GEOTHERMAL ENERGY POTENTIAL OF THE RM-GEOSPACE

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Abstract:*The geothermal energy potential of the Republic of Macedonia (RM) geospace is mainly the result of the residual geothermal effect of the (mid-ocean) paleorift in the Vardar tectonic zone. This rift was active in the Middle Jurassic, as part of the north continuation of the Iindian Ocean mid-ocean rift. With the closure of the mid-ocean rift, there started the final magmatism that lasted until the beginning of the Recent Quaternary. According to postmagmatic effects, in the RM-geospace, there dominate the Kratovo-Zletvo area and the Kozuf-Dojran area of neomagmatism. The stated areas are characterized by the most interesting anomalous geothermal field. The entire region of the Vardar zone and its surrounding are also interesting. Hydrothermal energy is used at a number of locations in the stated geospace. It is of a particular interest to use the petrothermal energy with a temperature 100-300^{o}C, which is expected to exist at depth between 2.0-5.0 km.*
Keywords:*geothermal energy, neomagnetism, pethrotethermal energy.*

1. INTRODUCTION

For the last decades, the energy turbulences that have taken place in the World from the aspect of disbalance of available reserves of conventional energy resources, market opportunities and non-synchronized exploitation and expenditures, additionally complicated with non-controlled enormous emission of greenhouse gases and respectively global disturbance of the ecological ambient, have undoubtedly generated a world energetic-ecological crisis.

The technologies of extraction of geothermal resources involve deep geothermal resources and near-surface geothermal resources (surface layer of warmth). These technologies are, in turn, divided into the following two types:

- Technologies for “dry rocks” geothermal resources;
- Technologies for “geothermal water” resources.

The technology for dry rock heat use is currently in the phase of research. In fact, the approach involves the following: injection wells or surface water from underground aquifers located above are used. Steam generated in the well with the required parameters is directed into a steam turbine to convert geothermal heat into electricity. Geothermal resources with insufficient temperature for direct use in a steam turbine require application of binary cycles with lower liquid boiling temperature.

The extraction technology from near-surface geothermal resources is divided into:

- Technologies for geothermal resources to the depth of 20 m, which are renewed in the summer by geotermal and solar energy;
- Technologies for geothermal resources to ground water-bearing up to 100m depth.

The temperature can reach the level of heating: subsurface soil to +20°C, water to +27 °C and air-conditioning systems to +35°C. To discharge heat power plants or the manufacturing process, the temperature level is much higher and it is possible to be +180°C plus.

Estimation of energy potential of solid rock is made by use of the following assumptions:

- Heat of dry rocks exploitation to maximal depth of 3000 m;
- It is accepted that the temperature inside the dry rocks to depths of 1500 m is only used to supply consumers, and that the average temperature in the range of 1000-1500 m thickness is 80^{O}C.
- Also, it is accepted that the average temperature inside the dry rocks in the depth interval 1500-3000 is 130^{O}C - this coolant is used (the experience of Western Europe) only for electricity turbines in dublet, in which low boiling working fluid is used as an intermediate heat carrier selecting directly from dry rocks.

2. Geologic structure of Vardar zone

The Vardar zone (VZ) is a paleorift, which was functioning only in Middle Jurassic. The geospace of RM is structured from tectonic zones parallel with the Vardar (paleorift) zones. VZ is situated among the tectonic units of East Macedonian (EMZ) on the east side, and the West-Macedonian (WMZ) and the Pelagonian (PZ) zone on the west side -Fig. 1.

With the closure of the Vardar mid-ocean rift, there started the processes of final base and acid magmatism that lasted until the beginning of the Recent Quaternary. The nowadays geothermal field in the goespace of RM is the result of the effects of the final magmatism in the Vardar paleorift.[1]

According to magmatic and postmagmatic effects, in the geospace of VZ and RM, there dominates Kratovo-Zletvo Area (KZA) and Kozufi-Dojran Area (KDA) of Tertiary-neogenic final magmatism. The stated areas are characterized by the most interesting anomalous geothermal field. From this aspect, the geothermal fields of the entire region of the large zone of the Vardar paleorift and its surrounding are also interesting. [2]

VZ is characterized by the predominant complex of Jurassic gabro-diabases and sedimentary rock units with general N-S stretching direction. In the complex of gabbro-diabases, there are granodioritic intrusions created in the period from the end of the middle Jurassic till the end of the Jurassic period. In the Paleogene, the Jurassic complexes were also entered by rhyolites, silts and dikes and basalts. Data is missing about granite and granodiorite intrussions from the period before the opening of the mid-ocean rift.[2,3]

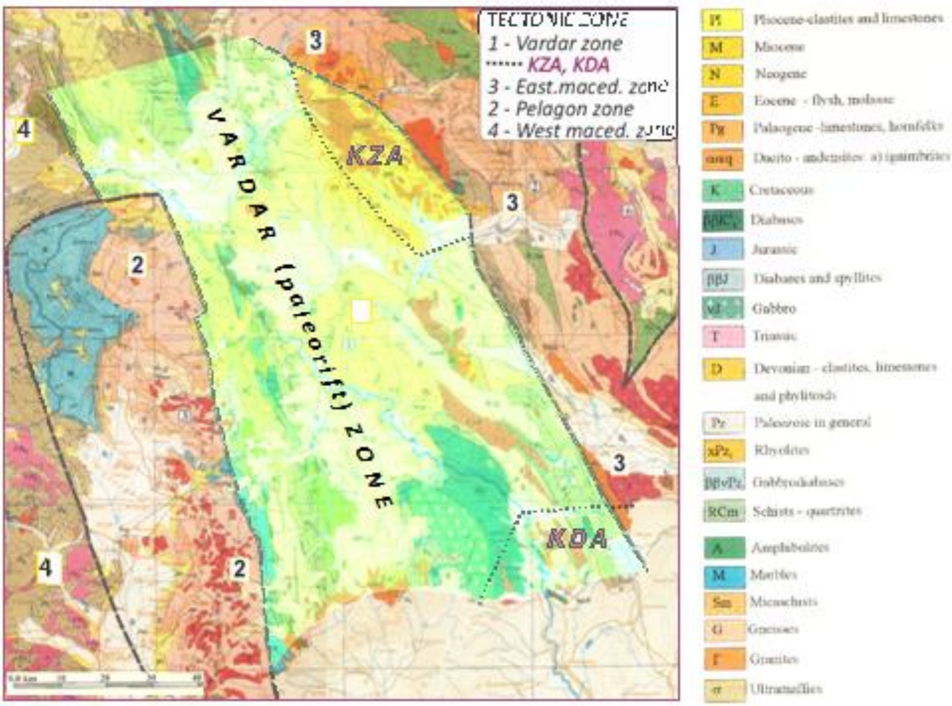

Fig. 1. Vardar (paleorift) tectonic zone with KZA and KDA neomagmatic areas

The KZA of the Tertiary acid magmatism was formed in the boundary belt between VZ and EMZ. According to magmatic and post magmatic effects, it is a very important structural unit of the geospace of the northeast part of RM from several geological aspects, and especially from geothermal aspect. The boundary belt of VZ and EMZ runs in NNW-SSE direction and its width is over 2-3km. From the surrounding geospace, it differs by:

- Presence of carbonate rocks (limestones, dolomites and schists) in the basic Paleozoic complex of schists and quartzite;
- Gabbro intrusions (before the middle Jurassic period) and more recent granodiorithic intrusion, very often in the same geospace with gabbro intrusions.

The structure of VZ is mainly characterized by weak porosity and weak permeability of rocks (cracked litho areas from gabbro, dyabases, granites, granodiorites, gneisses, sandstones, conglomerates), hydroisolators rock (michaschists, phylites and other Paleozoic schists, chalk and Eocene flysh, tertiary marls, cleyey and other). Porous and permeable lithomedias are characterized by intergranular, cracked and cracked –cavernous porosity. [4]

Crack porosity is necessary for the creation of hydrothermal systems of higher energy potential. Open cracks in the surface zone are important for sinking and conducting of the surface water to the thermoaquifer. Tight cracks (with high resistance to the flow water) are suitable for transfer of the litho-heat to the hydro-heat. Such a porosity and permeability is characteristic for granite, granodiorite, gneiss, gabbro-diabases, spyllites, and similar).[4,5]

3. Geothermal field in the Vardar zone geospace

According to undergoing deep geophysical surveys of VZ, the Moho-discontinuity is at depth of 30 – 35 km. According to this depth, the crust of the geospace of SIPR can be identified as “continental crust of reduced thickness”. Accordingly, the structure of the crust (down to the Moho-sphere) can be modeled from the following general layers – fig. 3

- Sedimentary cover with a thickness of 0.0-2.0 km;
- Metamorphic complex preent down to depth of 7.0-8.0 km dlabina;
- Granite layer (gneisses and granites) present down to depth of 10-15 km;
- Basalt layer composed of granulite layer with a depth of about 10 km and granulite-ecilogite layer with a thickness of about 5 km.

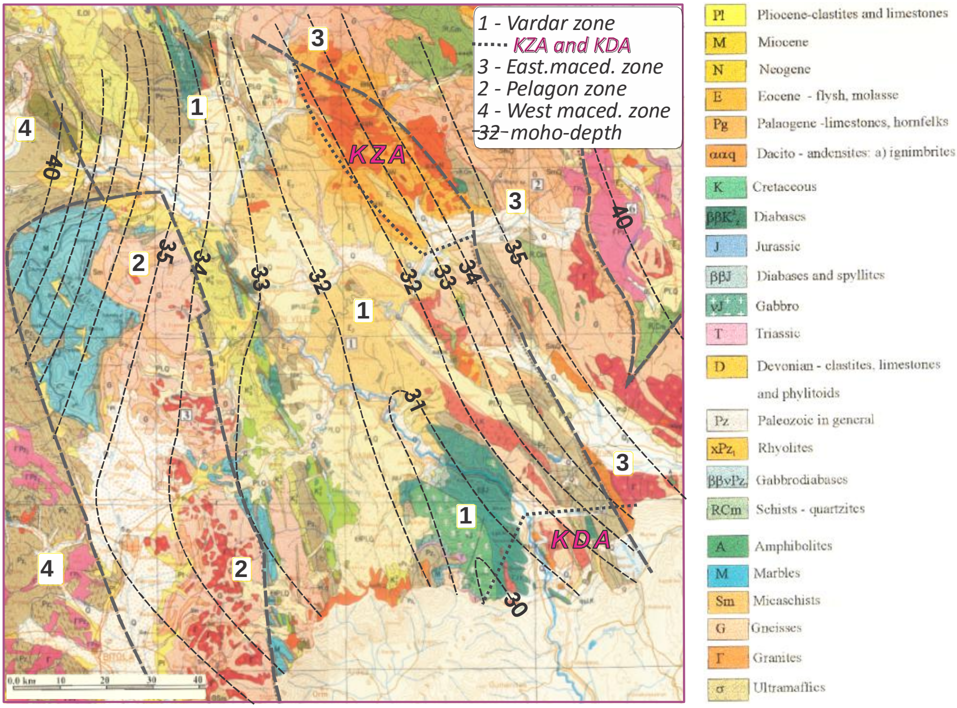

Fig. 2. Depth of Moho-discontinuity in the Vardar zone (Delipetrov T., 1986)

According to Fig 2, at the level of the Moho-sphere, at depth of 30-35km, a normal platform temperature in the interval of 400-800^{o}C can be expected. Taking into account the relative small thickness of the Mantle and the location of the VZ in the geospace under the impact of “paleorift with kept certain geothermal functioning as a rift”, the temperature at the level of the Moho-discontinuity can be expected to be in the interval around the maximal normal platform temperature- in the interval of 700-900^{o}C. In such a case, considering the variation of the depth of the Moho-discontinuity in VZ from 30-35km, there comes out the temperature of around 850^{o}C. [5,6]

The magmatic activity in KZA was most intensive in the Oligocene and Miocene, and less intensive from the beginning of the Quaternary. As a result of this, this zone can still be the carrier of the increased conductive litho-heat with expected temperature of 200-400^{o}C. [6,7]

The magmatic activity in KZA and KDZ could develop in the course of the entire duration of the Pleistocene (according to the Basic geologic map of RM). However, crystallization of the brought magma in the shallow parts of this zones can last longer, namely, there will exist “heating bodies” which accelerate the conductive geothermal processess in the surface zone (including the belt of underground water at 3-5km depth). [5,6,7]

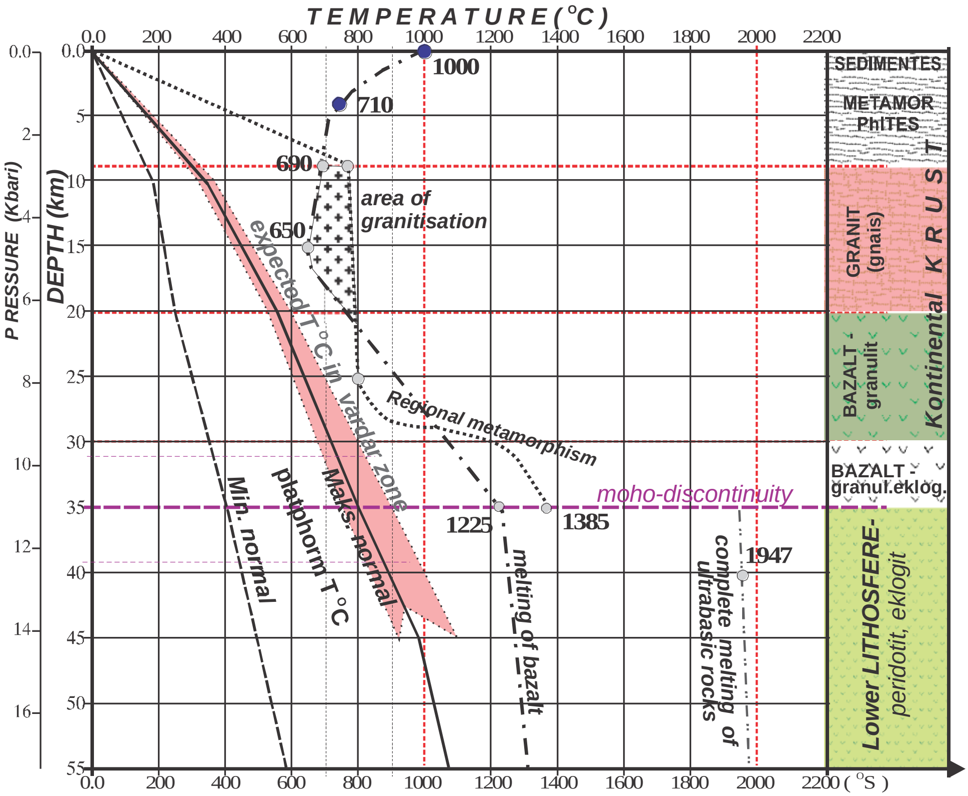

Fig. 3. Temperature Model of the Earth's crust in VZ
(according to E.A.Ljobimova et al.)

According to the same field of temperature, the following temperatures can be anticipated by tectonic zones in VZ- Fig. 4.:

- In the Vardar zone (VZ)-, in the interval of 750-820°C at Moho-depth from 31-35km(around the maximal platform temperature);
- Into KZA and KDA, and into the whole belt of branching of the Vardar zone and East Macedonian zone, in the interval from 800-850°C at Moho depth of 30-33km, (increased temperature and geoheat flow, with possibility of presence of higher temperature in KZV).
- the Asthenosphere of the VZ is predicted at depth of around 100km and with initial temperature of 1250-1450 °C.

To define the temperature field in the complex of the Tertiary sediments in VZ, the existing data from the temperature logging of the exploration boreholes for oil KR-1, TV-1, SN-1, OP-1 in the Ovche pole and Tikvesh basin can be used- Fig 4. Closest to the Tertiary sediments in KZA are boreholes SN-1 (Sv.Nikole) and OP-1 (Ovce Pole-Erdzelija). There is registered higher temperature in comparison with boreholes KR-1(Stobi) and TV-1 (T.Veles) in the Tikvesh basin. This can be associated with the smaller thickness of the sediments and closeness of KZA to boreholes SN-1 and OP-1. [7,8]

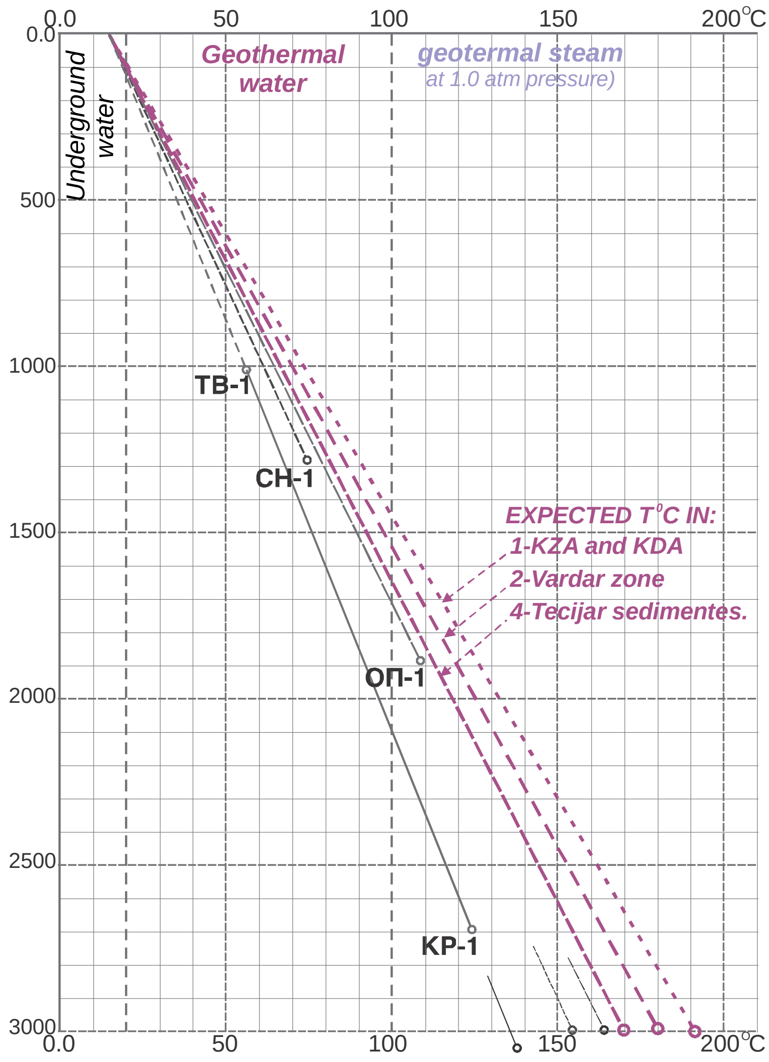

Fig. 4. Temperature in the basic litho-units in VZ according to the temperature logging diagrams of the boreholes in the Tertiary sediments (Marinkovik and Njegomir 1970)

Temperature difference in the used boreholes is app.10^{o}C at depth of 1.0km, app. 19^{o}C at depth of 2.0km to 27^{o}C at depth of 3.0km - Fig 4. With such a tendency, the weak permeability of the heat of the Tertiary sediments in comparison with the rock complexes is confirmed. In the metamorphous complex, a lower temperature field in comparison with the magmatic complexes can be expected. With such a concept, for the basic litho complexes in VZ, the following expected temperature fields can be expected- Enclosure-2:

- In the Tertiary sediments –at 3.0km depth, a temperature with app.170^{o}C is expected (higher temperature in comparison with borehole OP-1 due to short distance to KZA).
- In the metamorphous complex of EMZ– 180-185^{o}C, at 3.0km depth (10-15^{o}C higher temperature in comparison with that of the Tertiary sediments is expected);
- In the magmatic complex of VZ-195^{o}C, at 3.0km depth (10-15^{o}C higher temperature than that of the metamorphous complex of EMZ is expected);
- In the complex of KZA- above 200^{o}C, at 3.0km depth (10-15^{o}C higher temperature compared to that of the magmatic complex of VZ is expected).

From the aspect of petrothermal energy exploatation (as the most interesting type of geothermal energy), it is important that a temperature level of 100 ^{o}C can be expected at depth of 1.5-1.7km, whereat a temperature level of 300 ^{o}C can be expected at depth of around 4 km. As to the continental lithosphere without anomalous geothermal flow, the temperature level of 100 ^{o}C is achieved at depth of 2.7-3.0m[8,9,10]

4. Potential geothermal resource and basic explorations

Until present, there have been no confidential experimental data for the heat inflow in RM. In the area of VZ and KZA and KDA, above average to high Earth's heat inflow in the interval of 90 to above120 mW/m^2, is expected. In the metamorphous complex in the eastern and western parts of VZ, the inner Earth's heat inflow is decreasing.

Geothermal water resources in VZ can be present in:

- Hydrothermal (convective) systems – with feeding zone from atmospheric water and inflow water to the thermoaquifer, and thermoaquifer with discharging zone with a surface (spring) zone;

- Hydrothermal accumulations in the sediment basins – underground water in the sediment basin heated by the action of existing conductive heat inflow.

In the petropthermal resources, up to 95% of the Earth's heat reserves in the surface belt are stored. The generalized calculations show that the potential of the lithothermal resources in RM is significantly (up to 1000multiplied) bigger than that of the other resources which are in RM (hydroenergy, coal, and other). [10]

More significant potential litho-units for petrothermal and hydrothermal systems in VZ are gabbro and granodiorite intrussions, andesites necks, granite, granodiorite, spyllites, limestones rocks-hydrothermal systems with low temperature and energy potential, mainly for therapeutic and recreative purposes.

The origin of the lithoheat in KZA is related to granite intrusionsand acidic volcanic mass of around 700 km^3, over an area of 1000 m^2, in a number of phases in the period from Oligocene to Pleistocene covering over 40 millions of years. The flowing and intrusive neomagmatic processes are associated with the batholith of acidic magma situated at depth of over7–9 km, with expected area of 150-500km^2 and volume of 650-2500km^3. The potential of the existing hydrothermal resources is justified to be estimated as significantly higher then the manifested. However, KVA has also the potential for resources with higher temperature than 100^0C. Considering the stated parameter, investment in fundamental investgations of the geothermal energy potential in KZA is justified. [11]

The KDA is evaluated to have twice lower parameters, but to be characterized by a similar magmatic activity, lesser depth to Moho-discontinity, more pronounced fault-zones and other. From this aspect, the prospectives of the KDA do not leg behind those of KZA.

Exploitation of the lithoheat with exploitation of the geothermal water is most widely utilized and most developed system of geoheat exploitation. For transformation of the litho heat into hydro heat, it is necessary to have a suitable lithoarea for transfer of the litho heat into underground water heat, and the possibility for inflow of surface (or reinjected) water into it.

Existing geothermal explorations in VZ do not allow defining of the geothermal field in the surface part accessible for rational exploitation of the litho heat. On the basis of the existing explorations, a concrete project for investment cannot be initiated.

For rationalization and positioning of the geothermal explorations, it is necessary to perform basic geophysical explorations of the structural-tectonic units to a depth greater than 5km, and with optimal resolution in the depth belt of 1 to 3-5 km.

Economic effects from regional investigations and basic geophysical investigations are included in the rationalization of detailed investigations, and from them, one cannot expect direct economic effects. The implementation of projects for geothermal energy has the following risks:

- Financial risk- associated with the uninterrupted sustainable financing of projects;
- Technical risk - a risk associated with reliability of the equipment;
- Geological risk - a risk related to geological factors.

The preliminary calculated financial risk for implementation of renewable energy projects is equal to zero (i.e. it is considered that there is a steady and uninterrupted financing in full). However, in the case of geothermal (renewable) energy projects, there is a financial risk that can arise from “big initial investments”..

Technical risk is also not available for planned use of technical equipment and technologies that are already used in the industry of Western Europe.

Geological risk of the search stage is up to 10%, and of the exploration stage the possibility is 60% -70%. At the stage of operation (production drilling), the probability is 90%. [12]

5. Environmental impact and energy resources combining

Slow conductive transfer of the inner Earth’s heat to the Earth surface is reflected by “slow renewal of the litho heat in the surface belt”. Hence, the knowledge on the “origin of the geothermal heat” is still based on hypotheses. From this aspect, there arise concerns regarding the potential environment impact of heat exploitation from the surface Earth belt.

To a certain defined extent, exploitation of the Earth’s heat is regulated within the natural thermodynamic system. Besides that, due to lack of experience, the environmental impact from forced utilization of the Earth’s heat from the surface belt should be treated as “partly known”. For now, “similar to weaker” environmental impacts in comparison with impacts from forced exploitation of the solar heat (from decreasing of the solar radiation upon the surface belt) are expected.

The environmental impact from forced utilization of the Earth’s heat from the surface belt can be eliminated buy exploitation of Earth’s heat that will be equal to the inflow of inner Earth's heat toward the Earth's surface. It is only with this way of exploitation that the geothermal energy will be renewable. From this aspect, the using of the possibilities of combination of geothermal with renewable energy resources is of a special importance.

Geothermal and local renewable energy resources combining is with the following goals:

- Production of a higher total energy quantity;
- Achievement of more equalyzed energy production from the sources with variable energetic potential;
- Adjusting of the intensity of geothermal energy exploitation to the natural inflow of the inner Earth's heat;
- Saving of other types of slow renewable and not renewable energy (hydro energy from small accumulations, gas from organic waste and sewages, fossil and biodiesel fuels,).

Natural hydrothermal systems are functioning by a natural system of geothermal water production. So, the possibilities for technogene managing are limited to supporting their feeding with atmospheric water or re-injected water. Not used wind and solar energy with installed systems for exploitation is a non-reversible lost energy. From that aspect, these kinds of energy are suitable for substitution of the non-renewable and slowly renewable energy.

From the aspect of combining with renewable energy resources, the possibilities for managing the geothermal energy utilization are limited to:

- Managing of technogene systems for geothermal water exploitation- systems for direct litho-heat exploitation and litho-heat exploitation with transformation to hydro heat;
- Hydro-heat utilization in the periods when it is not used for the planned purpose;
- Re-injecting of not-reversible lost energy in the exploitation fields of the Earth's heat.

Solar energy in the geographic width of VZ can be exploited during most of the year (more than 200 days per year). The disadvantage is that it cannot be exploited during the nights and that the energy potential depends on the meteorological conditions (clouds, winds, air temperature,). The wind speed (at 80n) in VZ is 4 times greater than 8 m/s. Because the system of geothermal energy exploitation is stable enough, it is suitable for combination with the solar energy exploitation systems, and partially with the wind energy exploitation systems. [11,12]

6. CONCLUSIONS

The geospace of the Vardar (mid-ocean) paleorift-zone is the most prospective region for geptermal energy exploration. Within this zone, the most important geotermal regions are the Kratovo-Zletovo (KZA) and Kozuf-Dojran (KDA) area.

With the increased geothermal flux into the Vardar zone, ambitious investments in geothermal exploitation systems of resources with higher energy potential at depth greater than 2km, are justified..

If the magmatic activity of KZA and KDA were carried out during the entire Pleistocene, there would still be exit “heating bodies” which accelerate the conduction of geothermal energy in the surface zone of VZ (including the underground water to a potential depth of 3-5km).

Due to lack of experience, environmental impact from forced exploitation of the petrothermal heat from the surface belt of the Earth should be treated as “partially known”.

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