Evaluation of potential demonstration sites by outlining geothermal reservoirs above 50 °C

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1. Introduction

Geothermal energy and its most important carrying medium, thermal groundwater is strongly linked to geological structures, regardless of borders between countries. The studied region of TRANSENERGY is divided by state borders into four independent Member States (Austria, Slovakia, Slovenia, Hungary), but geologically the Eastern Alps, Western Carpathians and different sub-basins of the Carpathian basin system comprise the area which geological structures determine the spatial distribution of the main geothermal reservoirs.

To assure a sustainable and harmonized utilization of geothermal resources of the project area, it is important to outline and characterize the main reservoirs / thermal water aquifers of the region. This was based on the integrated interpretation of the different models of the supra-regional area (encompassing the entire project area): the geological model which outlines the main hydrostratigraphical units and provides their geological characterization (Maros et al. 2012), the hydrogeological model quantifying the most important hydrogeological characters and the main groundwater flow systems (Tóth et al. 2012), and the geothermal model providing the subsurface temperature distributions (Götzl et al 2012).

The outlined geothermal reservoirs at a supra-regional scale serve as a basis for further estimation of the existing geothermal potentials and resources in order to distinguish between prosperous and non-prosperous regions and thus also provides a basis for outlining areas where feasibility study for a potential plant can be performed.

2.Definition of reservoirs

Geothermal energy is strongly restricted to areas with appropriate geological buildup: high geothermal gradient, favorable reservoir rocks and sufficient transporting media (geothermal fluids). In the following the term of geothermal reservoir will be used as “a part of the geothermal field that is so hot and permeable that it can be economically exploited for the production of fluid or heat. It is only part of the field and part of the hot rock and fluid underground. Rock that is hot, but impermeable is not part of the reservoir." (M. A. Grant and P. F. Bixley, 2011). Applying this definition to the geological conditions of the TRANSENERGY area, permeable rock volumes having a temperature higher than 50 °C were considered as geothermal reservoirs.

3.Reservoirs in the TRANSENERGY project area

3.1.Reservoir types of the TRANSENERGY area

To be able to provide a simple and transparent characterization, some major reservoir categories were established based on the geological and hydrogeological properties of the rock units, which are the following:

- Pannonian (i.e. Uppermost Miocene-Pliocene) porous reservoirs,
- Miocene (i.e. Sarmatian, Karpatian, Badenian and Ottnangian) reservoirs (with 3 sub-types: porous, double-porosity, non-classified),

–Basement fractured crystalline reservoirs,
–Basement fractured carbonate reservoirs (partly karstified).

Figure 1. shows the reservoir types of TRANSENERGY project area.

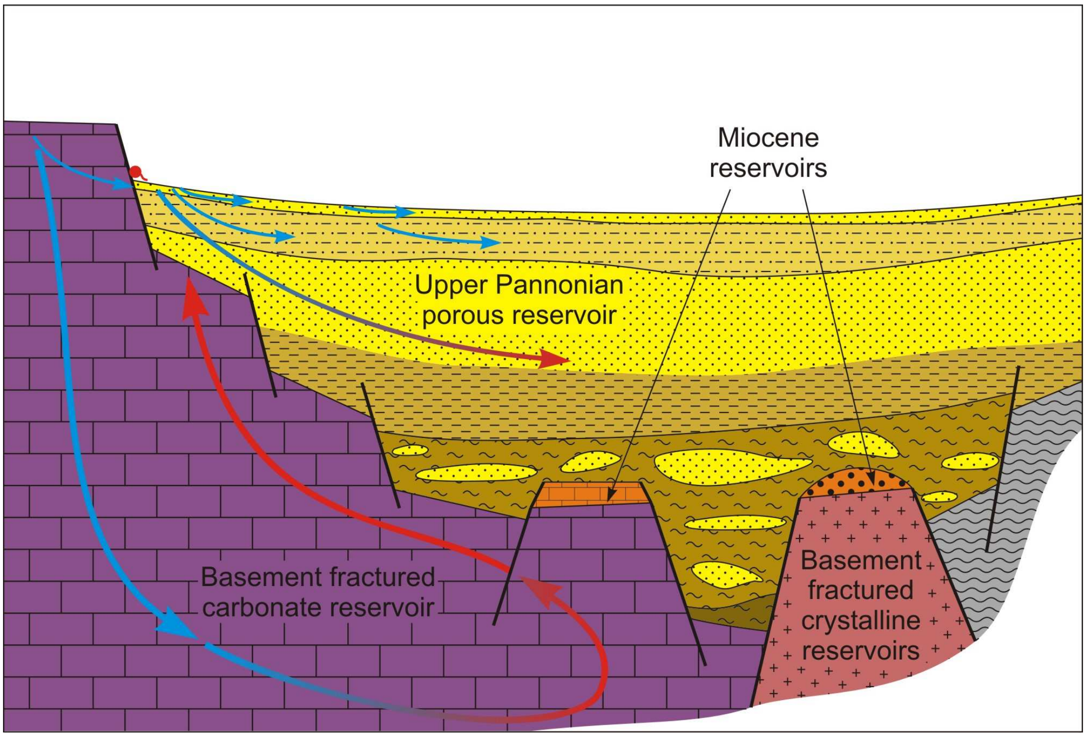

Figure 1: Reservoir types of the TRANSENERGY project area

These categories were than further sub-divided, where relevant according to different temperature intervals, such as:

–50-100 °C,
–100-150 °C
–above 150 °C.

3.2. Methods for outlining of reservoirs

The top surfaces of the reservoirs (the specified geological-hydrogeological type, i.e. porous, karst, fractured, double porosity combined with the relevant temperature intervals) were constructed by combining the different geological horizons, isotherm surfaces, and hydrogeological characterization of the different geological formations. For the outlining (i.e. combination of the relevant maps and properties) the software SURFER was applied. SURFER is a grid-based contouring and three dimensional surface plotting graphics program. It allows making calculations with different grid files, performing mathematical transformation on grids and creating grids that represents mathematical surfaces. It can present the surfaces in a grid format for further utilization with other softwares, or display the surfaces in different map types.

3.3. Characterization of different reservoir types

3.3.1. Pannonian porous reservoirs

During the post-rift thermal subsidence of the Pannonian basin in the Late Miocene, a single large depression developed which was occupied by the brackish to freshwater Lake Pannon and was filled up by sediments deriving from the surrounding Alpine-Carpathian mountain belt via large fluvio-deltaic systems prograding from the northwest and northeast (Bérczi and Phillips, 1985; Juhász, 1994). This resulted in the accumulation of up to 4000-6000 m thick sedimentary succession.

This vast porous basin fill complex is one of the main reservoirs of thermal groundwater. Within this several thousand meters thick sedimentary succession, Lower Pannonian layers mainly consist of clay, or sandy clay therefore act as regional aquicludes. The Upper Pannonian sedimentary succession is built up of altering sand and sandy clay layers. The entire system is characterized by a strong anisotropy (Kh/Kv often higher than 5000) at a larger, regional scale due to frequent alternation of the sand-silt-clay layers. Although the permeability of the clayey-marly layers is 1-2 magnitude lower than that of the sands, this is still enough to provide hydraulic connection between the sand layers, thus make the entire sedimentary succession one hydrostratigraphic unit. Within this thick Upper Pannonian sedimentary complex the best reservoirs are those large sand bodies which once deposited on the front of the prograding delta-systems. These 50-300 m thick permeable sand/sandstone bodies with an aerial extent of 200-2000 km^2 have good connectivity with each other. These delta-front sandstones can be characterized by intergranular permeability and confined groundwater levels. The porosity and permeability of the aquifers decrease with depth as a result of sediment compaction within the deeper zones of the sedimentary basin.

These reservoirs, referred as “thermal-water bearing unit” in the Pannonian basin are widely utilized for balneological purposes as well as for direct heat (mostly greenhouses), therefore yield and temperature drops due to overexploitation is an already existing problem at many locations.

The temperature exceeds 50 °C in the depth on a large area where Upper Pannonian formations occur in big thickness. Within this area two sub-types of reservoirs are distinguished based on the temperature. In the first sub-type the temperature at the top of the Upper Pannonian formations is 50 °C, while at their bottom it is max 100 °C (Figure 2). The top surface of this reservoir is elongated in NE-SW direction, from the Danube Basin to the Mura-Zala Basin and is located in the depth of -430 – -1040 m below see level, the deepest part is in the Danube Basin.

In the second sub-type of the Upper Pannonian reservoirs the temperature exceeds 100 °C, this occurs only in a small area in the Mura-Zala Basin in Slovenia, close to the Croatian border, and the central part of the Danube Basin (Figure 3.)

Usually the Upper Pannonian reservoirs get direct recharge via the overlying sediments or from their outcropping sandy layers and / or Quaternary aquifers on the hilly areas with a higher hydraulic potential. This is reflected in the chemical composition of the stored thermal waters with relatively low salinity, and a total dissolved solid content increasing with depth.

The deep regional thermal groundwater flow system developed in the Upper Pannonian sandy aquifers is generally characterized by an alkaline $NaHCO_3$ character.

Due to lithological heterogenity and porous character, re-injection into these reservoirs has to be planned cautiously, as the necessary injection pressure can substantially increase within a relatively short time. The most common problem is the plugging of screens (perforation) in the well and pore throats of the reservoir formation. The permeability may decrease due to clay swelling, pore-space blocking by fine particles, or precipitation of dissolved solids due to the mixing of injected and formation water. The precise mechanisms which determine injectivity are site specific and processes are not entirely understood yet. Therefore existing and well operating technologies in one place cannot be directly adopted to another site and no uniform policy, standardized know-how is available which would guarantee the success of a re-injection project.

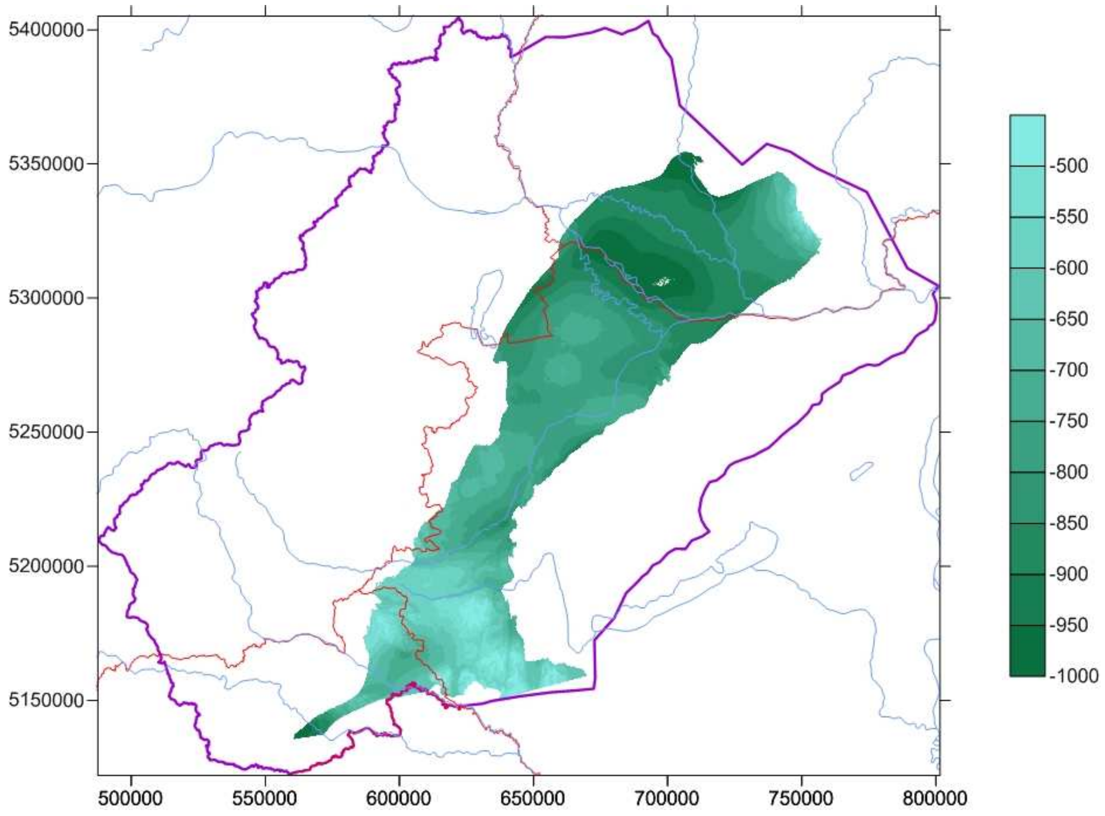

Figure 2: The top surface of the potential Upper Pannonian reservoirs with temperature of 50-100 °C

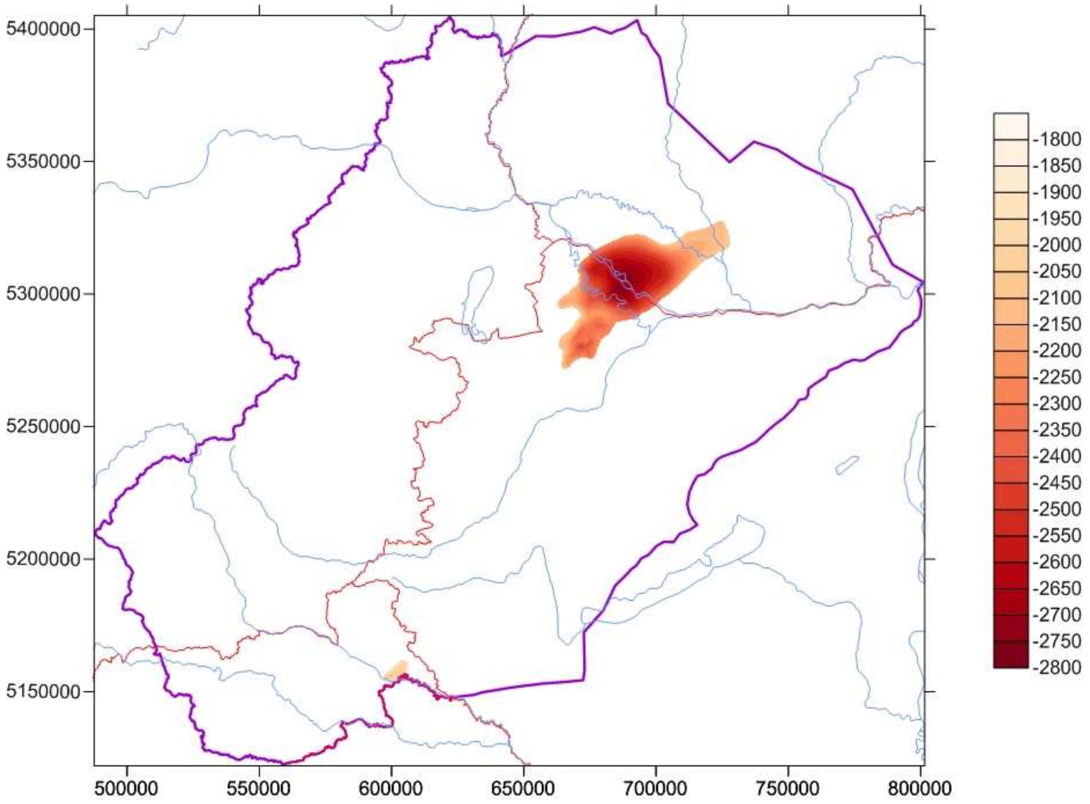

Figure 3: The top surface of the potential Upper Pannonian reservoirs above 100 °C

3.3.2. Miocene reservoirs

Due to extensional stress field in the Neogene, deep basins originated with various heteropic facies characterizing the margins, the rapidly sinking basin floors and the tilting basement highs. Repeated transgression resulted in the deposition of thick off-shore pelagic sediments in the basin interiors, and brackish-littoral facies sediments at the margins and on the basement highs. Based on hydrogeological properties of the Miocene formations, 3 sub-types were distinguished.

(1) At the beginning of transgression phases coarse grained sediments, conglomerate, sand, sandstone, deposited at several places. This thin (some tens of meters thick) layers contain polymict basal breccias made up of metamorphic and carbonate clasts, coarse-grained sand and silt, clay marl, with sandstone beds. These layers can be considered as porous thermal water reservoirs, with usually direct hydraulic connection to the basement reservoirs (Figure 4).

(2) The most important Miocene thermal water aquifers are the widespread Badenian and the Sarmathian shallow-marine clastic carbonates consisting of coarse to fine clastics at the base grading into massive and / or ooidic, biogenic limestone on basinal highs with intercalations of mollusc-bearing calcareous sandstones, which is passing into detrital limestones basinwards. The thickness of the Badenian units varies between 10-60 meters, while that of the Sarmathian ones between 50-120 meters. They are considered as reservoirs with double porosity (Figure 4).

(3) There are some known Miocene reservoirs (aquifers with operating wells), where the lithology of the screened interval cannot be identified due to missing geological information from well documentation, therefore these are displayed as "non-classified" (Figure 4).

All the above outlined Miocene reservoirs typically occur either on the marginal parts of the basins, or in elevated position on the basement highs, therefore they fall in a subsurface temperature range between 50-100 °C.

Depending on their position, the Miocene reservoirs are generally semi-open, or closed structures regarding recharge conditions. They store different waters depending on the burial depth. Where layers outcrop, the infiltrating Ca-Mg-HCO_3 water type is observed, while towards deeper parts the longer retention time, cation exchange, mixing, dissolved gas and other geochemical processes modify its composition, so Na-HCO_3 to Na-Cl types prevails and the reservoirs generally have high, sometimes extremely high TDS content. This high dissolved content may cause scaling problems during operations.

Despite the favorable porosity conditions, due to high dissolved content and the relatively small thickness, reinjection can be problematic into these reservoirs.

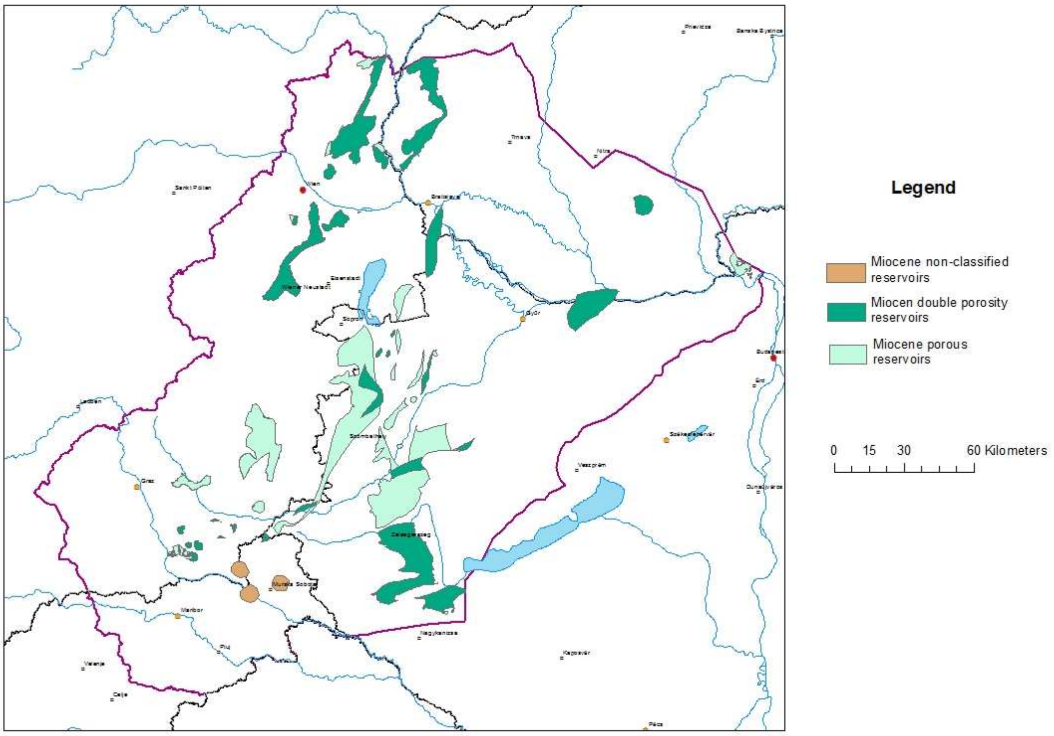

Figure 4: Extent of different sub-types of potential Miocene reservoirs, all in temperature range between 50 and 100 °C

3.3.3. Basement fractured crystalline reservoirs

The area shows complicated geological structure of the basement (Maros et al. 2012), which belongs mostly to the ALCAPA major tectonic unit (East Alpine-Central Western Carpathian-North Pannonian lithospheric segment). On the west, the basement is composed of Palaeo- and Mesozoic crystalline and sedimentary sequences belonging to the Lower to Upper Austroalpine nappe units, and the Penninic unit. In the north, the basement units belong to the Central Western Carpathians nappe system. The geological formations of the Austroalpine and Western Carpathian nappes mainly consist of crystalline sequences, with multiphase, medium grade amphibolite facies metamorfites and paleozoic-mezozoic cover on them. On the southeast the geological units of the basement belong to the Transdanubian Range unit and subsequently the inner and outer Dinaric related units. In several areas a number of Alpine and older metamorphic phases can be detected, while other areas are non-metamorphic.

From the structural point of view, the basement crystalline rocks are arranged into nappes and thrust sheets, separated and cross-cut by strike slip structures and normal faults, displaying a complicated structure. Along the major fault-zones in the basement, there is a possibility to explore high temperature and high-pressure mixed steam-fluid systems which are originated from bigger depth (>3000 m).

From hydrogeological point of view the crystalline basement formations are considered to be aquicludes. Nevertheless, locally they can form fractured aquifer systems, especially the weathered upper 50 m of the basement. The locations of these aquifers are very uncertain, and can be further specified only with detailed geophysical methods. Considering this uncertainty, the entire crystalline basement with temperature higher than 50°C is handled as potential reservoir. Due to the great depths of the basement, the temperature of the basement exceeds 50 °C in most of the regions beneath all Neogene sub-basins. The zone of 50-100 °C temperature interval is surrounding the deep basins and separates the Danube Basin from the Mura-Zala Basin. The regions where temperature exceeds 100 °C at the surface of the basement have great extension too in the central parts of the basins. Areas where temperature of the basement exceeds 150 °C are restricted to the basin interiors (Figure 55).

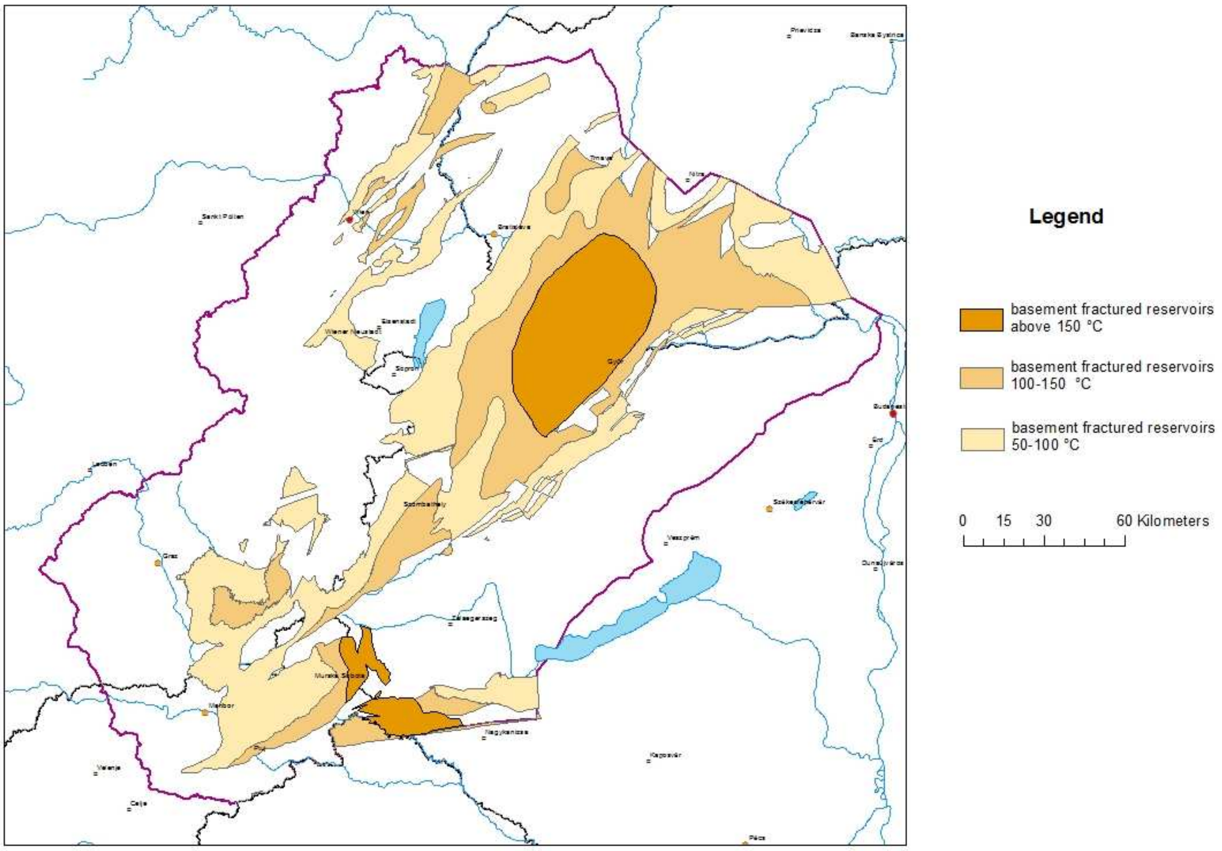

Figure 5: Extent of the fractured crystalline basement potential reservoirs displaying different temperature categories

Usually the fractured crystalline basement reservoirs are closed structures with restricted-, or without recharge, therefore the chemical composition of the geothermal fluids are expected to have high salinity and rather NaCl type (fossil waters). However the scattered hydrogeochemical data do not allow a more detailed characterization. Re-injection is feasible into these reservoirs, where the density of fractures and their hydraulic conductivity is sufficient.

3.3.4. Basement fractured carbonate reservoirs (partly karstified)

The non-metamorphic, Mesozoic formations of the ALCAPA nappe system and the carbonate formations of Graz Palaeozoic can be considered as fractured carbonate reservoirs. They occur in the Austroalpine nappe series in the basement of the Vienna Basin, in the Graz Palaeozoic (basement of Styrian Basin), and in the basement on the area of the Transdanubian Range Unit. They are fractured aquifers with different magnitude of permeability. Where the carbonate sequences could have been karstified during their geological evolution (especially the upper zone of the formations) permeability can be higher and form good to excellent aquifers / reservoirs.

Depending on the location, the temperature of these fractured carbonate basement rocks can be classified into 50-100 °C, can exceed 100 °C, rarely 150 °C (Figure 56).

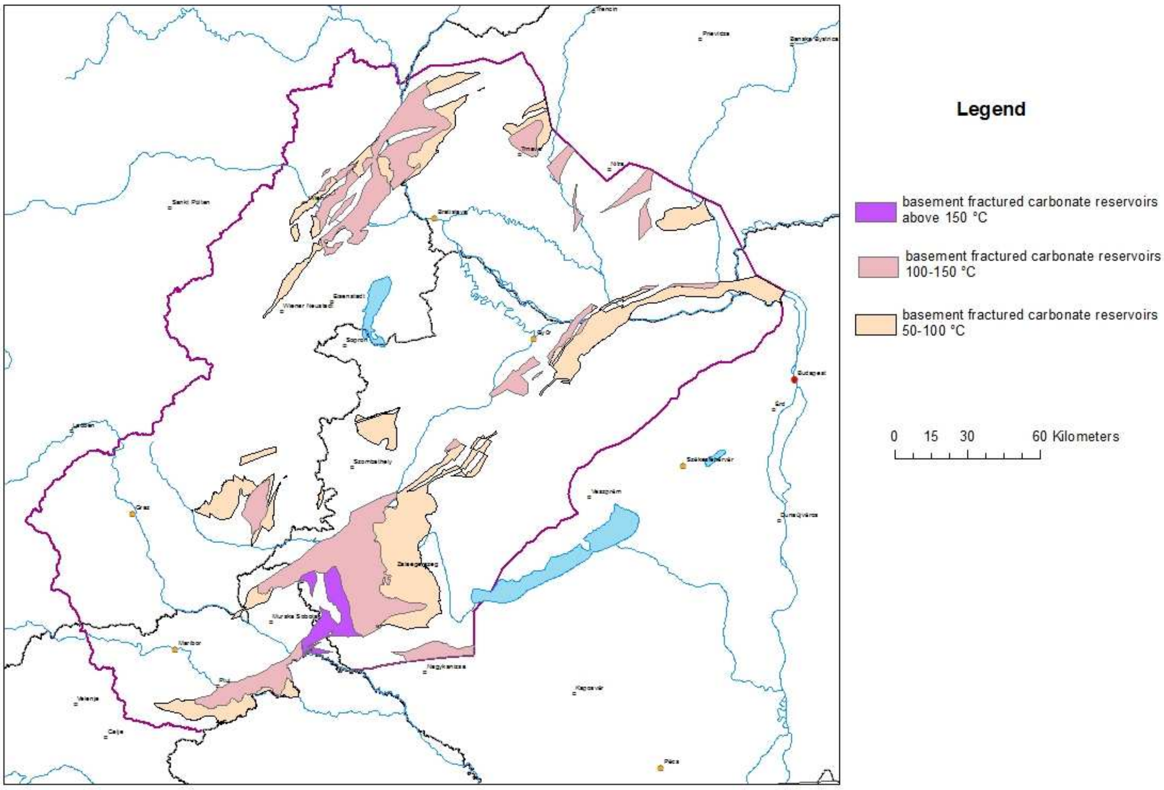

Figure 6: Extent of the potential fractured carbonate basement reservoirs displaying different temperature categories

The chemical composition of the basement carbonate reservoirs depends on the possible recharge. The Mesozoic carbonates of the southern part of the Vienna Basin and the carbonate formations of the Transdanubian Range have low TDS content, because they have direct connection to the surface outcrops (direct recharge). The hydrogeochemical nature of these waters generally show a mixture of low salinity Ca-Mg-HCO_3 character related to the infiltrating cold karstwaters. In addition Na-HCO_3 to Na-Cl types may also occur depending on the connection to other reservoirs or their isolation from the regional groundwater flow system. The carbonate sequences at northern part of the Vienna Basin usually form closed reservoirs without recharge. Their chemical composition can be characterized with high TDS content. Due to the lack of recharge, their sustainable utilization is possible only with well doublets.

Re-injection is feasible into these reservoirs, where the density of fractures and their hydraulic conductivity is sufficient. The best opportunities for re-injection are on those areas, where the carbonates are highly karstified and fluids have low TDS content.

4. Summary

Following the term of geothermal reservoir, different reservoir types were specified in the TRANSENERGY project area. Considering geological, hydrogeological and geothermal conditions, the potential parts of the subsurface according to selection criteria were outlined as reservoirs, their top surfaces were delineated. A short characterization of the main reservoirs was also provided.

The outlined reservoirs refer to the potential part of the subsurface at a supra-regional scale, which are suitable for further detailed evaluation of their geothermal resources. This will contribute to the more detailed geothermal modelling of the pilot areas. Site selection for specific geothermal utilization needs more detailed data and further specifications.

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