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Geothermal Atlas and Resources, Country Update for Belarus

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ABSTRACT

The territory of Belarus is located in geographical center of Europe. In geologic respect, it belongs to the western part of the East European Platform. The Precambrian crystalline basement is hidden under the platform cover within the whole area of the country. There are no visible geothermal manifestations such as geysers, fumaroles, mud volcanoes, etc. During a few decades, geothermal investigations were fulfilled in the country. A number of geothermal maps were prepared covering the studied territory. Among them are temperature distribution maps compiled for the a number of depths starting from 100 m within the whole territory of the country till 4 km within the Pripyat Trough, which is the deepest sedimentary basin in the southeastern part of Belarus, as well as maps of geothermal gradient, heat flow density and geothermal resources. Since the time elapsed after the World Geothermal Congress 2015 held in Melbourne, Australia, the Geothermal Atlas of Belarus was published. The density of geothermal resources for a number of geothermal horizons range from dozens of kg.o.e./m^2 for shallow depths till a few t.o.e./m^2 in deep horizons of the Pripyat Trough. Some part of resources are exploited in a number of localities mainly using small heat pump geothermal installations irregularly distributed within the territory of the country. No high enthalpy geothermal steam was revealed within the platform cover. Preliminary estimates show that a depths at which the temperatures reaches of 150–180 ºC corresponds only to the crystalline basement at the depth 8–12 km. The maximal temperature at the base of the platform cover around 140 ºC at the vertical depth of 6.4 km was recorded in the deepest in the Pripyat Trough the Predrechitsa-1 inclined borehole. Around 300 geothermal installations were constructed and used all over the country starting from the middle of nineties of the past century with their installed capacity around 10 MW$_{th}$ and a few more geothermal heating systems are under construction. All available installations are used for space heating and 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 near the Belarus-Poland state border. All heat pump installations, excluding the "Berestye" one, are using shallow depth intervals of the platform cover with rather low-enthalpy geothermal resources.

1. INTRODUCTION

The territory of Belarus is located in the geographical center of Europe, (fig. 1). In geologic respect it belongs to the vast Precambrian East European Platform.

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, which occupies the central and western parts of the country and is extending beyond its borders into eastern Poland, (Fig.2).

Besides the Paleozoic Podlaska-Brest Depression and the Pripyat Trough located in western and eastern parts of the country, respectively, the Precambrian Orsha Depression occupies its eastern part. It is less studied both in geologic and geothermal respect. Only less than 10 deep boreholes were drilled into several meters of the crystalline basement through the whole thickness of the sedimentary cover. The most of geothermal observations were fulfilled in such shallow wells within the Orsha Depression drilled for water supply for towns and settlements of this area. These measurements were added by temperature depth curves recorded within several wells for mineral water located in sanatoria and spas.

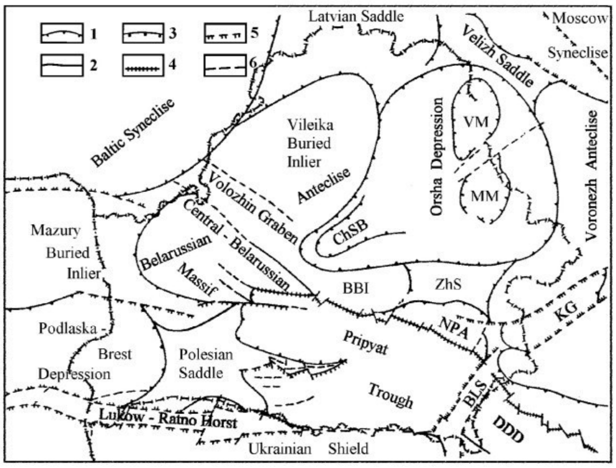

Figure 2: Main geologic units within the territory of Belarus.

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.

A thin sedimentary cover overlies the crystalline basement of the Belarusian Anteclise. It ranges from 80–100 m within the CentralBelarusian 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 starting from fifties of the last century. In many of them thermograms were recorded in the process of their standard logging when the temperature equilibrium, distorted by drilling process was not reached.

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 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 at the depth 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. Not numerous deep boreholes here have an irregular areal distribution. Most of them are grouped at the Pribug Gas Facility which occupies the area around 4 × 9 km.

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 and was observed within a small area stretched along the Belarus-Poland border.

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 at depths of 4–5 km.

2. TERRESTRIAL TEMPERATURE FIELD

Besides thermograms of standard logging, regular geothermal investigations since the end of sixties and beginning of seventies were undertaken in a number of boreholes, which reached the 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 there 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.

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, frequently influenced shapes of thermograms.

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.

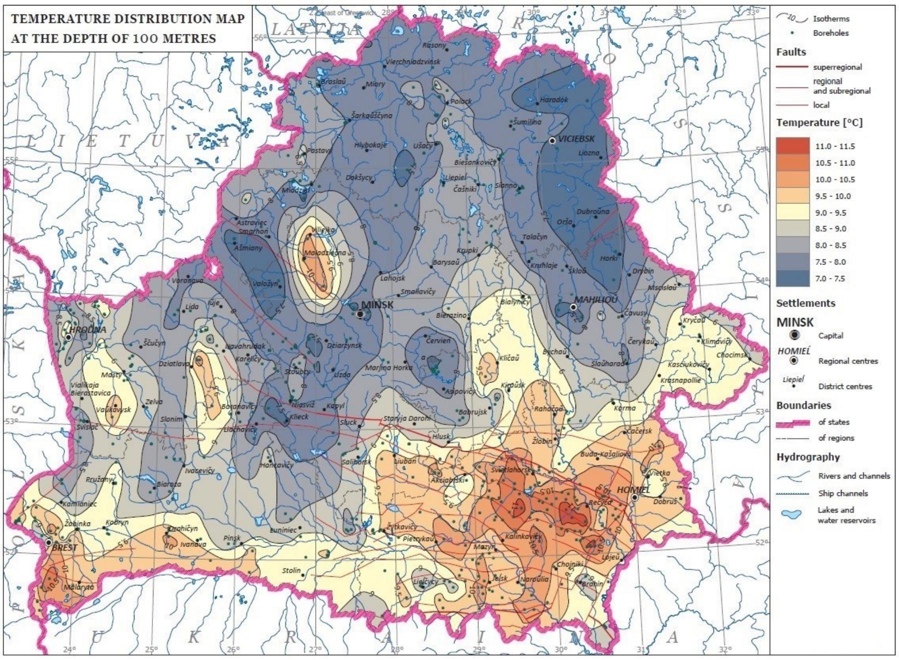

Figure 3: Temperature distribution map at the depth of 100 m within Belarus.

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 as it belongs to the zone of active water exchange, containing fresh water in pores of rocks. The isotherms were drawn within the territory of Belarus by means of an interpolation. Their contours near the state border were received in result of an extrapolation into adjoining areas, Zui (2013).

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 result a convective component of heat transfer is pronounced here, Zui, (2010).

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 in 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.

Temperature distribution at the depth of 200 м. 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.

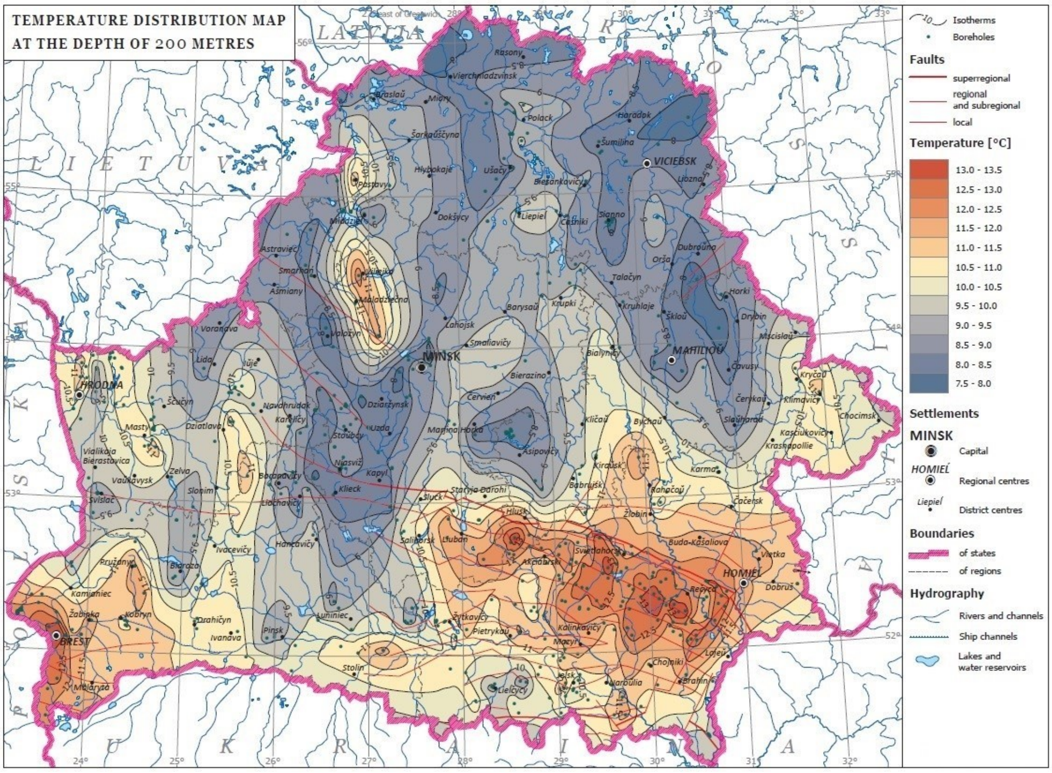

Figure 4: Temperature distribution map at the depth of 200 m within Belarus.

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 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 here 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.

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, 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.

Temperature distribution at the depth of 2 and 4 km. When the depth increases, the number of available thermograms within the whole territory of Belarus rapidly decreases as shown in fig. 5. The number of recorded thermograms and extrapolated ones (calculated temperatures) for the depth of 0.5 km, are almost equal. For boreholes of the Pripyat Trough, for instance for the depth of 3 km, this ratio becomes 40/60 %. For the depths exceeding 4 and 5 km only a few thermograms were really recorded by thermometers, when the time elapsed after their drilling was finished was not enough to reach the thermal equilibrium of wellbores and surrounding them massifs of rocks, and the majority of them, as a rule, were extrapolated, hence temperature values at these depths were calculated.

A lack of thermograms didn't allow compiling terrestrial temperature maps for depths deeper than approximately 500–700 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 prepare reliable temperature distribution maps. Temperature values at the sedimentary cover base within these two mentioned depressions reach 40–42 °C. 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 typically 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. Therefore, a majority of temperature data for such depths were used from extrapolated thermograms.

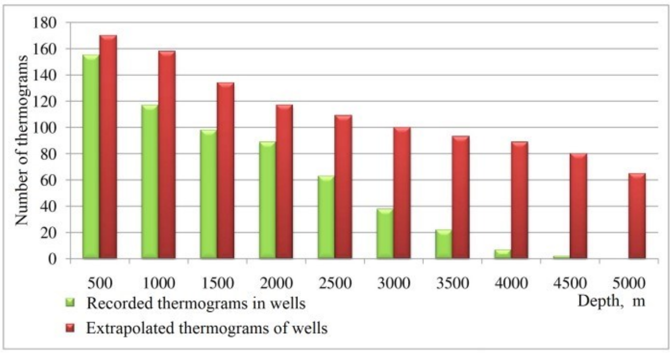

Figure 5: Number of reliable (green bars) and extrapolated (red bars) thermograms for the Pripyat Trough.

The maximal recorded temperatures not frequently exceed 100 °C, 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 vertical depth of 6.4 km was recorded in the deepest inclined oil prospecting well Predrechitsa-1.

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.

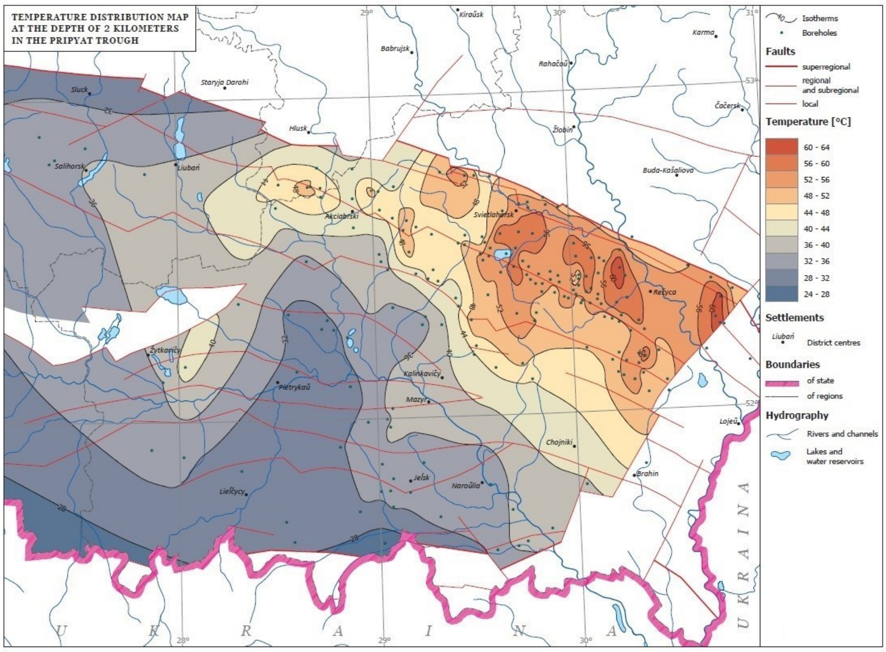

Figure 6: Temperature distribution at the depth of 2 km within the Pripyat Trough.

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 north-eastern 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 of anomalies exceeding 40 °C was 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.

The temperature distribution at the depth of 4 km is shown in fig. 7. 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 within the trough 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 take place in shapes of isotherms.

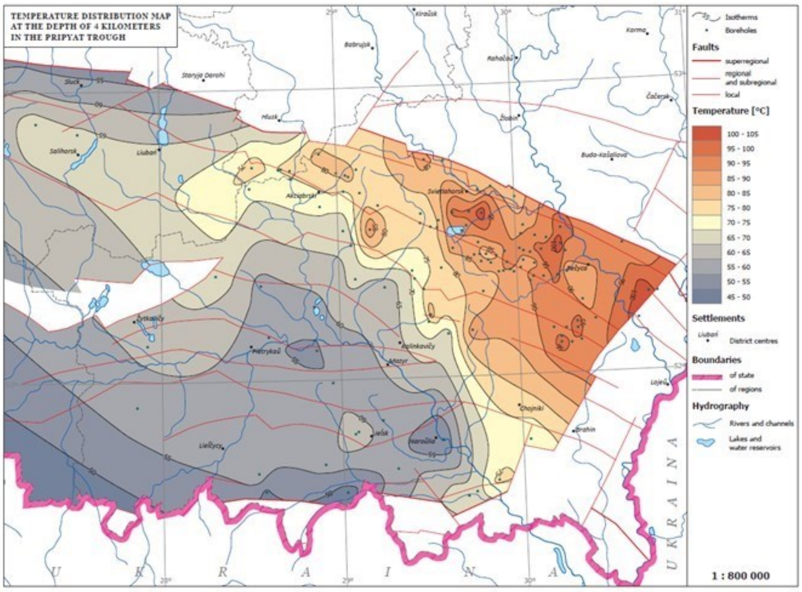

Figure 7: Temperature distribution at the depth of 4 km within the Pripyat Trough.

3. HEAT FLOW

Investigations on heat flow density determinations were based on recorded thermograms and thermal conductivities of collected 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 for the beginning of 2019, 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 close to Belarusian borders were also used when compiling this map. Heat flow density 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 mainly 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. Besides groundwater circulation this fact is the result of many other factors: thermal conductivity variations for rocks comprising the platform cover, velocity of 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), as well as the 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. The 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.

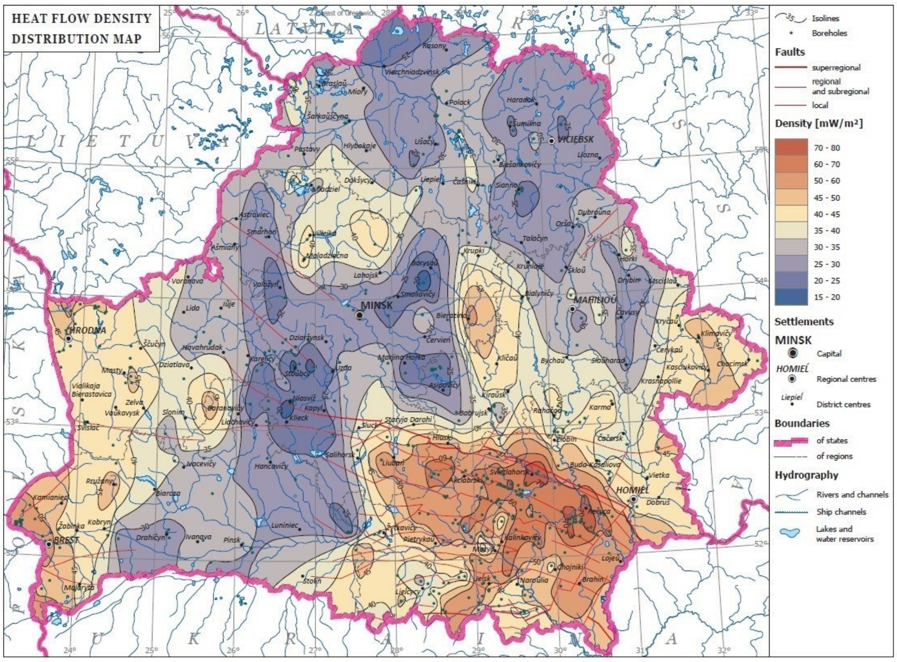

Figure 8: Heat flow density map for Belarus.

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 adjacent 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 a preliminary one. It concerns their configuration along both sides of state borders with Lithuania, Latvia and Russia.

4. GEOTHERMAL RESOURCES

Recoverable geothermal resources were calculated based on a widely used approach, 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./m^2 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, which complicates their utilization.

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 favourable 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 namely 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.

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 within the west Lithuania and the Kaliningrad Enclave of Russia.

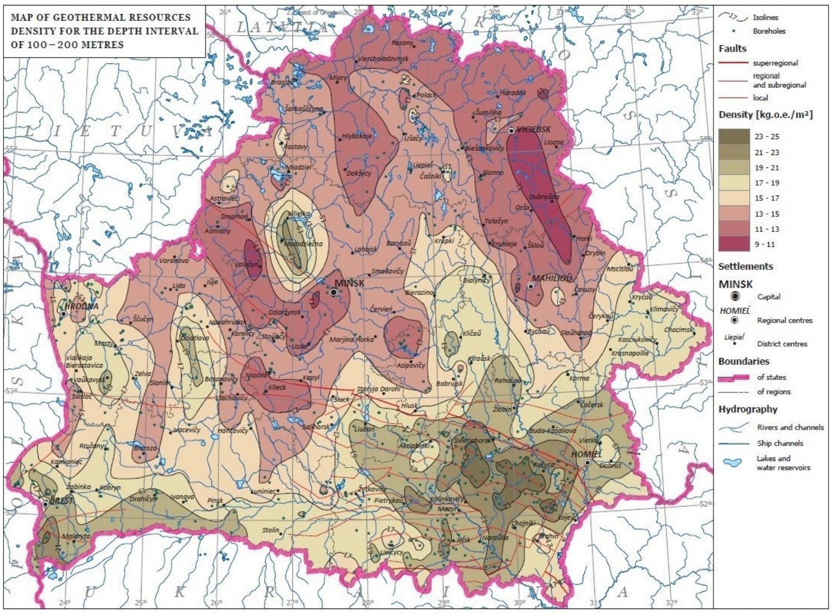

Figure 9: Recoverable density of geothermal resources from the interval of 100–200 m within the territory of Belarus.

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 Upper and especially Lower Salt complexes have very high mineralization of brines up to 420–450 g/dm^3 and even higher within some crustal blocks. There is 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 Carboniferous Complex of the Pripyat Trough, (Fig.10).

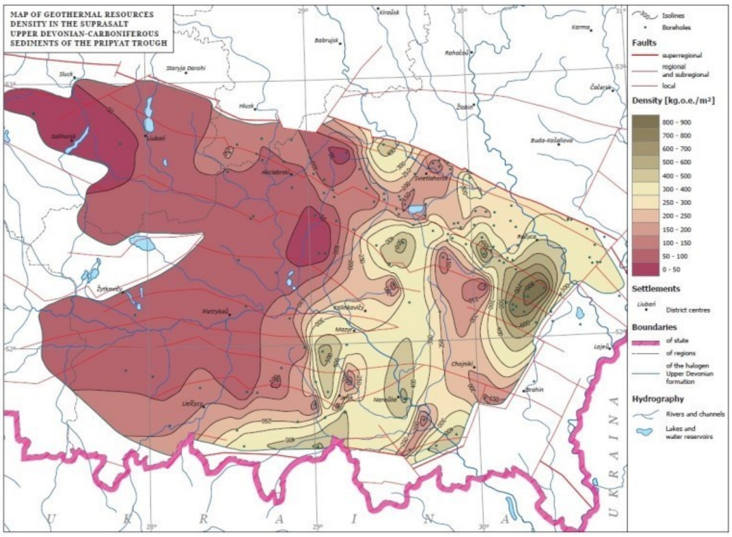

Figure 10: Density of Geothermal resources within the suprasalt Upper Devonian-Carboniferous sediments of the Pripyat Trough (kg.o.e/m^2).

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. Because of high mineralization of brines, 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 or overlying them horizons containing mineral or even fresh waters with lower geothermal resources, but still acceptable for their practical utilization. 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 first small heat pump systems were installed for heating of waterworks and sewage header buildings mostly in the Minsk District in 1997. The situation gradually increased during following years. At present, the total number of geothermal installations all over the country is estimated to be around 300.

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, Zui, Pavlovskaya, (2012). 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 300 with their heat capacity approaching to 9 – 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

During 2–3 last years the Geothermal Atlas of Belarus was compiled and issued in 2018 (the text is in Russian and English), Geothermal…, (2018). It includes 26 maps of temperature, geothermal gradient, heat flow density and heat flow catalogue for the country. It also has maps of the density of recoverable geothermal energy resources within the Republic.

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 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.

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Tables, relevant to Belarus (no electricity production and no direct use, only heat pumps)

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

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

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	1					
2016			1			
2017			1			
2018						1
2019			No			
Total						

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$ (All figures are estimated)

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	0.5	N/A	No	No	10	90
2000-2004	0.5	N/A	No	No	20	80
2005-2009	0.5	N/A	No	No	40	60
2010-2014	N/A	N/A	No	No	70	30
2015-2019	No	No	No	No	80	20

Table 4 GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

Locality	Ground or Water Temp.	Typical Heat Pump Rating or Capacity	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load	Thermal Energy Used[5]	Cooling Energy[6]
	(°C)[1]	(kW)				Hr/Year[4]	(TJ/yr)	(TJ/yr)
Greenhouse Complex “Berestye”, Brest town	24	2x505	2	W	3.0	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	2.20	No
Sewage header building No.24, Minsk District	8	330	1	W	3.5	5000	5.94	No
River waterworks, Novopolotsk town	3 - 10	230	1	W	3.5	5000	4.14	No
Waterworks “Mukhavets”, Brest	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 Reg.	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
Building of the IBA company in Minsk		8	~450		N/A	V	3.5	5000	6.12	No
Service house of the railway, Minsk		8	100		N/A	V	3.5	5000	1.70	No
Private apartment houses		8	~1500		N/A	V	3.5	5000	50	No
TOTAL			9000-10000		250-300		3.5	5000	145	No