Challenges of South Hungarian EGS Demonstration Project

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Keywords: EGS, geological prognosis, targeting approach, multi-zone stimulation, NER 300.

ABSTRACT

The South Hungarian EGS Demonstration Project aims to produce 8.9 MW_e net power with inlet temperature of 170 °C. The location of project is Békés county, in the vicinity of town of Mezőkovácsháza. The area is along the Battonya-Pusztaföldvár Ridge, where crystalline rocks consists of granite, granodiorite, gneiss, serpentinite, mylonite and quartzite. The targeted formation is poorly explored, and certain drilling risks are associated with overpressure and loss zones. A temperature model was developed based on the temperature data of deep wells. The targeted 170-180 °C is located at 2900-3125 m depth range. By the interpretation of available 3D seismic data set a targeting approach method was developed. The method is built on indication of homogeneity of rocks, the final well site is on an intermediate level of homogeneity. The present well design takes into consideration the associated drilling risks, the planned stimulation activities and the protection of groundwater resources. There are no well bore stress measurements in the basement in the vicinity of the well. The stress regime and principle directions can be inferred from earthquake focal mechanisms. For multi-zone stimulation AltaRock's TZIM Technology will be used. The expected date for drilling of first EGS well is autumn of 2016

1. INTRODUCTION

The South Hungarian Enhanced Geothermal System (EGS) Demonstration Project (SHEGSDP) jointly promoted by NER300 funding program, Hungarian Government and the Steering Group of the EU Strategy for the Danube Region is a technological initiative to test the suitability of an EGS pilot plant in the Pannonian basin of Central Europe. The project is managed by EU-FIRE EGS Hungary Kft. and aims to produce 8.9 MW_e net power utilizing a total production flow rate of 280 kg/s with inlet temperature of 170 °C and 90 °C outlet temperature. The EGS resource will be developed by drilling approximately 10 wells 3000-3500 m depth interval. The project is in Exploration Phase, the expected date for drilling of first EGS well is autumn of 2016. The project will be executed in Békés County, in the vicinity of town of Mezőkovácsháza. The area is an agricultural plain characterized by low population density within Hungary.

2. GEOLOGY

2.1 Geology of Battonya – Pusztaföldvár Ridge

The project area is located on the SE part of the Pannonian Basin which is a young sedimentary basin formed since the Mid Miocene to Quaternary. The Exploratory Area of Concession is located on the Battonya-Pusztaföldvár Ridge between the Makó and Békés Basins (Figure 1).

From a geological point of view, the crystalline rocks of this area belong to the Battonya unit, which is part of the Békési Terrane. The granitoid rocks have a compound crustal-mantle origin (Buda 1996). They are located along the middle axis of the Battonya-Pusztaföldvár high, and are bordered by a wide belt of migmatite and crystalline schist on the NE and SW side (Szederkényi 1998). Based on modal composition the studied granitic rocks are syenogranites, monzogranites and granodiorites, which has S-type granitoid character (Pál-Molnár et al 2001). In addition to granites and granodiorites (referred to as diatexite), Fülöp (1994) also described migmatite, mica schist, gneiss and amphibolite. The core lab of MOL Plc. was visited by geologists from Mannvit and AltaRock to examine the core samples from 54 boreholes drilled on the Battonya-Pusztaföldvár Ridge. During the evaluation granite, granodiorite, gneiss, serpentinite, mylonite, quartzite, rhyolite and dolomite were identified in the core. At several wells more than one types of crystalline rock have been recognized. The spatial distribution of pre-Tertiary rocks is presented on Figure 2 taking into consideration the evaluation during the core lab visit and the interpretation of Fülöp (1994). In most of the exploratory area granite and granodiorite have been identified. In the NW corner of exploratory area sediments of Triassic age are present, while in the SE corner mica schist. The presence of granitoid rocks between these opposite corners is not uniform. Fragments of metamorphic rocks, like gneiss, mylonite, quartzite and even serpentinite were recognized within the granitic body.

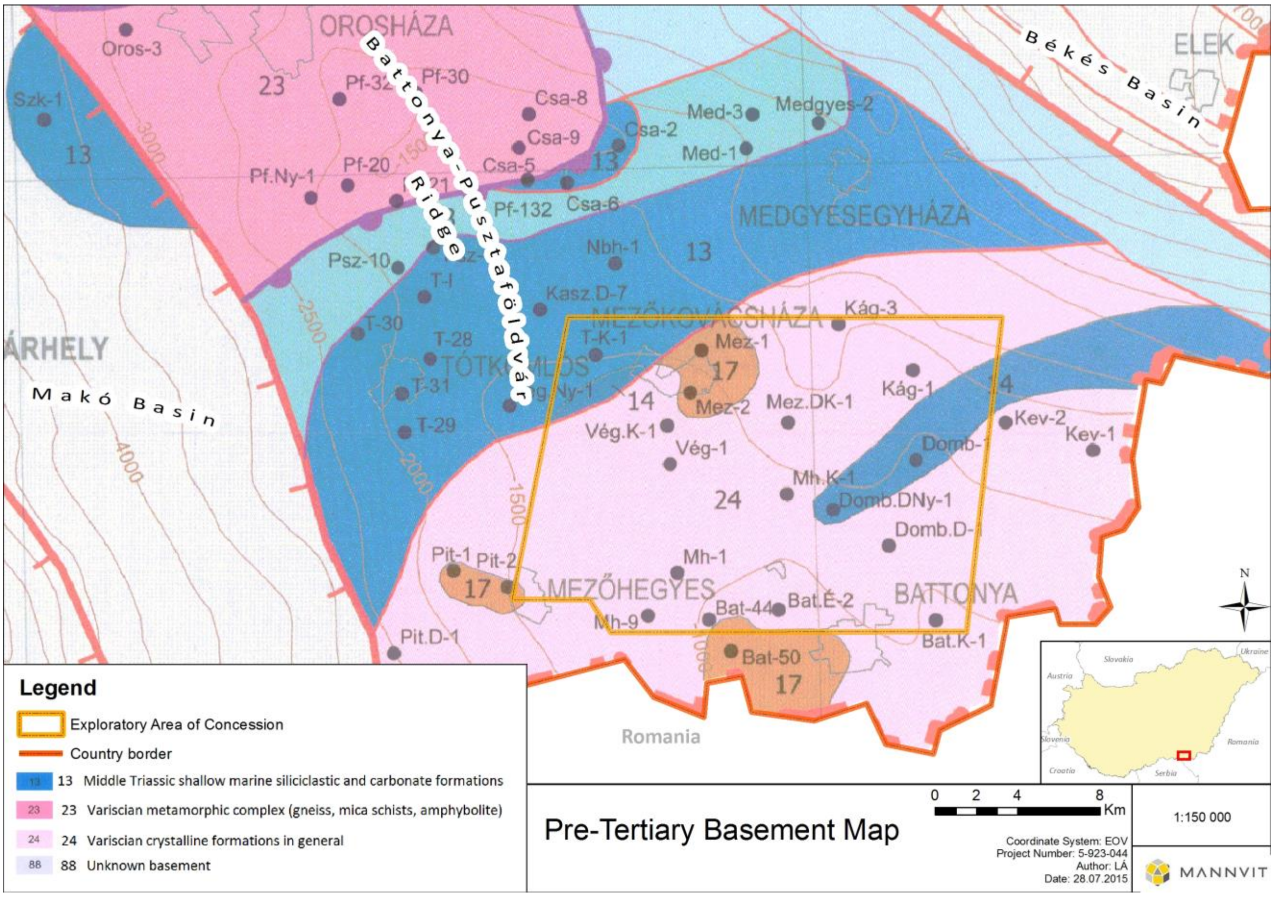

Figure 1: Pre-Tertiary basement map after Haas et al 2010 showing Exporatory Area of Concession in orange

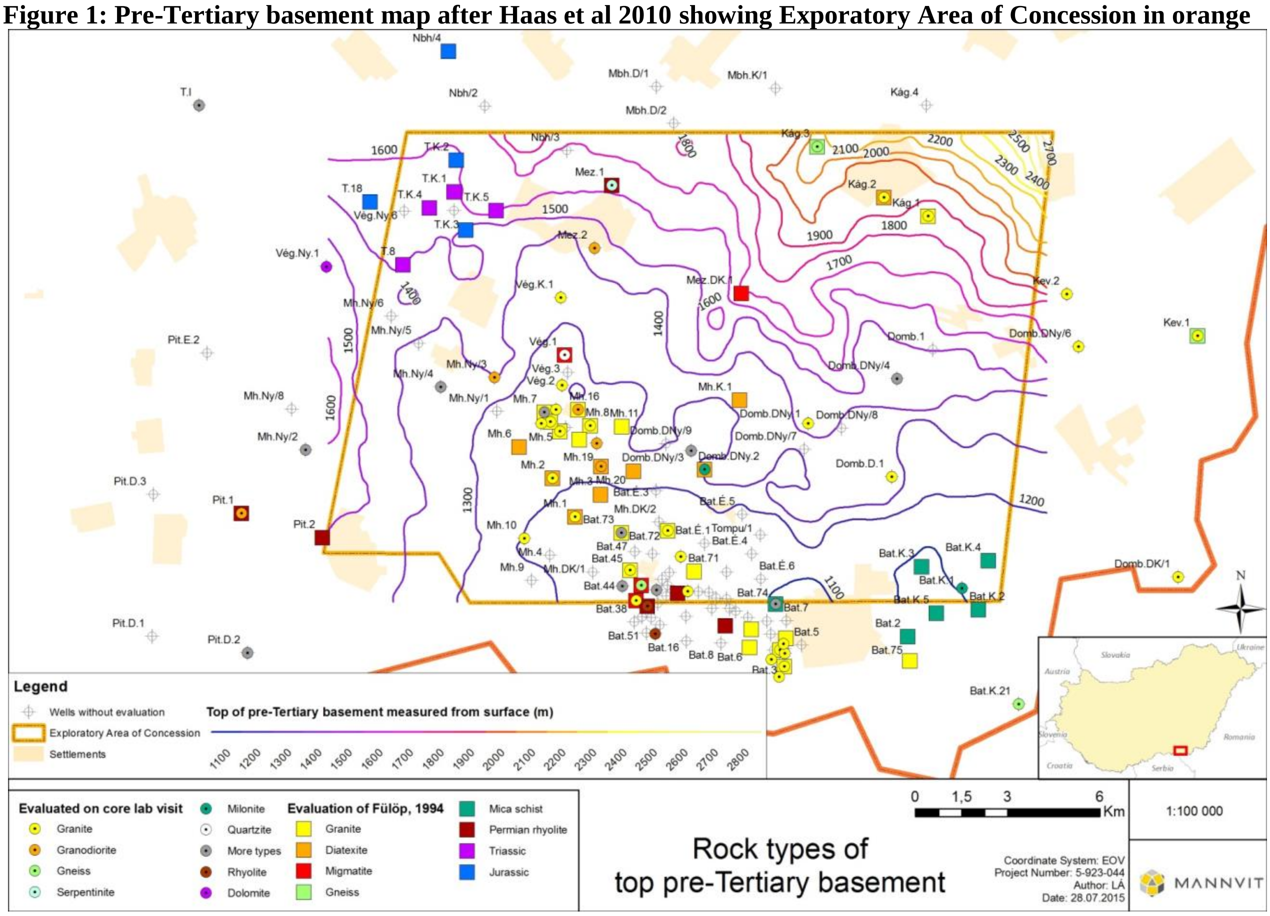

Figure 2: Rock types of top of pre-Tertiary basement based on visit to core lab and on earlier interpretation

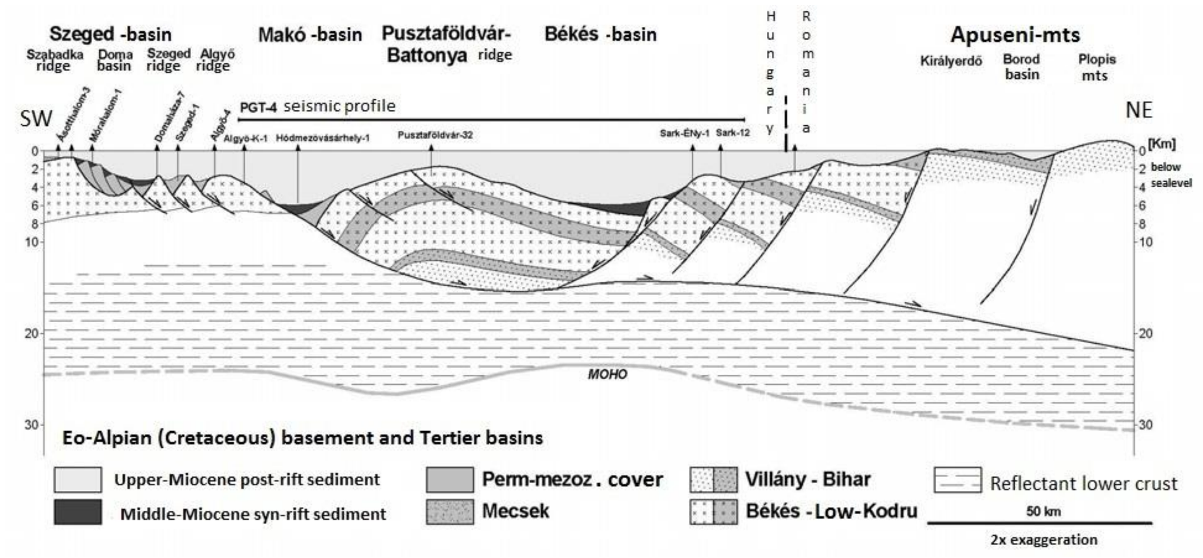

Figure 3: Structural interpretation of Battonya-Pusztaföldvár Ridge (modified after Tari et al 1999)

This observation corresponds to the description of analogous outcropping crystalline rocks located in the west slope of Codru Mountains, Romania. Rozlozsnik (1939) mapped igneous rocks such as granite, granodiorite, diorite and metamorphic rocks, like mica schist, shaley hornfels, mica-feldspar quartzite. In certain parts of the area (like in the Hasmas valley) the igneous rocks are predominant, but not uniform, while in other areas the metamorphic rocks are predominant.

The pre-Tertiary basement in the Pannonian Basin experienced compressional tectonics in the Cretaceous resulting in imbricate thrust sheets. The Battonya-Pusztaföldvár Ridge is interpreted to have formed during the Tertiary during three evolutionary stages: a syn-rift stage, a post-rift stage and a neotectonic stage.

In early Mid Miocene, during the syn-rift stage, the Makó Basin started to open as a result of low-angle normal faulting, which is explained by a nappe-shaped boundary within the Tisia unit of Cretaceous age. Originally the Algyő Ridge was in a lower position than the Pusztaföldvár-Battonya Ridge, and formed the Makó Basin by slipping downward (Figure 3). The downward slip of the nappes caused the surface appearance of a metamorphic core complex from the Algyő Ridge during the Miocene (Tari et al 1999). There are some syn-rift sediments of Miocene age in the intermediate and deepest parts of the basin.

The post-rift stage is coeval with the thermal sinking of the basin. This thermal sinking resulted in deposition of thick clastic sediments of Pannonian and Pliocene age by large delta systems. The neotectonic stage, a continuation of the post-rift stage characterized by transpressional tectonics - minor compressional inversion and left-lateral strike-slip faulting along NE-trending structures (Bada et al., 2007, Horvath et al., 2015) - has limited impact on basement structures; however, will be of importance to the EGS stimulation design and results.

2.2 Geological and geothermal prognosis for first drilling

Based on the available geological data the planned well Mez-EGS-01 is expected to penetrate similar lithological units as observed in neighboring hydrocarbon wells. Well-explored sediments of Neogene and Quaternary age with known conditions on drilling process overlie pre-Tertiary basement. The top of Palaeozoic crystalline rocks is expected at the depth of 1750 respectively. The surrounding wells penetrated through the Tertiary layers and usually sampled the top part of the pre-Tertiary basement in several 10 m long drilled sections. This means, that geological measurements are not available for areas of pre-Tertiary crystalline basement deeper than the topmost 10 meters of pre-Tertiary rocks, and only assumptions can be made for geological properties of rocks located at greater depth.

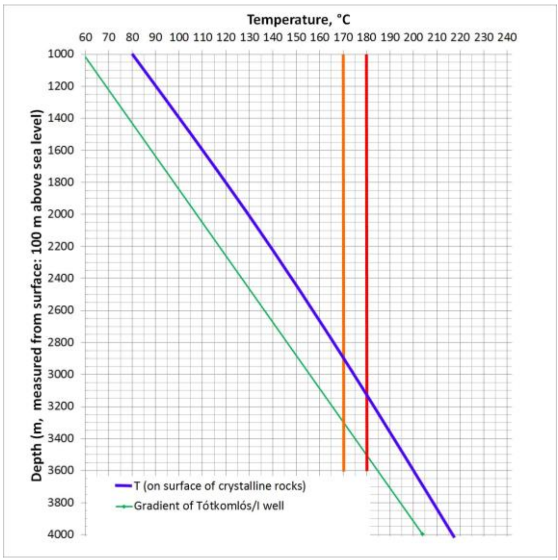

Figure 4: Temperature model for the SHEGSDP concession area

On Figure 4 the temperature model of the area is presented. This temperature model is built on measured data and theoretical considerations. As stated above reliable temperature data from deeper part of the basement is not available due to lack of well control past the top 10 m of the basement. Only the temperature at the surface of pre-Tertiary basement could be calculated based on the existing data.

The measured data along the 1000-2000 m depth interval close to the basement surface indicate 55-70 °C/km geothermal gradient, which starts to decline with increasing depth. At 2120 m (right above the granite layer) 139,2 °C was measured in production testing of well Mbh.K/1 located at the edge of the concession area, which indicates a 60 °C/km geothermal gradient at 2000 m depth. Reliable and representative temperature data of the 2500-4000 m depth interval is not available at all for the concession area. The most reliable data for this depth interval are connected to wells which are located at the NW end of the Pusztaföldvár-Battonya high at the towns of Békéssámson and Orosháza. Based on the evaluation of geothermal gradients of Oros/1 (50 °C/km), Oros/3 (53 °C/km) and Bés/1 (58 °C/km) wells the average value is 55 °C/km at 3000 m depth. The temperature model (blue line) in Figure 4 is a polynomial trend line fitted on 3 values (80 °C at 1000 m corresponding to 70 °C/km, 130 °C at 2000 m corresponding to 60 °C/km and 175 °C at 3000 m corresponding to 55 °C/km). The desired 170-180 °C temperature interval is expected at 2900-3125 m depth range respectively. The depth of the first drilling is suggested to exceed the indicated depth range with several hundred meter to provide confirmation about the expected temperature.

Based on experiences collected during the exploration of the surrounding hydrocarbon fields, a hydrostatic pressure regime is expected for the upper part of the Mez-EGS-01 drilling from the surface down to 1800 m depth. For the section deeper than 1800 m, only estimated or predicted pressure values can be given, because there are no representative pressure measurements at deeper than 1800 m in close vicinity to the Mez-EGS-01 drill site. The proposed Mez-EGS-01 drill site is located between two positions (T/I well, and Highis Mountains), where hydrostatic pressures were observed, so the predicted pressure gradient for the 1800-3650 m depth interval at Mez-EGS-01 is hydrostatic. Taking into consideration that exact pressure measurements have not been performed in the close vicinity of the Mez-EGS-01 drill site and that overpressure is frequently associated with pre-Tertiary basement rocks located deeper than 2000 m in the south part of the Pannonian basin (Somfai, 1976, Révész and Kókai, 1978, Almási, 2001, Almási and Tóth, 2001, Kovács et al., 2007), there is some risk of overpressure for the 1800-3650 m depth interval at Mez-EGS-01.

Presumably crystalline rocks, like granite, granodiorite, diorite, migmatite, mylonite, quartzite, mica-schist and gneiss will be encountered in the 1800-3650 m depth interval. Due to different tectonic phases in the past, especially Cretaceous thrust sheet movements, the pre-Tertiary basement is fractured and fractures with hardly predictable features (cave-ins, mud-loss, gas kick, stuck BHA, overpressure etc.) might occur all along the drilling between 1800 m and 3650 m.

There is no reliable direct well-bore measurement of the stress-field in basement rock around the planned well. Based on stress inversions of earthquakes in central and eastern Pannonia results of the area of SHEGSDP is characterized by NE-SW direction of SH_{max}, and strike-slip faulting is expected (Bada et al, 2007). Measurement of the magnitude and orientation of the principle horizontal stresses is planned during the first drilling through extended leak-off tests and well-bore image logging.

3. TARGETING APPROACH

At this stage a proven, well-defined targeting approach for the EGS project is not available. Only theoretical considerations could be used to suggest an approach based on several principles and conditions. By the interpretation of available 3D seismic data an attempt was made to identify suitable target zones for EGS drilling. At first an attribute analysis was made, and among the out comes the Reflection Intensity and GLCM Texture Direction seemed to provide significant help for distinction between homogenous and inhomogeneous parts along time-slices during interpretation. The targeted depth range for evaluation was 2500-4000 m.

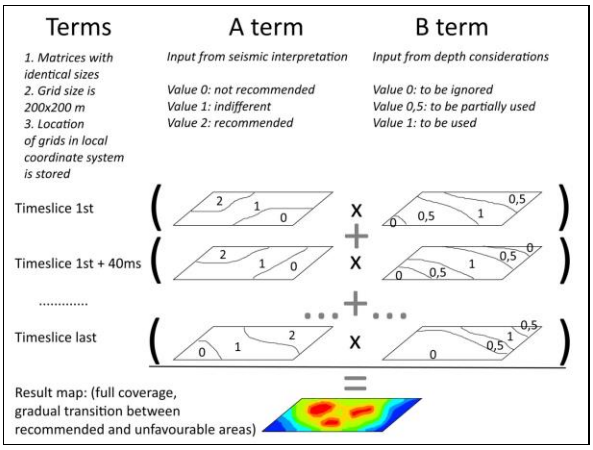

Figure 5: Proposed GIS calculation method SHEGSDP concession area

The seismic velocity is quite different in the overlying sediments compared to crystalline rock. Furthermore, the top of crystalline rock is an uneven, dipping surface there are areas within a timeslice, which fitted into the evaluated depth range, while other areas not.

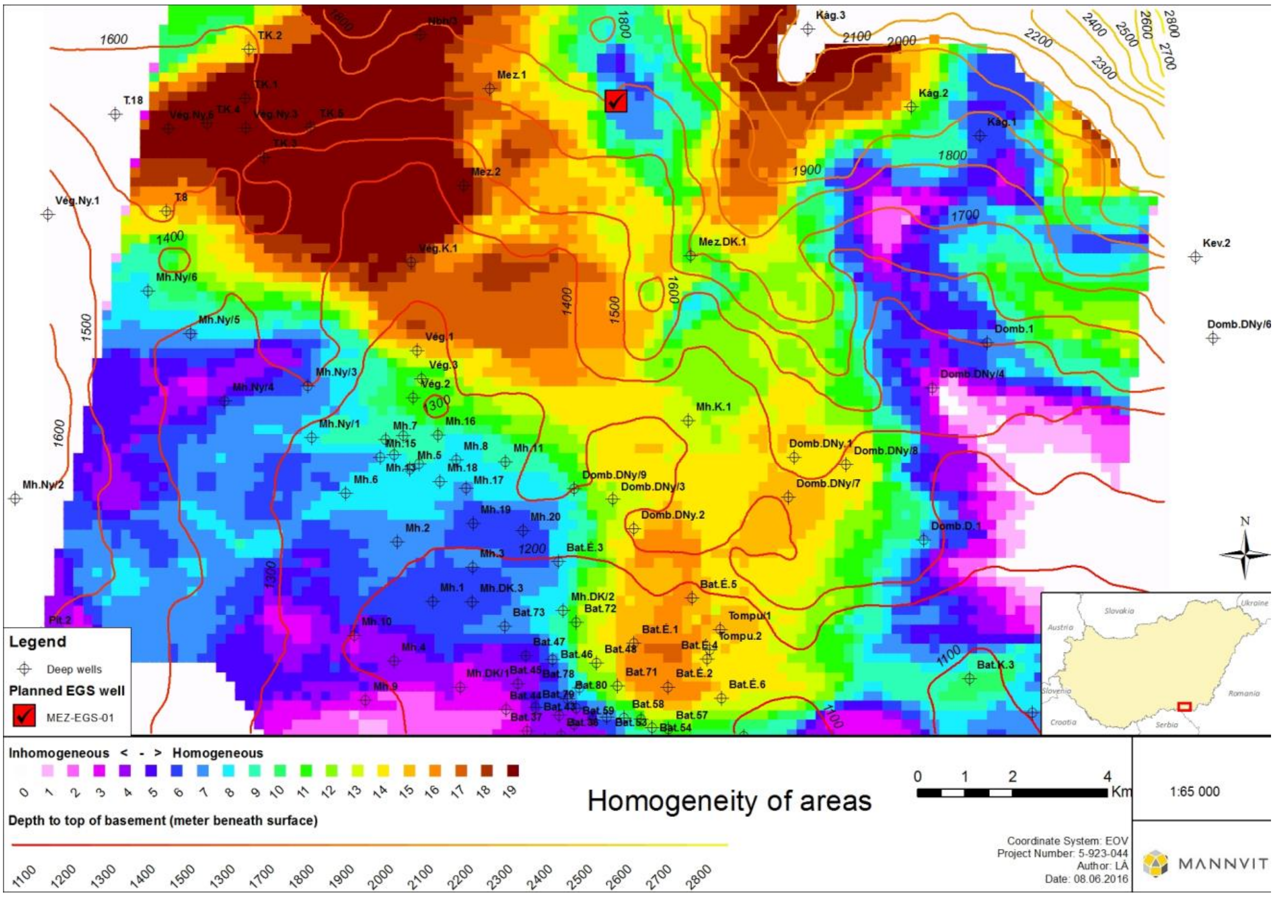

Figure 6: Homogeneity of crystalline rocks at targeted depth.

The top, 1000 m thick part of crystalline rock was not treated as target zone avoiding any conflict with several hydrocarbon field. The vicinity of young faults and the border zone of concession area was excluded as potential target zone.

By applying a GIS calculation method one can easily locate homogenous vs. inhomogeneous areas. The ingredients of the proposed GIS calculation method are depicted in Figure 5. The method operates with 3D matrices. The matrices are identical, their horizontal dimensions cover the concession area, their vertical extent reaches from 1280 ms and to 2440 ms two-way travel time (TWT) taking into consideration the velocity model of the area. The horizontal grid size is 200 m x 200 m, while the vertical grid spacing is 40 ms, which equals 110 m.

The inputs from seismic interpretation belong to the A terms (see Figure 5). A terms are derived from a vertical stack of time-slices. The first time-slice is 1280 ms, which contains the result of interpretation of GLCM Texture Directional. The second one is 1320 ms, which uses values from Reflection Intensity, the next one from GLCM Texture Directional, etc., alternating down to 2440 ms. The value of recommended areas is 2, for indifferent areas it is 1, while for not recommended areas it is 0.

B terms (see Figure 5) incorporate depth considerations into the calculation. They are also derived from vertical stack of time-slices at the same TWT position as A terms. Each B term is calculated from the depth to the top of the basement value, which is available at each grid point. For each given depth to top of basement value, the calculation method determines whether the intersection between the TWT/depth line and the given TWT value lies within the green areas (value 1) or outside (value 0). A slight transition zone with 0.5 values was implemented into the calculation for a two time-slice interval.

Figure 6 shows the result map of the evaluation. The more homogeneous areas are indicated with higher values. As the applied method does not provide direct indication about real level of homogeneity, in addition to the favorability of homogeneity vs. inhomogeneity is unclear for EGS reservoir development, the areas which has low or high level of homogeneity are not suggested for EGS development for the time-being.

Beside the level of homogeneity, the final site selection was based on other conditions, like level of cultural noise that would impact seismic sensitivity, estimated risk due to induced seismicity, access to land and to other utilities. The well site of MEZ-EGS-01 well (indicated on Figure 6) is located an area which is characterized by intermediate level of homogeneity, and there is an opportunity to aim target areas with different level of homogeneity.

A feature might be associated with the indicated level of homogeneity at the drill site area, and that is a connection to a fracture system with an active, natural flow. The drilling will provide information about its presence and its favorability for EGS reservoir development.

4. PLANNED DRILLING AND PREPARATION

4.1 Considerations

The main practical requirements of the drilling are:

1. protection of shallow aquifers with a separate casing string
2. a minimum 1000 m long casing string between the protected sedimentary aquifers of late Pannonian age and the EGS reservoir,
3. minimum 1000 m long open hole,
4. deviated well,
5. minimum 3350 m drilling depth (TVD)

4.2 Well design

The degrees of azimuth and inclination of drilling will be defined after the analysis of stress field being available. Table 1 present the top and bottom of planned casings at 30° inclination of drilling.

Table 1: The planned intervals of casings at well Mez-EGS-01 at 30° inclination.

Casings	top, m TVD	bottom, m TVD
711 mm	0	60
18 5/8”	0	600
13 3/8”	0	1600
9 5/8”	0	2567
openhole, 8 ½”	2567	3433

4.3 Microseismic array (MSA)

In order to characterize natural microseismicity in advance of stimulation, a MSA of at least 12 stations will be installed in the autumn of 2016. Seismometers will be installed to ~100 m deep boreholes to reduce surface noise and increase MSA sensitivity. The aperture of the array will be greater than 10 km, to provide wide focal sphere coverage for moment tensor calculation and improve depth control. At the end of drilling, calibration shots in the well will provide data for development of a precision 3D velocity model to the depth of interest.

4.4 Measurements

A density log is planned all along the drilled section, while borehole televiewer (BHTV) is planned along the sections of crystalline basement. An extended leak-off test will be performed at the top part of 8 ½” openhole section. The evaluation of local stress field could be made by the use of density logs, the BHTV images and the extended leak-off test.

A step rate injection test is planned at the end of drilling to calculate permeability and wellbore skin effects prior to stimulating the EGS reservoir.

5. PLANNED STIMULATION

During the reservoir stimulation several 10,000 cubic meters of water will be injected at moderate well head pressure inducing shearing on pre-existing fractures within the rock matrix (hydroshearing). The prevailing stress state will determine which fractures are and best oriented for shear failure. Sheared fractures will remain open because of self-propping characteristic of uneven surfaces. The growth of seismic cloud will be monitored by the MSA. An induced seismic mitigation plan will include a proactive traffic light system be used avoid damages caused by induced seismicity.

Previous stimulation jobs performed in EGS projects could stimulate only one fracture stage per well. A multi-zone stimulation program will be performed in which thermally-degradable zonal isolation materials (TZIM) are used to temporarily seal already-stimulated fractures zones and allow new fractures to be stimulated This method could increase the power output of each well by 3-5x. SHEGSDP will use AltaRock’s TZIM technology resulting in an increase in power production, cost savings and reduced operational risk.

Special attention will be given to EGS characterization tools. By using stress and fracture analysis from BHTV, hydroshearing numerical models, interpretation of size and shape of induced seismicity and data of distributed temperature sensing system significant dataset will be gathered to evaluate and characterize the relationships between observed phenomena and processes. To ensure steady operations at lower cost, stimulation pumps designed for long-term pumping will designed, procured and installed on site.

6. CONCLUSIONS

The SHEGSDP project is targeting a fractured crystalline rock complex at Battonya-Pusztaföldvár Ridge, South-East Hungary. The expected depth range of reservoir creation is between 2500 and 3500 m depth respectively. The temperature, pressure and other conditions, which will effect the drilling prognosis within the deep basement is inferred from wells which only penetrate the top tens of meters of the basement. The drill site of MEZ-EGS-01 is located on a slightly inhomogeneous area. The drilling will start at autumn of 2016. At the end of drilling extended leak-off test, calibration shot and step rate injectivity test will be performed for collecting information to design induced seismic mitigation plan and stimulation activities. For multi-zone stimulation AltaRock’s TZIM Technology will be used.

Acknowledgements

The authors would like to thank: EU-FIRE EGS Hungary Kft for managing SHEGSDP project; European Commission (NER300 funding program), Hungarian Government and the Steering Group of the EU Strategy for the Danube Region for supporting jointly the development of project. László Ádám would like to thank Steinar Þór Guðlaugsson for his professional support during the work on SHEGSDP.

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