2010, 2013).

In the northwestern corner of the country, the *Grodno anomaly* of increased temperature above 9 °C is stretched in the meridian direction and has its continuation into the territory of Lithuania.

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 the 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.

2.2 Temperature distribution at the depth of 200 m

Available database of temperature–depth profiles was used to compile the temperature distribution map for the depth of 200 m, (Fig. 4). However, to the number of temperature readings taken here from thermograms recorded in boreholes with equilibrium thermal state, dozens of them were added from extrapolated diagrams to the depth of 200 meters. Also a number of local temperature anomalies shown in this map, are similar to those ones described for the temperature distribution map at the depth of 100 m.

We will not discuss in details this map, but only mention some of its features. The available number of thermograms decreases for the depth of 200 m but it still remains around 250 including around 25-30 % of extrapolated temperature values. In result, small details starting disappear from the map and shapes of isotherms are slightly changing at the general background of increasing the temperature with the depth. Minimal temperature values at the map for the depth of 200 m ranges from 8.0 until 17 ºC. The configuration of isotherms in the map is slightly changed. One of reasons is a lack of thermograms for this depth for the Orsha Depression. As before, main anomalies of increased temperature are related to Paleozoic Pripyat Trough and the Podlaska-Brest Depression. Considerably lower temperatures are typical for the Belarusian Anteclise and the Orsha Depression.

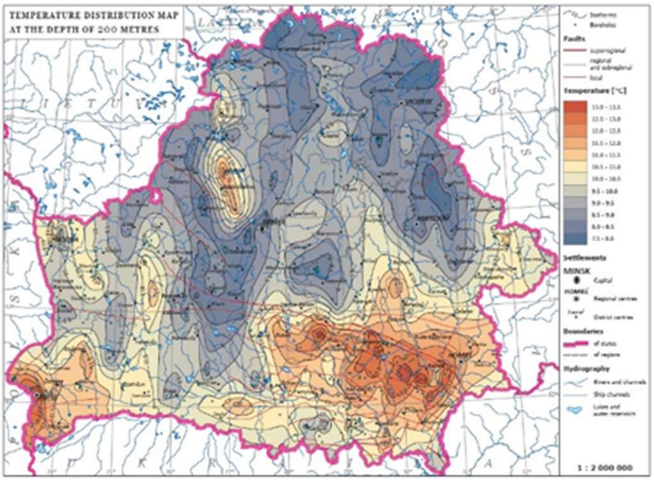

Figure 4: Temperature distribution map at the depth of 200 m within Belarus.

Actually all temperature anomalies, shown in the temperature distribution map for the depth of 100 m, exist also at the depth of 200 m with slightly changed shapes. Partly it is the result caused by ceased vertical component of the velocity of downward water filtration. First of all, it concerns the Molodechno-Naroch, Kobrin-Pruzhany, Mosty and Lyakhovichi-Elnya anomalies. It is well known that decreasing of the groundwater infiltration rate results in many instances in the reduction of the convective component of heat transfer in loose sediments.

2.3 Temperature distribution at the depth of 2 and 4 km

When the depth increases, the number of available thermograms within the territory of Belarus rapidly decreases as shown in fig. 5. For the depth of 0.5 km, the number of thermograms for boreholes of the Pripyat Trough, and extrapolated ones (calculated temperatures) are almost equal. For the depth of 3 km this ratio becomes 40/60 %. For the depths exceeding 4 5 km the majority of thermograms, as a rule, were extrapolated.

A lack of thermograms didn't allow compiling terrestrial temperature maps for depths deeper than approximately 700 m for the whole territory of Belarus. They are practically absent for the Belarusian Anteclise and only a few diagrams were available for deep boreholes within the Podlaska-Brest and Orsha depressions which do not allow to construct reliable temperature distribution maps. Temperature values at the sedimentary cover base within two last depressions reach 40–42 °C.

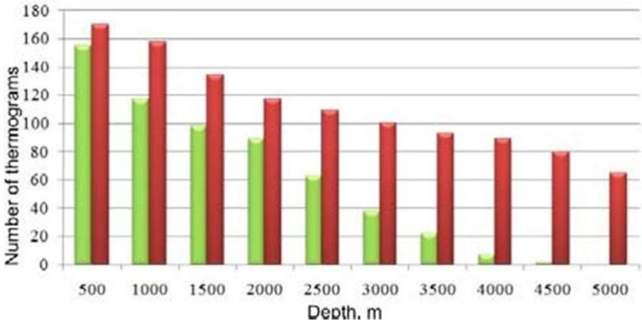

Figure 5: Number of reliable (green) and extrapolated (red) thermograms for the Pripyat Trough.

As thermograms of deep boreholes are available mostly for the Pripyat Trough, we consider its temperature field for deeper horizons. The trough represents the best-studied area in geothermal respect among other sedimentary basins of the country. In its northern zone the temperature at the base of the platform cover increases to 80–100 ºC. At the same time for the depth of 4–5 km the number of really recorded thermograms doesn't exceed 20, which is not enough to compile detailed temperature maps based purely on results of measurements. We used a majority of temperature data for such depths from extrapolated termograms.

The maximal temperature recorded, for instance, in the Barsuki 63 oil well, was 115 °C at the depth of 4 km and its maximal value approaching 140 °C at the depth of 6.4 km was recorded in the Predrechitsa-1 hole.

The temperature field pattern at the depth of 2 km is shown in (Fig. 6). There is a distinct asymmetry of the terrestrial temperature field within the whole structure. 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 below 35 °C exists in southwestern part of the Pripyat Though. Only a few thermograms were available in southwestern part, of this area that is 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 northeastern zones of the trough. The exploited oil fields exist mainly within this warm area, Zui (2013).

At the depth of 2 km, 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 until Luban town and continues to the southeast into the Gremyachy Buried Salient, Russia and the Dnieper-Donets Depression, the main part of which is in Ukraine. In the northern direction, the anomaly was traced into the North Pripyat Arch. Small area anomalies exceeding 40 °C were observed within the southern part of this geologic unit (the Elsk Graben and the Vystupovichi Step). The background temperature values here range from 35 to 40 °C.

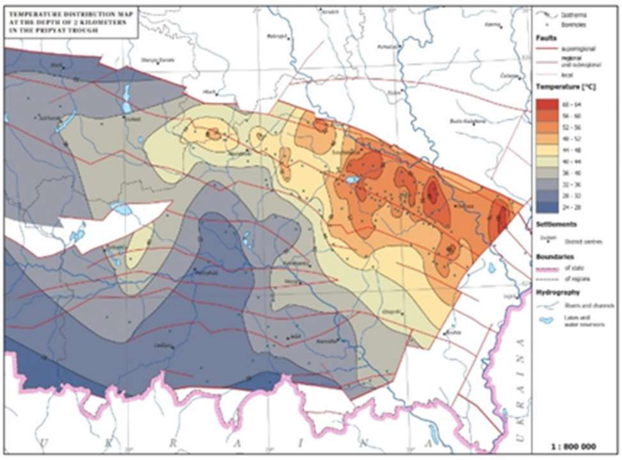

Figure 6: Temperature distribution at the depth of 2 km within the Pripyat Trough.

The temperature distribution at the depth of 4 km is shown in fig. 7.

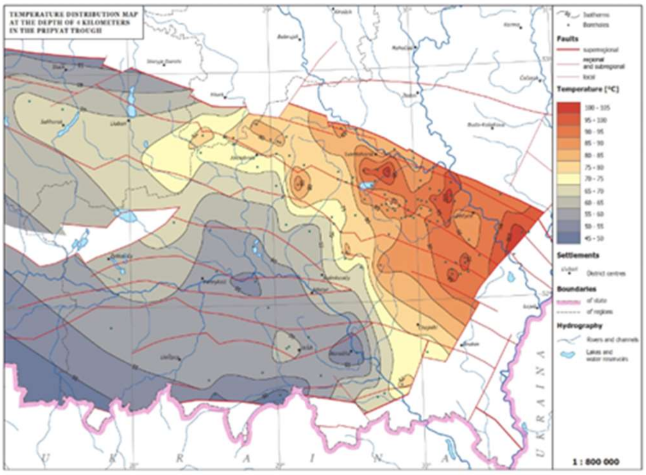

Figure 7: Temperature distribution at the depth of 4 km within the Pripyat Trough.

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. Only a few extrapolated thermograms were available in southwestern zone that is why it was not possible distinguishing small details in the map. At this background, the highest temperature exceeds 60–80 °C. When the depth increases to 4 km, small details in temperature distribution maps disappear, because the number of available thermograms also decreases. The terrestrial temperature field at the depth of 4 km is similar to those one shown at the depth of 2 km. The main differences are higher temperature values up to 80–100 °C in the northern zone of the positive anomaly and slight changes in shapes of isotherms.

3. HEAT FLOW

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

The heat flow density map (Fig. 8), was compiled using all available data, which were accumulated in the heat flow catalogue, Zui, (2013); Geothermal…, (2018). Some of available heat flow data from adjoining areas of foreign countries: Poland, Lithuania, Latvia, Russia and Ukraine were also used when compiling this map.

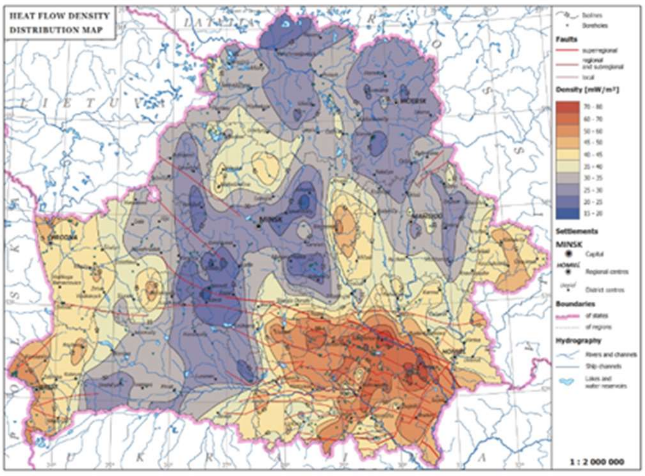

Figure 8: Heat flow density map for Belarus.

Heat flow density distribution is rather differentiated within the whole 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, Geothermal…, (2018). The geometry of salt tectonics was studied within the Pripyat Trough both by drilling and by geophysical methods. Geothermal measurements and heat flow determinations were fulfilled also in most of boreholes drilled through salt domes and swells. 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.

In the upper part of sediments overlying the Upper Salt formation (the so- called “above-the-salt” sediments), interval heat flow values are typically lower in result of the groundwater circulation. Therefore, heat flow, calculated in shallow intervals of boreholes shows its lower values comparing to adjoining areas of the trough with deep boreholes. That is 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 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 intrusions in the crystalline basement), Orsha Depression, North Pripyat Arch, Zhlobin Saddle, and the western slope of the Voronezh Anteclise.

As it was mentioned, 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 area limited by the isoline of 60–75 mW/m^2. Only less than 10 of them are located inside the area of 55–60 mW/m^2. A zone of 65–75 mW/ m^2 corresponds to two gas 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.

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 northern part of Lithuania 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 does not allow tracing it more correctly.

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

4. GEOTHERMAL RESOURCES

Recoverable geothermal resources were calculated based on a widely used approach, namely according to Hurter and Haenel (2002).

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 kilograms of oil equivalent per square meter (kg.o.e./m^2) within crustal blocks with thin sedimentary cover to 200–300 kg.o.e./m2 in the Podlaska-Brest Depression. 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.

4.1 Geothermal resources in the depth interval of 100–200 meters

Fresh ground waters are encountered until the depth of 200 m almost in the whole territory of Belarus. Only within relatively small areas this depth belongs to cracked rocks of the crystalline basement (central Belarusian Massif), their mineralization does not exceed 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 wells to return them into the aquifer, as there are no scaling and ecological 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.

This interval is composed of rocks with different age and lithology. As there are many hydrogeological windows in this interval, it was decided, as the first approach, to consider this interval as a “single aquifer”. It gives a possibility to determine and compare recoverable resources within different geologic units of the whole 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 9 shows a distribution of recoverable geothermal resources for Belarus contained within permeable rocks with fresh water in the depth interval of 100–200 m.

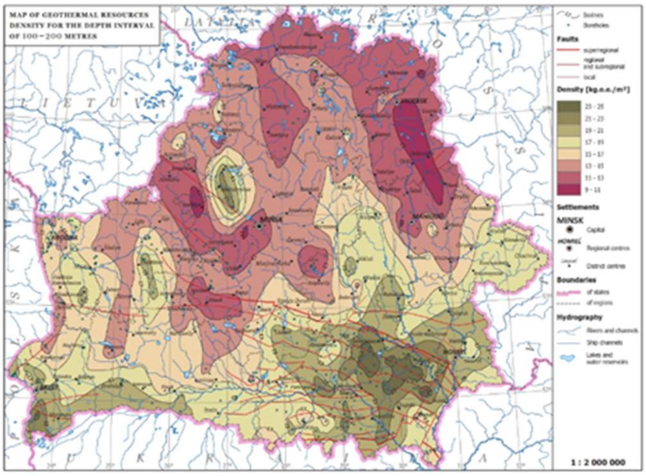

Figure 9: Recoverable density of geothermal resources from the interval of 100–200 m within the territory of Belarus.

The density of recoverable geothermal resources 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, extended into the western slope of the Voronezh Anteclise and continued beyond the North Pripyat Fault as a narrow strip of increased values, stretched in northern direction along the line crossing through towns and settlements: Stetlogorsk – Parichi – Kirovsk – Elizovo. Small anomalies exist in between Molodechno – Naroch, Volozhin – Vileyka, Slonim – Pruzhany towns. Another anomaly was traced near Grodno, its margin is open into the territory of Lithuania and probably it reaches the positive anomaly of within the west Lithuania and the Kaliningrad Enclave of Russia.

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 adjacent territory of Russia. In deep horizons of the Orsha Depression, the estimated density of geothermal resources reaches up to 50 kg.o.e./m^2. All isolines were drawn by interpolation inside the territory of Belarus.

The density of geothermal resources was calculated also for different water-bearing complexes, developed within Belarus. They are the Cretaceous, Middle Devonian, Paleogene deposits, etc. not discussed here.

4.2 Geothermal resources within deep horizons of the Pripyat Trough

The Pripyat Trough belongs to geologic units with higher heat flow in comparison to Precambrian blocks of the crust. Geothermal resources were calculated here for several geothermal horizons using the standard approach, Hurter and Haenel (2002). These horizons are: (a) Jurassic deposits, (b) Carboniferous, (c) Devonian sediments overlying the Upper Salt Formation (d) the Intersalt sediments, (e) Devonian thickness underlying the Lower Salt Formation (terrigenous and carbonate strata), (e) the Upper Salt complex and (f) the Lower Salt thickness. Rocks underlying the Lower Salt complex has very high mineralization of brines up to 420–450 g/dm3 and even higher in some localities. There are no world practice to utilize such brines to recover geothermal energy.

Here we consider only a couple of them. The density of geothermal resources for several horizons of the Pripyat Trough was discussed earlier, Zui, (2010). For instance, they range from 0.25 to 1 t.o.e/m^2 within the Intersalt Complex of the Pripyat Trough, (Fig.10).

Dozens of abandoned deep wells were drilled in the course of oil prospecting works in the Pripyat Trough outside the water-oil boundaries, later they were plugged. These abandoned boreholes represent the interest 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.

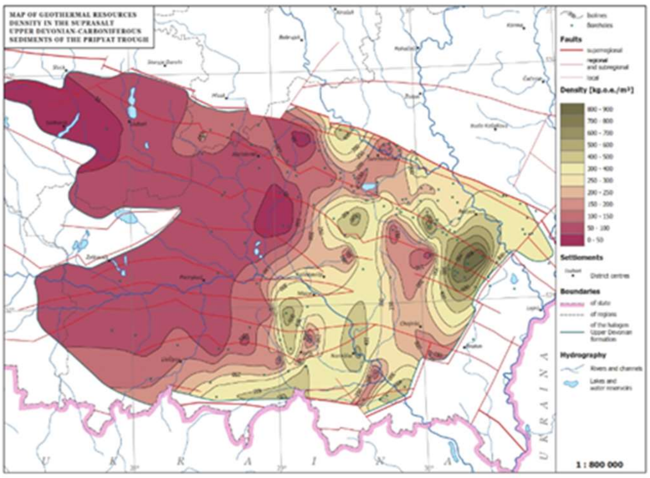

Figure 10: Density of Geothermal resources within the suprasalt upper Devonian-carboniferous sediments of the Pripyat rough (t.o.e/m^2).

The feature of the Pripyat Trough is high salinity of brines. Because of high mineralization of them, it is possible mainly to use these drilled wells to create borehole heat exchangers without direct extracting of brines itself. Using the old abandoned boreholes will allow reducing of expenses to construct corresponding geothermal systems.

Another possibility is to use geothermal horizons laying above the Upper Salt Complex, where the salinity of warm brines is much lower. For instance, the Carboniferous deposits (fig. 11) or overlying them horizons containing mineral or even fresh waters with lower geothermal resources, but still acceptable for their practical utilization.

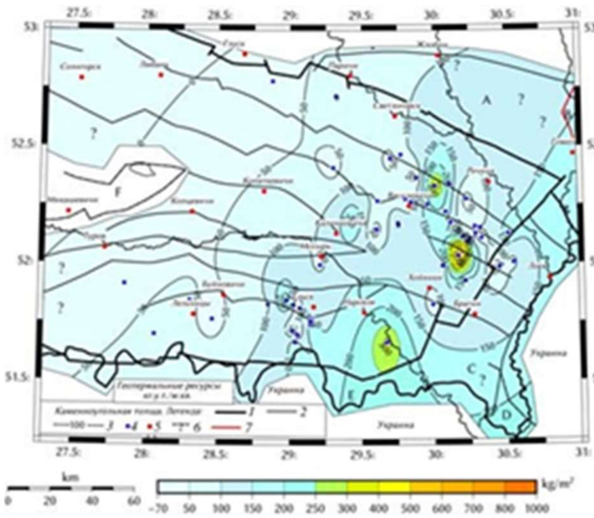

Figure 11: Density of Geothermal resources within the Carboniferous Complex of the Pripyat Trough, (kg.o.e/m^2).

Density of geothermal resources within the Carboniferous sediments ranges from less than 50 kg.o.e/m^2 in the western part of the Pripyat Trough up to approximately 500 kg.o.e/m^2 in some localities of the northern and eastern parts of the trough.

5. GEOTHERMAL INSTALLATIONS

Existing regulations in the country do not require registering geothermal installations in the Ministry of Mineral Resources and Environmental Protection. Therefore, their exact number is not known and only could be estimated. The very first small heat pump system was installed for heating of waterworks and sewage header buildings mostly in the Minsk District in 1997.

It gradually increased during the following years. At present, the total number of geothermal installations all over the country is estimated to be around 250. The biggest installation exists in the southwestern part of the country at the Greenhouse Complex "Berestye" in Brest town. It uses fresh warm water from Cambrian deposits, which is pumped out from a borehole Vychulkovskaya 201. This complex is spread to the depth up to 1000 m. Water temperature at the well mouth reaches of 24 ºC, 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.12), Zui, Pavlovskaya, (2012).

Figure 13: Heat pumps Daikin EWWD 440MBYN at the Greenhouse Complex "Berestye".

Other heat pump installations use an open circulation loop with pumping out of fresh water or closed loop systems with horizontal or vertical heat exchangers. The main consumers of the underground heat are a frontier point Novaya Rudnya at the Ukrainian border, dwellings, a church, etc. with the total number of installed heat pumps around 250 with their heat capacity approaching to 8 10 MW$_{th}$. We assume their power output is underestimated.

A few hundreds of small heat pump systems were installed in private cottages within and around the main towns and cities (Brest, Gomel, Grodno, Mogilev, Vitebsk, Minsk and others). Most of installations extract heat from actually cold groundwater taken from shallow boreholes with ambient temperature of 8–10 ºC as a primary energy source or have closed horizontal circulations loops. One installation is based on the utilization of the river water.

6. CONCLUSIONS

Both studied temperature and heat flow have a contrast pattern within the territory of Belarus. A contrast geothermal field is pronounced within areas with developed salt tectonics, like salt swells and domes of the Pripyat Trough. Its utilization represents an important national goal for the economics of Belarus.

Investigations show that low-enthalpy geothermal energy could be used within the whole territory of the country. However, there are no geothermal high enthalpy resources at acceptable by drilling depth suitable for electricity generation.

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 shallow horizons of 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 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.

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. A construction of a pilot geothermal station using one of deep and abandoned wells would be useful to stimulate the practical utilization of geothermal resources of deep horizons within the Pripyat Trough.

There is no underground water steam revealed within the sedimentary cover in the course of drilling of exploration wells for oil and drilling of other deep wells, hence no suitable for utilization in Belarus of geothermal resources for power generation was detected. All existing geothermal installations use heat pumps to extract low-enthalpy geothermal resources mainly for heating purposes.

A number of geothermal maps were compiled in the process of preparation of Geothermal Atlas of Belarus. Its was finished in December 2015 and published only in 2018, Geothermal…, (2018).

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Tables A-G

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

Table B: Existing geothermal power plants, individual sites

No such power plants in Belarus.

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

Table D1: Existing geothermal district heating (DH) plants, individual sites

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

No District Heating plants available (for towns, settlements, villages, etc.) in Belarus.

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

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2018		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2018	~250 *est.*	8.0-10.0 *est.*	7.0 *est.*	10 *est.*	1.0 *est.*	0.5 *est.*
Projected total by 2020	260 *est.*	10.5 *est.*	7.5 *est.*			

Comments to the Table E: All figures are estimated ones. 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 2018		Expected in 2020	
	Expenditures (million €)	Personnel (number)	Expenditures (million €)	Personnel (number)
Geothermal electric power	No	No	No	No
Geothermal direct uses	No*	No*	No	N/A
Shallow geothermal	0.2*	No*	0.5 – 1.0	N/A
total	**0.2***	**No***	**0.5 – 1.0**	**N/A**

* Estimated data. All installations available are for the use of geothermal energy by heat pump installations, at the same time all they are "shallow geothermal" (usually they use the fresh water pumping out, or the BHE technology). Typically there are no separate personell to exploit these installations; they are served by users themselves.

Table G: Incentives, Information, Education

No information available.