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1. Geothermal Energy Research in Slovakia and Cooperation on Geothermal Transboundary Project TRANSENERGY

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Abstract. The paper presents a brief overview of 40 years of research in geothermal energy sector in Slovakia and its current geothermal resources bound to 27 delineated areas with documented 141 boreholes on Slovak territory. In the light of merging European policy the transboundary resources (in this case water and geothermal energy) are in future focus. However few projects focused on transboundary geothermal resources were implemented in Central European region so far. The need for complex evaluation of geothermal energy sector was identified by geological surveys and institutions of four countries in the western part of the Pannonian Basin. The project TRANSENERGY - Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia was focused on harmonized geoscientific evaluation of the geological environment, coupled by geothermic and hydraulic models. The project was rather complex including issues of utilization of geothermal water, the analysis of legislative and management differences along with proposal for future harmonized evaluation of management in project partner countries. The results and the outputs were summarized in relevant reports that are accessible on the project web site (http://transenergy-eu.geologie.ac.at). Results of the project covered stakeholder needs as well, by relevant information accessible through web map application (http://www.arcgis.com/home/webmap).

Keywords: Slovakia, transnational cooperation, transboundary aquifer, geothermal energy, thermal water, groundwater

1.1. Introduction

The EU aims to get 20% of its energy from renewable sources by 2020 (2009/28/EC Directive on the promotion of the use of energy from renewable sources). Renewables include biomass, solar, geothermal energy, wind, as well as hydro-electric generation of energy. More renewable energy will enable the EU to cut greenhouse emissions and make it less dependent on imported energy, which nowadays becomes very important task for future. On the other hand boosting the renewables industry encourages technological innovations and employment. To fulfil the EU aims 20-20-20, the cooperation of European countries is needed on transnational level through common understanding the different attitudes applied in neighbouring countries, knowledge transfer, coordinated evaluation of the technology applied, and the best possible solution to be implemented.

Geothermal energy, as one of the renewable sources, is thermal energy generated and stored in the Earth that originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%) (Turcotte & Schubert, 2002). The adjective geothermal originates from the Greek roots γη (ge), meaning earth, and θερμος (thermos), meaning hot. Geothermal gradient is the rate of increasing temperature with respect to increasing depth in the Earth's interior. Away from tectonic plate boundaries, it is about 25 °C per km of depth in most of the world (Fridleifsson et al., 2008). In comparison thermal gradient in Slovak part of the Danube Basin is documented in the range 35.6-43.7 $°C.km^{-1}$ (calculated for depth interval 0-2,500, Franko et al., 1989) and in Hungarian part of the Pannonian Basin more than 50 $°C.km^{-1}$ (Tulinius et al., 2010). This gives the great potential for renewable source utilization.

The Earth's internal thermal energy flows to the surface by conduction at a rate of 44.2 terawatts (TW), (Pollack et al., 1993) and is replenished by radioactive decay of minerals at a rate of 30 TW (Rybach, 2007). These power rates are more than double humanity's current energy consumption from all primary sources, but most of this energy flow is not recoverable. In addition to the internal heat flows, the top layer of the surface to a depth of 10 meters is heated by solar energy during the summer, and releases that energy and cools during the winter.

From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation. Worldwide, 12,013 MWe of geothermal power was online in 24 countries in 2014 (Matek, 2014).

An estimate of the installed thermal power for direct utilization at the end of 2009 in 78 countries was up to 50 GWt. The distribution of thermal energy used by category is approximately 47.2% for ground-source heat pumps, 25.8% for bathing and swimming (including balneology), 14.9% for space heating (of which 85% is for district heating), 5.5% for greenhouses and open ground heating, 2.8% for industrial process heating, 2.7% for aquaculture pond and raceway heating, 0.4% for agricultural drying, 0.5% for snow melting and cooling, and 0.2% for other uses (Lund et al., 2010).

Systematic exploration of geothermal energy in Slovakia began in the early 70s of last century and lasts until today. Within the geothermal research and exploration in the Slovak territory research and exploratory geothermal wells were drilled. After fulfilment of research and geological targets they have become sources of geothermal water for various types of use.

1.2. Overview of geothermal resources in Slovakia

Nappe-folded Mesozoic strata setting, existence of the Tertiary basin, Neogene volcanism, Alpine-type and German-type tectonics along with favourable hydrogeological and geothermal conditions created suitable conditions for the presence and distribution of geothermal water in Slovakia. Geothermal water is connected mostly to the Triassic limestones and dolomites of Carpathian nappe systems, to a smaller extent the Paleogene clastic rocks, Neogene sands, sandstones, conglomerates and the Neogene andesites and pyroclastic. These rocks represent collectors of geothermal water and are found at depths of about 200-5,000 m (excluding spring areas). Reservoir temperature of geothermal water was documented in the range 20-240 °C.

Spatial distribution of hydrogeothermal structures allowed to define 26 prospective areas with potentially available resources of geothermal energy. Recently part of Lučenská kotlina Basin was delineated by Dzúrik et al. (2007). As a more appropriate name of this structure Remšík (2012) proposed the name "Rapovce structure", since according to current knowledge, not the entire basin (Lučenská kotlina Basin) is suitable in terms of geothermal water occurrence, but only a part delineated by authors.

Source of geothermal energy in the Slovak Republic is mostly geothermal water, which was tapped during the geothermal research by prospection or exploratory geothermal wells.

The first overview report summarizing the basic results of 37 research and exploratory geothermal wells was compiled by Franko (1986). The overview of geothermal wells and basic data about them including the utilization, ownership (at that time) is given in "Inventory of geothermal resources and their potential utilization in Slovakia" (Franko et al., 1993). It was the first inventory of geothermal resources.

Summary of the results of the geothermal wells drilled in the years 1971-1994 in Slovakia is delivered by works of Remšík & Fendek (1995) and Fendek et al. (1995). Comprehensive list of geothermal wells with geothermal installations is given in the Atlas of Geothermal Energy of Slovakia (Franko et al., 1995). In this publication was comprehensively evaluated and summarized knowledge gained during more than two decades of geothermal review investigations along with maps and description of geothermal structures. Occurrence of geothermal water in Slovakia in cartographic form is given in map of Geothermal Resources and Mineral Water published in The Landscape Atlas of the Slovak Republic (Fendek et al., 2002).

The list of geothermal energy resources, which are used in different regions of the Slovak Republic, is described in work of Fendek et al. (1999). Overview of geothermal wells taking into account the current state of geothermal water exploration in Slovakia until 2004 work is delivered by work of Fendek et al. (2004). The latest overview of geothermal wells as geothermal water sources in Slovakia along with selected characteristics and parameters is given in Remšík et al. (2011) and Remšík (2012).

The distribution of sources of geothermal water along with the type of geothermal structure is shown on Fig. 1.1. In the course of further geothermal research and exploration new geothermal wells will be added and therefore there is need of ongoing update. Table 1.1 shows a summary data on the geothermal water in Slovakia. Following text gives the basic information of research results (Remšík, 2012):

- wells as sources of geothermal water were drilled in the years 1956-2011, particularly in 1971 to 2011, the wells were research or exploratory geothermal boreholes, hydrogeological or geological boreholes, which tapped the geothermal water to use. Currently there are 141 wells that are exploited for geothermal water utilization (excluding wells used in spas and for medical purposes registered at Ministry of Health;
- depth of the wells is in interval between 64 and 3,616 m;
- screening interval in the borehole that yields geothermal water is located in the depth interval from 11 to 3,390 m under surface;
- geothermal water collectors are the Mesozoic rocks, mainly Triassic limestones and dolomites; and Paleogene clastic rocks (breccias, conglomerates and sandstones) and Neogene sands or gravels, sandstones and conglomerates, in less extent andesites and pyroclastics;
- yield of wells, mainly in case of overflow, is in the range of 1.5 to 100 $l.s^{-1}$; total cumulative yield of geothermal water is 2,084 $l.s^{-1}$;
- geothermal water temperature at the wellhead (on surface) is 18-129 °C;
- heat output from wells is between 0.05 and 29.0 MWt; cumulative amount of geothermal energy thermal power represents 345 MWt;
- TDS of geothermal water ranges from 0.4 to 90.0 $g.l^{-1}$; most values are in the interval of 0.7 to 12.0 $g.l^{-1}$; small part of TDS values reach 20-30 $g.l^{-1}$;
- chemical composition of geothermal water was documented with following types: Ca-Mg-HCO_3, Ca-Mg-HCO_3-SO_4, Ca-Mg-SO_4, Na-HCO_3, Na-HCO_3-Cl and Na-Cl type.

The assessment of geothermal areas also shows that the calculated amount of geothermal power in prospective geothermal areas of Slovakia is approximately 6.2 GWt. In contrast to that the quantity of geothermal power verified by wells (345 MWt) represents only 5.53%. The comparison of the total amount of geothermal power and verified heat power shows that in the area of Slovakia there is still appoximately 5.9 GWt to be verified (Remšík et al., 2011).

1.3. Transboundary geothermal areas in Slovakia

The EU Framework Water Directive is a general legal act oriented towards the sustainable utilization, protection and improvement of the water resources state, sets common approaches and goals for water management in 27

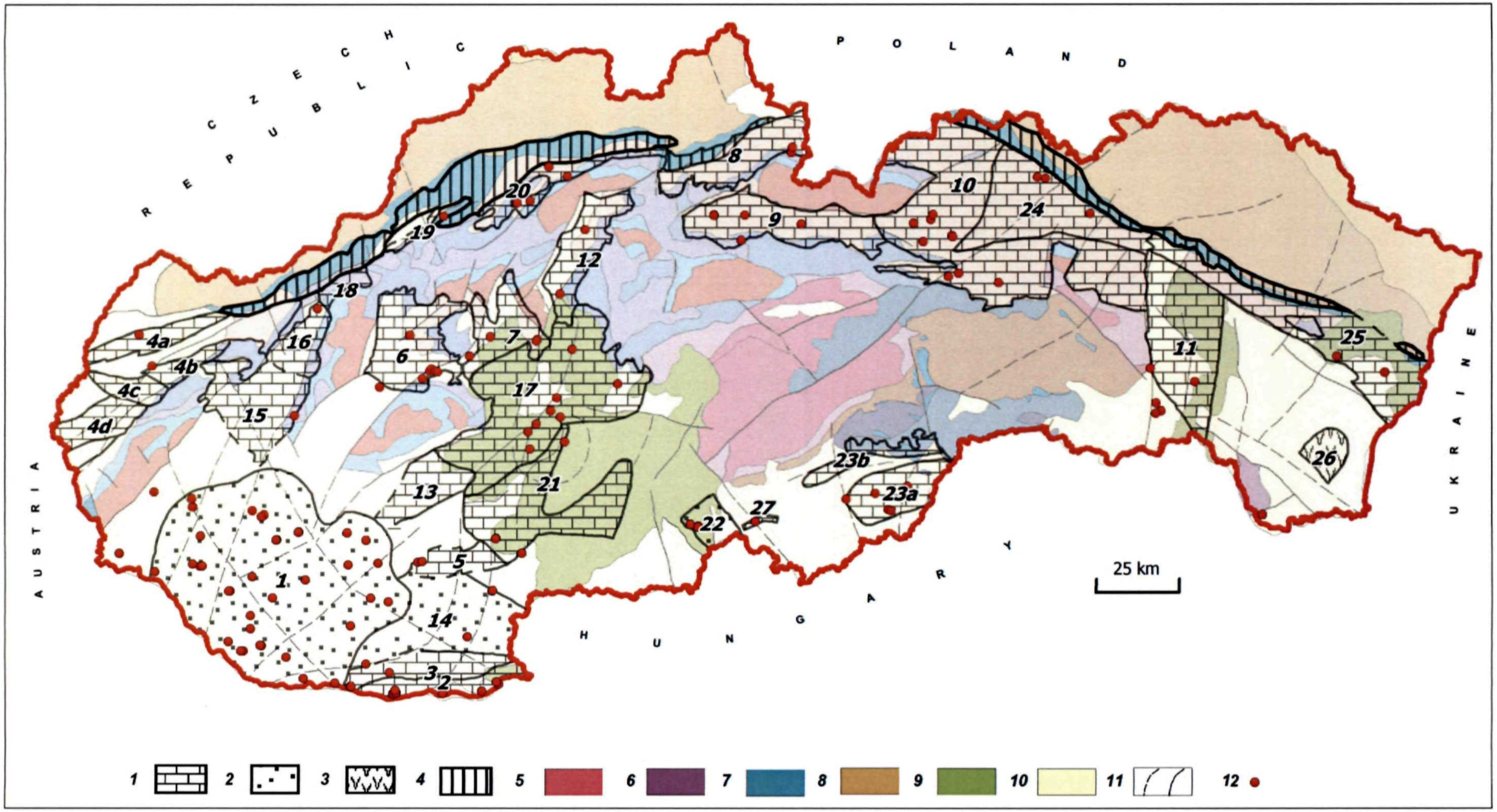

Figure 1.1 Geothermal prospective areas according to Remšík et al., 2011, based on Fendek, et al., 2002, and on geological map Biely et al., 1996
Explanation: (1 - 3 main aquifers of geothermal water) 1 - Triassic carbonates, 2 - Neogene sands, sandstones and conglomerates, 3 - Neogene andesites and related pyroclastics, 4 - Klippen belt, (5-10 geological structures) 5 - Early Paleozoic metapsamites, metapelites, predominantly acid metavolcanic and volcanoclastic rocks, 6 - Late Paleozoic (Crystalline) granitoids and metamorphic rocks, 7 - Mesozoic predominantly carbonate rocks (limestones and dolomites), minor sandstones, claystones, quartzite, 8 - Paleogene sandstones and claystones, 9 - Neogenic volcanic and volcano-clastic rocks, predominantly andesites, 10 - Neogene sandstones and claystones, 11 - main faults,12 - geothermal wells. Numbers of geothermal prospective areas are listed in Table 1.1

Table 1.1 Overview of the geothermal prospective areas and wells in Slovakia (based on Remšík, 2012)

Area nr.	Name of geothermal prospective areas	Code of geothermal water body	Amount of geothermal wells	Depth of wells (m)	Age and lithology of the collectors	Temperature on wellhead (°C)	Total yield of geothermal area ($l.s^{-1}$)	Total thermal power of geothermal area (MW_t)	TDS ($l.s^{-1}$)	Chemical type of geothermal water
1	Danube Basin Central Depression	SK300240PF	45	290-2,800	Dacian - Badenian, sand, sandstone, basal clastic sediments, andesites	18-91	479.7	99.17	0.5-20.1	Na-HCO_3, Na-HCO_3-Cl, Na-Cl-HCO_3 , Na-Cl
2	Komárno High Block	SK300010FK	10	125-1,021	Lias - Triassic, limestones, dolomites	20-40	265.0	17.42	0.7-0.8	Ca-Mg-HCO_3,Ca-Mg-HCO_3-SO_4
3	Komárno Marginal Block	SK300020FK	4	1,184-1,970	Neogene -Triassic, conglomerates, limestones, dolomites	42-64	15.9	2.62	2.2-90.0	mixed type, Na-Cl
4	Vienna Basin (Šaštín, Lakšár, Láb-Malacky elevation, with adjacent sunken belt and Závod-Studienska sunken belt)	SK300030FK	2	2,100-2,605	Eggenburgian, Triassic, clastic sediments, limestones, dolomites	73-78	37.0	9.50	6.8-10.9	Na-Ca-Cl-SO_4, Na-Cl
5	Levice Marginal Block	SK300210FK	2	1,470-1,900	Badenian, Triassic, clastic sediments, limestones, dolomites	69-80	81.0	20.74	19.2-19.6	Na-Cl
6	Topoľčany embayment and Bánovce Basin	SK300090FK	7	102-2,106	Paleogene, Triassic, breccias, carbonates	20-55	68.8	5.26	0.7-5.9	Ca-Mg-HCO_3, Ca-Mg-HCO_3- SO_4, resp. Cl
7	Upper Nitra Basin	SK300100FK	5	150-1,851	Paleogene, Triassic - Permian, breccias, carbonates, sandstones	19-59	57.9	7.05	0.4-1.9	Ca-Mg-HCO_3, Ca-Mg-SO_4-HCO_3
8	Skorušina Basin	SK300120FK	2	600-1,601	Triassic, dolomites	28-56	135.0	18.29	0.8-1.3	Ca-HCO_3,Ca-Mg-HCO_3
9	Liptov Basin	SK300130FK	6	400-2,500	Triassic, carbonates	25-66	121.4	20.36	0.5-4.7	Mg-Ca-HCO_3, prevailing Ca-Mg-HCO_3-SO_4
10	Levoča Basin W and S parts	SK300140FK	9	607-3,616	Mesozoic, dolomites, limestones	25-62	226.3	34.24	0.6-4.0	Ca-Mg-HCO_3-SO_4,Ca-Mg-HCO_3
11	Košice Basin	SK300170FK	7	160-3,210	Neogene, Triassic, gravel, sand, dolomites	18-129	207.4	78.88	0.7-31.0	prevailing Na-Cl, Na-Ca-Cl-HCO_3
12	Turiec Basin	SK300110FK	2	1,503-2,461	Triassic, carbonates	54	12.2	2.02	2.5	Ca-Mg-HCO_3-SO_4
13	Komjatice Depression	SK300250FK	0	-	-	-	-	-	-	-
14	Dubník Depression	SK300180PF	4	350-1927	Neogene, sand, sandstones, clastic sediments	18-75	36.0	3.7	1.6-30.0	Na-Cl, Na-Ca-HCO_3,Na-SO_4-Cl
15	Trnava embayment	SK300040FK	1	118	Triassic, dolomites	24			2.52	Ca-Mg-HCO_3-SO_4
16	Piešťany embayment	SK300050FK	1	1206	Mesozoic, carbonates	19,4			1.41	Mg-Ca-SO_4
17	Central Slovakian Neogene volcanics NW part	SK300190FK	10	64-2500	Neogene, Mesozoic, porphyres, limestones, dolomites	27-57	80.6	9.47	0.4-5.0	Ca-Mg-SO_4-HCO_3, Ca-Mg-SO_4,Ca-Mg-HCO_3
18	Trenčín Basin	SK300060FK	0	-	-	-	-	-	-	-
19	Ilava Basin	SK300070FK	1	1761	-	-	-	-	-	-
20	Žilina Basin	SK300080FK	4	600-2,258	Paleogene, Triassic, sandstones, carbonates	24-41	57.4	2.95	0.4-0.5	Ca-Mg-HCO_3, Ca-Mg-HCO_3-SO_4
21	Central Slovakian Neogene volcanics SE part	SK300200FK	4	65-910	Neogene, Triassic, andesites, sandstones, limestones	25-46	64.1	3.84	1.0-5.7	Ca-Mg-HCO_3-SO_4, Na-Ca-SO_4-HCO_3
22	Horné Strháre – Trenč graben	SK300260FK	4	320-625	Neogene, sand	21-38	16.0	1.04	0.4-3.1	Na-HCO_3
23	Rimava Basin	SK300220FK	5	158-1,050	Triassic, carbonates	18-33	61.3	1.76	1.7-5.9	Ca-Mg-HCO_3, Ca-HCO_3
24	Levoča Basin NE part	SK300150FK	3	3,400-3,500	Paleogene, Triassic, sandstones, carbonates	53-85	19.0	4.55	9.4-12.3	Na-Cl, Na-HCO_3-Cl-SO_4
25	Humenné ridge	SK300160FK	2	600-823	Neogene, Mesozoic, sand, sandstones dolomites, limestones	29-34	6.0	0.41	4.4-11.9	Ca-Na-Cl-SO_4, Na-Cl-SO_4-HCO_3
26	Beša – Čičarovce structure	SK300230FP	0	-	-	-	-	-	-	-
27	Lučenec basin (Rapovce structure)		1	1,501	Triassic, carbonates	38			12.6	Na-HCO_3
Summary of delined geothermal areas			**141**	**64-3616**	**Neogene-Mesozoic, sand, sandstones, breccias, andesites, carbonates**	**18-129**	**2,083,9**	**345,04**	**0.4-90.0**	**$NaHCO_3$ - NaCl, CaMg SO_4HCO_3, mixed type**

countries. In line with the WFD and following EU guidelines for classifying groundwater bodies (EC Horizontal Guidelines), with regard to long-term information database in the assessment of groundwater in Slovakia and national specifics three independent levels of groundwater bodies were identified: (1) Quaternary groundwater bodies, (2) Pre-quaternary groundwater bodies and (3) geothermal groundwater bodies. Delineation of the geothermal groundwater bodies respects the delineation of geothermal areas as shown on Fig. 1.1 and Tab. 1.1. As seen on the map there are several geothermal structures of anticipated or verified transboundary character, though on level of geothermal groundwater bodies only Komárno High Block (SK300010FK) and Komárno Marginal Block (SK300020FK) were identified and mutually agreed (with Hungary) as transboundary groundwater bodies. Skorušinská panva Basin (SK300120FK) was not internationally agreed with Poland as cross-border structure and will be evaluated at the national level with respect to confirm or reject the presumed mutual transfer of groundwater across the border area (Report of the Slovak Republic on the status of implementation of the Water Framework Directive, Kollár et al., 2005). Based on aforementioned report more attention is recommended to geothermal waters, mainly completing the database of geothermal resources and their exploitation, processing of geothermal water balance monitoring and implementation of geothermal groundwater bodies. Particular attention is recommended as well, to the selected transboundary water bodies, their evaluation and higher demands on the quantity and quality of the data.

Apart from the WFD, in the Danube River Basin there is the overall legal instrument for co-operation on transboundary water management - the Danube River Protection Convention (DRPC). The convention was signed in 1994 by eleven states from the Danube River Basin and came into force in 1998. The International Commission for the Protection of the Danube River (ICPDR, www.icpdr.org) is a transnational body, which has been established to implement the Danube River Protection Convention. In 2000, the ICPDR contracting parties nominated the ICPDR as the platform for the implementation of all transboundary aspects of the WFD in the Danube River Basin District (DRBD). In the Danube River Basin Management Plan (DRBMP) (ICPDR, 2009) the transboundary thermal water body Komárno High Block "Komárňanská vysoká kryha/ Dunántúli-khgs. északi r." was nominated as transboundary groundwater body of basinwide importance in the DRBD and marked as GWB-11.

Besides the international declarations and conventions regulating the transboundary water bodies, bilateral agreements between Slovakia and neighbouring countries exist though not exclusively specifying groundwater or geothermal water management issues.

Bilateral agreement between Slovakia and Hungary on transboundary water management came into force by the Decision of Council of Ministers 55/1978. (XII. 10.). The agreement focuses on surface waters, but also encompasses groundwater aquifers divided by the state border. A permanent Czechoslovakian-Hungarian Water Management Committee is set up, which holds a meeting once a year. The update of the agreement is ongoing. In addition to this bilateral agreement, Governmental Decision 2093/1999. (V.5.) on the general cooperation between the Republics of Hungary and Slovakia on environmental and nature protection, discusses general aspects of protecting the environment and its elements (such including water), but no specific water or groundwater relate points are included.

Bilateral agreement between Slovakia and Austria on the water management is based on the treaty between the Czechoslovak Socialist Republic and the Republic of Austria with the subject of border waters and transboundary water management, which was signed on December the 7, 1967 in Vienna. The permanent Slovak – Austrian commission for these Waters (water route March /Morava) was founded (BGBl. Nr. 106/1970; „Vertrag zwischen der Republik Österreich und der Tschechoslowakischen Sozialistischen Republik über die Regelung von wasserwirtschaftlichen Fragen an den Grenzgewässern"). This agreement concerns issues and measures for the preservation of watercourses along the state border as well as border crossing and neighbouring waters that may have an adverse effect on the other party. The treaty focuses on surface waters excluding fishing and any water utilization of energy-economic importance.

1.4. Transboundary groundwater structures under the scope of international cooperation

There have been couple of international projects implemented that were focused on geoscientific information sharing knowledge (eWater and OneGeology projects). Within the frame of international cooperation, the project DANREG was implemented by Austria, Slovakia and Hungary (1987-1997) (Tkáčová et al., 1998). The aim of the project was to develop a set of geological, geophysical and geo-environmental maps and explanatory notes, as well as the development of a separate study on the quality of water, geothermal energy and environmental aspects. Substantial part on the Slovak territory of the project DANREG was the Danubian Basin. From geothermal point of view Geothermal Potential Map was compiled in scale 1:200,000 (Kollmann, Rótar-Szalkai, Remšík in Tkáčová et al., 1998) displaying temperature of expected aquifer, basement surface and location of wells.

Other project that was designed for common evaluation of transboundary aquifers was project ENWAT (Environmental state and sustainable management of Hungarian-Slovak transboundary groundwater bodies), implemented within the frame of the European Union INTERREG IIIA during the years 2006-2008. In this project three transboundary groundwater bodies were investigated in the Hungarian-Slovakian border region: Ipoly/Ipeľ Valley, Bodrog region (both of them with

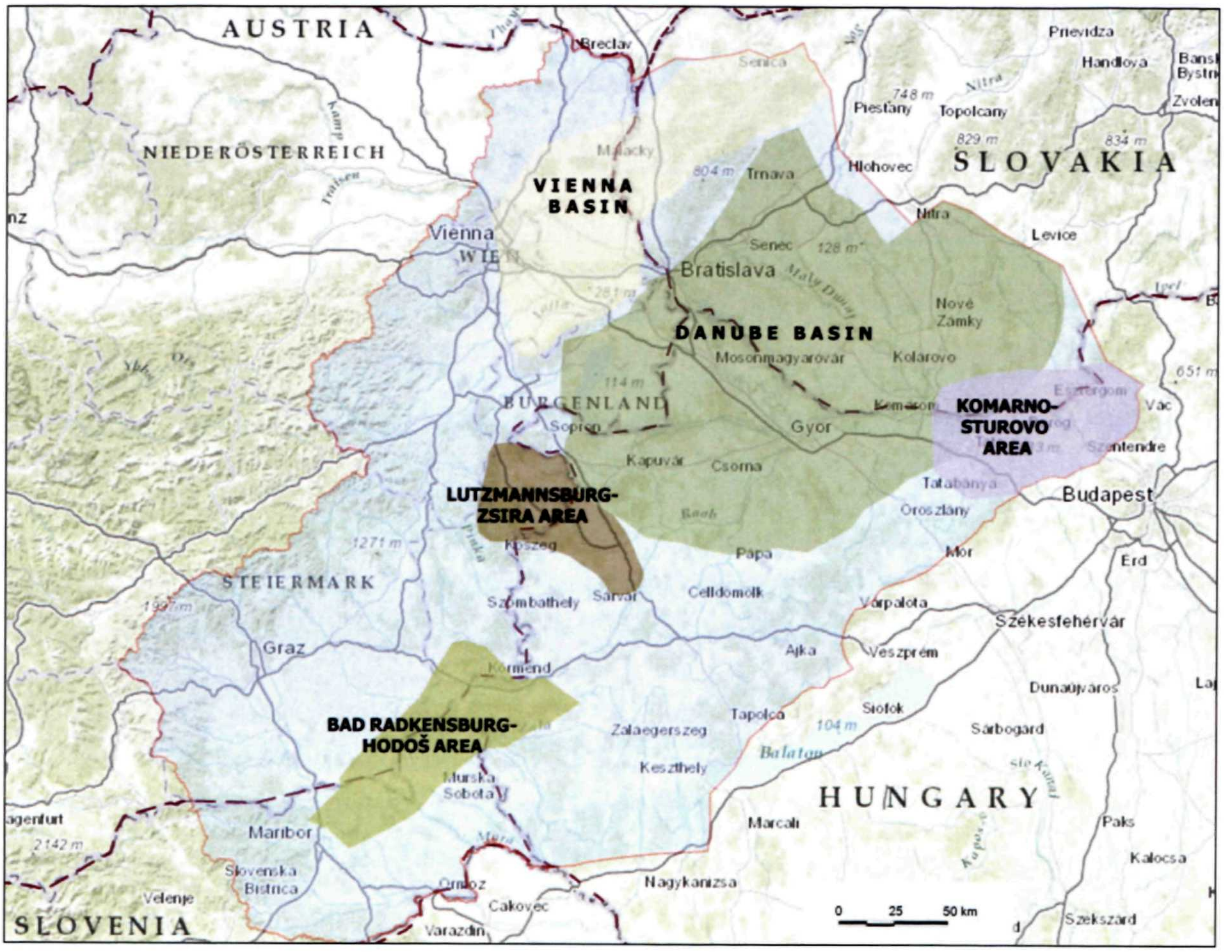

Figure 1.2 The supra regional and pilot model areas of the TRANSENERGY project

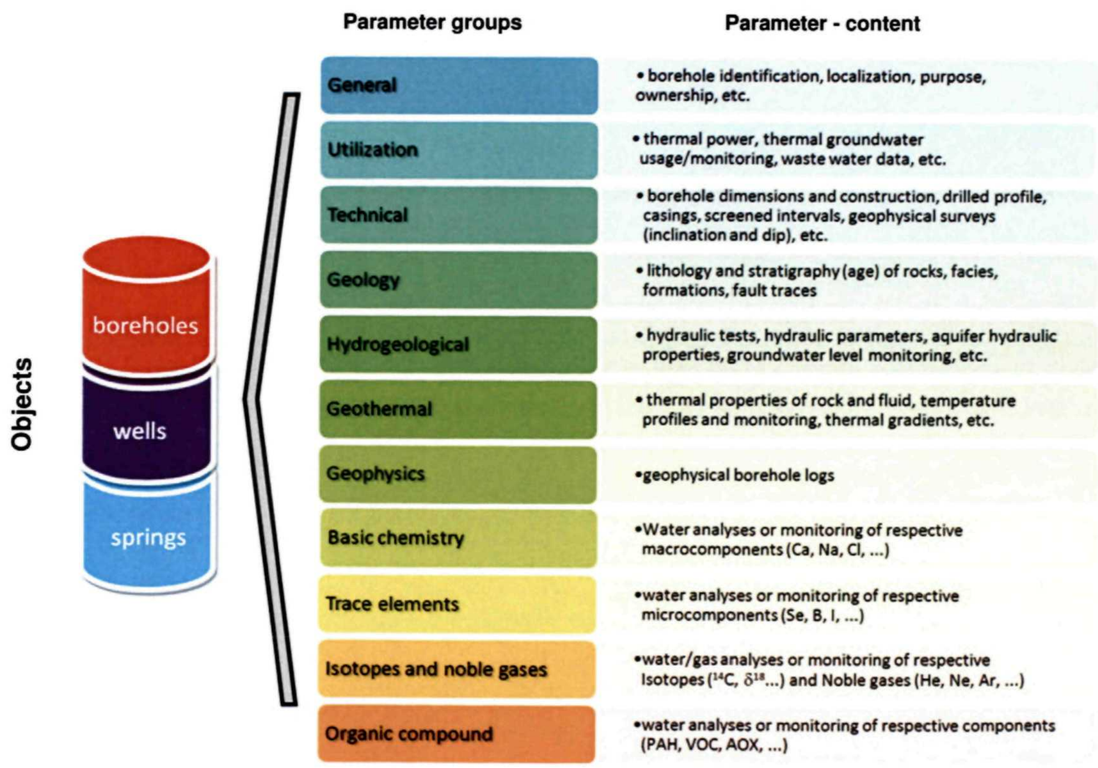

Figure 1.3 Parameters of the TRANSENERGY borehole database

porous aquifers) and Aggtelek-Slovak Karst region, with dominating karstic type of permeability. Despite the focus of this project only on "cold" transboundary groundwater aquifers, the project has shown the effective cooperation with partnership geological survey - Geological Institute of Hungary, MÁFI (Magyar Állami Földtani Intézet).

As mentioned above, no comprehensive study focused on transboundary geothermal resources has been done till 2010. The need for joint transboundary evaluation of the geothermal resources, along with the utilization evaluation, creation of geoscientific models and management aspects was recognized by four Central European countries (Hungary, Slovenia, Austria and Slovakia) that share transboundary geothermal energy resources in the western part of the Pannonian Basin. The project TRANSENERGY - Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia therefore addressed the key problem of using geothermal energy resources in cross-border regions in a sustainable way. The project was implemented through the Central Europe Program, Area of Intervention 3.1. (Developing a high quality environment by managing and protecting natural resources) and co-financed by ERDF with duration from April 2010 till September 2013. Partners in TRANSENERGY project were four national geological surveys: MFGI – Geological and Geophysical Institute of Hungary, Geo-ZS – Geological Survey of Slovenia, GBA – Geological Survey of Austria and SGIDŠ – State Geological Institute of Dionýz Štúr (Slovakia), that have long experience in cross-border co-operation in Central Europe and as governmental institutions guaranteed an independent assessment.

1.5. International cooperation on geothermal energy project TRANSENERGY

The aim of TRANSENERGY project was to summarize the relevant data, compile transboundary geoscientific models that were inputs for geothermal energy evaluation in project area and ***provide recommendations for a sustainable and efficient utilization of transboundary hydrogeothermal resources*** on regional level, respecting the natural boundaries of geothermal reservoirs that exceed national level of evaluation. These recommendations were based on the main project outcomes: a complex assessment of the present production and wide-range utilization of thermal groundwater, as well as the results of integrated evaluation of geological, hydrogeological and geothermal models at various scales. Appraisals were carried out by more than 80 experts of the four national geological surveys of the partner counties, providing an impartial assessment and common understanding of the hydrogeothermal systems of the western part of the Pannonian Basin. The developed problem-oriented approach of TRANSENERGY focused on the needs of decision-makers and might be applied in other regions in Europe, thus helping the countries to reach their National Renewable Energy Action Plans (NREAP) targets without threatening the environmental targets and/or interests of their neighbouring regions.

The TRANSENERGY project is complex in terms of the topics that were evaluated and studied throughout its implementation. Thus the matter of this chapter is rather an overview of the project focus and the areas covered by the project than its tangible results. These are accessible on the project website in the form of work package reports (http://transenergy-eu.geologie.ac.at/) or in following articles of this Slovak Geological Magazine volume that are focused on the Danube Basin modelling outcomes and the utilization of the geothermal energy.

The project area covered 47,750 km^2 with geological, hydrogeological and geothermal models in "supra regional scale" (covering the whole project area) and models studied in more detail in 5 pilot areas (Figure 1.2): (1) Danube Basin (A-SK-HU); (2) Vienna Basin (SK-A); (3) Komárno-Štúrovo area (HU-SK); (4) Bad Radkersburg - Hodoš area (A-SLO-HU); (5) Lutzmannsburg - Zsira area (A-HU).

The implementation of the project reflected the needs of complex evaluation of geothermal energy aspects and included:

- Transnational data management
- Geothermal water utilization aspects
- Cross-border geoscientific models
- Implementation tools for transboundary geothermal resource management and interactive map server

Three types of databases were elaborated incorporating geothermal sources (with thermal water at least 20 °C), their managers and users:

- Database of authorities (http://akvamarin.geo-zs.si/authorities/) holds information about 40 institutions active in the management of geothermal resources in the project area and presents their view on the regulatory regime of research and utilization of geothermal energy and thermal water.
- Database of thermal water users (http://akvamarin.geo-zs.si/users/) comprises 149 active and 65 potential users in the project area, as well as data about 403 geothermal wells and thermal springs, the temperature and use of water, and wastewater management. In Slovakia alone there were 23 active and 21 potential users identified in research area.
- Database used as a source of geological data for further evaluation and modelling purposes. Compiling this database was done in couple of steps. Data showed low uniformity as they were of different origin and from various sources - different formats, scales, projections, various types of geological maps and cross-sections, geophysical profiles, as well as borehole data. The final database contained 1,686 objects involving 242,811 records represented in 453 individual parameters. Parameters were grouped in 11 different groups (Fig. 1.3). The spatial distribution of the data is on Fig. 1.4.

Chosen information is available for public and is published on the official site of TRANSENERGY project (http://transenergy-eu.geologie.ac.at).

Figure 1.4 Spatial distribution of the source data objects (modified Mikita et al., 2011). Explanations: 1 - boreholes (including petroleum boreholes that show only location though data are confidential), 2 - springs, 3 - supraregional area, 4 - state boundaries

Overview of ***geothermal energy utilization*** was one of the main outputs of the project. Based on information of 214 geothermal energy users, the utilization maps were compiled. The geothermal water is utilized in 17 different ways in the project area, of which bathing and swimming (incl. balneology) is the most frequent way of utilization in all 4 countries. Drinking water use is applied mainly in Hungary, while space and water heating in Slovenia and Slovakia. Hydrodynamic changes in geothermal aquifers due to thermal water exploitation have been noticed in 303 wells from all 4 project countries.

Geoscientific models represent the simplified version of the existing hydrogeothermal systems (which are complex in reality) and by the interpretation and extrapolation of input data, they provide a continuous information in space (e.g. about the geological build-up, rock parameters, hydraulic heads that direct groundwater flow, temperature distributions in the subsurface, etc.) also for those areas, where measured data are not available. By quantifying the different parameters, the models also simulate the relevant interactions of the real systems and may provide information about their future responses (Rotár-Szalkai et al., 2010).

The ***geological*** models outlined rock geometry, determined the main geological units with similar hydrogeological characteristics (i.e. hydrostratigraphical units), which were important input data for the hydrogeological and geothermal models. The ***hydrogeological-hydrogeochemical*** models described the thermal water flow system, while the ***geothermal*** models expressed the 3D temperature distribution in the subsurface.

Modelling activity was performed at two scales and successive phases: first models (geological, hydrogeological and geothermal) were performed at 1:500,000 scale for the entire project area ("***supraregional models***"). The aim of these models was to handle the project area in a uniform system approach, to determine the main geological structures and flow systems and the relation between them, to describe distant hydrogeological processes, to describe the geothermal potential and quantify the hydrogeothermal resources, and to provide boundary conditions for the pilot models. The ***models*** developed for ***pilot areas*** at a scale of 1:100,000 to 1:200,000 focused on special transboundary problems which were varied accross areas. On the pilot areas both ***steady state*** (expected changes in the system under present utilization practice) and ***scenario*** models (responses of the system to different predicted/hypothetical utilization schemes in the future) were developed.

The web-based geothermal information system as one of the outputs of the project incorporated geological, hydraulic and geothermal conditions with the utilization characteristics of the geothermal resources. A web viewer was created for a spatial presentation of the collected data, helping the user at his orientation in space and giving the desired information about wells and way of their utilization. On the interactive map (Fig. 1.5), accessible on the website http://transenergy-eu.geologie.ac.at/, any desired combination of data in studied region can be displayed. Data are arranged into six groups: geology, geological cross-sections, geothermal potential, utilization maps, maps of potential reservoirs, and the database. A series of geological maps was created for the entire project area. In addition to the surface geological map in the scale of 1:200,000, 9 geological maps at the scale of 1:500,000 are available, showing geological composition beneath the selected younger rocks as given in the title of the map. In this way maps of the basement rocks of the Quaternary, Upper Pannonian, Lower Pannonian, Sarmatian, Badenian, Lower Miocene, Paleogene and Senonian sequences, as well as the map of the Pre-Cainozoic basement rocks beneath the sedimentary basins were created. Three geological cross-sections were made in the direction NW-SE through the entire project area, and 12 detailed cross-sections through the five pilot areas. The interactive maps show depths of the isotherms 50, 100, and 150 °C, maps of the surface heat flux density, and maps of the temperatures at depths of 1,000, 2,500 and 5,000 m. Thirteen utilization maps show the activity of thermal wells, tapped aquifers, monitoring set-up of the extracted thermal water and waste water, and its utilization purpose. The database is linked to individual wells, and by clicking on it, the user can obtain data about its location, drilling, geological composition, aquifers, and the chemical composition of thermal water.

In the evaluation and application of the data it has to be considered that numerous local phenomena are not shown due to the small scale and consequent generalizations. Therefore, an additional and more detailed study of local hydrogeological and geothermal conditions is still required to perform a high-quality project for any new implementations of geothermal energy use in the project area.

Apart from evaluation of the data, comparison of the utilization and geoscientific modelling special attention was dedicated to comparison of the ***legislation and management of the geothermal water***. Based on comparison of four Central European countries, different policies and attitudes in utilization, reporting, responsibilities, monitoring policies and delineation of geothermal water bodies were identified. The comparison of the legislation was very complicated task to do, as different schemes are applied, though common attitude on certain transnational level in geothermal water management is desirable in transboundary policies. For more detailed overview of the legal aspects, administrative procedures and conditions for licensing geothermal water utilization have been summarized in manuscript Lapanje & Prestor (2011). In legislation the threshold temperature for thermal water (at the point of seepage) is defined in Slovakia (Geological Act 569/2007) over 20 °C and in Hungary (Act LVII of 1995 on water management) over 30 °C. In Slovenia it is accepted in practice that thermal water is groundwater with temperature over 20°C, though without the legislation definition in the relevant Acts. The similar situation applies for Austria, where OEWAV-Regelwerk 215 (Guidelines for Utilization and Protection of thermal water in Austria) is applied for the definition of thermal water with minimum outflow temperature 20 °C.

Monitoring, as integral part of groundwater and geothermal energy management has been overviewed and analysed by several TRANSENERGY studies (Prestor et al., 2012, Rotár-Szalkai et al., 2013).

As a result of the different attitudes in geothermal water and geothermal energy sector on level of legislation, quantitative and qualitative monitoring, disposal of the used geothermal water the new methodology was proposed to evaluate the geothermal water management in project partner countries. The methodology is following guidelines for the protection of Lake Léman (Lachavanne & Juge, 2009) identified 10 crucial indicators that were used for evaluation of pilot areas of TRANSENERGY project (Prestor et al., 2012).

The project was designed from its beginning as ***stakeholder needs oriented***. All the relevant information, reports and outputs are accessible for wide public on web page http://transenergy-eu.geologie.ac.at/. As authorities dealing with everyday management, licensing, etc. of thermal groundwater/geothermal energy were among the main targeted stakeholders, a special attention was paid to identify them. Based on a questionnaire survey, altogether 40 authorities' data (10-Austria, 15-Hungary, 7-Slovakia, 8-Slovenia; information on organization, contacts, role, etc.) were organized into a database (http://akvamarin.geo-zs.si/authorities) (Prestor & Lapanje, 2010).

The final project results also target the ***decision/policy makers*** at international level, aiming to provide them scientifically based recommendations and evaluations supporting the performance of EU policies and elaboration of various strategies.

Nevertheless, ***other stakeholder groups*** can also largely benefit from TRANSENERGY results. The outlined potential geothermal reservoirs (Rotár-Szalkai, 2012) provide an excellent overview for ***project developers*** on the prospective areas for further possible explorations, while feasibility studies demonstrated for ***future investors*** that on the basis of project data and models tangible projects can be planned. The overview of current legislation (Lapanje & Prestor, 2011) and financial incentives (Nádor et al., 2013) deliver useful information on the non-technical issues. The elaborated geoscientific models (Rotár-Szalkai et al., 2013) can be also used in further

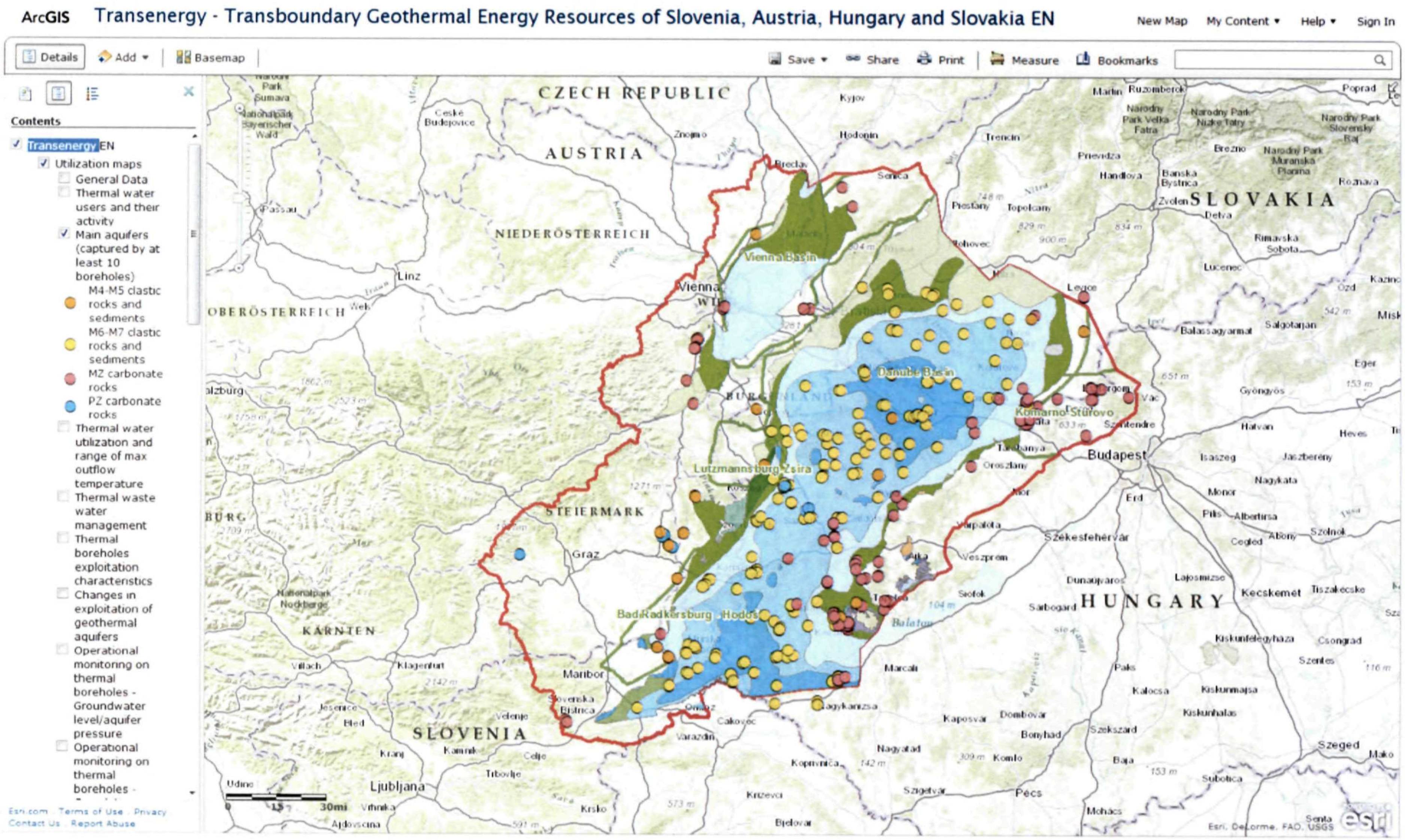

Figure 1.5 Example of an interactive web map, composed of a geological map of the Late Miocene clastic rocks and sediments and a map of captured geothermal aquifers, created from the users database http://transenergy-eu.geologie.ac.at)

academic research, while some results of pilot area models provide detailed information on reservoir properties for present and potential ***users***.

Besides the stakeholders approached through questionnaires, publishing activities and by project organized conferences and seminars, of the project directly involved stakeholders. From very beginning of the project proposal, the establishment of the External Evaluation Board (EEB) was designed. EEB members consisted of each country stakeholders, including one national and one local governmental representative, one current and one potential user, as well as 3 people from international agencies. The EEB members were providing an independent appraisal of the project results and were actively participating by implementing their needs and ideas into the project work and results.

1.6. Conclusions

The paper presents a brief overview of research results in geothermal energy sector in Slovakia and its current geothermal resources bound to 27 delineated areas with documented 141 boreholes on the Slovak territory. Though in the light of merging Europe policy the transboundary resources (in this case water and geothermal energy) are in future focus. The project "TRANSENERGY–Transboundary Geothermal Energy Resources of Slovenia, Austria, Hungary and Slovakia" addresses the key problem of using natural resources that are shared by different countries in a sustainable way. Natural resources, such as geothermal energy whose main carrying medium is groundwater is strongly linked to transboundary geological structures.

The project delivers multilingual web-portal for facilitating a sustainable use of the thermal water in the western Pannonian region that includes:

- Geological, hydrogeological and geothermal maps, cross sections, models;
- A multilingual borehole database;
- Thermal water utilization maps;
- Geothermal potential maps;
- A database of authorities dealing with management and licensing of transboundary geothermal aquifers;
- A summary of actual legal and funding framework in the participating countries with emphasis on cross-border geothermal facilities;

A strategy paper evaluating existing exploitation, future possibilities and recommendations for a sustainable and efficient geothermal energy production at the project area.

The web service (www.transenergy-eu.geologie.ac.at) as one of the main outputs of the project is public and can be used by the involved authorities (water management, mining, land use), by consultants and investors.

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1.7. References

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