XXXVIII IAH Congress

Groundwater Quality Sustainability

Krakow, 12–17 September 2010

Extended Abstracts

Editors:
Andrzej Zuber
Jarosław Kania
Ewa Kmiecik

University of Silesia Press 2010

abstract id: **315**

topic: **3**
Aquifer management

3.3
Geophysical, geological and geochemical methods in groundwater exploration

title: **Integrated groundwater flow system characterization in the Trans-Tisza region of Hungary**

author(s): **Brigitta Czauner**
Eötvös Loránd University, Hungary, brigicza@gmail.com

Judit Mádl-Szőnyi
Eötvös Loránd University, Hungary, szjudit@ludens.elte.hu

keywords: integrated methods, faults, fluid-potential anomaly, hydrocarbon entrapment, Hungary

INTRODUCTION

According to a regional scale hydrogeological study of the Great Hungarian Plain, Eastern Pannonian Basin of Central Europe (Tóth, Almási, 2001), near the villages of Berekfürdő and Kunmadaras a significant positive anomaly can be observed in the fluid potential field. The anomaly appeared as a "potential plume" on the NNW-SSE oriented (H4) hydraulic cross section of Tóth and Almási (2001, Figure 22). The authors explained the development of this phenomenon by hypothesizing the presence of structural elements, which cut through the thick and regionally extensive low-permeability (aquitard) Neogene strata. They supposed that these hypothetic faults facilitate water-upwelling and pressure dissipation from the overpressured Pre-Neogene basement into the shallower aquifers.

Basically, faults can both be barriers (seals) and conduits (leaks) for fluid flow. It depends on several factors, such as the petrophysical properties (porosity, permeability, capillarity) of the fault zone and the undeformed host rock, the relative orientation and dip-angle of the fault plane, the present stress state, as well as the spatial and temporal variation of these factors. The model of Matthäi and Roberts (1996) shows an example for the case when the distribution of fluid potential causes the spatial variability in a fault's hydraulic behaviour. They distinguished different cross-sectional models of faulted sand-shale sequences characterised by pressure-driven fluid flow systems, and found that in those situations where the fluids upwelling along the high permeability fault can flow out of the fault into intersected sands, no fluid flow occurs across the fault. In this case, the high permeability fault is acting as a fluid flow direction dependent barrier.

The objective of the present work was to characterize the geological framework and particularly the faults, as well as the groundwater flow system in the surroundings of Berekfürdő, in order to explain the development of the fluid-potential anomaly.

THE STUDY AREA

The Study Area (Figure 1) is located in the Trans-Tisza Region of the Great Hungarian Plain, Eastern Pannonian Basin. The Pre-Neogene basement of this sedimentary basin is divided into a number of deep local basins and troughs. Lithologically, it comprises brittle flysch, carbonate and metamorphic rocks. Hydrostratigraphically, the Pre-Neogene formations make up one unit, the hydraulic properties of which cannot be established reliably due to insufficient data. The 100-7000 m thick semi- to unconsolidated clastic basin fill of Neogene age has been divided into five regional units based on chronostratigraphic divisions, lithologic facies types, and reported values of permeability (Tóth and Almási, 2001; Mádl-Szőnyi and Tóth, 2009). The lowermost unit of the basin fill is the Pre-Pannonian Aquifer with an estimated hydraulic conductivity of $K \approx 10^{-6}$ m·s^{-1}, which is primarily due to tectonic fracturing and faulting. The superjacent Endrőd Aquitard is a regionally extensive but discontinuous unit of generally low-permeability ($K \approx 10^{-9}$ m·s^{-1}) calcareous and argillaceous marls. The following Szolnok Aquifer shows a cyclic alternation of sandstones, siltstones and clay-marl beds of the prodelta facies characterized by hydraulic conductivity of $K \approx 10^{-7}$-10^{-6} ms^{-1}. It is regionally discontinuous and occurs only in the deep subbasins. The lithology of the next Algyő Aquitard ($K \approx 10^{-8}$–10^{-7} m·s^{-1}) representing delta facies is sand-dominated above the basement highs, giving aquifer properties to the regional aquitard locally. Consequently, the regionally extensive Algyő Aquitard is leaky due to its sedimentological discontinuities and cross-cutting fractures and faults. The uppermost Great Plain Aquifer ($K \approx 10^{-5}$ m·s^{-1}) is characterized by the good spatial connectivity of highly permeable bodies of silts, coarse sands, and gravels.

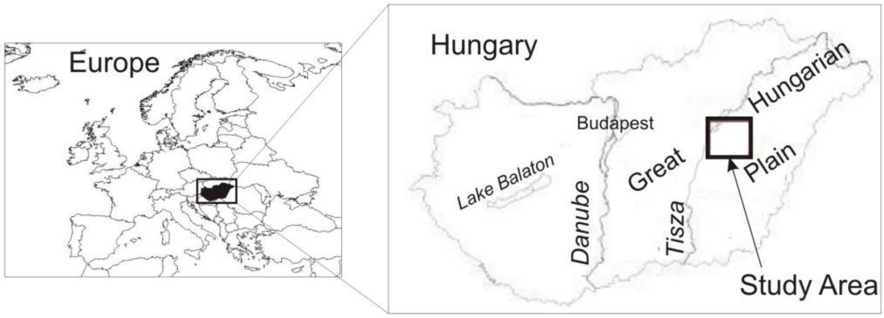

Figure 1. Location of the Study Area in Hungary, Central Europe.

Based on the interpretation of the observed subsurface fluid-potential patterns, Tóth and Almási (2001) have separated two superimposed and laterally extensive groundwater flow-domains characterized by different driving forces and water types in the Great Hungarian Plain. The lower domain of slightly saline water (TDS: 10–30 g·L^{-1}) is strongly overpressured (10–35 MPa in excess of hydrostatic pressure), whereas the upper regime of fresh water (TDS: 0.4–2.5 g·L^{-1}) is driven by gravity due to elevation differences of the topography (nearly hydrostatic pressure conditions). Communication between the two domains occurs by diffusion across geological strata and/or through discrete high-permeability structural and sedimentological discontinuities. The source of the saline (NaCl type) water (average TDS: 22 g·L^{-1}, and Cl^-: 11.9 g·L^{-1}) in the lower overpressured domain is probably the Pre-Neogene basement. On the other hand, in the Neogene hydrostratigraphic units $NaHCO_3$ type waters can be found, characterized by two orders of magnitude decrease in the TDS and Cl^- concentration compared to the waters of the Pre-Neogene basement (Mádl-Szőnyi, Tóth, 2009). Consequently, the appearance of Cl^- (above the 0.03 g·L^{-1} maximum value of infiltrated meteoric water) at shallower depths can be regarded as a natural tracer of the deep, basement origin water, and the mixing of the two water types.

DATA EVALUATION AND APPLIED METHODS

According to the study's objective, a wide range of data types were analyzed by applying geological, geophysical, hydraulic, and geochemical analyses.

First, 15 two-dimensional digital reflection seismic sections, as well as digital geophysical logs (spontaneous potential) were used to interpret the hydrotectonics and hydrostratigraphy of the Study Area. Additionally, lithostratigraphic subdivision data of Juhász (1992) were also applied during the hydrostratigraphic interpretation of the available well-logs. The structural interpretation was accomplished by creating two structural maps in 1700 ms and 400 ms depth, respectively.

Subsequently, archival hydraulic and hydrochemical data were analyzed in a depth interval extending from the Pre-Neogene basement to the shallowest appearance of the plume, in order to study the hydraulics and hydrochemistry of the Study Area. The data were collected from the original well documentation of government institutions and MOL Hungarian Oil & Gas Plc. The regrettably unfavourable quality and deficient quantity of data necessitated a profound culling, which consisted of the filtering and qualifying of hydraulic and water chemical data. The main selecting criteria were the (1) date of drilling, (2) date of measuring, (3) start of water or hydrocarbon production, and (4) type of measurement. Following these first steps of data processing, 61 hydraulic (pore-pressure and stabilized water level) data of 50 wells were chosen for further evaluation among 100 data of 64 wells.

During the hydraulic calculations pore pressure data were converted to hydraulic heads, and vice versa depending on which data was available. Afterwards, the results of the analyses were interpreted based on creating five p(z) profiles and two hydraulic cross sections.

From the numerous accessible hydrochemical parameters only the Na^+, Cl^-, and H_2SiO_3 data were chosen for further analyses, because these show the strongest correlation with the origin — Pre-Neogene basement or Neogene sediments — and the subsurface residence time of groundwater in the Study Area (Driscoll, 2003; Mádlné Szőnyi et al., 2005). As a result of data culling 184 water chemical analyses of 74 wells were selected among 233 analyses of 80 wells. The spatial distribution of these data was interpreted by creating hydrochemical cross sections, which did not show significant correspondence with the hydrogeological framework, and a depth distribution diagram of the standardized Na^+, Cl^-, and H_2SiO_3 values.

RESULTS

Based on the evaluation of seismic profiles, a north-south striking Pre-Neogene basement high located between Berekfürdő and Kunmadaras was identified (Figure 2).

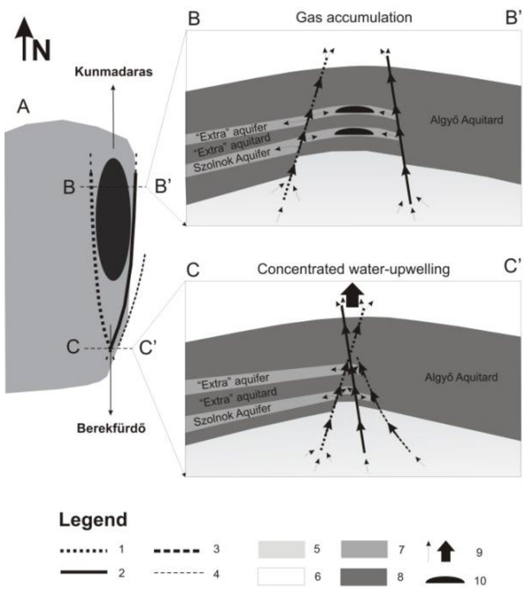

Figure 2. Diagram of the interpreted phenomena in the study area. Explanations: A — The Local Study Area in top view; BB', CC' — Cross sections from the northern and southern part of the local research area; 1, 2 — strike-slip master faults; 3 — reverse fault; 4 — trace of cross section; 5 — Pre-Neogene basement; 6–7 — aquifer units; 8 — aquitard units; 9 — fluid flow direction; 10 — gas field.

This basement high is bounded by two fault zones on its western and eastern margin (Figure 2).

These strike-slip faults are rejuvenations of basement normal faults, and both approach the land surface too. Additionally, they intersect each other to the south of Berekfürdő, in about -1200 m a.s.l. depth. Based on the seismic and well-log hydrostratigraphic analyses, beside the well-known aquifer and aquitard units of the Great Hungarian Plain (Tóth, Almási, 2001; Mádl-Szőnyi, Tóth, 2009) two more units could be identified on the Study Area (Figure 2). One of them is an ("Extra") argillaceous aquitard unit on the top of the Szolnok Aquifer, whereas the other is a ("Extra") sandy aquifer unit between the newly identified argillaceous aquitard and the Algyő Aquitard. These units are tectonically bounded by the strike-slip fault zones to the east and south, but their extent is unknown to the north and to the west. The pools of the Tatárülés-Kunmadaras gas field accumulated in the turbiditic sandstone groups of the "Extra" sandy aquifer unit and the Szolnok Aquifer located above the basement high, and between the two strike-slip fault zones.

The pressure-elevation profiles denote a deep source of hydraulic energy, which causes significant overpressure in the Pre-Pannonian Aquifer and Endrőd Aquitard, as well as consequently causes fluid-upwelling. Although, most of this energy is consumed during fluids flowing across the Endrőd Aquitard, moderate overpressure can be observed even in the Algyő Aquitard. Due to the quality and quantity of the available data, the pressure style of the Great Plain Aquifer is a little bit uncertain, but it might be characterized as close to hydrostatic. However, on the hydraulic cross sections stationary fluid flow field could not be established, partly because of the lack of data, and on the other hand because of the fluid potential reducing effect of gas and water production being typical of the Study Area. However, a boundary surface could be assigned. Below this boundary the system is overpressured, and above that the system is approximately hydrostatic within the limits of analytical error. The peak of this "overpressure-front" coincides with the basement high and the junction of fault zones in the south of Berekfürdő.

In the course of hydrochemical analysis the depth distribution of standardized Na^+, Cl^-, and H_2SiO_3 values could be interpreted. On one hand, the high H_2SiO_3 (max 226.2 mg·L^{-1}, standardized value: 2.73), Na^+ (max 23.4 g·L^{-1}, standardized value: 5.86), and Cl^- (max 36.1 g·L^{-1}, standardized value: 5.90) values beneath -1300 m a.s.l. depth refer to this water type having a deep, basement source. While on the other hand, the low Na^+ and Cl^- values (both 0-1.0 g·L^{-1}, standardized value: -0.88) above -1300 m a.s.l. depth indicate mixing with meteoric water.

The combined interpretation of the integrated geological, geophysical, hydraulic, and geochemical analyses have allowed the characterization of the groundwater flow system and the elucidation of the hydraulic role of those identified faults, which intersect each other near Berekfürdő. Furthermore, the presence of the thermal water at Berekfürdő, as well as the Tatárülés-Kunmadaras gas field was also explained.

On one hand, both fault zones are acting as a conduit for fluids in vertical direction. Consequently, the overpressure can dissipate from the basement along the fault, and at the same time causes water upwelling, as well as the development of the "potential plume" in the fluid potential field. On the other hand, both fault zones are acting as barriers for the transversal fluid flow, although the reasons are different respectively. The eastern fault (zone) impedes fluid flow across the fault plane, because a thick and homogeneous low-permeability sequence (Algyő Aquitard) was juxtaposed on the eastern side of the strike-slip fault zone against the Szolnok and "Extra" sandy aquifers on the western side (Figure 2B). Whereas, in the case of the western fault (zone), there is no fluid flow across the vertically conduit fault, because the ascending fluid flows out of the fault zone into the intersected sands of the Szolnok and the "Extra" sandy aquifer unit (Figure 2B). Eventually, these transversally barrier fault zones may act as lateral seals of the Tatárülés-Kunmadaras gas field, and might also ensure the active water pressure of the reservoir system.

The junction of the vertically conducting and transversally sealing fault zones represents the southern limit of the hydrocarbon bearing Szolnok and "Extra" sandy aquifer (Figure 2C), i.e. the gas field. At the same time, the junction of these faults causes more intensive water upwelling (Figure 2C), which induces the peak of the "overpressure front" near Berekfürdő. The Spa of Berekfürdő produces its thermal water from this overpressure peak or "potential plume".

The hydrochemical conclusions have corroborated the results of the hydraulic interpretation. The depth distribution of the normalized Na^+, Cl^-, and H_2SiO_3 values confirming the NaCl-type water upwelling — with high H_2SiO_3 content — up to about -1300 m a.s.l. correlates with the basement faults, most of which do not approach the surface, but terminate upward around -1300 m a.s.l. On the other hand, this deeper saline water can mix with meteoric water at shallower depth due to the presence of the Pannonian or younger growth fault zones, which can recharge the deeper aquifers.

SUMMARY

The present work displays an integrated geological, geophysical, hydraulic, and geochemical analysis, which has resulted in the characterization of the Study Area's groundwater flow system, and the hydraulic role of structural elements in it. In the Trans-Tisza Region of Hungary, basement fault zones approaching also the surface were identified and mapped on several seismic lines near Kunmadaras and Berekfürdő, while the heterogeneity of the Algyő Aquitard was established. Fluid potential data proved overpressure in the Pre-Neogene basement and indicated induced positive fluid potential anomaly ("potential plume") also in the shallower Pannonian strata near Berekfürdő. The presence of NaCl-type water upwelling with high H_2SiO_3 content was confirmed. This observation correlates with the basement faults, most of which do not approach the surface. The deeper saline water is mixing with meteoric water at shallower depth. The identified faults, which attach to the basement high and approach the land surface, represent direction dependent control over the fluid flow systems, cause deep water upwelling and might contribute to the development of the petroleum fields of the Study Area.

ACKNOWLEDGEMENTS

The study was financed by the Hungarian Oil & Gas Company Plc (MOL Nyrt.) and based on their data.

REFERENCES

Driscoll F.G., 2003: *Groundwater and wells.* St. Paul, Minnesota, Johnson Screens, 1021 p.

Juhász Gy., 1992: *A pannóniai (s.l.) formációk térképezése az Alföldön: elterjedés, fácies és üledékes környezet (Pannonian s.l. formations in the Hungarian Plain: distribution, facies and sedimentary environments).* Földtani Közlöny 122/2–4, pp. 133–165.

Mádlné Szőnyi J., Simon Sz., Tóth J., Pogácsás Gy., 2005: *Felszíni és felszín alatti vizek kapcsolata a Duna-Tisza közi Kelemen-szék és Kolon-tó esetében (Interrelationship between surface and subsurface waters at the Kelemenszék and Kolon Lakes, Duna-Tisza Interfluve, Hungary).* Általános Földtani Szemle 30, pp. 93–110.

Mádl-Szőnyi J., Tóth J., 2009: *A hydrogeological type section for the Duna-Tisza Interfluve, Hungary.* Hydrogeology Journal 17/4, pp. 961–980.

Matthäi S.K., Roberts S.G., 1996: *The influence of fault permeability on single-phase fluid flow near fault-sand intersections: results from steady-state high resolution models of pressure-driven fluid flow.* AAPG Bulletion 80/11, pp. 1763–1779.

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,pp.11–36.

International Association of Hydrogeologists

AGH University of Science and Technology

2-vol. set + CD
ISSN 0208-6336
ISBN 978-83-226-1979-0