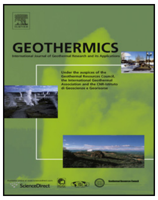
Geothermics 60 (2016) 156–174

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics



# Involvement of preliminary regional fluid pressure evaluation into the reconnaissance geothermal exploration—Example of an overpressured and gravity-driven basin

Judit Mádl-Szőnyi*, Szilvia Simon

*Department of Physical and Applied Geology, Eötvös Loránd University, Budapest, Hungary 1/C Pázmány P. stny., Budapest 1117, Hungary*

ARTICLE INFO

*Article history:*
Received 20 August 2014
Received in revised form 4 May 2015
Accepted 8 November 2015
Available online 19 January 2016

*Keywords:*
Geothermal exploration
Fluid pressure
Overpressure
Gravity-driven flow
Thermal water

ABSTRACT

The paper proposes the involvement of preliminary regional hydrodynamic analysis for the reconnaisance phase water-based geothermal exploration in sedimentary basins. This approach is based on basin-scale pore pressure evaluation, it complements the usual reservoir and temperature analyses. Understanding of subsurface pore pressure distribution is beneficial not only in planning thermal water production but also in reinjection. The method is demonstrated for a sedimentary basin characterized by overpressured and superimposed gravity-driven flow. The key point of the approach is the understanding of regional pressure regimes and the delineation of the boundary of overpressured and gravitational flow domains.

## 1. Introduction, goals

Sedimentary basins, siliciclastic and carbonate, are targets for the installation of geothermal power plans and for direct-use of thermal water depending on their temperature conditions (Goldscheider et al., 2010). It can be seen that the hydrogeological aspects of geothermal energy utilization has got to the focus of interest nowadays (Allen et al., 2014). However, our knowledge regarding geothermal resources in the context of basin scale operating hydrodynamic systems is restricted (Tóth, 1995). Recently, research methods on regional hydrodynamic analysis have been further developed for characterizing oil and gas resources for example in the Netherlands (Verweij and Simmelink, 2002; Verweij, 2003; Verweij et al., 2012) and also in Hungary (Czauner and Mádl-Szőnyi, 2013).

The heat can be functioning as natural tracer in groundwater flow systems (Saar, 2011). Due to advective heat transport by regional groundwater flow in sedimentary basins, recharge areas are characterized by lower temperature than discharge areas (Domenico and Palciauskas, 1973). This phenomenon has implications for geothermal development, too (Goldscheider et al., 2010; Hebig et al., 2012; Pimentel and Hamza, 2012).

In the course of preliminary phase of thermal water exploration, possibility and necessity of reinjection can be also a key factor because of sustainability and economic (expenses of operation) reasons. Reinjection used to be a disposal method, but it has become an essential part of geothermal reservoir management. Reinjection of low-enthalpy geothermal fluid into sandstone reservoirs of a sedimentary basins were rated as a poorly understood issue by Stefansson (1997). However, since that it turned out that it seems to be manageable with proper operational practice (Szanyi and Kovács, 2011). Nonetheless, reinjection provides pressure support to the long-term operation of geothermal field and reduces the potential for subsidence (Axelsson, 2008; Kaya et al., 2011). Understanding the influence of subsurface pore pressure regime on the possibilities and necessity of reinjection can also be a key issue in preliminary resource evaluation and planning.

In order to evaluate thermal water production possibilities in a sedimentary basin, the elements of the natural geothermal systems have to be characterized. This paper intends to emphasize and demonstrate that not only the temperature and geology of the reservoirs, but also the availability of water – depending on regional pore pressure regimes – is an essential factor in planning. Therefore, regional hydrodynamic analysis can be a key approach in reconnaissance phase geothermal investigations. In addition, it can provide background to plan reinjection.

---

* Corresponding author. Fax: +36 1 381 2130.
*E-mail addresses:* madlszonyi.judit@gmail.com, szjudit@ludens.elte.hu (J. Mádl-Szőnyi).

http://dx.doi.org/10.1016/j.geothermics.2015.11.001
0375-6505/

The proposed approach is based on well pressure data analysis. Pressure data processes can provide a snapshot of regional pore pressure field, thus representing the original, so called "natural" hydrodynamic conditions before geothermal intervention. Based on that knowledge thermal water production and reinjection can be planned.

The main goal of the paper is the demonstration of the hydrodynamic approach, based on regional pore pressure evaluation. The execution of the methods are presented for the Duna–Tisza Interfluve part of the Pannonian Basin, Hungary, which is characterized by overpressured and superimposed gravity-driven flow regimes. The results of the evaluation are compared with experiences of thermal water utilization of the region.

## 2. Hydrogeological environment of the study area: Duna–Tisza Interfluve, Hungary

The Duna–Tisza Region is located in the Pannonian Basin, in the western part of the Great Hungarian Plain which is characterized by flat-bottomed valleys at the River Duna and Tisza (80–95 m asl), and by a central ridge (100–130 m asl) along the divide (Fig. 1a and b).

### 2.1. Geological, tectonical and thermal settings

Geologically, the Pannonian basin is a back-arc basin of the Alpine–Carpathian–Dinaric orogen system (Fig. 1a). The basin evolution of the region was driven by the convergence of Africa and Europe with separate movement of the Adriatic block (Bada et al., 2007). The extensional basin evolution started in the Early Miocene, while the structural reactivation of the basin has been continuing from Late Miocene (Royden and Horvath, 1988; Horváth, 1995a,b; Bada et al., 2007). Around Middle/Late Miocene the isolated Lake Pannon evolved with a similar sedimentological characteristics as a deep marine basin (Sztanó et al., 2013).

The basement of the Duna–Tisza Interfluve is built up of Mesosoic nappe systems of crustal blocks with different origin (Fig. 2a). Owing to the tectonic settings, two different structural domains constitute the basement of the study area. In NW, the Mid-Hungarian Unit of the ALCAPA Mega Unit (Alpine–Carpathian–Pannonian) (Csontos et al., 1992), while in the SE, the Tisza Mega-Unit can be found. The two main units are divided by the Mid Hungarian Fault Zone/Lineamens (Kovács and Haas, 2010). The northern domain of the study area is characterized by dominantly NE–SW-oriented fold axes and NE–SW oriented left lateral strike-slip faults and it is part of the so called Mid-Hungarian Mobile Belt (MHMB) (Pogácsás et al., 2011; Juhász et al., 2007) (Fig. 2a). This is a broad bend of relaxation of the strike-slip system with significant lateral displacements (flower structures) rooted in the Pre-Neogene Mesozoic–Paleozoic basement (Juhász et al., 2007). The faults have been active during the late Miocene and Quaternary and are controlled by the preformed fault pattern and the configuration of the basement (Pogácsás et al., 2011). The SE domain is slightly folded or unfolded and characterized by dominantly ENE–WSW-oriented faults. The Mecsek Line and the Codru Line (Szederkényi, 1977) of the TISZA Unit also cross the study area (Fig. 2a). The Pre-Neogene basement of the sedimentary basin is divided into deep local basins by elevated highs and troughs. The basin-fill is characterized by normal faults and flower structures. Major faults dissect the rock framework from the basement to a few hundred meters within the land surface (Royden and Horvath, 1988).

Favorable geothermal conditions are closely connected to the basin evolution (Horváth, 2007). According to the Early Miocene extension (Fig. 2b), the Pannonian lithosphere was thinned out, resulting in elevated surface heat flow (Royden et al., 1983; Bada et al., 2007). The characteristic surface heat flow values vary between 80 and 110 $\mathrm{mW\,m^{-2}}$ (Dövényi et al., 2002) in the Pannonian Basin, which are considerably above the continental average of 65 $\mathrm{mW\,m^{-2}}$ (Pollack et al., 1993). The factors influencing the heat flow densities inside the basin are: volcanic activity, sedimentation/erosion, variability of heat capacity, tectonics and subsurface flow systems (Lenkey et al., 2002). The average geothermal gradient in Hungary is higher than the world average, namely 45 $^{\circ}\mathrm{C\,km^{-1}}$. Due to the increased geothermal gradient, groundwater with outflow temperature above 30 °C is available everywhere in the Great Hungarian Plain, below 500 m (Mádlné Szőnyi, 2006). The Neogene tectonic evolution of the region is displayed in Fig. 2b.

### 2.2. Hydrostratigraphy, flow regimes and temperature distribution of the study area

Lithologically the Pre-Neogene basement of the study area consists of carbonates, metamorphic formations and flysch (Royden and Horvath, 1988) (Fig. 2b). Their hydraulic properties are different but can not be determined reliably because of insufficient data. The carbonates have the highest hydraulic conductivity ($K \sim 10^{-6}\ \mathrm{m\,s^{-1}}$) while the other formations have smaller values.

The Neogene basin-fill is 100–7000 m thick and consists of semi—to unconsolidated clastic marine, deltaic, lacustrine, fluviatile and eolian sediments. Hydrostratigraphically it composes a sequence of aquifers and aquitards (Fig. 2b). Their hydraulic conductivity values were determined by qualitative estimation derived from the lithologic and facies conditions (Tóth and Almási, 2001; Mádl-Szőnyi and Tóth, 2009). In the sedimentary sequence the most significant formation is the extensive Algyő Aquitard ($K \approx 10^{-8}$–$10^{-7}\ \mathrm{m\,s^{-1}}$) which divides the Neogene basin fill into a lower and an upper sequence. The uppermost Great Plain Aquifer includes also two geological sequences but they are characterized regionally by one hydraulic conductivity value. The Quaternary sequence is mainly used for drinking water production, while the Neogene sequence is utilized for thermal water and hydrocarbon exploration (Fig. 2b).

Hydrogeologically the Duna–Tisza Interfluve region comprises two superimposed groundwater flow-domains, namely an overpressured deep and a gravitationally-driven upper regime (Tóth and Almási, 2001; Mádl-Szőnyi and Tóth, 2009; Varsányi and Ó-Kovács, 2009). The origin of overpressure is the disequilibrium compaction of the subsiding basin and tectonic compression (Van Balen and Cloetingh, 1994; Tóth and Almási, 2001; Mádl-Szőnyi and Tóth, 2009; Horváth et al., 2015). The overpressured lower domain contains saline, NaCl-type water (TDS (total dissolved solids): ~10,000–38,000 $\mathrm{mg\,L^{-1}}$)), while the upper regime contains fresh, $NaHCO_3$ type water (TDS: ~420–2500 $\mathrm{mg\,L^{-1}}$). The overpressured system is characterized by upward vertical flow component from the basement, while in the basin-fill, nested gravity driven flow systems operate with close to hydrostatic pressure conditions. Communication between the two systems occurs by diffusion, and seepage across aquitards through highly permeable, discrete structural and sedimentological discontinuities (Tóth and Almási, 2001; Mádl-Szőnyi and Tóth, 2009; Simon et al., 2011; Czauner and Mádl-Szőnyi, 2013). Czauner and Mádl-Szőnyi (2011) proved that the conductive faults can promote the overpressure dissipation and can produce hydraulic anomalies in the gravity flow regime. The way of overpressure dissipation to the extent of reaching near hydrostatic pressure values, depends on the diffusivity of aquitards which is controlled by its structural and sedimentological heterogeneity (Czauner and Mádl-Szőnyi, 2013). Accordingly, the main controling factors of flow regime distribution (gravity-driven and overpressured) are: the heterogeneities of the Endrőd Aquitard, and mainly