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Transboundary geothermal energy resources of Slovenia, Austria, Hungary and Slovakia (TRANSENERGY) – contributions to integrated resource management policies and regional development

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ABSTRACT

The Pannonian Basin has outstanding geothermal potential. Its hydrogeothermal resources are widely utilized by the countries of the Central Europe region. Due to the geographical-geological setting, much of these reservoirs are in transboundary regions, therefore exploitation might unfavorably impact the adjacent regions in the neighbouring countries.

TRANSENERGY project aims to provide a “good example” case study, how a sustainable resource management system can be set up for transboundary thermal water aquifers, where both the protection of the resources and their enhanced utilization are considered taking into account sustainability criteria. There is a growing number of different types of utilization (balneology, direct-heat) in the region, and a rapid growth is forecasted in the coming years (especially related to CHP), so it essential to get a profound knowledge on the available resources and reserves, impacts of exploitation, and a better understanding of the interactions of the different utilization schemes in order to avoid potential conflicts and set up priorities, if necessary. The developed problem-oriented approach of TRANSENERGY focusing on the needs of decision-makers might be applied in other regions in Europe, thus helping countries to reach their NREAP targets without threatening environmental targets and/or interests of their neighboring regions.

1. INTRODUCTION

The TRANSENERGY project - running in the frame of the Central Europe Program between 2010 and 2013 - aims to support a harmonized and integrated thermal groundwater and geothermal energy utilization management among Hungary, Slovenia, Austria and Slovakia, and as such, provide good example for other regions in Europe sharing trans-boundary hydrogeothermal resources. The Pannonian Basin is well-known of its good geothermal potential due to the favorable geological setting and being rich in thermal water, which is widely used for balneological purposes, as well as for direct heat. The intensive exploitation of the reservoirs, combined with the current insufficient re-injection practice may threat the long-term productivity of these aquifers. Due to the geographical-geological setting, much of the large thermal water aquifers are shared by neighboring countries, therefore unfavorable effects of exploitation (e.g. drop of temperature, yield) might be exposed in the adjacent regions, leading to potential conflicts among the countries.

In Hungary, Slovenia, Slovakia and Austria geothermal resources are under the competence of the water management/environmental protection and energy/mining sectors. This shared regulation also reflects the different approaches of the two segments: the protection-oriented approach of groundwater management policies (related to Water Framework Directive) often conflicts with the goals of the energy and mining sectors having the enhanced utilization of the resources in focus, shown also by the ambitious RES targets which envision a rather significant growth in geothermal by 2020 in all four countries.

The lack of rational compromises leads to discrepancies in the regulatory framework and may hold back the development of geothermal projects. This situation is even more complex when comparing national policies: different legislative and financial incentives may provide diverse environment in the different countries and possibly create more favorable conditions for investors to exploit the same trans-boundary resource “at the other side of the border”.

TRANSENERGY project aims to provide a “good example” case study, how a sustainable resource management system can be set up for hydrogeothermal resources shared by several countries, where both the protection and the potentially enhanced utilization of the aquifers are considered, as well as national interests and special characters of different types of uses (balneology, direct-heat, CHP).

In this paper we present the problem-oriented approach methodology of TRANSENERGY targeting the needs of policy-makers / authorities dealing with the management of hydrogeothermal resources, as well as some results related to the delineation and characterization of reservoirs of the region.

2. TRANSENERGY SUDY AREAS AND THEIR HYDROGEOTHERMAL SYSTEMS

At the very beginning of the project a two-step working method was established (Rotár-Szalkai et al 2010): understanding first the geological, hydrogeological and geothermal conditions at a large scale (i.e. “supra-regional” models covering the entire project area at 1: 500 000 scale), followed by more detailed studies at selected cross-border pilot areas at 1: 200 000 scales (Fig. 1).

Figure 1: The supra regional area (red line) of TRANSENERGY encompasses the W-ern part of the Pannonian Basin. Detailed studies are performed on five selected cross-border pilot areas.

2.1. Supra-regional area

The TRANSENERGY project encompasses the W-ern part of the Pannonian Basin. The project area has been delineated by considering the boundaries of the most important geological units and tectonic structures, the recharge areas supplying the thermal water system, the rivers as main discharges and the groundwater divides. The outlined territory (47 700 km^2) is mainly a lowland area with some smaller hilly regions, surrounded by the Eastern Alps and Northern Calcareous Alps at the NW, the Carpathians on the N, the Transdanubian Central Range in Hungary in the SE, and the Kozjak, Pohorje and Haloze Mountains in Slovenia in the SW. The largest lowland area is the Danube basin on the N-ern part of the project area, shared by Slovakia and Hungary, which is divided from the Vienna basin by the Leitha Mountains and the Little Carpathians. The area of the Vienna basin is divided between Austria and Slovakia. On the SW-ern part there are two important basins: the Styrian basin shared by Slovenia and Austria, and the Mura-Zala basin located in areas of Slovenia and Hungary. Two capitals of the partner countries lie within the project area: Vienna and Bratislava, but there are several populated cities, too, such as Győr, Graz, Maribor.

In geological terms the “supra-regional area” can be divided into two main parts (Fig. 2). The Alpine-Carpathian orogene (1) shows a complicated geological structure. The outcropping mountain regions, as well as their subsided parts forming the basement of the large sedimentary basins are built up of metamorphic and non-metamorphic Palaeo- and Mesozoic crystalline and sedimentary sequences. They have a complex structural pattern too, arranged into nappes along thrust sheets, dissected by strike-slip and normal faults. In the basement these rocks represent fractured-karstified reservoirs at a depth of 2000, or below, often cross-cutting political borders.

The intramontane basins (2) compromise the Palaeogene basins that evolved as a consequence of the compressional stress-field of the Alpine collision (the Flysch basins, the Gosau basins and the Inner Carpathian Paleogene Basin) as well as the Neogene basins (Vienna basin, Danube basin, Styrian basin, Zala basin, Mura-Dráva basin and the Neogene basins that formed during the Late Miocene-Pliocene („Pannonian basin”). These basins all have a wide range of sedimentary infill sequence: deep water cyclic turbidites, rhythmic coarse sand, conglomerate and sand, fine grained aleurite with marl intercalations (flysch deposits), shallow marine carbonates and paralic coal-bearing layers, sandy-clayey lagoon sediments, deep water sandy-clay marl, delta-front sand bodies, delta plain-to alluvial plain sandy-clayey sequences. These large sedimentary successions, often several thousand meters thick, comprise significant porous aquifers, the most widespread are the Late Miocene-Pliocene (“Upper Pannonian”) ones which are shared by all TRANSENERGY countries (Fig. 2).

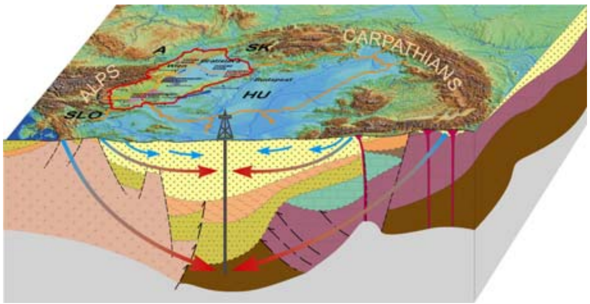

Figure 2: Sketch of the geological structure, main reservoir types and regional flow systems of the Pannonian Basin. TRANSENERGY area is contoured by red line.

The regional thermal groundwater flow system of the TRANSENERGY supra-regional area is linked to the geological structures, thus in many cases crosses country borders. It is controlled by the considerable hydraulic potential between the recharge and discharge areas (i.e. surrounding mountain chains and low-lying basin), sufficient recharge (precipitation) and extensive deep-lying permeable formations outrcropping on large areas. The regional flow system has two sub-systems (Tóth et al. 2012). One is related to the deep-seated fractured-karstified basement rocks that is supplied from the mountainous recharge areas. These flows might also feed the overlying porous sedimentary aquifers, otherwise they are separated. Some deep-seated, isolated basement reservoirs might also exist that do not have direct hydraulic connection to the surface, containing stagnant thermal groundwater with higher temperature and salinity with rather NaCl type (fossil waters).

The other major sub-system operates in the porous sediments of the Neogene sub-basins and is divided to an upper gravity-driven part and a deeper part, where stagnant fossil, confined groundwaters are found. The regional gravity-driven groundwater flow system of the porous aquifers collects heat from a large subsurface area and is mainly hosted by the delta-front and the delta-plain facies sandy units of the Mio-Pliocene sedimentary sequence at a depth range between 1000-2000 m. Under favourable conditions the sandy aquifer units are outcropping on the hilly areas with a higher hydraulic potential, therefore providing a fairly quick and direct recharge. This Mio-Pliocene sedimentary succession is characterized by a frequent alternation of sand-silt-clay layers. Although the permeability of the clayey-marly strata is 1-2 magnitude lower than that of the sands, this is still enough to provide hydraulic connection between the sandy units, thus make the entire sedimentary succession one hydrostratigraphic unit.

Regarding the geothermal conditions of the TRANSENRGY project area, it does not comprise the hottest areas of the Pannonian Basin. Nevertheless the overall geothermal potential is good in many parts (e.g. Mura-Zala and Styrian basins in the SW, Vienna basin, northern part of Danube basin), where heat-flow is up to 110-130 mW/m^2 and geothermal gradient can be as much as 45 °C/km.

2.2. Cross-border pilot areas and their utilization conflicts

Within the "supra-regional" project area five cross-border pilot areas (Fig. 1) have been selected for more detailed studies. In these transboundary pilot areas there are already existing utilization conflicts and they are extremely sensitivity for any further intervention by different management policies in the neighboring countries. The Slovenian–Austrian–Hungarian cross border pilot area (*Bad Radkersburg – Hodoš*) includes territories of the Styrian and Mura-Zala basins where thermal groundwaters are widely utilized. However unharmonized management strategies between the different utilization schemes (direct heat and balneology) led to unnecessarily excessive use of thermal waters, also including transboundary conflicts between Austria and Slovenia. A similar cross-border utilization conflict exists in the *Lutzmannsburg – Zsira* pilot area. The abstraction of thermal water for a recently built large spa in Lutzmannsburg (Austria) next to the border resulted in a continuously decreasing groundwater level on the Hungarian side, where some well-known spas are also known (Bük, Sárvár). The northern part of the *Vienna basin* is one of the most important hydrocarbon exploitation areas in Central Europe, therefore an ideal site to study links and potential conflicts between the multi-purpose utilization of the same reservoirs, in collaboration with Austria and Slovakia. The *Danube basin* pilot area provides excellent opportunities to establish closer links with groundwater management issues at international level, as in this region aggregated groundwater bodies, also storing large amount of thermal water have been already delineated at ICPDR level. The *Komarno–Sturovo* pilot area is a typical karstic transboundary aquifer shared by Slovakia and Hungary. The Hungarian part of this area was seriously affected by karstwater withdrawal due to bauxite and coal mining in the 1980-90's, when the depression of karstwater level led to the drying of many lukewarm springs. After mines were closed and withdrawal finished, the rehabilitation started in the region.

3. "WHAT TO WHOM?" - TARGETED STAKEHOLDERS OF TRANSENERGY AND THEIR EXPECTED NEEDS

Select the targeted stakeholder groups, identify their needs, focus project work according to these recognized demands and finally communicate results "in the language" they speak is the right method to maximize impacts of any projects. Each potential target group has different interests and demands, which were overviewed at the beginning of TRANSENERGY (Table 1).

Although TRANSENERGY's results contribute to some extent to almost all stakeholder groups, the project work has been conducted in a way from the very beginning that it should provide information to the *decision makers and authorities*, as primary target group. The reasons were multi-folded. The project partners are experts of the national geological surveys of the four participating countries, and as such, their organizations' mission is to provide the governments and decision makers comprehensive and impartial geoscientific information, support policy making related to the sustainable management of the environment and its resources.

Stakeholder group	Identified needs
Decision makers (ministries, authorities, governmental bodies), also at EU level (e.g. DG Energy, DR Regio, ICPDR)	-clear overview at a national/macro-regional scale on the current utilization schemes and its impacts, based on reliable data -expert-based information on the limits of an enhanced use of thermal waters and its impacts -concise thematic expert summaries supporting preparation of policy documents
Companies developing geothermal projects	-information on the geothermal potential at a regional-scale, including technical facilities -information on the current regulatory and financial environment
Users (present and potential, including municipalities)	-information on the targeted reservoir properties and limits on their sustainable use -transparent and reliable regulatory framework -short and easy licensing procedures
Project investors, financing institutions	-financial supporting schemes -viability and risks management of the projects
Academia (universities, research organizations, scientific / expert associations)	-up-to-date high-level scientific data, -interpretations, models
Education (universities, high-school)	-training materials at various levels
Wider public	-increase awareness of geothermal

Table 1: Stakeholder groups and their needs in TRANSENERGY project with highlighting the primarily addressed decision makers

A reason for focusing on complex regional evaluations instead of site-specific investigations is that all geological surveys are responsible for the systematic acquisition, interpretation, management and dissemination of geoscientific data of their country's landmass. Therefore by handling national geoscientific databases, they are qualified to provide scientifically based models and evaluations at national and macro-regional scales independent of sectorial/users interest. Consequently TRANSENERGY aims to give a regional overview on the geothermal potential of the selected study areas, provide recommendations on their sustainable utilization with a special attention to transboundary effects, based on firmly-grounded geoscientific models. It also implies that the resolution of the applied models does not allow more detailed local potential/reservoir assessments, e.g. plan drilling locations. This was also a reason why geothermal project developers were not among the primary target group.

After selecting decision-makers, as the main stakeholders, the next step was to identify in details what kind of information would assist their every-day work in preparing policy documents, strategies for a more efficient and sustainable management of thermal groundwater resources both from a "water"" and an "energetic" aspect, effective licensing, etc. with special regard to transboundary issues (Table 2).

It became clear that most of the addressed questions can be answered on the basis of the combined interpretation of results of geological, hydrogeological and geothermal models, which thus became the principal activity of the project. However these models can be based on harmonized datasets from the four countries, therefore establishment of a joint, multi-lingual database was one of the key-activities and core outputs of TRANSENERGY.

Although TRANSENERGY team experts are mostly geoscientists, they have been aware that for the development of the geothermal sectors in the region, favorable resource conditions are needed, however not yet enough. A reliable and transparent regulatory framework, financial incentives are also essential. Therefore a special emphasize was also put on the evaluation of the non-technical barriers, too, i.e. on the overview and gap identification of the regulatory and financial framework, as well as on the summary and comparison of the current groundwater management and renewable energy policies.

4. STATE-OF-THE ART OF THERMAL WATER UTILIZATION

Getting a clear picture on the current state of utilization of thermal water is indispensable for decision-makers, and was also the key starting point for other TRANSENERGY activities. The extensive research (Rman 2011, Rman et al. 2012) identified 148 active and 65 potential geothermal energy users with 401 geothermal objects. 307 active wells produced above 30 million m^3 of thermal water in 2009 (no data from Austria due to confidentiality reasons). The abstracted amount is constantly rising. Thermal water typically represents low-enthalpy geothermal resources, the majority of the wells have outflow temperature between 20 and 60 °C (Fig. 3), mostly used for balneological purposes. Individual space and district heating, sanitary water, greenhouse heating is applied in Slovakia and Slovenia. Unfortunately re-injection is not a common practice, only two periodical reinjection systems operate in

General information required	Tool for answer	Specific questions that can be answered
Basic information		
general geological framework	geological model	-Where and which depth are the most important potential reservoirs?
main hydrodstartigraphic units and their hydraulic parameters	hydrogeological model	-In which depth thermal water is? -What is the relation between the cold- and the thermal flow systems? -How much thermal water can be abstracted which has natural recharge (i.e. quantify free water resource)? -What is the current quantitative and qualitative status of the aquifers?
recharge and discharge zones, subsurface hydraulic potential field and flow directions		
groundwater budgets		
chemical composition of thermal water	hydrogeochemical investigations	Are there any gases, or dissolved content which might restrict utilization (scaling, corrosion)? Or contrary make them valuable as medicinal waters? -Can associated gases be utilized? -Is water treatment necessary?
subsurface temperature distribution	geothermal model	-What is the temperature at certain depths? -How much heat is stored/available?
geothermal resources, reserves		
Information related to thermal water aquifers/reservoirs and their utilization		
state-of-the art of utilization	questionnaires, field inspection, reporting users	-What is the abstraction history in the region? -What are the main types of utilization? Are there any conflicts among them? -What are the priorities of future utilization schemes? -What are the lessons learned from good/bad practices?
distribution of potential hydrogeothermal reservoirs	combined interpretation of geological, hydrogeological and geothermal model outputs	-Where are the potential reservoirs? -How deep one has to drill to hit a reservoir?
characterization of reservoirs	combined interpretation of geological, hydrogeological and geothermal model outputs	-Which areas are perspective/can be excluded for direct heat / CHP / balneology projects? -What are the limits of abstraction? -What is the interaction between the different reservoirs? -What kind of changes can be observed in the reservoirs and their reasons? (potential, temperature, hydrogeochemistry, etc) -Are there any overpressured zones which might imply risks?
monitoring	assessment of results of hydrogeological model, overview of current practices	-What type of information can be gained from the measurements of the existing monitoring wells? -Are they representative? -Is it necessary to expand the existing monitoring? If yes how?
re-injection	combined interpretation of geological, hydrogeological and geothermal model outputs	-Is reinjection necessary to maintain a sustainable production level at a given utilization? -Are there any alternatives and what are their impacts? -What are the technical aspects of re-injections into different types of reservoirs?

Table 2: Most often addressed management / licensing-related questions from authorities/decision-makers dealing with thermal groundwaters / geothermal energy resources in the TRANSENERGY region.

Mesozoic carbonates in Podhájska (Slovakia) and Upper Pannonian sands in Lendava (Slovenia). Drinking and industrial water as well as agricultural use are common in Hungary. Thermal water with outflow temperature of 109°C is the hottest known in the area, which is discharging from a Paleozoic carbonate reservoir and is used for electricity production in Bad Blumau (Austria) with constant reinjection.

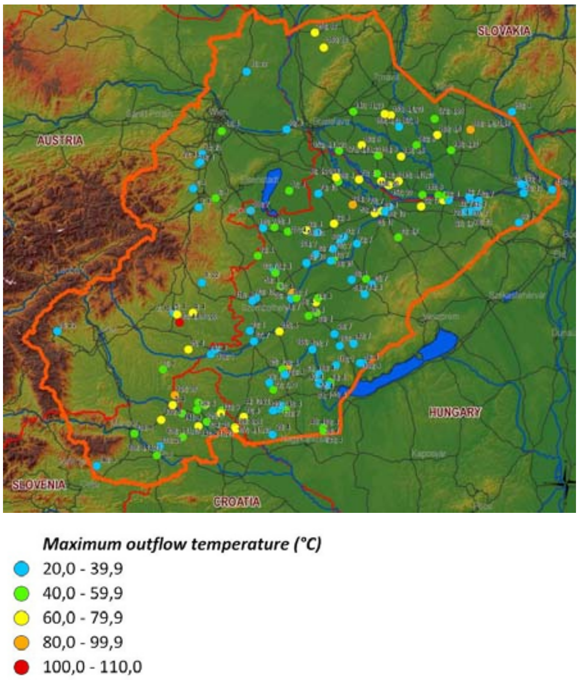

Figure 3: Identified thermal water users in TRANSENERGY project area showing outflow temperatures of the wells.

Summary evaluation of utilization is visualized on 16 interactive maps available under the web-map service of the project website (http://transenergy-eu.geologie.ac.at).

5. THE JOINT GEOTHERMAL DATABASE OF TRANSENERGY

The different geological, hydrogeological and geothermal models needed data input in the form of uniform and harmonized datasets. The established joint, multi-lingual expert database (Mikita et al. 2011) contains tens of thousands of data records from 1686 boreholes (Fig. 4) in the four countries, organized into 483 parameters and 11 major parameter groups including technical, geological, hydrogeological, geothermal and hydrogeochemical data.

In addition to provide experts by high-quality data, TRANSENERGY also aimed to make the key parameters of boreholes publicly available (considering confidentiality issues). Nearly 100 000 records regarding the key geological, hydrogeological, geothermal and hydrogeochemical properties from 1041 boreholes (AT-115, SI-128, HU-742, SK-56) were made freely accessible at the project website (http://transenergy-eu.geologie.ac.at). This public database also significantly contributes to the work of authorities, decision-makers, as they can check on-line the most important parameters of boreholes in the targeted regions.

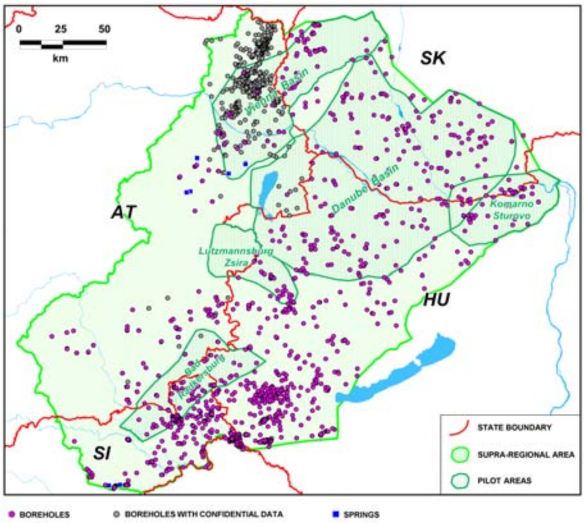

Figure 4: Distribution of boreholes of TRANSENERGY borehole database

6. GEOLOGICAL, HYDROGEOLOGICAL AND GEOTHERMAL MODELS

Geological, hydrogeological and geothermal models served the basis for getting answers on a firm geoscientific basis to most of the relevant questions the project addressed (Table 2). Modeling was performed at the entire project area and in the five trans-boundary pilot areas, too (Rotár-Szalkai et al. 2013).

The geological models (Maros et al. 2012) provided the bounding surfaces (base maps) of the main hydrostratigraphic units (altogether 8 horizons at the supra-regional scale), also showing their geology based on a harmonized legend. Correlation of several hundred individual geological formations in the four countries and establishing a joint, harmonized legend for all geological horizons composed of 219 elements was a major achievement contributing to the common understanding of the geological framework. The most important tectonic elements controlling groundwater flow systems were also determined, more in details for the pilot areas.

The numerical hydrogeological model (Tóth et al. 2012) quantified the potential fields, flow paths, scenarios for different drawdowns, as well as water budgets between the main aquifers.

The geothermal model (Goetzl et al. 2012) provided map series for heat-flow density, subsurface temperature distribution as well as calculations for heat in place and specific identified resources.

7. IDENTIFIED RESERVOIRS, THEIR CHARACTERIZATION AND POTENTIAL USE

Based on the integrated interpretation of model results, the most important hydrogeothermal reservoirs were outlined and characterized (Rotár-Szalkai et al. 2012) which are the main objects for phrasing recommendations for their sustainable utilization in the future, taking into account achieving and maintaining their good status (Water Framework Directive) and increasing the utilization of the energy-content of the thermal waters they store (NREAP targets).

Applying the definition of a geothermal reservoirs ("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" – Grant and Bixley 2011) to the geological conditions of the TRANSENERGY area, permeable rock volumes having a temperature higher than 50 °C were considered as geothermal reservoirs. To be able to provide a simple and transparent characterization for the decision-makers, three major reservoir categories were established based on the geological and hydrogeological properties of the rock units:

1) Upper Pannonian (i.e. Uppermost Miocene-Pliocene) porous reservoirs,
2) Miocene (i.e. Sarmatian, Karpatian, Badenian and Ottnangian) reservoirs (with 3 sub-types: porous, double-porosity, non-classified),
3) Basement fractured crystalline and carbonate (partly karstified) reservoirs.

The top surfaces of the reservoirs were constructed by combining the different geological horizons, isotherm surfaces, and hydrogeological characterization of the different geological formations.

The outlined *Upper Pannonian porous reservoirs* with a temperature range of 50-100 °C are the most widespread, ranging from the Danube basin to the Mura-Zala basin, crosscut by political borders (Fig. 5). These aquifers 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. 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. However based on the differences of water chemistry, this large reservoir unit was subdivided into 4 sub-categories with the highest total dissolved content on its northern part and the most dilute waters on the south (Fig. 6).

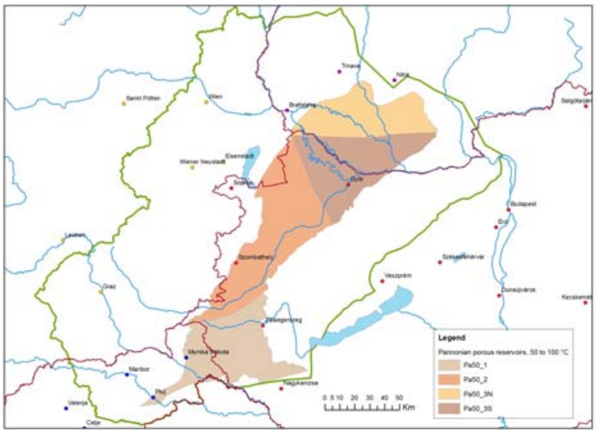

Fig. 5 Distribution of the Upper Pannonian porous reservoirs with a temperature range of 50-100 °C with different sub-categories related to chemical composition of stored thermal groundwater

These reservoirs can be potentially used for direct-heat purposes and balneology, the high total dissolved content can be a restricting factor.

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 precise mechanisms which determine injectivity are site specific, and processes are not entirely understood yet, therefore research and development is necessary before applications.

Upper Pannonian porous reservoirs above 100 °C occur in a much smaller region: the central part of the Danube Basin and in a small area in the Mura-Zala Basin in Slovenia, close to the Croatian border. As a consequence of the bigger depth, this reservoir is already partly separated from the regional gravitational flow system. The higher temperature makes it suitable also for combined heat and power applications, however restrictions of re-injection are similar as described above.

The identified *Miocene reservoirs* typically displayed a scatterd distribution occurring either on the marginal parts of the basins, or in elevated position on the basement highs (Fig. 6). Based on the geological and hydrogeological properties of the Miocene formations, 3 sub-types were distinguished.

(1) Coarse grained sediments, conglomerates, sands, sandstones, deposited at several places in small (some tens of meters) thickness form porous thermal water aquifers, with usually direct hydraulic connection to the fractured basement reservoirs.

(2) The most important Miocene thermal water reservoirs are the widespread Badenian and the Sarmathian shallow-marine clastic carbonates with a few tens of meters thickness, which are passing into detrital limestones basinwards. They are considered as reservoirs with double porosity and also often have direct hydraulic connection to the fractured basement reservoirs.

(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".

The depth of the different Miocene reservoirs show a wide range depending on their local geological settings.

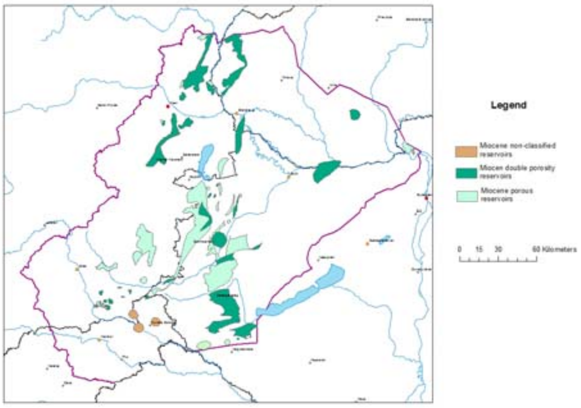

Figure 6: Extent of different sub-types of potential Miocene reservoirs

Depending on their position, the Miocene reservoirs are generally semi-open, or closed structures regarding their hydraulic connections. They store different types of groundwater 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 prevail and the reservoirs generally have high, sometimes extremely high TDS content, which may cause scaling problems during operations.

Despite the favorable porosity conditions, the high dissolved content and the relatively small thickness put a limit on the wide-range utilization of the Miocene reservoirs, furthermore re-injection can be also problematic. Nevertheless, balneological and direct-heat utilizations are feasible at certain locations with favorable settings, as well as combined heat and power in areas where temperature is above 100°C and reservoirs have a direct hydraulic connection to the fractured basement rocks.

The *fractured basement reservoirs* were subdivided into two main sub-categories: crystalline and (partly karstified) carbonates.

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 by detailed geophysical methods. Considering this uncertainty, the entire crystalline basement with temperature higher than 50°C was outlined as a potential reservoir, which encompass most of the regions beneath the Neogene sub-basins. Regions where temperature exceeds 100 °C at the surface of the basement also have great extension in the central parts of the basins, while areas having temperature above 150 °C are restricted to the basin interiors (Fig. 7)

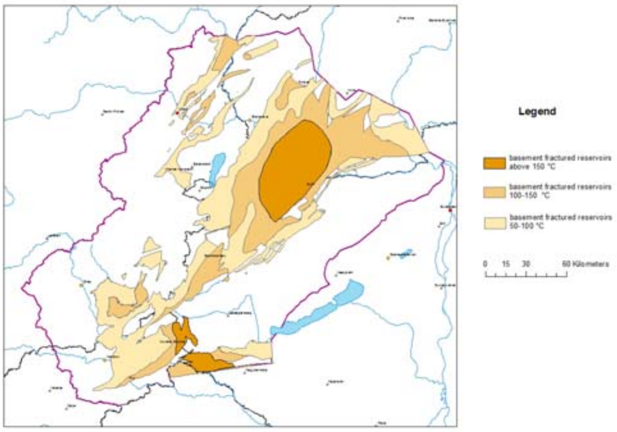

Figure 7: Extent of the potential fractured crystalline basement reservoirs displaying different temperature categories

The fractured crystalline basement reservoirs are usually closed structures with restricted-, or limited connections to the regional flow systems, therefore the chemical composition of the geothermal fluids is expected to have high salinity and rather NaCl type (fossil waters). The reservoirs have a wide range of utilization potentials of direct-heat, combined heat and power and even power generation in parts where temperature may exceed 150 °C, however both production and re-injection is limited to larger fracture zones with increased hydraulic conductivity.

The non-metamorphic, Mesozoic formations and the carbonate units of the Graz Palaeozoic can be considered as potential fractured carbonate reservoirs, which occur in the basement of the Vienna and Styrian basins and in the basement on the area of the Transdanubian Range (Fig. 8). 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 reservoirs.

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

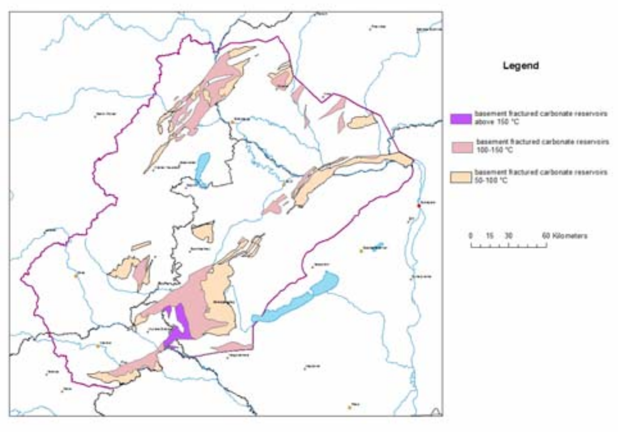

Figure 8: Extent of the potential fractured carbonate basement reservoirs displaying different temperature categories

The chemical composition of the basement carbonate reservoirs depends on their hydraulic connections to the regional flow systems. 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.

Similarly to the crystalline reservoirs, the fractured carbonate reservoirs also have great utilization potentials for direct-heat, combined heat and power and power generation in parts where temperature may exceed 100-150 °C. Nevertheless both production and re-injection is limited to larger fracture zones with increased hydraulic conductivity. The best opportunities are on those areas, where the carbonates are highly karstified and fluids have low TDS content.

8. NON-TECHNICAL BARRIERS

By a systematic comparison of legislation related to geothermal energy utilization (Lapanje and Prestor 2011), current practice in groundwater management (Prestor et al. 2012) and financial framework (Nádor et al. 2013) a set of gaps were identified:

-geothermal resources are owned by the state, except for Austria where it belongs to the land-owner

-geothermal resource management is shared by different ministries in all 4 countries: between “environment/rural development” dealing with abstraction of thermal groundwater and “energy /industry /economics” looking at geothermal energy utilization without water production. The most admissible regulatory framework exists in Austria, where even the energy content of the thermal water is not acknowledged in the legislation, while the most integrated approach exists in Slovakia by having a Geological Act.

-abstraction of thermal water is based everywhere on a water license (water concession in Slovenia), however geothermal concession for deep geothermal (below -2500 m) exists only in Hungary

-an environmental impact assessment for larger power plants, especially if it is on the area of water-, or nature protection is compulsory in all countries

-re-injection of the entire amount of abstracted thermal water for energetic use is compulsory in all countries, however defined in individual water permits in Slovakia. Temperature and chemical thresholds for emitting used thermal water into the surface are strictly regulated everywhere

-monitoring exists everywhere, however there is a great variety in the different national systems, measured parameters and their frequency, types of organizations performing observations and in reporting

-data confidentiality is a major restricting factor in Austria, in the other countries various governmental organizations are responsible for collecting data related to thermal water production and geothermal energy utilization, however uniform national registers do not exits

-although the Water Framework Directive sets up general goals for all member states to achieve and maintain good quality and quantity status of aquifers (including thermal water reservoirs), the execution of the River Basin Management Plans is quite different in the TRANSENERGY countries. The methods of delineating and classifying groundwater bodies also vary a lot: in Hungary it is based on aquifer lithology (porous and karstic) and temperature (above 30 °C considered as thermal); in Slovenia the aquifers are differentiated based on the depth, and no thermal water groundwater bodies are officially identified; in Slovakia there are 3 groups of groundwater bodies also referring to their depth (Quaternary, pre-Quaternary and thermal); in Austria there are “shallow” and “deep” groundwater bodies and there is only one thermal (outside of TRANSENERGY area).

-the available financial support schemes are fairly poor in TRANSENERGY countries: as there is no geothermal-based electricity generation (except for Austria), the sector cannot benefits from the otherwise existing feed-in-tariff / feed-in-premium systems at the moment. Tax incentives exist only in Slovakia. There is no off-take and support-scheme for green-heat in either of the countries. Direct subsidies and loans are restricted and mainly provided to large investors by European banks (EIB, EBRD). Risk insurance does not exist in TRANSENERGY countries. Most of the indirect support schemes are available for Hungary, Slovakia and Slovenia via EU funds (different "energy-related" operative programs financed by the Structural and Cohesion Funds).

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