CHARACTERIZATION OF FLUIDS AND EVALUATION OF THEIR EFFECTS ON KARST DEVELOPMENT AT THE RÓZSADOMB AND GELLÉRT HILL, BUDA THERMAL KARST, HUNGARY

SUMMARY OF PH.D. DISSERTATION

ANITA ERŐSS

Geology and Geophysics Ph.D. Program of the Earth Sciences Ph.D. School of the
Eötvös Loránd University

Chair of the Ph.D. School: Gyula Gábris, DSc

Chair of Ph.D. Program: Miklós Monostori, DSc

Supervisor: Judit Mádl-Szőnyi, Ph.D., Associate Professor

Eötvös Loránd University

Budapest, Hungary

2010

INTRODUCTION

In this study the Rózsadomb and Gellért Hill discharge areas of the Buda Thermal Karst were investigated to determine how the discharging fluids and adjoining phenomena (e.g. caves, mineral precipitates) can be telltales of their parent fluid systems, the processes acting along the flow path and operating directly at the vicinity of the discharge zone. As a basic approach of this study, the virtual spring concept of Tóth (2009) was applied, which considers all discharge phenomena together as one single entity in the terminal area of a groundwater flow-system, and whose investigation plays a crucial role in the understanding of the flow system itself (Tóth, 2009).

Being a marginal area at the boundary of uplifted carbonates and a sedimentary basin, the Buda Thermal Karst serves as a discharge zone of the regional fluid flow. This implies that it may receive fluid components from several sources resulting in a wide range of discharge features including springs, caves, and mineral precipitates.

Based on the previous considerations, next to the identification of active processes in the discharge area, such as cave development and mineral precipitation based on the evaluation of fluids and related phenomena, the aim of the study was also the recognition of markers of these processes that may help in the identification of products in palaeo systems. To accomplish these objectives new approaches and considerations were also applied for this area such as radionuclides, multivariate data analyses, and microbiological investigations. Furthermore, an experiment was designed to investigate the recent dissolution processes in the caves.

METHODS

Since the current hydrogeological system has an artificially influenced groundwater discharge, archive hydrogeological data were first evaluated to identify the primary discharge features in the surroundings of Rózsadomb and Gellért Hill. Recent hydrogeochemical measurements were carried out in order to give an overview about the current distribution of physico-chemical parameters including major and trace components, and radionuclides as well. The radionuclides of the ^{238}U series were involved in the hydrogeochemical investigations in order to use them as natural tracers for the characterization of mixing process, and on the other hand to determine with their help the fluid composition and temperature of the mixing end members based on the work of Gainon et al. (2007a,b). Similarly to the diagrams of Alföldi et al. (1968), and for comparison, the major components were first plotted against the temperature. The sampled wells have different screening depths, which means that the involved wells provide information about different depths of the aquifer. Therefore, additional diagrams were constructed to acquire information about the distribution of measured parameters with depth. Moreover, this study used multivariate data analysis methods in order to characterize the waters involving all measured parameters together.

Among the methods of multivariate data analysis, cluster analysis was applied to group objects of similar kind into respective categories. The identified groups were validated by discriminant analysis and characterized by box plots. Additionally, Wilks' lambda statistic was used to acquire information about the most influencing parameters of the identified groups. For the evaluation of some regional scale issues, geochemical characterization of fluids from different strata of the basin side was processed. Additionally to the data found in the literature, $\delta^{34}S$ analyses were carried out during this study from the waters around the Gellért Hill for the better evaluation of the sulphate issue. PHREEQC hydrogeochemical modelling program was used for saturation state calculation of waters and modelling of mixing. The mineral composition of the recently observed minerals was investigated by XRD. In the case of iron hydroxide total elementary composition analyses, γ- and Mössbauer-spectroscopy was applied. Furthermore, microbiological investigations of the iron-hydroxide precipitates were carried out. The morphology of intact microbial cells was investigated under light microscope, while the structure of biofilm by scanning electron microscopy (SEM). The phylogenetic diversity of biofilm bacterial communities was revealed by 16S rRNA gene based clone libraries as a culture-independent molecular biological method. For the investigation of recent dissolutional processes an experiment was designed. Rock samples were immersed into the water filling the cave whose polished surfaces before and after the experiment were investigated by SEM. Additionally, the weight loss of the samples were determined.

SUMMARY AND THESES

1. Applying the classification of karst systems in flow system context (Tóth, 1963; Klimchouk, 2007; Goldscheider et al., 2010), the Buda Thermal Karst, based on its position in the groundwater flow system at a regional discharge zone, is a hypogenic karst system. The end member fluids of this system are on the one hand meteoric fluids, which are "freshly" infiltrated cold karst waters, and on the other hand hydrothermal fluids, which are – using Deming's (2002) classification – evolved waters with various components according to complex rock-water interactions.

2. Based on retrospective data evaluation according to Engelen and Kloosterman's (1996) hydrological system analysis approach, the original discharge characteristics of the two study areas were revealed. Both discharge areas were characterized by structurally controlled discharge. Accordingly, in the Rózsadomb area the lukewarm (21-29°C) and hot springs (50-65°C) were spatially separated and characterized by distinct chemical compositions. The lukewarm springs had usually lower than 1000 mg/l TDS, while the hot waters contained more than 1200 mg/l TDS. High discharge rate (ca. 18000 m^3/day) characterized the

Rózsadomb, while lower (about 3200 m^3/day) values were reported from the Gellért Hill. The discharging waters in the Gellért Hill area were characterized by a rather uniform temporal and spatial distribution of temperature (35-47°C) and chemical composition (1500-2000 mg/l TDS content). The waters of both areas could be characterized by similar HCO_3^-, H_2SiO_3, Cl^-, Na^+, and K^+ contents, while the waters around the Gellért Hill contained more Ca^{2+}, Mg^{2+}, Li^{2+}, and SO_4^{2-} (Papp, 1942).

3. The North and South Systems as groups of waters were distinguished in this study on the basis of multivariate data analysis where all investigated parameters of the waters (major and trace components, in-situ parameters, and the radionuclide content) were simultaneously taken into account. The North System comprises all the waters around the Rózsadomb and deep wells on the opposite Pest side. The South System includes waters around the Gellért Hill and deep wells in South Budapest. Within the North System the lukewarm springs of the Rózsadomb could be further separated from the hot waters. Based on the Wilks' Lambda values, the Ca^{2+}, SO_4^{2-}, and Mg^{2+} content of the waters has major influence on the differentiation of the groups, whereas the role of temperature does not seem as dominant. In the North System there is (> ±0.82), whereas in the South System there is no significant correlation (< 0.67) between the major components and the temperature. Regarding the main components, the South System is characterized by elevated Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, and TDS content compared to the North System. These higher values correspond to lower temperatures within a narrower range (30-47°C). The above differences between the two systems can also be identified on the distribution of parameters with depth. However, with regard to Na^+ and Cl^- there are no differences between the two systems. At greater depth the parameters are characterized by rather constant values, meanwhile significant differences occur in the proximity of the discharge level, thus suggesting that the processes inducing changes in the parameters operate in the vicinity of the discharge level.

4. The use of radionuclides is a powerful method to characterize fluids debouching in a regional discharge area where flow systems of different order convey waters with different temperature, composition, and redox-state to the discharge zone. In the case of a two-component mixing system, the mixing end members' temperature, composition, and the depth of mixing can be determined. It is suggested, that the temperature or TDS of the hydrothermal end member component should rather be inferred from the uranium data. In the case of radon data, the degassing of radon in open systems or even during sampling may influence the inferred parameters. Furthermore, local radon sources in the vicinity of spring discharge, such as iron hydroxides, may also affect the measured radon content of waters. For the same

reasons, the $^{222}Rn/^{226}Ra$ ratio, as an indicator of the mixing rate and geothermometer for the hydrothermal end member suggested by Gainon (2008), cannot be used. The parameters of the meteoric end member can be inferred from the radium data. Due to the uncertainties of temperature measurements at higher temperatures, the use of TDS of waters for the end member characterization is suggested. Based on the linear relationship between the parameters, the composition of the end members can be determined in a two-component mixing system. Using chloride as a conservative component, the mixing ratio can be also calculated for the sampled objects. By the aid of hydrogeochemical modelling, the calculated mixing ratios for the sampled objects can be modelled and compared to the measured water-compositions.

5. This study provided an overview about the distribution of the radionuclides in the waters of the North and South Systems, and supplied further evidence and a new approach for the existing difference between the two areas. The waters of the North System can be characterized by increasing radium content (53-591 mBq/l) and decreasing uranium content (83-10 mBq/l) with increasing temperature, and generally low (1.8-98 Bq/l) radon content also showing negative correlation with temperature. The waters of the South System are characterized by higher radium (221-870 mBq/l) and radon (3-963 Bq/l) content than the members of the North System. Furthermore, some anomalously high (up to 963 Bq/l) radon concentrations can also be observed, which do not correlate with the temperature. The uranium values are generally low (11-33 mBq/l) in the South System. In both systems the radium of the deepest wells show the same values (about 500 mBq/l), which could indicate the common origin of the radium.

6. By the aid of the radionuclides, the mixing end members for the North System were identified: a meteoric end member with the temperature of 12 °C and 775 mg/l TDS, and a hydrothermal end member with the temperature of 76.5 °C and 1440 mg/l TDS, respectively. The mixing ratio of the sampled objects was determined by using chloride as a conservative component. The modelled compositions based on the inferred mixing ratio were in accordance (difference < 20%) with the measured values. In the case of wells the mixing might be artificially induced by water abstraction.

7. For the South System no end member could be inferred with the help of the radionuclides. Thus the radionuclide study revealed a new model for the Gellért Hill area. Accordingly, the hydrothermal waters with 35-47°C temperature and 1400-1800 mg/l TDS discharge directly in the Gellért Hill area. No mixing occurs between the meteoric and hydrothermal end members at this discharge zone, and even if mixing exists, it cannot be investigated by

radionuclides, as the end members are probably very similar to each other and rather hydrothermal waters.

8. The observed differences of the discharging fluids and the discharge distribution between the two areas can be explained partly by regional geological differences. The North System recharge area is composed of large exposed carbonate surfaces facilitating the recharge of the large amount (> 10000 m^3/day) of meteoric fluids discharging at the Rózsadomb area. As opposed to the unconfined recharge area, the discharge area at the Rózsadomb can be characterized by confined conditions, therefore the discharge of the meteoric and the upwelling hydrothermal fluids is structurally controlled having an important consequence on the mixing of these waters. Mixing can only occur through structures. Since the recharge area of the South System can be characterized by a limited surface of exposed carbonates, the meteoric fluid contribution is also limited to the discharge area, and the upwelling hydrothermal waters overwhelm among the discharging fluids, thus no lukewarm spring can be found there. The natural discharge rate of the system (3200 m^3/day) is lower compared to the Rózsadomb (18000 m^3/day) also indicating areal differences in the recharge area.

9. Based on the hydrogeochemical investigations, contribution of basinal fluids to the discharging waters of Buda Thermal Karst (in form of Na^+, K^+, Cl^-, H_2SiO_3, CO_2, H_2S, CH_4, and liquid hydrocarbons) has to be considered. The similar Na^+, Cl^-, and CO_2 content of the waters in both systems suggests common basinal origin. However, differences in methane and some trace element contents (eg. Li, Cs, Ba) between the North and South Systems may indicate different source areas. The basinal fluid contribution is probably the result of complex fluid-rock interactions, and might be controlled by structural elements and pressure conditions of the fluids involved. The suggested driving force of the basinal fluid contribution based on Almási (2001), Tóth and Almási (2001), and Bada et al. (2006) is the overpressure derived from tectonic compression.

10. Thermal waters usually have high sulphate content (Worthington and Ford, 1995; Gunn et al., 2006), as it is observed in the waters of the Buda Thermal Karst. The origin of the sulphate content of these waters can be explained by the dissolution of Permian-Lower Triassic evaporitic-carbonate strata, as suggested by Alföldi (1979) and Szabó et al. (2009) as well. The higher sulphate content of the South System (>300 mg/l) might be explained by the more uplifted position of these strata and by the reaction between gypsum, dolomite, and calcite. According to Bischoff et al. (1994) and Palmer (2000, 2007), the dissolution of gypsum forces calcite to precipitate and simultaneous dissolution of dolomite occurs, therefore the water will be enriched in both magnesium and sulphate at regional scale. However, this study

also suggests that other sources, such as the pyrite content of the Buda Marl and the basinal H_2S may contribute to the sulphate content of the waters as well. The former is rather responsible for the sulphate content of the lukewarm waters in the Rózsadomb area.

11. Iron hydroxides are characteristic recent precipitates besides calcite (as rafts) of the discharge zone of the Buda Thermal Karst. The mineral composition of these iron hydroxide precipitates is characterized by ferrihydrite and goethite based on Mössbauer spectroscopy results. Their occurrences indicate the change from reductive to oxidative realm resulting either from the direct oxidation of upwelling hydrothermal waters or from mixing of these waters with oxidative meteoric waters. Their occurrence in the Gellért Hill discharge area confirms the established direct discharge of hydrothermal waters becoming oxidized at the water table zone. As the precipitates were found in water table caves, the iron hydroxide precipitates could be used as markers of cave forming levels. These precipitates appear in deep, phreatic conditions in case of the Rózsadomb discharge area. Here the iron hydroxide precipitates may indicate the mixing of reduced hydrothermal and oxidative meteoric waters, and therefore could serve as signatures of mixing, as well as of cave forming.

12. The colloidal nature of iron hydroxide precipitates and the spring analogues found in the literature (Casanova et al., 1999; Fujisawa and Tazaki, 2003; Tazaki, 2009) suggested the role of microbes beside autoxidation during the formation of these precipitates. Microbiological investigations identified bacterial communities characterized by anaerobic ferri(III) or sulphate reducing, or aerobic ferro(II) or sulphide oxidizing metabolic properties suggesting that these bacteria may participate in diverse redox reactions in biogeochemical cycling of different elements (S, Fe, C) in both study areas. The microbial community structures from the samples at higher taxonomic levels showed similarity to those described from caves where microbiologically mediated sulphuric acid speleogenesis takes place (Engel, 2007). It may suggest that microbially mediated sulphuric acid speleogenesis might be an active cave forming process in both areas.

13. The characteristic feature of these iron hydroxides is their strong adsorption capacity (e.g. Casanova et al., 1999; Le Guern et al., 2003). The iron hydroxide precipitates of the Buda Thermal Karst area are also characterized by the adsorption of trace elements, such as As, Pb, Cr, Cu, Ni, Zn, Mo, U. Beside these elements the adsorption of radium was demonstrated by γ-spectrometry (up to 3680 Bq/kg). Thus this study identified the cause of high radon content of the waters, in the form of these iron-hydroxide precipitates, which adsorb radium efficiently and act as local radon source. However, the radon content of the waters will be elevated only if these precipitates accumulated directly at the discharge of the spring. In case

of the Gellért Hill area, these iron hydroxides accumulated in the spring caves, at the direct discharge of springs, therefore the spring waters have high radon content (up to 963 Bq/l). Whereas in the Rózsadomb area, the iron hydroxides are located in deep phreatic conditions inside the cave, and due to the surrounding water mass and the travelling time until the spring outlet, the radon content of the water will diminish.

14. The iron hydroxide precipitates were found together with calcite rafts in the already dry caves. Accordingly, their common occurrence in a palaeo system is conclusive for cave formation. The mineralogical composition of these palaeo iron hydroxide precipitates is dominantly goethite, also characterized by considerable trace element content corresponding to recent ones.

15. Based on the dissolution pilot experiment carried out during this study, the Buda Thermal Karst is an actively forming hypogenic karst. Dissolution was confirmed in both study areas. However, in the case of the Gellért Hill precipitation of minerals (mainly calcite and gypsum) and formation of biofilm on the samples could be observed beside the dissolution.

16. Regarding the cave forming processes, mixing might be the dominant process in the Rózsadomb area. Owing to the large discharge amount of the end member fluids (10000 and 8000 m^3/day, respectively) and a considerable difference between their CO_2 content (SI CO_2: -1.38 – 0.11), the mixing corrosion is efficient. Accordingly, the structurally controlled discharge mixing could only exist along structural lineaments, therefore the cave patterns also show strong structural control. Based on the results of microbiological investigations, microbially mediated sulphuric acid speleogenesis may also be active in this area, although it has probably a subordinate role.

17. In the Gellért Hill area the discharge of hydrothermal waters is overwhelming and no mixing could be identified by the radionuclides. The present study suggests microbially mediated sulphuric acid speleogenesis as dominant process since the recently formed gypsum crust on the cave walls close to the water table, and the identified bacteria groups were also reported from other caves that have recently undergone sulphuric acid speleogenesis (Engel, 2007), furthermore these caves were originally isolated chambers. This study proposes that the H_2S has rather basinal origin. However, based on the microbiological study, sulphate reducing bacteria producing H_2S could also be a possible scenario. The dissolution might be more effective in that time when the caves were isolated, and according to Palmer (2007) CO_2 caused an additional dissolution in this closed system.

18. Beside mixing and sulphuric acid speleogenesis, other processes can also contribute to the formation of the Buda Thermal Karst. According to the retrograde solubility of calcite

(Bakalowicz et al., 1987; Dublyansky, 2000; Andre and Rajaram, 2005), cooling of upwelling hydrothermal waters could enhance the fluid transport capacity of faults. Rejuvenated aggressiveness (Bischoff et al., 1994; Palmer 2000, 2007) by the dissolution of gypsum may enhance the fracture porosity of the dolomite reservoir on a regional scale.

19. The Buda Thermal Karst based on the results of the dissolution pilot study is an actively forming hypogenic karst. Several processes can be simultaneously present and active at this regional discharge zone where meeting of flow systems of different order conveying waters with different temperature, chemical composition, and redox-state can be observed. However, the predominance of one or other of the individual processes may determine the main character of the observed discharge phenomena (e.g. caves, precipitates). This area may serve as the type area of hypogenic karsts with similar geological settings. Based on the results of this study, new conceptual flow and process models were developed for the study areas.

REFERENCES

Alföldi, L., 1979, Budapesti hévizek (Thermal waters of Budapest) [in Hungarian]: VITUKI Közlemények, 20: 1-102.

Alföldi, L., Bélteky, L., Böcker, T., Horváth, J., Korim, K., Liebe, P., and Rémi, R. (eds.), 1968, Budapest Hévizei (Thermal waters of Budapest), Budapest, VITUKI, 365 p.

Almási, I., 2001, Petroleum Hydrogeology of the Great Hungarian Plain, Eastern Pannonian Basin, Hungary. PhD Thesis, University of Alberta, Department of Earth and Atmospheric Sciences, Edmonton, Alberta, 312 p.

Andre, B. J., Rajaram, H., 2005, Dissolution of limestone fractures by cooling waters: Early development of hypogene karst systems. Water Resour Res, 41: W01015.

Bada, G., Horváth, F., Dövényi, P., Szafián, P., Windhoffer, G., Cloetingh, S., 2006, Present-day stress field and tectonic inversion in the Pannonian basin. Global and Planetary Change, 58(1-4): 165-180.

Bakalowicz, M. J., Ford, D. C., Miller, T. E., Palmer, A. N., and Palmer, M. V., 1987, Thermal genesis of dissolution caves in the Black Hills, South Dakota: Geological Society of America Bulletin, 99: 729-738.

Bischoff, J. L., Julia, R., Shanks, W. C., Rosenbauer, R. J., 1994, Karstification without carbonic acid; bedrock dissolution by gypsum-driven dedolomitization. Geology 22: 995-998.

Casanova, J., Bodénan, F., Négrel, Ph., Azaroual, M., 1999, Microbial control on the precipitation of modern ferrihydrite and carbonate deposits from the Cézallier hydrothermal springs (Massif Central, France), Sedimentary Geology, 126: 125-145.

Deming, D., 2002, Introduction to Hydrogeology, New York, McGraw-Hill, 468 p.

Dublyansky, Y. V., 2000, Hydrothermal speleogenesis – Its settings and peculiar features. In: Klimchouk, A. B., Ford, D. C., Palmer, A. N., Dreybrodt, W. (eds.) Speleogenesis Evolution of Karst Aquifers, National Speleological Society, Inc. Huntsville, Alabama, USA, 298-303.

Engel, A. S., 2007, Observations on the biodiversity of sulfidic karst habitats. Journal of Cave and Karst Studies. 69(1): 187-206.

Engelen, G. B., Kloosterman, F. H., 1996, Hydrological systems analysis: methods and applications. Kluwer Academic Publishers, Dordrecht Boston London, 152 p.

Fujisawa, A., Tazaki, K., 2003, The radioactive microbial mats – In case of Misasa hot springs in Tottori Prefecture. In: Kamata, N. (ed.): Proceedings: International Symposium of the Kanazawa University 21st-Century COE Program Vol. 1., Kanazawa University, Kanazawa, Japan, 328-331.

Gainon, F., 2008, Les isotopes radioactifs de la série de l'uranium-238 (222Rn, 226Ra, 234U et 238U) dans les eaux thermales de Suisse: sites d'Yverdon-les-Bains, Moiry, Loèche-les-Bains, Saxon, Val d'Illiez, Bad Ragaz, Delémont, Lavey-les-Bains, Brigerbad et Combioula; Thèse CHYN, 109 p.

Gainon, F., Goldscheider, N., Surbeck, H., 2007a, Conceptual model for the origin of high radon levels in spring waters - the example of the St. Placidus spring, Grisons, Swiss Alps: Swiss Journal of Geosciences / Eclogae Geologicae Helvetiae, 100(2): 251-262.

Gainon, F., Surbeck, H., Zwahlen, F., 2007b, Natural radionuclides in groundwater as pollutants and as useful tracers; Water-Rock Interaction 12, Kunming, China, Taylor & Francis, London 1: 735-738.

Goldscheider, N., Mádl-Szőnyi, J., Erőss, A., Schill, E., 2010, Review: Thermal water resources in carbonate rock aquifers. Hydrogeology Journal, published online: DOI: 10.1007/s10040-010-0611-3.

Gunn, J., Bottrell, S. H., Lowe, D. J., Worthington, S. R. H., 2006, Deep groundwater flow and geochemical processes in limestone aquifers: evidence from thermal waters in Derbyshire, England, UK. Hydrogeol J 14: 868-881.

Klimchouk, A. B., 2007, Hypogene Speleogenesis: Hydrogeological and Morphogenetic Perspective Special Paper no.1, National Cave and Karst Research Institute, Carlsbad, NM, 106 p.

Le Guern, C., Baranger, P., Crouzet, C., Bodénan, F., Conil, P., 2003, Arsenic trapping by iron oxyhydroxides and carbonates at hydrothermal spring outlets, Applied Geochemistry, 18: 1313-1323.

Palmer, A. N., 2000, Hydrogeologic Control of Cave Patterns. In: Klimchouk, A. B., Ford, D. C., Palmer, A. N., Dreybrodt, W. (Eds.) Speleogenesis, Evolution of Karst Aquifers, National Speleological Society, Inc. Huntsville, Alabama, USA: 77-90.

Palmer, A. N., 2007, Cave Geology. Dayton, Ohio, Cave Books, 454 p.

Papp, F., 1942, Budapest meleg gyógyforrásai (Thermal medicinal springs of Budapest) [in Hungarian]: A Budapesti Központi Gyógy- és Üdülőhelyi Bizottság Rheuma és Fürdőkutató Intézet kiadványa, Budapest, 252 p.

Szabó, V., Fórizs, I., Halas, S., Pelc, A., Deák, J., 2009, A budapesti hévizek szulfátjának eredete stabilizotópos mérések alapján (Origin of the sulphate of the thermal waters of Budapest based on stable isotope measurements) [in Hungarian]: Miskolci Egyetem Közleménye, A sorozat, Bányászat, 77: 73-81.

Tazaki, K., 2009, Observation of microbial mats in radioactive hot springs, Sci. Rep. Kanazawa Univ., 53: 25-37.

Tóth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins. Journal of Geophysical Research, 68(16): 4795-4812.

Tóth, J., 2009, Springs seen and interpreted in the context of groundwater flow-systems, GSA Annual Meeting 2009 (18-21 October 2009) Portland, Geological Society of America Abstracts with Programs, 41(7) p. 173.

Tóth, J., Almási, I., 2001, Interpretation of observed fluid potential patterns in a deep sedimentary basin under tectonic compression: Hungarian Great Plain, Pannonian Basin. Geofluids 1(1): 11-36.

Worthington, S. R. H., Ford, D C., 1995, High sulfate concentrations in limestone springs: An important factor in conduit initiation? Environmental Geology, 25: 9-15.

PUBLICATIONS BY THE AUTHOR

Papers

Erőss, A., Mádl-Szőnyi, J., Csoma, É. A., 2008, Characteristics of discharge at Rose and Gellért Hills, Budapest, Hungary. Central European Geology, 51/3, 267-281.

Erőss, A., Mádl-Szőnyi, J., Mindszenty, A., Müller, I., 2006, Conclusions from a negative tracer test in the urban thermal karst area, Budapest, Hungary. In: Tellam, J. H., Rivett, M. O. and Israfilov, R. G. (eds.): Urban groundwater management and sustainability, NATO Science Series IV. Earth and Environmental Sciences Vol. 74., Springer, Dordrecht, The Netherlands, 289-298.

Goldscheider, N., Mádl-Szőnyi, J., **Erőss, A.**, Schill, E., 2010, Review: Thermal water resources in carbonate rock aquifers. Hydrogeology Journal, published online: DOI: 10.1007/s10040-010-0611-3

Mádl-Szőnyi, J., **Erőss, A.**, 2005, Újabb hidrogeológiai vizsgálatok a budai termálkarszt területén. Hidrológiai Tájékoztató, 28-30.

Extended conference abstracts

Erőss, A., Csoma, É. A., Mádl-Szőnyi, J., 2008, The effects of mixed hydrothermal and meteoric fluids on karst reservoir development, Buda Thermal Karst, Hungary. In: Sasowsky, I.D., Feazel, C.T., Mylorie, J.E., Palmer A.N., and Palmer, M.V. (eds.), Karst from recent to reservoirs: Special Publication 14, Karst Waters Institute, Leesburg, Virginia, USA, 57-63.

Mádl-Szőnyi, J., **Erőss, A.**, 2007, Hydrogeological studies on the Buda Thermal Karst system (Budapest, Hungary). In: Ribeiro, L., Chambel A., Condesso de Melo, M.T. (eds.): Proceedings on CD (ISBN 978-989-95297-3-1) of the XXXV. Congress of International Association of Hydrogeologists, 17-21 September, Lisbon, Portugal, 9 p.

Palotai, M., Mádl-Szőnyi, J., Horváth, Á., **Erőss, A.**, 2006, Potential Radon and Radium sources of groundwaters of Gellért and József Hills (Budapest, Hungary). In: Goldscheider, N., Mudry, J., Savoy, L., Zwahlen, F. (eds): Proc. 8th Conference on Limestone Hydrogeology, Neuchatel (Switzerland) 21-23 sep. 2006, Presses universitaires de Franche-Comté, Besancon, France, 201-204.