GEOTHERMAL ENERGY

of the western margins of the Pannonian basin

Transboundary geothermal energy resources of Slovenia, Austria, Hungary and Slovakia

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Subtitle: **Transboundary geothermal energy resources of Slovenia, Austria, Hungary and Slovakia**

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THE TRANSENERGY PROJECT

Heated groundwater is the main carrying medium of the Earth's heat or geothermal energy to the surface. Regional thermal water flows are mostly controlled by natural geological structures which are not limited by the state borders and are independent of any socio-political arrangements. Geothermal energy is one of more important natural resources of Central Europe, and will gain more and more importance in the energetic and climatic policy of the partner states and of the entire European Union in future.

The project "TRANSENERGY – Transboundary geothermal energy resources of Slovenia, Austria, Hungary and Slovakia" deals with the shared use of transboundary geothermal energy resources. The evaluation of the regional geothermal potential, the preparation of guidelines for the sustainable utilization of geothermal energy, and the prevention of possible negative impacts due to overexploitation of the reservoirs are only possible with a joint approach of the neighbouring countries. The project is running in years 2010-2013, and is implemented through the CE Programme, and co-financed by the European Regional Development Fund. Partners in the project are geological surveys of Austria, Hungary, Slovenia and Slovakia.

Detailed maps, their legends and descriptions are available on the project website http://transenergy-eu.geologie.ac.at/, which is the central source of information and is intended as well for stakeholders as also for the general public. The main output of the project is a web-based decision supporting tool for the research activities and the utilization of geothermal resources. The results can be used by different authorities (ministries, local and regional administrations, municipalities, specialist services), users of thermal water, investors, educational and research institutions, and other different interest groups.

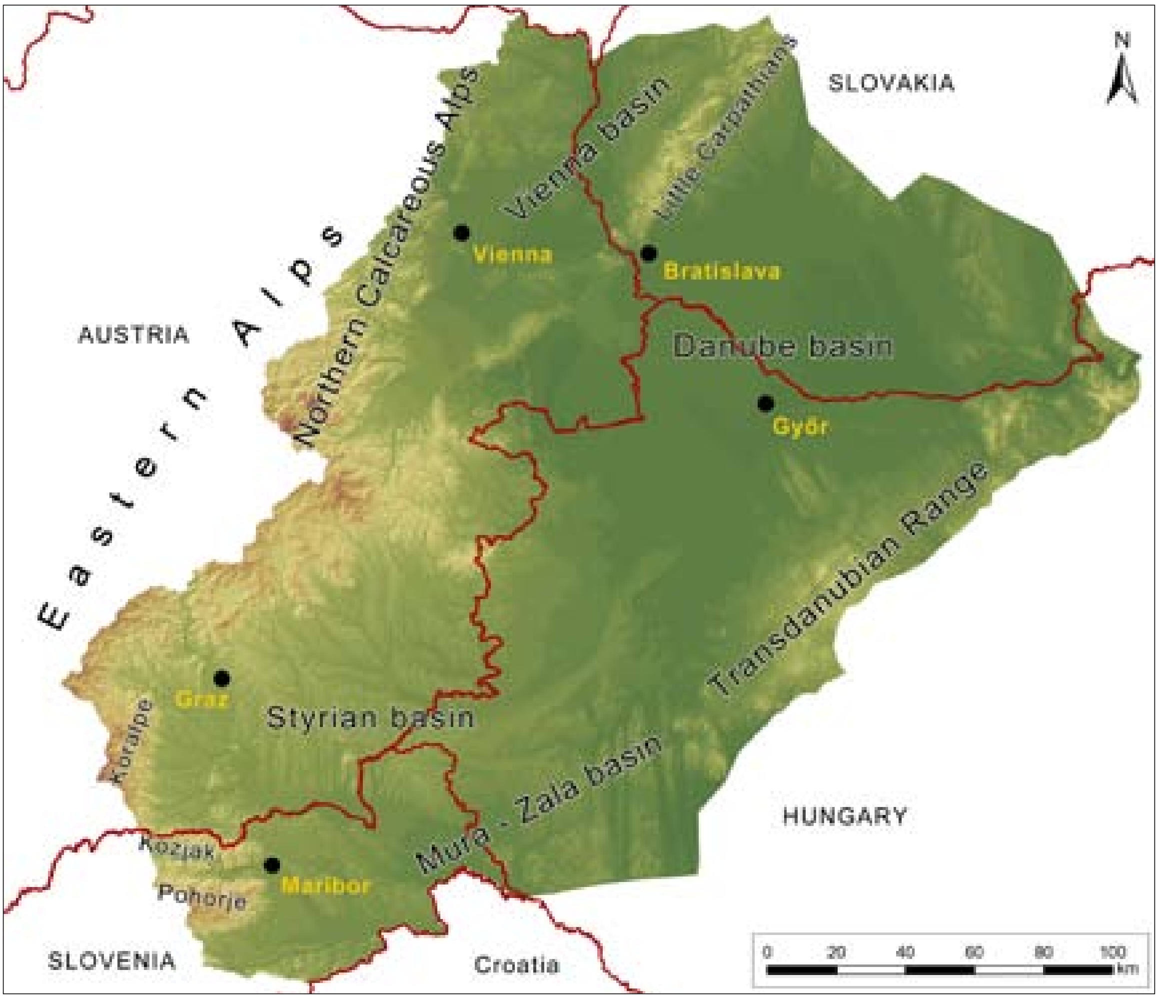

Figure 1: *The area of the TRANSENERGY project with the most distinctive geographic units*

PROJECT AREA AND FIVE PILOT AREAS

Descriptive and numerical regional models at scale 1: 500 000 were elaborated for the entire project area. They explain the most important geological, hydrogeological and geothermal phenomena which resulted in the formation of extensive regional and transboundary geothermal resources in the western part of the Pannonian basin. At the same time the main processes are dealt with, describing their impact on the regional flow of thermal water and its relation to the shallower fresh water aquifers.

In some areas near the state borders utilization conflicts related to the use of geothermal resources were found, and therefore five pilot areas were selected in which conceptual and numerical models at a larger scale of 1: 100 000 or 1: 200 000 were developed:

- **The Danube basin between Austria, Hungary and Slovakia**: availability of thermal water utilization in the alterating thin aquifer-aquitard system,
- **The Vienna basin between Austria and Slovakia**: possibility of exploiting geothermal energy in the area of historic hydrocarbon exploitation,
- **The Komarno-Sturovo area between Hungary and Slovakia**: the effect of previous mining activity and karst water recovery on thermal karst system,
- **The Lutzmannsburg-Zsira area between Austria and Hungary**: thermal water overexploitation and hydrochemical changes due to its abstraction,
- **The Bad Radkersburg-Hodoš area between Austria, Slovenia and Hungary**: impact of a new geothermal doublet onto current utilization sites.

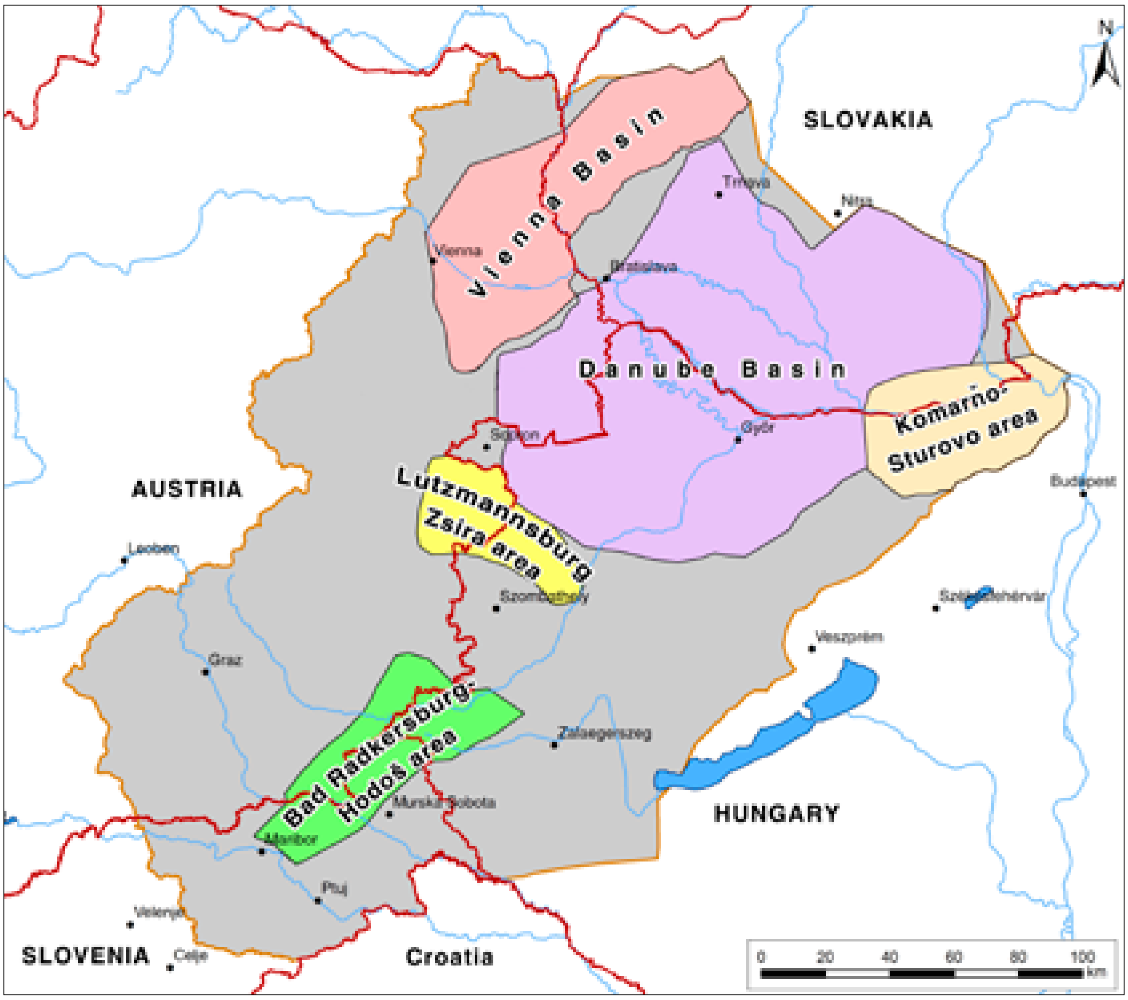

Figure 2: *The five pilot areas within the project area*

KEY DATABASES

Three databases were elaborated with data about geothermal wells yielding thermal water of 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. It is only in English.
- **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. It is only in English.
- **Interactive website** (http://transenergy-eu.geologie.ac.at) enables a display of more than 100,000 entries about 1,041 geothermal objects, about geological and hydrogeological composition of the territory plus chemical composition and temperature of thermal water. Information is provided in five languages: English, German, Slovakian, Slovene and Hungarian.

In addition to data presented within the TRANSENERGY project also a database of the bilateral Slovenian-Hungarian project T-JAM is available in Slovene, Hungarian and English languages (http://akvamarin.geo-zs.si/t-jam_boreholes/). It provides information about 257 geothermal objects between the town Maribor in Slovenia and the Balaton Lake in Hungary.

Figure 3: *The database of thermal water users in the TRANSENERGY project area*

INTERACTIVE WEBSITE

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 their utilization. On the interactive map, accessible on the website http://transenergy-eu.geologie.ac.at/, any desired combination of data in the area between Zreče (SI), Vienna (AT), Nitro (SK) and Budapest (HU) can be displayed. Data are arranged into six groups: geology, geological cross-sections, geothermal potential, utilization maps, maps of the 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 sequence, as well as the map of the Pre-Cenozoic 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 geothermal potential is shown on maps of depths of the isotherms 50, 100, and 150°C, maps of the surface heat flux density, and maps of the temperatures at a depth of 1000, 2500 and 5000 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.

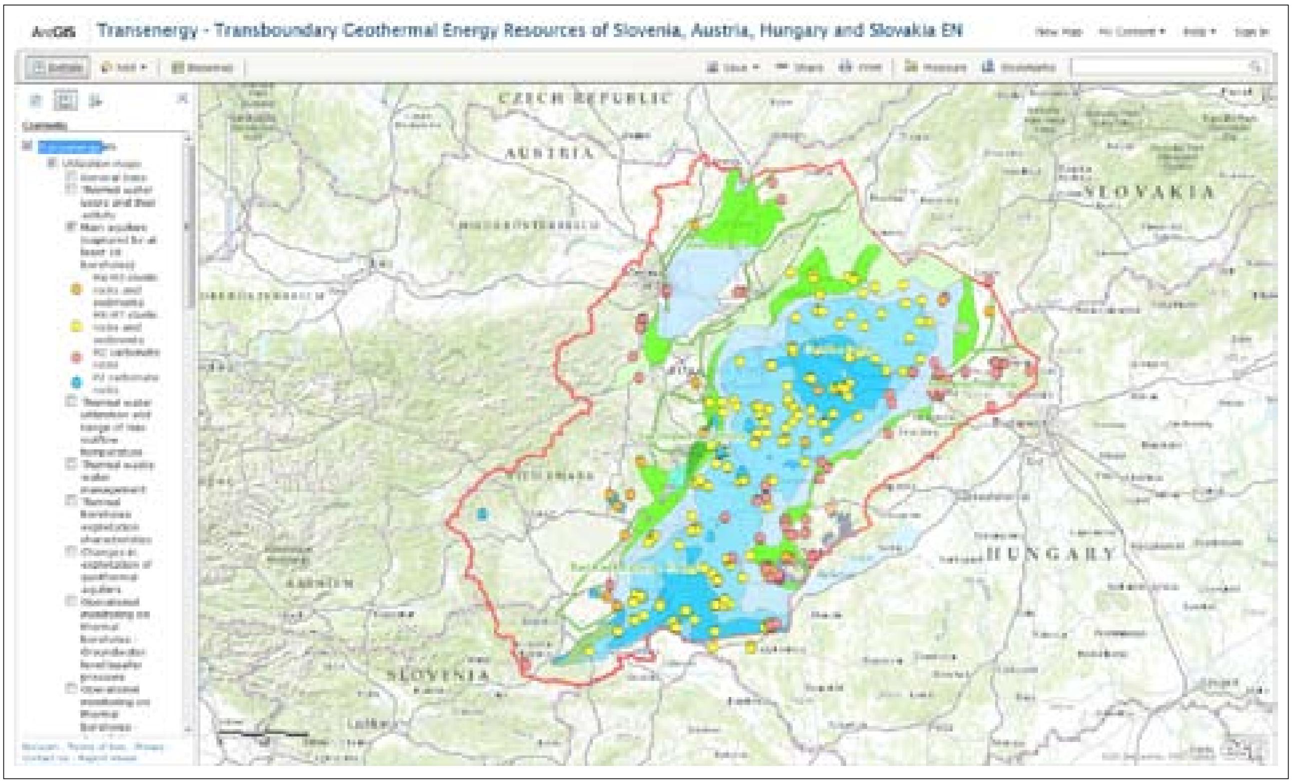

Figure 4: *Example of an interactive web map, composed of a geological map of the Upper Miocene clastic rocks and sediments and a map of captured geothermal aquifers, created from the users database*

GEOLOGICAL SETTINGS

The TRANSENERGY project area is surrounded by the Alps and the Carpathians, which consist of carbonate, metamorphic and igneous rocks of predominately Mesozoic and Paleozoic age. The Little Carpathians rise to the north of the area, and the south-eastern part is closed by the central chain of the Transdanubian Mountains. Both mountain ranges are built primarily from limestone and dolomite. Because of the subsidence and thinning of the lithosphere, which started approximately twenty million years ago, this bedrock has subsided by several kilometers. Such tectonic activity enabled a constant deposition of the Paleogene and Neogene sediments in the newly formed intramontane Pannonian sedimentary basin. Lithospheric thinning is important also because it allows the existence of an increased geothermal gradient in the entire Pannonian basin, causing the groundwater to be warm and very suitable for the utilization of geothermal energy. Today, the greater part of the area is again subjected to the rising and compression of tectonic blocks.

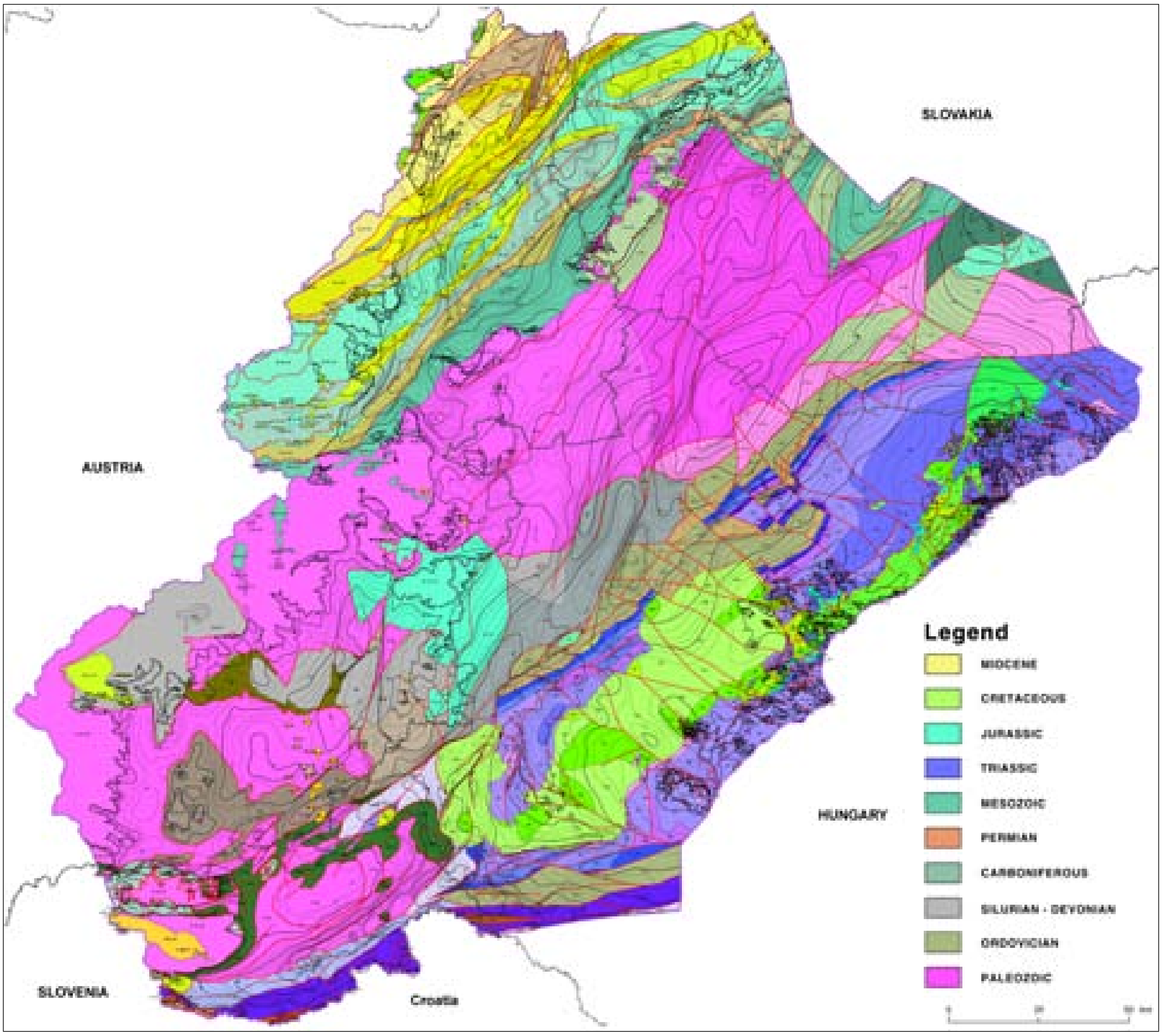

Figure 5: *Geological map of the basement rocks below the sedimentary basin with a simplified legend. Neogene igneous rocks in the project area and Paleogene rocks in Austria are classified as basement rocks despite their relative young age.*

The deposition of sediments in the Pannonian basin started in the Paleogene, and extended over the entire basin only later in the Neogene, during the period of the most intensive subsidence. The predominately marine sedimentation did not have an even course, because the entire area disintegrated into large tectonic blocks with different subsidence rates. This caused the formation of several Neogene sedimentary basins: the Vienna basin in the northwest, the Danube basin in the northeast, the Mura-Zala basin in the south and the Styrian basin in the west. At the end of the Badenian, approximately 14 million years ago, the Paratethys Sea separated from the Mediterranean Sea and the salinity of the newly formed Pannon Lake started to decrease gradually. Towards the end of the Miocene a uniform area of the expanding delta deposition system was formed, which was filling up from the northwest and northeast with clasts from rivers carrying eroded material from the surrounding mountains and hills. During the Pliocene, less than 5 million years ago, the accumulation of lacustrine, alluvial and terrestrial sediments took place, which was greatly covered by the loess in the Pleistocene. The intensive tectonic activity caused the formation of numerous andesitic-rhyolitic volcanoes in the Middle and Upper Miocene. The volcanic activity in the Upper Miocene and Pliocene, several million years ago, resulted in the formation of basalt volcanoes, which are found also in the Goričko hills in Slovenia and near the Balaton Lake in Hungary.

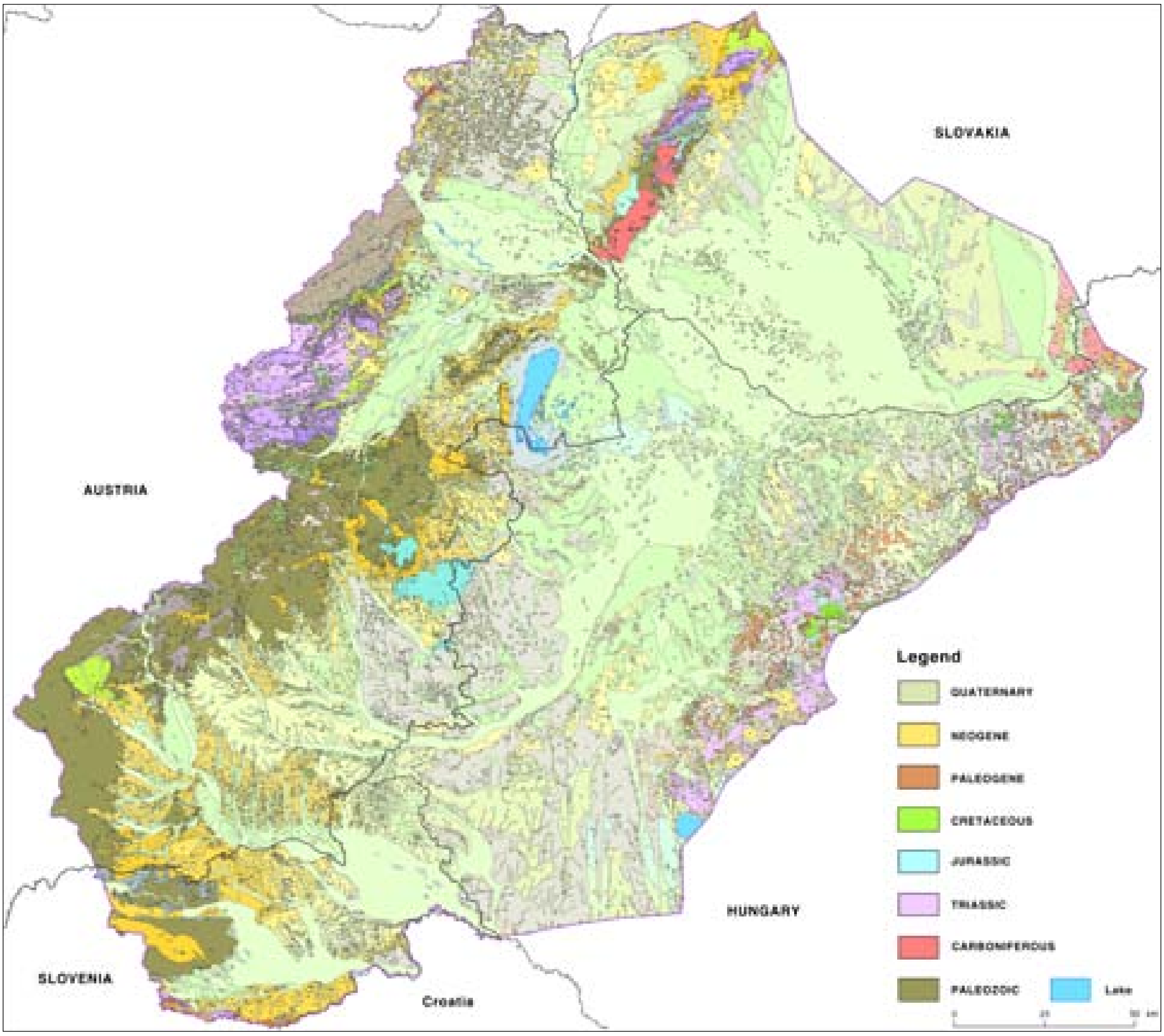

Figure 6: *Surface geological map of the project area with a simplified legend*

EARTH'S HEAT AND GEOTHERMAL RESERVOIRS

A geothermal system consists of a heat source, a geothermal aquifer and a fluid, which is usually water and transports the Earth's heat to the surface. The system comprises the entire hydrogeologically connected area with the recharge, aquifer and outflow zone. A constant heat source enables an increased geothermal gradient and there with an elevated groundwater temperature. The geothermal aquifer is the volume of heated and well permeable rocks which can be exploited by the extraction of heat or thermal water. With regard to their heat source and geological composition, aquifers in sedimentary basins and in their basement are the prevailing types of geothermal aquifers in the project area.

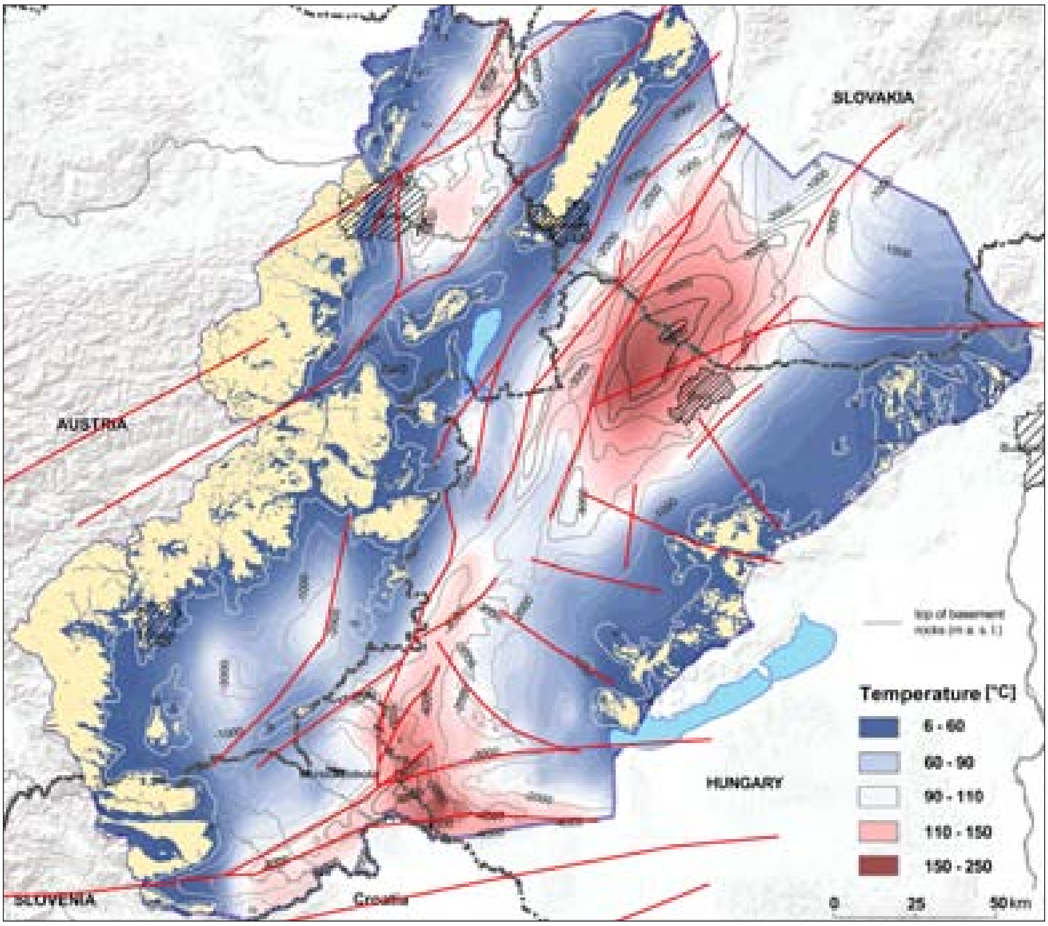

Figure 7: *Simulated temperature at the top of the sedimentary basin basement rocks*

In the Pannonian basin, several ten thousand square kilometers in size, the temperature measured at the depth of the Earth's crust is higher than average, which is the consequence of complicated Neogene geological processes of subsiding and thinning of tectonic plates. The heat source in this case is the relatively shallow asthenosphere, even shallower than 30 kilometers in comparison to the average of 50 to 70 km, and enables abundant heating of the area by the principle of conduction. In this case the heat is conducted through the solid matter and static fluids; and therefore its exploitation is usually similar to mining. The temperature below the surface is primarily conditioned by the geological composition of the territory and thermal properties of the rocks, and as a rule, increases with depth. Heat is mainly conducted by the basement rocks below the sedimentary basin, while the less heat-permeable Neogene rocks hold it in the depths and prevent its loss to the surface. The local distortion of the temperature field is significantly influenced by the convective flow of groundwater, which can either heat or cool an area. Areas with an increased temperature are attributed to local convection cells, i.e. to the rising of thermal water through spatially confined high-permeability zones. In Benedikt in Slovenia, thermal water rises up the fissured metamorphic basement rocks in the Raba fault zone. Moreover, west of the Balaton Lake in Hungary, thermal water flows into the Hévíz Lake through a deep karst flow system. On the contrary, in the areas of the Eastern Alps, the Transdanubian Range and the Carpathians, lower temperatures than expected were measured due to strong and deep infiltration of cooler precipitation.

In the entire project area, four categories of potential geothermal aquifers were identified:

- Upper Miocene and Pliocene aquifers with intergranular porosity,
- Miocene aquifers with intergranular, double, or undefined porosity,
- Aquifers in metamorphic basement rocks with fissured porosity, and
- Partly karstified carbonate aquifers with fissured porosity.

For the four categories three types of maps were created, showing their spatial distribution, taking into account the fact that they contain thermal water with the following temperatures:

- between 50 and 100°C,
- between 100 and 150°C, and
- above 150°C.

No aquifers with a temperature of over 150°C, suitable for extensive production of geothermal energy from steam, were identified in the project area. Also, because of insufficient temperature and the presence of metamorphic rocks, the possibility of EGS systems development is questionable. Some potential aquifers with a temperature between 100 and 150°C were identified, and which could be suitable for the construction of binary geothermal power plants, however their economic effect is substantially lower than that of the conventional steam plants. Aquifers with a temperature below 100°C are already used in direct utilization schemes, but a more effective cascade use of the acquired thermal water is recommended in future.

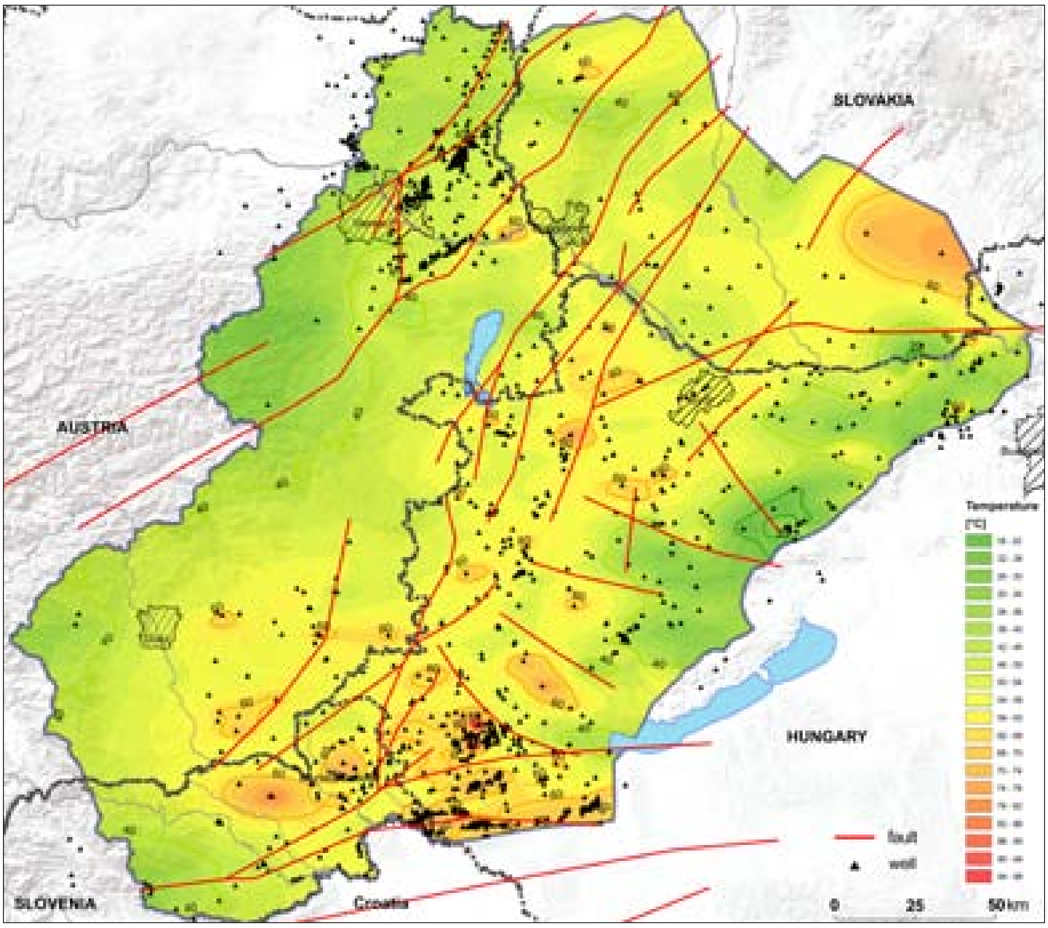

Figure 8: *Simulated temperature at depth of 1000 m below the ground*

CHARACTERISTICS OF REGIONAL GROUNDWATER FLOW

The different velocities and directions of groundwater flow are largely determined by the topography and geological settings of an area. Mountains and hills usually present the natural divides of different systems of groundwater flow, and are at the same time their recharge areas. The direction and strength of groundwater flow in shallow aquifers are mostly defined by the forced convective flow of cold precipitation. Part of the infiltrated rainwater soon flows to the surface in springs on the fringes of mountain valleys, forming a local flow system, while the other part penetrates into deeper layers and develops a regional groundwater flow. On its way downwards the water is heated and changed due to chemical reactions with the rock matrix and gasses. The regional groundwater flow is primarily caused by the difference in its density: colder and denser water sinks, while heated and therefore lighter thermal water is brought towards the surface by buoyancy forces. In the central parts of sedimentary basins the water flows very slowly or is even at a standstill, and therefore it can be of several ten to hundred thousand years old. Thus the brine of the former Pannon Lake flows from some wells even today at some places.

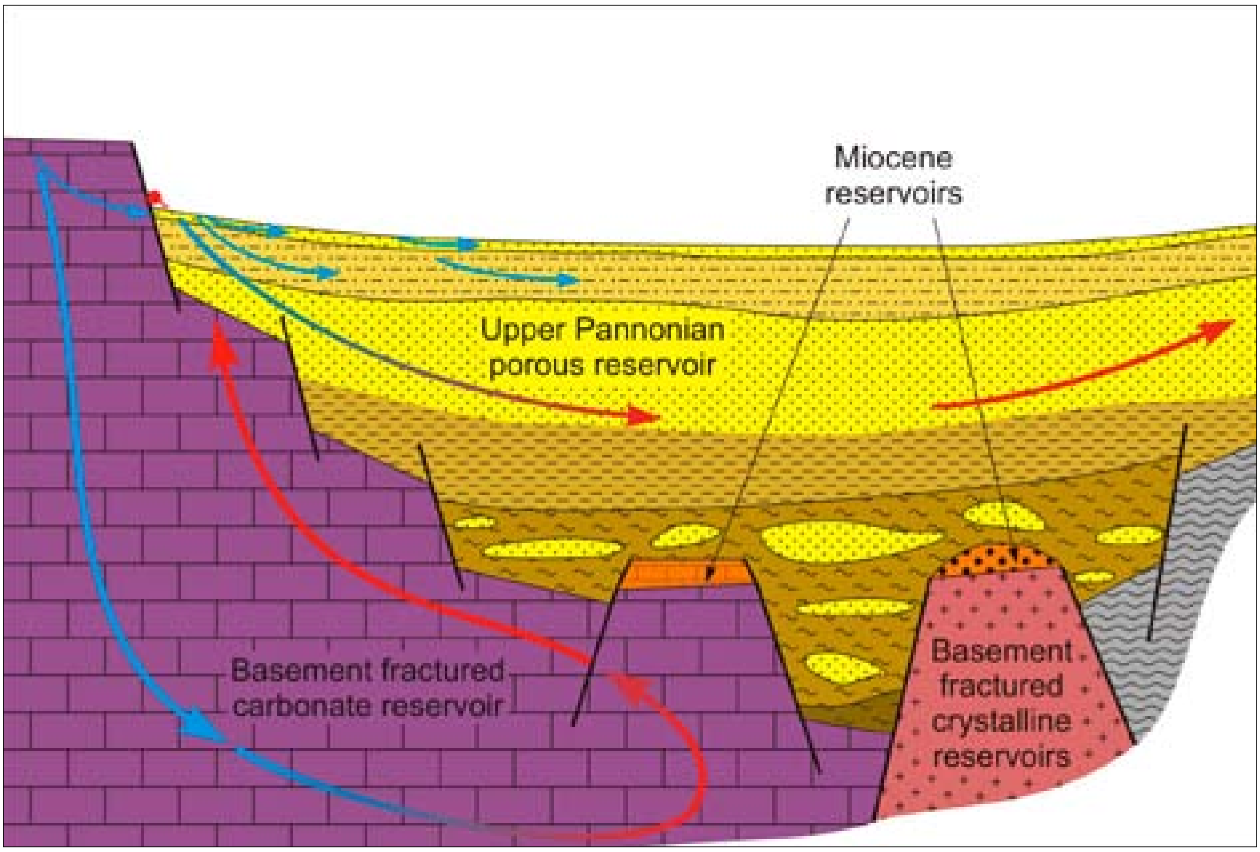

Figure 9: *Conceptualization of the regional thermal water flow in sedimentary basin and its basement rocks*

The regional groundwater flow in fissured and karstified limestone and dolomite in the basement of the sedimentary basin in Hungary forms in the so called thermal karst.

Beside, lenses of high-permeable Lower- and Middle Miocene sandstone in the sedimentary basin are often surrounded by low permeability sediments because of their turbiditic origin, and contain highly mineralized thermomineral water with much gas, either CO_2 or natural gas; at some places oil deposits were also found. In Hungary, in thick strata of clay and silt areas with overpressure were formed several kilometers deep. The thermomineral water, highly enriched in dissolved substances, very slowly seeps from this sandstone either into below or above lying aquifers. Although the quantity of this water is very small, it has an important influence on chemical properties of the produced thermal water; and therefore the identification of this process is very important. The mixture of these thermal waters is mainly used for balneology.

The regional groundwater flow occurs also in other intergranular geothermal aquifers in sedimentary basins, and the most important is the transboundary Upper Miocene aquifer.

In the permeable Pliocene sedimentary rocks of the delta and alluvial plains, the intermediate system of groundwater flow is developed. Here, infiltrated precipitation of an age of up to several thousand years is stored, being heated only in the deepest part of the sequence, as for example in Ptuj in Slovenia. The flow of young fresh groundwater is typical of numerous local flow systems, formed in shallow Quaternary and Plio-Quaternary deposits.

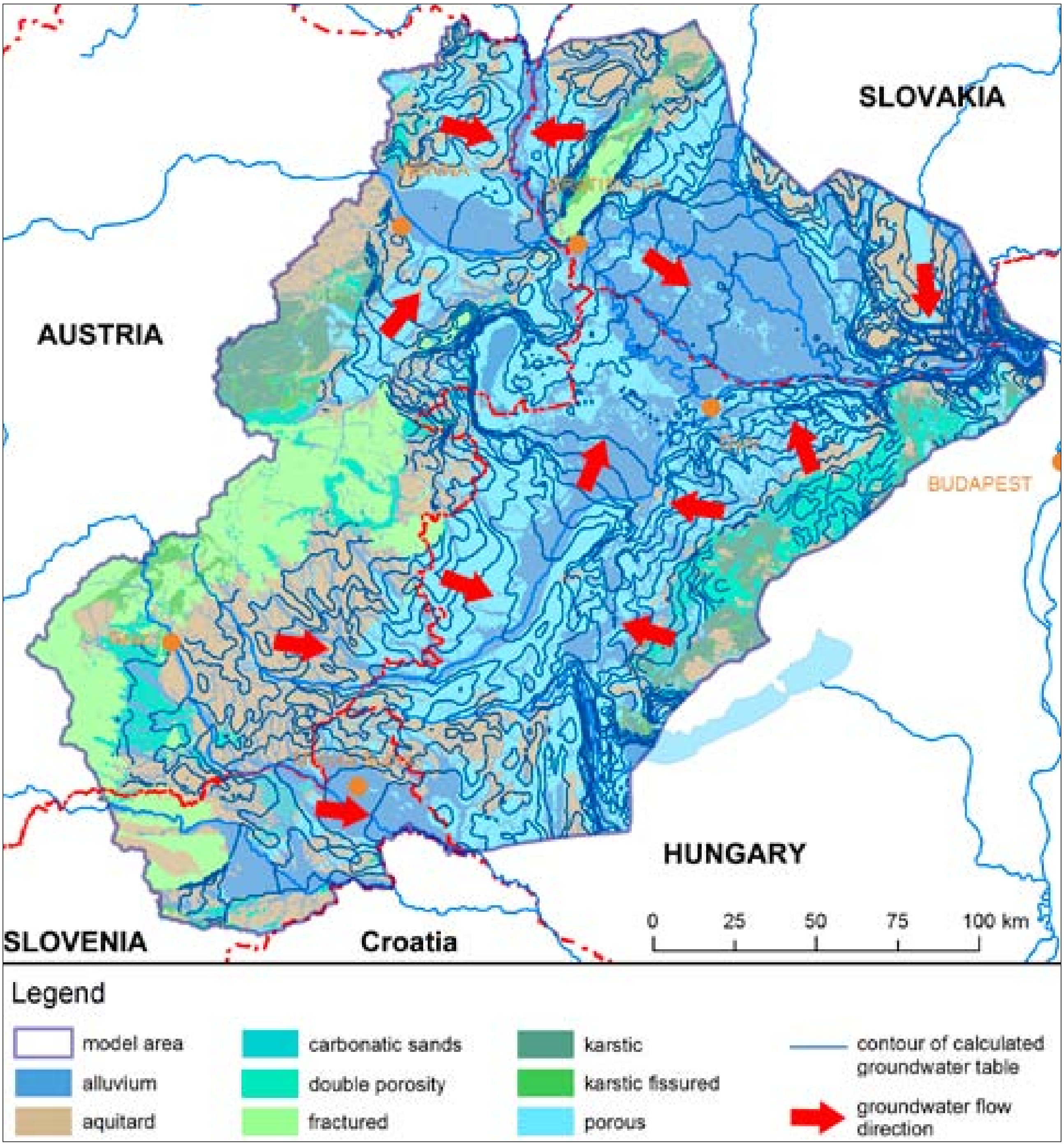

Figure 10: *Porosity type of shallow fresh water aquifers and a map of piezometric groundwater level with directions of groundwater flow*

THERMAL WATER FLOW IN THE BASEMENT ROCKS BELOW THE SEDIMENTARY BASIN

The bedrock of the Pannonian sedimentary basin is formed from three major tectonic units, built primarily of metamorphic and igneous rocks. Because they have very low permeability, local convection cells developed only in areas with extensive and deep faults, as for example in Benedikt in Slovenia. The regional thermal water flow in the basement rocks occurs mainly in karstified limestone and dolomite in the Alps, Little Carpathians, Carpathians, and in the Transdanubian Range, where rocks crop out to the surface. Infiltrated water sinks into depth towards the deepest parts of the basins along fissured or karstified high permeability zones, is heated there, and then because of lower density starts to rise to the surface. The water flows out in thermal springs on the outskirts of the mountains. The outflow area is usually significantly smaller than the recharge area and the entire territory from which groundwater extracts heat, and therefore it forms a local geothermal anomaly.

In the Vienna basin, the fissured Mesozoic carbonate rocks extend in SW-NE direction and can be found in depths from the surface to up to 5.5 km in the deepest part of the basin. The stored thermal water can reach a temperature of over 100°C. The flow of thermomineral water in the central and northern part is extremely slow, while in the southern part of the area the thermal water flows considerably faster from the Alps towards the north. Several kilometer-thick karstified Mesozoic carbonate rocks of the Transdanubian Range extend on the outskirts of the Mura-Zala and of the Danube basin, and their groundwater flow is determined also by regional faults. This groundwater flow system is called the thermal karst, known for a number of karst thermal springs, e.g. in Hévíz, Tapolca, Esztergom and Budapest in Hungary.

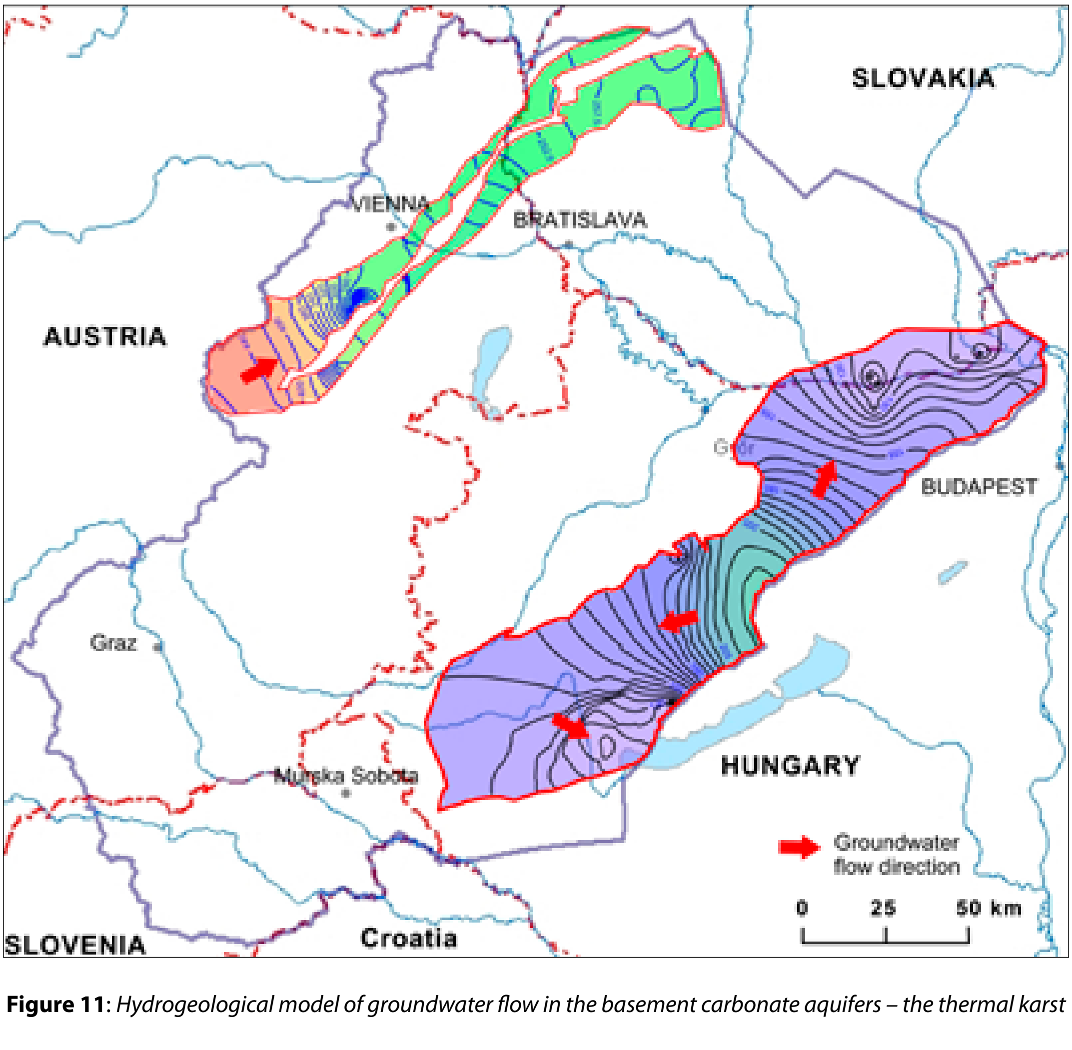

Figure 11: *Hydrogeological model of groundwater flow in the basement carbonate aquifers – the thermal karst*

THERMAL WATER FLOW IN THE UPPER MIOCENE SANDY AQUIFER IN SEDIMENTARY BASIN

Regional thermal water flows are also linked to smaller sedimentary basins, such as the Vienna, Danube, Styrian, and Mura-Zala basins. The main transboundary geothermal aquifer in the Pannonian sedimentary basin is formed from some ten to one-hundred-meter-thick sequence of the Upper Miocene sand. This is more or less cemented and extends to the areas of all four project countries. The sand stores several ten-thousand-year-old (Pleistocene) rainwater, which is medium-mineralized and heated to a temperature of up to 80°C at approximately 2 km. The origin of these water-bearing layers is the following: in the Upper Miocene, about 10 million years ago, the area was covered by the Pannon Lake, at that time similar to the present Caspian Lake. It was isolated from larger sea environments, and the high quantities of fresh water brought by rivers from surrounding mountains were gradually reducing its salinity. The rivers also brought diverse rock clasts and deposited it in extensive river deltas. When the rivers reached the sea, their flow velocity decreased rapidly, causing larger grains, mostly sand, to be deposited in the so called delta fronts, while finer grains of silt and clay were transported further into the sea. Because of constant material influx, the delta fronts prograded further into the deeper parts of the sea towards southeast, forming a large delta plain environment behind them. The new environment was mainly swampy and often flooded by rivers. Sandy delta front sediments were thus covered by silty and clayey alluvial sediments of the delta plain. A similar process can be observed today in deltas of big rivers, for example the Nile. In Pliocene, less than 5 million years ago, the filling of the remaining lake basin ended. The Pannon Lake withdrew to Hungary, leaving wide alluvial plains behind in the other countries. The constantly rising Alps ensured the influx of new material with which the precursors of today's rivers the Drava, Mura, Zala and the Danube filled the shores and bottom of the dried out Pannon Lake.

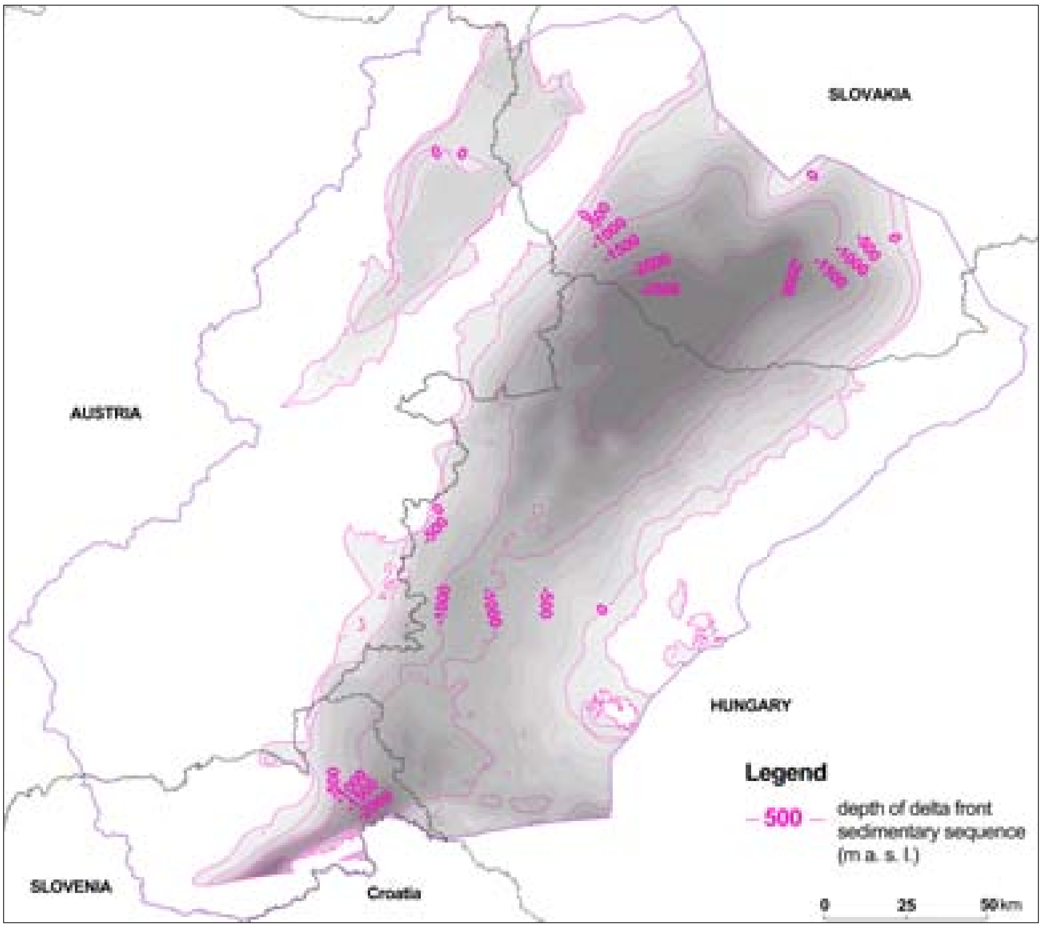

Figure 12: *Map of the maximum depth (bottom of the sequence) of the Upper Miocene delta front sand*

The regional Upper Miocene geothermal aquifer is recharged by the infiltration of precipitation in areas where layers reach out to the surface or by vertical and horizontal leakage of water from the near-by hydraulically connected layers. Hills such as Pohorje, Goričko and Slovenske gorice in Slovenia, the Transdanubian Range in Hungary, the Eastern Alps in Austria, and the Carpathians in Slovakia determine the direction of gravitational fresh water flow from the outskirts towards the central part of the sedimentary basin. The cooling effect of such infiltration can be observed to about 2-km depth. During its slow flow into greater depths the groundwater is heated. The resulting thermal water rises, and flows towards springs containing thermal or already cooled water, the latter is due to its very slow flow towards the surface.

One of well-known natural discharges from this system is the thermal Hévíz Lake west of the Balaton Lake in Hungary. About five percent of its inflow comes from the described regional Upper Miocene aquifer, and the rest of the thermal water originates from the thermal karst.

High age of thermal water indicates a very slow regional groundwater flow, and therefore the water has to be abstracted in as little quantities as possible for various utilizations (bathing, healing and heating). Only its geothermal heat should be extracted, followed by water reinjection back into the producing aquifer, so as not to change its natural flow considerably.

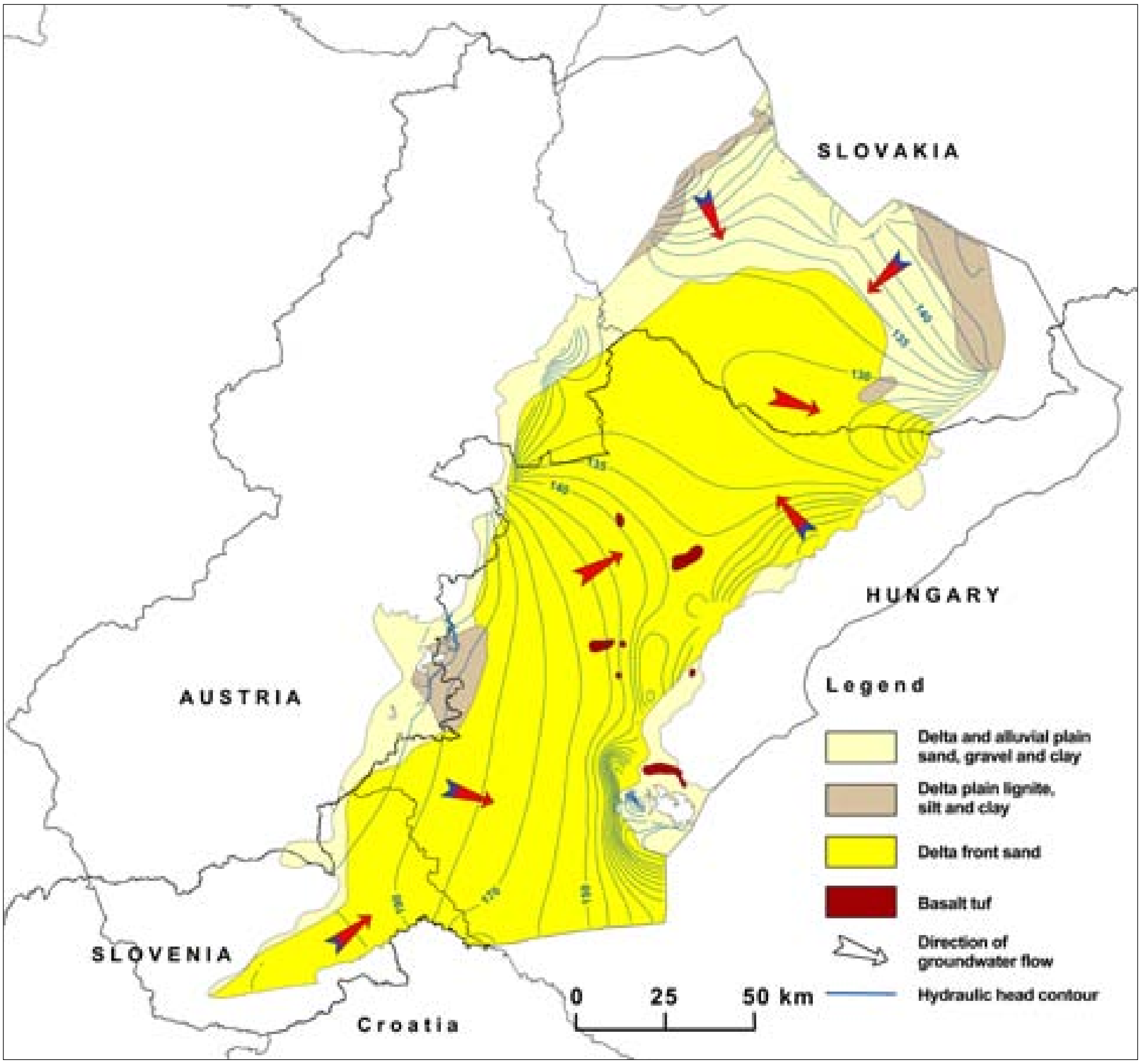

Figure 13: *Hydrogeological model of the Upper Miocene sandy geothermal aquifer*

THE BAD RADKERSBURG-HODOŠ PILOT AREA

Two main geological structures are found in the Bad Radkersburg-Hodoš pilot area: the Neogene sedimentary rocks and the Pre-Neogene basement rocks built from the rare Mesozoic carbonate rocks and the prevalent Paleozoic metamorphic rocks. In the wider area of the Raba fault zone these rocks are fractured and fissured, allowing thermal water to flow through, and thus forming a geothermal aquifer. Thermal water is abstracted from this aquifer in Benedikt in Slovenia and in Bad Radkersburg in Austria, while it is not yet exploited in Hungary. In Korovci near the Slovenian-Austrian state border, a 2-km deep geothermal well was drilled in 2008 at only 5-km distance from Bad Radkersburg. Because of the possibility that the extraction of thermal water in Korovci could reduce the quantity of thermal water available for the existing user in Bad Radkersburg, a numerical model of groundwater and heat flows was used to determine how thermal water flows through the aquifer and how it is heated due to the conductive heat transfer.

The calculations showed that the hydraulic influence of Korovci on Bad Radkersburg is less probable even after 50 years of exploitation, yet it can be sped up or caused by the (so far undiscovered) preferential flow paths in well permeable fault zones. A simulation of heat and hydraulic influence during the use of a geothermal doublet (a system of two wells: the first one is used to bring thermal water to the surface, through the second one the cooled water is reinjected back into the aquifer) in Korovci was also made and the formation of the local convection cell in Benedikt was explained.

Detailed results of this and also of the other four pilot models are available in reports on the project website.

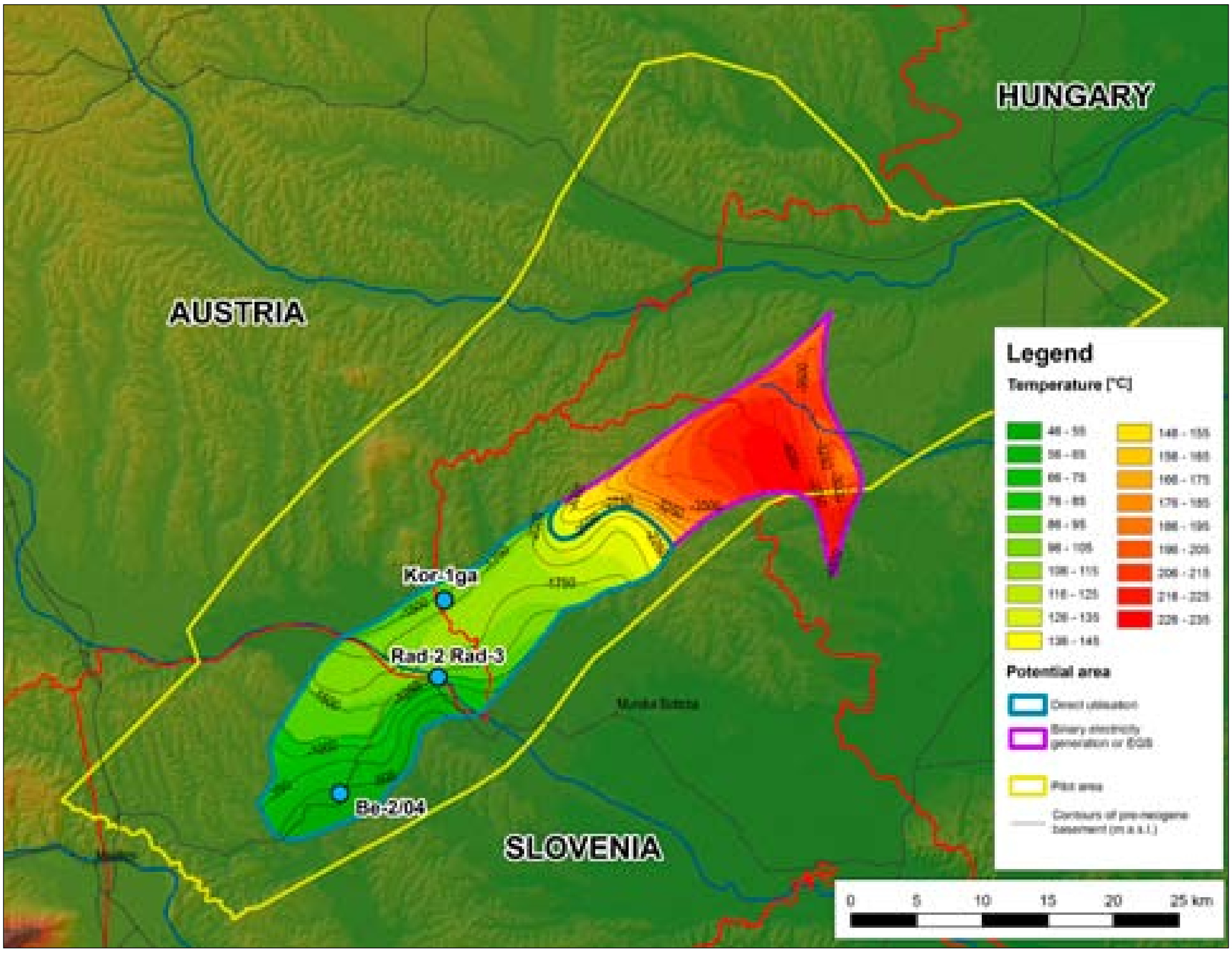

Figure 14: *Depth to the Pre-Neogene geothermal aquifer in the basement rocks and its geothermal potential*

USE OF THERMAL WATER

In total, data about 387 thermal wells and 16 thermal springs were collected, which are managed by 214 organizations. An overview of the state of geothermal resource exploitation for the year 2011 showed that thermal water with a temperature of above 20°C was exploited by almost 70% of the identified users through 307 active wells. The highest outflow temperature, 110°C, was measured in Bad Blumau (AT), where thermal water from the fissured Paleozoic dolomite is used in the production of electricity in a binary geothermal power plant by means of a geothermal doublet. Utilized thermal water is also reinjected into the Upper Miocene sandy aquifer within the district heating system in the city of Lendava (SI), and in the Mesozoic carbonate aquifer in Podhájska (SK) where it is previously used for greenhouse heating system. The average temperature of extracted thermal water in Slovenia and Slovakia is relatively high, between 60 and 80°C, and therefore its cascade use is quite common; first geothermal water is used for various types of space heating systems, then, somewhat cooled, it is used in swimming pools and for balneology. The average temperature of thermal water in Austria and Hungary is slightly lower, mostly about 40°C; and therefore it is not surprising that it is primarily used for bathing and balneology. In Hungary, water below 30°C is very often used as a drinking or industrial water resource.

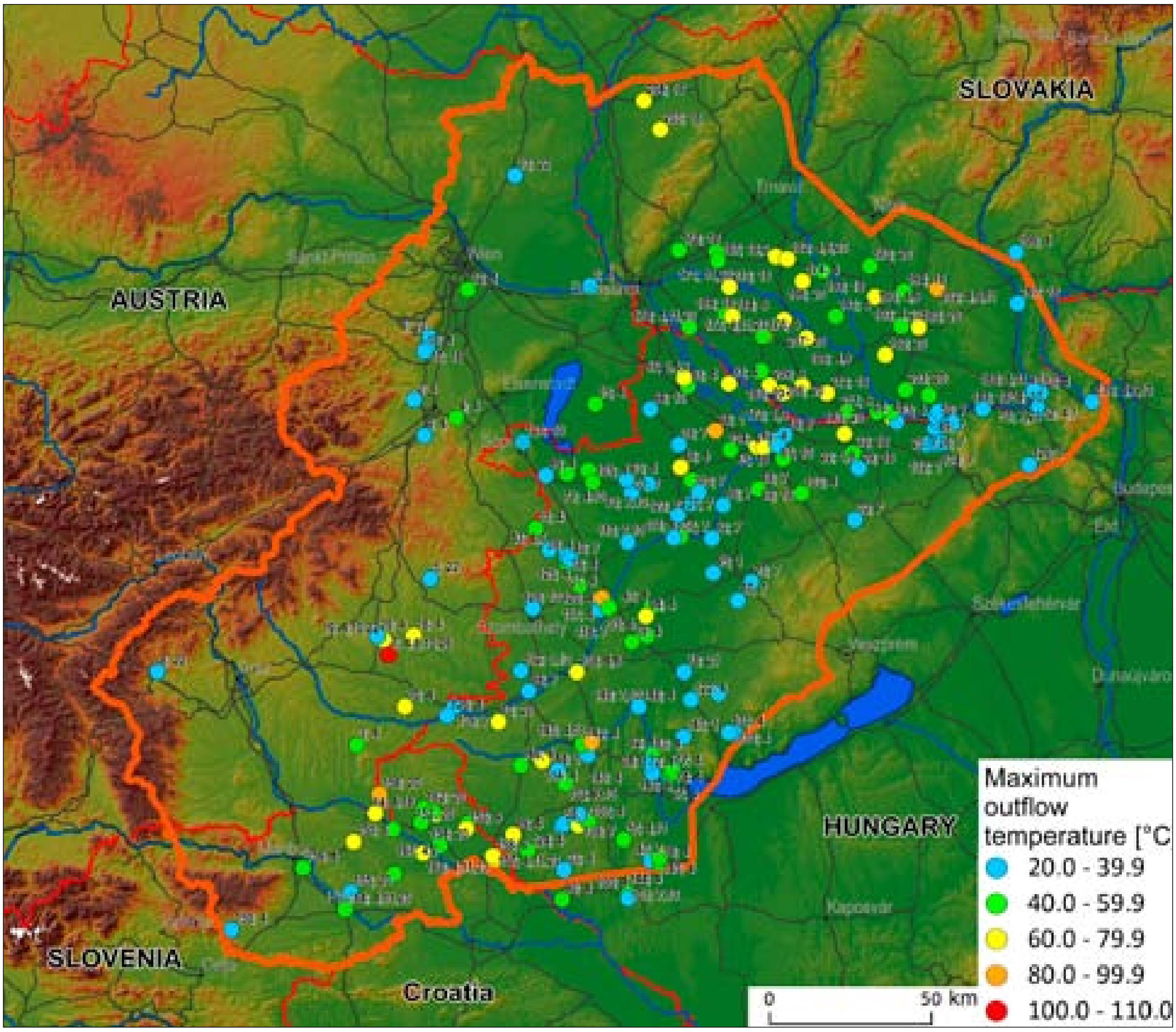

Figure 15: *Locations of thermal water users with the highest thermal water outflow temperature*

Because of data confidentiality, the yearly withdrawal of thermal water from geothermal aquifers in Austria is not known. In the project area of Hungary, Slovakia and Slovenia the total extraction of thermal water in 2009 reached just over 30 million m^3 and it is increasing with time. The largest volume, of as much as 12 million m^3, was pumped from the transboundary Upper Miocene aquifer. The largest thermal spring in the project area is the termal Hévíz Lake, contributing as much as 65% of the total extraction from the Mesozoic carbonate rocks. The total technical potential of geothermal wells is estimated at 36 million m^3, however, taking into account the concessions granted and applied for, the expected quantity of extraction reaches as much as 60 million m^3 a year.

Because of several decades of thermal water abstraction, changes in the chemical composition of obtained thermal water, in the piezometric groundwater level in aquifers, and in the quantity of outflow can often be observed. At the beginning, water flowed freely from the wells, while submersible pumps are needed now for water production from as many as 69% of the wells.

In NE Slovenia, 21 users with a total of 37 wells were identified, of which 26 were production wells. Thermal water extraction in 2011 exceeded 3.2 million m^3. Most of the thermal water was gained from the Upper Miocene sands of up to 2-km depth. In north-eastern Slovenia nine swimming pools, spas and their therapeutic pools are heated with this thermal water. Besides, during the cold period of the year, it is used for municipal heating network in Lendava and Murska Sobota, and to heat the orchid greenhouse in Dobrovnik and tomato greenhouse in Tešanovci. Interesting applications are also the use of thermal water for melting snow on public areas in Lendava and for heating the football field in Moravske Toplice.

A more detailed overview of the situation is available on the project website in the form of a user database (http://akvamarin.geo-zs.si/users/), reports, 12 thematic maps (http://transenergy-eu.geologie.ac.at/index-Dateien/Page959.html), and interactive web maps (http://transenergy-eu.geologie.ac.at/).

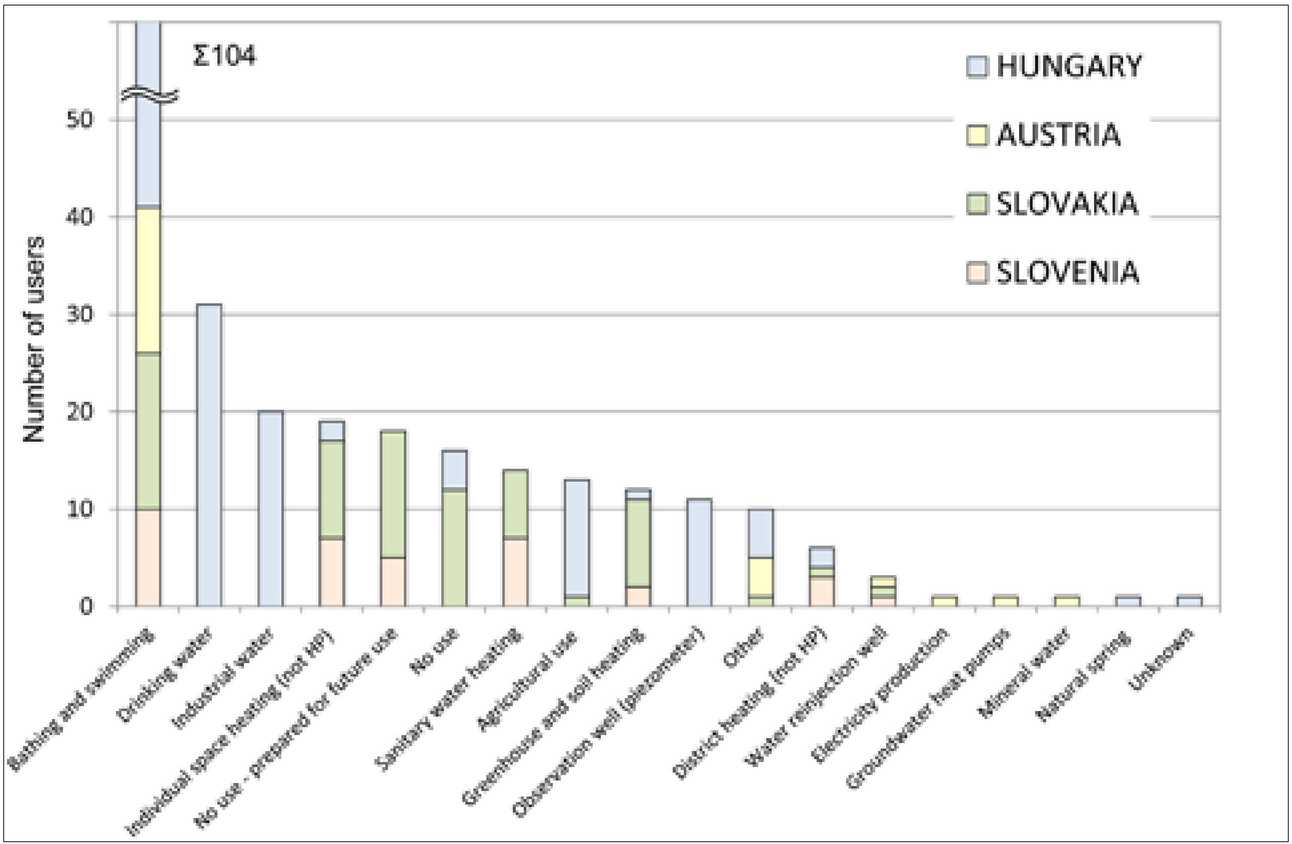

Figure 16: *Comparison of different utilization types by countries*

CONSEQUENCES OF THERMAL WATER EXPLOITATION FOR THE STATUS OF GEOTHERMAL AQUIFERS

Each abstraction of groundwater from an aquifer without reinjection causes changes in the direction and velocity of groundwater flow, at least in the vicinity of active wells. Long-term abstraction in areas with a high density of production wells causes a decrease of groundwater levels to expand quickly in the aquifer, and in the case of a transboundary and regional geothermal aquifer (there are quite a few identified within the TRANSENERGY project) result in a regional lowering of the groundwater level. This is also reflected in a reduced yield and changed chemical composition of thermal water, and its temperature. The deterioration of the aquifer's status is not alarming only from the ecological point of view of retaining its natural status, but will eventually result in economic damage for the users, as the acquisition of thermal water will become increasingly difficult and less economical.

Additional problems are a least two: only rare cases of reinjection, and emissions of chemically untreated thermal water with rather high temperature of discharge (very frequently 20 to 30°C) into surface waters, thus changing their natural thermal and chemical status.

In the case of transboundary aquifers it is important to understand that by interfering into an aquifer in one of the countries hydrodynamic conditions are changed also in the neighbouring countries. Therefore the mode of exploitation and the consequences of thermal water withdrawal have to be known and monitored even in more detail in those areas.

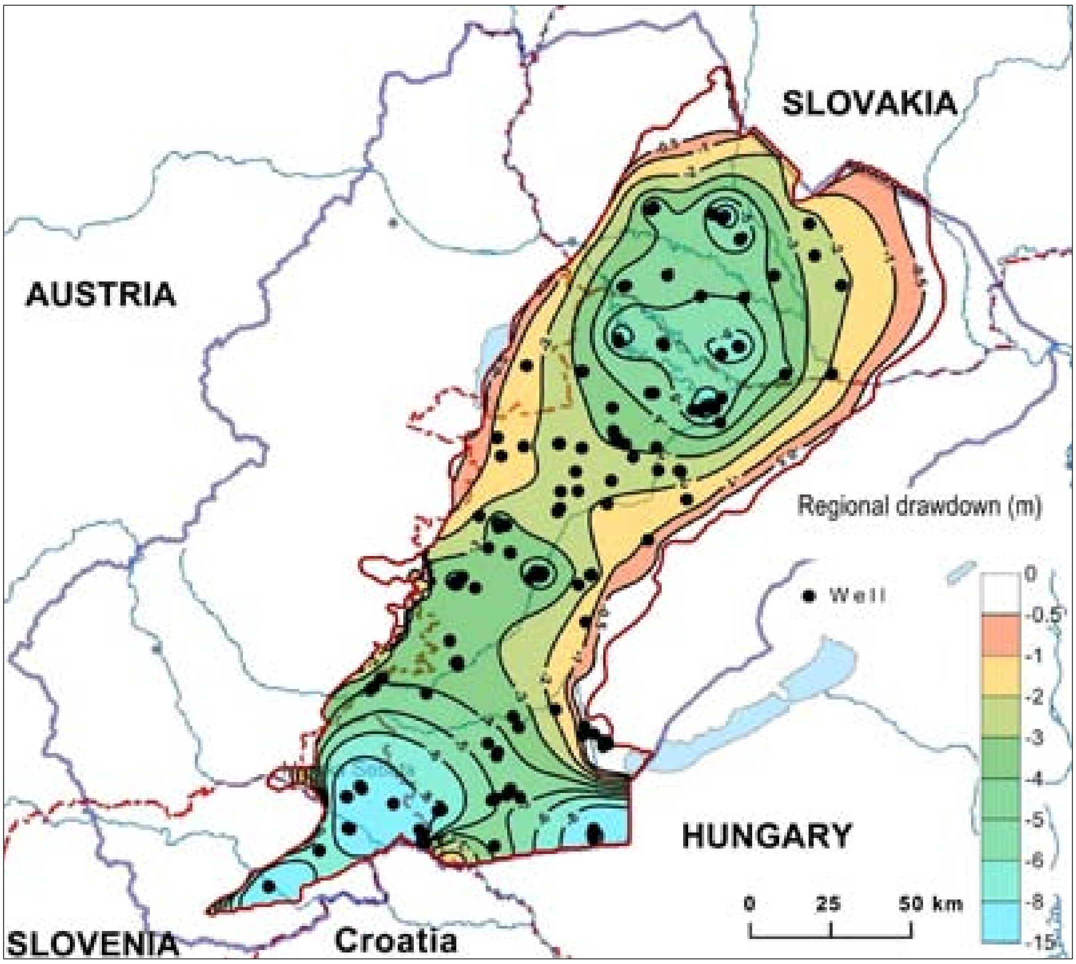

Figure 17: *Simulation of a quasy steady-state regional drawdown of piezometric groundwater level in the Upper Miocene geothermal aquifer due to current thermal water abstraction*

THE SUGGESTED RESEARCH PROCEDURE AND PERMITS FOR THERMAL WATER USE

Drilling of a new geothermal well requires a gradual and interdisciplinary approach. On the basis of natural factors, determined with geophysical, hydrogeological and geochemical investigations, the anticipated use of thermal water can be determined. Its highest efficiency and economic profitability can be attained by a gradual development of the resource:

- **Review study**: Review and reinterpretation of the existing data,
- **Pre-feasibility study**: additional surface investigations and selection of three most promising options,
- **Feasibility study**: selection of the best option, drilling and testing of the research geothermal wells, and
- **Development and exploitation of a geothermal resource**: the research wells can be transformed into the production ones; this is followed by constant optimization of the production scenarios and monitoring of the aquifer behaviour.

A system of continuous annual monitoring of key indicators of exploitation has been developed. Utilization of geothermal energy resources has to fulfill certain criteria:

- Protection of equipment and facilities for the use of thermal water,
- Operational monitoring,
- Energy efficiency of thermal water,
- Balneological efficiency of thermal water,
- The best available technology,
- Management of thermal waste water.

When the annual evaluation of key indicators is good, the concession is granted to the desired extent. In the opposite case, the responsible user has to meet all indicators, otherwise his permit is reduced or discontinued.

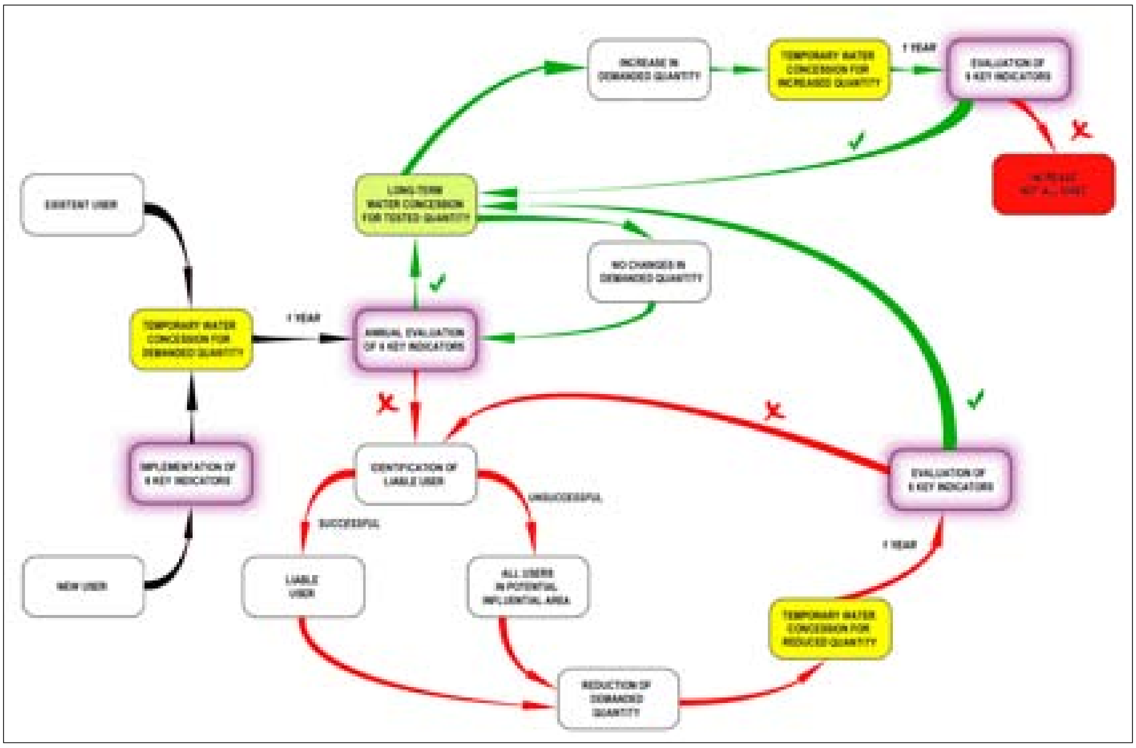

Figure 18: *Proposition of the procedure of granting a concession permit for the use of thermal water and its annual monitoring*

APPROPRIATE MONITORING OF THERMAL WATER USE

An appropriate monitoring of thermal water utilization should ensure reliable data about the energy contribution of a geothermal system and the achievement of environmental goals. Energy goals can be determined if the following parameters are known:

- Mass flow of geothermal fluid (usually water), and
- Temperature difference before and after setting up the unit for geothermal heat extraction.

It is also advisable to know the installed capacity and the utilization factor of available heat.
The achieving of environmental goals is controlled by observing the natural system's response to the extraction and emission of thermal water, and the efficiency of its utilization. This requires monitoring of the listed parameters at constant intervals:

- Quantity of abstracted thermal water,
- Thermal water temperature,
- Pressure at wellhead or piezometric level in active wells,
- Chemical and isotopic composition of thermal water,
- Quantity of reinjected thermal water,
- Temperature of reinjected thermal water,
- Pressure at wellhead or piezometric level in reinjection wells,
- Pressure in the aquifer, at wellhead or piezometric level in observation wells,
- Temperature in the aquifer obtained from temperature profiles in observation wells,
- Technical status of wells,
- Specific yield of production wells or injection capacity of reinjection wells,
- Chemical composition of emitted waste thermal water, and
- Temperature of emitted waste thermal water.

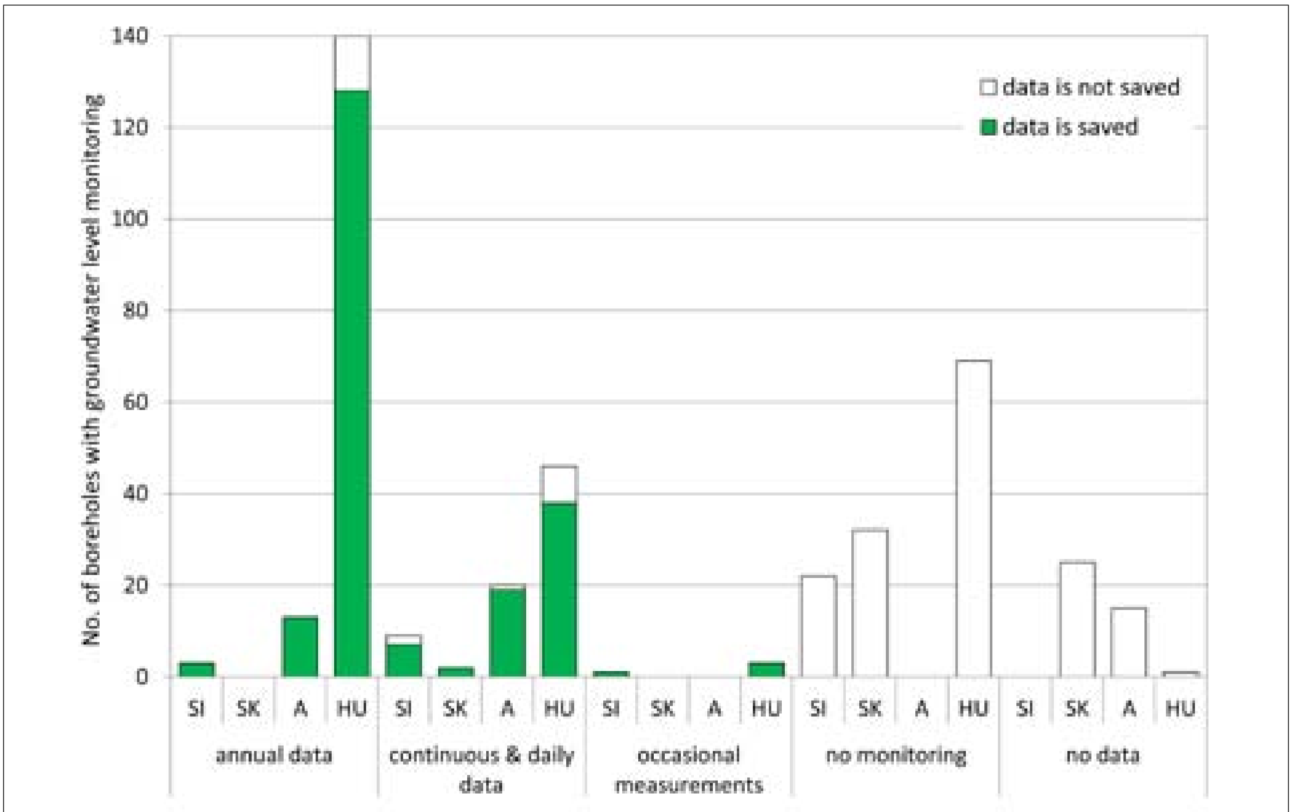

Figure 19: *Existing monitoring network of piezometric groundwater levels by countries*

INDICATORS OF APPROPRIATE AQUIFER MANAGEMENT

Several environmental and energy objectives need to be pursued in geothermal resource management. Environmental goals are primarily determined by the implementation of the Water Framework Directive 2000/60/EC. They are focused on maintaining a good quantitative and qualitative status of geothermal aquifers with a long-term positive water balance. Energy goals mostly follow national plans about increasing the share of renewable energy resources by 2020. In the exploitation of transboundary geothermal aquifers there can be pronounced differences between their (successful) management. In following both objectives, a conflict of interests may emerge; and therefore it is necessary to know the advantages and shortcomings of the present management system. The exploitation is regarded as sustainable when the costs of today's exploitation are not put off to the next generation.

A comparative analysis of managing the same geothermal aquifer in several countries (benchmarking) takes into account the indicators which point out the degree of its sustainable exploitation. The data are interpreted according to the adapted »Lemano« methodology, which comprises a numeric and illustrative evaluation of ten indicators:

- Status of monitoring of production wells,
- Use of best available technology,
- Energy or thermal efficiency,
- Utilization efficiency,
- Balneological efficiency,
- Reinjection rate,
- Recharge of geothermal aquifers,
- Overexploitation of aquifers ,
- Quality of discharged waste thermal water, and
- Information on exploitation available to the public.

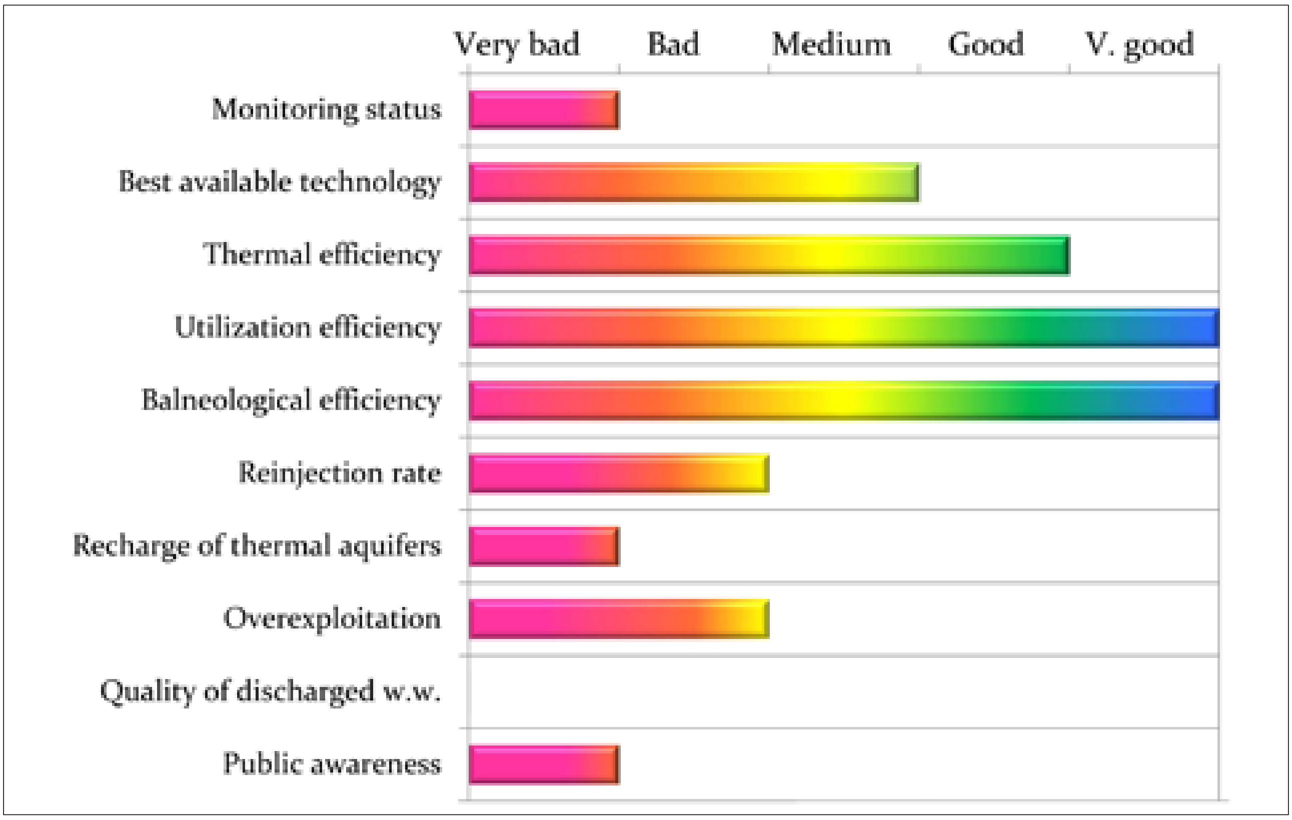

Figure 20: *Benchmarking results for the Upper Miocene geothermal aquifer in the north-eastern Slovenia*

CONCLUSIONS

Results of the TRANSENERGY project have highlighted the existence of transboundary geothermal resources in the area between east Austria, north-east Slovenia, west Hungary and south-west Slovakia. Despite the fact that only low temperature resources have been exploited, we have also outlined the potential areas for intermediate temperature resources. These may be applicable for geothermal electricity production by binary power plants; however, these projects will probably be economically feasible only when the electricity price will increase dramatically. The available data do not foresee the existence of high temperature geothermal resources with steam in the project area.

Geothermal energy is an extremely important natural resource in Central Europe and therefore its exploitation has to be further increased but only in a sustainable way.

Direct use is expected to prevail also in future because of the rather low thermal water temperature. We evaluate that it is possible to sustainably exploit the current resources by applying best available technology, cascade use and reinjection. Consequently, further development of geothermal resources in the region is not questionable but only if proper exploitation and management practice is established. Besides, it is also crucial to establish joint and systematic monitoring systems of exploitation, quantity and quality state of transboundary geothermal resources.

Additional information can be found on the project website http://transenergy-eu.geologie.ac.at/ or at the representatives of the partner's geological surveys.

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REFERENCES

Magdalena Bottig, Gregor Goetzl, Stefan Hoyer, Fatime Zekiri. 2013. Report on the Vienna Basin pilot area model. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Tadej Fuks, Mitja Janža, Dejan Šram, Andrej Lapanje. 2013. Report on Bad Radkersburg – Hodoš pilot area model. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Emese Gáspár, György Tóth et al. 2013. Report on the Komárno - Štúrovo pilot area model. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Geotermia Expressz Mérnöki Tanácsadó Iroda. 2012. Geothermal energy feasibility study - Geothermal power plant at Csömödér and Direct heat utilization in the area of Ács-Gönyű-Zlatá na Ostrove. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Gregor Goetzl, Stefan Hoyer, Fatime Zekiri et al. 2012. Summary report of geothermal models at supra-regional scale. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Attila Kovács, Ágnes Rotár Szalkai et al. 2013. Report on the Zsira- Lutzmannsburg pilot area model. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Andrej Lapanje, Joerg Prestor. 2011. Overview of EU, national and regional legislation. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Andrej Lapanje, Simon Mozetič. 2013. Detailed cross-border monitoring and reporting assessment of the Bad Radkersburg - Hodoš pilot area. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Gyula Maros, Gáspár Albert, Rita Barczikayné Szeiler et al. 2012. Summary report of geological models. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Slavomír Mikita, Jaromír Švasta, Radovan Černák et al. 2011. Common multilingual database with harmonized datasets. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Annámaria Nador. 2013. List of legal and economic deficiencies - Non-technical barriers of geothermal development. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Mario Pleničar et al. 2006. Geološki terminološki slovar. *Jernej Pavšič* (Ed.). Ljubljana : Založba ZRC.

Joerg Prestor, Andrej Lapanje. 2010. Questionnaire for authorities involved in management of geothermal energy and Database of authorities. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Joerg Prestor, Annámaria Nador, Andrej Lapanje. 2012. Methodology for joint groundwater management. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Joerg Prestor, Andrej Lapanje. 2013. Catalogue of monitoring and reporting measures. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Joerg Prestor, Nina Rman, Andrej Lapanje, Teodóra Szőcs. 2013. Benchmarking - sustainability of thermal groundwater management. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Ágnes Rotár Szalkai. 2012. Evaluation of potential demonstration sites by outlining geothermal reservoirs above 50°C. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Ágnes Rotár-Szalkai, György Tóth, Emese Gáspár et al. 2013. Summary report of the steady-state modelling. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Nina Rman, Tadej Fuks. 2012. Database of users and database of current and potential utilization parameters. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Nina Rman, Andrej Lapanje, Dušan Rajver. 2012. Analiza uporabe termalne vode v severovzhodni Sloveniji = Analysis of thermal water utilization in the northeastern Slovenia / Geologija, 55/2, 225-242.

Nina Rman, Tadej Fuks, Špela Kumelj. 2012. Utilization maps. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

Jaromír Švasta, Anton Remšík, Radovan Černák et al. 2013. Report on the Danube basin pilot area model. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

György Tóth, Ágnes Rotár-Szalkai, Tamás Kerékgyártó et al. 2012. Summary report of the supra-regional hydrogeological model. Ljubljana : GeoZS; Bratislava : SGUDS; Budapest : MFGI; Wien : GBA.

GLOSSARY

Alluvium: sediments which were deposited by flowing water, usually silt, clay, sand and gravel.

Andesite: an intrusive igneous rock of the diorite group.

Aquifer: a permeable rock or sediment filled with water, and from which it is possible to economically produce groundwater.

Asthenosphere: a ductile region of the upper part of the Earth's mantle where upon tectonic plates are moving.

Basalt: an intrusive igneous rock of the gabbro group.

Delta: a depositional environment that is formed at the mouth of a river where it flows into the lake or sea.

Diagenesis: chemical, biochemical and physical processes which control and enable formation of rocks.

Fissured and fractured porosity: empty space in rocks due to cracks and fissures.

Geothermal doublet: a pair of a production and a reinjection well which enable exploitation of geothermal heat energy.

EGS: an enhanced geothermal system where the reservoir is artificially developed.

Infiltration: a process of water transfer from the ground surface into the soil and rocks and therefore enables formation of groundwater.

Cascade use: exploitation of geothermal heat in multiple steps and different utilization schemes.

Clastic sediments and rocks: they are formed by weathering, erosion and transport of older rocks whose grains and minerals were deposited by sedimentation in aqueous or terrestrial environment.

Conduction: a heat transfer in direction from higher to lower temperature through the not moving matter.

Convection: a combination of heat transfer by conduction and moving matter, usually water.

Intergranular porosity: pore spaces between grains or minerals in rocks.

Paratethys: the Neogene sea which spread from the Pannonian plain to the Black Sea, and was parallel to the Tethys Sea.

Reinjection: a procedure of returning thermally exploited groundwater back into the aquifer through a reinjection well.

Rhyolite: an intrusive igneous rock of the granite group.

Sedimentary basin: a subsided area where sedimentation in the marine, brackish, lacustrine or terrestrial environment occurred.

Thermal karst: karstified carbonate rocks in the basement of the sedimentary basin with a significant thermal water flow.

Turbidites: clastic rocks which were formed due to mudflows or underwater avalanches. Sand lenses are usually separated by sequences of silt or clay.

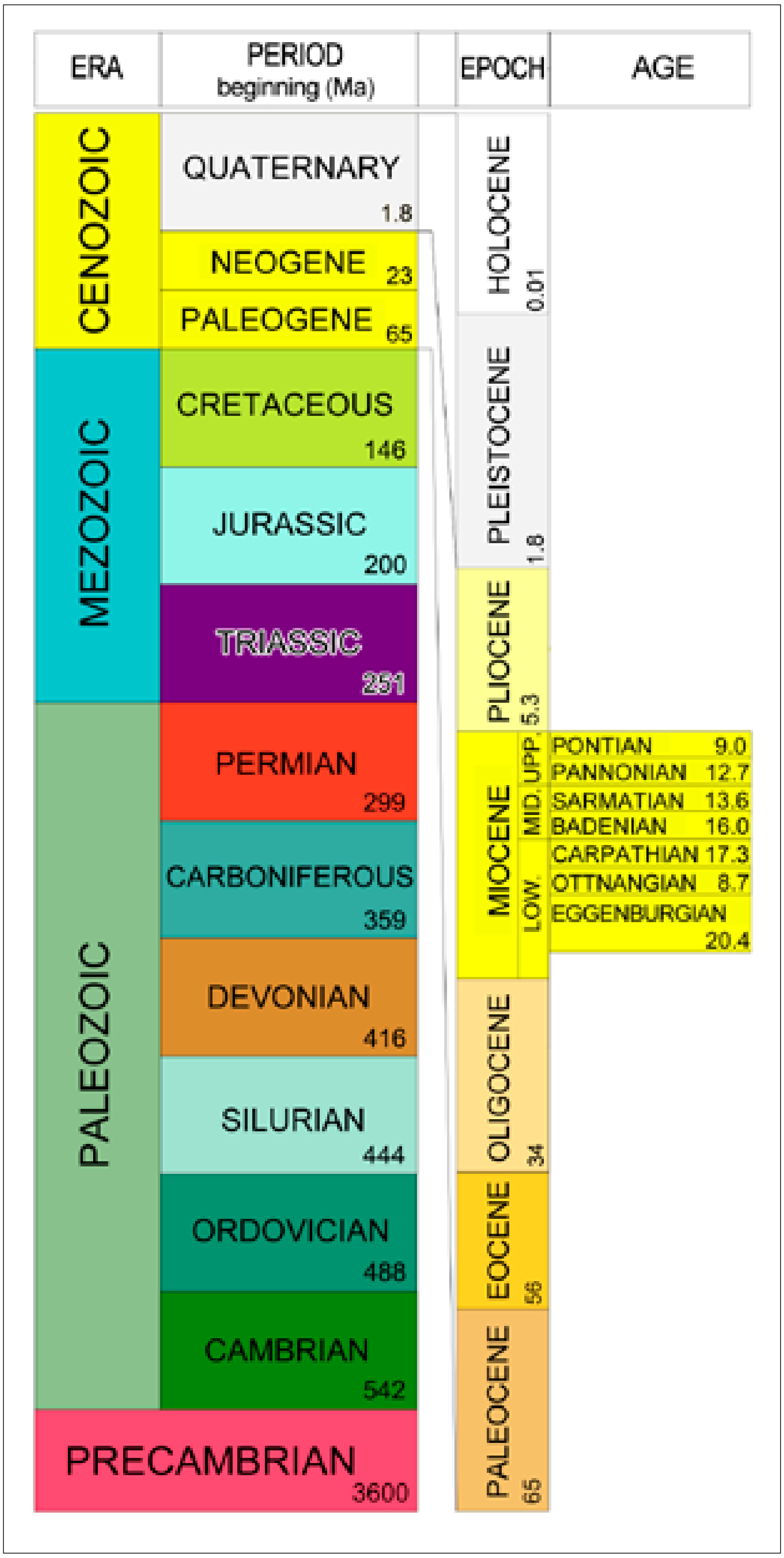

Figure 21: *Geological time scale for the Central Paratethys*

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