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Geothermal Resources, Country Update for Belarus

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ABSTRACT

Temperature distribution maps were compiled for several depths from 100 to 500 m for the whole territory of Belarus, as well as for the depths from 1 to 4 km for the Pripyat Trough. Terrestrial geothermal field of the platform cover of the country shows a contrast pattern. Temperature values within the platform cover range from 7–9ºC for shallow horizons of Precambrian crustal blocks to 100–115ºC at the depth of 4-5 km within the Paleozoic Pripyat Trough. Similar features were observed for the heat flow map of Belarus.

Geothermal resources were estimated for several of the water-bearing horizons within the sedimentary cover. Only very preliminary estimates were fulfilled for a depth position at which it could be possible to reach temperatures of 150 – 180ºC, necessary to create geothermal power plants. These depths reach 7 – 12 km even within different crustal blocks of the Pripyat Trough with higher heat flow among other geologic units of the country. Such temperatures exist only within the crystalline basement, which, at the moment it is considered to be economically not acceptable for the geothermal electricity generation.

At present only direct use of geothermal energy resources ground source heat pump (GSHP) systems are available in Belarus. All geothermal installations are based on heat pumps technology. Their total installed capacity is around to 6–6.5 MWt and their number is estimated to be 100–130. The biggest installation with the total capacity of 1 MWt was put into operation at the autumn of 2010 at the Greenhouse Complex named Berestye and located close to the Belarus-Poland border in the eastern suburb of the Brest town. Other heating installations were put into operation for a number of cottages, small industrial buildings, for a local hospital, one church, a railway station, a frontier point, sport rowing channel, etc. A number of other installations are planned to be constructed in the near future.

1. INTRODUCTION

The whole territory of the Republic of Belarus belongs to the rather cold Precambrian East European Platform. Therefore there are no high-enthalpy geothermal resources, like the underground steam, within the platform cover suitable to create the electricity production. In result the available low temperature and low-enthalpy geothermal resources are used as a rule for heating purposes.

First temperature-depth profiles in deep boreholes were recorded in Belarus during oil prospecting works organized within the deepest sedimentary basin Pripyat Trough located in the southeastern part of the country in the fifties of the last century. The first heat flow density estimates were fulfilled in the beginning of sixties, (Belyakov (1954); Protasenya (1962a); Protasenya (1962b)). Since that time, regular geothermal investigations were undertaken which were continued till now (Bogomolov et al. (1972); Atroshchenko (1975); Zui (2013)).

The first works on geothermal resources were started during the second part of nineties (Zui, Levashkevich (1999)) and continued at the beginning of the current century (Zui (2006); Zui (2010)). They were concentrated mainly on the density of geothermal resources in within different geothermal horizons of the platform cover both for the whole territory of the country and individual geologic structures. Some maps of geothermal resources were prepared but this work in continued as well at present time.

Geothermal installations were put into operation in Belarus since the middle of nineties of the last century. They represent ground source heat pumps (GSHP) systems used for heating of buildings at territories of water supply plants located in the vicinity of Minsk city (the capital of Belarus). Later GSHP installations were constructed and put into operation in other towns and settlements all over the whole territory of the country. Most of them are used for heating of houses and different buildings such like dwelling houses, greenhouses, waterworks, border station, hospital, etc. The country belongs to the area of lukewarm climate, therefore some of them also provide cooling of living quarters during summer time. Their number at present time exceeds 100-130 installations and their total installed capacity is above 6 MWt.

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 150-180ºC, 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. In general the whole territory of the Republic of Belarus belongs to the rather cold Precambrian East European Platform. Therefore there are no high-enthalpy geothermal resources, e.g. underground steam or water-steam sources.

2. GEOLOGIC BACKGROUND

There are three major crustal segments of different ages existing within Belarusian territory. The Fnnoscandia is traced in the north into the Baltic Shield, Volgo-Uralia is stretched to the East and Sarmatia exists 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).

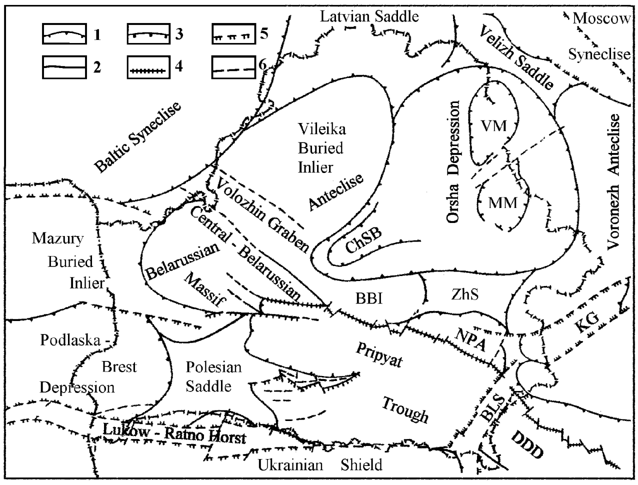

Figure 1: Main geologic units within the territory of Belarus. Legend: 1 – the largest, 2 – large, 3 – medium-size platform faults: 4 – super regional, 5 – regional, 6 – sub regional and local faults. Abbreviations: BBI – Bobruik Buried Inlier; BLS – Bragin-Loev Saddle; ChSB – Cherven Structural Bay;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

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 the main part of which is continued into Poland, and the Pripyat Trough in southeast, separated of the Dnieper-Donets Depression by the Bragin-Loev Saddle.

The Precambrian 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, separate it from the Bobruisk Buried Inlier, the North-Pripyat Arch and the Zhlobin Saddle. The Bragin-Loev Saddle joins two Paleozoic units: 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, Makhnach et al. (2001). The tectonic activity, which formed the Pripyat Trough, took place during the Devonian and its main stage of downwarping belongs also to the Lower and Middle 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, (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 individual basement block. Terrigene sediments separate the Upper Salt and Lower Salt deposits. They comprise so-called Intersalt Complex. The depth to its surface varies on average from 1.5 to 3.0 km and its thickness ranges from 100 m in the western part of the area to 1,000 m in some of the deep parts. The complex geometry of these rocks influences the terrestrial temperature field pattern. There is developed salt tectonics which formed salt domes and swells all over the trough. Carbonate and terrigene 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 Belarus-Poland state border. A few dozens of deep boreholes were drilled here, but their areal distribution within the depression is irregular.

The upper part of the sedimentary cover within the whole territory of Belarus contains fresh water. Its base was observed at variable depths ranging from 150 to 400 m, Kudelsky, et al., (2000). It deepens within the westernmost part of the country to more than 400 m. The deepest position of the fresh water base up to 1,000-1,100 m exists along the Belarus-Poland border (Fig. 2). Fresh water was also encountered in the fractured uppermost part of the crystalline basement within some parts of the Belarusian Anteclise with thin sedimentary cover.

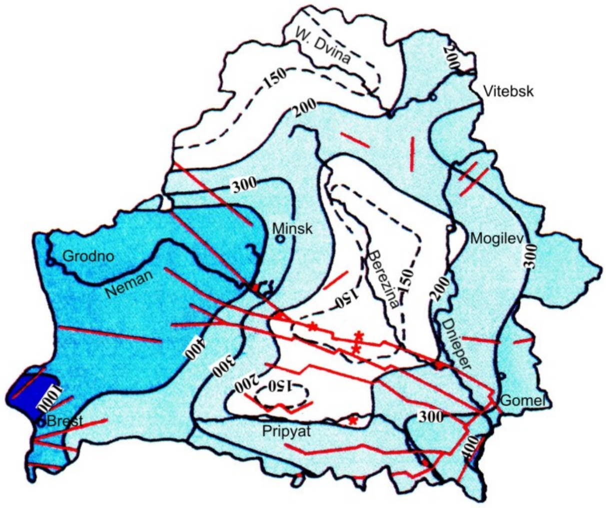

Figure 2: Fresh water base position within Belarus. Legend: black lines represent depth isolines (m); red lines show positions of main deep penetrating faults; red stars indicate localities with surface water mineralization exceeding 1 g/dm3 (usually small springs).

3. TERRESTRIAL TEMPERATURE FIELD

As it was mentioned, the first temperature-depth profile, recorded in one of the deep boreholes of the Pripyat Trough, was published in the middle of fifties, Belyakov (1954). A gradual accumulation of temperature records occurred since the second half of the fifties of the last century after oil prospecting works were organized and the first oil field was discovered. Regular geothermal investigations were undertaken afterwards since the beginning of sixties within the whole territory of the country in boreholes that reached their temperature equilibrium after the drill works were finished. They are continued till the present time.

Nowadays hundreds of thermograms were recorded during more than five decades of geothermal investigations. They were used to compile temperature distribution maps for selected depths and at roofs of selected geothermal horizons. In the early stage of geothermal observations it was believed that the thermal state of rocks is rather uniform within Precambrian platforms.

A position of studied boreholes with available temperature-depth diagrams is shown in (Fig. 3). In most of them were fulfilled calculations of interval heat flow values.

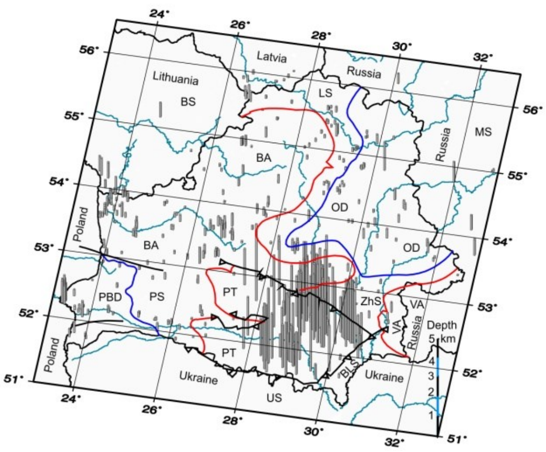

Figure 3: Location of boreholes within Belarus with available thermograms. Legend: heavy black lines – deep penetrating platform faults; heavy blue lines – margins of negative structures; heavy red lines – margins of positive structures. Abbreviations: BA – Belarusian Anteclise; BLS – Bragin-Loev Saddle; 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 and there oil deposits are absent and mostly shallow boreholes were accessible for geothermal measurements. Most of these holes were drilled for drinking water and were finished within the fresh water zone. Sometimes we recorded thermograms in boreholes drilled for mineral water.

Available thermograms could be subdivided into two groups. The first one represents curves recorded in boreholes that reached the equilibrium of their wellbores temperatures and rock massifs after their drilling was finished. Many observational holes, used to monitor seasonal variations of water levels are among them. The second group includes curves recorded when the temperature of rocks, around 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 1,000 temperature-depth diagrams, recorded in boreholes all over the country, were used to compile temperature distribution maps.

Using available geothermal measurements it was possible to compile small-scale temperature distribution maps for the whole country only to the depths from100 to 200 m. Extrapolation of thermograms into deeper strata gave a possibility to compile such maps to the depths from 300 to 500 m.

3.1 Temperature maps for depths of 100 and 200 m

The depth of 100 m belongs to the fresh water zone, (Fig. 2) and the depth of 200 m in some of the local areas belongs to horizons with mineral waters. Mainly results of temperature readings from temperature-depth profiles were used for their preparation, but in some of cases where depths of studied shallow boreholes were less than 200 m, the temperature values were received in result of the downward extrapolation of thermograms. The mentioned maps are shown in Fig. 4.

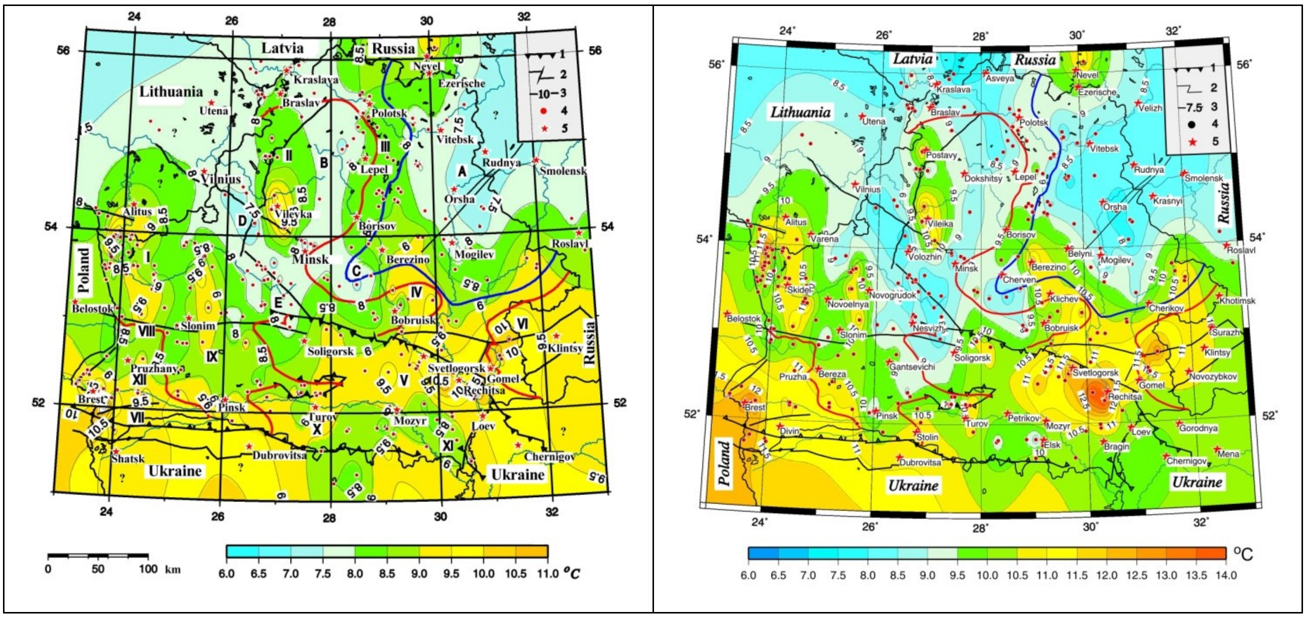

Figure 4: Temperature distribution maps at depth of 100 (left) and 200 m (right) within Belarus. Legend: 1, 2 – superregional and regional faults within the crystalline basement, 3 – isotherms, ˚C, 4 – studied boreholes, 5 – towns and settlements. Anomalies of increased temperature: I – Grodno, II – 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).

Thermograms, recorded in around 400 holes, were used to compile the map, Zui, (2010). These maps indicate a contrast pattern of the terrestrial temperature field within the territory of the country. In many boreholes the influence of downward water filtration is reflected in shapes of thermograms which is reflected in their concaved shape. The convective component of heat transfer was pronounced there.

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 only as preliminary ones, as they were received in result of an extrapolation outside the country state border with small amount of available thermograms in these areas.

Temperature values at the depth of 100 m range from 7 to 11.5°C. Values above 8ºC are typical for Palaeozoic geologic units: they are the northern zone of the Pripyat Trough and the Podlaska-Brest Depression. The isotherm of 9ºC 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 information, recorded in the course of standard logging, have very low quality to be used for temperature readings at the depth of 100 m because the natural temperature field of rock massive still not reached after the drilling of boreholes was finished. Regional and local anomalies are clearly distinguished in both maps, (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 6.5-7.5ºC at the depth of 100 m. It includes almost the whole area of the Mogilev Mulde. Its shape within the adjoining area of Russia beyond the state border is very preliminary as there are no reliable thermograms outside the state border.

A strip of increased temperature values of 8.5-10ºC (100 m depth) 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 a preliminary shape as only one thermogram was recorded in the adjoining area of Russia.

The isotherm of 9.5ºC at the depth of 100 m 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. It is oriented in an eastern direction and 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 and continues into Russia, Zui (2004, 2010).

One more *Grodno anomaly* of increased temperature above 9°C (depth of 100 m)| 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 8ºC (depth of 100 m) 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 here 9ºC, has also the same meridian orientation.

At the depth of 200 m (Fig. 4) 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 for the depth of 100 m. Actually all temperature anomalies exist in both maps with slightly changed shape with increasing temperatures at isolines at the depth of 200 m. It is necessary to mention that some of them occupy smaller areas. It is a result of 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.

3.2 Temperature maps for depths of 300 and 400 m

The temperature field contrast increases with depth which is clearly distinguished at depths of 300 and 400 m, Fig. 5.

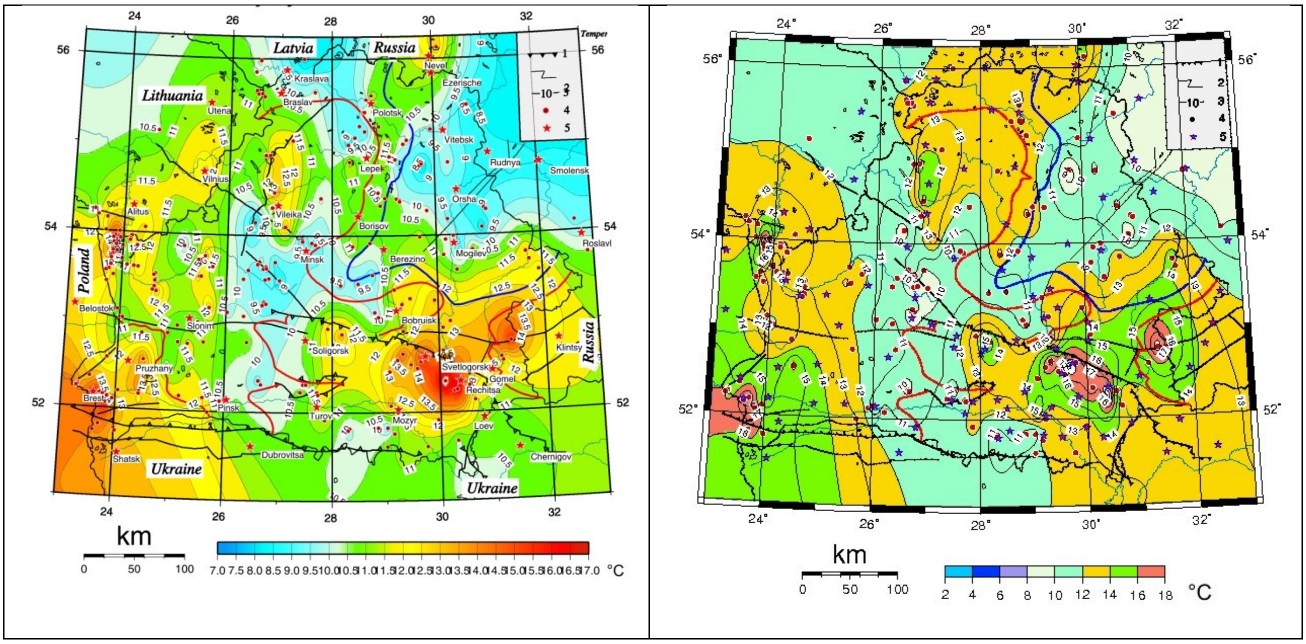

Figure 4: Temperature distribution maps at depth of 400 (left) and 400 m (right) within Belarus. Legend see in Fig. 4.

We will not discuss in details these maps, but only mention some of their features. The available number of thermograms decreases for the depth of 300 m and even less for the depth of 400 m. For instance, for the depth of 400 m only 214 of them were used including around 50% with extrapolated temperature values. As a result small detail disappear from these maps and the shape of isotherms is changing. At the general background of increasing of temperature values with the depth. Minimal temperature values at the map for 400 m ranges from 8.5 till 19ºC. The configuration of isotherms, especially at the last map sufficiently changed. One reason is a lack of thermograms available for this depth for the Orsha Depression and adjoining blocks of the crust. As before the main temperature anomalies with increased values are related to the Paleozoic Pripyat Trough and the Podlaska-Brest Depression and considerably lower temperatures are typical for the Belarusian Anteclise and the Orsha Depression.

3.3 Temperature maps for depths of 2 and 4 km for the Pripyat Trough

For depths deeper than 1 km it was possible to compile maps for the Pripyat Trough which is the deepest sedimentary basin in the country as only a few temperature diagrams were recorded in deep boreholes within the Podlaska-Brest and Orsha depressions. Temperature values at the surface of crystalline basement at the depth up to 1.5-1.7 km reach from 36 till 42°C.

At the same time many thermograms are available for the Pripyat Trough, which is the best studied area in geothermal respect among other sedimentary basins of the country. The temperature field pattern at the depths of 2 and 4 km is shown in Fig. 6. Temperatures at the base of the sediments in the northern zone here increases to 80-90ºC, but for the depth of 4-5 km the number of reliable thermograms doesn't exceed 20, which is not enough to show all details of the temperature distribution on maps. The maximal temperature recorded, for instance, in the Basuki 63 oil well, was 115°C at the depth of 4 km.

At the depth of 3 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 till Luban town and continues to the south-east into the Gremyachy Buried Salient 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 the southern part of this geologic unit (the Elsk Graben and the Vystupovichi Step). The background temperature values here ranges from 35 to 40°C.

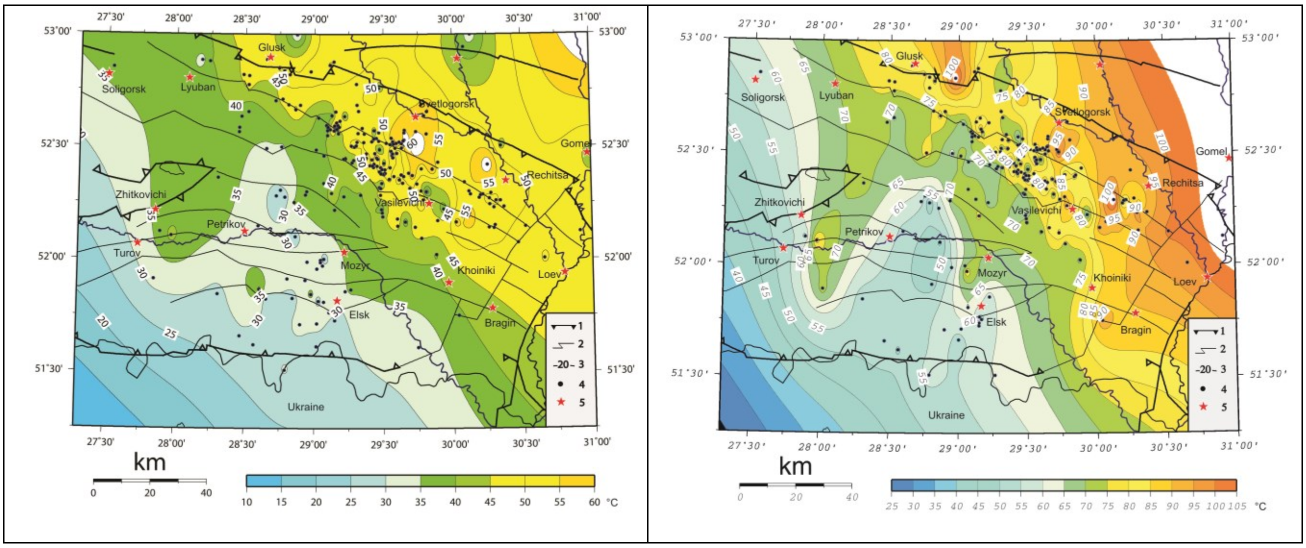

Figure 6: Temperature distribution maps at depth of 2 km (left) and 4 km (right) within the Pripyat Trough, Zui, (2013).

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 (depth 1 km). 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 at the former map within the northern and north-eastern zones of the trough.

When the depth increases to 4 km, small details in temperature distribution maps disappear, because the number of available thermograms also decreases. Though the terrestrial temperature field at the depth of 4 km is similar to those shown at the depth of 2 km. The main difference is higher temperature values up to 90-100°C in the northern zone of positive anomaly and slightly changes in shapes of isotherms. The main exploited oil fields were encountered namely within this warm area.

4. HEAT FLOW

Investigations to fulfill heat flow density determinations were based on recorded thermograms and thermal conductivities of rock samples measured in laboratory conditions. These works were started during 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. 7), was compiled using all published data, which were accumulated in heat flow catalogues, Zui et al., (1993). Data published after 1993 were also used, Zhuk et al., (2004); Zui, (2005); Zui, Zhuk, (2006), Zhuk, Tsalko, (2009). The updated heat flow catalogue was recently published, Zui, (2013). Published data for adjoining areas of Poland, Lithuania, Latvia, Russia and Ukraine were also used when compiling this map.

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.

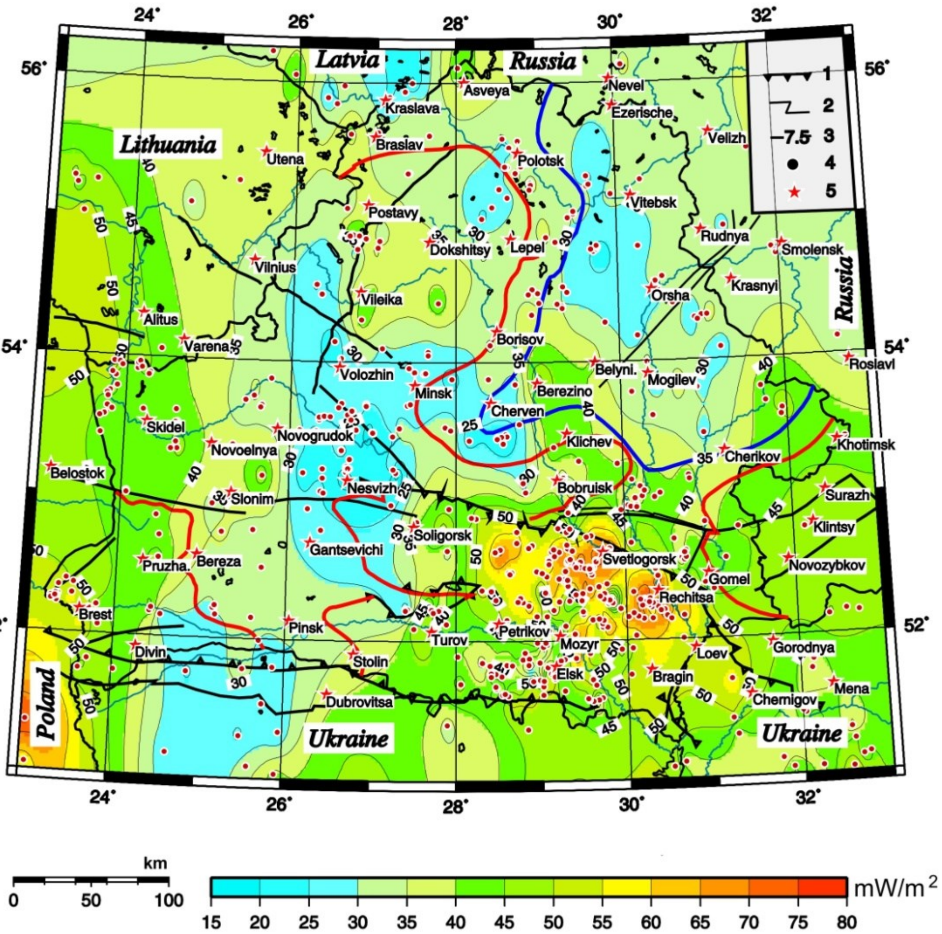

Figure 7: Heat flow density map for Belarus. Legend see in Fig. 4.

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 heat flow values, 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 the surrounding terrigenous sediments and distorts sub horizontal course of isotherms, as shown in Fig. 8, Zhuk, Tsalko, (2009).

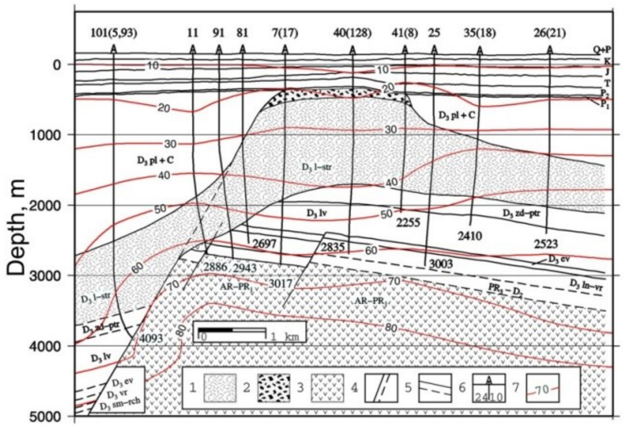

Figure 8: Temperature profile along the Rechitsa Dome in the northern part of the Pripyat Trough. Legend: 1 – rock salt, 2 – cap rock, 3 – crystalline basement, 4 – deep faults, 5 – boundaries between rocks of different lithology, 6 – studied boreholes with their numbers and their bottom hole depths, 7 – isotherms, °C.

In the upper part of geological section within the so-called "above-the-salt" sediments interval heat flow values are typically lower as a 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).

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.

Heat flow density values below 30 mW/m^2 form a chain of small anomalies, partly located along the Volyn – Orsha – Krestsy Paleodepression, 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 and Nesvizh towns.

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 locations near the Belarus-Poland border. 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 Lithuania, Latvia, Russia and Ukraine.

5. GEOTHERMAL RESOURCES

Investigations to estimate geothermal resources for different geothermal horizons were undertaken several years ago and this work is still continued at the present time. In most cases it was accepted underground artesian reservoirs as "geothermal horizons" for which we estimate a density of geothermal resources.

The 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 rather 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, which complicates their practical utilization. Recoverable geothermal resources were calculated on the basis of widely used approach, namely according to Hurter and Haenel (2002). This 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, the information on the porosity of rock samples and their volumetric heat capacity.

5.1 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 (Fig.2). They often were used to create geothermal heat pump installations. Only within relatively small areas their mineralization not much exceeds 1 g/dm^3. Therefore using these waters for heat recovery from shallow horizons of the platform cover is a favorable condition from a technologic point of view as it is not necessary to drill additional wells to return them after the heat pumps to an underground horizon.

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. Though geothermal resources were calculated for some geothermal horizons, it was decided to calculate them for the interval of 100 – 200 m using the described approach, Hurter and Haenel (2002). Geothermal resources were calculated also for several other geothermal horizons.

It was decided, as the first approach, to suppose rocks of the depth interval of 100–200 m as a "single aquifer". It gives a possibility to consider and compare recoverable resources within different geologic units of the whole territory of the country. Shallow boreholes or horizontal circulation loops are typically used for small geothermal installations in the country this zone of so-called active water exchange. From this point of view there was a sense to assess the geothermal resources density in this shallow horizon.

This depth interval 100-200 m is composed of rocks of different age and lithology. Geologic cross-section in this interval represents interlaying of aquifers and aquitards, having numerous hydrogeologic "windows", allowing hydraulic connection of different aquifers" (Fig.9).

Figure 10 shows a distribution of recoverable geothermal resources for the whole territory of Belarus available in the depth interval of 100-200 m in kilograms of oil equivalent per square meter (kg.o.e/m^2).

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 the 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 the 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.

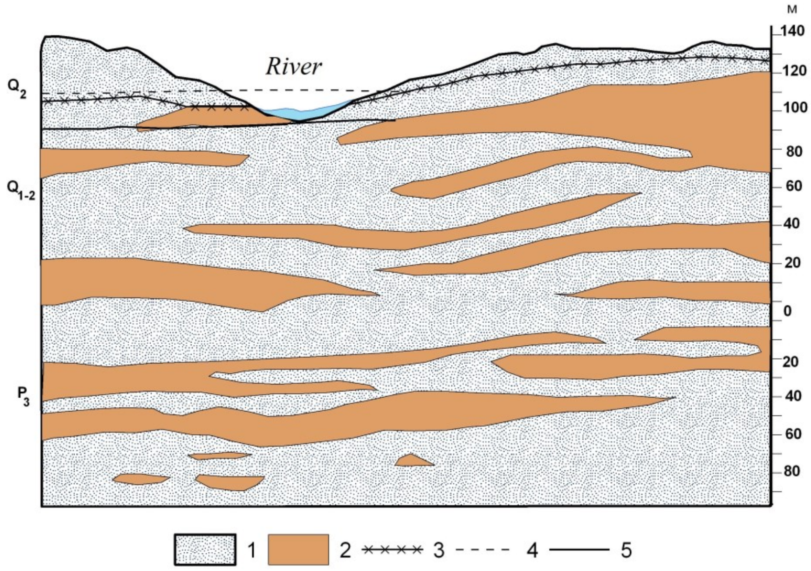

Figure 9: Typical structure of many Paleogene-Quaternary aquifers. Legend: 1 – aquifers, 2 – aquitards, 3 – water table, 4 – estimated water table during flood time periods, 5 estimated water table below a river during very low water periods.

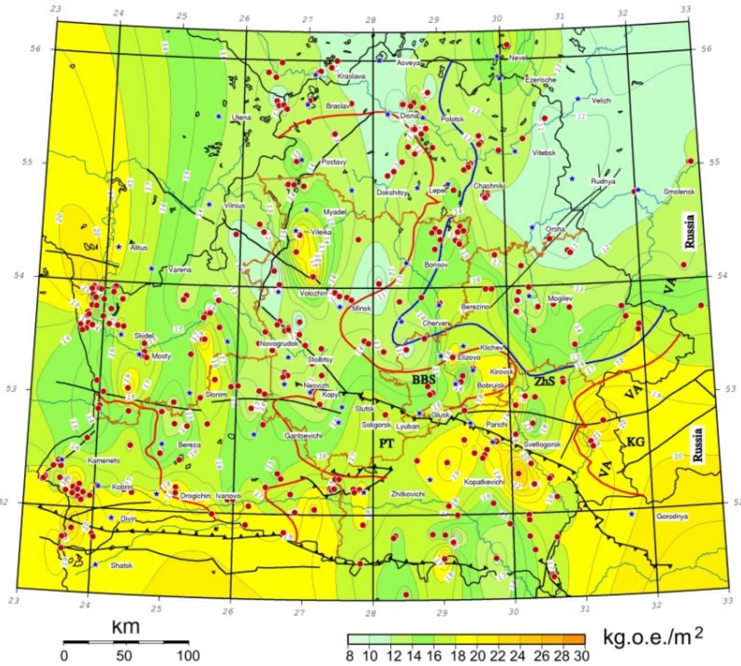

Figure 10: Recoverable density of geothermal resources from the interval of 100 – 200 m within the territory of Belarus. Legend: BBS – Bobruisk buried Salient, KG – Klintsy Graben, VA – Voronezh Anteclise, PT – Pripyat Trough, ZhS – Zhlobin Saddle. Red heavy lines indicate margins of positive structures: 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).

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 process now.

5.2 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 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 (40-42ºC) than within the Cambrian deposits (c.a. 25ºC). Therefore, the Cambrian Complex is the most favorable one to use its geothermal potential, Zui, (2007)(Fig. 11).

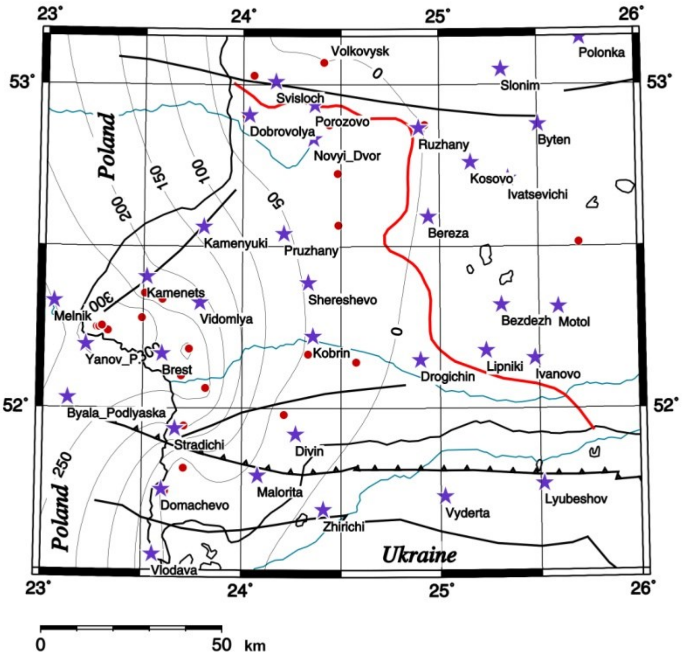

Figure 11: Density of geothermal resources within Cambrian rocks in the eastern part of the Podlaska – Brest Depression, Belarus. Legend: The red line shows limits of the Podlaska-Brest Depression within Belarus; black lines show positions of tectonic faults. Isolines are given in kg.o.e./m^2. Zero isoline 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 it takes place a wedging-out of Cambrian deposits, to more than 350 kg.o.e./m^2 at their deepest parts. 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 the outer borders of the depression the density geothermal resources decreases. Within the area around Brest the density of geothermal resources varies from 250 to 300 kg.o.e./m^2.

In the southern part of the 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 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. As a result the recoverable resources in the 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.

5.3 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. Terrigene 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 more in some localities.

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.12).

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. Using the old abandoned boreholes will allow reducing expenses to construct corresponding geothermal systems.

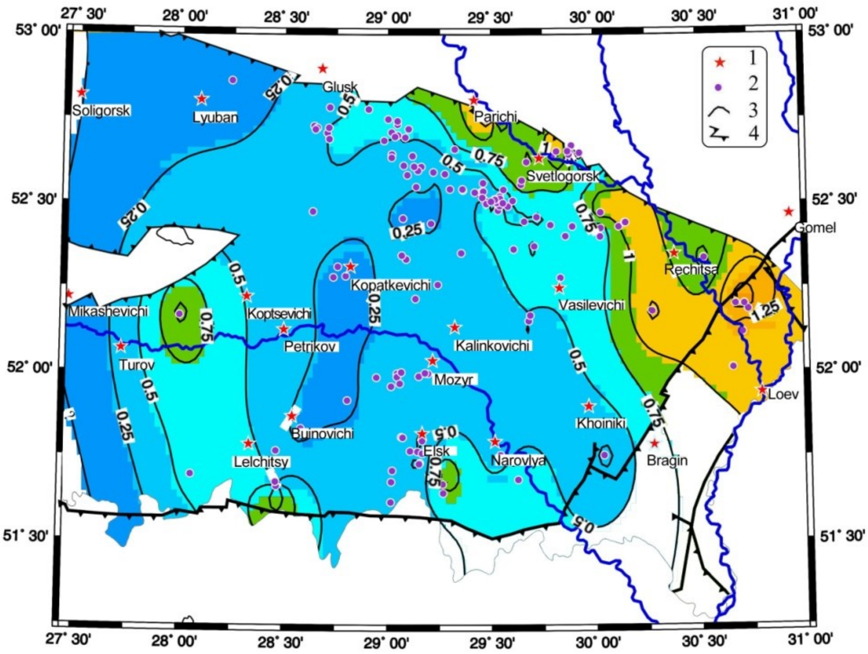

Figure 12: Density of Geothermal resources within the Intersalt Complex of the Pripyat Trough, Belarus (t.o.e/m^2).

6. GEOTHERMAL INSTALLATIONS

Since 1997, the 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 100-130. Their exact number is not known, as it was not necessary until now to register such systems in the Ministry of Natural Resources and Environmental Protection. The biggest installation exists at the Greenhouse Complex “Berestye” in Brest, heat pumps of which are shown in the process of their installation in Fig.13.

Figure 13: Heat pumps Daikin EWWD 440MBYN at the Greenhouse Complex “Berestye”

It uses fresh warm water pumped out from Cambrian sandstones using one borehole of 1,000 m deep. The water temperature reaches 24 ºC at the well mouth at the well flow rate of around 42 m^3/hour. Two heat pumps Daikin EWWD 440MBYN, with heat output of 505 kW each, are used in this installation, Zui, Pavlovskaya, (2012).

Additionally, several dozen small heat pump systems were installed in private cottages within and around the main towns and cities (Brest, Gomel, Grodno, Minsk, Mogilev and Vitebsk) with total thermal capacity around 1.0-1.5 MWt. Most of installations use cold groundwater taken from shallow boreholes with ambient temperature of 8–10ºC as a primary energy source. Others use horizontal or vertical circulations loops. A few installations are based on the utilization of lake or river water. Names of the main 28 installations with their locations, primary heat sources and thermal capacities are listed in Table 1.

Existed geothermal installations in the country are mainly used for supplying space heating for some small industrial buildings, frontier point Novaya Rudnya at the Belarus-Ukraine border, dwellings, etc. with the total installed heat pump capacity approaching to 6-6.5 MWt.

Table 1: Some existed of geothermal installations in Belarus

Location	Primary heat source	Heat capacity, kWt	Location	Primary heat source	Heat capacity, kWt
Greenhouse Complex “Berestye”, Brest	Ground water	2 x 505	Sewage header building No.46, Minsk District	Ground water	156
Waterworks “Vitskovshchina”, Minsk District	Ground water	43	Water purification station, Minsk	Ground water	165
Sewage header building No.9, Minsk District	Ground water	45	Pump plant “Uruchye”, Minsk	Ground water	48
Waterworks “Vodopoy”, Minsk District	Ground water	40+390	Pump plant “Sosny”, Minsk	Ground water	40
Sewage header building No.19, Minsk District	Ground water	122	Waterworks “Felitsianovo”, Minsk District	Ground water	29
Sewage header building No.24, Minsk District	Ground water	330	Waterworks No.11, Minsk District	Ground water	80
River waterworks, Novopolotsk town	River water	230	Waterworks “Sokol”, Minsk	Ground water	150
Waterworks “Mukhavets”, Brest	Ground loop	3x60	Rowing channel, Gomel	Ground water	2x46
Frontier point “Novaya Rudnya”, Elsk District, Gomel Region	Ground water	273	Waterworks in Svetlogorsk town	Ground water	≈50
Hospital, Nesvizh town	BHE	375	Church near Braslav town, Vitebsk Region	BHE	≈40
Waterworks “Drozdy”, Minsk District	Ground water	36	Office building, Vitebsk	BHE	≈40
Adamovo railroad station, Vitebsk Region	N/A	≈40	Waterworks in Gorki town, Mogilev Region	Ground water	≈140
Zaozeriye, Brest Region	N/A	≈50	Mogilev Region (total 10 GSHP’s)	Mostly BHE	607
Recreation center near Beshenkovichi. Bitebsk Reg.	N/A	6	Private apartment houses	Mostly BHE	≈1500

7. 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 density of geothermal resources varies in a wide range from 10 to more than 1,000 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. 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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STANDARD TABLES

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2014

Locality	Ground or water temp. (°C)	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type	COP	Heating Equivalent Full Load Hr/year	Thermal Energy Used (TJ/yr)	Cooling Energy (TJ/yr)
Greenhouse Complex "Berestye", Brest town	24	2x505	2	W	3	5000	18.18	No
Waterworks "Vitskovshchina", Minsk District	8	43	1	W	3.5	5000	0.77	No
Sewage header building No.9, Minsk District	8	45	1	W	3.5	5000	0.81	No
Waterworks "Vodopoy", Minsk District	8	40+390	2	W	3.5	5000	7.74	No
Sewage header building No.19, Minsk District	8	122	1	W	3.5	5000	2.2	No
Sewage header building No.24, Minsk District	8	330	1	W	3.5	5000	5.94	No
River waterworks, Novopolotsk town		230	1	W	3.5	5000	4.14	No
Waterworks "Mukhavets", Brest town	9	3 x 60	3	W	3.5	5000	3.24	No
Frontier point "Novaya Rudnya", Elsk District, Gomel Region	9	273	1	W	3.5	5000	4.91	No
Hospital, Nesvizh town	8	375	1	V	3.5	5000*	6.75	No
Waterworks "Drozdy", Minsk District	8	36	1	W	3.5	5000	0.65	No
Adamovo railroad station, Vitebsk Region	8	40	1	V	3.5	5000	0.72	No
Zaozeriye, Brest Region	9	50	1	N/A	3.5	5000	0.9	No
Recreation center near Beshenkovichi. Bitebsk Region	8	6	1	N/A	3.5	5000	0.11	No
Sewage header building No.46, Minsk District	8	156	1	W	3.5	5000	2.81	No
Water purification station, Minsk	8	165	1	W	3.5	5000	2.97	No
Pump plant "Uruchye", Minsk	8	48	1	W	3.5	5000	0.86	No
Pump plant "Sosny", Minsk	8	40	1	W	3.5	5000	0.72	No
Waterworks "Felitsianovo", Minsk District	8	29	1	W	3.5	5000	0.52	No
Waterworks No.11, Minsk District	8	80	1	W	3.5	5000	1.44	No
Waterworks "Sokol", Minsk	8	150	1	W	3.5	5000	2.7	No
Rowing channel, Gomel	8	2 x 46	2	W	3.5	5000	1.66	No
Waterworks in Svetlogorsk town	9	50	1	W	3.5	5000	0.9	No
Church near Braslav town, Vitebsk Region	8	40	1	V	3.5	5000	0.72	No
Office buildind, Vitebsk	8	40	1	N/A	3.5	5000	0.72	No
Waterworks in Gorki town, Mogilev Region	8	140	1	W	3.5	5000	2.52	No
Mogilev Region (total 10 GSHP's)	8	~607	N/A	V+H	3.5	5000	10.93	No
Private apartment houses	8	~1500	N/A	V	3.5	5000	27	~10
		6307					113.53	~10

V=vertical ground coupled, H=horizontal ground coupled, W=water source (well or lkae water); * currently under construction

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2010			2			
2011			2			
2012			2			1
2013			2			1
2014			2			1
Total			10			3

(1) Government (4) Paid Foreign Consultants
(2) Public Utilities (5) Contributed Through Foreign Aid Programs
(3) Universities (6) Private Industry

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2014) US$

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	0.5					100
2000-2004	0.5					100
2005-2009	0.5				50	50
2010-2014	0.75				50	50