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Dear Participants and Interested Readers,

The trend towards a more intense and diverse use of our groundwater resources means that there is a growing need for professional hydrogeologists who can provide adequate answers to help with long term complex groundwater management. The international Association of Hydrogeologists (IAH) with its more than 4000 members is the largest association which aims at promoting international co-operation and sharing knowledge across geographical and political borders, encouraging worldwide application of hydrogeological skills through education and technology transfer programmes, as well as publishing, sponsoring meetings and co-operating with many agencies in the UN and other organisations.

The members of some National Chapters have already realized that working together and cooperating in joint actions as an association can result in a more efficient sharing of information and knowledge dissemination. In the framework of enhancing the regional activities of the IAH, the Hungarian National Chapter has initiated a series of conferences, starting with the organization of the first Central European Groundwater Conference.

The Central European region is rich in (transboundary) thermal waters and there is a continuous and growing need for their exploitation. Therefore the focus of this conference is on geothermal topics. One of the key issues in the long term sustainable management and governance of groundwater, not just now but also for post 2020, is how to ensure that there are enough properly qualified hydrogeologists to meet societal needs. A special session will be reserved to discuss the challenges and relevant directions in education. In accordance with the aims of IAH I am pleased to welcome the more than 80 participants from 9 countries representing 6 National Chapters

I hope this will be a productive conference for all participants, and a nice time in Morahalom. For those who have time for a break, I hope you have a nice time exploring Hungary!

I hope this initiative from the Hungarian National Chapter will not only be successful, but will also lead to a fruitful cooperation in the coming years. We hope that other National Chapters will also continue to follow this initiative.

István Fórizs

Chair of the IAH Hungarian National Chapter

To the Reader,

Inspired by the fact that groundwater related issues has been gaining their importance, the Hungarian National Chapter of the International Association of Hydrogeologists (IAH) has decided to launch a series of conferences entitled "Central European Groundwater Conference", shortly CEG Conference.

This volume contains the abstracts and short papers of the first CEG Conference to be held in Mórahalom, Hungary, between 8^{th} and 10^{th} of May, 2013. Since the spot light is on the different applications of thermal waters, the majority of the papers are linked to this topic, but other topics are represented as well like "Advanced modelling: flow and heat", "Drilling technologies, well completion and hydrodynamic investigations", "Regulation and legislation" and "Education and training in Hydrogeology".

Our vision is to hold this conference annually or biannually in the countries of Central Europe providing a regional forum for everybody whose work is involved with groundwater, and giving the participants an opportunity to know each other, the problems of each other and to make professional contacts. Why regional? Because most of the groundwater issues are manifested on a regional scale. So a good regional co-operation is essential for proper solving of problems.

I hope the reader will like this volume and will find interesting ideas in the abstracts and short papers.

IAH CEG Conference Program

<u>Tuesday – 7 May, 2013</u>

16.00 – 20.00	Registration
18.00 – 20.00	Ice-breaker party

<u>Wednesday – 8 May, 2013</u>

8.30 – 12.30	Registration
9.00 – 09.45	Welcome ceremony
9.45 – 10.00	Report of previous event:4th European Geothermal PhD Day
10.00 – 10.30	<u>Keynote 1:</u> József Tóth (University of Alberta): ***Geothermal phenomena in the context of gravity-driven basinal groundwater flow***
10.30 – 11.00	*Coffee break*
11.00 – 11.30	<u>Keynote 2:</u>László Rybach (ETH Zurich): ***Innovative energetic use of shallow and deep groundwaters: Examples from China & Switzerland***
11.30 – 12.00	<u>Keynote 3:</u> Judit Mádl-Szőnyi (ELTE Budapest): ***Geothermal potential of Hungary: what can we learn from the flow-system approach?***
12.30 – 14.00	*Lunch*
14.00 – 16.30	Oral Presentations (concurrent sessions)
16.30 – 17.30	Poster Presentations
18.00 – 19.00	Social event
19.00 – 21.00	*Dinner*

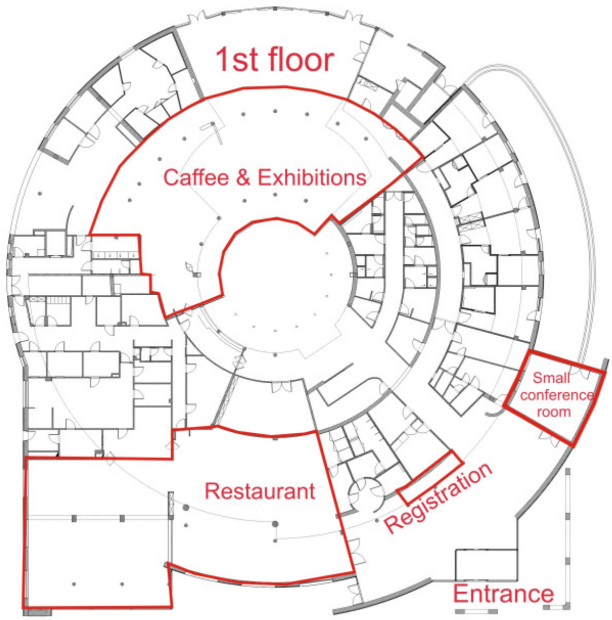
<u>Thursday – 9 May, 2013</u>

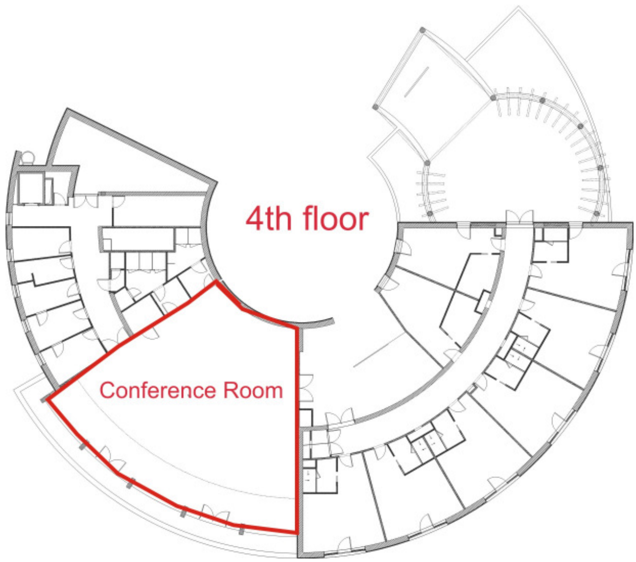
8.00 – 9.30	Introduction of the Central-European IAH National Chapters
9.30 – 10.00	Brand-new technology session
10.00 – 10.30	*Coffee break*
10.30 – 13.00	Oral Presentations (concurrent sessions)
13.00 – 14.30	*Lunch& Press conference*
14.30 – 16.00	Round Table Discussion on Education in Hydrogeology
16.00 – 18.30	Visiting the Geothermal System of Mórahalom (on foot)
19.00 – 21.00	*Closing - Gala Dinner*

<u>Friday – 10 May, 2013</u>

08.00 – 12.00 Field trip to the South-East Hungarian Geothermal Field (by bus)

Conference venues





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Plenary Events

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Thursday, May 9, 2013 – Conference Room
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14.30 – 16.00
Round table discussion on Education in Hydrogeology

Wednesday, May 8, 2013 – Conference Room

Chaimen: *Gyula Dankó / Marco Petitta*

Section	Time	Author(s)	Title
Origin of thermal waters: hydrogeology, chemistry, age, isotopes	14.00 - 14.15	Fabbri P.	Characteristics of the geothermal Euganean Basin (Veneto region, NE Italy)
	14.15 - 14.30	Stevanovic Z., Dulic I., Duncic M.	Some experiences in tapping deep thermal waters of Triassic karstic aquifer in Pannonian basin of Serbia
	14.30 - 14.45	Borović S., Marković T., Larva O.	Hydrogeological and hydrochemical characteristics of Daruvar geothermal aquifer (Croatia)
	14.45 - 15.00	Kuz'mina E. A., Didenkov Y., Veshcheva S.	Genesis of thermal waters in the Baikal Rift System (based on physical and chemical simulation)
	15.00 - 15.15	QUESTIONS	
	15.15 - 15.30	Weyer K. U., Ellis J. C.	Groundwater dynamics of thermal areas and geysers in Yellowstone National Park
	15.30 - 15.45	Varsányi I.	How does the chemical composition of water relate to the hydraulic continuity in the Great Hungarian Plain
	15.45 - 16.00	Erőss A., Mádl-Szőnyi J., HorváthÁ.	Radionuclides as mixing indicators of thermal waters
	16.00 - 16.15	Grassi S., Doveri M., Ellero A., Palmieri F., Vaselli L.*	Study of the Montecatini and Monsummano Terme low temperature geothermal prospects (Tuscany- Central Italy)
	16.15 - 16.30	QUESTIONS	

Wednesday, May 8, 2013 – Small Conference Room
Chaimen: *Péter Szűcs / Andrzej Kowalczyk*

Section	Time	Author(s)	Title
Others	14.00 - 14.15	Szőcs T., Tóth Gy., Rotár-Szalkai Á., Gál N., Nádor A., Zilahi Sebess L., Gulyás Á., Merényi L.	Combined hydrogeological-geophysical surveys in geothermal resource evaluations and sustainable thermal water exploitation, Hungary
	14.15 - 14.30	Kovács B., Kolencsik-Tóth A.	Evaluation of groundwater-surface water interaction along the Tisa river
	14.30 - 14.45	Bernáth Gy.	Calculating measured pressure values to different depths in the case of producing and non-producing wells
	14.45 - 15.00	Madarász T., Szűcs P., Kovács B., Lénárt L.	Well aHead – a source of fresh thoughts in groundwater management
	15.00 - 15.15	QUESTIONS	
	15.15 - 15.30	Kowalczyk A.˒Sitek S., Witkowski A. J.	Impact of theTarnowskie Gory urbanised area (Poland) on groundwater contamination by chlorinated hydrocarbons
Renewable electricity supply: geothermal power plant	15.30 - 15.45	Dankó Gy., Bőthi Z.	Optimization of geothermal system for sustainable power generation
	15.45 - 16.00	QUESTIONS	

Thursday, May 9, 2013 – Conference Room
***Chaimen**: László Rybach / Balázs Kovács*

Section	Time	Author(s)	Title
Advanced modelling: flow and heat	10.30- 10.45	Hokr M., Rálek P., Balvín A., Straka T.	Thermal interaction of rock and water controlled by temperature variations in a tunnel
	10.45 - 11.00	Kaiser B. O., Cacace M. , Scheck-Wenderoth M.	Three-dimensional convection within the Northeast German Basin
	11.00- 11.15	Pola M., Fabbri P., Piccinini L., Zampieri D.	A new hydrothermal conceptual and numerical model of the Euganean Geothermal System - NE Italy
	11.15 - 11.30	Weyer K. U., Ellis J. C.	Effect of gravitational forces on thermal groundwater flow
	11.30 - 11.45	QUESTIONS	
	11.45 - 12.00	Szűcs P., Székely F., Zákányi B.	Different modeling methods to simulate groundwater flow to multi screen wells
	12.00 - 12.15	Merényi L.	Simulation of thermal interaction between groundwater and borehole heat exchanger
	12.15 - 12.30	Kovács A., Rotár-Szalkai Á.	A coupled geothermal model of the Alpokalja area, Hungary
	12.30 - 12.45	Lux M.	Hydrodynamic modelling and geothermal potential in an overpressured basin
	12.45 – 13.00	Gáspár E., Tóth Gy., Švasta J., Remsik A., Bodis D., Černák R.	Hydraulic and Geothermal modelling on the Komarno-Šturovo Pilot Area of the TRANSENERGY project

Thursday, May 9, 2013 – Small Conference Room
Chaimen: *Judit Mádl-Szőnyi / Zoran P. Stevanovic*

Section	Time	Author(s)	Title
Drilling technologies, well completion and hydrodynamic investigations	10.30- 10.45	Mező Gy., Andrássy M., Korpai F., Dankó Gy.	Cross-hole test in geothermal wells
Direct geothermal energy use: heating, balneology, etc.	10.45 - 11.00	Erőss A., Zsemle F., Pataki L., Csordás J., Zsuppán K., Pulay E.	Heat potential evaluation of effluent and used thermal waters in Budapest, Hungary
Sustainable thermal water reservoir management	11.00- 11.15	Buday T., Bódi E.	Effects of approaches generating different solid models on hydrodynamic models based on the case study of Hajdúszoboszló, East-Hungary
	11.15 - 11.30	Novák P., Hokr M.., Lachman V., Štrunc J., Hladký R.	Significance of a water bearing fracture for underground thermal energy storage - a model of middle scale laboratory experiment
	11.30 - 11.45	QUESTIONS	
	11.45 - 12.00	Piscopo V., Baiocchi A., Lotti F.	Hydrogeological approach in sustainable management of thermal waters: two examples from Italian volcanic aquifers
	12.00 - 12.15	Petitta M., Brunetti E., Carucci V., Sbarbati C.	Groundwater flow and geochemical modeling of the Acque Albule thermal basin (Central Italy): influences of human exploitation on flowpath and thermal resource availability
	12.15 - 12.30	Rotár-Szalkai Á., Gál N., Szőcs T., Tóth Gy., Lapanje A., Cernak R., Scubert G., Götzl G.	Geothermal reservoirs in the western part of the Pannonian Basin
	12.30 - 12.45	Milanović P.	Specific Investigation methods in karst

Poster section

Wednesday, May 8, 2013 – Conference Room ***Chaimen:** Ágnes Tahy / Tamara Marković*	
Fejes Z., Szűcs P.	Potential thermal water resources in Szerencs area
Mikita V., Kovács B., Szanyi J., Virág M., Kiss M.	Geothermal conditions of the Szabolcs-Szatmár-Bereg and Satu Mare transboundary region
Székely F.	Evaluation of packer tests in deep open boreholes
Mádl-Szőnyi J., Simon Sz.	Hydraulic framework of sustainable thermal water production from a gravitational-overpressured system on the example of Duna-Tisza Interfluve, Hungary
Kompár L., Szűcs P., Palcsu L., Deák J, Dobos E.	Isotope measurements at different sites to estimate the recharge at the Danube-Tisza Interfluves
Szongoth G., Buránszki J.	Inspection of thermal wells in Szentes area
Ötvös V., Erhardt I., Czauner B., Erőss A., Simon Sz., Mádl-Szőnyi J.	Hydraulic evaluation of the flow systems of Buda Thermal Karst, Budapest, Hungary
Zákányi B., Szűcs P., Tóth M.	Sensitivity of DNAPL transport simulations concerning the relative permeability data
Kun É., Székvölgyi K., Gondárné Sőregi K., Gondár K.	Inferences from 3D modelling of thermal karstic reservoir (SW Bükk Mountain)
Bálint A., Kiss S.	Development plan of the Szentes geothermal field based on hydrodynamic modeling
Madarasi A.	Electrical conductors in basement – a magnetotelluric insight into the geothermal potential
Pulay E., Mádl-Szőnyi J.	Hydraulic and thermal evaluation of Gödöllő Area, Hungary, for geothermal purposes
Czinkota I, Szanyi J, Kovács B, Vadkerti Zs., Papp M.	The effect of the thermal water aeration and water-rock interaction
Lénárt L., Szegediné Darabos E.	Hydrodynamics of cold and warm karst systems in the Bükk region
Kis B. M., Kármán K., Baciu C.	Origin of mineral water springs from Rodna-Bârgău area (Eastern Carpathians, Romania)
Mádl-Szőnyi J., Virág M., Zsemle F.	Hydrogeological establishment of the installation of water based geothermal heat pump systems in Budapest, Hungary
Cerutti P., Ducci, D., Fabbri P., Fidelibus M. D., La Vigna F., Lo Russo S., Manzella A., Mazza R., Polemio M., Sottani A.	Sustainable use of geothermal resources in Italy: first inventory of data, applications and case studies

Geothermal phenomena in the context of gravity-driven basinal groundwater flow

József Tóth

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Gravity-driven groundwater flow systems function as subsurface conveyor belts in topographic basins. They pick up, move and deliver fluids, gases, solutes, colloids, particulate matter and heat from loading sites in recharge areas and on their way to the discharge areas. Flow systems of various horizontal and vertical extents are organized into hierarchically nested complex patterns controlled by the configuration of the water table's relief and modified by the rock framework's heterogeneities. The systems are ubiquitous and act simultaneously on broad ranges of the spatial and temporal scales of measurement. Their universal geologic agency is manifest by a great number of different and widely disparate natural processes and phenomena, several of which are associated with geothermal heat flow. The understanding of geothermal phenomena in the context of basinal flow systems requires, therefore, a general familiarity with the umbrella "theory of regional groundwater flow" which, in turn, comprises two component theories, namely: 1. "The hydraulics of basin-scale groundwater flow systems" and, 2. "The geologic agency of basin-scale groundwJater flow- systems." The talk's structure is based on the above view.

The *Introduction* reviews the evolutionary history, principal aspects and current state of the art of the theory and its practical applications. In Section 2, the *hydraulics of basin-scale groundwater flow systems*, the progressive historical stages of the analysis of flow patterns and fluid dynamic parameters are presented, while Section 3, the *geologic agency of basin-scale groundwater flow,* exemplifies different natural processes and phenomena mediated by moving groundwater. Section 4, *geothermal phenomena in the context of gravity flow of groundwater,* focusses on geothermal effects of groundwater flow and presents examples from the very first theoretical models through case studies of thermal springs and wells, hypogenic karst development, and petroleum accumulations. The C*onclusion* conveys the author's conviction that geothermal studies conducted for whatever purpose can not be complete without consideration of the area's groundwater flow regime.

Innovative energetic use of shallow and deep groundwaters: Examples from China & Switzerland

Ladislaus Rybach

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The heat content of shallow or deep aquifers can be used for space heating. Two innovative systems will be described in detail: a geothermal heat pump system based on a single well, and a cascading use of tunnel waters.

The "Single Well System" (HYY SWS) was invented and developed by Beijing Ever Source Science & Technology Development Co., Ltd (HYY) to provide buildings with heating & cooling as well as with domestic hot water. The powerful system operates at about 500 kWth capacity. Unlike traditional groundwater heat pump systems, in which two wells are used (one for pumping groundwater out and the other to dispose of cooled water), the HYY SWS uses one specially designed well for production and reinjection. A borehole with a depth of about 70-80 m and a diameter of 0.5 m is drilled for HYY Single Well Systems. The necessary local geological site condition is to have a shallow aquifer with a hydraulic conductivity of 10^{-3} m/sec or higher. Many such systems operate now in China, several of which serve e.g. the 2008 Summer Olympic Facilities in Beijing.

Switzerland has, in its mountainous parts, hundreds of deep tunnels. Tunnels drain the rock overburden and, depending on its thickness, water temperatures up to 50 °C can be encountered and utilized. The most straightforward and cheapest form of tunnel heat usage is to collect and transport inflowing waters via ducts to the portals, with as little temperature drop as possible. The thermal power depends on flow rate and temperature. At or near the portals the heat content of the waters can be used for various applications. When the temperature level of the tunnel water outflows is too low for direct applications (e.g. for district heating), heat pumps are employed. From Switzerland a whole suite of uses can be reported: space heating, greenhouses, balneology & wellness, fish farming. At the northern portal of the 35 km long Loetschberg base tunnel at Frutigen, the tunnel water is used subsequently ("cascading") for space heating, greenhouse, and fish farming (incl. caviar production).

Geothermal potential of Hungary: what can we learn from the flow-system approach?

Mádl-Szőnyi Judit

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The objective of the presentation is to give an insight into the favourable geothermal conditions of Hungary and to demonstrate the possibilities of applying the regional groundwater-flow approach in understanding and exploiting the natural geothermal systems of the country.

Hungary is located in Central-Europe. In geological sense, the area is part of the Pannonian Basin. The center of the Basin has favourable geothermal conditions for exploitation, with a thinned lithosphere of 60-100 km thickness (Horváth 2005) resulting in an elevated heat flow density of 80 to 110 mWm^{-2} (Dövényi et al. 2002). The region is characterized by an average geothermal gradient of ~45°C/km, which is well above the 30°C/km global value. Also the hydrogeological conditions are favourable. Thermal water is found in carbonate reservoirs of the Pre-Neogene basement and Neogene siliciclastic reservoirs over 70% of the country's area (Mádl-Szőnyi 2006). The deep crystalline rocks and the rock temperature of ~200°C at a depth of ~-4000, the so called „seismic calm" environment (Dövényi et al. 2005), may be a reason for interest in geothermal exploration in the future by the EGS (Enhanced Geithermal Systems). The utilization of thermal water has a long tradition in Hungary. However the current share of geothermal energy in the renewable energy mix is only 0,42% (KSH 2011).

As it is demonstrated, the required components of a natural geothermal systems, namely, heat, reservoir and water, are provided by the geological conditions in Hungary. Owing to the regionally extensive aquifer systems and their high hydraulic conductivity and transmissivity, hydraulic continuity exists for the gravitationaly driven part of the systems (Tóth 1995). Moreover, the effect of regional fluid-flow patterns on the temperature distribution in these systems as shown, e.g., by Domenico and Palciauscas (1973), should not be neglected. Consequently, understanding the operation and processes of geothermal systems can, and should, be built on the study and knowledge of the regional flow patterns.

The presentation will show examples for the influence of regional flow systems on some issues of geothermal exploitation, such as: i) sustainability – renewable or non-renewable resources; ii) geothermal well alignment - hydraulic behaviour of faults; iii) geothermal installations in deep carbonates – transmissivity enhancement by hypogene speleogenesis.

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Characteristics of the Geothermal Euganean Basin (Veneto region, NE Italy)

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The low-temperature (i.e. liquid-dominated) geothermal system in the Euganean area extends over a plain covering about 23 km^2 immediately east of the Euganean Hills, which comprises the towns of Abano Terme, Montegrotto Terme, Battaglia Terme and Galzignano Terme (NE Italy). "Terme" is the Italian word for "spa". About 134 mining claims have been issued in the area (57% in Abano, 31% in Montegrotto and 12% in Battaglia and Galzignano), and more than 400 groundwater wells have been drilled. At present about 250 wells are under exploitation, only 8% of which are flowing artesian wells (Battaglia-Galzignano area). The total volume of hot water extracted in the year 2010 was about 10 millions m^3 in Abano, and about 5.0 millions m^3 in Montegrott o. Most of the groundwater wells in the Euganean geothermal area are drilled for several hundred meters into rock formations, mainly limestones, but the cased intervals are restricted to the Quaternary cover. The depths of the wells range from about 300 m to more than 1000 m. The temperature of the thermal waters ranges from 60 to 86 °C (Fabbri and Trevisani, 2005), and their total dissolved solids content (TDS) is approximately 6 g/l, with a primary presence of $Cl^-$and Na^+ (70%) and secondary of SO_4, Ca^{2+}, Mg^{2+}, HCO^{3-}, SiO_2.

Piccoli et al. (1973) were the first to hypothesize that the Euganean groundwaters are of meteoric origin, i.e. deriving from precipitation that infiltrates at about 1500m asl (meters above sea level). These authors reached this conclusion on the basis of a detailed geological knowledge of the region, hydrogeological and geophysical studies, and above all, data on $\delta^{18}O$ and saltwater contents. Gherardi et al. (2000) confirmed this hypothesis.

Tritium measurements performed in the early 1970s suggested that groundwater residence time was greater than 25 years (Norton and Panichi, 1978). A study by Sartori et al. (1997) extended the lower limit of the fluid residence time to 60 years. On-going accelerator mass spectrometry (AMS) investigations of ^{14}C content indicate that residence time could be much longer than 60 years, perhaps even several thousands of years (Boaretto et al., 2003).

At present, the groundwater level in the Euganean geothermal area seems to have stabilized, after the aquifer had been overexploited during the 1970s and 1980s. For example, the potentiometric level in the Abano field is now about 3m a.s.l. during periods of low exploitation (winter and summer), and about -3 m a.s.l. during periods of intense groundwater extraction (spring and autumn). The thermal water is mainly used for therapeutic purposes and in popular spa facilities, including more than 170 hotels, at Abano, Montegrotto and Battaglia-Galzignano. In the Battaglia-Galzignano field the hot fluids are also used to heat greenhouses. The Veneto region at present has local legislation prohibiting the private use of the Euganean hot waters for domestic heating purposes.

These groundwater heads correspond to that of the aquifer located in the Biancone limestone at a depth of 300–500 m, whose transmissivity ranges between 13 and 500m^2/day; the spatial distribution of the transmissivities was presented by Fabbri (1997).

Recently, deep wells (up to 1000 m depth) have been drilled in the Euganean area, especially in the Abano field, where the water temperatures in the limestone reservoir ranged between 60 and 70 °C. The results were very interesting: not only were temperatures of about 80 °C measured in the deep wells, but the potentiometric levels were also higher than in the 300–500 m deep aquifer. Most of these wells are flowing artesian (i.e. their potentiometric level is about 10–11m a.s.l.). A study of the characteristics of the different aquifers in the area confirmed that the shallow and deep aquifers are hydraulically interconnected (Antonelli et al., 1995). All the wells, many completed in different aquifers and depths, show similar water-level fluctuations over a given year, with two minima (spring and autumn) and two maxima (winter and summer).

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Some experiences in tapping deep thermal waters of Triassic karstic aquifer in Pannonian basin of Serbia

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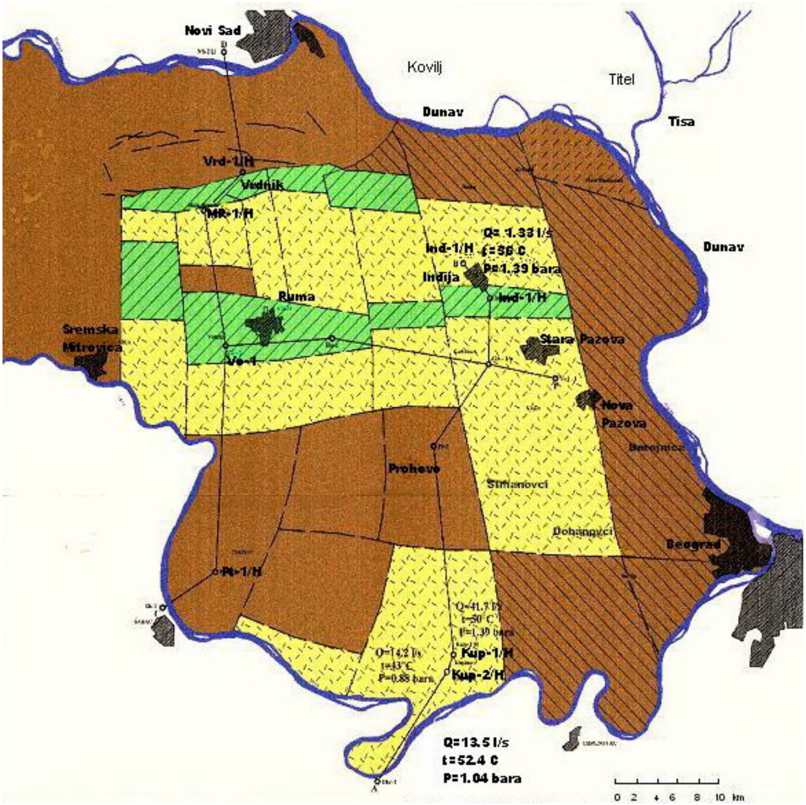
In the Pannonian basin (Great Hungarian basin) of northern Serbian province of Vojvodina, four hydrogeological (HG) systems were defined and described (Marinovic, 1982, Aksin et al. 1991). HG system I as the first from the top (Quaternary and Middle and Upper Pliocene), is most prominent and till nowadays mostly exploited in water supply. HG system II is the next deeper (Pontian, Panonian - Lower Pliocene and Upper Miocene a ges' sediments), while in HG system III (Miocene, Paleogene, Cretaceous) the presence of highly mineralized water has been confirmed during drilling of oil or geothermal wells. The deepest one is HG system IV, the fissured aquifer of the basement (Paleozoic, Triassic).

The basement of thick Tertiary sedimentary complex of the Pannonian basin in Serbia consists of various litho-stratigraphical units of Paleozoic and Mesozoic ages. They represent extension of the Alpine, geostructural branches (Dinarides and Carpathians), including metamorphic, magmatic and sedimentary rocks of Tiszia Mega-Unit, Serbian-Macedonian Massif and Vardar Zone. Among them the largest prospect for tapping geothermal waters has Triassic carbonate rocks.

The Lower, Middle, and Upper Triassic carbonate–clayey aleurolites, sandstones, sandy limestones, dolomite limestones and reefal zones various limestones were found in drilled deep boreholes at a depth of 470 m and 2890 m near Hungarian border (northern part of Vojvodina) and several other localities in eastern and northern parts of the basin. The thickness of drilled Triassic sediments has been estimated to range between 11 m and 620 m. However, larger extension in paleorelief and prospect for tapping geothermal flow has Triassic carbonate sediments in the southern and SW part of Pannonian basin (Srem) and in adjacent area (Mačva, Semberija in Sava tectonic graben). In Srem area, the Triassic carbonate sediments were encountered at a depth of 10 m (close to horst structure of Fruska Gora) and 1037 m (Fig. 1), while in other localities in adjacent area (Semberija, Posavina) they are drilled at a depth of 1192 m and 2410 m. The thickness of the carbonate sediments ranges from 21 m to 400 m. In that area Triassic karstic aquifer has been tapped by several boreholes with depths ranging from 400 m to 2400 m. The hottest water has temperature which exceeds 75^0C, while maximal discharge is 40 l/s.



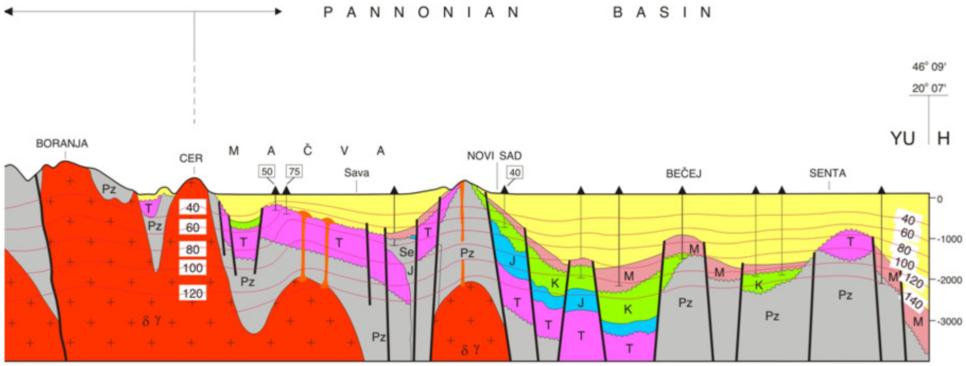
Most prosperous for utilization of geothermal energy is the southern rim of the Pannonian basin in Mačva region where several highly productive deep boreholes were also drilled in the Triassic aquifer (Table 1). The most productive are the wells drilled in Bogatić village. Their depths are in range of 418-670 m, yields are about 40 l/s and water temperatures 75-80^{0}C (Martinovic & Milivojevic, 1998).

Well (location)	Discharge (l/s)	Temperature (^{o}C)	Thermal power (MWt)
BB-1 Bogatić	37	75	8.5
BB-2 Bogatić	60	80	15.1
DB-1 Dublje	15	50	1.9
DB-2 Dublje	10	30	0.4
BBe-1 Belotic	12	35	0.8
BMe-1 Metkovic	15	67	2.9

Table 1.- Geothermal wells of Mačva region (after Milivojevic & Martinovic, 2000)

Although generally well fractured and karstified not all of Triassic horizons are promising for tapping and utilization. It is typical non-homogenous anisotropic media with various porosity degrees, both vertical and lateral. Additional limitation for productivity of Triassic aquifer is when marly and clayed sequences are prevailing in lithology. And finally, when the thick and compact impermeable rocks such as Cretaceous flysch is overlying Triassic carbonates the later are regularly compressed and their porosity is additionally reduced.

Such situation has been proven by several boreholes drilled north of Danube River in Backa region of Vojvodina (Fig. 2). In some cases Triassic limestones are overthrusted and sandwiched between metamorphic rocks of Tiszia Fm. and underlying Jurassic ophiolites (Dulić et al. in press). The permeability of Triassic rocks is then very low and presence of geothermal flow limited.



Most prosperous from geothermics point of view are therefore limestones or dolomites covered by Tertiary sediments, exclusively.

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Hydrogeological and hydrochemical characteristics of Daruvar geothermal aquifer (Croatia)

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The geothermal aquifer of Daruvar supplies water to the springs near the centre of the town, in the Toplica River valley. The town of Daruvar lays in the westernmost part of the Croatian region of Slavonija, at the foothills of Papuk Mountain to the east, and Ilova River valley to the west. Geothermal waters have been in use since ancient Roman times. They were known as *Aquae Balissae*, Latin for strong springs. The buildings of the baths dating from 18th and 19th century still exist in Julius' park, just over the river from town centre. Nowadays the waters are used for health and recreational tourism in the *Termal* complex and for recreation in *Thermal water park Aquae Balissae*. The largest natural springs are Ivan's, Antun's, and Mary's, with temperatures ranging from 40 to 48 °C.

Due to continuous pumping and utilization of geothermal water by aforementioned facilities, there arose a necessity for thorough understanding of the geothermal aquifer system of Daruvar. Research has been conducted over decades, with higher or lower intensity, in order to ensure a sustainable utilization regarding water quantity, quality and temperature. Geological, hydrogeological, hydrochemical, isotopic, geothermal and geophysical studies were included.

The phenomenon of geothermal springs can be elucidated through understanding of geological setting, tectonic relations and hydrogeologic function of aquifer and surrounding rocks.

In the case of Daruvar geothermal aquifer, the rock containing thermal water has been identified and demonstrated beyond doubt through exploratory drilling. It comprises middle and upper Triassic limestones and dolomites underlying the Pliocene and Quaternary alluvial deposits. Geothermal aquifer was reached in the D-1 borehole at depth of only five meters in Julius' park, and the dolomite even surfaces at one location there. The natural upwelling of water is enabled via N-S strike transcurrent fault in the Toplica River valley. The water is forced upwards because the aquifer is brought in contact with impermeable Miocene and Pliocene sediments and sedimentary rocks by faulting (Fig. 1).

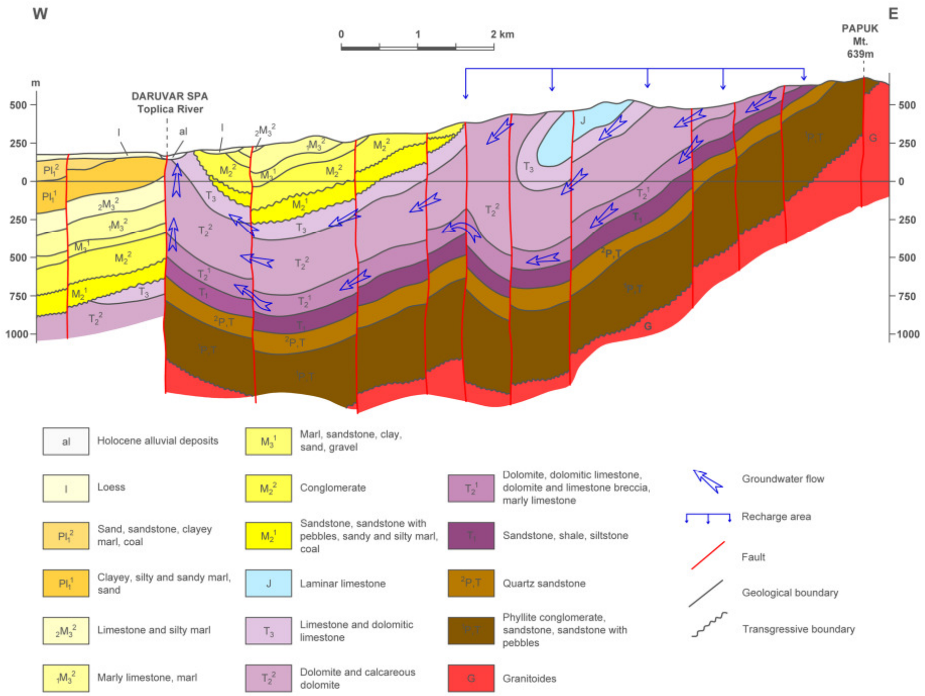

Fig.1.- Geological profile of Daruvar area, modified from Crnko et al., 1998

Geothermal water is meteoric in origin, which is proven by stable isotope analyses: stable isotope ratios (δ^2H and $\delta^{18}O$) in thermal waters from seven individual localities in Daruvar are scattered very close to nearest constructed local meteoric water line (LMWL), Zagreb (Marković & Larva, 2012). The recharge area of the aquifer is eastward from the springs, in the western part of Papuk Mountain (Fig. 1). There are permeable middle and upper Triassic and Jurassic carbonates on the surface, underlain by impermeable lower Triassic and Permian clastics which prevent water flowing downwards. The infiltrated waters therefore flow laterally, in direction of l ayer dip and potential drop, which is westward (Fig. 1).

According to existing data on geological setting of Daruvar and surrounding area, Triassic aquifer reaches the depth of approximately 1100 m. Taking into account the geothermal gradient of the area, which is measured at 5 °C/100 m, and the mean annual temperature in Daruvar of 10,7 °C, the water can get heated to about 65 °C (Crnko et al., 1998). If the heat loss on the way up along the subvertical fault plane is included into equation, water temperature reaches just about the temperature of the natural springs found in Julius' park.

Hydrochemical composition of geothermal waters leads to the conclusion about the aquifer in which they reside (Fig. 2). The obvious domination of Ca^{2+}, Mg^{2+} and

HCO_3^- ions points to their origin from dolomite aquifer. Triassic dolomites are well known as geothermal water aquifers throughout the continental part of Croatia (Šimunić, 2008). In case of Daruvar, not only is it proved by hydrochemistry, but by structural boreholes, as well. Other than that, depending on hydrological conditions, i.e. seepage of meteoric water through thin Quaternary alluvial deposits, the composition of major cations changes slightly. In conditions of heavy rainfall (represented by the situation in 2008) there is a notable increase of Na^+ and K^+, which even changes the type of water from CaMg-HCO_3 to mixed type , i.e. CaNaMg-HCO_3 (Fig. 2). This change reveals that in Julius' park, where the aquifer is near the surface, there exists a contact of recent meteoric water and geothermal water. Nevertheless, in Dar-1 borehole, where the aquifer is present in greater depth (60 – 190+ m), the contemporary rainfall doesn't affect geothermal water's major constituents ratio.

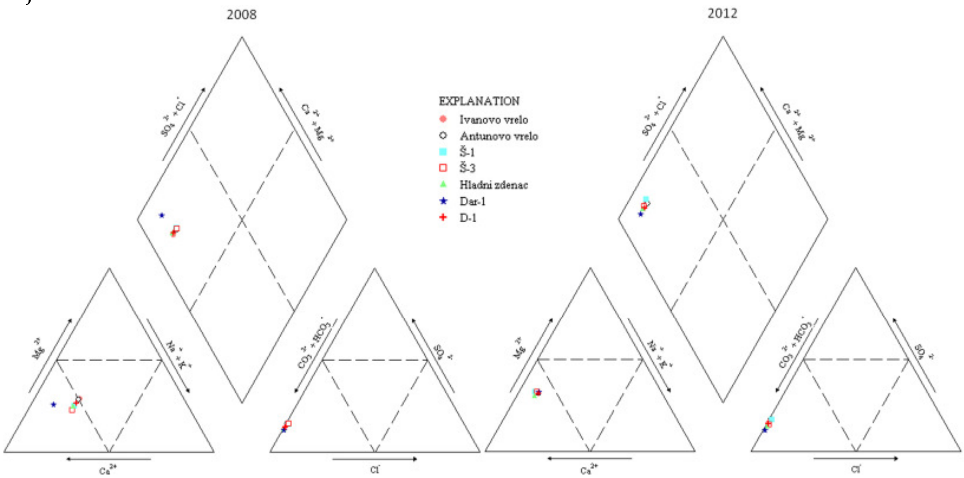

Fig.2.- Piper diagrams of major constituents in waters from Daruvar localities in 2008 and 2012

Isotopic and hydrochemical data also indicate the uniformity of Daruvar geothermal aquifer. The origin of water from a single geothermal aquifer has been proven by numerous pumping tests conducted over decades. Each test has shown a decline of groundwater levels in all springs and boreholes during the pumping on a single object.

Physical and chemical characteristics of waters from Daruvar geothermal aquifer make them an excellent medium for balneological treatments. Since health tourism is the most propulsive branch of tourism (Kovačić et al., 2011), it is to be expected that the demand for extraction will increase in time. The reinterpretation of data gathered through past decades, creation of an integrated model of the geothermal system and monitoring are therefore necessary in order to ensure a sustainable utilization of this valuable resource.

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Genesis of thermal waters in the Baikal Rift System (based on physical and chemical simulation)

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The location of the region in the continental Baikal rift zone enables to study peculiarities of the groundwater origin in terms of fluid geodynamics and lithosphere plate tectonics. Rifting is the critical factor in forming hydro-geological structures in the region and in determining water composition.

The rifting geodynamic regime in the Baikal region evolution predetermines, first of all, its present-day morphology that is a basis for forming hydro-geological conditions. Relative to the critical geological-structural elements, we distinguish three types of hydro-geological structures that significantly differ in distribution and formation of groundwaters: rift depressions - hydro-geological basins; rift "shoulders" (mountain surrounding) - hydro-geological massifs; rifting rupture tectonic dislocations – watered faults (Didenkov, 2006).

The analysis of the groundwater distribution in hydro-geological structures of the region indicates that their largest accumulations are found within basins and watered faults; moreover, cold fresh groundwater is usually observed in crushing zones of near-surface faults, whereas fissure-veined waters of deep-seated faults feature an increased temperature, specific trace element and gas composition, as well as low mineralization.

An important component of hydro-geological conditions in the region is the presence of thermal mineral groundwater with a wide balneal spectrum. There is an evident association between features of groundwater origin and rifting, and this association does not call any doubt with researchers. However, we find useful to comparatively analyze formation conditions in terms of plate tectonics, and, as a consequence, in terms of present-day hydrotherm composition, located in different lithosphere plates, to the corresponding geodynamic regime. So, we analyzed hydrotherms of the Baikal rift zone, East African rift system, Iceland, Shansy rift zone (China) formed in the setting of spreading and rifting, on the one hand, and New Zealand, the Kuril-Kamchatka island arcs with characteristic feat ures of the compression and subduction geodynamic setting, on the other. The structural-hydro-geological analysis shows that hydrotherms are similar in their elevated temperature; other parameters (gas, major and trace element composition) are essentially different. The increased mineralization of hydrotherms located in the subduction zones is due to the subducted material, especially, to the marine water brine that penetrates into the sedimentarylayer of the subducted oceanic plate.

The structural-hydro-geological analysis of the hydrosphere origin is accompanied by physical and chemical simulation. Along with qualitative geologic-geochemical plots, analytical and numerical solutions of heat- and mass-transfer problems, simulation appears to be the only suitable means to study characteristic features in hydrogenous system formation. We use a new approach to study hydrogenous processes via simulation using the Selector software package (Karpov, 1995).

The structural-hydro-geological studies and thermodynamic simulations show that the present-day Earth degassing occurring through the rift zones and determining localized flows of oxygen-bearing hydrocarbon fluids leads to a possible existence of a freshwater deep-seated source. The basic dissolved components of juvenile waters generated during the ascending fluid evolution are methane and carbon dioxide. We suggest that this mechanism provides stable freshwater conditions for the Baikal region hydrosphere in general, and, together with biological processes, ensures conservation of the unique and stable water composition in Lake Baikal.

Now, we investigate genetic peculiarities of the thermal water content in one of the region's depressions. The Barguzin depression of the Baikal rift system features prevalence of mainly nitrogenous thermal natural and artificial water-development with water temperature reaching 84°. The thermal water genesis, as well as the effect of the mantel springs and processes occurring in the crust top, has not been studied sufficiently. As a research subject, we chose the Alga hot spring close to the eastern side of the Barguzin depression.

To generalize the data from chemical analysis of trace element composition of the rift and island-arc groundwaters in order to separate their genetical groups, we addressed both continental rifts (Tajura, Azal, Red Sea, the Sheba Range area, Ethiopian and Baikal) and oceanic rift areas of Northern Atlantic: Iceland, Reykjanes Ridge, East Pacific uplift area, as well as the present-day suduction regions (Kuril-Kamchatka trench and Pacific ring) (Kononov, 1983). These regions are various suburbs of lithospheric plates, divergent and convergent, where ascending endogenic fluid components participate in forming the groundwater composition. The objective of this research based on physical and chemical simulation was to reveal the trace element origin in natural waters.

Comparison of the Barguzin depression granites' chemical compositions to the clarkes of the elements in the Earth's crust and in the igneous rocks of both regional (Angara-Vitim bathlith in general), and local prevalence (Angara-Vitim batholith Zazin Complex) showed that the concentration of some elements (B, V, Rb, Mo, Sr, Cs, U, Ga, Zr, Ba, Hf, Co) in granites corresponds to background concentrations. Upon comparing the values for average contents of elements in the Alga hot spring to the seawater, to the hypergenesis region solutions, to the average composition of Baikal rift system waters, and the composition of other hot springs within the Barguzin depression, we note that some of the elements present in granites at the background level have higher concentrations compared with the average values in the aqueous medium. Such elements are B, V, Rb, Mo, Sr, Cs, U.

Thus, we singled out the elements distinguishing the Alga hot spring from the natural waters in the region under consideration. Further, these elements will be used in physical and chemical simulation of their inflow into thermal waters in order to reveal their genesis.

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Groundwater dynamics of thermal areas and geysers in Yellowstone National Park

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The volcanic caldera at Yellowstone National Park (YNP, Fig. 1) has been selected for documenting the physical processes which concentrate the flow of geothermal water to discharge areas of gravitationally-driven regional groundwater flow systems. At Yellowstone the location of the hotspot has been static with reference to the earth mantle but has, over the last 12.5 million years, migrated about 400 km along the Snake River Plain due to the westward movement of the North American plate. The depth of the rhyolite magma chamber is thought to be about 5 km within the crust while in the dee per part of the crust a basaltic magma chamber resides at about 25 km depth (Fig 2).

Buoyancy-driven groundwater flow is often thought to be the motor for flow of geothermal groundwater within convection cells. This is, however, not the case under hydrodynamic conditions prevailing onshore (Weyer, 2010). Convection cells may, however, develop offshore under hydrostatic conditions. On land, gravitationally-driven groundwater flow systems occur as described by Tóth (1962) and Freeze and Witherspoon (1967). They are caused by topographical elevation differences between recharge and discharge areas. These flow systems may penetrate to depths exceeding 5 km (Tóth, 2009). The underlying physics of Force Potential Theory has been developed by Hubbert (1940). Fluid flow in the surface is driven by force potentials not by velocity potentials as assumed in Continuum Mechanics (Bear, 1972). Continuum Mechanics takes the pressure gradient (grad p) as the driving force for subsurface fluid flow. That is, however, physically incorrect. Hence all geothermal modelling based on continuum mechanical principles and assumptions leads to unreliable results.

Before the 1970s, groundwater recharge for the geysers in Yellowstone National Park was thought to be on the nearby rhyolite plateaus, such as the Madison Plateau, the Central Plateau, and others. The application of deuterium isotope studies then resulted in the birth of a new concept caused by measured and back-calculated isotope values (Truesdell et al., 1977; Fourier, 1989). The new concept argued that the recharge of the deep groundwater was to have taken place at colder temperatures either in the high areas of the Gallatin Range or dating back to the Pleistocene.

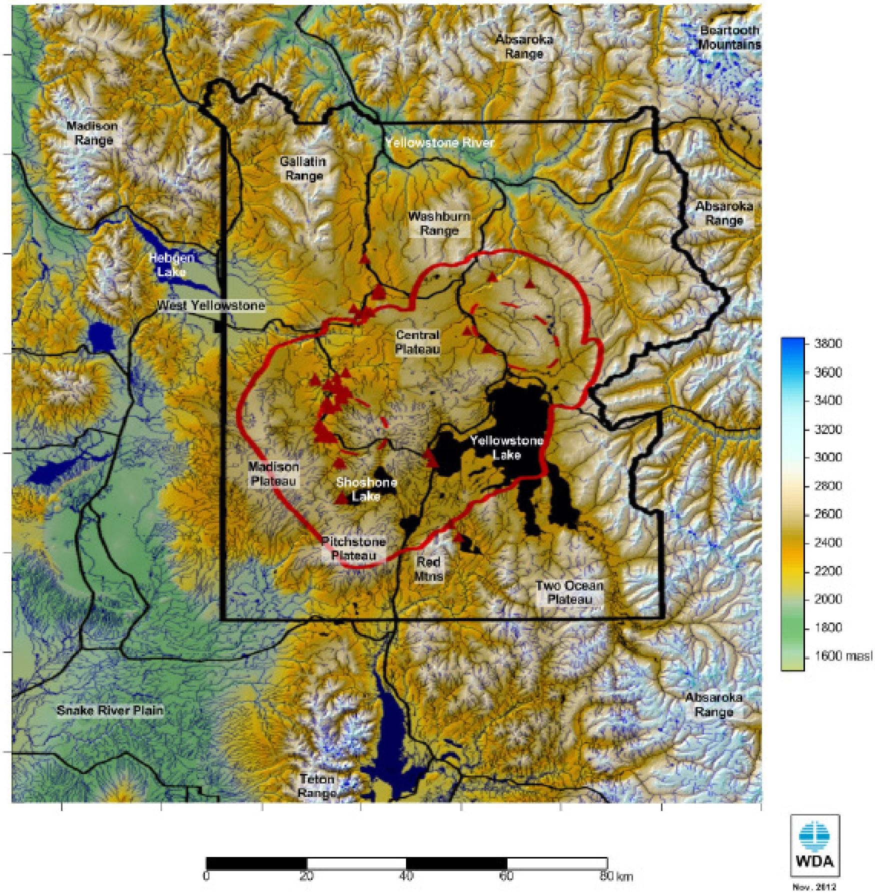
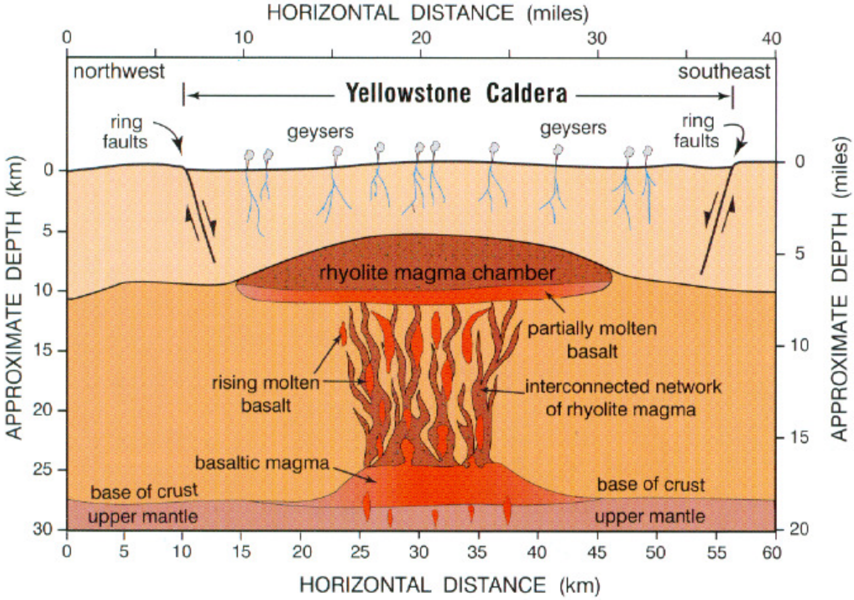


Fig.1.- Yellowstone National Park

During the Pleistocene age Yellowstone National Park was covered by ice caps/glaciers on two occasions: (1) about 150,000 years ago at the height of the Bull Lake glaciation (covering much of the West Yellowstone Basin), and (2) about 17,000 to 20,000 years ago at the peak of the Pinedale glaciation (covering much of YNP).

By applying various chemical and isotopic methods (Fourier, 1989) it has been argued that only 0.2 to 3% of the discharged groundwater originated from the magma chambers. The other 97+% would have recharged at the surface, penetrated to depth, and subsequently ascended to the surface by buoyant forces to discharge as hot springs and geysers. Hydrograph base flow evaluations of the Firehole and Gibbon Rivers indicate that the groundwater discharge in their catchment basins would be approximately 7.5 m^3/s and 2.5 m^3/s respectively

(Gardner et al., 2010). Transmission of these amounts through major fault zones only (as is often assumed) does not appear to be feasible for two reasons: (1) the large amount of flow, and (2) the role of groundwater dynamics. Recharge from the ice sheet and delayed discharge is improbable due to time delays, relatively high permeabilities and hydraulic gr adients involved. Additional stable isotope investigations by Gardner (2009) on deuterium, oxygen and noble gases and their interpretation (ibid, p.73) indicate that the previous and new data do not need recharge by cold waters in Gallatin Mountains or during the Pleistocene. In fact, proponents of the previous concept used geologic reasoning to assume simple groundwater systems which can neither be supported by Continuum Mechanics (Bear, 1972) nor by Hubbert's (1940) Potential Theory.



Generalized cross section of the crust under Yellowstone.

Fig.2.- Geologic cross-section YNP

White et al. (1971) report water temperature gradients for the geyser areas of YNP, whereby the temperature at 1 km depth would be oC. Nevertheless, at greater crustal depth and closer to the rhyolite magma chamber, temperature and pressure would exceed the critical point of water (373^{o}C at 25 MPa). At the critical point water exists as liquid, supercritical fluid and as vapour simultaneously. Any upward deviation of temperature or pressure would directly cause the water to turn supercritical. Under supercritical conditions water loses its surface tension enabling it to penetrate low permeable geologic layers with much higher efficiency than liquid water possessing surface tension. The water content of magma is sufficient to sustain significant flow of supercritical water upwards into the domain of liquid water. Supercritical water is subject to the same hydraulic force fields as liquid water. Due to very significant density reduction for supercritical water as compared to liquid water, the resultant flow directions within the same force field will be very different than the flow directions for liquid water. As the supercritical water may occur at a depth of only 2 km under discharge areas, the low percentage (above: 0.2 - 3 %) of water released by the magmatic chambers probably needs to be revised upwards significantly.

The application of Hubbert's Potential Theory and Groundwater Flow Systems Theory leads to an improved understanding of the role of groundwater recharge on the various Yellowstone Plateaus, supporting the occurrence of thermal areas and geysers. In the area of silica-dominated dissolution processes (Upper, Midway and Lower Geyser Basins) and other dissolution processes (Norris Geyser Basin) permeabilities are continuously enhanced by heated water flow thereby improving the effectiveness of both shallower and deep regional groundwater flow systems. The groundwater recharge calculated from base flow in surface catchment areas to the groundwater flow systems exceeds 350 mm precipitation per annum for the Firehole River basin and 270 mm precipitation per annum for the Gibbon River basin and may locally be considerably higher.

We argue that the concept of recharge on the adjacent plateau mountains into shallow and deep groundwater flow systems and the application of modern gravitational groundwater dynamics is a simple, straightforward, and physically consistent explanation for the occurrence of discharge in thermal areas of the Yellowstone National Park, within and outside of the reach of the present Yellowstone caldera. The systems are not driven by convection or buoyancy forces. The application of gravitational groundwater dynamics thereby withstands the necessary and unforgiving test of physical causality in applying groundwater flow to geological processes.

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How does the chemical composition of water relate to the hydraulic continuity in the Great Hungarian Plain

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In the Great Hungarian Plain (central part of the Pannonian Basin), hydrochemical and isotopic data were evaluated in different aquifers down to 2500 m. The chemical and isotopic composition of water is influenced by its origin, by the type of rocks accommodating the water, and by the hydrogeological character of the study area. Spatial variability of dissolved components suggests that subsurface water in the study area consists of distinct water bodies (bulks of water with specific origin and/or evolution) which can be distinguished on the basis of certain dissolved components. The position of samples in the diagram of $\delta^{18}O$ vs. $\delta^{2}H$ indicates the origin of subsurface water. When the samples are located on the meteoric water line (MWL), the source of water is precipitation, i.e. the water is of meteoric or paleometeoric origin. The more negative δ values suggest infiltration in a colder, the less negative in a warmer period. Samples off the MWL indicate non-meteoric origin. During water-rock interaction ion exchange, redox processes and dissolution are the most significant chemical processes. There are two types of chemical reactions; one reaches equilibrium and the other proceeds during the whole contact time between water and minerals. Ion exchange and dissolution of minerals with simple structure, like carbonates or gypsum are equilibrium reactions. The concentration of dissolved material is limited by the equilibrium constant of chemical reactions. Ion exchange occurs if clay minerals are in equilibrium with Na^+ dominated water. In this case the exchange positions are occupied by Na^+, and alteration of relief conditions initiates the infiltration of $Ca/Mg(HCO_3)_2$ type meteoric water. Towards the groundwater flow direction, due to ion exchange, the total concentration of Ca^{2+} and Mg^{2+}, and that of Na^+ show mirror-image behaviour. The other type is the weathering when partial dissolution of primary silicates occurs together with formation of clay minerals. Transformation of organic matter provides CO_2, which promote weathering. Equilibrium is not reached, but reaction rate, contact time and flow rate determine the concentration of dissolved components. If the other things are equal, the longer the contact time the higher the amount of Na^+ is, while the concentration of Ca^{2+} and Mg^{2+} remains constant. The aims of the present work are to reveal the spatial patterns in the chemical and isotopic composition of water, to separate water bodies, and to establish the impact of fluid potential on the chemical evolution of water.

The study area (about 22.000 km^2) is the central part of the Pannonian Basin (Great Hungarian Plain) filled with Neogene sediments. The Pannonian Lake was formed at the beginning of the Late Miocene with closing the Paratethys from the oceans. Sedimentation initially occurred in deep and brackish, later in freshening and shoaling water. Subsidence throughout the area during the early Late Miocene (Lower Pannonian) is supposed. From the N/NW and N/NE to the S/SW deltas were prograding. The freshening and shoaling environment was represented by fine-grained delta-slope facies at the end of the Lower Pannonian. In the early Upper Pannonian (end of Late Miocene) the subsidence slowed down, and delta-slope, delta-plain followed by alluvial plain facies became characteristic. In the late Upper Pannonian (Pliocene) tectonic inversion and uplift became dominant establishing conditions for meteoric infiltration. During the Quaternary the subsidence rate increased in the central part of the basin while uplift continued in the flanks. The top of the Uppetr Pannonian and the Quaternary are represented by variegated lacustrine, fluvial and terrestrial sequences (Horváth & Pogácsás, 1988, Horváth & Cloething, 1996). In the study area there are three main aquifers and two aquitards. The Lower and Upper Pannonian aquifers are separated by the Algyő aquitard, which represents the upper part of the Lower Pannonian.

Using isotope signature meteoric and non-meteoric water was separated. Samples off the LMWL are thermal waters. They are located on mixing lines between (paleo)meteoric and Lower Pannonian non-meteoric end-members. High Cl^- concentration and a Cl^- to Br^- ratio similar to that of the present sea water suggests that the non-meteoric end-member is of sea origin trapped in the Lower Pannonian layers during sedimentation. Formation water with sea contribution is found in the Upper Pannonian sediments, the proportion of sea contribution is decreasing towards the surface. Depending on the location three groups with non-meteoric contribution were distinguished. In the Upper Pannonian aquifers formation water of (paleo)meteoric origin is of $NaHCO_3$ type thermal water. The source of Na^+ is feldspar weathering. One group is located in the upper part of the Upper Pannonian in the Körös basin, the other two in the south Tisza basin, in the upper and the lower part of the Upper Pannonian, respectively. In the Pleistocene sediments the water is of meteoric origin, it is either $Ca(HCO_3)_2$ type with significant $Mg(HCO_3)_2$ content, or $NaHCO_3$ type. The Ca^{2+} and Mg^{2+} originate from carbonate minerals; the source of Na^+ is ion exchange. Based on the ion exchange pattern and geographical location, two water bodies with complete flow paths (recharge, transition and discharge), one in the Duna-Tisza intefluve and south Tisza basin, and other in the River Maros alluvial fan were distinguished. Further discharging water bodies were separated in both the south Tisza and the Körös basins. In the Pleistocene sediments the wide range of δ values in the complete flow system implies wide range of temperature during the infiltration of meteoric water, while in the Upper Pannonian layers the limited range of δ values together with the higher $NaHCO_3$ concentrations show much longer contact time and more restricted climatic change during infiltration. The distinct, vertically superimposed water bodies suggest intermittent infiltration which occurred in particular time periods depending on the alteration of the surface relief.

The Chemical composition of water bodies was compared to the hydraulic cross-section in the south Great Plain, and to the elevation-pressure profiles in Kiskunhalas, Endrőd, and Dévaványa areas published by Tóth & Almási (2001), and in one basement high area (Püspökladány-Földes). Pressure-elevation profiles demonstrate the significance of the Algyő aquitard in pressure conditions. In the sub-basin areas there is a sharp break in the pressure profile within the Algyő aquitard, with the exception of the present recharge area around Kiskunhalas. Below this formation overpressured, above normally pressured regime is characteristic. Above basement highs the conductive character of the Algyő aquitard (Tóth & Almási, 2001) explains the lack of the break and the superhydrostatic gradient at the Püspökladány-Földes area. Chemistry of water bodies reflects the pressure conditions especially in the deeper layers. In the Upper Pannonian the δ values and the elevated Cl^- concentration decrease upward due to the mixing of the upward moving deep non-meteoric brackish water with pore water of meteoric origin. The chemical and isotopic pattern confirms that the vertical component of the driving force is upwards everywhere in the lower overpressured regime (Tóth & Almási, 2001). The effective range of the overpressure can be detected with ^{18}O and ^{2}H isotopes and Cl- concentration. In the south Tisza basin the Upper Pannonian sediments contain two vertically superimposed water bodies of meteoric origin with different $NaHCO_3$ concentration. They remained separated during the discharge through the Pleistocene layers towards the surface and merged with the discharging water bodies in the Pleistocen. The extent of the complete groundwater flow system within the Pleistocene layers can be traced with the mirror image of the mono and bivalent ions.

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Radionuclides as mixing indicators of thermal waters

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Radionuclides of the 238U decay series, i.e. uranium, radium and radon, are ubiquitous in groundwater. As these radioisotopes are members of the same decay chain, they are interdependent of each other. Moreover, they have different geochemical behaviour. For this study, we used uranium, radium and radon to characterize the fluids in the Buda Thermal Karst system (Budapest, Hungary). High radioactivity, reported already by Weszelszky (1912), especially around the Gellért Hill, supported the idea of the application of radionuclides. Hence in the Buda Thermal Karst mixing of lukewarm and thermal karst waters was as signed to be responsible for cave formation (e.g. by Takács-Bolner and Kraus 1989; Leél-Őssy 1995), we used uranium, radium and radon to identify mixing of fluids and to infer the temperature and chemical composition of the end members based on the different geochemical behaviour of these radionuclides.

The dissimilarity of the discharging lukewarm and thermal waters within Budapest was long recognized on the basis of hydrogeochemical studies (e.g. Papp 1942; Alföldi et al. 1968). Similarly, differences were identified regarding the radionuclide content of the waters in the investigated discharge areas during this study.

As the result of this study, it was possible to characterize the mixing end members for the Rózsadomb area, whereas for the Gellért Hill discharge zone, mixing components could not be identified with the aid of radionuclides. Therefore, it is suggested that different processes are responsible for cave formation in the two areas. In the Rózs adomb area, structurally-controlled mixing is the dominant c! ave forming process, whereas in the Gellért Hill area, due to the lack of mixing members, other processes have to be found, which are responsible for the formation of the caves. The application of radionuclides thus further supported the differences between these two areas and refined our understanding about the fluids of Buda Thermal Karst.

This study identified, moreover, that the source of elevated radon content of the waters in the Gellért Hill discharge area was the iron-hydroxide precipitate that accumulated in the spring caves. These precipitates are highly efficient in adsorbing radium, which generates radon by alpha decay, and hence act as local radon source for the waters. Because of this local radon source, radon cannot be used here as natural tracer for the characterization of mixing end members.

Our study showed that the application of uranium and radium as natural tracers represents a novel approach to identify mixing and its fluid end-members in r egional discharge zones of carbonate aquifers, where different order flow systems convey waters with different temperature, composition and redox-state to the discharge zone.

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Study of the Montecatini and Monsummano Terme low temperature geothermal prospects (Tuscany- Central Italy)

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Tuscany, the northernmost region of the Pre-Appenine Tyrrhenian Belt of Italy, beyond three exploited high temperature geothermal fields (Larderello, Travale and Mt. Amiata), contains a large number of low to medium temperature geothermal prospects. About 25% of the Italian thermal springs are located in Tuscany, where mostly utilized for bathing and therapeutic purposes, they represent an important economic resource. About 3.5 millions of tourists visit the Tuscany spas and thermal areas every year, with remarkable economic advantages for the local population. This favourable situation depends on the coexistence of: a) high heat flow conditions, tied to granitic intrusions at relatively shallow crustal levels, and thinning of the crust, b) a regional aquifer made up of Mesozoic carbonates of the Tuscan Nappe, characterized by a Triassic evaporitic sequence at its base. It is a matter of fact that generally wherever the carbonates formations outcrop or approach the surface, thermal springs or group of springs occur.

Relatively high temperature (^{3} 50 °C) springs (5%) are generally found at the periphery of the exploited geothermal field, where high heat flow condition (~300 mW/m^2) exist. Most (~50%) of the springs, widespread in the region territory, exhibit however temperature in the range (20-37 ° C). From the chemical point of view (Bencini et al., 1977) most of the Tuscany low temperature geothermal prospects show chemical facies of the Ca-SO_4 type due to the interaction with Triassic anhydrites (Fig.1). Relatively few, mostly located in the northernmost part of the region, conversely deliver waters of the Na-Cl type, thus suggesting likely interaction with an evaporitic sequence containing halite horizons. This situation is particularly evident when considering the Montecatini and Monsummano thermal prospects which, although located only 2000 m far apart, are characterized by quite different geochemical characteristics. Montecatini delivers waters of the Na-Cl type with salinity in the range 2000-17000 mg/L and significant SO_4 content, whereas Monsummano waters show TDS of about 2700 mg/L and are of the Ca-SO_4/HCO_3 type with Cl content in the range 250-350 mg/L (Fig.1). A significant geological discontinuity necessarily occurs between them at least at the scale of the thermal reservoir, since in both cases it is represented by the Mesozoic carbonate formations of the Tuscan Nappe.

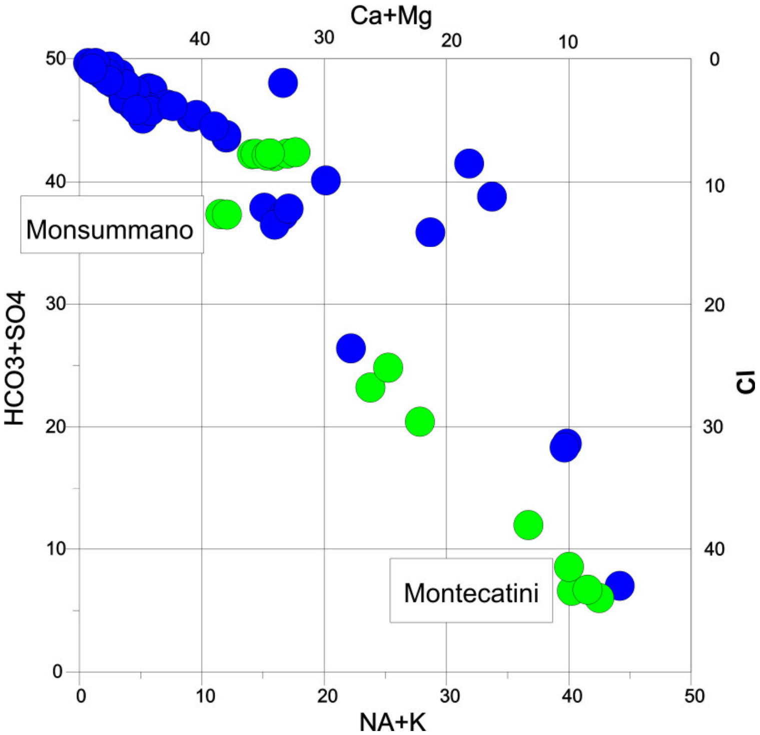

Fig.1.- Ludwig Langelier diagram for the thermal springs of Tuscany occurring in the northern (green circles) and central- southern (blue circles) parts of the region.

A study, financed by the Tuscany Region Authority, was carried out on these prospects from May 2009 to February 2011 to better clarify their hydrogeological characteristics and their possible interconnections. The study consisted in performing: a) geological investigation aimed at defining the main features of the area and the existing fracture trends; b) a gravimetric study to define the main structures at depth; c) periodic repeated water sampling followed by chemical and isotope ($d^{18}O$, tritium, $d^{34}S$) analyses; and d) interpretation of a long term pumping test.

The geological investigation indicated that two major high-angle NNW and NNE trending fracture and fault systems exist in the study area (Fig.2), at the intersection of which small travertine outcrops occur. According with the gravimetric investigations, these faults could have led to important displacement of the main positive structures, which exhibit trend similar to them and lye in front of a deep buried depression.

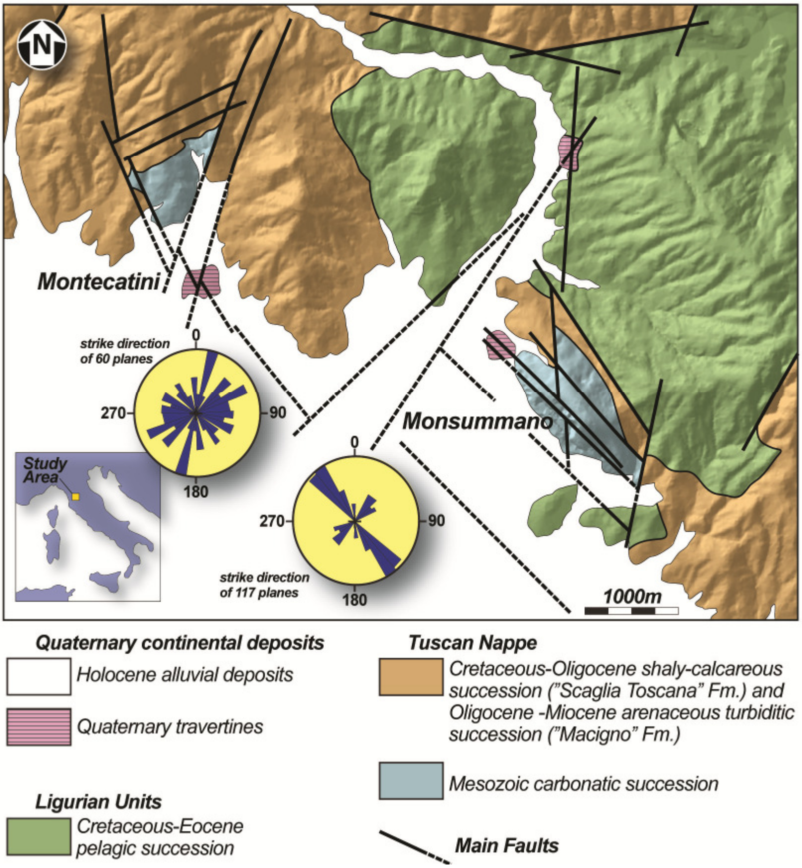

Fig.2.- Geological sketch map of the Montecatini – Monsummano area. Stereograms with strike direction of the main fault and fracture system are also indicated.

This coincides with the alluvial plain in Fig.2. The large geochemical data set, coupled with hydrological observations, confirm (Brandi et al., 1967) that Montecatini exhibits a "plunger" behaviour, with the most saline component prevailing during rainy periods, whereas during the same periods, Monsummano undergoes to main dilution processes. This suggests for the latter prospect a direct recharge from Mesozoic carbonate formations locally outcropping, as confirmed also by the $d^{18}O$ content of the Monsummano thermal waters. The $d^{18}O$ data have allowed also to dispel the myth that Montecatini prospect ($d^{18}O$ most concentrated component = -6.5‰ Vienna SMOW) could be significantly fed by the Lima creek ($d^{18}O$ = -8‰ Vienna SMOW), found about 10 km to the N of the prospect (not shown in Fig.2). The interpretation of the data of a long term pumping test carried out at constant discharge in 2004 has, moreover, permitted us to point out that the Mosummano thermal reservoir behaves as a closed system characterized by a constant linear decrease of the water level with time. This aspect has been confirmed also by a further pumping test properly carried out during the summer 2011 in absence of water recharge.

The author’s conclusion is that thermal reservoirs feeding the study prospects are separated by a tectonic discontinuity which likely plays an important role also at the regional scale. It, in fact, distinguishes the northern part form the central-southern one of the region, being the former characterized by a complete Mesozoic evaporite sequence in which also halite horizons exist.

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Combined hydrogeological-geophysical surveys in geothermal resource evaluations and sustainable thermal water exploitation, Hungary

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The Pannonian Basin is rich in geothermal resources which have been exploited since centuries. A significant increase of thermal water has been observed especially in the last two decades which require a complex governance, in order to achieve and maintain the good status of thermal waters required by the Water Framework Directive and enabling a greater use of geothermal energy to meet targets of the National Renewable Action Plans for each country.

The Geological and Geophysical Institute of Hungary elaborated geothermal potential calculation methods both for shallow and deep geothermal usage. These unique methods provide a better understanding of available and extractable resources.

As Hungary shares many of its aquifers with the neighbouring countries a joint survey and management plan proposal were prepared with some of the neighbouring geological surveys. A transboundary thermal groundwater body was proposed for delineation across the Hungarian-Slovenian border with an areal extent of 4974 km^2 (T-JAM Thermal Joint Aquifer Management project). A proposal for a joint aquifer management plan resulted, now considered a classic example for common aquifer management. The European Union recently co-funded an international project (TransEnergy) focussing on the implementation of good geothermal resources governance. The project supports a harmonized thermal water and geothermal energy utilization management strategy for Hungary, Slovenia, Austria and Slovakia, and is seen as a good example for other regions in Europe sharing transboundary resources. The survey provides a regional understanding of the investigated geothermal reservoirs and thermal flow systems at the entire project area (Fig.1) and in more details of the five selected cross-border pilot areas (Bad Radkensburg-Hodos, Lutzmannsburg-Zsira, Vienna basin, Danube basin, Komarno-Sturovo). The results of the project are presented through a web-map service at http://transenergy-eu.geologie.ac.at.

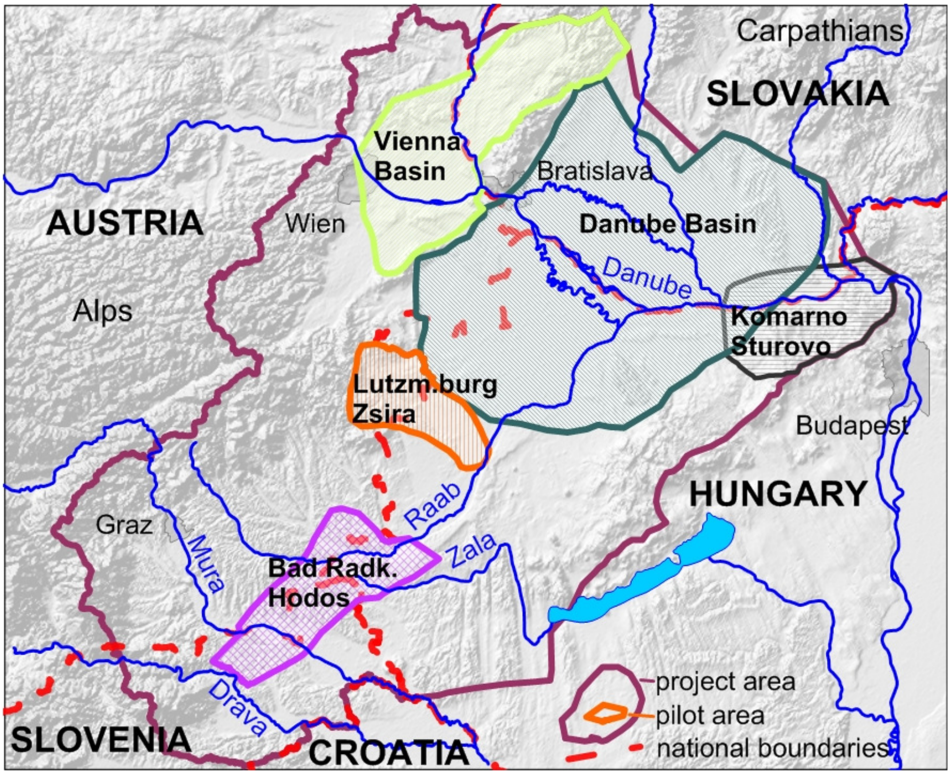

Fig.1.- Project area with the five cross-border pilot areas

Evaluation of groundwater-surface water interaction along the Tisa river

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Introduction

Surface and groundwater interaction was widely investigated during the past (Völgyesi, 1993; Rózsa, 2000, and others) but in most cases only from groundwater supply aspects of using bank-filtrated groundwater. Since the aim was to provide as high production rates as possible the wells were settled along the river side and the zones behind the productive area were only investigated from point of avoiding background contaminations. The main aspects of hydrogeological investigations were accurately determine the strengths of hydraulic interaction between the surface water and the groundwater body through the leaky clogged zone of the aquifer using both analytical and numerical solutions.

The site and the existing monitoring system

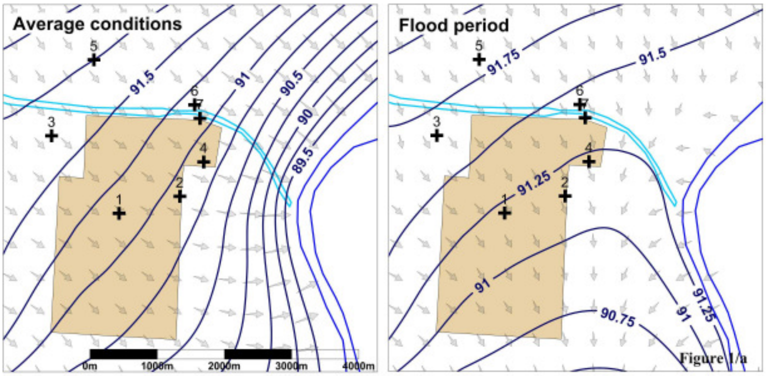
Due to a detailed investigation of an industrial site located closed to the Tisa river in middle Hungary there was a possibility risen to circumstantially investigate the effects caused by the intensively changing Tisa river heads in the alluvial fan of the Hernad-Sajo rivers. The sediments of the alluvial fan are coarse sands and partially gravelly formations divided into two parts by a dominantly existing semi-permeable silty layer. The alluvial formations are cut by the riverbed of the Tisa river. The site of interest has an extent of over 12 km^2, lying in up to 4 km distance from the river. There are over 150 monitoring wells drilled on the site screened both to the upper and lower part of the aquifer. The long term monitoring of the hydraulic head field was started in 2004 using dataloggers providing approx. 140 measurements daily from over 50 wells. There are also many field campaigns to make measurements in all suitable wells. The system gave us enough information to accurately describe the regime of GW-SW interaction in the distance from the river up to 3000 m.

Evaluation of measurement data

Based on time series and head distribution maps it was proven that the hydraulic effects of the river head changes are bigger in the upper part of the aquifer but even in the deeper one some signal of quick or large changes can also be detected.

From measurement data the domination of river discharge was proven as it was described by all previous investigations before. It was the reason why all GW flow modeling jobs were using steady conditions with discharge by the Tisa river. Upon the collected data of over 8 years we could state that besides this dominant state when the GW flow has W-E direction there are different and relevant other situations as well.

At flood periods not only the surface water intrusion into the river bank aquifer occurs but also there is a large zone along the river where the direction of the flow turns to the opposite. We measured the change of seepage direction even at 2.5 km from the river, and we also could discover such measurement results from earlier times, but this outliers were previously evaluated as failed measurements and therefore they were excluded from further analyses. Besides this effect of the river head a third factor was also detected: the rate of regional recharge. At average meteorological conditions or even in dry years the system behaves as it was described above, but in wet years the GW levels rise that activates an additional discharge caused by an artificial channel. In this situation the dominant W-E or E - W flow is mixed with an S-E component that may overwrite the flow pattern of the site. As it was collected from agricultural records of wet and drought seasons, we could prove that almost each 8th-9th year is rather wet which cannot be neglected in long-term analyses.



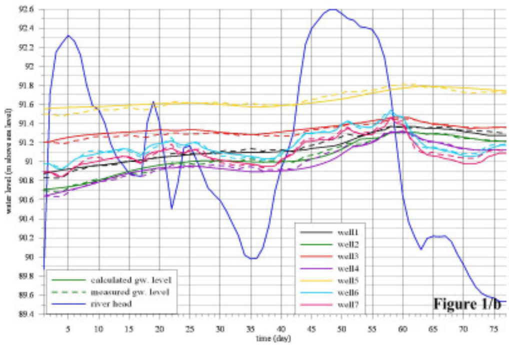


Figure 1.
a) Hydraulic head dsitributions in two specific periods
b) Calibration results for the time series of some monitoring wells

Based on the lessons learnt from the analyses of the time series we have built a very detailed transient model of the site instead of the previous steady ones, that used over 100 stress periods with linearly changing river heads each year, and which could follow the natural cycles of wet, normal and draught years. We calibrated the model using the time series segments (Figure 1/b) of the most dramatic changes for the whole domain.

The results were unexpectedly different from that of steady-state model. The average conditions were found similar to the steady-state situation, but during the flood period the flow field is very distorted (Figure 1/a.) We got reasonably different flow paths and extremely dynamic flow field that was hardly comparable to the smooth character of the steady conditions.

To investigate more deeply the differences we cut a cross section perpendicular to the river from both the steady and the transient model. We calculated the head changes, the seepage velocity dynamics at different distances from the river. We prove that the flow velocity distribution changes with the distance, moreover the Gaussian type frequency curve (normal distribution) stepwise passes into a lognormal one coming closer to the shoreline (Figure 2/a). The seepage distribution becomes rather stable only at larger distance as 2000 m from the river, but the changes are rather small in the 800-2000 m distance interval (Figure 2/b-c). The seepage distribution curve was found the most suitable tool to determine the different zones of influence instead of the rather subjective and error contai ning evaluation of flow maps.

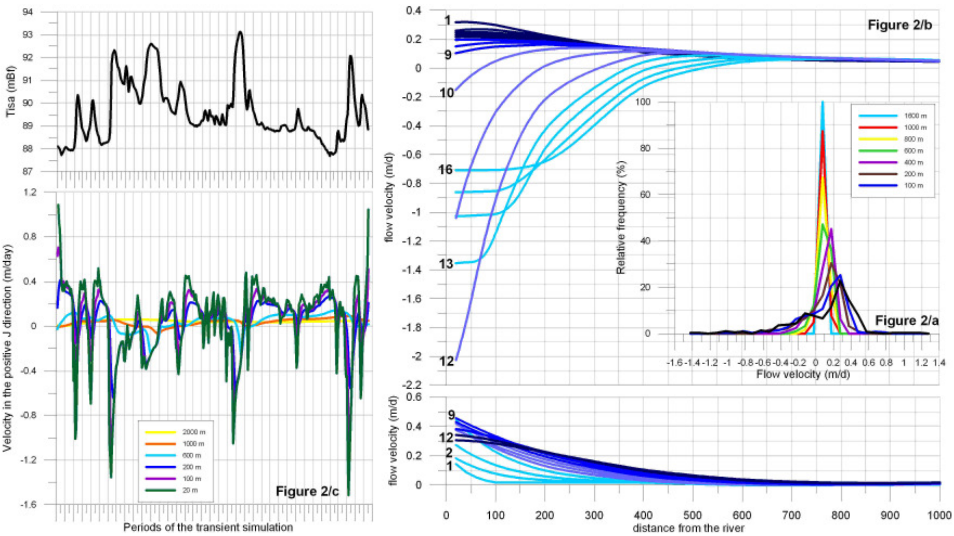


Figure 2.
a) Velocity frequency distributions in different distances
b) Flow velocity in distance from the river
1 - 16: flood time periods
1 - 12: river head declining time periods
c) Flow velocity and the river head in time

With examination of the flow velocity distributions we also showed how the accuracy of the calculated flow paths changing with resolution of the transient simulation, and the dynamic flow pattern what a highly influenced by even a short flood period.

We designed the distribution of virtual path lengths (VPL's) that was defined as the product of seepage velocity and period length at a given element of the model. Drawing the VPL vs. distance from river plot we have proven that there is an over 10 times longer transit path of a given particle near the river as it was calculated using the steady model. This fact influences not only the groundwater motion but also the migration, and especially the spreading (dispersion) of possibly existing contaminants as well that should be taken into consideration at contaminant transport modeling.

Conclusions

Based on a detailed evaluation of long term continuous monitoring of a site it was proven that instead of the widely used steady description of the system a transient characterization is needed. The measurements showed that even in large distances (above 1500 m) not only the heads but also the direction of the flow can be changed. To evaluate the zone of influence an evaluation of a cross section perpendicular to the river was used. There were two models compared a steady model calibrated to the average conditions and a transient one calibrated to the most dynamic parts of the time series of hydraulic heads. Comparing the results it was proven that the pathlines are reasonable different, the virtual path lengths (VPL) of the transient simulation are much longer than in the steady one.

The described work was carried out as part of the TÁMOP-4.2.2/A-11/1-KONV-2012-0049 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, co-financed by the European Social Fund.

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Calculating measured pressure values to different depths in the case of producing and non-producing wells

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Pressure measurement is an important task of well inspection for example in the case of well capacity and well recovery testing. According to the accepted usage pressure measurements can be performed at the bottom of the hole (BHP) or above the uppermost screen, but always below the bubble point where the fluid is in single-phase. Sometimes measurements cannot be performed at the planned depth, for example if the probe sticks at stuffing box.

During inspection of elder well, previous well tests' pressure data measured in different depths are often available. It would be desirable if measurements performed in different depths were comparable with each other by calculating them to the same depth level. Considering thermal wells it might have an important role because long-term tendencies of the well and the aquifer may be understood.

In my presentation a suggested method of the calculation is demonstrated. I take the physical factors one by one which might have a significant effect to the pressure of a static (non-producing well) and a flowing liquid column (producing well). Accuracy of the estimating method is demonstrated by comparing the results with real, measured pressure data of the same well.

Well aHead – A source of fresh thoughts in groundwater management

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The new European Planning period, launching in 2014 often referred to as Horizon 2020 has several priorities related to protection of water resources. Two out of the seven priorities of the national New Széchenyi Plan assigns top preference to better utilization of groundwater resources. The Health industry development program and the Green economy development program strongly relies on mineral-, cure- and thermal water resources of the Carpathian basin. The national health industry development program includes the investigation and utilization of Hungary's unique thermal- and curewater resources. The potential for the groundwater related development program is given in the globally unique mineral water, cure water quantity and quality of Hungary. The complex utilization of the available geothermal energy resources is also mentioned among the top priorities of the New Széchenyi Plan.

The Faculty of Earth Science and Engineering of the University of Miskolc, as a key technical research entity of North East Hungary, is dedicated to find solution to regional issues of the global sustainable water resource management challenges, thus further developing its range of competence. Our goal is to strengthen the international prestige of the research centre and improve the international scientific visibility of our young researchers through collaboration with research institutions and key players of the market. The development concept is described in the detailed Research Plan and by its implementation we support the regional employment of approximately 20 young researchers and improve regional groundwater management practices.

Research goals and working hypothesis

A remarkable milestone of modern hydrogeology is the introduction of the local and regional groundwater flow systems theory, published by Joseph Tóth in 1963. Concerning the technical (engineering) applicability of the theory there was no any research conducted in Hungary before, thus the planned fundamental research agenda of the project mainly covers the engineering and water management aspects of the flow system theory applications. Covering issues such as sustainable thermal water-, mineral water-, cure water-, and drinking water management, anthropogenic effects on groundwater resources, ecohydrogeology, and complex multidisciplinary research of porous and karstic aquifers.

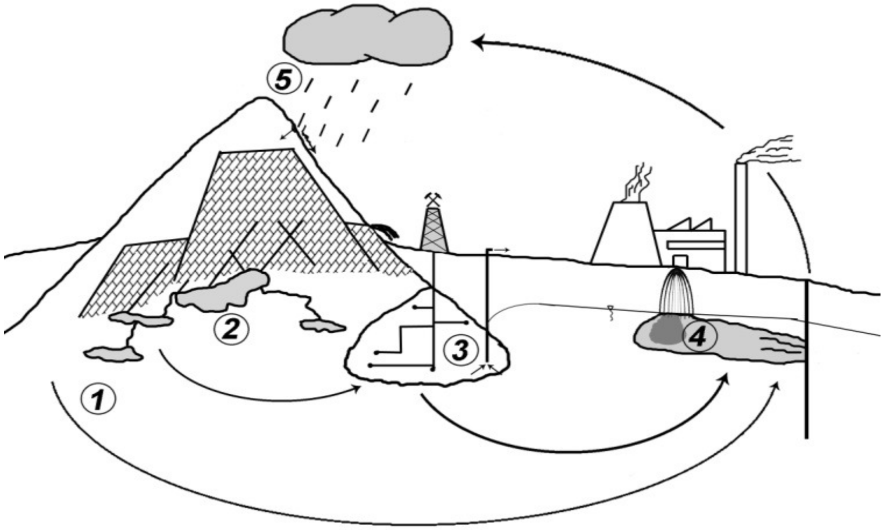

Fig. 1.- The project research modules and their connection to the flow system theory concept

Our research goals are structured around five relevant subtopics and their technical investigation. These are defined as 5 research modules (Figure 1):

1. Complex hydrogeological research on mineral-, cure-, and thermal water investigation and utilization in North-East Hungary

2. Better understanding of the interaction between cold and warm karst water bodies

3. Investigating the quantitative and qualitative impact of mining activities on groundwater resources

4. Better and more reliable understanding of transport processes of special contaminants

5. The impact of extreme weather conditions on groundwater recharge and subsurface water cycle

Each module set up its research teams working on 3-4 R&D ideas involving more than 70 researchers (Figure 2) altogether. Besides the five research modules the project aims to develop its own technical knowledge transfer concept (module 6). Some of the research results shall be utilized via direct industrial partnership (e.g. patents, technology developments) while other shall be further developed through the international networking activity of the project and through the formulation of new proposals in the Horizon2020 calls, starting from 2014.

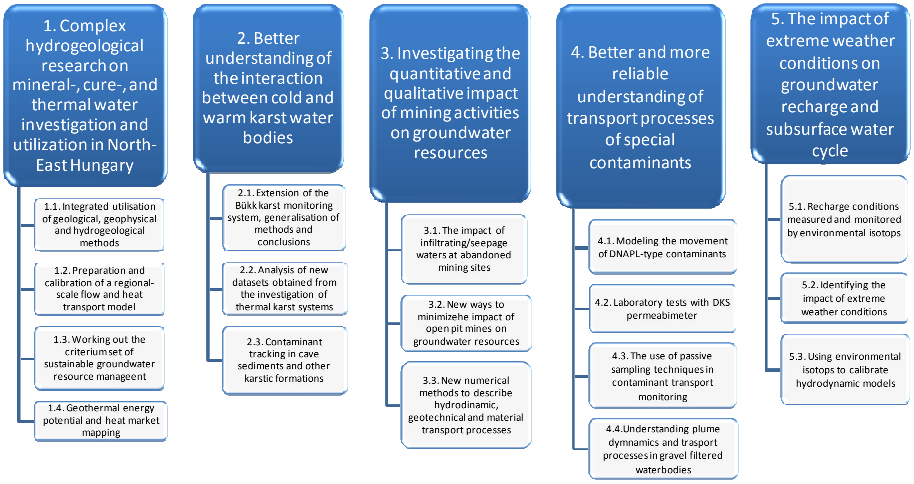

Fig.2.- The 5 research modules and the involved R&D ideas

The research lead by the Institute of Environmental Management includes the setting up and calibration of a regional scale flow and heat transport model at a selected location in North East Hungary. The model shall be capable to give accurate information on mineral-, cure-, and thermal water resource characterization, the simulation of real and assumed consumption scenarios, and the fine tuning water balance equations.

The Bükk karst system monitoring network has been operated for 20 years, playing an important role in forecasting water resource quantities for Miskolc and several other stakeholders of the system. The monitoring system can also contribute to the better understanding of cold-warm water body interaction.

Lots of settlements are impacted by abandoned mining sites, mining wastes piles and tailings where the impact of infiltrating water and the compatibility of tailings material and groundwater resources were not assessed. There is a demanding need to find new solutions to decrease the impact of open pit mines on shallow and deeper groundwater resources, by decreasing the amount of dewatering volumes.

Special behavior of contaminants in the subsurface must be better understood by more advanced modeling tools and new type of laboratory analysis. The 4th module is dedicated to testing new methods for modeling, measuring and monitoring.

The fifth research team shall investigate the impact of extreme weather conditions (e.g. intense precipitation events) on the recharge of shallow groundwater bodies. They evaluate the possible use environmental isotopes as calibration for contaminant transport models.

Other social goals of the project

It is an important aim of the project to develop the research potential at the research unit, primarily at the Department of Hydrogeology and Engineering Geology with adjacent competences of the Faculty of Earth Science and Engineering. We also put a strong emphasis on the networking activity both in a domestic and international scope.

Similarly important goal is to support the new generation of researchers. We intend to use the resources of the project to employ young scientists (PhD students, postdocs) keeping well educated experts in the North-East Hungary region.

We expect that our success rate shall increase in Framework program proposals, especially as we approach the Horizon 2020 calls. The University of Miskolc must step a major step ahead in this activity to finance its strategic research disciplines, such as groundwater resource management. We seek the possible collaborations in joint proposals with European research entities.

The project shall serve as a catalyst in collaboration between SMEs and the academic research communities. Those business entities that are invited into the collaboration can be our future R&D contractors.

Our special voluntary undertaking is to develop a new Knowledge management plan which highlights those channels through which the intellectual portfolio of the research team can be utilized on international markers.

Project facts:

Funded institution: Miskolci Egyetem

Amount of financing: 476 902 260 Ft

Project duration: 28 months (October 1, 2012 – January 31, 2015)

Responsible project manager: Madarász Tamás, PhD

Technical director: Péter Szűcs, DSc

„The research was carried out in the framework of the Sustainable Resource Management

Center of Excellence at the University of Miskolc as part of the TÁMOP-4.2.2/A-11/1-KONV-2012-0049 „WELL aHEAD"project in the framework of the New Széchenyi Plan. Funded by the European Union, co-financed by the European Social Fund."

Impact of theTarnowskie Gory urbanised area (Poland) on groundwater contamination by chlorinated hydrocarbons

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Trichloroethene (TCE) and tetrachloroethene (PCE) contamination have been monitored in groundwater of Triassic carbonate aquifer in Tarnowskie Góry area since 1994. The source of the contamination is industry, located in the urban area of Tarnowskie Góry (Southern Poland). The major problem is related to the fact that the mentioned Triassic aquifer is the most important source of potable water for that region. Due to significant groundwater contamination by TCE and PCE reaching 650µg/L many important potable water intakes have been closed.

Complex geological structure of the carbonate aquifer with karst-fracture-porous hydraulic network additionaly disturbed by extensive shallow underground and surface old mining activity resulted in its strong heterogeneity and complicated groundwater and pollution flow pattern. Significal spatial differentiation of TCE and PCE concentration in the aquifer has been confirmed. Maximum concentration is observed in the city and immediate vicinity (Fig.1). However within the town there are some wells where the TCE and PCE are below detection limit. Generally the concentrations of TCE and PCE decrease with increase distance from Tarnowskie Góry in the west, south-west and north-west direction. The results demonstrate that contamination plume is spreading out up to 15 km in the west direction from the source of the contamination. Confirmation of migration of these constituents is continuous increase of TCE and PCE concentrations in the water from wells uncontaminated at the beginning of the research studies. Substantial decrease of TCE and PCE concentration (from 500 – 600 µg/L to below 200 µg/L) in groundwater in recharge area located within the town area has been observed. Simultaneously increase concentration (up to more than 10 µg/L in outside area of the town was observed (Fig.2). Assumed contaminated area of the aquifer is at least 50 km^2 and the average thickness of the aquifer is 100 m, so the volume of contaminated aquifer is at least 5x10^9 m^3. The paper summarizes results of the investigation for years 1994 to 2010. It was indicated that important role in spreading the TCE and PCE in the groundwater play geological structure, hydrodynamic and hydrogeochemical properties of the Triassic carbonate aquifer.

Reliable prediction of temporal and spatial TCE and PCE concentration changes require to take into consideration all mentioned above factors.

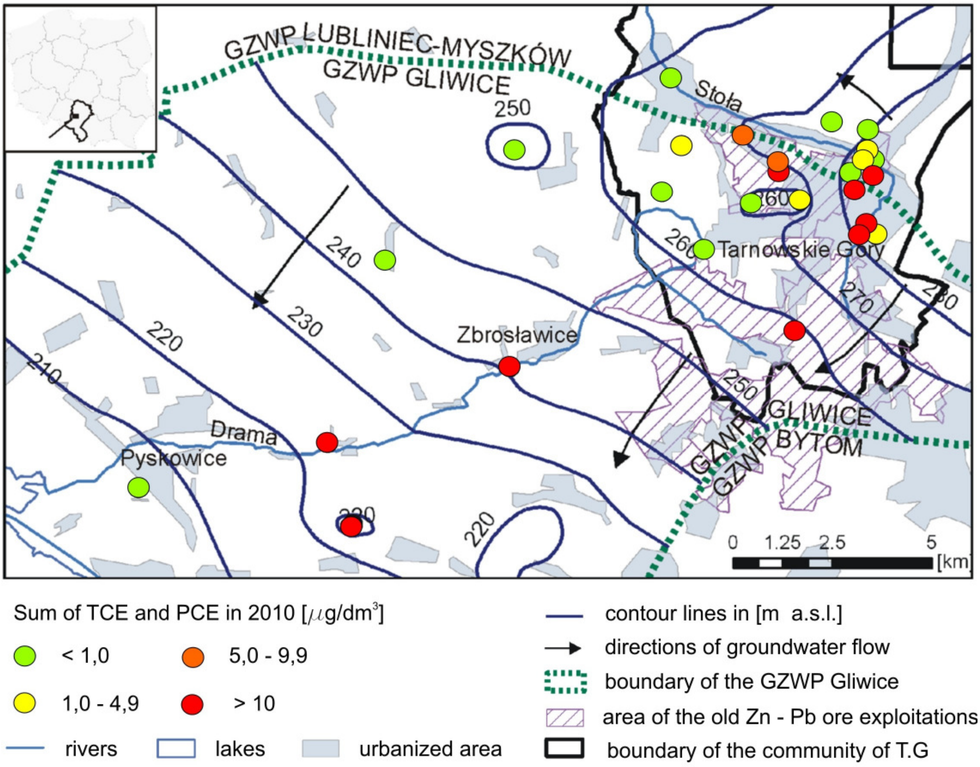

Fig 1.- Concentration of the TCE and PCE in groundwater of the Triassic aquifer in the year 2010

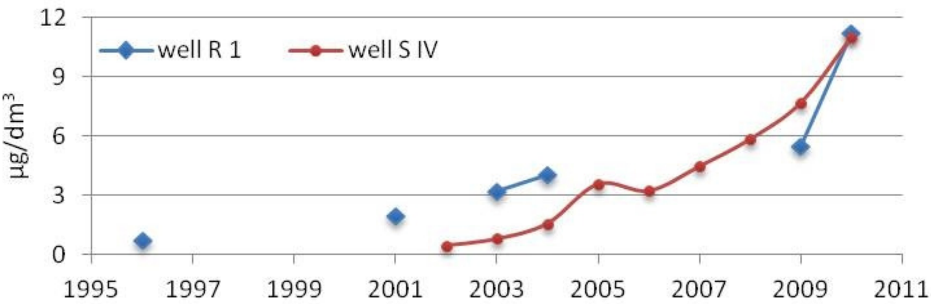

Fig. 2.- Changes of the TCE and PCE concentrations in groundwater in selected wells.

Optimization of geothermal system for sustainable power generation

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The rising demand for electrical power and the necessity to decrease fossil fuel consumption requires development of renewable power generation systems with higher efficiencies. One of the potential renewable sources is the geothermal energy from the Earth's interior supplies heat for direct use and to generate electric energy. Geothermal energy has the potential to provide long-term, secure base-load energy and greenhouse gas (GHG) emissions reductions.

An overall geothermal system (shown schematically Figure 1 below) is complex, involving not just the below ground elements such as the wells and geothermal reservoir, but also the above ground elements such as turbines, cooling systems, etc.

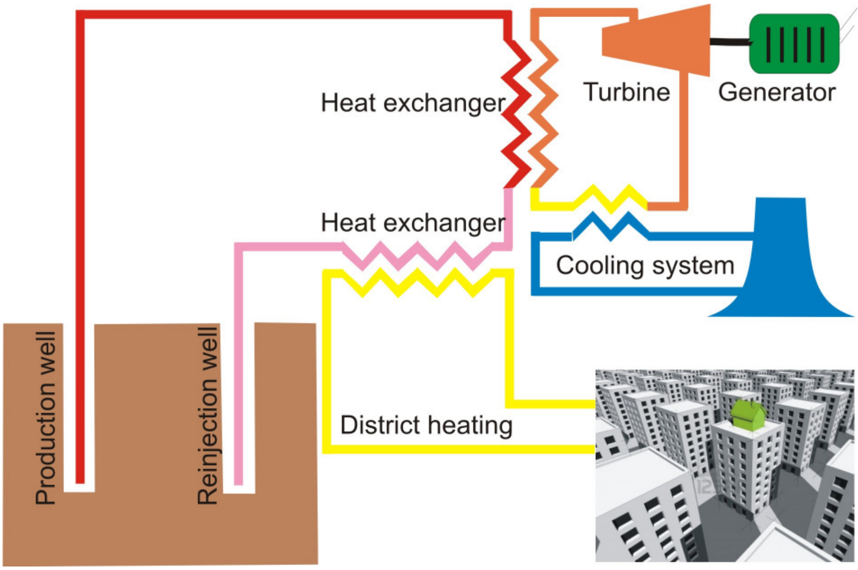

Fig. 1.- Geothermal system for producing electricity and for direct heating

These are all important, but are only indirectly related to the driver for any project - to generate electricity and/or heat in a saleable form, in sufficient quantities and at low enough cost to make the project economically viable. The geothermal systems are capital intensive because the cost of the wells and plant is high yet the cost of the 'fuel' is very low. However, the fuel is not free, because parasitic energy loads are needed to operate the system – these loads can be large, reducing the gross plant output by up to 30%. Such parasitic losses have a huge impact on the economics of deep geothermal systems, yet because of the complex interaction between system elements they are difficult to quantify using existing design tools.

The system modelled by our own developed tool is a low to moderate temperature geothermal power scheme where water temperatures do not exceed 250 °C such that the most economical and efficient method of energy generation is use of a binary power plant (the turbine is operated by a secondary working fluid with a lower boiling point than water).

Once a geological prospect has been identified, various key factors must be determined before potential power outputs can be assessed such as location (where to drill and distance between extraction and re-injection wells), depth of drilling, power conversion technology, mass flow rate (pumping and re-injection rate), parasitic losses, reservoir pressure drawdown, reservoir temperature drawdown.

Most simple, and many relatively complex, systems can be handled by spreadsheet based analysis, but it can be difficult to capture options, uncertainty and interactions. Tools like GoldSim are flexible modelling environments for probabilistic (Monte Carlo) simulation of complex dynamic systems. This model is able to interact with other modelling environments to produce coupled models. In GoldSim modelling environment it is very easy to build relatively complex system and is capable to investigate changes in key system parameters, and assess the sensitivity and the uncertainty of the system.

The model presented focuses on the optimising the net power generated by the system, typically number of kWh over a specified period. By dynamic system model, like GoldSim, it is possible to control the uncertainty and to define different scenarios applied at a variety of project stages.

Sustainable Use of Geothermal Resources in Italy: first inventory of data, applications and case studies

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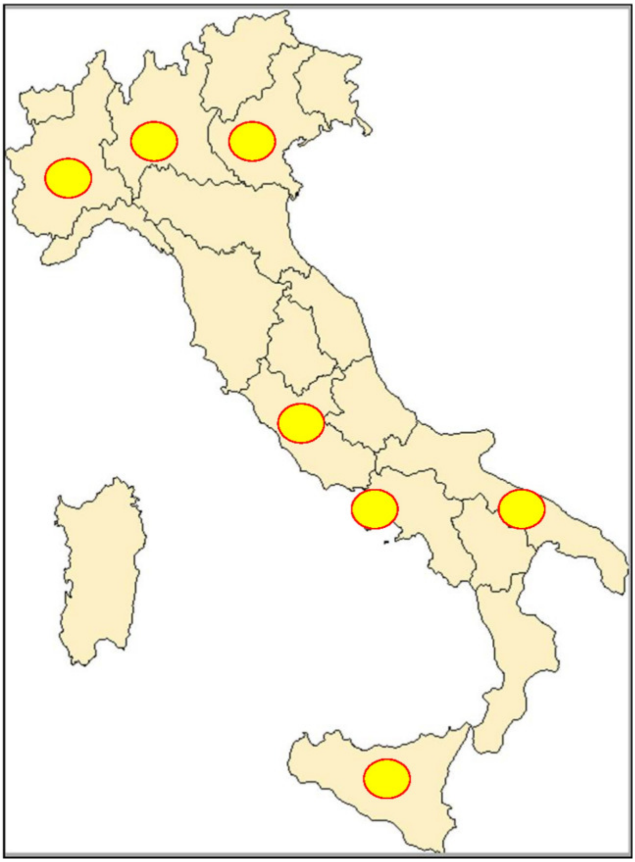
Considering the increasing interest in the use of geothermal resources in Italy in the last decade, as well as the key role hydrogeology plays in the study of geothermal systems and design of installations, within the framework of activities aimed at studying current and future exploitation and the related sustainability of geothermal resources and within the IAH (International Association of Hydrogeologists) Italian Chapter, the Working Group IDROGEOTER was set up in October 2012 and started operating in February 2013.

With regard to the workplan of the Working Group, the first step is an analysis of the state of the art in the current use of low-to-high enthalpy geothermal resources in Italy; this will be achieved through an inventory of data, applications and case studies, aimed at determining the relationship between the hydrogeological settings resulting from features such as hydrostratigraphy, hydraulic and hydrodynamic conditions, hydrogeochemistry, and the availability of the resource and the potential of the systems; a further development will form part of the activities of IDROGEOTER, corresponding to the preparation of a proposal of guidelines, specifically focused on sustainability, for hydro-geothermal studies.

Whatever the type of geothermal system, groundwater plays a key role in the study of geothermal installations. The hydrogeological characteristics, such as the piezometric pattern, the recharge mechanism, hydraulic parameters, hydrodynamic conditions and hydrochemical features, influence the availability of the resource in terms of temperature, amount and quality. Detailed hydrogeological studies, carried out in Italy (Figure 1) in order to optimize the use of geothermal resources, regarding different enthalpy levels and various geological environments (volcanic, carbonate rock aquifers,….), are described.



In the Lombardy Region (N Italy), currently the most populated and industrialized region in Italy and therefore the area where the highest number of Groundwater Heat-Pump (GW-HP) plants are installed, a representative sample of both open-loop and closed-loop systems could be selected, considering the need to identify the critical hydrogeological factors contributing both to the geothermal potential and to a sustainable use of the resource in the current trend of urban sprawl.

In the Piedmont Region (NW Italy) several experimental sites have been investigated in order to assess the potential subsurface effects of open-loop GW-HP plants for the cooling and heating of buildings; a comparison between field measures and numerical modelling results reveals that the most important aquifer parameters affecting the developing of the Thermal Affected Zone (TAZ) around the injection wells are those related to advective heat transfer.

In the Veneto Region (NE Italy), with regard to high enthalpy, the Euganean Geothermal Field (EGF) is the most important thermal field in northern Italy. At present about 250 wells are active (flow rate = 17 Mm3/y) and the thermal waters (temperature = 65-86 °C) are mainly used for spas; recently, a new conceptual model of the Euganean Geothermal System (EGS) has been proposed: the waters are of meteoric origin, infiltrate 80 Km to the north of the EGF in the pre-Alps, flow to the south in a Mesozoic carbonate reservoir, reach a depth of about 3000 m and warm up by a normal geothermal gradient; the conceptual model is tested in a numerical model.

In other areas of the Veneto Region and with regard to low enthalpy, other studies are in progress on sites potentially suitable for closed-loop and open-loop systems, and together with data from automated monitoring of several wells, these could be used for advanced analysis of different hydro-geothermal systems; advanced analyses have been carried out at the pilot site of Vicenza, to characterize different hydro-geothermal systems. The design of the GCHP system, combining a heat pump with a ground heat exchanger (closed loop systems), was authorized temporarily, until the results of the monitoring phase become available; these results may be useful for completing in particular the hydrogeological and environmental assessment and achieving a more specific knowledge of the local application for a vertical closed loop heat exchanger system, which in the studied area is marked by the presence of excellent aquifers, in terms of both qualitative features and quantitative peculiarities.

Research activities in the Lazio Region (Central Italy) also focus on low enthalpy and are specifically aimed at two main objectives: at a regional scale, and together with the local regional administration, the mapping of the geothermal potential of aquifers, and at a more local scale, pilot studies of sites located in Rome and characterized by gravel aquifers, alluvial Holocene deposits of the Tevere River and alluvial pre-volcanic Pleistocene deposits.

In the Campania, Apulia and Sicily Regions (S Italy), in the framework of the geothermal exploration programme known as "VIGOR" (Evaluation of Geothermal Potential in Convergence Region), hydrogeological characterization has proved very important for geothermal assessment and together with other data has been used to produce local and regional geothermal assessments. Some examples are shown on a regional (Sicily Region) and local scale (Campania Region). In the latter case, in the Mondragone area, a groundwater balance, verifying the recharge area of thermal springs (temperature 33-54 °C) connected to a large carbonate aquifer, has permitted the identification of the most suitable area in which to drill a geothermal well. In the Apulian case of the Santa Cesarea coastal springs (temperature 23-28 °C) the thermal field trend consequent to groundwater advection and the influence of seawater intrusion for two karstic coastal aquifers (Murgia and Salento) at various elevations between -5 and -100 m amsl was reconstructed and the maximum temperature of deep groundwater assessed. These analyses are intended to provide required basic knowledge for correctly implementing low enthalpy Heat-Pump plants in the saturated zone.

New well-completion and rework technology by laser

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Introduction

Thermal wells have been operated for over 140 years in Hungary. While there are more than 600 production wells operating on porous thermal aquifers only a few injection wells have been drilled into sandstone as the direct use of thermal water without injection has been the standard procedure in Hungary. This project aims to help the methodology of a sustainable reinjection technology that is economical in the context of communal and agricultural heating operations in addition to facilitating a variety of rework tasks using laser.

About the Team

The research team of Zerlux Inc. Houston, Texas, has been engaged in the development of laser technology solutions and commercial applications for several years in Hungary with the active contribution of university professors and laboratories. We have developed an economical and environmentally safe technology in subsurface laser drilling.

Principles of Laser Drilling Technology

Zerlux's high power laser device will utilize cutting-edge, underbalance laser well completion and rework technology in fluid mining, including oil and gas as well as the geothermal industry. The system is comprised of a high power laser generator and a specially designed directional laser drilling head. The laser head is attached to a coiled tubing or an umbilical system to maximize production and to carry out special jobs.

The laser tool will superheat the subsurface formation, melt the target material and will remove the molten debris while the borehole is being drilled.

The technology allows the operator to adjust the permeability of the borehole wall (Fig. 1).

Laser drilling complies with standard industry safety standards and rules and fits into existing drilling equipment and offers an in-situ, real-time fully controlled procedure with video and spectroscopy feedback to the operator, with no wearing parts, no chemicals and low maintenance while maintaining formation integrity and environmental safety.

In this phase of the development effort the laser technology is especially well suited for economically drilling short laterals from existing wells in a single work phase, drilling through the casing, cement and the formation as well, with one tool in and out.

Elements of the technology are patent pending.

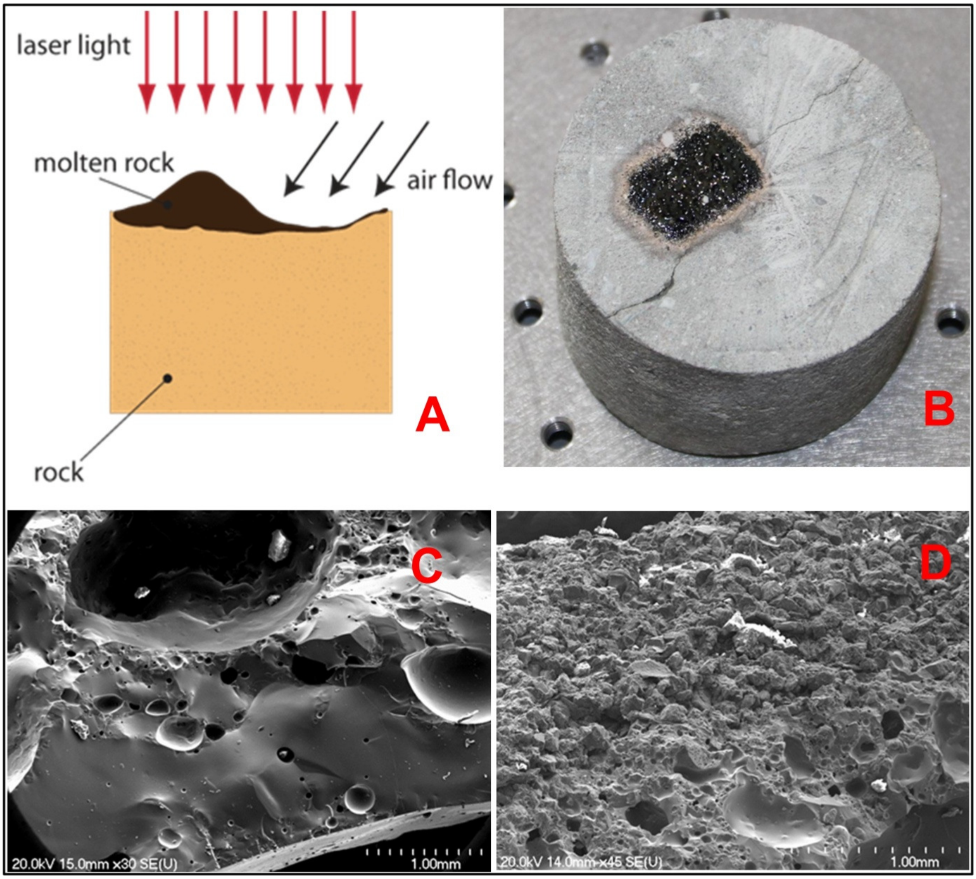

Fig.1. A.) Rock melting and removing process by laser

B.) Sand sample with molten glass layer

C.) Sealed glass layer (unpermeable)

D.) Open glass layer with micro channels (pereable)

Potential Use

The technology is well positioned in several specific markets:

1. Well completion: increased drainage area resulting in low pressure gradient
2. Geothermal water re-injection
3. Rework: decreased water coning effect
4. Finding and precisely adding new intervals in depleted onshore or offshore reservoirs
5. Drilling in thin reservoirs where hydraulic fracturing carries high risk
6. Underground Coal Gasification: exploration and analysis
7. Coal-Bedded Methane: exploration and analysis
8. CO2 re-injection
9. Exploratory drilling: real-time formation analysis during drilling
10. Scale removal without damaging pipe integrity, including Barite depositions
11. Nano-mining
12. Drilling from small platforms where high cost rigs are not economical or technically feasible

Technical Benefits

- Non-mechanical drilling
- Real time in-situ analysis (absorption and emission spectroscopy, video)
- Small diameter (-1.5 inch) or umbilical small footprint enables platform application and low cost transportation
- Small size compact, separately transportable
- Reliable and long lifetime (30,000 Hours)
- Low cost additional components in the well
- No mechanical formation damage
- No formation contamination (N_2 as assist gas)
- Increased flow efficiency (Fig. 2.)

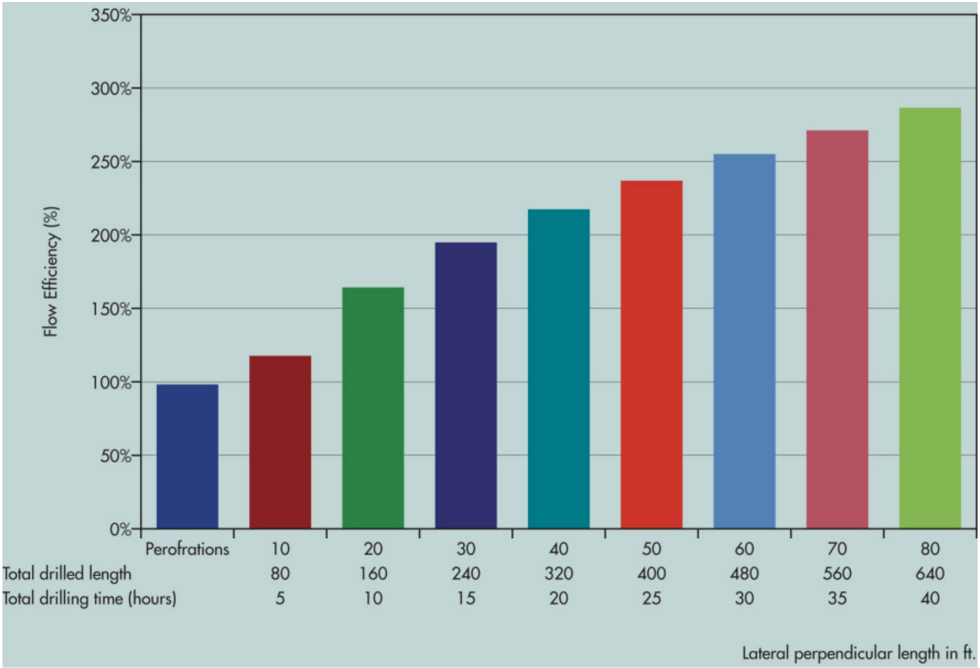

Fig.2.- Flow efficiency – comparison of perforating versus laser drilled laterals

Conclusions

The pilot laser head has been built and a series of laboratory investigations have been completed.

Measurements indicate that this innovative new technology will help save reservoir integrity and will increase productivity.

In geothermal well completion and rework laser offers distinct advantages. Because it is a non mechanical way of drilling which can be easily steered and controlled and integrated into coiled tubing systems.

The laser head uses Nitrogen to displace all fluids during the drilling process. This will prevent the formation from being contaminated by drilling mud and will facilitate unimpeded flow through the borehole. The technology is especially suitable for reinjection wells in porous formations as the highly porous glass will serve as a filter and will also prevent the flowing fluids from ripping off particles from the borehole wall.

Our laser drilling technology was referred to by an industry executive as having the potential of being a "step-changing" technology in subsurface applications.

Analysis of the Thermal Decomposition of Alkaline-Earth Sulphates

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Introduction

Hard scales often precipitate in the production tubes of geothermal wells, which radically reduce the effective flow diameter of the tube. Scales may even totally block the effective cross section of the pipe.

The ion bonded salts of alkaline-earth elements will contain very high electrostatic bonding energies due to the high charge of these ions.

They are practically insoluble in water and consequently are likely to produce scale precipitates in pipes. Typical examples of such scales include $CaCO_3$, $SrCO_3$, $BaCO_3$, $CaSO_4$, $SrSO_4$, $BaSO_4$ and their crystals, often mixed with various SiO_2 content substances. The most frequently scale forming materials are $CaCO_3$, and $BaSO_4$ (Bellarby, 2009) because of their high insolubility. Carbonate salts will become soluble by acid treatment. Sulphate salts, however, will require very high temperatures and a reductive environment to become soluble. Barium-sulfate precipitates are an especially frequent occurrence in sulphate ion containing mineral waters (Quddus et Allam, 2000). Several patented solutions were found to remove such scales, sometimes with physical impact (Brown et al, 1991) and sometimes with chemical treatments (Nasr-El-Din et al, 2004). These methods offer less, rather than more, chance to succeed. Thermal decomposition, however, is a possibility for every salt. Carbonates start to thermically decompose at a temperature range of approximately 1,000 K and in a solid phase. For sulphates this temperature range is close to the melting point or above.

Materials and Methodology

We were using the following mixed samples for experiments:

A. 100% $BaSO_4$,

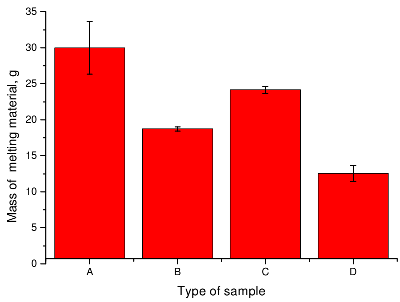
B. 75 % $BaSO_4$ + 25% $CaSO_4$

C. 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% $CaCO_3$,

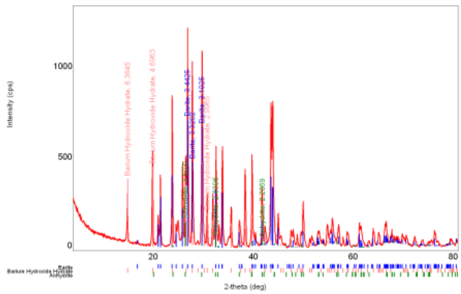
D. 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% SiO_2, The powder mixture was inserted into an aluminum tube of a diameter of 25 mm and a length of 100 mm and was compacted. The samples were impinged by laser for a duration of 1 minute with an SLD-B 850 infra-red laser of an electric capacity of 3 kW and light capacity of 850 W, wavelength: 915 nm. The solid lumps were removed after being melted and were cleaned of the original powder. We measured the mass of the molten substance and the mineralogical composition was determined immediately by X-ray diffractometry (XRD). To analyze the thermal decomposition of the molten substance we extracted samples of 5-5 g with 100 cm^3 0.1 mol/dm^3 KCl solution and 0.1 mol/dm3 HNO_3 solution, respectively. After 2 hours of shaking from a 10 ml aliquot of clear solution was titrated by 0.1 mol/dm^3 HCl from the KCl extract and 0.1 mol/dm^3 of NaOH solution from the $HNO_{3.}$ extract. We were using a methyl orange indicator. The extracted Ba concentration was measured by flame emission spectrometry. The Ca concentration was measured by atomic absorption spectrometry. We replicated the tests three times.

Results and Evaluation

Only the original state powder mix touched the molten substance continuously . Consequently, the quantity of the opening state powder mix could not affect the quantity of the substance melted by the laser. To assess the efficiency of the melting process we used the measured molten substance mass of the different compositions. Fig 1. and Table 1. show these data.



Mass of molten substance of particular mixtures



XRD pattern, Sample of 75% $BaSO_4$ and 25% $CaSO_4$ after laser light treatment

Fig 1.- XRD spectrum, Sample of 75% $BaSO_4$ and 25% $CaSO_4$ after laser light treatment

The left side of Fig 1. will show that there appeared significant differences between the molten substance masses of particular mixtures. At a given laser light energy level the barite sample produced the largest molten substance mass. The smallest energy level was produced by the SiO_2 containing sample. The data also confirm that calcite will facilitate the generation of molten substance.

Uncontaminated barium sulphate will decompose at a temperature not much lower than its melting point (~1580 °C) according to the following reactions:

$BaSO_4 = BaO + SO_3$, and $BaSO_4 = BaO_2 + SO_2$ The resulting oxide and peroxide will react with water according to the following reactions:

$BaO + H_2O = Ba(OH)_2$, and $BaO_2 + 2 H_2O = Ba(OH)_2 + H_2O_2$

Similar reactions apply to calcium compounds as well.

To follow the decomposition we were using the XRD pattern of the molten substance. The spectrum reading indicated the presence of barite (~70%), anhydrite (~15%), and barium-hydroxide (~15%). These results harmonise well with the anticipated decomposition reactions. The measurements were made 2 days after the laser treatment, and the water in the air induced the emergence of hydroxides.

Marking and composition of sample	Ba content, g/kg, HNO_3	Variance g/kg	Ba content, g/kg, KCl	Varian ce g/kg
A, 100% $BaSO_4$	79.3	5.1	46.4	10.4
B, 75 % $BaSO_4$ + 25% $CaSO_4$	33.3	1.1	0.6	0.1
C, 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% $CaCO_3$	5.0	0.1	7.2	0.3
D, 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% SiO_2	20.9	5.8	28.8	0.4

Table 1. Soluble Ba content in different mixtures

In addition to semi quantitative XRD measurements we also used fully quantitative measurements to measure the concentration of decomposed and hence soluble, barium and calcium in the molten substance. There were two different solutions used to extract the calcium and barium compounds of the molten substance as they have chemically changed and became soluble. We used a 0.1 mol/dm^3 KCl solution in a neutral environment to extract the water soluble compounds, primarily aimed at the generated hydroxides. A 0.1 mol/dm^3 nitric acid was applied to solve the acid soluble compounds, which primarily meant carbonates. The calcium and barium hydroxide compounds react with the carbon-dioxide of the air and will generate water insoluble carbonates, which, however, are very easy to solve in light acids. Having been exposed to the air prior to the measurements the samples could easily form carbonates. That is why acidic extraction was a sensible action.

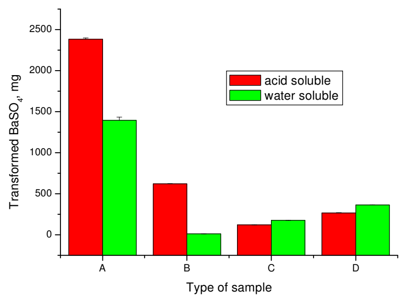
Having measured the barium and calcium concentration of the extracts we could make inferences on the quantity of metallic ions that turned soluble. This also allowed us to calculate the soluble ion content of the original molten substance (Fig 1).

The largest amount of soluble barium ion came from clean barite.

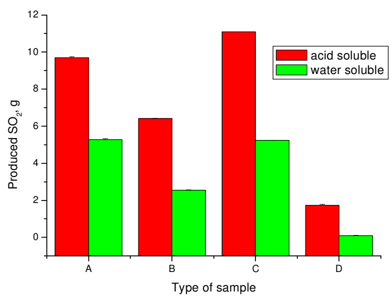
It is important to note that in the 25% $CaSO_4$ sample the water soluble barium concentration decreased over its proportionate rate. This possibly means that heating the substances together will decompose the $CaSO_4$ more than anything else, though confirming this requires additional experiments. Intriguingly, glass was created in the sample that included silicon dioxide but the soluble barium concentration failed to substantially decrease.

The equations presented above show that decomposition will lead to sulphur oxides (sulphur-dioxide and sulphur-trioxide) leaving the system. We used titration to identify them, relying on the fact that the absence of sulphur-oxide will cause the substance to turn alkaline.

With the KCl solution we simply titrated the extract with acid and measured the amount of departing sulphur-dioxide. With the acidic extraction the extracting agent was titrated with alkaline and the absence of the acid content was identified with the alkalinity of the sample: that is to say with the equivalent quantity of the generated sulphur-dioxide. The quantity of the molten material and the measured barium concentrate will allow us to calculate the total quantity of the barium sulphate, either decomposed or transformed by the particular dosage of laser energy. The titrated hydroxide quantity will allow us to calculate the total quantity of sulphur-dioxide generated by the particular dosage of laser energy (also expressed as sulphur-dioxide/sulphur trioxide. This is what Chart 2. presents.



Total quantity of decomposed sulphates expressed in $BaSO_4$



Gas state sulphur compounds calculated from alkalinity, expressed in SO_2

Fig 2. - Total quantity of decomposed sulphates expressed in $BaSO_4$ and gas state sulphur compounds calculated from alkalinity, expressed in SO_2

At a given energy level impingement the largest amount of soluble barium ions are made out of clean barite. The smallest quantities will be produced by samples that contained carbonate and silicon dioxide, roughly in equal measure. The barite-anhydrite mixture results showed a substantial degree of carbonate generation. It is clear that clean barite will produce a significantly larger amount of sulphur-dioxide than barite-anhydrite mixtures do. The values were significantly higher with the sample that contained carbonate, too. However, in this case the departing carbon-dioxide was also measured into the sulphur-dioxide quantity. This is why the results from nitric acid shaking are immaterial with the C sample. The D sample shows the significant impact of silicon dioxide as we cannot use alkalinity to measure the departing sulphur dioxide. The reason is that the alkaline earth compounds that emerged during glassification no longer were alkalinic, while the sulphates decomposed and produced sulphur dioxides.
As we know the amount of energy communicated, we can calculate the melting and transformation (decomposition) efficacy (Fig. 2). Obviously barite has the best efficacy while the worst efficacy was measured with the SiO_2 content sample. The worst decomposition efficacy was measured with the $CaCO_3$ content sample.

Marking and Composition of Sample	Melting Efficacy, mg/kJ	Variance mg/kJ	Decomposing Efficacy, mg/kJ	Variance mg/kJ
A. 100% $BaSO_4$	588.2	71.92	46.65	0.367
B. 75 % $BaSO_4$ + 25% $CaSO_4$	367.3	5.81	12.23	0.006
C. 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% $CaCO_3$	473.8	9.22	2.37	0.001
D. 50 % $BaSO_4$ + 25% $CaSO_4$ + 25% SiO_2	246.4	22.25	5.15	0.129

Table 2. Efficacy of $BaSO_4$ Melting and Decomposing as a function of Light Energy

Summary

We used $BaSO_4$, $CaSO_4$, $CaCO_3$, SiO_2 content samples, mixed at various rates. The samples were impinged by 850 W infrared laser light for a duration of one minute. The solid molten chunks were removed and were cleaned of the original powder to the extent possible. We measured the mass of the resulting materials and the mineralogical composition of molten substances were measured by XRD. We used titration to identify the quantity of hydroxides generated through the decomposition. We saw that melting will lead to sulphate decomposition and will generate oxides and hydroxides. The largest amount of molten substance was produced by clean barite and the smallest quantities came from the silicon dioxide containing samples.

The largest amount of soluble barium ion concentration came from clean barite, whereas the smallest quantities were from carbonate samples. In the presence of calcium ions the largest amount of soluble barium ion concentration came from anhydrite containing samples and the smallest quantities were from the carbonate samples. The largest amount of barium ions was extractable from barite but all the other samples yielded roughly the same amounts. The titration measurement results, the higher alkalinity, confirmed that the clean barite samples

produced the largest mass, whereas silicon oxide content of samples greatly reduced alkalinization.

In all sample compounds it was clear that laser induced melting prompted the originally water insoluble alkaline earth sulfates to decompose to water soluble hydroxides and gas state water soluble sulphur dioxides. The results of the experiments indicate that if the appropriate mechanical solution is available, laser induced heat treatment is a suitable alternative to effectively remove otherwise almost immovable deposits and scales from thermal water well pipes.

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Thermal interaction of rock and water controlled by temperature variations in a tunnel

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Heat exchange between the rock and the flowing groundwater is important e.g. for geothermal applications. The process can be influenced by heterogeneity of flow - e.g. in a single fracture/channel or spread in a porous rock. In this work we study a thermal interaction in-situ for a groundwater inflow into a tunnel, by a comparison of monitoring data and a numerical model.

The site is a water-supply tunnel of 2.6km length through compact granite up to 150m below the surface, in Bedrichov, Jizera mountains, Czech Republic. Except of the shallow part, the inflow is concentrated to few places of fault zones crossing the tunnel (several meters of tunnel length, shotcrete covered, typical flow rate tens of ml/s) and single fractures in a bare rock (decimeters to meter scale, typical flow rate from drops up to few ml/s).

The thermal variation come from a water supply pipe transporting hundreds liters per second. The temperature is changing with season (periodic with some irregularities from reservoir abstraction control, 5-10 degrees min/max difference) and it controls the tunnel air and the adjacent rock temperature.

We can assume the temperature (of both the rock and water) deep in the rock as constant, while it is disturbed by rock quasi-periodic temperature changes in the last meters of flow before the discharge. It is documented by 1-2 year long measurement of water temperature which is within the range of the tunnel air temperature variations but with smaller amplitude.

We made a numerical model based on simplified periodic tunnel temperature variations, with a neighbourhood of a single water-conductive plane (fracture or fault zone) perpendicular to the tunnel. The model is 2D axisymmetric: the plane in radial direction, parallel to the tunnel axis, perpendicular to the expected fracture, the model rectangle size is 8m in the radial direction and 6m in the axial direction from the fracture on both sides. Coupled water flow and heat transport simulation in the FEFLOW code is used. Hydraulic parameters are set to fit the measured flow rate, the thermal parameters are typical literature data. The predicted changes of water temperature are consistent with the observation - smaller variations for large flow rate and larger variations for smaller flow rate. We further parametrized the ``thickness'' of the water-conductive plane.

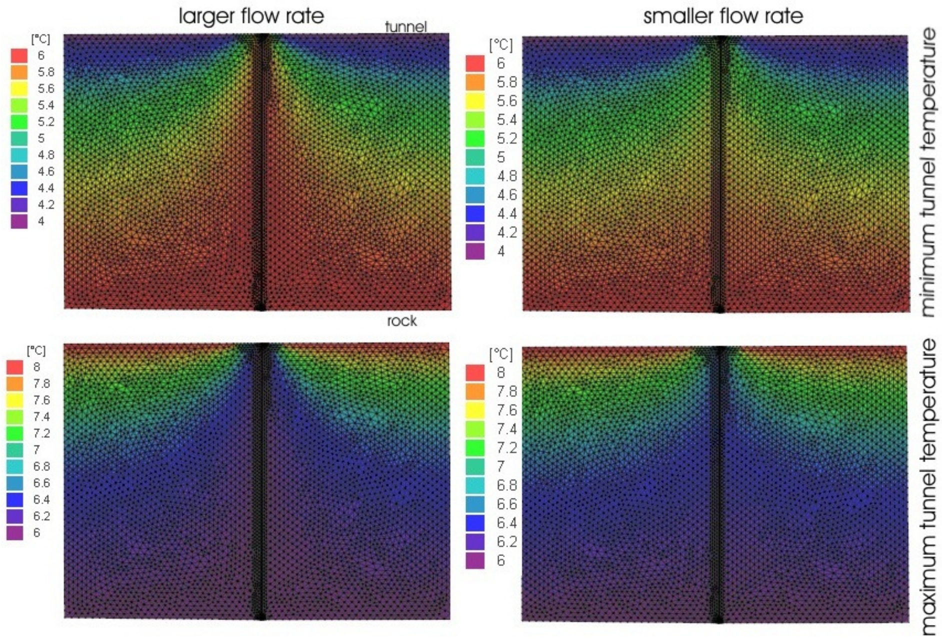

Fig. 1.- Example of the model results - distribution of the temperature in the model plane, horizontal is the axial direction of the tunnel, vertical is the radial direction of the tunnel, water flow is from the bottom to the top side.

Three-dimensional convection within the Northeast German Basin

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The identification of geothermal target sites for potential energy supply requires a regional understanding of the thermal setting of sedimentary basins. The Northeast German Basin (NEGB, in northern Germany) hosts a significant amount of groundwater and heat resources. However, the main physical transport processes responsible for these resources are still not completely understood.

The NEGB represents a complex heterogeneous geological system characterized by several stratified aquifer complexes of regional relevance. The sedimentary structure of the NEGB is affected by a highly mobilized thick salt sequence (the Zechstein salt) which was deposited during Permian times. As a result of salt mobilization during the Mesozoic, and Cenozoic the present-day configuration of the Zechstein salt is highly structured in numerous salt pillows and diapirs piercing the overlying Mesozoic aquifers. At shallower depths, an embedded aquitard consisting of fine clayey deposits (Rupelian Clay) separates the Quaternary to late Tertiary freshwater aquifer from the underlying Mesozoic saline aquifers. An important feature is that discontinues within this aquitard exist in areas where the Rupelian clay was not deposited or ha s been eroded leading to hydraulic connections between the upper and lower aquifers (hydrogeological windows). As a consequence of both salt diapirism and due to existing geological discontinuities in the Rupelian aquitard (hydrogeological windows) the depths and thicknesses of the major Mesozoic aquifers vary widely on the basin scale. Moreover groundwater in the vicinity around salt structures may be subjected to lateral fluid density gradients triggered by abrupt variations in the fluid temperature and salinity. As a result, a complex groundwater flow field is expected within the basin system which is affected both by the complex geometry of the different horizons (aquifers and aquitards) as well as by external (hydraulic gradient) and internal (buoyancy) driving forces.

Three-dimensional physical coupled numerical simulations are carried out to discriminate diffusive and convective heat transport processes and taking into account the complex geological structure of the NEGB. The governing equations for coupled fluid, heat and mass transport are solved by using the commercial Finite Element based simulator FEFLOW®.

In a first group of numerical simulations coupled groundwater flow and heat transport processes are investigated on a regional scale. It is found that impermeable geological layers inhibit groundwater flow to be effective at depth, thus resulting in a predominately conductive thermal regime in the deeper parts of the basin. In contrast, the thermal field within the shallower aquifers is widely affected by forced convective heat transport induced by pressure gradients. Free thermal convection triggered by buoyancy forces due to gradients in fluid density evolves only locally within relatively thick permeable successions.

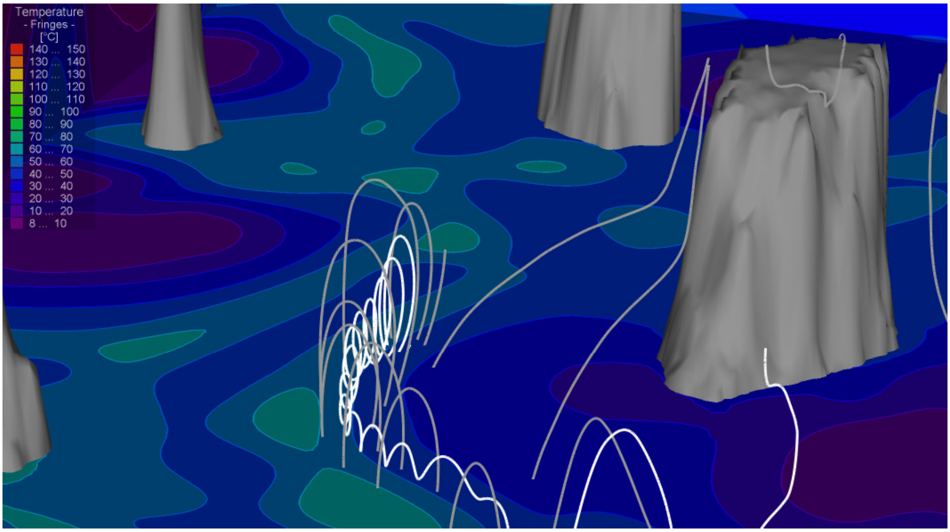

Fig. 1.- Groundwater dynamics represented by streamlines and temperature distribution in a depth of -1,250 m within a salt dome environment derived from a thermohaline numerical simulation. A linear directed downward groundwater flow occurs in the vicinity of a major salt dome causing anomalously smaller temperatures. Offside the salt structure buoyancy forces induce a helical flow pattern in the area of a positive thermal anomaly (thermal convective in nature).

In a second group of simulations, additional effects of salt mass transport on the groundwater dynamics and resulting thermal field have been also considered. The goal of this study is to investigate (1) the additional influence of salinity induced forces and (2) the impact of hydrogeological windows in the Rupelian aquitard on the evolution of the shallow temperature field. A closed area within the basin has been selected to run the thermohaline simulations. The results demonstrate that hydrogeological windows enable inter-aquifer connectivity favoring strong heat and mass transport which causes a mixing of warm and saline groundwater with cold and less saline groundwater within both aquifers.

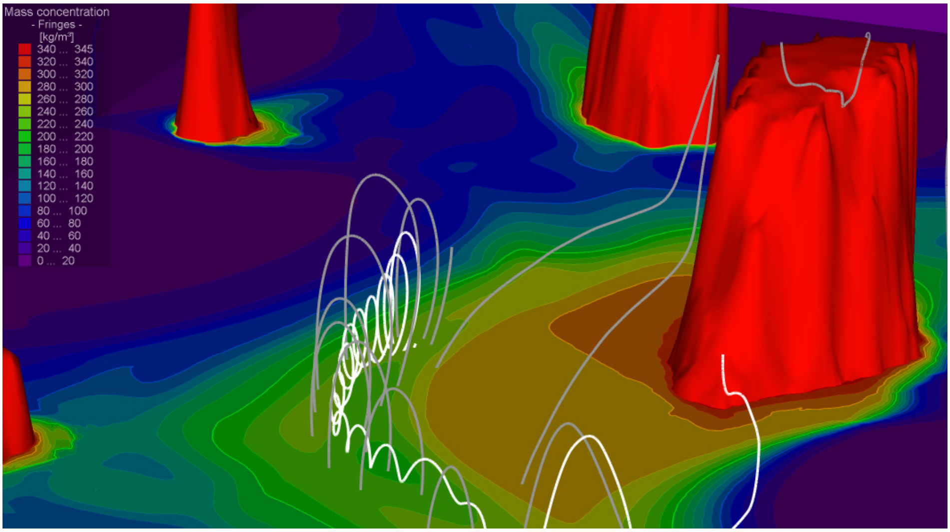

Fig. 2.- Groundwater dynamics represented by streamlines and salinity distribution in a depth of -1,250 m within a salt dome environment derived from a thermohaline numerical simulation. A linear directed groundwater flow path occurs in the vicinity of a major salt dome causing a large lateral saline plume. The boundary of the saline plume spatially converges with a helical groundwater flow motion and with the positive thermal anomaly (Figure 1).

In areas where the Rupelian aquitard confines the Mesozoic aquifer, dissolved solutes from major salt structures are transported laterally giving rise to plumes of variable salinity content ranging from few hundreds of meters to several tens of kilometers. Additional thermal convective currents triggered by buoyancy forces may overwhelm counteracting stabilizing salinity induced forces offside of salt domes. This may result in buoyant upward groundwater flow transporting heat and mass to shallower levels within the same Mesozoic Aquifer.

A new hydrothermal conceptual and numerical model of the Euganean Geothermal System - NE Italy

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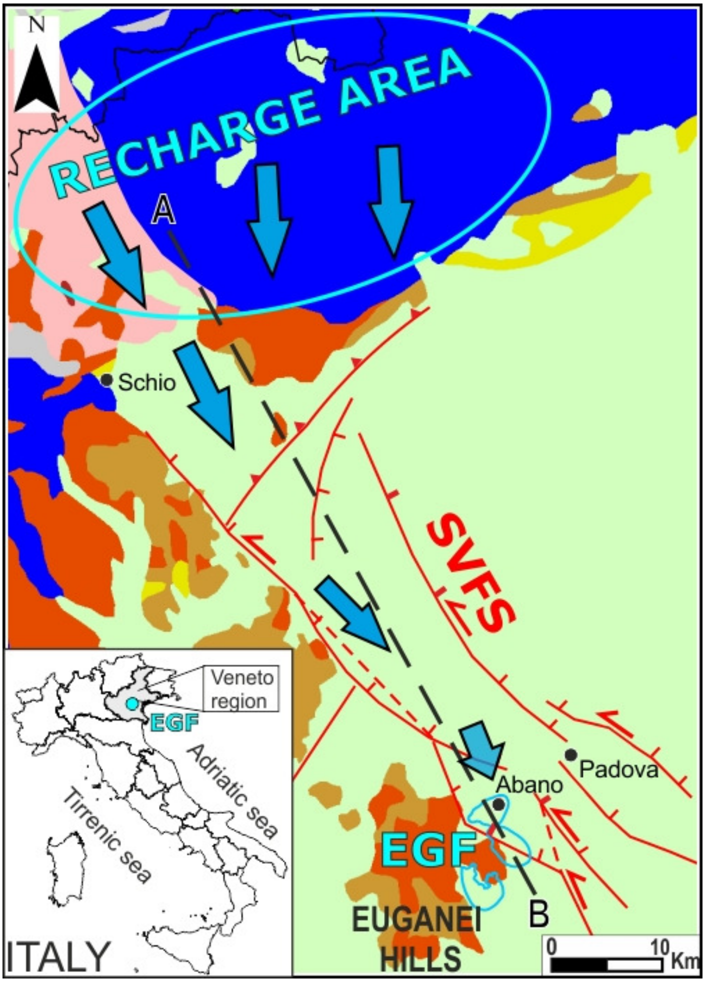
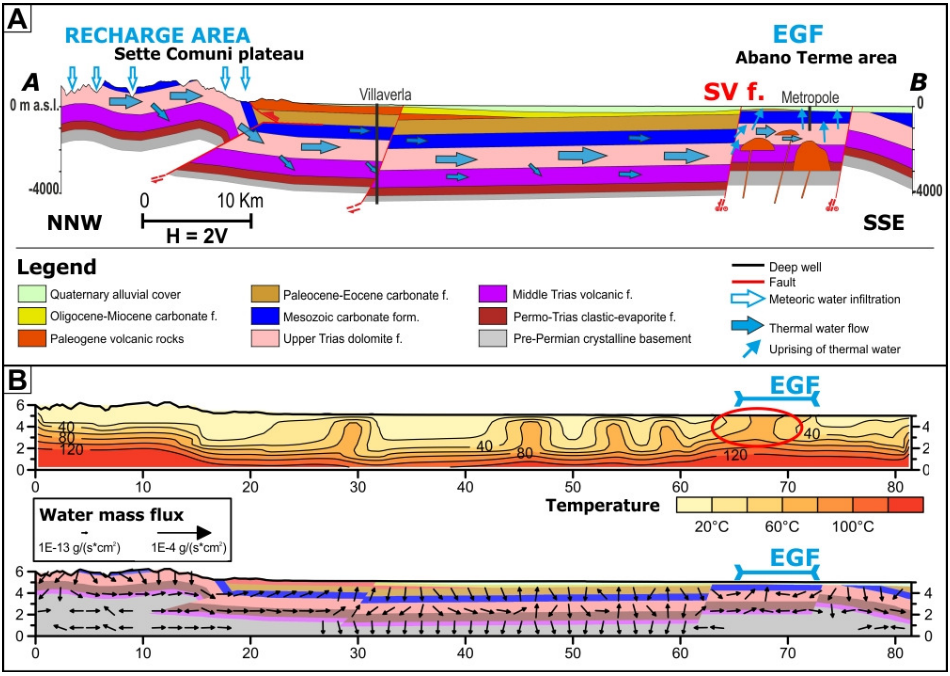
The *Euganean Geothermal Field (EGF)* is the most important thermal field in the northern Italy, covering a plain band of about 36 km^2 to the southwest of Padova (Veneto; Italy; Fig. 1). Approximately 250 wells are active in the EGF and exploit 17 M m^3/y of thermal fluids with a temperature from 60°C to 86°C (Fabbri, 2001) and a total dissolved solids (TDS) from 3.5 to 6 g/L (primary constituents Cl^- and Na^+; Gherardi et al., 2000). Isotopic analyses suggest a meteoric origin of the thermal waters (recharge area up to 1500 m a.s.l.) with a residence time greater than 60 years, approximately a few thousand years. The aim of this work is to renew the *Euganean Geothermal System (EGS)* conceptual model using the knowledge developed in the last 30 years of hydrogeological, structural and geochemical studies on both the EGF and the central Veneto.

A reviewed interpretation of the central Veneto structural setting evidences a buried, complex fault system (*Schio-Vicenza fault system - SVFS;* Zampieri et al., 2009) composed by a network of NE dipping, high-angle faults synthetic with the regional, 100-km long, Schio-Vicenza fault. A left stepover structure (*transtensional relay zone*) between two distinct fault segments of the SVFS is evidenced near the EGF (Fig. 1), suggesting a linkage between the fault and the thermal systems in agreement with the well established, structural-controlled, hydrothermal, conceptual models (Faulkner et al., 2010). The renewed knowledge on the structural framework of the Veneto alluvial plain were used in the proposed EGS conceptual model. Original meteoric waters infiltrate in the Veneto pre-Alps to the East of the SVFS, about 80 Km to the North of the EGF. The recharge area is located in the Sette Comuni-Tonezza plateau and the reliefs facing the area (max altitude of 2341 m a.s.l. and mean altitude of 1317 m a.s.l.), where large outcrops of permeable carbonate rocks allow the infiltration of the meteoric waters. The potential recharge of the thermal system is estimated in approximately 230 M m^3/y, enough to feed the exploited 17 M m^3/y, produced by a 23% of the infiltration not discharged by the springs located at the base of the relief (unbalanced infiltration of 260 mm/y; Aurighi et al., 2004).



The waters flow to the South in a Mesozoic carbonate reservoir (Fig. 2A) and reach a depth of about 3000 m, warming up to 100°C by a normal geothermal gradient (Gherardi et al., 2000). The thermal water flux is enhanced by the high permeability of the Schio-Vicenza fault damage zone, thanks to a Riedel-type network of secondary fractures (Faulkner et al, 2010). In the EGF area, the thermal fluids are intercepted by the SVFS transtensional relay zone that produces a local fracture mesh that increases the local fracturing of the bedrock, the permeability and the migration to the surface of the thermal waters.



The proposed conceptual model is constrained by 2D and 3D numerical simulations. It is the first numerical modelling developed for the EGS and allows to evaluate the control of different factors (e.g., permeability, thermal conductivity, basal heat flux, width of the damage zone) on the EGS development. A 82 km long, 6 km deep, standard cross section of the hydrothermal system (Fig. 2A) is implemented in the software HYDROTHERM (Kipp et al., 2008) that simulates thermal energy transport in two-phase, hydrothermal, ground-water flow systems. A collection of input parameters (porosity, permeability and thermal conductivity) of the 9 formations involved in the EGS is obtained from literature. The applied boundary conditions are: a recharge of 260 mm/y at! the upper boundary in the infiltration area; a seepage-face at the upper boundary in the EGF area, which permits the groundwaters outflow from the simulated region maintaining their enthalpy; a basal heat flux of 0.1 W/m^2 at the lower boundary; a constant value of initial pressure/temperature at the upper, right and left boundary. After preliminary simulations, a sensitivity analysis on permeability and thermal conductivity of the rock units is performed to obtain a configuration of parameters that develops an higher temperature in the thermal aquifer. The best values are: the mean value of the permeability for all the formations (k = 3*10^{-6} m/s for the formations of the thermal aquifer), low thermal conductivity values for the formation of thermal aquifer (λ from 2.1 to 3.1 W/m*K), high thermal conductivity values for the formation below the thermal aquifer (λ from 3.2 to 4.7 W/m*K). This set of values is tested in a simulation obtaining a temperature of 50-60°C in the EGF and a chaotic development of fluid flux. An anisotropic configuration of permeability is applied to reduce the fluid flux and to permit a better development of temperature. The best result is obtained using the previous configuration of thermal conductivity, a permeability of the thermal aquifer a little bit lower than the mean one and an anisotropic permeability k_z/k_x=0.2. This simulation (simulation length of 55100 years) shows a 60-70°C temperature-plume in the EGF area (temperature of 72°C in the middle part of the plume near the surface; t=55000y; Fig. 2B), according to the temperature of 70-80°C measured in the EGF thermal wells. The numerical modelling of the EGS is improved through 3D simulations with the software SHEMAT (Clauser, 2003). Preliminary results give similar evidence of the 2D modelling obtaining a temperature of about 70°C in the EGF area. Moreover the 3D modelling will allow to appreciate the influence of the SVFS damage zone (i.e., width, permeability) on the development of the thermal system. In conclusion, the obtained temperature, approaching the real one, demonstrate that this new conceptual model can be simulated in realistic way through 2D and 3D numerical simulations of groundwater flow and heat transport.

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Effect of gravitational forces on thermal groundwater flow

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Introduction

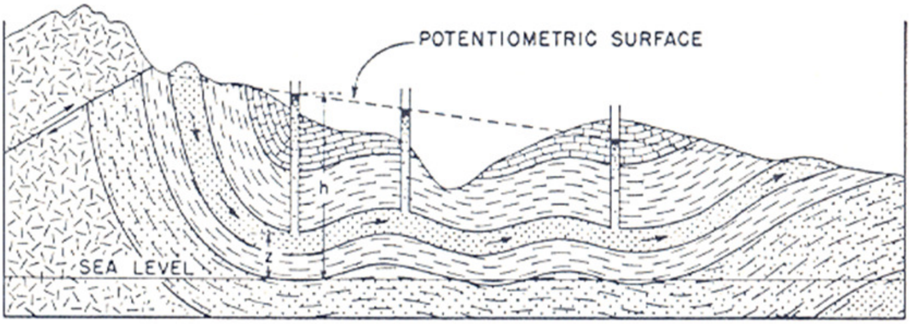
Traditionally thermal convection cells are often cited to explain geologic processes such as the genesis of various ore deposits (i.e. uranium or MVT lead-zinc deposits) and of hydrothermal systems in general (summarized in Ingebritsen et al., 2006). To facilitate mathematical convenience, hydraulic heads are typically replaced by pressure and temperature as driving forces. Thereby the flow of water through a given cross-section would analytically be given by the product of permeability and pressure gradient. Within flow systems cold water is thought to sink from the site towards a heat source, is heated at depth, and then travels upwards driven by buoyant behaviour of the lighter (less dense) heated water (Rinehart, 1980, Fig. 5.1).

Pressure-based numerical flow models such as TOUGH2 (Pruess, 1991) are used as an alternate approach “to switch variables, solving for pressure and temperature under single phase conditions and pressure and saturation under two-phase conditions” (Ingebritsen et al., 2006, p.128). Thereby the physics of mass-related fluid flow (Hubbert’s 1940 force potential; energy per unit mass) has been supplanted by mathematical pseudo-physics making use of the velocity potentials of continuum mechanics (mass and energy per unit volume) as described by Bear (1972) and de Marsily (1986). Velocity potentials have been successfully used in solving engineering problems. They are, however, not suitable to deal with physical problems of regional and geothermal fluid flow.

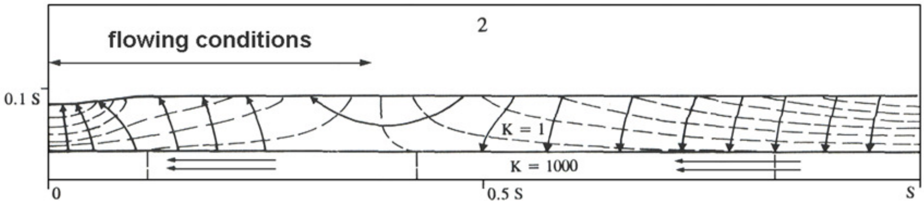
Gravitational groundwater flow systems

Velocity potential systems assume the existence of convection cells in both the hydrostatic off-shore environment and the hydrodynamic onshore environment. Applying the physics of Hubbert’s force potentials limits the existence of hydrothermal convection cells to the hydrostatic offshore subsurface conditions. They do not exist in the hydrodynamic onshore environment, where gravitational forces drive groundwater flow systems from recharge areas of higher elevation to discharge areas of lower elevation (Weyer, 2010). In groundwater flow, gravitational forces are much more powerful than geothermal forces. Thus, onshore, geothermal forces only modify (usually slightly) the direction of the resultant hydraulic forces rather than change them significantly. Therein lies the reason that, under natural conditions, convection cells do not form onshore.

Based on the physics of force potentials (Hubbert, 1940), groundwater flow systems theory was advanced by Tóth (1962) and Freeze and Witherspoon (1967). A previous legacy concept confined regional groundwater flow to the 'confined' aquifer systems with groundwater recharge occurring only at the aquifer outcrops in mountainous areas (Fig. 1A). This concept was replaced nearly 50 years ago by groundwater flow systems theory which recognized that aquitards were an essential part of regional groundwater flow (Fig. 1B).



A – legacy concept of groundwater flow (from Hubbert, 1953)



B – revised concept (from Freeze and Witherspoon,1967)

Fig. 1.- Comparison of legacy (Fig. 1A; Hubbert, 1953) and modern (Fig. 1B;Freeze and Witherspoon, 1967) concepts regarding the role of aquitards in regional groundwater flow with artesian discharge areas. Artesian wells conditions indicate upwards-directed flow directions penetrating aquitards under discharge areas.
Fig. 1B shows a modelled case with twice as much groundwater flowing in the aquitard (downward flow under the recharge area and upward flow under the discharge area) as in the aquifer (lateral flow only between recharge area and discharge area).

In fact, under certain geometric conditions, there may be twice as much groundwater flowing in aquitards as in underlying aquifers (Fig. 1B): under recharge areas groundwater flows downwards through the aquitard into the aquifer then laterally within the aquifer from recharge to discharge area and then again upwards through the aquitard to the discharge area. The new concept of flow through aquitards also supplanted the notion that substantial groundwater flow was limited to fault zones. In the meantime it has also been established that gravitational groundwater flow systems may penetrate to depths beyond 5 km (Tóth, 2009).

Buoyancy

Continuum mechanics assumes so-called vertical 'buoyancy forces' to be omnipresent under hydrostatic and hydrodynamic conditions. In reality, however, vertically-directed buoyancy is only present under hydrostatic conditions (Weyer, 1978). In terms of force potentials, the 'buoyancy forces' are represented by the pressure potential forces [-(grad p)/rho] which happen to point vertically upwards under hydrostatic conditions (Fig. 2A; no water flow). Hydrostatic condition are a special case of the general hydrodynamic conditions where the pressure potential forces point in an oblique direction (Fig 2B). It follows that under hydrodynamic conditions of flowing groundwater the so-called 'buoyancy force' (actually: the pressure potential force) is not directed vertically upwards but assumes an oblique direction. Under certain conditions of downward flow of groundwater the pressure potential force of groundwater may even be directed downwards, the condition of 'buoyancy reversal' (Weyer, 1978, Fig. 9). Typically, in continuum mechanics, numerical models do not and cannot replicate these 'buoyancy' conditions. Instead they may return convection cells which do not exist in reality. Fig. 2C and 2D show only minor divergence for lighter water of 100°C and for denser water of ocean-type salinity.

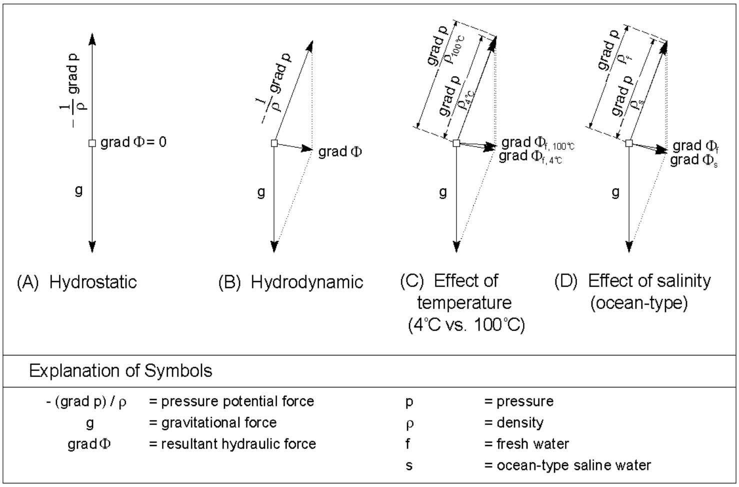


Fig. 2.- Resultant force calculations A: Under hydrostatic condition: no flowing groundwater; B: Under hydrodynamic conditions: groundwater flows; C: Similarity in flow directions between fresh water at 4°C versus 100 °C.;
D: Similarity in flow direction between fresh water and water with ocean-type salinity.

Conclusions

Applying the velocity potential of continuum mechanics to geothermal flow returns unsatisfactory results which do not adhere to the physical principles of flow in porous media. Geothermal water migrates as part of gravitational groundwater flow systems. Convection cells do not exist within gravitational ground water flow systems.

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Different modeling methods to simulate groundwater flow to multi screen wells

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Introduction

Real pumpage from aquifers is commonly more complex. Heads in aquifers that surround a well are likely to vary along the length of a screen that penetrate the aquifer or has a long horizontal extent (Szucs et al., 2006). Because of this special flow behavior, a simulation program called the drawdown-limited, Multi-Node Well (MNW) Package was developed for MODFLOW (Halford & Hanson 2002). The MNW package enables MODFLOW specialists to simulate wells with short or multiple screens. Multi-node wells can simulate wells that are completed in multiple aquifers or in a single heterogeneous aquifer, hydraulic effect of partially penetrating (see Fig. 1.), and even horizontal wells. The multi-node aspect of the MNW package can enhance model calibration and groundwater simulation opportunities of MODFLOW.

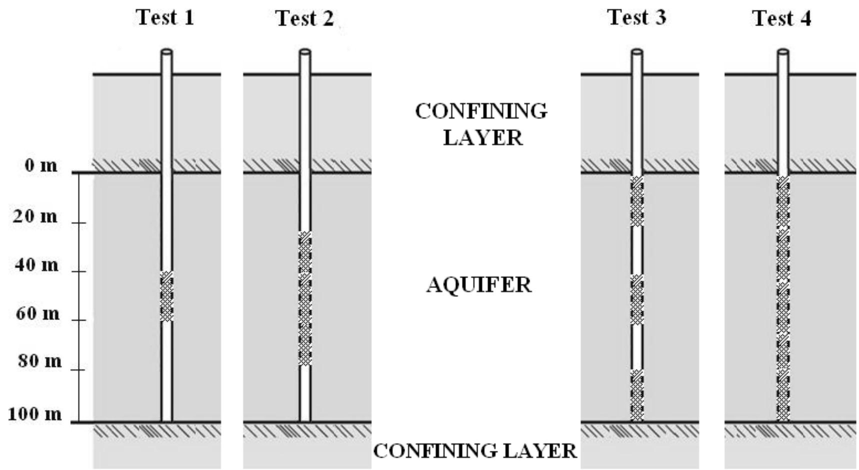

Fig. 1.- Fully (Test 4), partially (Test 1, Test 2) penetrating and multi screen (Test 3) wells for case-study simulation investigations (after Konikow et al. 2009).

An alternate numerical multiscreen well flow simulator FLOW was created and improved by Székely et al. (1996, 2000). The well flow module of FD (finite difference) groundwater flow simulator estimates the well bore drawdown and screen fluxes with the effects of laminar and turbulent skin losses. The point centered FD scheme generates the cell drawdown due to distributed flux W, whereas the additional local drawdown in well bore is calculated for the actual (confined or leaky) flow conditions around the screen(s).

Comparison of different simulation approaches

The case-study comparison study facilitates a specific hydraulic modeling job using different solution methods. Four different tests were carried out to show how the MNW and FLOW packages work concerning the simulation results. Results of calculations are listed in Table 1. The confined simulation model comprises 5 homogeneous horizontal layers with equal parameters as follows:

Thickness: 20 m.

Initial hydraulic head: 0 m.

The hydraulic conductivity: 0.0001 m/s.

Horizontal and vertical anisotropy: 1.

Specific storage: 0.00001 1/m.

Parameters of the model area:

Left bottom corner coordinate is: (0 m, 0 m).

Right uppermost corner coordinate is: (510 m, 510 m).

Grid system used by MODFLOW: 51 rows, 51 columns. The basic grid size: dl = 10 m.

Well data:

A pumping well is located in the middle of the modeled area. The coordinate is: (255 m, 255 m).

The radius of the pumping well is: 0.2 m.

The discharge rate of the pumping well is: -0.1 m^3/s.

The FLOW package uses 50 blocks in both x and y directions and the square blocks have dl = 10.2 m long sides. Thus, the well can be positioned at the common corners of four neighboring blocks as required by the point centered FD schemes or finite element simulators.

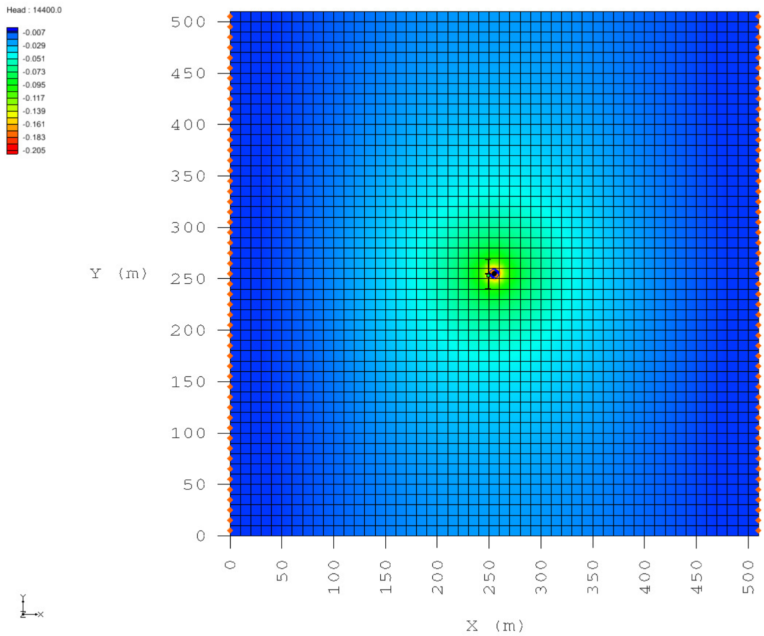

Fig. 2.-The applied grid system with the boundary conditions, the production well in the middle of the model area and drawdown contour lines of Test 3.

To use the MNW package with MODFLOW, the hydrodynamic model of the investigated area was compiled using the Groundwater Modeling System (GMS 7.1) modeling package. The applied grid system with the boundary conditions and the well in the middle can be seen in Fig. 2. Constant head boundary conditions were set on the west and east side of the model area. No flow boundary conditions were set in the north and south side of the model area.

The skin effect can be expressed as the change of hydraulic conductivity (or permeability) around productions wells. The MNW package allows the experts to incorporate the skin effect into the simulations. The skin effect can be pictured as head loss occurring across a cylinder of radius, r_{Skin}, around the investigated well with a finite radius, r_w. The skin zone has a transmissivity T_{Skin}, that differs from the formation transmissivity T. The dimensionless skin coefficient can then be described in terms of a transmissivity contrast (T/T_{Skin}) over the finite difference between r_w and r_{Skin} or by:

$$Skin = \left(\frac{T}{T_{Skin}} - 1\right) ln\left(\frac{r_{Skin}}{r_w}\right). \quad (1)$$

In most cases the Skin is positive. The skin coefficient is equal to zero or negative if T_{Skin} is equal to or greater than T. The additional (+ or -) drawdown ds_{Skin} caused by the skin effect can be calculated as:

$$ds_{Skin} = \frac{Q}{2\pi T} \cdot Skin. \quad (2)$$

Tests 1, 2, 3 and 4 (see Fig. 1) were performed at the same rate of 0.1 m^3/s and demonsrate effect of different screening shemes in the 5-layer-model. In case of Test 1 only one layer was screened. This scheme may involve five different options, as the screen can be installed separately at the top (in layer 1), at the bottom (in layer 5), in the middle (in layer 3), and in layers 2 or 4. In case of Test 2 layers 2, 3 and 4 are screened, whereas layers 1, 3 and 5 are tapped in Test 3. Finally, in case of Test 4 all the five layers are screened simultaneously.

Results and discussion

Results of comparative simulations are summarized in Table 1. Column 4 displays 3D_A data obtained by WT simulation considering 5 model layers and l_{scr} = 20 m long screens represented by line sinks. Column 5 exhibits results of an enhanced 3D_B modeling where each screen is split into 80 sections of l_{scr} = 0.25 m. This segmentation provides a very detailed flux distribution along screens therefore these data are considered as the "true" solution to the test problem analyzed and used as reference values. The last two columns show results of numerical MODFLOW and FLOW simulations with close s data and higher discrepancy in calculated fluxes.

Table 1. Summary of comparative evaluation of well flow simulators.

Tests	**Screened layers**	**Data**	**3D_A** l_{scr}**=20 m**	**3D_B** l_{scr}**=0.25 m**	**MODFLOW dl=10 m**	**FLOW dl=10.2 m**
1	1 or 5	s	40.648	39.986	42.087	42.030
	2 or 4		36.608	35.822	39.274	39.212
	3		36.275	35.486	38.950	38.887
2	2-3-4	s	16.409	16.253	16.730	16.730
		Q% 2 & 4	34.578	34.577	34.872	34.001
		Q% 3	30.843	30.846	30.245	31.999
3	1-3-5	s	15.724	15.507	16.305	16.304
		Q% 1 & 5	32.284	32.223	32.071	32.727
		Q% 3	35.432	35.554	35.855	34.547
4	1-2-3-4-5	s	12.053		12.052	12.053

Data for Test 4 (fully penetrated well) confirms good fit among all the drawdown data. The three models resulted in uniform Q% = 20 screen fluxes in this test. For the other tests numerical well bore drawdown data show close overestimation. This, however, can be reduced through vertical refinement of the 100 m thick flow domain. Thus, by applying 50 model layers and 10 sub-screens (l_{scr} = 2 m) in the upper 20 m thick section the first s value in the last column reduces to 40.226 m. The latter is a close approximation to the 3D_B simulation. Closer inspection of Q% data reveals that the 3D_B fluxes (reference data) are positioned between the two numerical solutions.

Conclusions

The following summary can be made on the obtained results of the present study:

1. Two analytical (3D_A, 3D_B) and two numerical (MODFLOW, FLOW) methods were involved and compared to test their multiaquifer well flow simulation abilities.
2. The obtained results confirmed that the numerical MODFLOW MNW and FLOW packages can provide reliable and accurate simulations even in complex hydraulic situations in multilayer aquifers.
3. In case of multiscreen well flow simulation several modeling techniques are proposed to establish and minimize the approximation error of different origin and range. This may help in finding the optimum solution to simulate flow metering data, contaminant transport and to involve this database into model calibration.

Acknowledgements

The described work was carried out as part of the TÁMOP-4.2.2.A-11/1/KONV-2012-0049 project in the framework of the New Hungarian Development Plan. The realization of this project is supported by the European Union, and co-financed by the European Social Fund.

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Simulation of thermal interaction between groundwater and borehole heat exchanger

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Ground source heat pump (GSHP) systems employing borehole heat exchangers (BHEs) are promising alternatives of conventional heating and cooling technologies. Generally only pure conductive underground heat transfer is assumed in design and optimization procedures and other studies related to GSHP systems. However, the installed BHEs can cross saturated permeable layers. In such cases natural groundwater flow and buoyancy groundwater flow can considerably contribute to the underground heat transfer. Some recent research studies attempts to predict the possible performance increase of GSHP systems due to groundwater flow. These calculations are mainly based on analytical and/or numerical simulations. In these models some elements of the whole GSHP systems are generally neglected or treated in a simplified way. We present a complex numerical simulation system that is an integration of different sub-models simulating different heat transfer phenomena and different elements of GSHP systems. The simulation system can take into account the underground conductive and advective heat transfer, underground thermal buoyancy, heat transfer between BHE and ground, heat transfer inside BHE, heat pump operation and the transient heating/cooling loads of buildings. We present some simulation results where groundwater flow and thermal buoyancy can play an important role, and where the performance of BHE and the whole GSHP system are increased due the groundwater. For the demonstrated examples, we also present the underground temperature disturbance and temporal evaluation of the underground thermal effect area.

A coupled geothermal model of the Alpokalja area, Hungary

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A coupled groundwater flow and heat transport model of the Alpokalja area is presented in this study. The study area lies in the western part of the Pannonian Basin located on the current border between Hungary and Austria, thus representing a transboundary situation.

The study area contains several geothermal water utilisations on both sides of the border, which have impact on natural groundwater conditions. The aim of the modelling study was to evaluate the natural state and production state groundwater conditions, and to make predictions on cross-boundary interferences.

There are three independent thermal water reservoirs identified in the region. The porous Upper Pannonian reservoir is separated from the porous Miocen and Devonian carbonate reservoirs by a thick aquitard of lower Pannonian age.

The Devonian dolomite reservoir is of particular interest. This aquifer comprises three tectonically separated blocks. According to hydrochemical characteristics of the groundwater, the dolomite blocks can be considered as isolated reservoirs with no or insignificant recharge. Due to the extraction of thermal groundwater from the dolomite aquifer, groundwater leakage developed between the Miocene and Devonian reservoirs. As a consequence, the hydrochemical composition of the Devonian reservoir has changed significantly.

A three-dimensional finite element type coupled geothermal model was constructed to provide a coherent quantitative representation of geothermal flow systems. The model described the hydraulic behavior of the flow system, the interaction between different reservoirs, and the geothermal conditions of the system.

Hydrodynamic modelling and geothermal potential in an overpressured basin

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Geological setting

The focus of this study is a sub-basin of a larger neogene basin. When the basin was formed, the surroundings uplifted therefore intensive erosion was taking place and the erosional products (sediments) were transported by rivers towards the lowlands and started to fill –up the basin so a deltaic depositional system formed. Accordingly the succession above the pre-miocene basement starts with suspension-originated basal marls which are followed by distal and proximal turbidites that have a continuous transition to the deltaic sediments.

Figure 1. illustrates a simplified depositional model of the area. Deltas were prograding from NW and NE. Therefore sediments arrived to the starving basin from these two different directions.

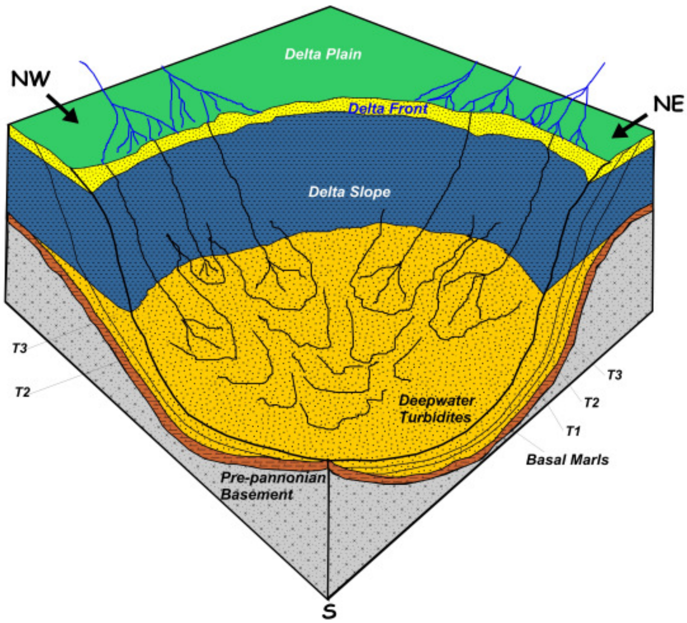

Fig. 1.- Simplified depositional model of the studied basin

Turbidity currents were mobilized from the delta slope by earthquakes and changes in water-level. These turbidity currents deposited a thick turbidite sequence which was divided into three parts. The NE deltas deposited T1 and mainly T2 and T3 was deposited by both deltas. However sediments of T3 differ in lithology depending on which delta they were transported by.

Hydrogeology, reservoir parameters

The described lithologic units also represent regional hydrostratigraphic units. Basal marls and delta slope sediments are regionally aquitards while distal and proximal turbidites are aquifers. Proximal turbidites have greater porosity than distal turbidites even at the same depth. Values range between more orders of magnitude depending on the position in the basin and the distance from the sediment source. Values in the depocenter of the basin are typical of tight sand reservoirs.

Hydrodynamic modelling

In order to better understand the hydrodynamic behaviour of the basin a hydrodynamic model was constructed. As the model aims to simulate the natural flow system steady-state conditions were assumed. The model geometry was based on well data and seismic interpretation. Four confined layers were defined which were divided into 3 sub-layers to enhance vertical resolution. Hydrogeological parameters (hydraulic conductivity and porosity) were available from parameter distribution maps. Hydraulic head data were calculated from static pressure data resulting from drill-stem tests (DSTs). Boundary conditions were provided by fixed head cells at the top and bottom of the model space. The simulation was run with two different methods: finite difference and finite element method.

Hydraulic cross sections on Figure 2. represent the results of the hydrodynamic simulation with both methods. Flow is mainly directed upwards since it is perpendicular to the equipotential lines. Potentiometric mounds can be observed above basement highs which suggests that extreme overpressures are related to the horsts of the basement. Above basement highs flow directions have horizontal components that show toward deep grabens. No significant discrepancy can be observed between the results of the two calculation methods however the congestion of equipotential lines is more expressed by the finite element method which is in more accordance with the abrupt pressure change on p(z) profiles.

Geothermal conditions

The study area is characterized by above-average geothermal heat flow (80-100 mW/m^2) and geothermal gradient (50-60 °C/km) which is due to the thin continental lithosphere, the upwelling of the hot asthenosphere and mantle diapers. Heat transport is predominantly conductive in the basin, however well temperature data indicates that advective (convective) heat flow can also be observed in some areas where local upward directed flow pathways (e.g. conduit faults or fault zones) are present. Advective heat transport causes a significant change (decrease) in geothermal gradient locally.

Considering average heat flow and geothermal gradient the studied basin has desirable geothermal characteristics. From the aspect of thermal water production, overpressure itself is a favourable condition since it provides excess energy to geothermal reservoirs. On the other hand it stands as an extensive barrier to reinjection from the technical point of view. Other disadvantages of overpressured geothermal reservoirs are usually low permeability and porosity which can limit production flow rates significantly. However local sandstone bodies or the weathered and fractured reservoirs of the crystalline and carbonate basement may have sufficient porosity and permeability to sustain adequate flow rates.

In conclusion effective and economical exploitation of overpressured geothermal reservoirs provide a great challenge to both geoscientists and engineers.

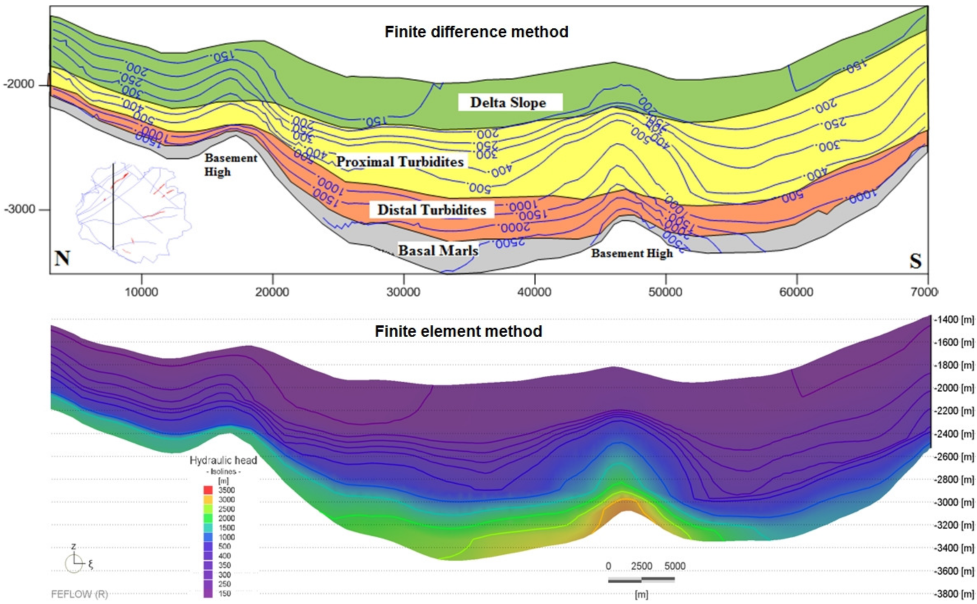

Fig. 2.- N-S hydraulic cross section

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Hydraulic and Geothermal modelling on the Komarno-Šturovo Pilot Area of the TRANSENERGY project

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The Komarno-Šturovo (Komárom-Párkány) Pilot Area of the Transenergy Project is situated in the north-eastern part of the Transdanubian Range in Hungary and its basinal part in Slovakia. The groundwater bodies are divided by national boundaries and are in focus of International Commission for the Protection of the Danube River (ICPDR).

The large karstwater-aquifer contains of mainly Upper-Triassic limestones and dolomites (Dachstein Limestone, Main-dolomite) affected by bauxite (Fenyőfő) and coal mining (Dorog, Mány, Tatabánya, Balinka, Dudar) and its growing dewatering since the 1950's. Due to the intensive water extraction the water table significantly decreased and cold and/or warm springs disappeared (Tata-, Dunaalmás-, Esztergom springs) or the yields reduced (Budapest thermal springs, the Patince spring/well lost its artesian characteristic) along the whole Transdanubian Range since the 1960's. After the mine-closures the water abstraction of the mines decreased or stopped (somewhere replaced by drinking water supply, e.g. Tata) the karstwater level started to increase and springs reappeared and their yields increased: the Csokonai spring reappeared in 1999, the Fényes-spings in 2002.

In the last few years this increasing in the water levels sets a lot of new problems. How does regenerate the karst-flow system? Can the system totally regenerate? Is it possible that the current utilizations develop their services? Shall new investments get permissions? What will be the effects of the developments and/or new investments?

A complex 3D hydraulic and geothermal model based on geological, hydrogeological and geothermic data from both countries is looking for answers to the questions above. The regeneration of the discharge zones, the present and future utilizations can be determined by the help of flow and geothermal modelling the refilling of the system.

Cross-hole test in geothermal wells

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The primary aim of the test conducted in 2012 was to obtain hydraulic properties of a water well drilled for injection of cooled water into a geothermal reservoir. The test programme was extended to involve four nearby wells from which two wells were drilled for abstraction of geothermal fluid and the other two wells were drilled for injection of cooled water. The extended test programme allowed the determination of the hydraulic connection between wells and the hydraulic properties of the geothermal reservoir. On the basis of the preliminary results of the interpretation of measurements the direct hydraulic connection between the pumped and the two other observed wells was proven, also the hydraulic characteristics of the reservoir could be determined. The results of the interpretation provided input data for a numerical groundwater model which was developed to study the behaviour of the potential hydrogeological features.

Heat potential evaluation of effluent and used thermal waters in Budapest, Hungary

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The capital of Hungary, Budapest has a particular hydrogeological setting: Europe's largest naturally flowing thermal water system can be found here. The springs and wells that supply the famous baths of Budapest discharge mainly from a regional Triassic carbonate rock aquifer system. The discharge zone of the system is situated essentially within the city districts, which is nowadays a fully urbanized environment. The natural springs have been substituted mostly by wells, only few natural springs are known today, which are drained mostly unused into the Danube.

In this study firstly the heat potential of these unused springwaters was assessed. Secondly, in the case of four baths, the heat potential of used thermal waters was calculated.

The Boltív-spring at the foot of Rózsadomb feeds the artificial Malom-lake, which is drained through a sluice and canal into the Danube. First the discharge and the physico-chemical parameters of the springwater were measured, then the heat potential was calculated. Two methods were used to measure the discharge. Over the course of a month, we took measurements every four days in the Lukács-bath basement with a propeller current-meter. The discharge calculated from the average speed values across the canal was in average 7350 m^3/day. The second technique we used was based on tracer's attenuation method. This method resulted in 6200 m^3/day. The physico-chemical parameters were measured at two locations: hourly where the Boltív-spring outcrops to the surface, and every four days in the canal. The temperature of the water was stable, 20-21 °C, the pH turned out neutral (7.3) and the conductivity values varied around 960-1080 µS/cm. The heat potential calculation (Table 1.) shows that cooling the springwater to 5 °C would give 5 MW_{th} thermal capacity. This amount would be enough to cover the heating needs of the Lukács-bath, furthermore the surrounding buildings energy related expenses could also be mitigated. The stable temperature and the huge discharge rate of the spring provide a stable energy source for heat pumps.

The overflowing water of the springs at the foot of Gellért Hill is collected in a canal and directed without utilization into the Danube. The measured overflowing discharge of the springs is 78 m^3/day during low water conditions, and the temperature in the canal is 33.5°C. By cooling this water to 5°C, a total of 108 kW_{th} heat could be utilized, possibly by heat pump system (Table 1.).

	Flow rate q (m^3/day)	T (°C)	Thermal capacity P (MW)	Yearly heat content Q (TJ/yr)
Paskál spa	246	27	0.26	8
Széchenyi spa	6179	35	8.97	283
Dagály spa	5135	36	7.70	243
Lukács spa	1342	37	2.08	66
Malom lake, Boltív-spring	7350	21	5.69	179
Gellért Hill springs	78	34	0.10	3

Table 1. Thermal capacity of waste thermal waters when cooled to 5 (°C)

Among the thermal water utilizing spas four with the largest thermal water consumption (Paskál, Széchenyi, Dagály and Lukács) were investigated regarding their water management. The used amount of thermal water, lukewarm springwater, cold groundwater and tapwater was firstly assessed. Secondly, the amount and temperature of the wastewater from the pools were investigated regarding its further use.

By analysing the resulting data and own on-site measurements it can be concluded that waste water of these six investigated areas carry a total of 782 TJ/yr (25 MW_{th}) waste heat (Table 1.), which is a considerable amount compared to the needs (300-3000 GJ/year) of a public institution (schools, kindergartens, etc.).

The importance of this study is the assessment of such potential heat sources (unused lukewarm and thermal springs, wastewater of spa pools) which are present either naturally or artificially, and do not require further thermal water production for heating purposes.

The Hungarian Scientific Research Fund (OTKA) has provided financial support to the project under the grant agreement no. K 72590 and NK 101356.

Effects of approaches generating different solid models on hydrodynamic models based on the case study of Hajdúszoboszló, East-Hungary

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Introduction

Quality and quantity of the groundwater is predictable by hydrodynamic models, in addition according to legislative regulations its conservation is pivotal. One of the requirements of water using permission is building hydrodynamic models about the effects of water extraction; in addition the water base protection also requires hydrodynamic modeling. Similar approach of these models would be necessary to avoid that a new hydrodynamic model revises the consequences of the old one only because of the different approach.

To determine the connection between the penetrated strata in wells is an important task in the hydrodynamic modeling. The effects of water extraction, the flow pattern around a well and the extension of the discharge area firmly depend on the stratification, the presence or lack of horizontal beds, the amount of lenticular bodies and many other geological phenomena.

Solid model via its geological approach determines the geometry of the hydrodynamic model layers. Different types of stratigraphic classifications are used in studies written for different purposes in different scales including lithostratigraphic, sequence stratigraphic and formation-based classifications. Lithological classification is based on the mapping of different types of sediments or rocks. In depositional systems the generally used units are sand and clay layers and their bedding is usually considered horizontal, unless information exists about the real stratification. This classification results well-detailed sequences. However, this approach can be not appropriate if pinching outs, lenticular bodies, tectonic disturbances occur or the bedding is not horizontal. The number of the determined layers may be too many for the calculation or there is not enough information about each layer (e.g. hydraulic head or conductivity). Moreover, if water is extracted from several layers the yield from each unit must be known.

Sequence stratigraphic studies can handle some tasks detailed above, since genetically coherent sediment units are regarded to one layer in the hydrodynamic model, since their units are usually lithologically homogeneous. It could also help to determine the connections between similar beds at different depths (subhorizontal stratification). Its resolution could be the most appropriate for geological and hydrologic modeling; however, it has the greatest demand for data, time and knowledge comparing the approaches.

In a formation-based or facies-based classification the model unit (formation/facies) is seldom homogenous litologically. These units have greater extent; in addition, they are well-defined in large scale. The number of layers is moderate and the resolution is lower. This approach is appropriate for building regional models.

Methods and geological frame

Based on an earlier research a high resolution stratigraphic (solid) model is determined around the thermal wells of Hungarospa Hajdúszoboszló. Well logs and seismic sections are applied to divide the stratigraphic columns for lithostratigraphic units in the thermal water reservoir. After that the genetically connected bodies were appointed, and then larger units (sequence stratigraphy based and facies based units) were built from the lithostratigraphic units (Fig. 1.).

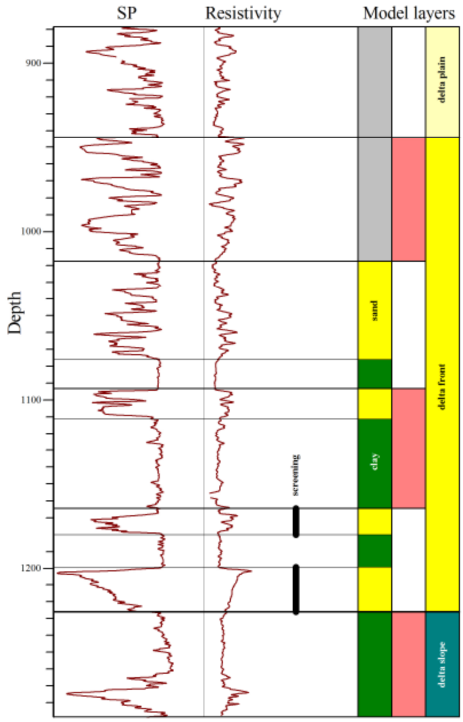

Fig. 1.- Part of the Ebes-9 well with the hydrodynamic model layers derived from different stratigraphic approaches

In the studied area the most important geothermal reservoirs are connected to the sandy delta front deposits, which settled near to the shoreline of the Pannonian Lake in the so called Upper Pannonian. The relative sea/lake level changes caused transgression in this area and the delta systems developed in four and five periods. The thickness values of delta slope sediments (silts and clays) between the sand bodies are various in the studied area, in its centre the total thickness of fine grained sediments is greater than the total thickness of sandy deposits which is not common in the Upper Pannonian thermal water reservoirs in Hungary.

Three hydrodynamic models were built from the three solid models in PMWIN 5.3. The hydraulic conductivity of each layers is derived the portion of sand and clay beds based on the well logs, the distribution of hydraulic head values based on the static level of wells. Steady state flow pattern and drawdown caused by a theoretical thermal water extraction from the Ebes-9 well (190 m^3/day) were calculated in each model. The area from which a water molecule reaches the well within 50 years is also determined, which is important in the aspect of water base protection processes.

Results and conclusions

The higher resolution of model means greater recharge area and more significant drawdown. The recharge area of 50 year in the formation based hydrodynamic models is approximately double than in the lithostratigraphy based model, while the calculated parameters of sequence stratigraphy based model are between the parameters of the two other models. The differences between these models strongly depend on the geological frame of the studied area.

In the case of well documented horizontal sand bodies the complex and time consuming sequence stratigraphy based modeling is not necessary. If the stratification is more complicated the determination of flow pattern may require more data and another approach. In thermal water utilization two other questions occur: determination of well interference (e.g. thermal water extraction from a given reservoir by numerous wells for a spa) and the depth of reinjection.

Further research is needed to understand which approach is more appropriate for typical sedimentary environments in basin filling processes (different delta facies, marine facies, and fluvial environments) and can help the ground water management more efficiently. It is important to note that there is no reason to modify existing models based on lithostratigraphic classification, if they represent the real flow pattern correctly.

Geothermal Reservoirs in the Western Part of the Pannonian Basin

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Geothermal energy and its most important carrying medium, thermal groundwater is strongly linked to geological structures, regardless of borders between countries. Thermal water reservoirs at the western part of the PannonianBasin were studied in the frame of the TRANSENERGY project carried on by four neighbouring countries (Austria, Hungyary, SlovakRepublic and Slovenia) (Fig.1). To assure a sustainable and harmonized utilization of geothermal resources of the project area, it is important to outline and characterize the main reservoirs / thermal water aquifers of the region. This was based on the integrated interpretation of geological, hydrogeological and geothermal models of the project area. The geological model outlined the main hydrostratigraphical units and provided their geological characterization, the hydrogeological model quantified the most important hydrogeological characters and the main groundwater flow systems, and the geothermal model provided the subsurface temperature distributions.

Chategorization of the reservoirs

Chategorization of the main reservoirs were based on on the geological and hydrogeological properties of the rock units. Six major reservoirs types were differentiated (Fig. 2). These categories were than further sub-divided, where relevant according to different temperature intervals (50-100 °C; 100-150 °C; above 150 °C).

During the post-rift thermal subsidence of the Pannonian basin in the Late Miocene up to 4000-6000 m thick sedimentary succession accumulated. Within this several thousand meters thick sedimentary porous basin fill complex the Lower Pannonian layers mainly consist of clay, or sandy clay therefore act as regional aquicludes. The Upper Pannonian sedimentary succession is built up of altering sand and sandy clay layers which is one of the main reservoirs of thermal groundwater.

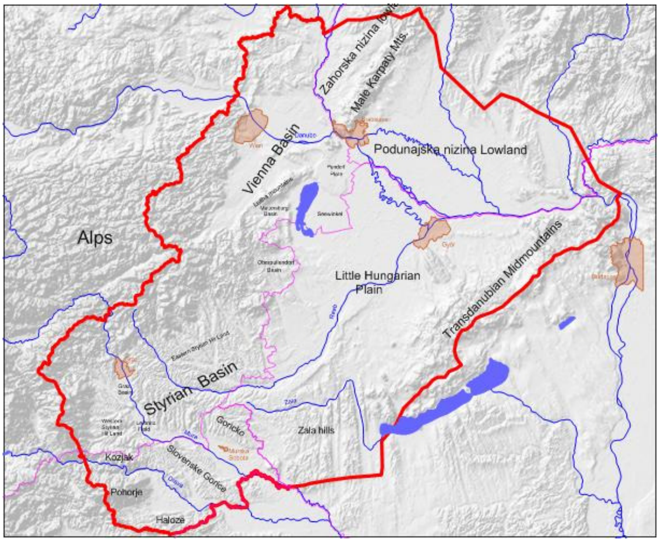

Fig. 1.- Geographical settings of the TRANSENERGY project area

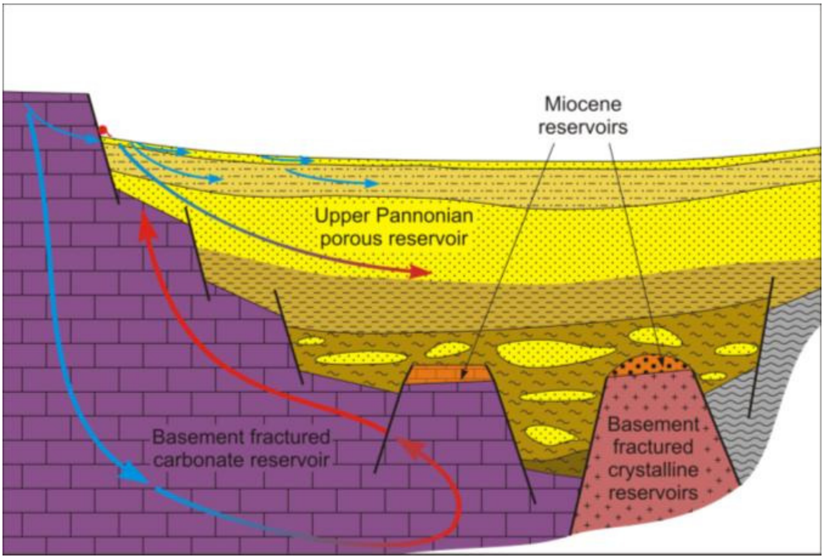

Fig. 2.- Main reservoir types of the Pannonian Basin

Due to extensional stress field in the Neogene, deep basins originated with various heteropic facies characterizing the margins, the rapidly sinking basin floors and the tilting basement highs. At the beginning of the repeated transgression phases coarse grained sediments, conglomerate, sand, sandstone, deposited at several places. These layers can be considered as porous thermal water reservoirs, with usually direct hydraulic connection to the basement reservoirs.

The most important Miocene thermal water aquifers are the widespread Badenian and the Sarmathian shallow-marine clastic carbonates consisting of coarse to fine clastics at the base grading into massive and / or ooidic, biogenic limestone on basinal highs with intercalations of mollusc-bearing calcareous sandstones, which is passing into detrital limestones basinwards. They are considered as reservoirs with double porosity.

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 called "non-classified".

The basement has got complicated geological structure of the different nappe systems of the ALCAPA tectonic unit. From the structural point of view, the basement crystalline rocks are arranged into nappes and thrust sheets, separated and cross-cut by strike slip structures and normal faults, displaying a complicated structure. Along the major fault-zones in the basement, there is a possibility to explore high temperature and high-pressure mixed steam-fluid systems which are originated from bigger depth (>3000 m). From hydrogeological point of view the crystalline basement formations are considered to be aquicludes. Nevertheless, locally they can form fractured aquifer systems, especially the weathered upper 50 m of the basement. The locations of these aquifers are very uncertain, and can be further specified only with detailed geophysical methods.

The non-metamorphic, Mesozoic formations of the ALCAPA nappe system and the carbonate formations of Graz Palaeozoic can be considered as fractured carbonate reservoirs. They are fractured aquifers with different magnitude of permeability. Where the carbonate sequences could have been karstified during their geological evolution (especially the upper zone of the formations) permeability can be higher and form good to excellent aquifers / reservoirs.

Characterization of the reservoirs

The different types of utilization of hydrogeothermal systems (e.g. power generation, direct heat, balneology) require different reservoir properties (temperature, yield, chemical component of thermal waters, etc.), e.g. a reservoir with high potential for heating of greenhouses (therefore ranked “high” according to a certain aspect) might not have sufficient temperature and yield for electricity production. The outlined potential reservoirs were characterized according to the main determining utulization aspects, such as type of aquifer, hydraulic connections, hydrochemical character, total dissolved content, re-injection possibility, max and min depth of top of reservoir, as well as indications for potential utilization. Where additional data (e.g. water chemistry) made it possible, and the originally outlined potential reservoir had a significant aerial distribution, a further sub-division was made. These sub-categories were characterized individually.

As the thermal water reserves are limited (to an extent of their natural recharge), sustainable utilization require re-injection. The precise mechanisms which determine injectivity are site specific and processes are not entirely understood yet. Re-injection into fractured crystalline and carbonate reservoirs is more promising, but research and development is necessary before applications in porous medium. Based on all these considerations, the outlined potential reservoirs are grouped into 3 categories related to re-injection: research and development necessary before routine applications (these are typically the Pannonian and Miocene reservoirs), re-injection is possible into larger fracture zones or caverns (basement fractured carbonate reservoirs) and re-injection is feasible into larger fracture zones (basement fractured crystalline reservoirs)

Due to a wide range of rock-water interaction processes along the subsurface flow, thermal waters might get enriched in a wide range of chemical components and dissolved gases. However the high total dissolved content may cause utilization problems. Based on water chemistry the general hydrogeochemical character and the significant total dissolved content were considered in the characterization of the reservoirs.

The depth of a potential reservoir is one of the most important information for planning exploration and exploitation strategies, as it might significantly increase drilling costs. The characterization provided information on the maximum and minimum expected depth of the top of the potential reservoirs.

Considering utilization schemes, it can be concluded that high-enthalpy systems (temperature above 150-200°C) which would be suitable for electricity generation through flash steam turbines do not exist on the TRANSENERGY project area. The deep subsurface geology of the project area is not really suitable for enhanced geothermal systems (EGS) either. Nevertheless the outlined potential crystalline and fractured carbonate reservoirs with temperatures above 150°C maybe prosperous sites for generation of electricity with small capacity power plants (< 5 MW_e). Medium enthalpy systems with temperature range between 100–150°C and high yield are typically suitable for electricity generation in binary power plants, where thermal water heats up a secondary working fluid with lower boiling temperature, especially combined with utilization of the heat. The low-enthalpy reservoirs (temperature below 100 °C) have potential for a wide range of direct heat utilization.

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

Groundwater flow and geochemical modeling of the Acque Albule thermal basin (Central Italy): influences of human exploitation on flowpath and thermal resource availability

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The Acque Albule basin is a 30 km^2-wide morphological depression located about 10 km east of Rome (central Italy) at the eastern margin of the meso-cenozoic carbonate Central Apennine fold-and-thrust belt. The stratigraphic sequence in this portion of the Apennine chain consists of medium to very high permeability limestones with interbedded marly limestone and marls. During the middle-upper Pleistocene, a new tectonic regime affected the pre-existing stratigraphic pattern and the volcanic activity reached its climax as a consequence of the crustal extension. This tectonic pattern heavily influenced the upward movement of deep hydrothermal fluids causing the deposition of an endogenic travertine sequence. The average thickness of the travertine deposits is about 60 m and reaches its maximum of 85 m in the region around a N-S oriented fault zone.

The subsurface flows move predominantly from the north to the south within the travertine aquifer and then discharge into the Aniene River. From the northern margin the lateral recharge from the regional system is about 4000 L/s (Fig. 1). The western and eastern margins of the aquifer are considered to be lateral no-flow boundaries. The zenithal recharge was estimated to be 275 mm/y for the rural areas and 82.5 mm/y for the urbanized regions. Under undisturbed conditions the hydraulic gradient of the groundwater system ranges between 0.5 and 1.0% in regions not impacted by withdrawals. Groundwater flow primarily occurs within the travertine aquifer, characterized by relatively high hydraulic conductivity (5.3×10^{-3} m/s). A sandy and clayey-silt low-permeability layer separates the shallow system from an extensive deep confined carbonate aquifer where groundwater is mineralized by thermally-active volcanic complexes. The groundwater characteristics are influenced by shallow groundwater mixing with deep hydrothermal fluids and gases uprising along the N-S trending fault zone where tectonic discontinuities act as preferential pathways. The primary thermal spring of the basin is an area located along this fault zone by which deep thermal waters rapidly migrate up to the Regina and Colonnelle Lakes. The groundwater discharging from this spring is used by the “Terme di Roma” Spa, and exhibits a mean temperature of 23°C. In addition the Basin is affected by large scale quarry dewatering operations.

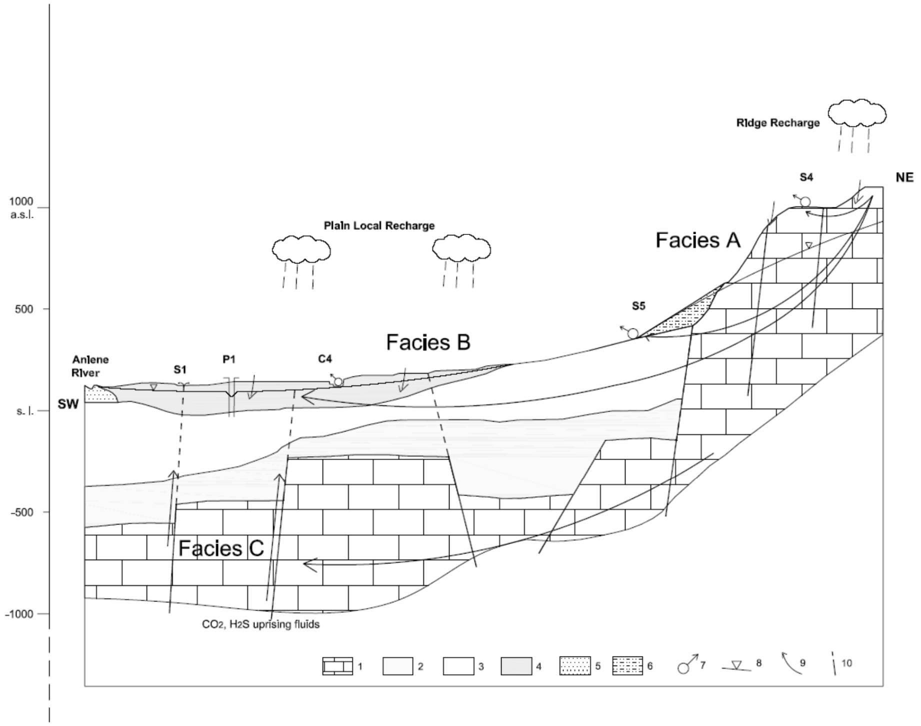

Fig. 1.- Conceptual hydrogeological and hydrogeochemical cross section from hydrological, geochemical and isotope results. 1: Meso-Cenozoic carbonate aquifer; 2: Plio-Pleistocene aquitard; 3: Pleistocene volcanic and alluvial layers; 4: travertine aquifer; 5: Aniene river deposits; 6: colluvium; 7: spring; 8: water table; 9: groundwater flowpath; 10: main faults (after Carucci et al., 2012)

Geochemical investigations indicate that the hydrochemistry of groundwater is characterized by mixing between end-members coming directly from carbonate recharge areas (Facies A) and from groundwater circulating in a deeply buried Meso-Cenozoic carbonate sequence (Facies C). The travertine aquifer is fed by both flow systems, but a local contribution by direct input in the Plain has also been recognized (Fig. 1). The stable isotope data (^{18}O, ^{2}H, ^{13}C and ^{34}S) supports the flow system conceptual model inferred from the geochemical data and represents key data to quantify the geochemical mixing of the different groundwater circulating in the Plain.

A numerical modelling approach was proposed to calculate the system's water budget and isolate the effects of individual anthropogenic activities on the basin's groundwater regime (Fig. 2). Results indicated that the dewatering activities in the quarries have drastically modified the groundwater flow pattern in the basin with a 85% reduction of the thermal spring discharge and, as a consequence, have had a corresponding detrimental effect on the basin-scale water budget. The numerical model suggested that the pumping activities employed since 2002 to supply the "Terme di Roma" spa caused the cessation of the thermal spring discharge and a water level drop of about 2.9 m in the area affected by land subsidence.

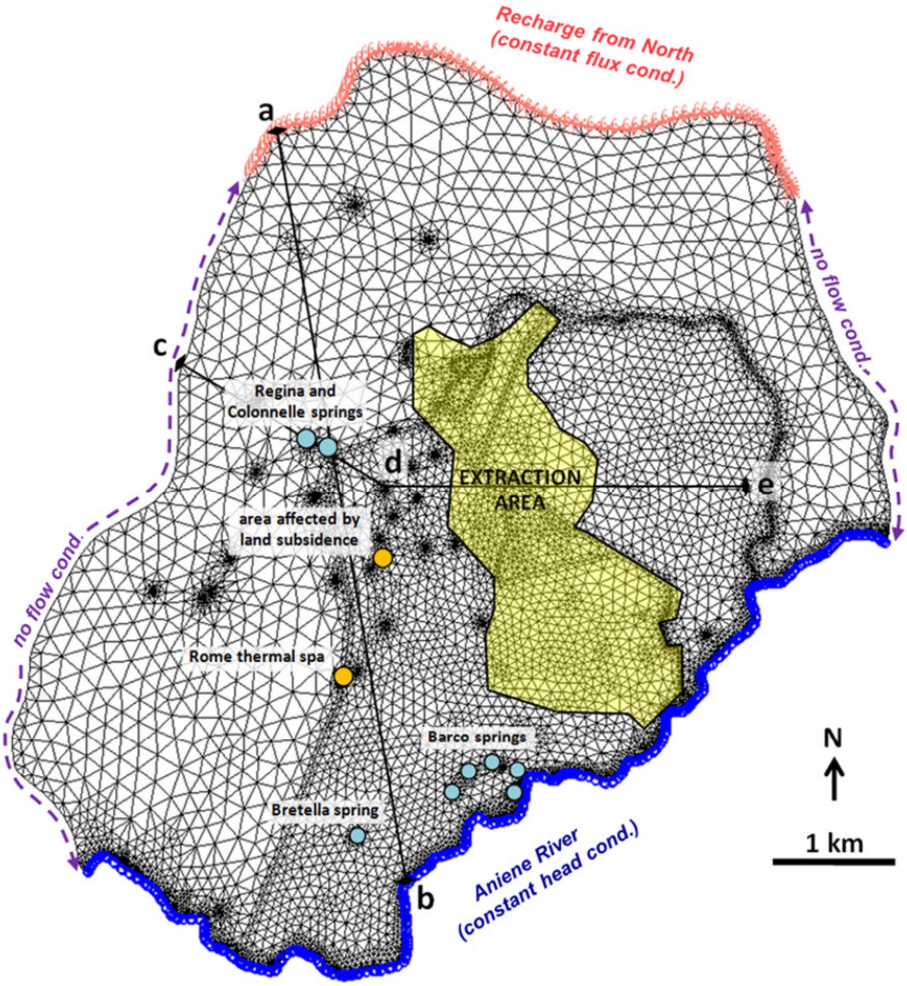

Fig. 2.- Main characteristics of the simulation flow model of the study area (after Brunetti et al., 2012).

Furthermore, geochemical and isotope modeling demonstrates an increasing influence of groundwater from the deeply buried aquifer in the travertine aquifer.

The quarry activity is modifying the main geochemical characteristics of the travertine aquifer, because deep mineralized groundwater is extracted during quarry exploitation, which affects discharge, and feed the Spa springs (S1).At the same time, water table lowering is causing an additional contribution from the deep mineralized groundwater to the travertine aquifer. Groundwater stratification in the travertine aquifer associated with mixing of the carbonate ridge recharge groundwater with mineralized fluids from the deep aquifer has recently been modified by enhanced water extraction in the quarries. This disturbance has increased the water salinity and caused the disappearance of the input from the shallow aquifer fed by groundwater of local origin. This scenario is causing a different degree of mixing of infiltration water with deep groundwater (Facies B), linked also to a reduction of recharge due to a decrease in rainfall in the last decade.

Carbon dioxide plays an important basic role in the groundwater mixing process. The C isotope patterns in the travertine aquifer corroborate the hypothesis of an increasing contribution from the deep to the shallow aquifer. Mixing processes are responsible for the geochemical evolution observed in the travertine aquifer.

The resulting conceptual model includes both hydrodynamic and geochemical changes along flowpaths, considering the travertine aquifer as a dynamic system. The different contributions from the flowpaths can vary in space, because of natural flowpaths, recharge and tectonic pattern, and time, due to the influence of pumping activities in the quarries. Consequently, the travertine aquifer reflects the groundwater inputs, showing a change in the percentage contribution from deep mineralized groundwater and from the recharge area, and is particularly enhanced in the quarry area, which has been affected by a sharp drop in the water table. Correct evaluation of mixing processes can be useful from a resource water management perspective aimed at more sustainable control of human interference in the Tivoli Plain, taking into account the needs of both thermal Spa and quarries. The intense pumping of water in the quarries area is accelerating the natural mixing, previously caused only by tectonic patterns, and the risks associated with subsidence and sinkhole formation in the Acque Albule Basin. This process is modifying the main geochemical characteristics of the travertine aquifer, and is increasing the contribution of seepage rising from the deep aquifer, whose groundwater is more aggressive than the original groundwater in the travertine aquifer.

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Significance of a water bearing fracture for underground thermal energy storage - a model of a middle scale laboratory experiment

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Efficient and inexpensive energy storage systems undoubtedly play a significant role in the modern western-based sustainable energy strategy. The thermal energy storage, defined as the temporary storage of thermal energy at high or low temperatures (Ercan Altar 2006), appears to be the most appropriate method for correcting the mismatch occurring sometimes between the energy supply and demand (Dincer and Rosen 2010). In the Underground Research Laboratory Josef, located in Central Bohemia, granite is being studied as a host rock of the underground thermal energy storage recently. In-situ experiment has been set up to evaluate cyclic heating and cooling on the thermohydromechanical characteristics of the granite. At the preparatory stage, a medium sized laboratory experiment had been employed to assess a possible influence of mobile fracture water on the in-situ experiment.

For the laboratory experiment a granite block 800 x 600 x 300 mm was prepared (Fig. 1, right). The block consists of two complementary parts separated by a comb-like fissure approximately 0.5 mm wide. Fifteen micro-wells were drilled into the upper part of the block to monitor the experiment. Except for the discharge point (number 16 on the fig. 1, right), sides of the block were insulated both hydraulically and thermally. Thermometers were installed into the micro-wells and an infrared camera was set to observe a temperature change on the block's surface. Subsequently, water of 45°C was being pumped into the fissure in the block at the rate approximately 1.5 ml per second for 862 hours. Water flow was controlled on the discharge point manually. The block was monitored during both heating and cooling period.

During the experiment 4736 litres of water flowed through the block. Fig. 1 recapitulates elementary input data of the experiment. At the beginning of the experiment, a mildly unstable water flow rate was caused by coagulations of iron oxides in a feeder pipe. Intended rate of flow 1.6 ml per second was established and kept on after the hour 150. The temperature of water on the input ranged between 44 and 46°C mostly, while the typical temperature dropout in the block was about 10°C. Pre-experiment simple trace tests had revealed water travelled less than 30 seconds between the input and discharge points. The temperature dropout in combination with the flow rate enabled a calculation of a thermal exchange. The cumulative water-rock thermal exchange was about 238 MJ during the experiment.

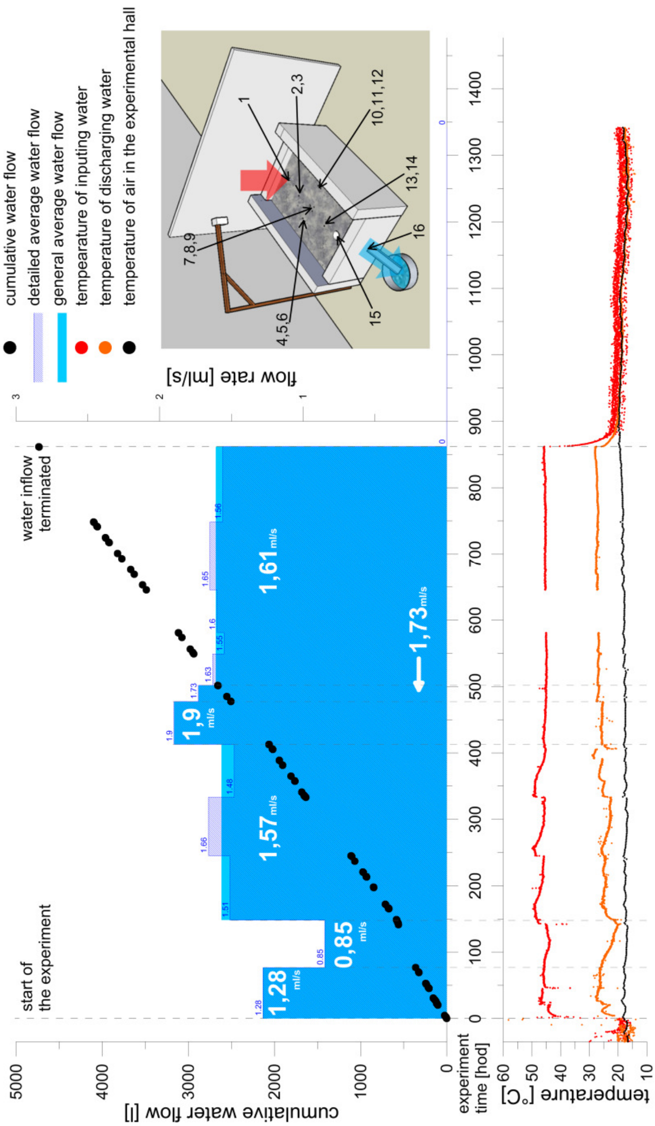

Fig. 1.- A basic graphical description of the experiment. Top on the left flow rate during the experiment, on the right the experiment scheme (insulated block with monitoring points and infrared camera above, the red arrow delineates input, while the blue discharge), on the bottom temperature of water on the input and discharge.

The experiment has clearly pointed out the eminent importance of water flow in fracture system over on the rock temperature. Temperature within the block reached equilibrium in about 45 hours after both the experiment start and the water inflow termination. The varying water flow during the experiment highlighted, that the temperature within the block also was also reacting steadily to the change of both temperature and flow rate of water.

This work was supported by the Ministry of Industry and Trade of the Czech Republic during the project "Research on a thermally loaded rock – perspectives of underground thermal energy storage" (Grant Number: FR-TI3/325). We are grateful to our colleagues from the Czech Geological Survey for their leadership of the project. We thank the Centre of Experimental Geotechnics, Czech Technical University for hosting the project in the URC Josef Facility.

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Hydrogeological approach in sustainable management of thermal waters: two examples from Italian volcanic aquifers

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Thermal waters have great economic importance in many countries. In Italy, approximately 78×10^6 m^3/yr of thermal waters are used for therapeutic and bathing purposes with a number of visitors of about 12 million in 2008. Several springs and wells, tapping water with temperature higher than 35 °C, fall in the volcanic region located along the Tyrrhenian margin from Tuscany to Campania. Different volcanic complexes developed along this margin (Fig. 1) as a consequence of the intense rifting in the Pliocene-Quaternary that affected the internal Apennine Chain. The structural setting and related magmatic domains of these volcanic areas affect the heat flow (from 150 up t o 450 mW/m^2) and temperature variation with depth! (up to 150-300°C at 1000 m depth).

Although different measures have been used to protect and control the use of thermal waters at the national level, there are no consistent criteria for the sustainable management of these groundwater resources. Two significant cases of the potential impact of groundwater withdrawals on hydrothermal systems are reported: the Viterbo (Central Italy) and Isle of Ischia (Southern Italy) systems (Fig. 1).

In the area around the city of Viterbo two overlapping aquifers exist in the upper 100-200 m, a main shallow aquifer (SA), consisting of the Pleistocene volcanites, and a thermal aquifer (TA) that is mainly contained within the volcanites at the contacts with the sedimentary substratum or within of its upper portion. The two aquifers are generally separated by a low-permeability layer.

The unconfined SA has a transmissivity values ranging from 10^{-5} m^2/s to 10^{-2} m^2/s. The waters are generally Ca(K)-HCO_3 type and characterized by low temperatures (less than 23 °C) and salinities (electrical conductivities less than 700 µS/cm).

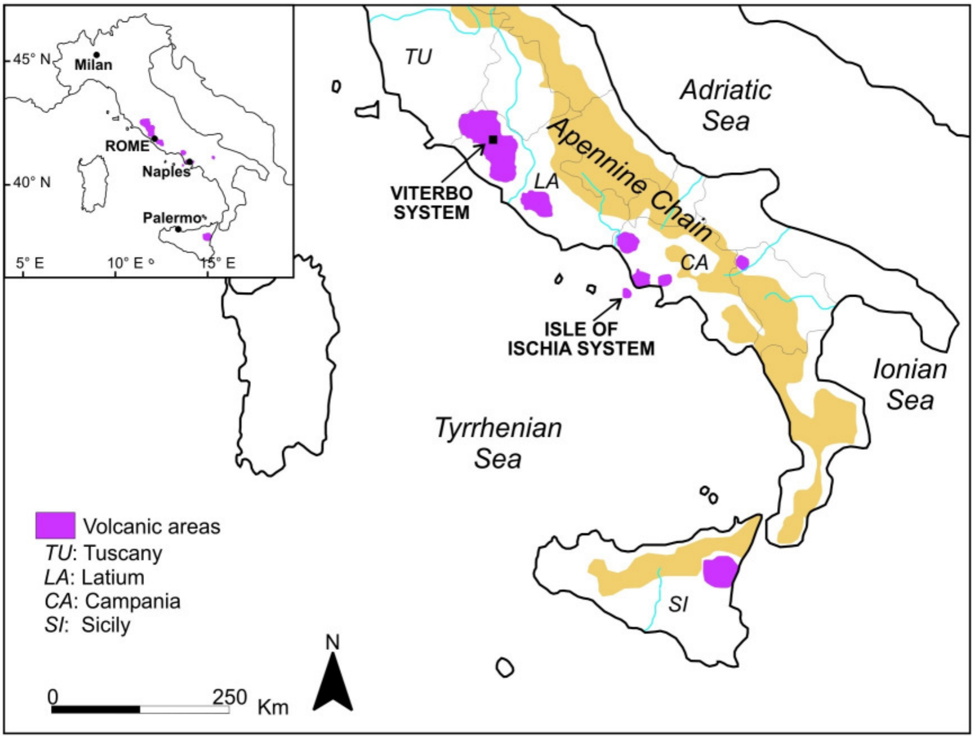

Fig. 1.- Location map of the studied volcanic system in the Italian peninsula

The confined TA has transmissivity values ranging from 10^{-2} m^2/s to 10^{-4} m^2/s. The yield of this aquifer is at least 0.17 m^3/s. Waters are characterized by Ca-HCO_3 facies, temperature from 40 to 62 °C, high contents of dissolved gases (CO_2 and H_2S), high salinities (electrical conductivities ranging from 2,800 to 3,600 µS/cm). The TA discharges into thermal springs and wells and feeds the SA vertically and laterally.

The low-permeability layer that divides the SA from the TA is the main feature that regulates the vertical gradient, the flow between the two overlapping aquifers and the percentage of mixing between cold and thermal waters in the SA.

The SA is tapped for private irrigation, through numerous wells, and for the public water supply. At present, thermal waters are tapped either directly at the springs or through wells and are used to supply thermal spas at a rate of approximately 0.035 m^3/s. Increases in spa tourism and in the use of geothermal energy are expected in the near future.

Potential thermal water resources in Szerencs area

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Introduction

The Tokaj Mountain range is located in the north-eastern part of Hungary as a part of the Carpathian Basin. This is the most famous volcanic mountains of Hungary. The direction of mountain is north-south and it is approximately 100-120 km long. The mountain runs between Tokaj and Eperjes (Slovakia) (Kiss 2007). The thermal and geothermal research in the Tokaj Mountains has always had secondary importance from the point of view of hydrogeologists, due to its complex geological structure and the insufficient number of deep exploration wells. In spite of the complex geological situation of the Tokaj Mountains some warm and hot water wells have been drilling for years. These wells have been producing good quality and high temperature water for years although water level declines were observed at a few places. Recently, there is a strong demand for more thermal water production in the region which initiates new hydrogeological research programs.

Regional data collection

Area of Szerencs lies in the border of many landscape contacts so it characterized by morphological diversity. In our work Szerencs have been analyzed within their administrative boundaries, but also the wider environment is mentioned. The area is bordered by Abaújdevecser from the North, Nyíregyháza from the East, Tiszaújváros from the South and Szikszó from the West (*Figure 1.*), respectively.

In the wider environment hundreds of wells and geological exploration drillings were installed. The wells, in which effluent water is over 20 °C provide the main information for the thermal water research. It means 74 pieces of wells and drills right now. We collected many parameters of the wells (sign, EOV coordinates, depth, temperature, filtering, etc.). From these data we made the basic database. The major lukewarm and hot water wells are illustrated on the *Figure 1.*

From the wider environment we located a narrower area where we made detailed researches for Szerencs city. This area is bordered by Tállya from the north, Prügy from the south, Mád from the east and Megyaszó from the West, respectively. Based on the available information, Szerencs is in hydrogeologically disadvantageous environment. In spite of this fact, we attempt to mark the places with hot water potential which can be used in long term hot water supply.

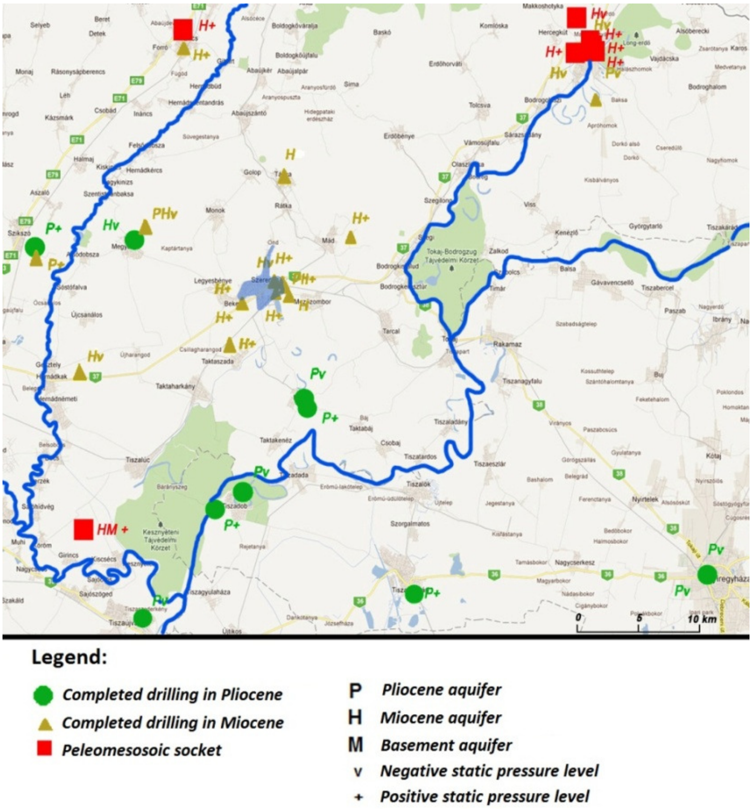

Fig. 1.- Map of the regional area with the warm- and hot water wells

Geomorphological characterization of Szerencs area

We have wide knowledge from the geological documentations, but depth parameters of the basement are insufficient. The depth and the material of the basement are professionally indefinite (*Table I.*).

The tectonical and structured lines of the basement maps are approximately parallel. The lines of three basement maps are coincide and these lines lie on the West part of Szerencs in North-South direction (Haas 1985). This line is probably the Hernád tectonic line which could be the possible fractures of the hot water upwelling.

Table I. Suspected materials of Basement under Szerencs

Year	Editor	Legend
1967	Viktor Dank, József Fülöp	Trias rock
1987	József Fülöp, Viktor Dank	Unknown material
1989	K. Brezsnyánszky, J. Haas	Unknown material
1990	Viktor Dank, József Fülöp	Unknown material
1990	János Takács, R. Lászlóné	Unknown material
2010	János Haas	Unknown material

Different rock types are formed due to the upwelling solutions: hydrothermal quartz, geyserite and lake water quartz (Mátyás 1985). These rock types imply to postvolcanic activity. Mád and Szerencs are bounded with two fault lines: North-Southern and the East-Western direction. In their cross-line there is the Aranka-mountain. On higher levels the peaks are covered with hydrothermal quartz, while the hollows are covered with lake water quartz (Boczán 1966) (Miklós 2003).

We measured the potential temperature values of the depth from the temperature of effluent water to complement the lack of geothermic data of the depth. From this we defined the geothermal gradient, which is 7.1 °C/100 m, hereinafter we used it as a constant in this area.

Summary of geothermal research activity in Szerencs

In surroundings of Szerencs there is a North-Eastern hydrothermal zone. It can be seen on the surface: Fekete Hill – Aranka Mountain – Árpád Mountain to the North and also to the South at the Bocskai church (*Figure 2*). Further to the South it tends to the deep and can only be traced in the stratigraphical lines of drills. The filtering of the transverse drills through the hydrothermal quartz is on this layer, because of its high permeability (see Table II).

Table II. Comparison of warm water anomalies in wells of Szerencs

Well name	Sign	Static water level [aBSl]	Outlet temp. [°C]	Yield [l/min]
Bakery	K-43	99,8	20	270
Chocolate factory-III	Cs-III	102	25	1500
Motel Fridez	K-60	100	24,8	1300

The Chocolate factory drill (Cs-III) has the highest static water level, effluent temperature and yield. With these conditions we can assume in the depth there is a plentiful yield of warm water from the aquifer layer, due to the drainage capacity of the hydrothermal quartz's zone. Approaching the centre of the Taktaköz Basin the hydrothermal quartz dip of formation increases, so the temperature of the water increases. The tectonic breccia is intersected by disaggregated hydrothermal quartz and fractured siliceous rhyolitic tuff at a depth of approximately 220-230 m. Water with a temperature of approximately 28°C can potentially be found at this depth. If we assume 0.5°C /100 m upwelling cool, the temperature of fissure is still around at least 26.5°C. When further geophysical experiments show the continuation of hydrothermal quartz to the depth (around 360 m at the periphery border), the base temperature could be about 39°C. In this case the temperature of effluent water is around 37°C. Surface investigations should be carried out in Vince Tanya (a dairy farm) to the south of Szerencs, in the area of Mád and Ond (Szűcs 2012).

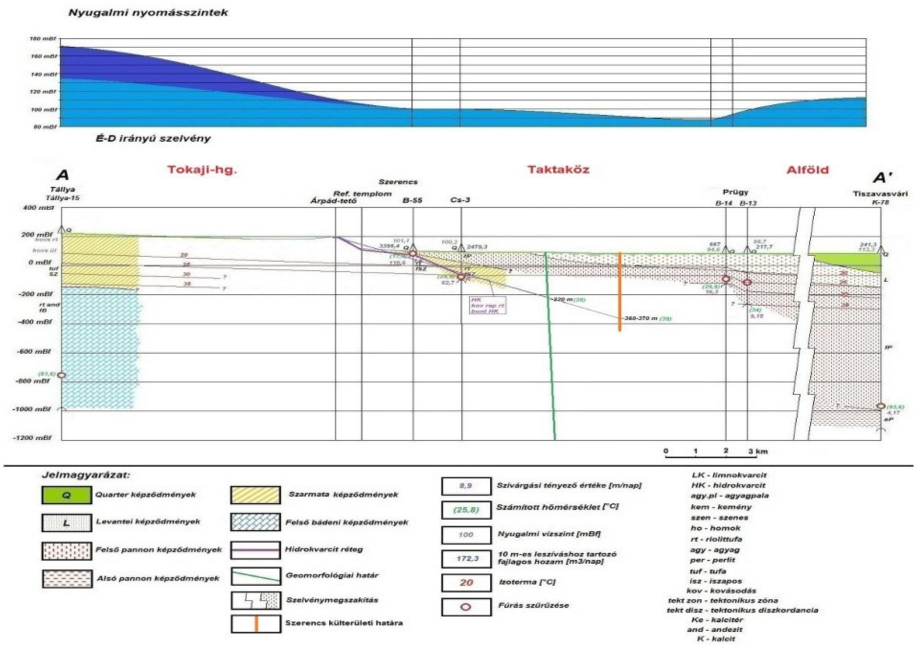

Fig. 2.- North-South hydrogeological profile

Acknowledgements

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Geothermal conditions of the Szabolcs-Szatmár-Bereg and Satu Mare transboundary region

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Introduction

The interest for the geothermal energy resources is rapidly increased in the last decades. The available heat applications are very site-specific. In all cases the efficient structure of the usage depends not only on the geothermal conditions but on the social and geographic aspects as well. The population, the industrialization, living conditions, technical specification of the communal infrastructure, traditions and lot of other things are affecting the reasonable use of the geothermal energy, therefore not possible to define a standard and suggested kind of usage. An atlas has been made from the series of 32 maps, which is compiled in the general scale of 1: 500 000 to present the geological setup of the region, to demonstrate the hydrogeological and geothermal conditions of the investigated area.

This paper presents the part of the atlas, focus on the specific heat resource at the investigated area to serve the process of the assessing the geothermal resource.

Hydrogeological conditions

The most important thermal aquifers of the Carpathian basin are the coastal sandy aleuritic sediments of the Újfalu Sandstone Sequences that were formed in deltaic facies. The sandstone bodies were formed at the front banks of the delta and the riverbed sediments of the delta, the coastal sands are of lower but not negligible importance.

The sandstones are proportioned by the clayey–aleuritic sediments and lignite formed on the delta plane or in swamps. The whole unit may have a thickness of 200-300 m, but it can also be missed. This formations are classified into the traditional Upper Pannonian sequences, that is more a kind of facieses that are progressively advancing into the direction of the middle of the basin, than a given time horizon. These formations contain not only the biggest thermal water reservoirs but also the large petroleum hydrocarbon reservoirs of Algyő as well.

The thickness of the Upper Pannonian sequences at Csenger – Baktalórántháza - Tiszavasvári area reaches 1000 m. The permeability of the aquifers may change in the interval of 50-200 mD, but the permeability of the best aquifers may reach 500 mD. The Upper Pannonian layers consist of up to 30-40 % sandy and sandstone layers of 0,5 to 5-7 m/d hydraulic conductivity. In lot of places the Upper Pannonian aquifers are hydrodynamically connected to each other.

In the Szamos-Somes trench there is an upper part to be discovered by the help of electro-geophysical logs in the upper Pannonian (Plicene) sediments, where the porous aquifers are frequent (above 40%). At the top of the Lower Pannonian formations some porous, hardly cemented sandstone aquifers in the 1000-1500 m depth interval are also characteristic. At the area the deepest aquifers lying below 1500 m, but at Ady Endre they can also be found below 2000 m.

Above the mentioned Pannonian thermal water reservoir there are overlying Upper Pliocene and Quaternary fluvial deposits situated. The sandy and partly gravelly aquifers contain the most of the drinking water potential of the region. The groundwater of the Upper Pannonian hydrogeological unit communicates the overlying colder potable water bearing aquifer systems.

Thermal resource estimation of the formations

To present the geothermal conditions of the investigated area specific heat resource maps were made, based on borehole (well) data and subregional maps. We have focused on the Upper Pannonian and Pleistocene formations.

The Pleistocene alluvial layers are the main targets of the heat pump systems. At regions where high hydraulic conductivity gravelly deposits occur it is possible to establish open heat pump systems with production wells and infiltration objects. On other regions the Pleistocene layers are possible targets of vertical borehole heat exchangers (BHE) but also lateral heat exchangers can be used.

The Upper Pannonian layers are the most important formations which containing medium to high enthalpy waters. Lower Pannonian layers are dominantly clayey, silty, argillaceous aquitards, in lot of places they are very compacted siltstones, mudstones, marls. Some delta formations may contain more or less sandy sediments, where inbed storage of groundwater may occur.

The specific heat resources maps were calculated upon the geometry of the layers, the calculated temperature distributions and using an average portion of aquifers and aquitards in each formation. At the Upper Pannonian layers an additional factor was taken into consideration that at greater formation depth the portion of aquitards is higher that was simulated using a correcting factor. The calculations of the H_0 heat resource in a given volume based on the equation of Muffler and Cataldi (1976). By the equation the specific heat resource is depends on the porosity (n), density (ρ), specific heat (c), thickness of the layer (Δz), temperature on the upper and lower surfaces (T_1, T_2) and the area (A).

$$H_0 = [(1-n)\cdot \rho_m \cdot c_m + n \cdot \rho_w \cdot c_w]\cdot (T_2 - T_1)\cdot A \cdot \Delta z$$

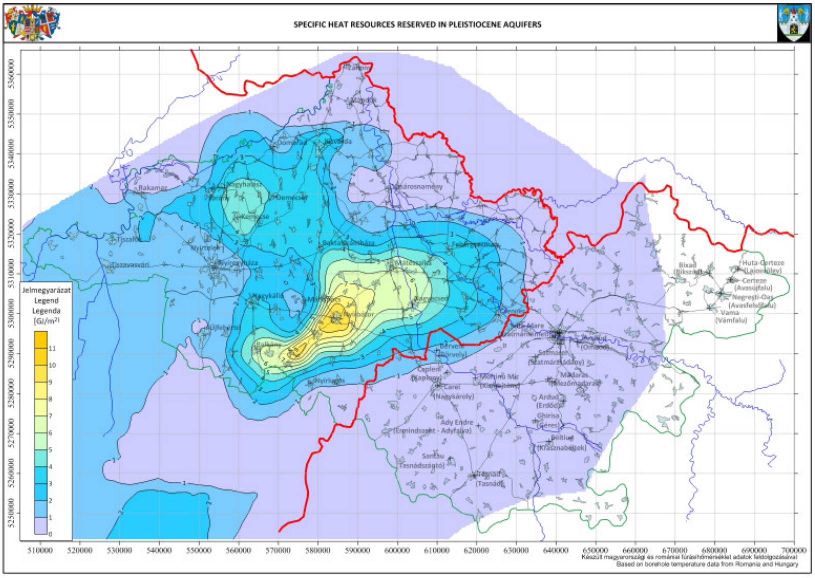
Since the specific heat resource is calculated to a unit surface, therefore

$$H_s = \frac{H_0}{A} = \left[(1-n)\cdot \rho_m \cdot c_m + n \cdot \rho_w \cdot c_w\right]\cdot (T_2 - T_1)\cdot \Delta z$$

Geothermal conditions

The base heat flow due to the heat produced by the radioactive decay in the Earth's crust is rather high in Hungary (90,4 mW/m^2 derived from an average value of 38 measurements), meanwhile the average on the European continent is approx 60 mW/m^2. On the Hungarian side of the investigated area this value is 80-110 mW/m^2 that on the Romanian side lies in the 70-90 mW/m^2 interval.

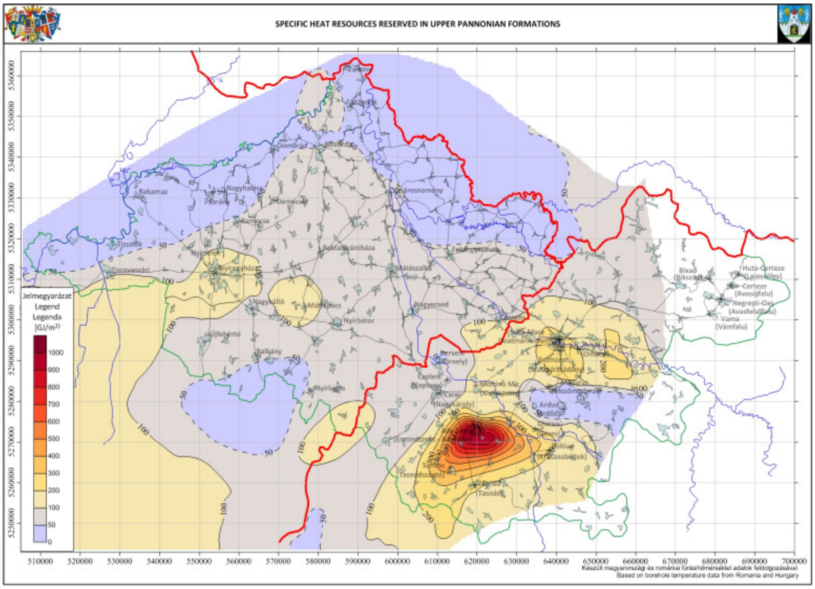
The annual mean temperature on the surface is 11 °C, therefore due to the geothermal gradient above the European average the temperature of the rock matrix and the pore water is approx. 60-80 °C temperature in 1 km depth, and 100-130 °C in 2 km depth.



In the investigated area the geothermal gradient calculated for the Pannonian formations alters in the range of 45-75 °C/km, which is lower in the sedimentary basin and higher – due to the higher heat conductivity rocks – at the mountainous area.

The deepest aquifers along the axis Tiszavasvári – Nyírbátor – Nyíregyháza – Csenger – Satu Mare situated below 900 m. At the final part of the axis below 1100 m, while at Ady Endre it lies below 2000 m. At the Tiszavasvári – Satu Mare axis the temperature can rise above 60°C but at the Szamos-Somes trench above 80 °C, and at the bottom of the basin near Ady Endre it can be higher as 130 °C.

The specific heat resource was calculated: the specific heat for the rock matrix was estimated to 3000 KJ/m^{3}K for the argillaceous rocks, 1400 KJ/m^{3}K for the sandy and gravelly aquifers. For the water 4179 KJ/m^{3}K was accepted. In the Pleistocene formations 45 % of the volume was considered as aquifer, in the Upper Pannonian formations the same value was 25%.



Summary

By our work we established a coherent geothermal approach to characterize the investigated trans-boundary area of Szabolcs-Szatmár-Bereg County (Hungary) and Satu Mare (Szatmár) County (Romania) with the help of Romanian experts A. Iancu and S. Olah.

Maps are made as a part of an atlas (series of 32 maps), which is compiled in the general scale of 1: 500 000 to present the geological setup of the region, to demonstrate the hydrogeological and geothermal conditions of the investigated area.

Acknowledgement

This paper was made as the part of TÁMOP-4.2.1. B-10/2/KONV-2010-0001 project with financial support of European Union and the European Social Foundation in frame of the New Hungary Development Plan.

Evaluation of packer tests in deep open boreholes

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An axe-symmetrical numerical modeling technique is presented for packer test data analysis in open boreholes. Both the pumping and slug tests are elaborated. The formation is considered heterogeneous in both vertical and radial directions. In general case of double packer tests the hydraulic stress is applied to the test interval located between two sealed intervals accommodating the packers. The upper and lower borehole intervals above and below the packers are also open to the formation except for sections with optional casing. Tests with single packer are applied to the bottom part of the open borehole. In case of partial penetration the deep zone of the formation below the bottom of the borehole is also included into the finite difference (FD) simulation model. The flow in the test interval is simulated by considering the uniform well-face drawdown (UWD) boundary condition and the test pipe storage. UWD conditions prevail in the upper and lower borehole intervals and are emulated through modifying parameters of the FD simulation grid. The borehole storage factor is also incorporated into grid parameters. In case of incomplete sealing by packers an additional vertical bypass flow to or from the test interval develops, the modeling scheme and data analysis includes this optional process. The formation and borehole parameters may be estimated via computer aided calibration procedure.

A short term slug test and a medium term pumping test document the practical application. The fissured granite formation at the Bátaapáti (Üveghuta) is selected as the underground radioactive waste disposal site in Hungary. Modeling of single and double packer tests in the boreholes showed good fit between the measured and simulated head data and yielded reliable parameters for the test intervals in the formation exhibiting high variation in hydraulic conductivity.

Hydrogeological Establishment of the Installation of Water Based Geothermal Heat Pump Systems in Budapest, Hungary

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The near surface gravel terraces are in most cases suitable for the installation of water based production-injection Geothermal Heat Pump Systems (GHPS). The gravel formations are present in the area of Budapest, the capital city of Hungary. The possibilities of the installation of GHPS were examined with a GIS based map series and with a final potential map derived from these. The most important features of the favourable potential are near surface water level in gravel, adequate gravel depth and thickness, and limited sulphate content of groundwater. The required well depth is 5-15 m. In the individual maps the depth of gravel strata, gravel thickness, elevation and depth of the water table and sulphate aggressivity of the water were represented. The values of the individual parameters were sorted in ranges. The final potential map (Fig. 1) was derived from the joint interpretation of parameters with the help of a matrix system. The map shows the patched character of the natural potential for the installations of GHPS in the area of the city, at 1:40 000, scale. Moreover, it displays the uncertainty factor of the categories. The research was supported by the Erdélyi Mihály Foundation and the OTKA 72590 K.

Hydraulic framework of sustainable thermal water production from a gravitational-overpressured system on the example of Duna-Tisza Interfluve, Hungary

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The research demonstrates those hydraulic criteria which can give the background for sustainable thermal water production in a gravitational and overpressured flow regime. These criteria are discussed in the frame of reservoir and temperature data. The principles are demonstrated for the Duna-Tisza Interfluve part of the Pannonian Basin, Hungary which is one of the best understood part of Hungary from hydraulic point of view. There is intense geothermal activity in the area: geothermal doublet systems have been operating (Fülöpjakab, Kistelek etc.) for years, there is a declared geothermal concession area in Kecskemét. So the results can be checked and used for long-term thermal water production from the Neogene and Pre-Neogene reservoirs.

Isotope measurements at different sites to estimate the recharge at the Danube-Tisza Interfluves

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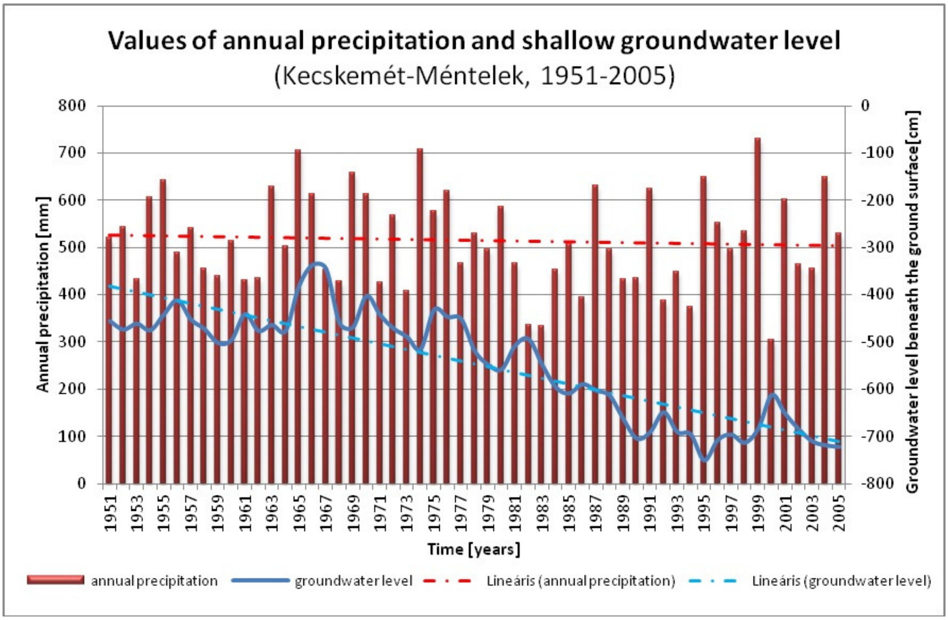
In Hungary the water supply is mainly satisfied from the groundwater, more than 95% of the drinking water come from subsurface aquifers so nowadays the priority of the groundwater researches is high. The requirement for enough and high-grade drinking water significantly increased in the last decades. Different quality and quantity of water is necessary for the communal, agricultural and industrial usage of the water. In order to help planning of water supply simulations, labor tests and field measurements must be performed.

The Danube-Tisza Interfluves is one of the largest recharge areas in the Carpathian Basin also in Europe. A huge decreasing of water-table was observed in the 1970s on the site. Major and Neppel investigated the decrease of the water-table near Nyárlőrinc and Méntelek. The causes of water level decreasing were the drainage of ridge and the increasing of water demand and the degree of deceasing was several meters near Kecskemét and Cegléd and.

According to Major and Neppel the decreasing of shallow groundwater level is experienced on the Danube-Tisza Interfluves in the last 40 years. The bases of their statement are the data of the wells near Nyárlőrinc and Méntelek. Their investigations based on wells which were screened in shallow and deep groundwater. A significant hydraulic relationship was also determined in their works between the 2 main groundwater types. They mentioned there is a watershed on the ridge near Kiskunfélegyháza in west-east direction furthermore the thickest and the best conductivity sand layer can be found in the Budapest-Kecskemét-Kiskunfélegyháza line.

The Figure 1 shows the relationship between the annual precipitation and shallow groundwater level from 1951 to 2005. These precipitation values have been measured by the hydrometeorological station in Kecskemét however the groundwater level was measured on the formed VITUKI (Environmental and Water Management Research Institute) research site in Méntelek. There is a good specified periodicity in the values of the precipitation, but observed a small decreased in the annual precipitation in time. The groundwater level follows the meteorological changes, but since 1980s the decreasing of the values have been higher than before. The graph also represents Major's statement; the natural recharge is determinant in the hyrdogeological researches, it is not negligible during calculations.



In the previous studies there were demonstrated our researches through the estimation of the natural recharge, which is an important task in the applied hydrogeology. The selected test sites have been found on the Danube-Tisza Interfluves since 2010. The main reason of chosen was the position of investigation points which must be located on the ridge on the regional recharge area, and the parameters of the field tests for the further modeling must be well known. The test site of Méntelek is an old research plant of the VITUKI. There were some investigations with lysimeters to estimate the migration of several dissolves chemicals. We used a well-group during the isotope hydrogeological tests to estimate the natural recharge. The results clearly show the numerical transport modeling is a possible additional tool for the tritium measurements.

Another site on the ridge was chosen, which locates near Kecskemét. Our tool for the tests also was a well-group, which locates on the highest point in the area. We explored significant differences in the geological parameters compared to Méntelek. The site in Kecskemét is used by the agriculture; furthermore agriculture tests were done with sewage disposal during 10 years.

Pedological investigations were performed to know accurately the geological parameters and the soil properties to understand the flow conditions which operated partly in groundwater recharge. According to several authors the sand is the bedrock of the area which originates from the alluvium of the Danube but the previous pedological investigations represent the differences between the 2 test sites. In case of Méntelek the main mother rock of soil is the sand but the loess sand is the significant in Kecskemét. The essential property of these sites the vertical movement of the infiltrated water so during calculations the lateral groundwater flow is negligible.

The soil profile of Méntelek indicates the periodically high water table. This fact comes from the geomorphology position and the recognizable features of the profile. This amount of the lime is blocks the infiltrating processes; the water stagnates and reductive conditions can be created. The gleyizated and lime accumulated layers clearly indicates that the infiltration slows down in two different depths, furthermore the lower lime accumulation level becomes quasi-sealing.

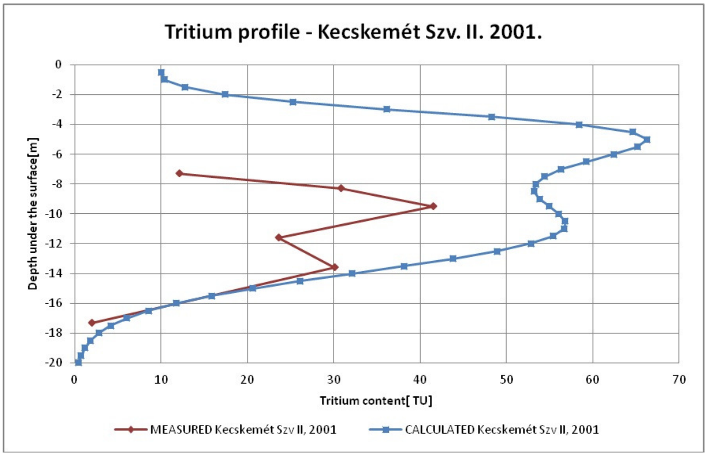
There is loess sand on the surface in case of Kecskemét with higher starting calcium content than the lower sandy layers, furthermore comparable lime accumulations is missing. During the rainy spring weather the found lime dissolves and leaches, in summer also accumulates by the evaporation. Permanent and intermittent water exposure could not be identified. This test site located on the top of the ridge, so we could investigate just near vertical flow.

The ^{3}H is the radioactive isotope of the hydrogen. The only difference is the number of the neutrons. The tritium is formed in the upper atmosphere during $-\beta$ decay. It has a half time, during the tritium decays to ^{3}He, which is 12.4 years in this case. The tritium is a suitable environmental isotope to estimate the groundwater research. This method uses the nuclear bomb peak in 1963. During these researches we found the highest tritium content in the groundwater; we can calculate the rate of the recharge with the movement of the soil moisture

The main aspects of selection of another test site were the follows: on the site there was sewage disposal approximately for more than 5 years; the site was used by the agriculture; the sites must be on the Danube-Tisza Interfluves; the depth and the quality of the groundwater must be suitable to model the movement of sewage components.

The choice was based on these parameters, so for test site Kecskemét was chosen. Kecskemét can be found near Méntelek on the ridge. The test site in Méntelek operates just for research, only a meteorological station works on the site. This test site in Kecskemét was installed in 1944 for research purposes on an agricultural area. In that time there was a plan to join the Duna and the Tisza rivers with a channel. At the station in Méntelek the decreasing of groundwater level would be monitored, but this plan was never realized. The wells in Kecskemét were installed in loess and sand bedrock on the Duna-Tisza ridge. This area has a moderately warm and arid climate. The average annual precipitation was about 550 mm/year in the last 70 years. The soils of the site were investigated before the research works. The test site is physiologically heterogeneous; there are some soil types on the area.

The model results of Kecskemét show the same results than model of Méntelek. We got a tritium profile from the transport model. The wells were drilled in 2001, and the groundwater was sampled during the drilling works. From these drillings the largest TU value was established at 9.5 m. The simulates show 2 peaks, which is an interesting thing; the agricultural researches started in 1971 on this site, during 10 years of the sewage disposal, when the splashed water had a TU value, which was 0 TU (the deep groundwater has 0 TU tritium content). After the research work the tritium content of the precipitation appeared in the shallow groundwater, this look likes as the second peak at 13.6 m under the surface. The calculated values are also representative on the graph. These model values nee d to be clarified and calibrated, as the obtained line is an adducing result. But it can be seen the model works in an acceptable manner, and it shows the character of the curves.



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Inspection of thermal wells in Szentes area

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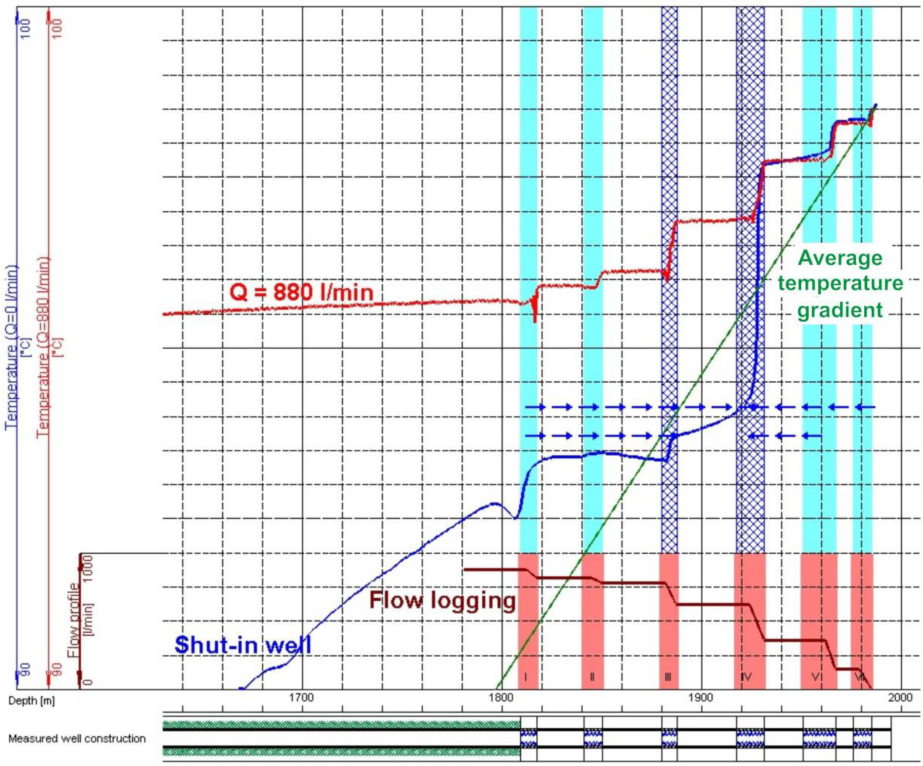
Between 2009-2010 Geo-Log Ltd. inspected 20 thermal wells with an average depth of 2000 m and 100 °C bottomhole temperature in Szentes area located in the Great Hungarian Plain.

The wells have produced since 25-40 years, but this was the first comprehensive inquiry including well construction logging, production geophysics (flow rate, temperature, pressure measurements) and gas analysis.

In this paper we present the conditions and results of the measurements and also give interpretation. Inspection of 20 wells close to each other made it possible to compare the results of temperature and pressure measurements from different aspects, to plot stratigraphic isoline maps from well log interpretation, and to plot the isoline map of the reciprocal temperature gradient.

With the new interpretation of the temperature logs some phenomena containing relevant information could be recognized, which raise the value of temperature logging of well inspections. Temperature logs enable us to study crossflow, refine geothermal gradient, detect well structure failures, detect permeable strata or gain information from those productive strata where the probe can not run in.

Typical measurement setup



Interpretation of temperature logs (Szentes I.)

Interpretation:

In the shut-in well the lower (Nr. V, VI) and also the upper screens (Nr. I, II) produce some water because of the pressure differences developed, and this water leaks off to the formation at screens Nr. III and IV. In the case of producing well all screens work according to the flowmeter and temperature measurements, and about 60 percent of the total yield is produced by just the same two middle screens.

Hydraulic evaluation of the flow systems of Buda Thermal Karst, Budapest, Hungary

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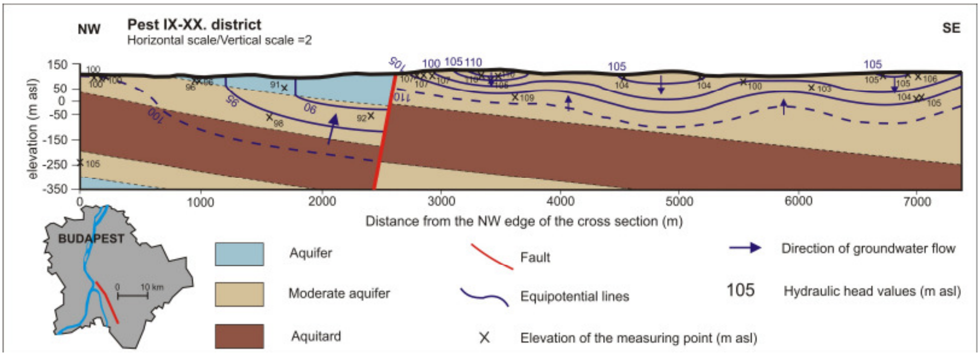
The Buda Thermal Karst (BTK) area is in the focus of research interest because of the thermal water resources as well as the on-going hypogenic karstification processes. The aim of the present study was the hydraulic evaluation of the flow systems based on measured, archive well (hydraulic head, pressure, TDS and temperature) data.

According to previous retrospective, hydrochemical, and radionuclide studies (Erőss et al., 2008, 2012a, b) a northern (Rózsadomb area) and a southern system (Gellért Hill area) can be distinguished with a hypothesized structural and hydraulic boundary between them. This study aimed the evaluation of this boundary as well.

Considering the data distribution, firstly pressure and hydraulic head vs. elevation profiles /p(z) and h(z) profiles, respectively/ were constructed, which primarily refer to the vertical fluid flow directions. Secondly, so-called tomographic fluid-potential maps were compiled for two consecutive depth intervals (50-100 asl and 100-150 asl). By interpreting these maps, the lateral flow directions can be interpreted in particular. Finally, hydraulic cross-sections were made in order to study the vertical and lateral flow directions in the sections' plane. In these cross-sections hydrostratigraphical build-up was illustrated as well.



As a result, it could be concluded that the hydraulic behaviour of the local-scale study areas shows robust correspondence with the topographic conditions, thus represents gravitational flow systems. In other words, in the system topographic highs act as recharge areas, and the depressions as discharge areas, while the Danube proved to be the base level. In addition, equipotentials in the deeper elevation intervals are shifted eastward, particularly in the Danube valley, reflecting upward flow conditions. This conclusion is also supported by the results of the p(z) and h(z) profiles. Hydraulic cross-sections represent fluid flow directions following the topography as well. Furthermore, fluid-potential anomalies can be observed around faults and in areas where faults are not known, but as a consequence their presence could be presumed based on hydraulic interpretation. Regarding the differences in temperature, hydrochemistry, and discharge between the northern (Rózsadomb area) and southern (Gellért Hill area) systems, these deviations could be caused presumably by the ”Northeastern Margin-fault” running between the two systems. Barrier function of this fault could be established in Pest by a hydraulic cross-section (*Fig. 1.*), and consequently can be presumed in Buda as well where though there are no wells in the vicinity of the fault, but potentiometric maps show at least 15m regional fluid-potential differences on its two sides.

This study demonstrates as well that hydraulic evaluation based on measured, archive data is crucial in order to facilitate the sustainable thermal water utilization. The success of thermal water exploration in a hydraulically continuous system (Mádlné Szőnyi, 1996) like BTK depends on the knowledge of flow systems and hydraulic function of faults (Czauner and Mádl-Szőnyi, 2011).

The Hungarian Scientific Research Fund (OTKA) has provided financial support to the project under the grant agreement no. NK 101356.

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Sensitivity of DNAPL transport simulations concerning the relative permeability data

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Introduction

The environmental problems connected to chlorinated hydrocarbons have been started in Hungary more than three decades ago. As we have more and more experience about these special contaminants, new in situ remediation methods have been elaborated all over the world during the last decade (Kueper et al., 2003). In every case, additional laboratory tests and technological investigations are required in advance to plan the remediation process (Mercer & Cohen, 1996). It is always necessary to know the concentration of the contaminants, the underground flow system and the detailed geology of the investigated site (Pankow & Cherry, 1996). More information can improve the planning process of remediation. To control and check the complete process, transport models are valuable tools (Halmóczki & Gondi, 2010). But the transport simulations of chlorinated hydrocarbons have many weak points concerning input data. Further research activity is required to make these simulations more accurate and reliable (Zakanyi & Szucs, 2012).

The main point of the presented applied research is to find and select appropriate transport-modeling programs, which can handle the underground transport processes of chlorinated hydrocarbons. In our research the Groundwater Modeling System (GMS) was used to handle case-study problems connected to DNAPLs. For modeling objectives the UTCHEM code was applied which is suitable for modeling continuous aqua-phase. Relative permeability curves from laboratory measurements were used to make more accurate the calculations. A new method applying immiscible displacement was proposed at the University of Miskolc to provide these petrophysical properties (Zakanyi & Szucs, 2012).

Materials and methods

In the laboratory of Research Institute of Applied Earth Science at the University of Miskolc a measuring and calculation methodology was developed to investigate and describe the process of transient radial water displacement in core samples (Toth et al, 1998a, 2002; Tóth et al, 1998b; Bódi et al 2005). The calculation of relative permeability curves are derived from labor measurements performed using a simple apparatus that could be utilized in the UTCHEM transport modeling module instead of application of data from literature.

To investigate the model performance two parallel models were built, one using relative permeability curves from literature (Grant et al., 2004) and the other one with parameters from the above mentioned labor measurements (Table 1.).

The models were created in UTCHEM with following parameters:

- initial hydraulic head: 6 m,
- hydraulic conductivity: k_{aq}= 0.00001 m/s,
- anisotropy: 1.2,
- flow direction: from the left side to right, hydraulic gradient 0.001,
- porosity: n_{aq}=0.3.

Table 1. Parameters of relative permeability curves.

Origin of data for UTCHEM	Aqueous phase		TCE phase	
	K_r endpoint	Residual saturation	K_r endpoint	Residual saturation
Literature	0.24	0.17	0.15	0.45
Measurement	0.1	0.4	0.2	0.65

The created mesh consisted 32 rows and 120 columns (Figure 1). After the simulation the transit time of contamination to the confining layer, the peak concentration of the plume and the extension of plume were investigated. The results of the two transport models are presented in Table 2.

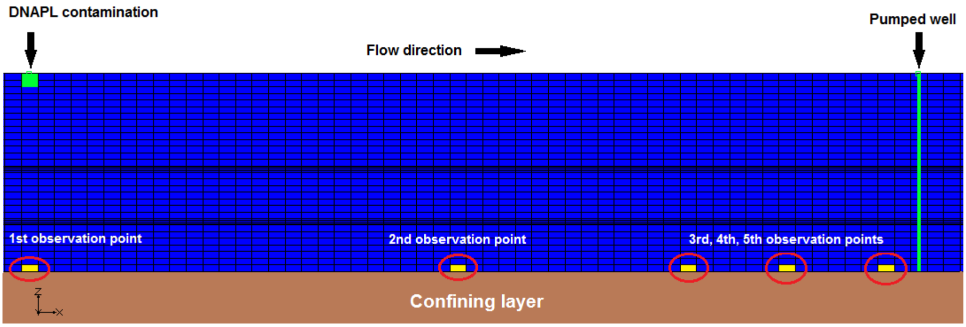

Fig. 1.- Mesh of UTCHEM transport model and observation points.

After that a remediation process was simulated. A pumped, fully screened well of Ø0.11 m was installed at 27.5 m distance from the source of contamination with

100 m^3/d discharge. In order to compare the two model runs, observation points were defined in the model (Figure 1) The TCE concentration was investigated in these points after 60, 120, 180, 240, 300, 360 days.

Table 2. Results of models by using of different relative permeability curves.

	Transit time to confining layer (d)	**Highest observed concentration (µg/l)**	**Length of plume (m)**
Relative permeability curve by literature	**15**	**582**	**25,5**
Relative permeability curve from measurements	**20**	**663**	**24,5**

Results

The spread of contamination is quicker, the highest observed concentration is lower, and the longitudinal extension of plume is higher in the model which based on data of literature (henceforth Case 1) than in model which is based on measured data (henceforth Case 2). Difference between extensions of plumes is 1 m.

The concentration changes in time are shown on Figure 2/a and b. At the first observation point beneath source of contamination, the concentration of pollutant is higher in Case 2 than in Case 1 at the initial of remediation modeling, and stays higher until the end of simulated 360 day long period. Significant difference is only experienced in case of initial concentrations (Figure 2/a).

The differences between concentrations are more relevant in the fifth observation point than in the first one. At the start of remediation modeling the contamination was not yet detected at this point because of slow transport of pollutants. But after 60 days the contamination appeared. The calculated concentrations of the two models differ significantly at the beginning of the process (after 60 and 120 days) but later they start to decrease. At the end of the simulation period (after 360 days) the concentration in Case 1 is almost the double of the concentration in Case 2 (Figure 2/b).

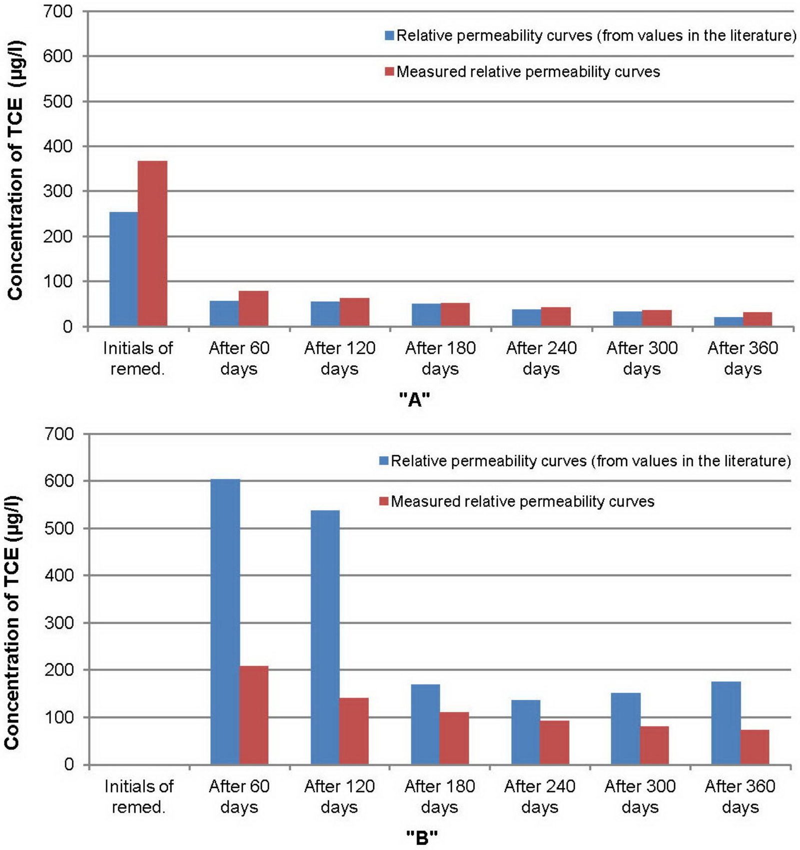

Fig. 2.- Concentration of TCE in the 1st ("A") and 5th ("B") observation point.

Conclusion

In this paper the sensitivity of transport modeling based on data of relative permeability curves was proven. The transport models are integrant elements in the planning process of remediation, so the confidence of these models is a relevant aspect. In the application of the measuring method developed by J. Tóth and his colleagues, the accuracy of transport modeling of chlorinated hydrocarbons and also the modeling of the remediation progress could be improved.

A significant difference was experienced between the results of modeled scenarios based on data from the literature and those from the measurements. The simulation is more accurate in case of applying the data from the measurements than from the literature but the data of more measurements could further increase the accuracy of models. The most correct model could be built on the data of field experiments. Putatively, the observed concentrations are pollutant-specific and they also depend on the velocity of dehalogenization.

Acknowledgements

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Inferences from 3D modelling of thermal karstic reservoir (SW Bükk Mountain)

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The western part of the Bükk Mountain's foothill has outstanding relevance in thermal tourism e.g. famous bath in Eger as medieval Turkish heritage. Nowadays the significance of the thermal water usage became more and more relevant. Till now this area was investigated as "the side effects" of waterworks' delineation or hydrocarbon exploration process.

Here the geothermal system is strongly connected to cold karts system of the mountain. As our previous experience revealed examining the subsurface flow systems could only be a rough approach without density dependency. E.g. in case of thermal karst at the discharge area the water of significant temperature could reach the surface. Without buoyancy driven mechanism these flows are not depicted in complex.

The regional pilot area:

- Triassic limestone rocks of the Bükk Mountain constitute a continuous karst water reservoir to the verge of the mountain where the reservoir dips to depth of a few thousand metres in the area of the basin
- The karstic rocks were covered by thick sediment (Jurassic schist, diabase, gabbro and metabasalt, Oligocene clay, marl, Miocene tuff, sand) of considerable insulating effects in point of heat potential.
- In town of Eger the total yield of the warm (~30 °C) springs is 9 000 – 15 000 m^3/day. Radiometric age of karst springs applying $\delta^{13}C$ correction is 4 600 – 5 200 years.
- Thermal waters are discharged by supply wells in the covered parts and are utilized in spas and hospitals (therapeutic purposes). Radiometric age of Egerszalók supply well's (De-42) water is 13 200±400 years applying $\delta^{13}C$ correction.

3D coupled and fully-coupled (gravitation and density driven) fluid and heat transport models are prepared by FEFLOW software (WASY Ltd) and compared to each other. The regional scale model covers an area of about 40 km (N–S) x 30 km (E–W). The modelling process started with a simplified hydrogeological approach distinguishing the upper porous formations and the karst unit.

Different thermal properties are assigned according to the depth and temperature conditions. Thermal boundary conditions are derived from estimated heat flow density (10 368 $J/m^2/d$) at the bottom and the yearly average temperature on the surface.

Results of the model are compared with available head and temperature measurements and the values of parameters are adjusted.

Generally, the fluid density varies with pressure, temperature and concentration. Since the low values of TDS in water samples the dependence of concentration regarding to the density variation was neglected. With the help of Interface Manager both variable thermal fluid expansion and fluid compressibility were considered for a wide range of pressures (0.1 – 100 MPa) and temperatures (0 - 350 °C) (Magri, 2009).

We present the results of relative influence of various heat transport processes through the difference in head and temperature distribution.

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Development plan of Szentes region based on hydrodynamic modeling

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We present our investigation and newest results about the geothermal field of Szentes region which is located in Southern Hungary. The area has a highly intensive production from the Upper Pannonian sequence, from delta front–delta plain sediment facient layer since the 1950's. From 2010 to 2011 the measurement team of Geo-Log Ltd. has completed complex geophysical logging and well inspection on the thermal wells owned by Árpád-Agrár Co. Ltd., under the Hungarian National Technology Program. We used this data to improve the available stratigraphic model, and build a new hydrodynamic model.

The main task of Hungarian National Technology Program (No. TECH 08 A4 DA THERM), and the NIO (No. DA HALO 06/007 GEOTERMA) is using the technological expertise of used thermal water reinjection into sandstone and adaptation of the specific area to Upper Pannonian reservoirs in accordance with hydrodynamic and heat transport properties. Further goals of the program is the determination and modeling of the Southern region of the Great Plain's porous sequences (mainly Upper Pannonian) reservoir's hydrodynamic and thermodynamic parameters, with application of the most recent geological, geophysical hydrological knowledge and refining the models based on the logged data on the examined area. In Figure 1 we can find the examined thermal wells. Some of the wells has got gamma logs, while others has spontaneous-potential and resistivity logs. The spontaneous-potential and resistivity data were collected when the wells were constructed. As the old data were logged in paper form, we had to digitalize them in order to use them as the basis of the geological model. Then we merged and corrected them with newly logged data, and afterwards we have created the latest corrected geological model.

Geological background

The wells near Szentes, based on the Upper Pannonian sequence, is the most significant geothermal field of Hungary.

The most important aquifers are part of the Újfalui Formation. On the examined area the hydraulic situation is very beneficial to the effective pressure gradient and exceeds the hydrostatical gradient by 0,15 MPa/km (Tóth J., Almási I., 2001), due to the gravitationally rising waters.

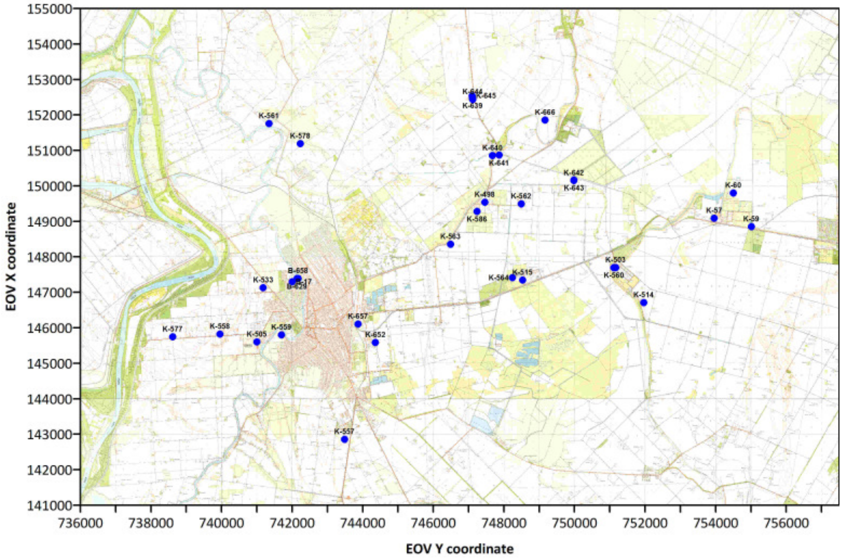

Fig. 1.- The location of the thermal wells near Szentes

Szentes, and its region, is geologically characterized by young tertiary and quaternary sediment in great thickness. 11,5 million years ago the Pannon basin lost its connection to the sea (Juhász et al.,2006). Dissimilar basins were formed at different areas of the Pannon Sea, which elapsed to various levels, however they remained connected with each other more or less. Szentes and its neighborhood is located over the Makó – Hódmezővásárhely Through. The arriving rivers from NW and NE created prograding delta systems with the transport of great amounts of sediment, finally filled up the Neogene sinking territory.

The first thermal well was prepared in Szentes in 1958 from barren CH drilling. Until the end of the 1980's 32 wells were drilled, of which 12 produced 90°C and the others more than 60 °C hot water. Initially they used the hot water only for sanitary hot water then a district heating system was built for 1300 flats and public institutions. In addition the heating of 30 ha greenhouse, 30 ha foil tent and 35 ha poultry farm was based on thermal water.

The wastewater flows into the Kurca-creek and 2 lakes which is not compatible with the current legislation. Until 1990 they produced more than 7 million m^3 water per year, which caused 25-40 m depression head. Since then the yield is decreasing 5,7 million m^3 per year, so the hydraulic heads (water levels) have risen 4-8 m in some places. Comparing to the original state, we can experience 12-38 m hydraulic level decrease (Figure 2.) (Szanyi & Kovács, 2010). In addition the piezometric water levels of the aquifers reduced significantly.

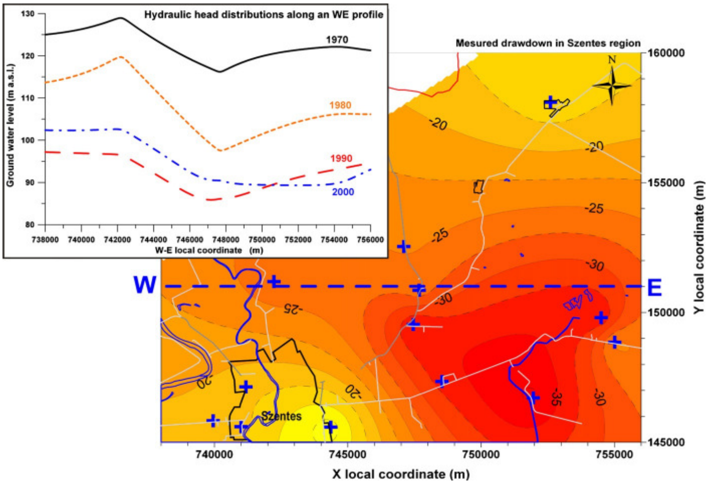

Fig. 2.- Measured drowdown in Szentes region (Szanyi, Kovács 2010)

Development plan of the Szentes geothermal field based on hydrodynamic modeling

Based on the updated geological model a hydrodynamic model was created using Processing Modflow. The hydrodynamic model parameters were defined by analyzing pressure build-up and capacity tests. Recent testing confirmed former results which state long term production of thermal water from the geothermal reservoir created 2-4 bar pressure decrease in the Upper Pannonian aquifer group. We examined the effect of both the actual production of the wells and different production stages on the reservoir. In order to achieve sustainable thermal water management, reinjection wells were settled in the hydrodynamic model. To determine the location and depth of the selected injection wells we take into account the created injection surface maps, geological information, the distance of the wells, the chemical properties of the thermal waters and the available amount of injectable thermal water. Based on the numerical simulation of different production and injection conditions recommendations were proposed to attain sustainable reservoir development in the Szentes geothermal region.

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Electrical conductors in basement – a magnetotelluric insight into the geothermal potential.

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Introduction

The magnetotelluric (MT) method which makes use of naturally occurring electromagnetic fields, is one of the most widely used electrical prospecting techniques due to its potential for very deep exploration. This method has been successfully applied to evaluate geothermal resources around the world. The MT method shows the spatial variation of electrical resistivity, which may be related to changes in the hydrological properties of the formations.

Physical background

Archie's law – a purely empirical law – relates the in-situ electrical resistivity of a sedimentary rock to its porosity, brine resistivity and brine saturation. Resistivity decreases when the porosity or brine saturation or the brine conductivity increases. Due to the increase of salinity and the temperature the brine resistivity is reduced significantly, even if in case of appreciable low porosity. Reality is complex, while the presence of the vapour phase grows up the resistivity while the occurrence of clay minerals is to be reduced this parameter. In general, the low-resistivity basement is a potential geothermal reservoir.

Case history

In the 80s, several organizations carried out magnetotelluric measurements in the CarpathianBasin. These soundings have been reinterpreted by an advanced two-dimensional (2D) inversion procedure recently. From this activity we present some examples of the Hungarian Great Plain region.

The Pannonian Geotraverse magnetotelluric profile is a 205 km long cross section in the Hungarian Great Plain, situated from the BükkMountains up to the BékésBasin. Along a 150 km long part of that section it was found that the resistivity of the Pre-Cenozoic basement is less than 50 Ohm.m. (Kiss and Madarasi 2011, Posgay et al 2011)

We believe that the low resistivity of the basement cracks are filled with hot saline fluids. What does support our conception? The Pannonian Geotraverse is 40 km from two boreholes, which may be geothermal indications. These are the well-known Fábiánsebestyén and Nagyszénás areas.

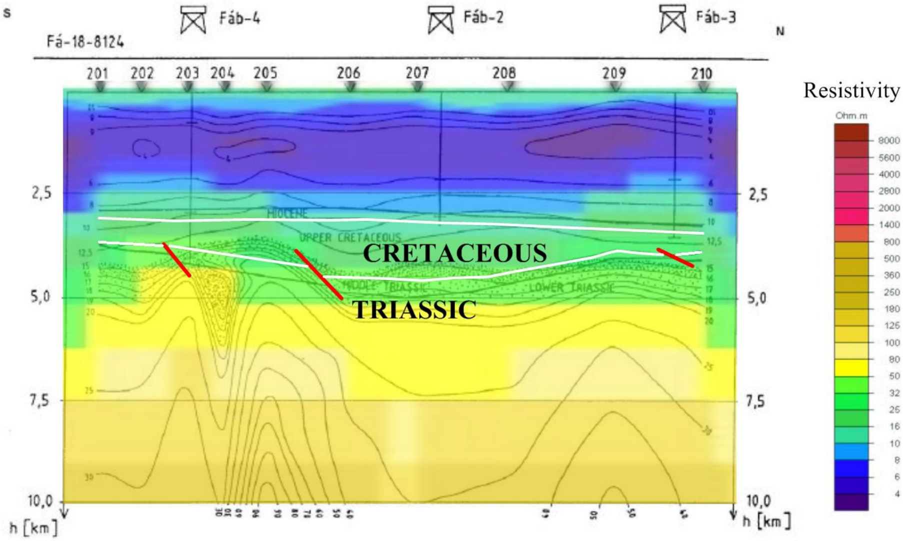

Fig 1.- Fábiánsebestyén area, magnetotelluric cross section.

Legend:
Colour image – resistivity distribution from 2D MT inversion.
Red line – fracture. White line – layer boundary from seismic reflection.
Black lines – modified apparent resistivity isolines (step approx. 1 Ohm.m) in Bostick depth (Stegena et al 1992)

In December 1985 was a huge steam eruption (190 degree Celsius) in the Fábiánsebestyén-4 (Fáb-4) borehole. Some MT measurements were carried out along the seismic line after the breakout (Nagy et al 1992). The measured data have been processed into a simple apparent resistivity section (see the gray background). The results of the advanced 2D inversion (colourful image) show that the resistivity of the Triassic formations is higher than 100 Ohm.m, only beyond 7.5 km depth. The resistivity on the surface of the Triassic carbonate formations is less than 50 Ohm.m, entire length of the section.

In the year1981 in the borehole Nsz3 steam production was made. In 1990 the Hungarian oil industry measured 89 MT sites (Nagy et al 1992), and a "Z" shape deep tect. zones was determined (see dotted band). The results of the 2D inversion (colourful image) show that the resistivity of the basement in depth 7.5 km is in a large area less then 50 Ohm.m.

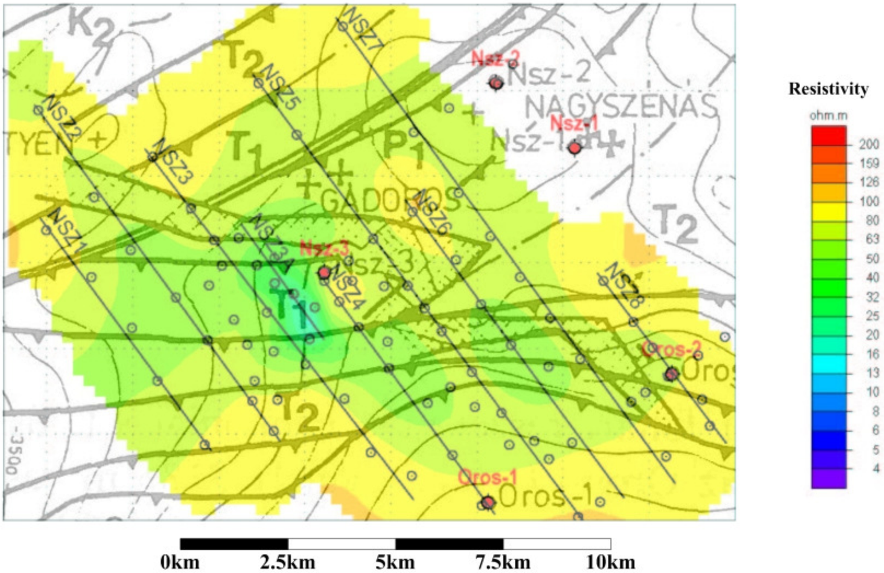

Fig. 2.- Nagyszénás area, resistivity map in depth 7.5 km

Legend:
Red point – well, blue circle – MT site.
Gray background – geological map of basement (Pap 1993.)
P1: Permian quartz porphyry, T1: Lower Triassic sandstone and conglomerate, T2: Middle Triassic brecciated dolomite, K2: Upper Cretaceous clastics.

Conclusion

In the southern part of the Hungarian Great PlaneMT measurements - unfortunately of small numbers – show low resistivity basement in many cases. Two of these cases, the drilling of geothermal reservoirs have been identified. The magnetotelluric measurements may facilitate the expansion of potentially areas.

Let us be grateful to the Hungarian pioneers of deep electromagnetic research!

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Hydraulic and thermal evaluation of Gödöllő Area, Hungary, for geothermal purposes

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Hungary has a geothermal potential that is considered significant even on a global scale. The cause of this is the thinned lithosphere and the presence of thermal water reservoirs with high hydraulic conductivity values. This allows for the effective operation of hydrothermal doublet systems throughout most of the country. Designing such systems, local reservoir models are built detailing small areas around the well sites. This procedure does not allow for the consideration of the effects generated by regional groundwater flow.

The aim of the research is to construct and compare two different models of a carbonate reservoir. The first model is based on locally interpreted data while the second model contains the flow systems of the broader environment. This comparison enables to assess the relevance of the flow field on the model effectiveness.

The research process consists of four main segments. One consists of reviewing the hydrogeological setup aiming to construct a geological structural model of the area in question. The second is the assessment of the hydraulic- and temperature conditions, based on preliminary data collection and evaluation. Third is building a regional hydrodynamic and transport model. Lastly, regional and comparative analysis of reservoir models are conducted.

The research area for the carbonatic geological environment is in the 375 km^2 Gödöllő and Mogyoród area, East of Budapest. The Gödöllő area is characterized by Paleogene and Neogene sequence, underlain by the Triassic carbonate basin and faulted by a characteristic structural element, the Szada normal fault zone, along which a 1000m shift can be detected (Kiss et al. 1999). Based on literature, this is expected to have a decisive effect on the flow field around it, as well as the position of the potential geothermal reservoirs (Czauner and Mádl-Szőnyi, 2011). Understanding the hydraulic effect of the structure is of primary importance in the interpretation of the whole hydrogeological system and geothermal exploration in the surroundings (Czauner and Mádl-Szőnyi, 2011).

Theoretical studies (Domenico and Palciauskas, 1973, Saar, 2011) and case studies point out how the groundwater flow influences the heat transport processes and how these phenomena can be observed. Taking into account the hydraulic role of faults is of special importance, since these structures can have various effects on the groundwater flow systems, depending on their location, relative position, inclination, and conductive properties (Czauner and Mádl-Szőnyi, 2011). Information on these structures and their effects can be gained through hydrostratigraphic, hydraulic and geophysical analysis. For the interpretation of the collective effects, hydrogeological and transport modeling is a widely used method. Therefore, the research is based on these methods.

The study area is also overlapping with the Gödöllő geothermal concession area in which intensive geothermal exploration is expected to start at a later date. There are over 8500 data available for investigation from 520 waterwells, 10 of which are reaching below 500 m depth. From depths below 1400m, thermal water is extracted with temperatures higher than 60°C.

The hydraulic evaluation, based on interpretation of pressure-elevation profiles, hydraulic cross sections and potentiometric maps has shown that the area is situated primarily above a recharge regime with subhydrostatic or near hydrostatic pressure patterns. Fine characterization of the pressure field yields an insight to the effective role of the structural elements, thus gaining valuable input data to the numerical model. After acquiring this knowledge of the real system, finite element numerical simulations will be conducted, using the heat and mass transport modeling software FEFLOW. The research is fitted into the framework of NK 101356 OTKA research grant.

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The effect of the thermal water aeration and water-rock interaction

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Introduction

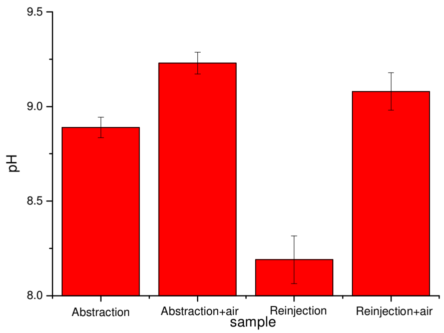
The aim of this research is to examine what happens to the thermal water brought to the surface. In relation to the above concern, it is also studied how the reinjection process affects the rock and the reinjection well itself. The biggest issue is that reinjection wells have a tendency to clog during the reinjection process. Our main concern was to find a method which is suitable for modeling both the changing state of water on the surface, and water-rock interaction. Water examination were carried out within aerob and anaerob conditions through the measurement of the pH and salinity, and potentiometric titration. We used two different rock milling products for our examinations. The measurements were carried out with two types of water samples (from the production and reinjection wells, respectively): one of the samples was ventilated for 2 hours, and the original, raw samples were left intact. We set the pH of water samples to 2, 4, 6, 8, 10, for this sedimentation study, and each treatment was performed three times. Sediment volume examinations well-known from colloid chemistry were used to analyze water-rock interaction. Final results were assessed through the statistical evaluation of the measurement data provided by three consecutive sampling processes.

Substance and method

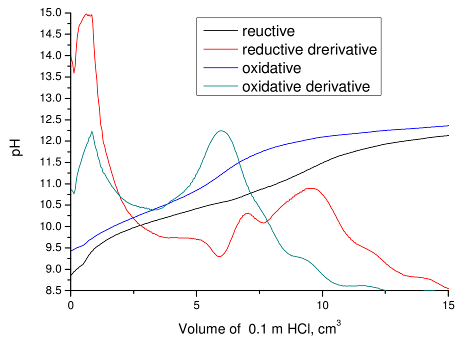
Measurements were carried out with two water samples: sample I. was taken from the production, while sample II. was taken from the two puffering tanks of the reinjection well. Two water treatment processes were applied on all samples:
a, reductive treatment – the container was transported to the laboratory filled completely with the original water sample, and stored like this till its use in order to prevent the water sample from reacting with atmospheric oxigen.
b, oxidative water treatment: the original water sample was air ventilated for two hours. The aim of this above procedure is to simulate the conditions of geothermal use, and to make water-air contact possible, thus keeping water in an oxidation state. Water samples used in the course of sedimentation tests were set to pH

values 2, 4, 6, 8, 10 respectively. The setting accuracy measured with glass electrodes was ±0,2 pH.
In the course of salt effect examinations 1, 3, 5, 7, 9 ml KCl solution with 5moles/litre concentration was added to 10 ml water sample. Then the solution to be measured was pipetted from this solution.
All treatments were repeated three times.
Sedimentation tests were carried out in 20 ml test tubes, all tubes contained 2 g of rock sample and 10 ml of water sample. After shaking and 2 two hours of settlement, we took photos of all tubes to document the results.

Results
Results of pH measurements are shown in Figure 1. All samples differ significantly from others the explanation for which is as follows: in the case of both wells we shall see that pH of the ventilated water sample is significantly higher than that of the original one. It results from the fact that intense ventilation extracts a large amount of carbon dioxide from the sample which leads to a decrease in carbonic acid and, consequently, in hydrogen ion concentration, too.
The initial pH of the injection well is higher. The reason for this is that the sample gets oxidized by getting into contact with atmospheric oxigen on different surfaces. During this process, compared to intense ventilation much less carbon dioxide leaves the system. Souring effect of oxidation intensifies compared to the effect of carbonic acid triggering much higher pH level
Small-scale yet significant pH decrease observed in ventilated samples refers to the very same phenomenon. In the course of ventilation, the pH increasing effect of carbonic acid reduction can be regarded more or less equal in the two samples, thus difference may be explained by the samples' exposure to oxygen for a longer period of time.



The change of the pH of the water samples the getting some air his effect.



The reinjection wells titration curve and its derivative, and absence of air ventilated case.

Fig. 1.- Results of pH measurements

Analyzing alkaline titration we shall see that the pH of the first inflection point is around 9-9,5. This cannot be explained by the organic and carbonic acid balances. Among inorganic compounds (mostly among complex ones) there are several which can be deprotonated within this domain. Such can be aluminium or iron complexes with small or medium molecular mass ligands.

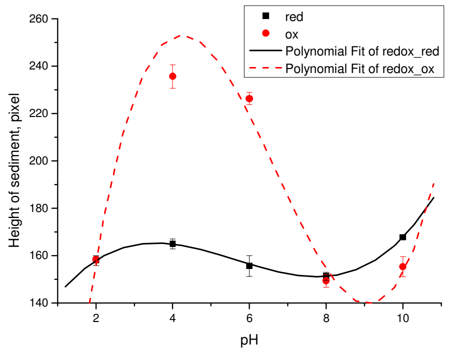
The second inflection point can be easily identified with its approximately 11 pH value:

$$HCO^{-}_{3(aq)} + H_2O_{(aq)} \longleftrightarrow H_3O^{+}_{(aq)} + CO^{2-}_{3(aq)}$$

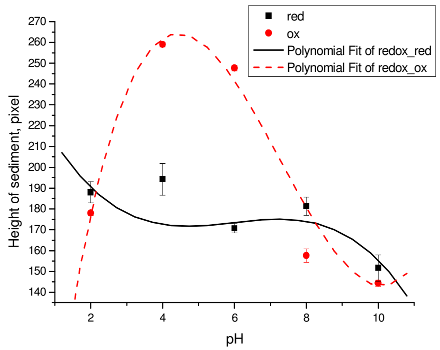
$$K_{a2} \approx 10^{-11}$$

That is, in this case, carbonate ions in water transform into hydrogen carbonate ions while reacting with hydrogen ions. Here we can find significant differences between the samples. As we shall see, as a result of ventilating, a new compound is formed, which may be the transformation of some organic compound, or a inorganic compound formed by oxidation (for instance some Fe^{3+} complex).

We received the following results for pH-sediment examinations:



The β in case of a rock sample the producer for the water of a well pH – the curve of sediment volume



The α in case of a rock sample the producer for the water of a well pH – the curve of sediment volume

Fig. 2.- Results results for pH-sediment examinations

The curve rundown is similar, but much sharper due to oxidation, and a more significant increase can be observed between pH 4 and 5. This leads us to the conclusion that at nearly neutral pH values attraction increases between particles as a result of oxidation, while in alkaline conditions (8 pH and higher) the whole process is the other way around: particle adhesion decreases due to oxidation. As parameters of fitted curves in Figure 2 show, due to ventilation and oxidation significant change in particle adhesion can be observed. In the case of the reductive process, sediment volume shows a slight minimum approximately at pH 4. This indicates that adhesion force between particles is the smallest at this value, it is the easiest to shift them from each other at this pH level.

In both cases it is shown that the pH of the aerated water sample was significantly higher than that of the original water sample. An explanation this could be that intense ventilation removed large quantities of carbon dioxide from the sample. Consequently, carbonic acid, and thus hydrogen ion concentration decreased. Souring effect of oxidation intensifies compared to the effect of carbonic acid triggering much higher pH level. In the case of alkaline titration, no difference can be observed between the samples. Based on the measured inflection points it can be stated that the initially low-amount substance corresponds with carbonic acid balance. Analyzing alkaline titration we shall see that among the first inflection point inorganic compounds (mostly among complex ones) there are several which can be deprotonated within this domain. Such can be aluminium or iron complexes with small or medium molecular mass ligands. The second inflection point shows how carbonate ions transform into hydrocarbonate ions. In the case of both rock samples maximum value /curves could be observed as a result of aeration with respect to sediment volume at 4-5 pH values. This means that within slightly acidic conditions and with increased pH values oxidation intensifies the attraction between the particles.

Hydrodynamics of cold and warm karst systems in the Bükk region

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Introduction

The Bükk Mountain area is located in Northern Hungary. The size of the naked (cold water) karst of the Bükk is 207 km^2. The thermal karst water system of the Bükk is an estimated 1000 km^2 and its boundaries cannot be delineated exactly.

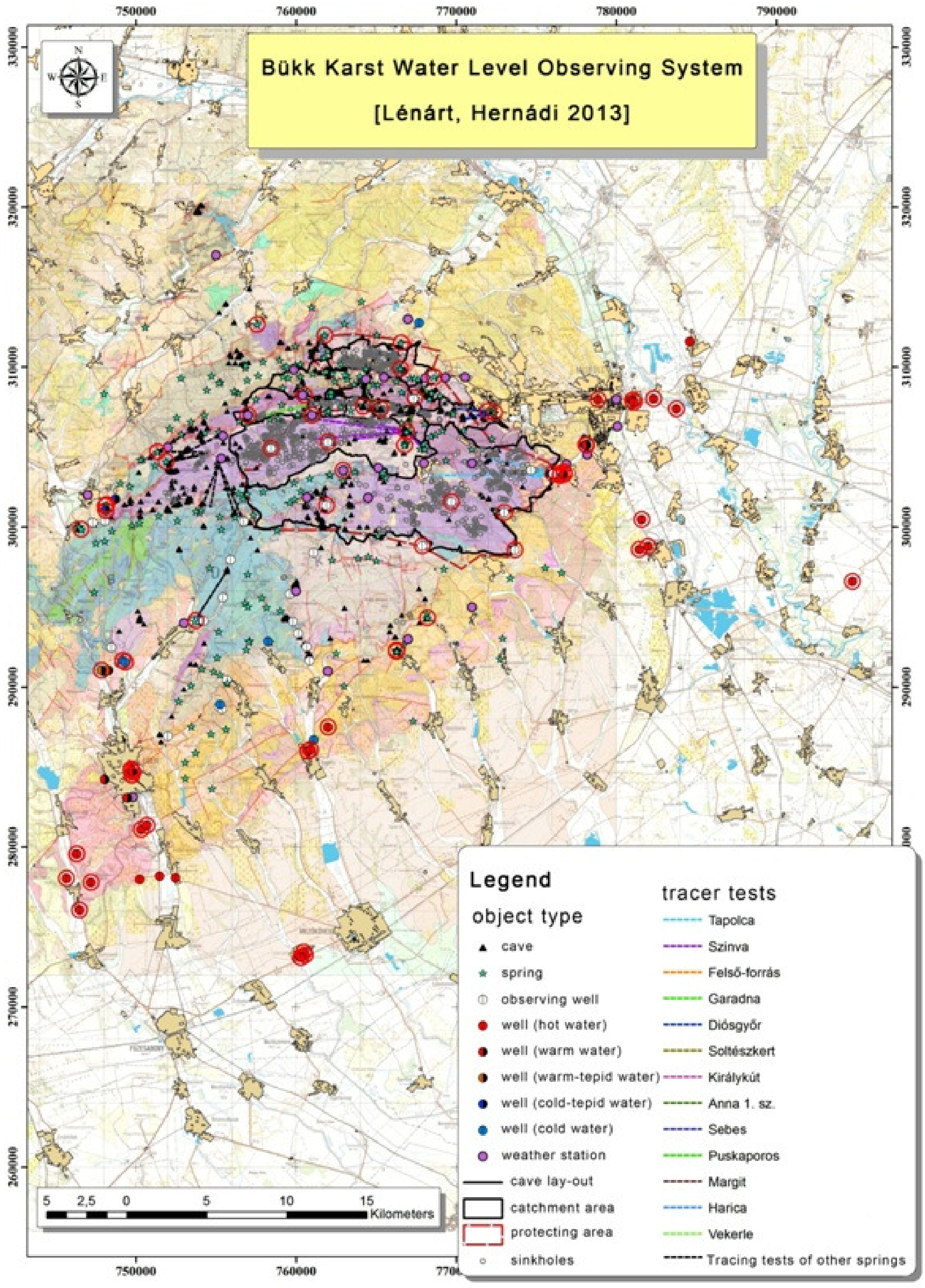
Firstly, in our research the geological, geophysical and thermal maps of the Bükk have been investigated. Thereafter we prove the relationship between cold and warm karst water in correlation investigations which were based on water level and temperature data of the Bükk monitoring system.

In 90 observation points (output wells, observing wells, caves and springs) of Bükk there are continuous water level, temperature and conductivity registering within the frame of Bükk Karst Water Level Observing System. The biggest advantage of this monitoring system is that it covers the whole Bükk Mountain (Figure 1), so we have possibility to make comparative and correlation investigations on different measuring points.

According to the correlation investigations the cold and warm karst water bodies are related therefore cannot be separated into two independent aquifers. We based our investigations on data of more measuring points, the relationship between the two most important ones is shown in Fig. 2.

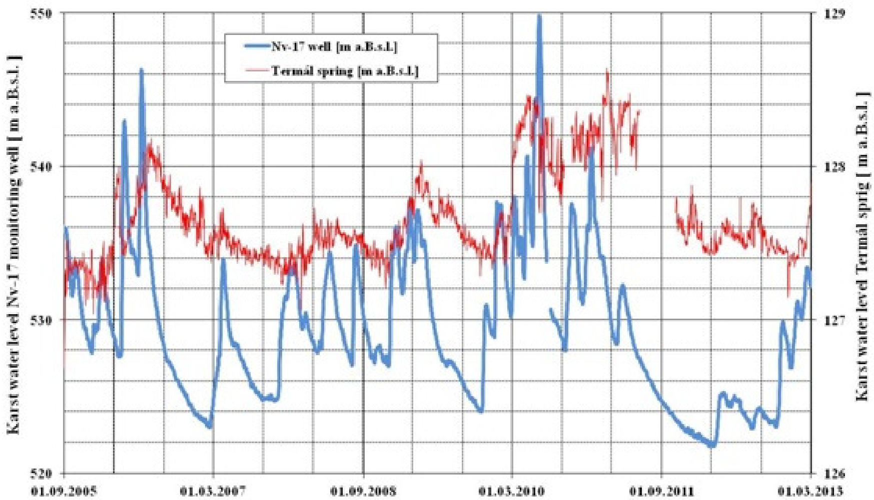
Miskolc is the third largest city of Hungary with a famous cave-bath which is based on the thermal karst water of Bükk Mountains. The average daily production of Thermal-well of the bath is 2.700 m^3. The Nv-17 is the most significant measuring point of the cold water body. This observing point is the base of water resource calculations about the peak position of water relief.

These investigations can help to plan the optimum water utilization and they can provide information for the next water explorations. The cold and warm karst water shall be treated as a united system. If we would like to use both the cold and warm karst water system for the long term we must take serious care of both the exploitation and its effects.


Bükk Karst Water Level Observing System
[Lénárt, Hernádi 2013]
Legend
object type
cave
spring
observing well
well (hot water)
well (warm water)
well (warm-tepid water)
well (cold-tepid water)
well (cold water)
weather station
cave lay-out
catchment area
protecting area
sinkholes
tracer tests
Tapolca
Szinva
Felső-forrás
Garadna
Diósgyőr
Soltészkert
Királykút
Anna 1. sz.
Sebes
Puskaporos
Margit
Harica
Vekerle
Tracing tests of other springs
5 2,5 0 5 10 15 Kilometers
750000
760000
770000
780000
790000
330000
320000
310000
300000
290000
280000
270000
260000

Results

According to the correlation investigations which have been based on the water level data of 20 years long measurements, the relationship between the cold karst water level and warm karst water level (pressure level) is clear but its tightness differs. The tightness of the relationship increases in case of wells situated in the east-west carbonate patches, but it weakens in case of wells situated perpendicular to such patches. Figure 2 shows the water levels of Nv-17 observing point and Thermal-well between 09. 2005 and 02. 2013.



Comparing the temperature data with geological and thermal maps, it can be stated that the temperature of the thermal karst water increases when moving further away from the mountain boundaries, evenly with the depths in the Miskolc area. But due to the horst structure in the area of Egerszalók and Demjén the increase of temperature is independent of depth.

The thermal karst water moves along tectonic zones (Egerszalók, Demjén area) or in the karstic zones which were naked (unconfined) karst surfaces (Miskolc area) in the earlier geological ages.

According to available data, the cold karst water of the Bükk with its 42 bar pressure push the thermal water (30°C) into 900-1400 m deep layers. So the thermal water explorations in the centre of the Bükk Mountains and its rims are needless. Because the zone with the necessary temperature is at great depths or the porosity of the aquifers in these depths is very low (it cannot serve enough water). If there was adequate porosity (for example a cave) in the required depths, the cold karst water would flow into the well and it would cool off the thermal karst water. Also a confirmation of this statement is the thermal karst water exploration work of F. Pávai-Vajna in the centre of the mountains near Lillafüred, which actually failed.

Acknowledgement

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Origin of mineral water springs from Rodna-Bârgău area (Eastern Carpathians, Romania)

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The presence of CO_2-rich mineral waters in the Carpathian region is the result of the Neogene to Quaternary volcanic activity. The bottling-industry, balneology and tourism mainly focused on the youngest segment of the volcanig chain, the Harghita Mts., because there are the most intensive post-volcanic manifestations. The county of Bistrița-Năsăud, located relatively far away from this youngest volcanic range is rich in mineral water springs of different types, ranging from the CO_2-rich to the saline waters. Remarkable areas are the valley of Someșul-Mare, where a fault system and a number of magmatic intrusions are responsible for the venting of mineral waters. Saline waters are mostly related to the leaching of the Badenian salt from the Transylvanian Basin.

In the present study the chemical and stable isotopic assessment of the mineral waters is presented based on their survey from 2012. According to the main dissolved ions the mineral waters were grouped in three major cathegories, Ca-Mg-HCO3, Na-K-HCO3 and Na-Cl. Mixing phenomena within the main water types is detected as the result of the tectonic fragmentation of the area, which enhances fluid circulation. The stable isotopic composition reveals the meteoric origin of mineral waters and low-temperature induced water-rock interactions.

Acknowledgements

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Exploiting the geothermal potential of Central-Eastern Europe; the GEOCOM project

Gábor Kitley[1], István Pári[1], Tamás Medgyes[2]
Balázs Kóbor[2], József Pásztor[3]

Renewable energy resources (RES) have great importance in the principle of sustainable development. Geothermal resources are one of the least known renewable energy sources though both their potentials and engineering qualities are among the best ones concerning RES. At the same time, Central Eastern European (CEE) countries (both new EU members and Western Balkan Countries) have exceptional geothermal resources although the traditional investment-heavy procedures face major difficulties to be applied in these countries. In the past European geothermal research has not placed enough emphasis on the CEE opportunities despite the high number of medium- and high-enthalpy resources available in the region. These resources are either unexploited due to the lack of technological know-how or their utilisation is carried out in an unsustainable way (geothermal district heating projects lack the energy efficiency component and the used thermal water is generally not re-injected but instead released to surface waters).

The Geothermal Communities (GEOCOM) project, co-financed under the European Union's Seventh Framework Programme (FP7), demonstrates the best available technologies in the use of geothermal energy combined with innovative energy-efficiency measures and integration of other renewable energy sources at three different pilot sites (Hungary, Slovakia and Italy). Furthermore, the project integrates a large number of cities as project partners (from Serbia, Romania, Poland and Macedonia) that either already have ongoing geothermal initiatives and are keen on adopting the latest technologies (e.g. Oras Sacueni, Romania) or they would like to realise brand new systems by taking advantage of the project's competent consortium (e.g. Subotica, Serbia).

[1] Geonardo Ltd
[2] University of Szeged
[3] Municipality of Mórahalom

In addition to its demonstration component, through the parallel implementation of three ambitious development works there is also a strong complementary research aspect to the project focusing on making geothermal investments more cost efficient and technologically sound. Research work includes:

Integration of the geothermal energy with other RES to outline ways of a more efficient and sustainable green-energy production (e.g. solar energy, biomass, wind) in Europe – with special focus on combustible gas (eg. CH4) separation from thermal waters and its use for energy production.

Trans-boundary issues of the utilisation of geothermal energy (4D modelling of geothermal reservoirs along the Hungarian/Serbian border)

Socio-economic modelling of geothermal investments, with special focus on the public perception and understanding of RES/RUE measures

Although the GEOCOM project has an all-European dimension it takes into account the specifics of Central-Eastern European conditions. The lack of innovation and awareness for the importance of energy efficiency measures integrated with geothermal initiatives in the region has resulted in grossly inefficient systems at several sites (poorly performing heat exchangers, non-cascade utilisation of thermal water combined with the release of such waters into surface water bodies, space heating with virtually no insulation and heating old buildings that do not satisfy even the most basic energy efficiency standards etc). The project demonstrates the cost-effective innovative solutions for geothermal heat utilisation with research and pilot efforts dedicated to the small-scale integration of other RES. This approach contributes to increase the competitiveness of geothermal technology even in the relatively highly subsidised CEE energy utility systems.

The direct objective of GEOCOM is to demonstrate successful, innovative and inspiring examples for the utilisation of *geothermal energy* for heat generation employing innovative, environmentally sustainable and cost competitive technologies combined with innovative energy efficiency measures and retrofitting. The project results and approach are expected to trigger future investment on geothermal resources and to help its better understanding and perception among the investors, local and regional decision makers, the public and other stakeholders.

Positive experience of innovative district heating projects are the best to illustrate how to go ahead, particularly when strict energy efficiency measures are implemented and the systems are properly integrated. Lessons learnt from European initiatives on Passive House technology and super insulation methods can be readily applied and there is a broad variety of external wall insulation technologies that are state-of-the-art and can also be used for retrofitting inefficient buildings. The inclusion of other RES is also very promising although still in the pre-operative phase with several technological and especially economical challenges that will need to be solved. There is still a long way to go for further research but at the same time it is essential to show some demonstration elements which are to sparkle further interest. The integration of the three pilot initiatives under this project's single umbrella should provide enough impetus to reach the much needed critical mass in boosting investors' interest, raising support from the public and changing the geothermal landscape in Europe once and for all.

The Morahalom Geothermal Cascade System

The development of the core elements of the Morahalom Geothermal Cascade System is being financed from the Hungarian Structural Funds (*„KEOP-4.1.0-2007-0006: Geothermal Cascade System of Morahalom (2008-) – EURO 2,147,000"*). Once the geothermal cascade system is completed and starts to operate the proportion of renewable energy within the energy utilization of public institutions will instantly grow from 0% up to more than 80% - resulting in saving 14,441 GJ of fossil energy sources per year. 2620 kW heat capacity will be built in the geothermal heat supply system, offsetting the use of over 482,000 m^3 natural gas per year, resulting in the reduction of energy-generation-related annual emissions by 866 t of CO_2, 318 kg of N_xO_x and 605 kg of CO. The cascade system furthermore is complemented by the innovative CH_4 separation element (demonstrating total utilisation of geothermal energy) and is supplemented with energy efficiency/retrofitting measures that are currently lacking from geothermal projects in Central Eastern Europe.

System Features:

The brand new district of the town called "New Town Centre" (new town hall, service and public institutions, 12 dwelling units) is proposed to be supplied by a high power heat-pump heating station as a new element of the cascade system.

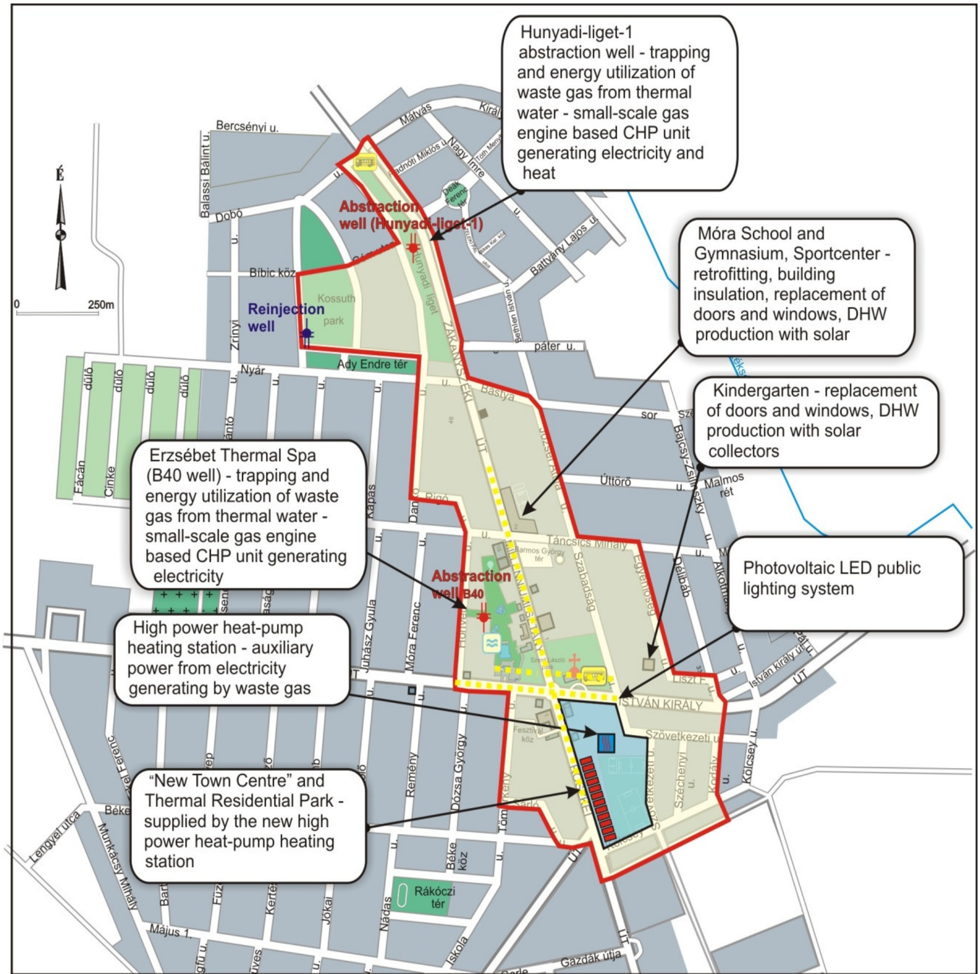
The auxiliary power demand of 60 kW of the heat-pump heating station will be met by the combustion of methane separated from the water extracted through the new abstraction well of the cascade system, while the power produced the same way at the local spa (from a separate well) will be used in situ. Currently this methane is directly emitted into the air (causing a twenty-one times higher greenhouse effect than CO_2). Complex, so called combined energy utilization gas engine based CHP units are to be installed to run partly on the waste gases (CH_4: 65-98%) of the abstracted thermal water, which generates electric power, and supplies auxiliary power to the system. The used methane is technically free of charge and its utilisation will reduce the greenhouse effect of previously un-trapped gases significantly.

The proposed system represents full energy utilisation of the thermal water (including its gas content) by gradually removing heat from the initially 65-70C° water to reach a temperature of 5-6 C° before reinjection. Currently there is no thermal water and heat pump combined system with similar efficiency either in Hungary or elsewhere in Central-Eastern Europe. The potential application of renewable cooling will also be demonstrated at this site by developing plans for the summer utilisation of the heat pump centre for residential cooling purposes.

The operating wells of the geothermal system will be part of the Hungarian-Serbian water base protection monitoring system, and also will serve as practical training site for the launch of a geothermal technician and engineer training at the University of Szeged (SZTE).

Also, a total of ~2000m^2 public building area (Mora Cultural Centre, School and Sports Hall) is subject of retrofitting (thermal insulation of the facades and replacement of doors and windows) and a set of energy efficiency measures are to be carried out which aim to significantly reduce the amount of 140,000 m^3 of natural gas which is used for heating purposes per year. The wasteful boilers with diffusion burners currently in place represent outdated technology and have very poor efficiency. (The geothermal cascade system is calculated to offset ~122000 m3 natural gas/annum only at this very site.) When the project started 82% (!) of the school's total annual operation cost was given by the gas bill. On the other hand the buildings of poor insulation and heat supply were moving around the upper limit of the EU energy recommendations in terms of thermal energy efficiency indicators (135- 210 kWh/m^2/yr), this value was extreme in the case of the Sports Hall (590 kWh/m2/yr). Also at places with high water consumption (such as the kitchen or the showers), the gas-fired boiler based DHW production contributed also to the bad energy efficiency (UNDP audit, 2007). The outdated, non-efficient boiler system is to be replaced by a new cascading RES (geothermal/solar-thermal) solution combined with intelligent energy efficiency measures.

To replace the described installation, 175 m^2 of vertical plate solar thermal collectors and the related engineering are planned to be installed with a capacity up to 17,500 l/day hot water. The solar collectors are to be placed on the horizontal and southern-south-western roofs of the buildings (Mora Cultural Centre, School and Gymnasium – Sports Hall, Kindergarten – Day-care Centre Complex). It is worth mentioning that the Szeged-Morahalom region counts the highest number of sunny hours and receives the most intensive solar radiation in Hungary. Similarly to all solar-based DHW systems, the full-capacity operation is not continuous, and the available heat capacity is also used to complement the heating systems of the buildings as well. An intelligent control unit will optimise the use of solar-thermal and geothermal in the building taking into consideration the peak demands and the usual school cycle (45 minutes class/15 minutes break) for ventilation control. It needs to be mentioned that façade insulation and refurbishment measures take into account the fact that the old building is part of the local cultural heritage and is under local protection. Windows are custom made (triple glass with argon fills) of wooden frames in a style that matches the initial style of the building.



CONCERTO PROJECT DEVELOPMENT IN MÓRAHALOM
the Concerto Area equals to the operational area of the geothermal cascade system

Short presentation of the geothermal cascade systems in downtown Szeged and Újszeged

Szeged is an old dept of the Hungarian geothermal R&D sector and energy industry. A heat market serving 180,000 people is situated above the Upper Pannonian thermal reservoir with probably the most favourable geothermal features of the country. The major part of the country's geothermal R&D sector is concentrated in the town, the area is geologically well researched thanks to the petroleum industry, the Hungarian interest, social and professional organizations dealing with thermal energy are present, and thus the possibility for the demand and potential to meet is given from every aspect. However, with the excellent geological, thermal and knowledge-based features both above and under the ground, almost the entire town is heating with gas.

Despite the fact that several towns in the South Great Plain region have their own geothermal heat supply systems and they are working on their *development*, the use of thermal energy in the regional centre, alongside Mórahalom, Szentes, Kistelek, Csongrád, Makó and Békéscsaba, is limited to one small-scale housing estate heating circuit and several regional greenhouse horticultures.

With the current project, we wish to achieve a breakthrough in Szeged. As the first step of our systematic geothermal development strategy, we wish to make the town's heat supply structure more efficient, inexpensive and environmentally friendly with the construction of a high-capacity, deep *cascade system* – the thermal systems in *downtown* Szeged and in *Újszeged* – using every range of the produced heat quantity.

The downtown project will heat with thermal energy 23 buildings of the University of Szeged – the town's "soul" and biggest gas consumer – as well as the town library and a hotel connected to the thermal system through its secondary system. The Újszeged project creates a *cascade system* including 6 buildings of the University of Szeged, 4 buildings owned by the town in Újszeged, the buildings of the Railway Health Care Non-Profit Ltd. (Vasútegészségügyi Nonprofit Kft.) and of the Policy Administration Service of Public Health of the Government Office of Csongrád County. Only a part of the profit will remain at the investor and the project will result in a significant saving of expenses for the public institutions.

The town of Szeged selected the current project as a priority public development project, recognizing the environmental importance and its role to form the public awareness beyond the financial profit of the investment.

The initial situation

Downtown Szeged

In downtown Szeged, on the territory delimited by the institutional and clinical buildings of the University of Szeged we find a closed thermal well constructed in 1965, while the majority of the buildings is heated from a central boiler room with gas-operated equipment of 20 MW. 70 TJ of heating energy is supplied from the heating station on the pipeline circle with a temperature difference of 105/70 ^{o}C. The temperature difference values of the institutions' internal heating systems vary between 90/70 and 55/40 ^{o}C.

Újszeged

In the suburban-like part of town called Újszeged, the university and academic research institute, the dormitories, town institutions and other public institutions supply their heat demands with their own gas boilers. The temperature differences of the internal heating systems vary between 90/70 and 60/40 ^{o}C, thus they are all suitable for the utilization of the geothermal energy below them, they can significantly moderate their natural gas consumption and replace it by a cheaper local energy source.

Project objectives

The planned main results of the project for the downtown of Szeged are as follows:

Renewable heat capacity of 4.4 MW

Production of 55,239 GJ of thermal energy per year and its use for heating

Replacement of 1.8 million m^3 of natural gas per year

Reduction of greenhouse gas emission equivalent to 3,633 t of CO_2

Saving of energy costs in university and town institutions

Diversification of energy sources in the energy structure of Szeged.

The planned main results of the project for Újszeged are as follows:

Renewable heat capacity of 4.5 MW
Production of 37,167 GJ of thermal energy per year and its use for heating
Replacement of 1.2 million m^3 of natural gas per year
Reduction of greenhouse gas emission equivalent to 2,343 t of CO_2
Saving of energy costs in university and town institutions
Diversification of energy sources in the energy structure of Szeged.

Technical content

The initial point of the downtown project is the old thermal well B-415 of the clinic that will supply a thermal heating medium with a water temperature of 90°C and with a flow of 70-80 m^3/h after a complex renewal and transformation into a production well.

The initial point of the Újszeged project is the production well to be constructed on the territory of the Kisstadion (small stadium) that will supply a heating medium with a water temperature of 90° C and a flow of 70-80 m^3/h.

After a proper treatment (degassing, purification), a pump system carries the produced fluid through an underground pipeline network to the heating stations of the cascade-connected institutions - 25 in downtown and 12 in Újszeged. The cooled fluid flows into the buffer reservoir of the reinjection station, from where, reinjection pumps together with the two reinjection wells pump the water into the deep reservoirs close to the production point. This guarantees the sustainability of the thermal water resource, the maintenance of the reservoir pressure, and the renewal of the geothermal energy as a whole, since the fluid reheated by the deep-seated rocks can be produced and used again in many years.

The fully automatic operation of the thermal cascade system is computer-controlled, and the water and energy efficient and cheap heat supply technology is guaranteed with a modern system controlled by temperature.

Main operational data

Downtown Szeged

Electricity consumption: 508,260 kWh/year

Personnel: 4 dispatchers

Operating costs: HUF net 61,937,634/year; HUF 1,121.27/GJ

Supplied thermal energy: 55,239 GJ/year

Initial service fee: HUF 2,590 /GJ

Initial revenue: HUF net 143,069,010/year

Újszeged

Electricity consumption: 458,380 kWh/year

Personnel: 4 dispatchers

Operating costs: HUF net 57,793,007/year; HUF 1,555/GJ

Supplied thermal energy: 37,167 GJ/year

Initial service fee: HUF 2,590 /GJ

Initial revenue: HUF net 96,262,530/year

Planned financing, profitability

Downtown Szeged

The investor plans to finance the investment costs of HUF net 2,001,500,000 of the project from three sources: HUF 996,747,000 from KEOP assistance, HUF 500,000,000 from commercial loan and HUF 504,753,000 from own resources.

The project's dual profit:

Saving of expenses of institutions: they do not buy an annual amount of 1,805,206 m^3 (61,377 GJ) of natural gas at a price of HUF 3,575/GJ (– HUF 219,422,775); instead they buy 55,239 GJ of thermal energy at a price of HUF 2,590/GJ (+ HUF 143,069,010). Total saving: HUF 76,353,765 + VAT/year.

The profit of the investing organization: (HUF 143,069,010 – HUF 61,937,634) HUF 81,131,376/year, forecasting a simplified payback period of 24.67 years for the total investment costs. The payback period of the own contribution is 12.3 years.

Újszeged

The investor plans to finance the investment costs of HUF net 1,254,250,000 of the project from three sources: HUF 596,737,765 from KEOP assistance, HUF 300,000,000 from commercial loan and HUF 357,512,235 from own resources.

The project's dual profit:

Saving of expenses of institutions: they do not buy an annual amount of 1,221,118 m^3 (41,518 GJ) of natural gas at a price of HUF 3,551/GJ and HUF 3,844/GJ (– HUF 156,063,370); instead, they buy 37,167 GJ of thermal energy at a price of HUF 2,590/GJ (+ HUF 96,262,530). Total saving: HUF 59,800,840 + VAT/year.

The profit of the investing organization: (HUF 96,262,530 – HUF 57,793,007) HUF 38,469,523/year, forecasting a simplified payback period of 32.6 years for the total investment costs. The payback period of the own contribution is 17.1 years.

Phases of implementation:

The projects can be implemented within two years; both systems can be commissioned at the end of 2014 in case of a project start in March 2013 and by planned financing.

LIST OF BUILDINGS, NOTATION

1 id. Jancsó Miklós Student Hostel
2 Teleki Blanka Student Hostel
3 SZTE Juhász Gyula Primary School
4 JGYPK Dean's Office
5 Clinic of Obstretricy and Gynecology
6 Irinyi building (with the Eötvös Student Hostel)
7 Building of chemistry and physics (Béke building)
8 Apáthy István Student Hostel
9 Art Hotel Szeged
10 Somogyi Library
11 SZTE ÁOK Educational Building
12 Blood transfusion station
13 Clinic of Internal Medicine and Cardiology, Nr. 2
14 Clinic of Intensive-care medicine
15 Clinic of Internal Medicine, Nr. 1
16 SZTE-ÁOK Clinic of surgery
17 SZTE Clinic of Ophthalmology
18 Finance office of SZTE Clinic
19 Semmelweis Ignác Student Hostel
20 Knowledge Center of Neurobilogy
21 Clinic of Pediatrics, division 'B'
22 New building of the SZTE Clinic, heat distributor Nr. 1
23 New building of the SZTE Clinic, heat distributor Nr. 2.
24 Szent-Györgyi Albert Institute of Pathology
25 SZTE-ÁOK Central Pharmacy

Thermal water conveyor
VS-1 Reinjection Well, Nr. 1
VS-2 Reinjection Well, Nr. 2
T Production Well

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